National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Padre Island National Seashore

Natural Resource Condition Assessment

Natural Resource Report NPS/PAIS/NRR—2014/747

ON THE COVER
Shorebirds resting on Malaquite Beach at Padre Island National Seashore.
Photograph by: Shannon Amberg, SMUMN GSS

Padre Island National Seashore

Natural Resource Condition Assessment

Natural Resource Report NPS/PAIS/NRR—2014/747

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January 2014

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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This report received formal peer review. Peer review was conducted by highly qualified individuals with subject area technical expertise and was overseen by a peer review manager.

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Please cite this publication as:

Amberg, S., A. Nadeau, K. Kilkus, S. Gardner, and B. Drazkowski. 2014. Padre Island National Seashore: Natural Resource Condition Assessment. Natural Resource Report NPS/PAIS/NRR—2014/747. National Park Service, Fort Collins, Colorado.

NPS 613/123431, January 2014

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Executive Summary

The Natural Resource Condition Assessment (NRCA) Program aims to provide documentation about the current conditions of important park natural resources through a spatially explicit, multi-disciplinary synthesis of existing scientific data and knowledge. Findings from the NRCA will help Padre Island National Seashore (PAIS) managers to develop near-term management priorities, engage in watershed or landscape scale partnership and education efforts, conduct park planning, and report program performance (e.g., Department of the Interior's Strategic Plan "land health" goals, Government Performance and Results Act).

The objectives of this assessment are to evaluate and report on current conditions of key park resources, to evaluate critical data and knowledge gaps, and to highlight selected existing stressors and emerging threats to resources or processes. For the purpose of this NRCA, staff from the National Park Service (NPS) and Saint Mary's University of Minnesota – GeoSpatial Services (SMUMN GSS) identified key resources, referred to as "components" in the project. The selected components include natural resources and processes that are currently of the greatest concern to park management at PAIS. The final project framework contains 17 resource components, each featuring discussions of measures, stressors, and reference conditions.

This study involved reviewing existing literature and, where appropriate, analyzing data for each natural resource component in the framework to provide summaries of current condition and trends in selected resources. When possible, existing data for the established measures of each component were analyzed and compared to designated reference conditions. A weighted scoring system was applied to calculate the current condition of each component. Weighted Condition Scores, ranging from zero to one, were divided into three categories of condition: low concern, moderate concern, and significant concern. These scores help to determine the current overall condition of each resource. The discussions for each component, found in Chapter 4 of this report, represent a comprehensive summary of current available data and information for these resources, including unpublished park information and perspectives of park resource managers, and present a current condition designation when appropriate. Each component assessment was reviewed by PAIS resource managers and NPS Gulf Coast Network staff.

Existing literature, short- and long-term datasets, and input from NPS and other outside agency scientists support condition designations for components in this assessment. However, in a number of cases, data were unavailable or insufficient for several of the measures of the featured components. In other instances, data establishing reference condition were limited or unavailable for components, making comparisons with current information inappropriate or invalid. In these cases, it was not possible to assign condition for the components. Current condition was not able to be determined for 12 of the 17 components (70.5%) due to these data gaps.

For the five components with sufficient available data, the overall condition varied. These components include colonial waterbirds, water quality, air quality, dark night skies, and sea turtles. All five components were determined to be of moderate concern based on available data. Sea turtles, air quality, and dark night skies all had stable trends, while colonial waterbirds was determined to have a declining trend in resource condition. Detailed discussion of these designations is presented in Chapters 4 and 5 of this report.

Several park-wide threats and stressors influence the condition of priority resources in PAIS. Those of primary concern include extreme weather events (e.g., hurricanes, tropical storms, and drought), relative sea level rise, energy development within and around the park (i.e., oil and gas drilling, wind farms), and human impacts (i.e., vehicular and pedestrian traffic). Understanding these threats, and how they relate to the condition of these resources, can help the NPS prioritize management objectives and better focus conservation strategies to maintain the health and integrity of park ecosystems.

Acknowledgments

We acknowledge Padre Islands National Seashore staff for the technical expertise provided during scoping, through multiple stages of review, and via phone and email; specifically, Jim Lindsay, Wade Stablein, and Dr. Donna Shaver. Gulf Coast Inventory and Monitoring Network staff, including Martha Segura, Joe Meiman, Whitney Granger, and Jeff Bracewell provided logistical insight, support, and critical review of interim documents. Diana Del Angel, Coastal Geoscientist for the Harte Research Institute of Texas A&M Corpus Christi, provided review of the coastal dunes and beaches component. Ellen Porter of the NPS - Air Resources Division, provided review of the air quality component. R. Dale McPherson, Southeast Region Natural Resource Condition Assessment Coordinator, helped with project implementation and document reviews. Jeff Albright, National Natural Resource Condition Assessment Coordinator, provided program guidance. Thank you to all others who assisted the development of this document.

Acronyms and Abbreviations

ABC – American Bird Conservancy

ARD – NPS Air Resources Division

ARK – Animal Rehabilitation Keep

ATVs – All-terrain vehicles

BBS – Breeding Bird Survey

CAA – Clean Air Act of 1977

CASTNet – Clean Air Status and Trends Network

CBBEP – Coastal Bend Bays & Estuaries Program

CBC – Christmas Bird Count

C-CAP – Coastal Change and Analysis Project

CCD – Charge-coupled Device

CL – Condition Level

CVI – Coastal Vulnerability Index

DAM – Water Impoundments Database

DEM – Digital Elevation Model

DO – Dissolved Oxygen

DRINKS – Drinking Water Supplies Database

Dv – Deciviews

EIS – Environmental Impact Statement

EPA – Environmental Protection Agency

GAGES – Water Gages Database

GIS – Geographic Information System

GIWW – Gulf Intracoastal Waterway

GPRA – Government Performance and Results Act

Acronyms and Abbreviations (continued)

GRI – Geologic Resources Inventory

GULN – Gulf Coast Network

HAB – Harmful Algal Bloom

I&M - Inventory and Monitoring

IFD – Industrial Facilities Discharge

IMPROVE – Interagency Monitoring of Protected Visual Environments Program

IRMA – NPS Integrated Resource Management Applications

ITIS – Integrated Taxonomic Information System

LiDAR – Light Detection and Ranging

LLM – Lower Laguna Madre

MHW – Mean High Water

MLW – Mean Low Water

MSL – Mean Sea Level

MW – Milliwatt

NAAQS – National Ambient Air Quality Standards

NMFS – U.S. National Marine Fisheries Service

NADP – National Atmospheric Deposition Program

NOAA - National Oceanic and Atmospheric Administration

NPS - National Park Service

NRCA – Natural Resource Condition Assessment

NST – Night Sky Team

NVCS - National Vegetation Classification Standard

NWI - National Wetland Inventory

O_3 – Ozone

Acronyms and Abbreviations (continued)

ORV – Off-road Vehicle

PAIS - Padre Island National Seashore

PM – Particulate Matter

ppb – Parts per Billion

RF3 – River Reach File

RSS – Resource Stewardship Strategy

SL – Significance Level

SMUMN GSS – Saint Mary's University of Minnesota, Geospatial Services

SSAP – Shoreline Shape and Projection Program

STORET – Storage and Retrieval

STSSN – Sea Turtle Stranding and Salvage Network

TCEQ – Texas Commission on Environmental Quality

TED – Turtle Excluder Device

TCWS – Texas Colonial Waterbird Society

TPWD – Texas Parks and Wildlife Department

TSS – Total Suspended Solids

ULM – Upper Laguna Madre

USACE – United States Army Corps of Engineers

USFWS – United States Fish and Wildlife Service

USGS – United States Geological Survey

UTMSI – University of Texas Marine Science Institute

VOCs – Volatile Organic Compounds

WCS – Weighted Condition Score

WHSRN – Western Hemisphere Shorebird Reserve Network

Acronyms and Abbreviations (continued)

ZLM – Zenith Limiting Magnitude

Chapter 1 NRCA Background Information

Natural Resource Condition Assessments (NRCAs) evaluate current conditions for a subset of natural resources and resource indicators in national park units, hereafter "parks." NRCAs also report on trends in resource condition (when possible), identify critical data gaps, and characterize a general level of confidence for study findings. The resources and indicators emphasized in a given project depend on the park's resource setting, status of resource stewardship planning and science in identifying high-priority indicators, and availability of data and expertise to assess current conditions for a variety of potential study resources and indicators.

> ***NRCAs Strive to Provide…***
> *Credible condition reporting for a subset of important park natural resources and indicators*
> *Useful condition summaries by broader resource categories or topics, and by park areas*

NRCAs represent a relatively new approach to assessing and reporting on park resource conditions. They are meant to complement—not replace—traditional issue- and threat-based resource assessments. As distinguishing characteristics, all NRCAs:

- are multi-disciplinary in scope;[1]
- employ hierarchical indicator frameworks;[2]
- identify or develop reference conditions/values for comparison against current conditions;[3]
- emphasize spatial evaluation of conditions and GIS (map) products;[4]
- summarize key findings by park areas; and[5]
- follow national NRCA guidelines and standards for study design and reporting products.

Although the primary objective of NRCAs is to report on current conditions relative to logical forms of reference conditions and values, NRCAs also report on trends, when appropriate (i.e., when the underlying data and methods support such reporting), as well as influences on resource

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[1] The breadth of natural resources and number/type of indicators evaluated will vary by park.

[2] Frameworks help guide a multi-disciplinary selection of indicators and subsequent "roll up" and reporting of data for measures ⇨ conditions for indicators ⇨ condition summaries by broader topics and park areas

[3] NRCAs must consider ecologically-based reference conditions, must also consider applicable legal and regulatory standards, and can consider other management-specified condition objectives or targets; each study indicator can be evaluated against one or more types of logical reference conditions. Reference values can be expressed in qualitative to quantitative terms, as a single value or range of values; they represent desirable resource conditions or, alternatively, condition states that we wish to avoid or that require a follow-on response (e.g., ecological thresholds or management "triggers").

[4] As possible and appropriate, NRCAs describe condition gradients or differences across a park for important natural resources and study indicators through a set of GIS coverages and map products.

[5] In addition to reporting on indicator-level conditions, investigators are asked to take a bigger picture (more holistic) view and summarize overall findings and provide suggestions to managers on an area-by-area basis: 1) by park ecosystem/habitat types or watersheds, and 2) for other park areas as requested.

conditions. These influences may include past activities or conditions that provide a helpful context for understanding current conditions, and/or present-day threats and stressors that are best interpreted at park, watershed, or landscape scales (though NRCAs do not report on condition status for land areas and natural resources beyond park boundaries). Intensive cause-and-effect analyses of threats and stressors, and development of detailed treatment options, are outside the scope of NRCAs.

Due to their modest funding, relatively quick timeframe for completion, and reliance on existing data and information, NRCAs are not intended to be exhaustive. Their methodology typically involves an informal synthesis of scientific data and information from multiple and diverse sources. Level of rigor and statistical repeatability will vary by resource or indicator, reflecting differences in existing data and knowledge bases across the varied study components.

The credibility of NRCA results is derived from the data, methods, and reference values used in the project work, which are designed to be appropriate for the stated purpose of the project, as well as adequately documented. For each study indicator for which current condition or trend is reported, we will identify critical data gaps and describe the level of confidence in at least qualitative terms. Involvement of park staff and National Park Service (NPS) subject-matter experts at critical points during the project timeline is also important. These staff will be asked to assist with the selection of study indicators; recommend data sets, methods, and reference conditions and values; and help provide a multi-disciplinary review of draft study findings and products.

NRCAs can yield new insights about current park resource conditions but, in many cases, their greatest value may be the development of useful documentation regarding known or suspected resource conditions within parks. Reporting products can help park managers as they think about near-term workload priorities, frame data and study needs for important park resources, and communicate messages about current park resource conditions to various audiences. A successful NRCA delivers science-based information that is both credible and has practical uses for a variety of park decision making, planning, and partnership activities.

Important NRCA Success Factors

Obtaining good input from park staff and other NPS subject-matter experts at critical points in the project timeline

Using study frameworks that accommodate meaningful condition reporting at multiple levels (measures ⇨ indicators ⇨ broader resource topics and park areas)

Building credibility by clearly documenting the data and methods used, critical data gaps, and level of confidence for indicator-level condition findings

However, it is important to note that NRCAs do not establish management targets for study indicators. That process must occur through park planning and management activities. What an NRCA can do is deliver science-based information that will assist park managers in their ongoing, long-term efforts to describe and quantify a park’s desired resource conditions and management targets. In the near term, NRCA findings assist strategic park resource planning[6] and help parks to report on government accountability measures.[7] In addition, although in-depth analysis of the effects of climate change on park natural resources is outside the scope of NRCAs, the condition analyses and data sets developed for NRCAs will be useful for park-level climate-change studies and planning efforts.

NRCAs also provide a useful complement to rigorous NPS science support programs, such as the NPS Natural Resources Inventory & Monitoring (I&M) Program.[8] For example, NRCAs can provide current condition estimates and help establish reference conditions, or baseline values, for some of a park's vital signs monitoring indicators. They can also draw upon non-NPS data to help evaluate current conditions for those same vital signs. In some cases, I&M data sets are incorporated into NRCA analyses and reporting products.

Over the next several years, the NPS plans to fund a NRCA project for each of the approximately 270 parks served by the NPS I&M Program. For more information on the NRCA program, visit http://nature.nps.gov/water/nrca/index.cfm

NRCA Reporting Products…
Provide a credible, snapshot-in-time evaluation for a subset of important park natural resources and indicators, to help park managers:
Direct limited staff and funding resources to park areas and natural resources that represent high need and/or high opportunity situations
(near-term operational planning and management)
Improve understanding and quantification for desired conditions for the park's "fundamental" and "other important" natural resources and values
(longer-term strategic planning)
Communicate succinct messages regarding current resource conditions to government program managers, to Congress, and to the general public
("resource condition status" reporting)

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[6] An NRCA can be useful during the development of a park's Resource Stewardship Strategy (RSS) and can also be tailored to act as a post-RSS project.

[7] While accountability reporting measures are subject to change, the spatial and reference-based condition data provided by NRCAs will be useful for most forms of "resource condition status" reporting as may be required by the NPS, the Department of the Interior, or the Office of Management and Budget.

[8] The I&M program consists of 32 networks nationwide that are implementing "vital signs" monitoring in order to assess the condition of park ecosystems and develop a stronger scientific basis for stewardship and management of natural resources across the National Park System. "Vital signs" are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values.

Chapter 2 Introduction and Resource Setting

2.1 Introduction

2.1.1 Enabling Legislation

Padre Island National Seashore (PAIS) is the longest stretch of undeveloped barrier island in the world (Cooper et al. 2005). On 28 September 1962, PAIS was authorized by Congress and 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 the Secretary of the Interior shall take appropriate action in the public interest toward the establishment of the following described lands and waters as the Padre Island National Seashore (Public Law 87-711).

2.1.2 Geographic Setting

PAIS is approximately 52,609 ha (130,000 ac) and is located near the southern tip of Texas on the coast of the Gulf of Mexico. The barrier island that makes up PAIS is a relatively young landform in geological terms, as deposits found on the unit date back only a few thousand years (Weise and White 1980). Gulf currents and tidal movements formed this barrier island, in part, by pushing sand on to the mainland beach ridge (Weise and White 1980).

Most of the National Seashore is less than 6.1 m (20 ft) above sea level. On the southern end of the National Seashore, the erosion rate is higher due to a drier climate and lack of vegetation; as a result, the dune ridge in this area is low and segmented (Weise and White 1980). There are areas of the park that are as high as 15.2 m (50 ft) above sea level. The northern fore-island dune ridge is an example of one of these elevated areas in the park, and was largely created by prevailing southeasterly winds (Weise and White 1980).

The Laguna Madre, a portion of which is also part of the park, separates PAIS from the Texas mainland. The Laguna Madre is approximately 200 km (124 mi) long, stretching from Corpus Christi Bay to the Mexican border. The Laguna is divided into two separate sections by a 20-km (12.4 mi) stretch of sand and mudflats that rarely flood (Onuf 2002). The upper section is approximately 80 km (50 mi) long, reaching up to Corpus Christi Bay, while the lower section is 95 km (59 mi) long, extending nearly to the Mexican border. The average depth of both portions of the lagoon is 1 m (3.3 ft) (Onuf 2002). It is one of five coastal environments in the world known for its hypersaline water (Onuf 2002). The high salinity of the Laguna is attributed to limited runoff and few freshwater systems that empty into the Laguna Madre (Frey and Jones 2008).

The gulf climate is influenced by several regional factors including the El Niño-La Niña oscillation. Regional drought events can be linked with La Niña events, while El Niño causes cooler winter and spring temperatures as well as unusually high winter precipitation (Segura et al. 2007).

Winter in PAIS is mostly mild due to the warm Gulf of Mexico waters, and temperatures typically remain just below 20 °C (68 °F) (Table 1). The summer months in PAIS are typically hot, with average high temperatures in July and August of 32.3 °C (90.1 °F) and 32.4 °C (90.4 °F), respectively (Table 1).

Table 1.Monthly temperature and precipitation normals for PAIS (Station TX417704, Rockport, Texas) (http://www.climate-charts.com/USA-Stations/TX/TX417704.php).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Temperature (°C)													
Max	17.2	18.6	21.8	24.9	28.1	31.0	32.3	32.4	31.2	27.6	22.6	18.7	25.5
Min	7.2	9.1	13.5	17.4	21.6	24.6	25.3	25.1	22.9	18.5	12.8	8.4	17.2
Average Precipitation (cm)													
Total	6.1	5.5	6.0	5.3	9.3	8.9	6.2	8.0	14.0	10.7	6.5	4.9	7.6

2.1.3 Visitation Statistics

In 2012, PAIS had 573,855 visitors to the park (NPS 2012); most visits occurred between May and August (NPS 2012). The average number of recreational visitors to the park from 2004-2012 was 634,135 visitors (NPS 2012). The Gulf beach and the Laguna Madre provide areas that allow visitors to fish, camp, bird watch, and swim. Some popular activities on the Gulf beach include riding bicycles, four-wheel drive vehicle use, collecting seashells, picnicking, and observing the hatching of sea turtles. Windsurfing and hunting are popular activities on the Laguna Madre (NPS 2011b).

2.2 Natural Resources

2.2.1 Ecological Units and Watersheds

PAIS is part of the Environmental Protection Agency's (EPA) Western Gulf Coastal Plain Level III Ecoregion. This ecoregion stretches south from the Mississippi River delta in Louisiana, and extends southwest down the Gulf coast to the southern tip of Texas. According to the EPA (2010, p. 7),

> The principal distinguishing characteristics of the Western Gulf Coastal Plain are its relatively flat coastal plain topography and mainly grassland potential natural vegetation. Inland from this region the plains are older, more irregular, and have mostly forest or savanna-type vegetation potentials. Largely because of these characteristics, a higher percentage of the land is in cropland than in bordering ecological regions. Urban and industrial land uses have expanded greatly in recent decades, and oil and gas production is common.

The EPA divides the Level III Ecoregions into smaller Level IV Ecoregions. In PAIS, the Western Gulf Coastal Plain Ecoregion includes one Level IV Ecoregion: the Laguna Madre Barrier Islands and Coastal Marshes (EPA 2010). PAIS lies within three watersheds, all of which are part of the Texas-Gulf Water Resource Region (USGS 2013). The three watersheds present in the park are the North Laguna Madre Watershed, the Central Laguna Madre Watershed, and the South Laguna Madre Watershed (Plate 1, USGS 1994).

2.2.2 Resource Descriptions

Vegetation

PAIS supports approximately 400 plants species from more than 75 plant families (NPS 2010). Little vegetation is found on the park's beaches due to steady winds, rising and receding tides, and violent storm activity. However, a few salt-tolerant plant species have established on the beaches including glasswort (*Salicornia* spp.), sea purslane (*Halimione portulacoides*), and sea dropseed (*Sporobolus heterolepis*). Active dunes also largely lack vegetation due to strong winds and constantly shifting sand; the few species that do grow on active dunes include beach croton (*Croton monanthogynus*), sedges (*Cyperaceae* spp.), and sea oats (*Uniola paniculata*) (NPS 2010).

The foredunes of the park are a region of the beach that has been stabilized due to the establishment of vegetation on the elevated sands. Representative species of this region include bitter panicgrass (*Panicum amarum*), sea oats, gulfdune paspalum (*Paspalum monostachyum*), prairie senna (*Senna obtusifolia*), and morning glory (*Ipomoea sagittata*) (NPS 2010).

The low coastal grasslands make up the majority of the interior of the park. This area is composed mainly of grass species such as seashore saltgrass (*Distichlis spicata*), red lovegrass (*Eragrostis secundiflora*), bushy bluestem (*Andropogon glomeratus*), and marshhay cordgrass (*Spartina patens*). Other species, such as phlox (*Phlox subulata*), ragweed (*Ambrosia artemisiifolia*), gulfdune paspalum, and sea oats occur in this region of the park.

Species such as cattails (*Typha* spp.), sedges, starrush whitetop (*Rhynchospora colorata*), marshhay cordgrass, and gulfdune paspalum are found in the pond and marsh habitats across the park. Vegetation in these habitats is very tolerant to inundations of both salt and freshwater because of the variable length of time the land is submerged. On the western side of the island, the wind tidal flats support species that are both flood- and saltwater-tolerant, including sea heliotrope (*Heliotropium curassavicum*), sea blight (*Suaeda australis*), sea dropseed, glasswort, and sea purslane.

The Laguna Madre is dominated by marine grasses, particularly widgeon grass (*Ruppia maritima*), manatee grass (*Syringodium filiforme*), shoal grass (*Halodule wrightii*), and halophila (*Halophila johnsonii*). Spoil islands, areas in the Laguna Madre created by dredging activity, support ragweed, sea dropseed, glasswort, and dune paspalum (NPS 2010).

Mammals

Twenty-four species of terrestrial mammals have been documented in PAIS. Common native mammals in the park include spotted ground squirrels (*Spermophilus spilosoma*), Gulf coast kangaroo rats (*Dipodomys compactus*), Texas pocket gophers (*Geomys personatus*), black-tailed jackrabbits (*Lepus californicus*), coyotes (*Canis latrans*), and white-tailed deer (*Odocoileus virginianus*) (NPS 2013). Less common native mammals include the Virginia opossum (*Didelphis virginiana*), American badger (*Taxidea taxus*), and the seldom seen bobcat (*Lynx rufus*) (NPS 2013). In addition to the native species found in PAIS, there are three non-native mammals: the black rat (*Rattus rattus*), house mouse (*Mus musculus*), and nilgai (*Boselaphus tragocamelus*) (NPS 2013).

Birds
PAIS has confirmed the presence of 370 bird species within park boundaries (NPS 2013), of which approximately 40% are migratory species. Common migratory species found in PAIS include the indigo bunting (*Passerina cyanea*), northern waterthrush (*Parkesia noveboracensis*), Lincoln's sparrow (*Melospiza lincolnii*), Swainson's thrush (*Catharus ustulatus*), and the gray catbird (*Dumetella carolinensis*) (Blacklock 1998, NPS 2013). Substantially fewer resident bird species (67) occur in the park (NPS 2013). Examples of resident bird species in the park include the northern pintail (*Anas acuta*), eastern meadowlark (*Sturna magna*), and the burrowing owl (*Athene cunicularia*).

The Laguna Madre is a unique and biologically rich habitat that supports a variety of waterfowl, marine, and resident/migratory species. Colonial waterbirds are a unique group of birds that nest in large numbers on islands in the Laguna Madre. This group of birds is one of the more studied avian assemblages in the park, and has been monitored annually by the Texas Colonial Waterbird Society (TCWS) since 1974. Examples of common colonial waterbirds seen in PAIS include the American white pelican (*Pelecanus erythrorhynchos*), laughing gull (*Leucophaeus atricilla*), and the royal tern (*Sterna maxima*).

Herptiles
According to the NPS Certified Species List, 25 species of reptiles are found within PAIS boundaries (NPS 2013). While lizards, turtles, and American alligators (*Alligator mississippiensis*) are found in the park, snakes are the most diverse reptile group in the park (15 species documented). Common snakes in the park include the western diamondback rattlesnake (*Crotalus atrox*), the Texas glossy snake (*Arizona elegans arenicola*), and the Gulf coast ribbon snake (*Thamnophis proximus orarius*).

Considerably fewer amphibian species occur in PAIS, as only five species have been documented in the park (NPS 2013). Species such as the green tree frog (*Hyla cinerea*), spotted chorus frog (*Pseudacris clarkii*), and Hurter's spadefoot toad (*Scaphiopus hurterii*) are typically observed near the park's ephemeral ponds (Cooper et al. 2005).

Islands in the Park
The original dredging of the Gulf Intracoastal Waterway (GIWW) created 27 spoil islands in the Laguna Madre, ranging from less than 1 ha to 16.2 ha in size (NPS 1996, 2001). To maintain navigable depths, the GIWW and associated channels are re-dredged every 1-3 years (NPS 2001). Oil and gas companies also dredge channels to reach their facilities throughout the

Photo 1. Aerial photo of a Laguna Madre spoil island (from Weise and White 1980).

Laguna Madre. Some of the resulting dredge spoil may be placed on existing spoil islands along the waterway or may be used to create new islands. Vegetation becomes established on many spoil islands from seeds carried by the wind, water, or nesting birds (NPS 2001).

The dredge spoil islands within the park are of high importance to nesting colonial waterbirds. Within PAIS boundaries, there are 11 man-made dredge spoil islands in the Laguna Madre that have acted as the primary nesting habitat for colonial waterbird species; several of these islands support thousands of nesting pairs from many different species. For many species (e.g., American white pelican and black skimmer [*Rynchops niger*]), the colony sites in PAIS represent >25% of their coast-wide population (TCWS 2011). However, the unstable nature of these man-made islands has become evident in recent years, as several of the islands have experienced elevated rates of erosion.

The National Audubon Society and the Coastal Bend Bays and Estuaries Program (CBBEP), in cooperation with the U.S. Fish and Wildlife Service (USFWS), have spent large amounts of money to re-establish islands in the Laguna Madre (not in PAIS) that have historically acted as rookery islands but have since been lost due to erosion (Wade Stablein, PAIS Biological Technician, email communication, 27 March 2013). The colonial waterbird nesting populations are monitored annually in the park by the TCWS, and the data are provided to the park for analysis of potential trends in species abundance and island health.

There are also two natural islands within PAIS' administrative boundaries, North and South Bird Islands. These islands have not supported nesting colonial waterbirds for some time, but should the dredge spoil islands in the Laguna continue to erode at an elevated rate, these naturally occurring islands could see an increase in colonial waterbird use (Stablein, email communication, 27 March 2013).

2.2.3. Resource Issues Overview

Changes in the Laguna Madre

The Gulf of Mexico supports as much as 50% of the United States' seagrass population (Beck et al. 2007). These seagrass communities have experienced dramatic changes in recent years, as vegetation on the bottom of the lagoon has decreased by almost 3,000 ha [1,214 ac] from 1960 to 1998 (approximately 4% of the entire lagoon bottom) (Onuf 2002). According to Beck et al. (2007), loss of lagoon vegetation is due to climate changes, variations in water level, erosion of sediment, turbidity, and physical removal by dredging or other human-induced methods. The salinity of the lagoon has decreased by half since the 1960s (Pulich and Onuf 2002), with several changes on the landscape found to be the main reasons for this shift, including the dredging of the GIWW, the opening of the "Land Cut" between the upper and lower Laguna Madre, and the creation of the Mansfield Channel at the south end of the park. As a result, plant composition has transitioned to more salt-intolerant plants, such as manatee grass and turtle grass (*Thalassia testudinum*). This transition has stressed the shoal grass population, as shoal grass's composition decreased from 64% to 40% in the time following dredging of the GIWW (Onuf 2002). A decrease in shoal grass density is likely to affect other species, as shoal grass is an important food source for the redhead duck (*Aythya americana*) and many other waterfowl species (Onuf 2002, Pulich and Onuf 2002).

Non-native Species

While vegetative sampling efforts in PAIS have only recorded two non-native plant species (buffelgrass [*Pennisetum ciliare]* and annual rabbitsfoot grass [*Polypogon monspeliensis*]; Drawe et al. 1981, Nelson et al. 2000), James Lindsay (written communication, October 2012) indicates that PAIS is home to over 40 species of non-native plant species (See Chapter 4.1 for a list of all non-native plant species). While the exact locations and extent of these non-native plant species has not been mapped, these species have the potential to outcompete native species, and may result in a non-native dominated landscape.

Non-native plant species are prevalent on the park's dredge spoil islands. Several of these species were planted on the islands by cabin owners prior to PAIS assuming ownership of the islands; plants were placed on the islands in order to stabilize the soil and prevent rapid erosion (Stablein, written communication, 15 March 2013). Examples of non-native plant species that were planted on these islands include Brazilian peppertrees (*Schinus terebinthifolius*), oleander (*Nerium oleander*), bermudagrass (*Cynodon dactylon*) and saltcedar (*Tamarix ramosissima*). The presence of non-native plant species on these islands is of substantial concern to the nesting colonial waterbirds, as several of these nesting species require bare ground or a specific degree of vegetative cover in order to successfully nest.

A non-native wildlife species in the park that is uncommon is the nilgai. Nilgai, a species of antelope from Pakistan and northern India, were introduced to Texas in the first half of the 20th century (NatureServe 2011), and occasionally can be found roaming the grasslands of the park. In the 1980s, Lochmiller and Sheffield (1989) reported a nilgai population of approximately 10,000 in southeastern Texas. It was later reported that the population grew to around 15,000 (Schmidly 2004).

Hurricanes and Tropical Storms

Hurricanes and tropical storms strike the Gulf Coast of Texas at an average rate of 0.67 storms per year, or approximately two storms every 3 years; most of these weather events occur between late spring and early fall, with prime storm activity occurring from August through October (Weise and White 1980). When wind velocities reach 119 km/hr (74 mi/hr), tropical storms become categorized as hurricanes; the most severe hurricanes have sustained winds in excess of 322 km/hr (200 mi/hr) (Weise and White 1980). Such strong winds can cause significant geomorphological change to the beach and dunes and impact vegetation communities. During storm events, vegetation can be uprooted and large amounts of sand can be displaced inland or into the bay or lagoon (Weise and White 1980). An equally destructive force is the tidal storm surge that accompanies hurricanes. These surges expend tremendous energy, causing erosion and transporting and depositing huge amounts of coastal sediment in the process (Weise and White 1980).

Barrier islands along the central Gulf coast of Texas serve as the first land feature in the path of hurricane storm surges and high winds. The well-developed foredune ridge along the Gulf side of PAIS provides a significant defense for the mainland against damaging winds and tidal storm surges; the barrier helps to block much of the tidal inflow and dissipate wave energy that could cause substantial damage to shorelines (Weise and White 1980). However, the barrier islands in the path of such storms experience significant changes in this process. Storm surges do not always stop at the beach; they can wash across through low-lying areas and flood into washover channels and tidal flats on the backside of the dune ridge, carrying sediments inland and toward the Laguna Madre (Weise and White 1980). PAIS has experienced significant coastal and island changes due to tropical storms and hurricanes in the last 60 years, making the barrier island a highly dynamic landscape.

Harmful Algal Blooms (HABs)

Red tides are unusually high concentrations of algal blooms, specifically *Karenia brevis* (NPS 2006), and are a naturally occurring phenomenon in marine ecosystems. Red tides are characterized by a discoloration of water (usually reddish in color) and an ammonia-like smell. Blooms are pushed toward shore by the tides and become a problem not only in open water, but also on shorelines and coastal areas that are protected from wind and tides (NPS 2006). Red tide events are a cause for concern because the microscopic algae release a neurotoxin that paralyzes fish, makes seafood unsafe for consumption, and can cause difficulty in breathing for visitors and park staff (NPS 2006, EPA 2012). Although little is known about what instigates a red tide, the most common time of year for red tides is between August and February. It has been hypothesized that high temperatures and periods of little to no wind or rain create favorable conditions for red tides (NPS 2006), but it is unclear what other conditions contribute to events.

Relative Sea Level Rise

Being surrounded by water on both sides of the park, relative sea level rise is a concern for the park. According to Douglas (1997), sea level around the earth has increased an average of 18 cm (7.1 in) over the last century. Meehl et al. (2007) estimate that changing climates will cause global sea levels to rise approximately 20-60 cm (7.9-23.6 in) during the 21st century (assuming the polar ice sheets remain stable). Sea level rise could impact the beaches of PAIS through increased rates of shoreline erosion, inundation of groundwater aquifers with saltwater, flooding of wetlands and estuaries, as well as damage to park infrastructure (Pendleton et al. 2004).

Pendleton et al. (2004) conducted a sea-level rise vulnerability assessment at PAIS in 2004. A coastal vulnerability index (CVI) was used in order to estimate and map the potential effects that future sea-level rise would have on the park; areas of the park that were most vulnerable to the physical effects of sea-level rise were highlighted in this report. Coastal evolution is a process that involves unique shoreline variables. In order to more accurately predict the effects that sea-level rise may have at the park, Pendleton et al. (2004, p. 3-4) focused on six variables that strongly influence PAIS's coastal evolution:

1. Geomorphology;
2. Historical shoreline change rate;
3. Regional coastal slope;
4. Relative sea-level change;
5. Mean significant wave height;
6. Mean tidal range.

The vulnerability of each of these variables was assessed using a 5-tiered ranking system (Table 2).

Table 2. Vulnerability rankings and ranges of values for the six selected PAIS variables (table modified from Pendleton et al. 2004).

Variables	Very Low (1)	Low (2)	Moderate (3)	High (4)	Very High (5)
Geomorphology	Rocky cliffed coasts, fjords	Medium cliffs, indented coasts	Low cliffs, glacial drift, alluvial plains	Cobble beaches, estuary, lagoon	Barrier beaches, sand beaches, salt marsh, mud flats, deltas, mangrove, coral reefs
Shoreline Erosion/Accretion (m/yr)	> 2.0	1.0 - 2.0	-1.0 - 1.0	-2.0 - -1.0	< -2.0
Coastal Slope (%)	> 1.20	1.20 - 0.90	0.90 - 0.60	0.60 - 0.30	< 0.30
Relative Sea-level Change (mm/yr)	< 1.8	1.8 - 2.5	2.5 - 3.0	3.0 - 3.4	> 3.4
Mean Wave Height (m)	< 0.55	0.55 - 0.85	0.85 - 1.05	1.05 - 1.25	> 1.25
Mean Tide Range (m)	> 6.0	4.0 - 6.0	2.0 - 4.0	1.0 - 2.0	< 1.0

Figure 1 displays the relative coastal vulnerability of PAIS as determined by Pendleton et al. (2004)'s CVI analysis. The areas of the park with very high vulnerability to sea-level rise (represented as red sections in Figure 1) include shorelines located in washover canals and dunes where shoreline erosion is the highest. The central portion of PAIS is least vulnerable to sea-level rise, primarily due to high levels of shoreline accretion and elevated dune ridges (Pendleton et al. 2004).

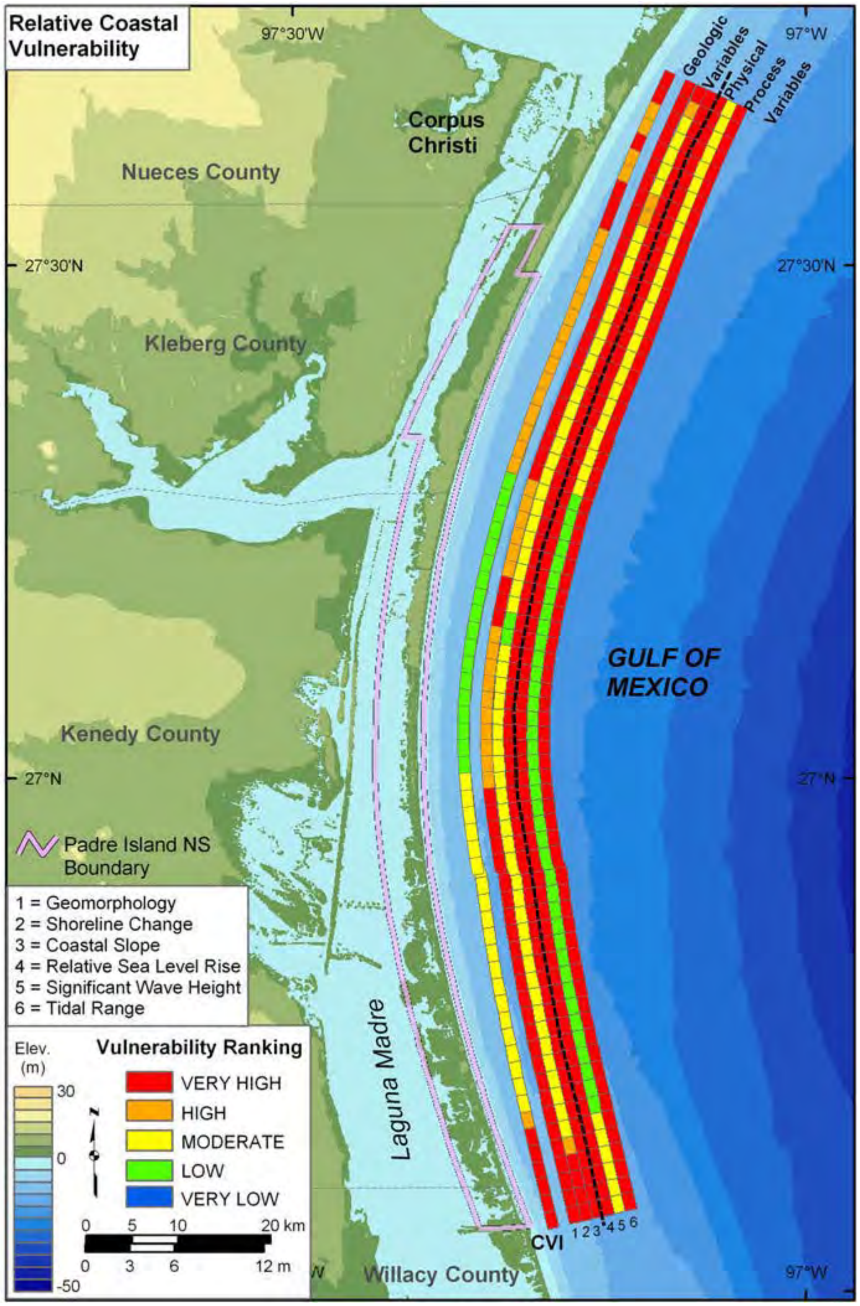

Figure 1. Relative coastal vulnerability for PAIS. The innermost color bar is the CVI, while the remaining six color bars are separated based on the variables outlined earlier in this text (Image reproduced from Pendleton et al. 2004).

2.3 Resource Stewardship

2.3.1 Management Directives and Planning Guidance

The broad resource management goals of PAIS, according to NPS (1996, p. 9-10), are to:

1. Preserve, understand, protect, and manage the cultural and natural resources of the park within naturally functioning ecosystems, consistent with cultural resource preservation;

2. Provide the means and opportunity for people to study, understand and enjoy the resources of the seashore without compromising the resources or ethnographic values.

From a natural resource-specific viewpoint, the park's established natural resource management objectives are to:

1. Restore and sustain natural ecosystem conditions and processes unimpaired from human influence, to the degree practical given landscape, insuring visitor safety, and cultural resource constraints;

2. Carry out a management program, which preserves and restores resource conditions and values defined by law and policy and is compatible with cultural resource objectives;

3. Preserve a comprehensive natural resource base for its innate value to promote scientific and educational interest (NPS 1996, p. 10).

Furthermore, all park management activities are prioritized based on where they fall within the following management strategy (NPS 1996, p. 4):

1. Minimize the loss of resources/information;

2. Meet legal requirements;

3. Mitigate management and visitor caused impacts;

4. Mitigate external impacts.

2.3.2 Status of Supporting Science

The Gulf Coast Inventory and Monitoring Network (GULN) identifies key resources for each of its parks network-wide. The identified resources, called "Vital Signs", are used to determine the overall health of the parks. In 2007, the GULN completed and released a Vital Signs Monitoring Plan (Segura et al. 2007); Table 3 shows the GULN Vital Signs selected for monitoring in PAIS.

Table 3. GULN Vital Signs selected for monitoring in PAIS (Segura et al. 2007).

Category	GULN Vital Sign	Category 1	Category 2	Category 3	No Monitoring Planned
Air and Climate	Ozone		X		
	Air Contaminants		X		
	Weather/Climate	X			
Geology and Soils	Coastal Dynamics	X			
	Subsidence/Relative Sea Level Rise		X		
	Soil Biota				X
	Soil Chemistry				X
	Soil Compaction				X
	Soil Structure and Stability				X
Water	Groundwater Hydrology				X
	Water Chemistry	X			
	Water Nutrients	X			
	Water Toxics	X			
Biological Integrity	Non-native Vegetation	X			
	Non-native Animals			X	
	Freshwater Wetland Communities	X			
	Marine and Estuarine Submerged Aquatic Veg.	X			
	Forest Health	X			
	Marine Invertebrates				X
	Terrestrial Invertebrates				X
	Marine and Estuarine Fish		X		
	Amphibians	X			
	Non T&E Reptiles				X
	Migratory Birds	X			
	Resident Birds	X			
	Non T&E Small Mammals				X
	Terrestrial Vegetation	X			
	T&E Rare Birds			X	
	T&E Rare Plats			X	
	T&E Rare Reptiles		X		
Human Use	Visitor Usage				X
Landscapes (Ecosystem Pattern and Processes)	Fire and Fuel Dynamics	X			
	Land Cover/Land Use	X			
	Soundscape				X

[A] **Category 1** represents Vital Signs for which the network will develop protocols and implement monitoring.

[B] **Category 2** represents Vital Signs that are monitored by PAIS, another NPS program, or by another federal or state agency using other funding.

[C] **Category 3** represents high-priority Vital Signs for which monitoring will likely be done in the future.

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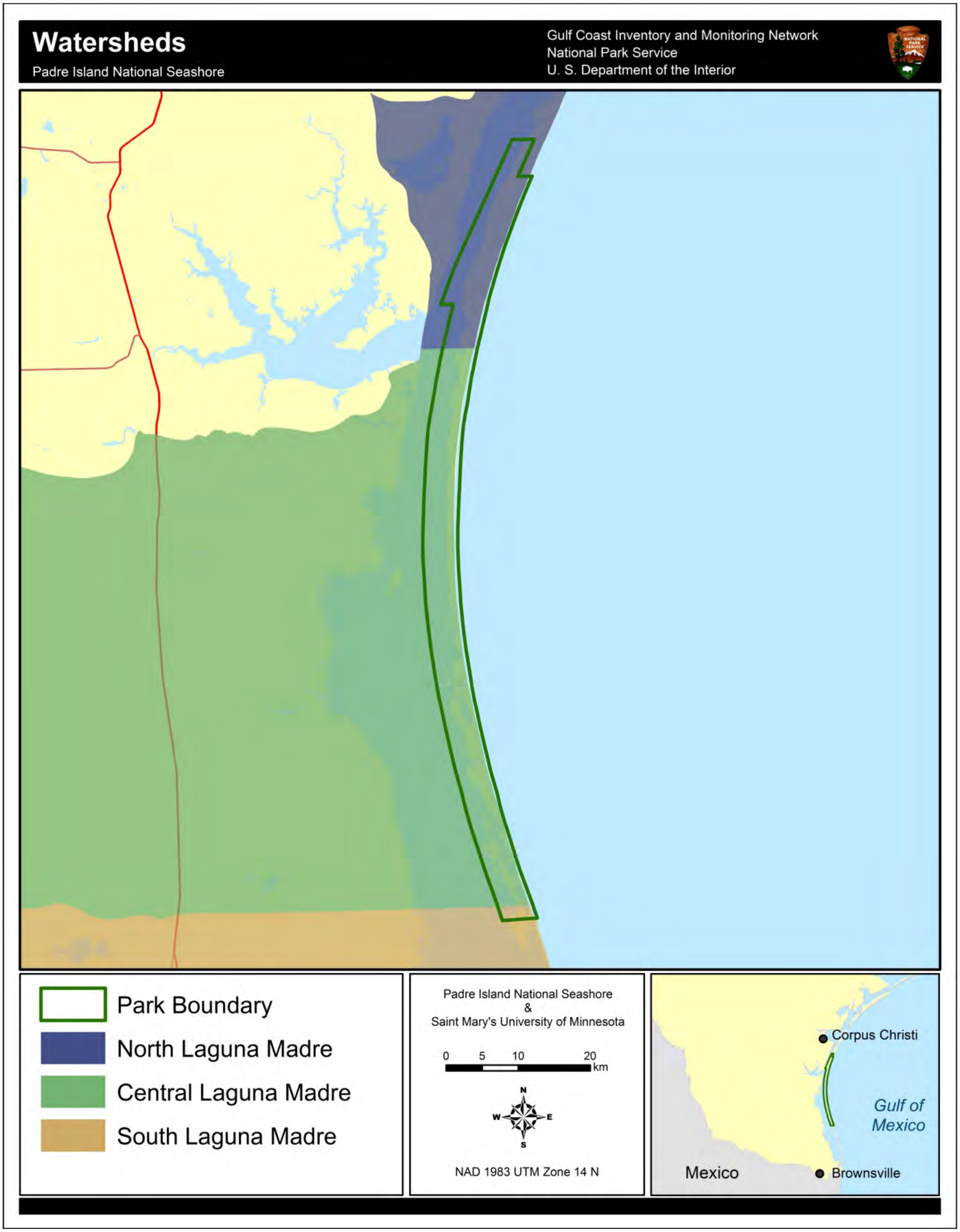

Plate 1. The three watersheds that occur within park boundaries (USGS 1994).

Chapter 3 Study Scoping and Design

This NRCA is a collaborative project between the NPS and Saint Mary's University of Minnesota Geospatial Services (SMUMN GSS). Project stakeholders include the PAIS resource management team and GULN Inventory and Monitoring Program staff. Before embarking on the project, it was necessary to identify the specific roles of the NPS and SMUMN GSS. Preliminary scoping meetings were held, and a task agreement and a scope of work document were created cooperatively between the NPS and SMUMN GSS.

3.1 Preliminary Scoping

A preliminary scoping meeting was held on 12-13 December 2011. At this meeting, SMUMN GSS and NPS staff confirmed that the purpose of the PAIS NRCA was to evaluate and report on current conditions, critical data and knowledge gaps, and selected existing and emerging resource condition influences of concern to PAIS managers. Certain constraints were placed on this NRCA, including the following:

- Condition assessments are conducted using existing data and information;
- Identification of data needs and gaps is driven by the project framework categories;
- The analysis of natural resource conditions includes a strong geospatial component;
- Resource focus and priorities are primarily driven by PAIS resource management;

This condition assessment provides a "snapshot-in-time" evaluation of the condition of a select set of park natural resources that were identified and agreed upon by the project team. Project findings will aid PAIS resource managers in the following objectives:

- Develop near-term management priorities (how to allocate limited staff and funding resources);
- Engage in watershed or landscape scale partnership and education efforts;
- Consider new park planning goals and take steps to further these;
- Report program performance (e.g., Department of Interior Strategic Plan "land health" goals, Government Performance and Results Act [GPRA]).

Specific project expectations and outcomes included the following:

- For key natural resource components, consolidate available data, reports, and spatial information from appropriate sources including PAIS resource staff, the NPS Integrated Resource Management Application (IRMA) website, Inventory and Monitoring Vital Signs, and available third-party sources. The NRCA report will provide a resource assessment and summary of pertinent data evaluated through this project.

- When appropriate, define a reference condition so that statements of current condition may be developed. The statements will describe the current state of a particular resource with respect to an agreed upon reference point.

- Clearly identify "management critical" data (i.e., those data relevant to the key resources). This will drive the data mining and gap definition process.

- Where applicable, develop GIS products that provide spatial representation of resource data, ecological processes, resource stressors, trends, or other valuable information that can be better interpreted visually.

- Utilize "gray literature" and reports from third party research to the extent practicable.

3.2 Study Design

3.2.1 Indicator Framework, Focal Study Resources and Indicators

Selection of Resources and Measures

As defined by SMUMN GSS in the NRCA process, a "framework" is developed for a park or preserve. This framework is a way of organizing, in a hierarchical fashion, bio-geophysical resource topics considered important in park management efforts. The primary features in the framework are key resource components, measures, stressors, and reference conditions.

"Components" in this process are defined as natural resources (e.g., birds), ecological processes or patterns (e.g., natural fire regime), or specific natural features or values (e.g., geological formations) that are considered important to current park management. Each key resource component has one or more "measures" that best define the current condition of a component being assessed in the NRCA. Measures are defined as those values or characterizations that evaluate and quantify the state of ecological health or integrity of a component. In addition to measures, current condition of components may be influenced by certain "stressors," which are also considered during assessment. A "stressor" is defined as any agent that imposes adverse changes upon a component. These typically refer to anthropogenic factors that adversely affect natural ecosystems, but may also include natural processes or disturbances such as floods, fires, or predation (adapted from GLEI 2010).

During the PAIS NRCA scoping process, key resource components were identified by NPS staff and are represented as "components" in the NRCA framework. While this list of components is not a comprehensive list of all the resources in the park, it includes resources and processes that are unique to the park in some way, or are of greatest concern or highest management priority in PAIS. Several measures for each component, as well as known or potential stressors, were also identified in collaboration with NPS resource staff.

Selection of Reference Conditions

A "reference condition" is a benchmark to which current values of a given component's measures can be compared to determine the condition of that component. A reference condition may be a historical condition (e.g., flood frequency prior to dam construction on a river), an established ecological threshold (e.g., EPA standards for air quality), or a targeted management goal/objective (e.g., a bison herd of at least 200 individuals) (adapted from Stoddard et al. 2006).

Reference conditions in this project were identified during the scoping process using input from NPS resource staff. In some cases, reference conditions represent a historical reference before human activity and disturbance was a major driver of ecological populations and processes, such as “pre-fire suppression.” In other cases, peer-reviewed literature and ecological thresholds helped to define appropriate reference conditions.

Finalizing the Framework

An initial framework was adapted from the organizational framework outlined by the H. John Heinz III Center for Science’s “State of Our Nation’s Ecosystems 2008” (Heinz Center 2008). This initial framework was presented to park resource staff to stimulate meaningful dialogue about key resources that should be assessed. Significant collaboration between SMUMN GSS analysts and NPS staff was needed to focus the scope of the NRCA project and finalize the framework of key resources to be assessed.

The NRCA framework was finalized in March 2012, following acceptance from NPS resource staff. It contains a total of 17 components (Table 4) and was used to drive analysis in this NRCA. This framework outlines the components (resources), most appropriate measures, known or perceived stressors and threats to the resources, and the reference conditions for each component for comparison to current conditions.

Table 4. Padre Island National Seashore natural resource condition assessment framework.

Padre Island National Seashore
Natural Resource Condition Assessment Framework

Component	Expert Contact	Measures (Significance Level)	Stressors	Reference Condition
Biotic Composition				
Ecological Communities				
Terrestrial Vegetative Communities	Jim Lindsay, Wade Stablein	Native plant species richness (3), % coverage of grassland and dune veg (3), % of bare ground (3), extent of oak mott areas (3), presence vs. absence of non-native species (3)	Human disturbance (pedestrian/vehicle), altered fire regime, disease (insects/pests), drought, oil and gas exploration and development	Conditions prior to intensive cattle ranching/grazing on the island
Algal Mats on Mud Flats (wind tidal flats)	Jim Lindsay, Wade Stablein, Travis Clapp (mapping GIS)	Extent of algal mats (3), density and richness of benthic macroinverts. (3)	Off-road vehicle and boat (prop scarring) disturbance, sea-level rise, marine debris, sedimentation, oil/contaminant spills, water quality, oil and gas exploration and development	Conditions like that of Nine-mile hole tidal flats, south of the land-cut tidal flats (these are preserved tidal flats)
Seagrass Community	Jim Lindsay, Wade Stablein, Ken Dunton (UTMSI, Port Aranses)	Species composition (3), % cover (3), canopy height (3)	Light attenuation, water transparency (similar to turbidity) water depth, total susp. solids, chlorophyll A (more present results in more phyto plankton), physiochemical water quality parameters (DO, pH, Salinity, temp), nutrient loading in estuary, oil and gas exploration and development and spills, prop scarring	Undefined
Emergent Wetland and Pond Communites	Jim Lindsay, Wade Stablein	Extent (3), native species composition (3), wetland/pond elevation (3)	Phragmites (Cane), giant reed, drought, oil and gas exploration and development, sand blow over, storm surge, salt water innundation	Undefined
Birds				
Migratory Bird Species	Wade Stablein, David Newstead	Neotropical species abundance and diversity (3), raptor abundance (3), waterfowl abundance (3)	Oil and gas exploration and development, fallout events (weather-related), drought, human disturbance, predation, invasive species, habitat loss/alteration	Undefined
Resident Bird Species	Wade Stablein, David Newstead	Species abundance and diversity (3), species distribution (3), raptor abundance (3), waterfowl abundance (3)	Oil and gas exploration and development, drought, human disturbance, predation, invasive species, habitat loss/alteration	Undefined
Colonial Waterbirds	Wade Stablein, David Newstead, Beau Hardegree (USFWS), Robyn Cobb (USFWS), Chad Stinson (USFWS)	Species abundance and diversity (3), species distribution (3), nesting success (3)	USACE maintanance (sediment) of rookery islands, potential wind farm development offshore, fire ants, human disturbance, predators (coyotes and raccoons), invasive species (plants), erosion, oil spills, marine debris (hasmat)	Undefined

Table 4. Padre Island National Seashore natural resource condition assessment framework (continued).

Padre Island National Seashore
Natural Resource Condition Assessment Framework

	Component	Expert Contact	Measures (Significance Level)	Stressors	Reference Condition
Mammals					
	Coyotes	Jennifer Frey (New Mexico State University), Wade Stablein	Population density (3), distribution (3)	Mercury, red tide, drought, poaching, disease (rabies, heartworm), vehicle collision, habituation to humans (need to be removed)	Conditions prior to intensive cattle ranching/grazing on the island
	Small Mammals	Jennifer Frey (New Mexico State University), Wade Stablein	Distribution (3), density (3), species diversity and abundance (3)	Invasive species, drought, oil and gas development/exploration, predation (raptors and coyotes), marine debris (hazmat), flooding and inundation, management actions (e.g., prescribed fire), erosion	Conditions prior to intensive cattle ranching/grazing on the island
Aquatics					
	Macroinvertebrates	Kim Withers, Jim Lindsay	Distribution (3), density (3), species diversity and abundance (3)	Vehicle disturbance on dunes/beaches, flooding in wind blown tidal flats, chemical spills, algal blooms (red tide, brown tide), habitat loss, soil compaction, sea level rise, water quality and hydrology, recreational impacts (pumps used to extract inverts for fishing)	Undefined
Herptiles					
	Reptiles	Jim Lindsay	Species abundance and diversity (3), species distribution (3), reproductive success (3), sex ratio (3)	Flooding and salt-water innundation, erosion, human disturbance, vehicle strikes, chemical spills, hazmat, drought, predation, habitat loss, disease, oil and gas development/exploration	Conditions prior to intensive cattle ranching/grazing on the island
	Sea Turtles	Donna Shaver	Number of nests (3), number of hatchlings released (3), diversity and distribution (3), abundance (3), density (3)	Beach driving, oil spills, shrimp nets and boats, commercial fishing, marine debris, extreme weather (cold stunning events), harmful algal blooms, predation, human disturbance (boat traffic) and poaching potential, dredging, disease	Established management objectives for nesting success and population growth within park boundaries for each species of sea turtle present in the park
	Amphibians	Jim Lindsay, Robert Woodman (GULN), Wade Stablein	Species abundance and diversity (3), species distribution (3), reproductive success (3) age class structure (3)	Flooding and salt-water innundation, erosion, human disturbance, vehicle strikes, chemical spills, hazmat, drought, predation, habitat loss, disease, oil and gas development/exploration	Conditions prior to intensive cattle ranching/grazing on the island

Table 4. Padre Island National Seashore natural resource condition assessment framework (continued).

Padre Island National Seashore
Natural Resource Condition Assessment Framework

Component	Expert Contact	Measures (Significance Level)	Stressors	Reference Condition
Environmental Quality				
Water Quality	Joe Meiman (GULN)	Dissolved oxygen (3), temperature (3), pH (3), salinity (3), turbidity (3), nutrients (3)	Oil and gas exploration and development, boat traffic, dredging, spills, natural events (hurricanes - major inundations), depletion of seagrass, fish kills	Texas state water quality standards
Air Quality	Ellen Porter (NPS Air Resources Division)	Ozone (3), mercury (3), atmospheric dep. of N and S (3), particulate matter (3), visibility (3)	Harmful algal blooms, power plants, oil and gas exploration and development, fires, vehicle emissions, fish kills	National Air Quality Standards, Texas state standards (TCEQ)
Dark Night Skies	NPS Night Skies Team	NPS NST Suite of Measures (3)	Oil and gas exploration and development, recreational lights (fishing), new lightbulb regulations (blue lights)	NPS Dark Night Skies Program guidelines
Physical Characteristics				
Geologic & Hydrologic				
Coastal Dunes and Beaches	Jim Lindsay, Diana Del Angel (Texas A&M), Jeff Bracewell (GULN)	change in shoreline position (3), dune migration (3), rate of deposition/erosion (3)	Vehicle disturbance, dredging and dredge spoil, storm surges, loss of vegetation, human disturbance, marine debris, drought, oil spills, relative sea level rise, off shore sand mining (deprive shores of sediments), dams on rivers (restricting flow of sediment), proposed off shore wind farm	Unnecessary due to the highly dynamic nature of the landscape

3.2.2 General Approach and Methods

This study involved gathering and reviewing existing literature and data relevant to each of the key resource components included in the framework. No new data were collected for this study; however, where appropriate, existing data were further analyzed to provide summaries of resource condition or to create new spatial representations. After all data and literature relevant to the measures of each component were reviewed and considered, a qualitative statement of overall current condition was created and compared to the reference condition when possible.

Data Mining

The data mining process (acquiring as much relevant data about key resources as possible) began at the initial scoping meeting, at which time PAIS staff provided data and literature in multiple forms, including: NPS reports and monitoring plans, reports from various state and federal agencies, published and unpublished research documents, databases, tabular data, and charts. GIS data were provided by NPS staff. Additional data and literature were also acquired through online bibliographic literature searches and inquiries on various state and federal government websites. Data and literature acquired throughout the data mining process were inventoried and analyzed for thoroughness, relevancy, and quality regarding the resource components identified at the scoping meeting.

Data Development and Analysis

Data development and analysis was highly specific to each component in the framework and depended largely on the amount of information and data available for the component and recommendations from NPS reviewers and sources of expertise including NPS staff from PAIS and the GULN. Specific approaches to data development and analysis can be found within the respective component assessment sections located in Chapter 4 of this report.

Scoring Methods and Assigning Condition

Significance Level

A set of measures are useful in describing the condition of a particular component, but all measures may not be equally important. A “Significance Level” represents a numeric categorization (integer scale from 1-3) of the importance of each measure in assessing the component’s condition; each Significance Level is defined in Table 5. This categorization allows measures that are more important for determining condition of a component (higher significance level) to be more heavily weighted in calculating an overall condition. Significance Levels were determined for each component measure in this assessment through discussions with park staff and/or outside resource experts.

Table 5. Scale for a measure’s significance level in determining a components overall condition.

Significance Level (SL)	Description
1	Measure is of low importance in defining the condition of this component.
2	Measure is of moderate importance in defining the condition of this component.
3	Measure is of high importance in defining the condition of this component.

Condition Level

After each component assessment is completed (including any possible data analysis), SMUMN GSS analysts assign a Condition Level for each measure on a 0-3 integer scale (Table 6). This is based on all the available literature and data reviewed for the component, as well as communications with park and outside experts.

Table 6. Scale for condition level of individual measures.

Condition Level (CL)	Description
0	Of **NO** concern. No net loss, degradation, negative change, or alteration.
1	Of **LOW** concern. Signs of limited and isolated degradation of the component.
2	Of **MODERATE** concern. Pronounced signs of widespread and uncontrolled degradation.
3	Of **HIGH** concern. Nearing catastrophic, complete, and irreparable degradation of the component.

Weighted Condition Score

After the Significance Levels (SL) and Condition Levels (CL) are assigned, a Weighted Condition Score (WCS) is calculated via the following equation:

$$WCS = \frac{\sum_{i=1}^{\#\ of\ measures} SL_i * CL_i}{3 * \sum_{i=1}^{\#\ of\ measures} SL_i}$$

The resulting WCS value is placed into one of three possible categories: condition of no to low concern (WCS = 0.0 – 0.33); condition of moderate concern (WCS = 0.34 - 0.66); and condition of significant concern (WCS = 0.67 to 1.00). Figure 2 displays all of the potential graphics used to represent a component's condition in this assessment. The colored circles represent the categorized WCS; red circles signify a significant concern, yellow circles a moderate concern and green circles a condition of low concern. Gray circles are used to represent situations in which SMUMN GSS analysts and park staff felt there was currently insufficient data to make a statement about the condition of a component. The arrows inside the circles indicate the trend of the condition of a resource component, based on data and literature from the past 5-10 years, as well as expert opinion. An upward pointing arrow indicates the condition of the component has been improving in recent times. A right-pointing arrow indicates a stable condition or trend and an arrow pointing down indicates a decline in the condition of a component in recent times. These are only used when it is appropriate to comment on the trend of condition of a component. A gray, triple-pointed arrow is reserved for situations in which the trend of the component's condition is currently unknown.

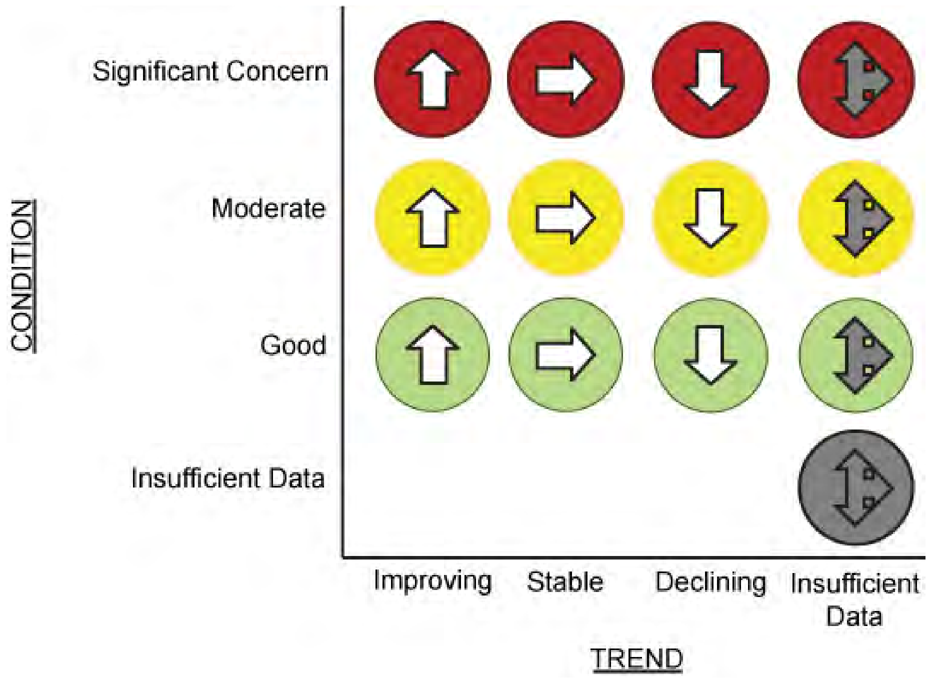

Figure 2. Symbols used for individual component assessments with condition or concern designations along the vertical axis and trend designations along the horizontal.

Preparation and Review of Component Draft Assessments

The preparation of draft assessments for each component was a highly cooperative process among SMUMN GSS analysts and PAIS and GULN staff. Though SMUMN GSS analysts rely heavily on peer-reviewed literature and existing data in conducting the assessment, the expertise of NPS resource staff also plays a significant and invaluable role in providing insights into the appropriate direction for analysis and assessment of each component. This step is especially important when data and/or literature are limited for a resource component.

The process of developing draft documents for each component began with a detailed phone or conference call with an individual or multiple individuals considered local experts on the resource components under examination. These conversations were a way for analysts to verify the most relevant data and literature sources that should be used and also to formulate ideas about current condition with respect to the NPS staff opinions. Upon completion, draft assessments were forwarded to component experts for initial review and comments.

Development and Review of Final Component Assessments

Following review of the component draft assessments, analysts used the review feedback from resource experts to compile the final component assessments. As a result of this process, and based on the recommendations and insights provided by PAIS resource staff and other experts, the final component assessments represent the most relevant and current data available for each component and the sentiments of park resource staff and resource experts.

Format of Component Assessment Documents

All resource component assessments are presented in a standard format. The format and structure of these assessments is described below.

Description
This section describes the relevance of the resource component to the park and the context within which it occurs in the park setting. For example, a component may represent a unique feature of the park, it may be a key process or resource in park ecology, or it may be a resource that is of high management priority in the park. Also emphasized are interrelationships that occur among the featured component and other resource components included in the NRCA.

Measures
Resource component measures were defined in the scoping process and refined through dialogue with resource experts. Those measures deemed most appropriate for assessing the current condition of a component are listed in this section, typically as bulleted items.

Reference Conditions/Values
This section explains the reference condition determined for each resource component as it is defined in the framework. Explanation is provided as to why specific reference conditions are appropriate or logical to use. Also included in this section is a discussion of any available data and literature that explain and elaborate on the designated reference conditions. If these conditions or values originated with the NPS experts or SMUMN GSS analysts, an explanation of how they were developed is provided.

Data and Methods
This section includes a discussion of the data sets used to evaluate the component and if or how these data sets were adjusted or processed as a lead-up to analysis. If adjustment or processing of data involved an extensive or highly technical process, these descriptions are included in an appendix for the reader or a GIS metadata file. Also discussed is how the data were evaluated and analyzed to determine current condition (and trend when appropriate).

Current Condition and Trend
This section presents and discusses in-depth key findings regarding the current condition of the resource component and trends (when available). The information is presented primarily with text but is often accompanied by detailed maps or plates that display different analyses, as well as graphs, charts, and/or tables that summarize relevant data or show interesting relationships. All relevant data and information for a component is presented and interpreted in this section.

Threats and Stressor Factors
This section provides a summary of the threats and stressors that may impact the resource and influence to varying degrees the current condition of a resource component. Relevant stressors were described in the scoping process and are outlined in the NRCA framework. However, these are elaborated on in this section to create a summary of threats and stressors based on a combination of available data and literature, and discussions with resource experts and NPS natural resources staff.

Data Needs/Gaps
This section outlines critical data needs or gaps for the resource component. Specifically, what is discussed is how these data needs/gaps, if addressed, would provide further insight in determining the current condition or trend of a given component in future assessments. In some cases, the data needs/gaps are significant enough to make it inappropriate or impossible to

determine condition of the resource component. In these cases, stating the data needs/gaps is useful to natural resources staff seeking to prioritize monitoring or data gathering efforts.

Overall Condition

This section provides a qualitative summary statement of the current condition that was determined for the resource component using the WCS method. Condition is determined after thoughtful review of available literature, data, and any insights from NPS staff and experts, which are presented in the Current Condition and Trend section. The Overall Condition section summarizes the key findings and highlights the key elements used in determining and justifying the level of concern, if any, that analysts attribute to the condition of the resource component. Also included in this section are the graphics used to represent the component condition.

Sources of Expertise

This is a listing of the individuals (including their title and affiliation with offices or programs) who had a primary role in providing expertise, insight, and interpretation to determine current condition (and trend when appropriate) for each resource component.

Literature Cited

This is a list of formal citations for literature or datasets used in the analysis and assessment of condition for the resource component. Note, citations used in appendices and plates referenced in each section (component) of Chapter 4 are listed in that section's "Literature Cited" section.

Literature Cited

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Chapter 4 Natural Resource Conditions

This chapter presents the background, analysis, and condition summaries for the 17 key resource components in the project framework. The following sections discuss the key resources and their measures, stressors, and reference conditions. The summary for each component is arranged around the following sections:

1. Description
2. Measures
3. Reference Condition
4. Data and Methods
5. Current Condition and Trend (including threats and stressor factors, data needs/gaps, and overall condition)
6. Sources of Expertise
7. Literature Cited

The order of components follows the project framework (Table 4):

4.1 Terrestrial Vegetative Communities
4.2 Algal Mats on Mud Flats
4.3 Seagrass Community
4.4 Emergent Wetland and Pond Communities
4.5 Migratory Birds
4.6 Resident Birds
4.7 Colonial Water Birds
4.8 Coyotes
4.9 Small Mammals
4.10 Macroinvertebrates
4.11 Reptiles
4.12 Sea Turtles
4.13 Amphibians
4.14 Water Quality
4.15 Air Quality
4.16 Dark Night Skies
4.17 Coastal Dunes and Beaches

4.1 Terrestrial Vegetative Communities

Description

Photo 2. A grassland in PAIS, with vegetated dunes in the background (photo by Shannon Amberg, SMUMN GSS).

The terrestrial vegetative communities of PAIS can generally be divided into two broad categories: vegetated dunes and interior grasslands. Little vegetation is found on the beach due to winds, tides, and storms; those species that are present must be salt tolerant (NPS 2010). Vegetation stabilizes dune formations by rooting into the sand and holding it in place (Baccus et al. 1977). Common plant species in the dunes include seaoats, bitter panicgrass, gulfdune paspalum, and morning-glories (*Ipomoea* spp.) (Baccus 1977, NPS 2010). Much of the island's interior is dominated by grassland, with species such as red lovegrass, bushy bluestem, shore little bluestem (*Schizachyrium scoparium* var. *littorale*), cordgrasses (*Spartina* spp.), and coastal indigo (*Indigofera miniata*), as well as gulfdune paspalum and seaoats (Carls et al. 1991, NPS 2010). Several relict live oak (*Quercus fusiformis*) mottes also occur within PAIS (Nelson et al. 2000). A geographic profile of the island and its vegetation types is shown in Figure 3.

Measures

- Native plant species richness
- Percent coverage of grassland and dune vegetation
- Percent of bare ground
- Extent of oak motte areas
- Presence vs. absence of non-native species

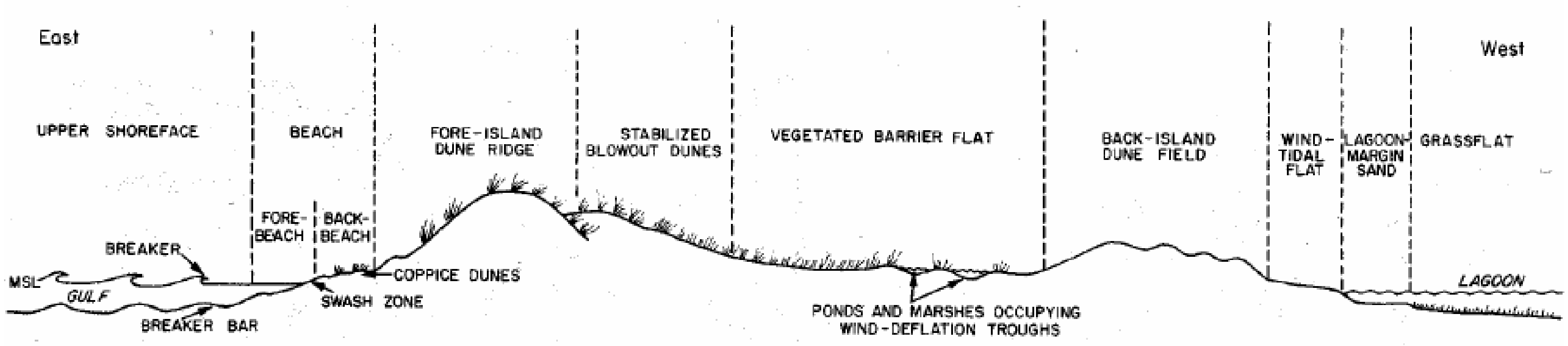


Figure 3. A geographic profile of Padre Island with typical vegetation communities (NPS 2001, adapted from Weise and White 1980). MSL = mean sea level.

Reference Conditions/Values

The reference condition for the park's terrestrial vegetative communities will be the condition prior to intensive cattle ranching/grazing (late 1800s through 1971). Historical records from early explorers of the island suggest that it was "originally well covered with tall grass" (Recenthin and Passey 1967, as cited in Kattner 1973, p. 1).

Data and Methods

Descriptions of the park's vegetative communities from the 1970s and early 1980s were found in Kattner (1973), Baccus et al. (1977), and Drawe et al. (1981). The park's vegetation was also sampled and described by Carls et al. (1991) and Nelson et al. (2000), who focused particularly on the Big Ball Hill Region south of the Visitor Center. Drawe and Kattner (1978) and Lonard et al. (2004) studied the effects of fire on the park's terrestrial vegetation, while McAtee (1974) and McAtee and Drawe (1981) explored the impacts of vehicle and pedestrian traffic at PAIS.

The first landcover classification for the park was completed by Laine and Ramsey (1998), and provides information on the extent of grassland and sparse (i.e., dune) vegetation in PAIS based on mid-1990s aerial photography. Laine and Ramsey (1998) followed classification and interpretation protocols developed by the National Oceanic and Atmospheric Administration (NOAA) Coastal Change and Analysis Project (C-CAP) program and used map descriptions that fit National Vegetation Classification Standard (NVCS) guidelines. Since 2000, several vegetation maps of selected areas within the park have been created for energy development proposals (Plate 2). However, these maps cover just small areas and are not reflective of conditions in the park as a whole. In 2007, the NPS created a surficial geology GIS map for PAIS, based primarily on 2003 aerial photography (NPS 2012). Map classifications are loosely based on land cover and include four classes that could be considered terrestrial vegetative communities (NPS 2007). This map and associated data are considered the most up-to-date and accurate information regarding the distribution of terrestrial vegetative communities in PAIS.

Current Condition and Trend

<u>Native Plant Species Richness</u>

Several researchers have sampled the terrestrial vegetative communities of PAIS and documented species richness by habitat type. These studies occurred in different areas of the park with some differences in methodologies and are therefore not directly comparable, but provide a broad picture of native species richness within PAIS. Species lists for the dunes and interior grasslands are included as Appendix A.

A total of 115 native plant species have been documented in the dune and grassland habitats of PAIS by the sources discussed in this assessment (Appendix B), including two species (*Flaveria brownii* and *Sporobolus tharpii*) endemic to western Gulf of Mexico barrier islands (Nelson et al. 2000). While the dune and grassland habitats have many plant species in common, the grasslands appear to be slightly more diverse. Approximately 100 plant species have been documented in PAIS grasslands, while just less than 70 species are known to occur in the dunes.

<u>Percent Coverage of Grassland and Dune Vegetation</u>

Some of the first estimates of grassland and dune vegetation coverage in PAIS come from the 1998 landcover mapping and classification project, based on mid-1990s aerial photography

(Laine and Ramsey 1998). The landcover classes that include these two communities are described by Laine and Ramsey (1998) as follows:

- Grassland - areas containing dune hummocks that are densely vegetated with grasses including shore little bluestem, cordgrass species, gulfdune paspalum, bushy bluestem, and others.

- Sparse vegetation - sand dunes of varying height that are sparsely vegetated with shore little bluestem, sea oats, bitter panicgrass, other grasses and forbs.

According to this landcover GIS data, grassland covered 5,549.2 ha (13,712.4 ac) or approximately 10.5% of the park while dune or sparse vegetation covered 2,392.8 ha (5,912.7 ac), approximately 4.5% of the park (Plate 3 and Plate 4).

In 2007, the NPS created a surficial geology map for PAIS, based primarily on 2003 aerial photography (NPS 2012a). This classification system included three terrestrial vegetation mapping units: fore-island dune ridge, sparsely vegetated barrier flat, and vegetated barrier flat. All grassland area would be included in the latter category, while dune vegetation includes the first two units and perhaps some of the vegetated barrier flats as well. The vegetated barrier flat unit included several wetland subunits, which were excluded from this area analysis (but will be included in section 4.6 of this assessment). The non-wetland portions of these three mapping units cover a total of 12,250 ha (30,272.6 ac) within the park. The area of each map unit is shown in Table 7 and Plate 6.

Table 7. Area of terrestrial vegetation mapping units, according to surficial geology GIS data (NPS 2007).

Map Unit	Area (ha)	% of park
Fore-island dune ridge	176.4	0.3
Sparsely vegetated barrier flat	998.5	1.9
Vegetated barrier flat (non-wetland)	11,076.0	21.0
Total	12,250.9	23.2

<u>Percent of Bare Ground</u>

Very few studies have addressed the percentage of bare ground in PAIS terrestrial vegetative communities. Only Drawe et al. (1981) documented the percent of bare ground in various terrestrial habitats. Their study included three habitats that could be considered terrestrial, non-wetland communities: coastal dunes, low coastal sands, and shoregrass flats. Of these three habitats, the coastal dunes exhibited the most bare ground with 52% cover. The shoregrass flats followed with 45% bare ground, while the low coastal sands habitat consisted of just 18% bare ground (Drawe et al. 1981). Vegetation sampling during the summer of 2012 collected some data regarding bare ground coverage, but this has not yet been analyzed or published.

Photo 3. Dune vegetation at PAIS, with bare ground exposed (photo by Shannon Amberg, SMUMN GSS).

Extent of Oak Motte Areas

According to Kattner (1973), Padre Island historically supported an extensive live oak forest. In the early 1970s, several sizable oak mottes (clonal groves) existed in the northern portion of the island, with a few smaller mottes in the southern part (Kattner 1973). These are believed to be remnants of the historic live oak forest (NPS 1996). To date, PAIS staff have mapped the locations of two remaining oak mottes identified as sensitive resources in the northern portion of the park. These are shown in Plate 6. According to 2009 NAIP imagery, these stands are approximately 600 and 900 m^2 in size. Other stands of live oak likely occur further south in the park but have not been investigated thoroughly by PAIS staff or researchers (Stablein, e-mail communication, 29 August 2012).

Presence vs. Absence of Non-Native Species

Forty-eight non-native plant species have been documented within PAIS boundaries (Table 8) (NPS 2012b; Lindsay, written communication, October 2012). However, vegetation sampling efforts in the park’s terrestrial vegetative communities have only recorded two non-natives: Buffelgrass and annual rabbitsfoot grass (Drawe et al. 1981, Nelson et al. 2000). The locations and extent of these non-native species have not been mapped.

Table 8. Non-native species documented in PAIS (NPS 2012b; Lindsay, written communication, October 2012).

Scientific name	Common name	Scientific name	Common name
Pennisetum glaucum	pearl millet	*Chenopodium ambrosioides*	Mexican tea
Sonchus asper	spiny sowthistle	*Cyperus rotundus*	nutgrass
Sonchus oleraceus	common sowthistle	*Bothriochloa ischaemum* var. *songarica*	king ranch bluestem
Cakile lanceolata ssp. *pseudoconstricta*	coastal searocket	*Arundo donax*	giant reed
Nasturtium officinale	watercress	*Avena fatua*	wild oat; flaxgrass
Amaranthus viridis	slender amaranth	*Cynodon dactylon*	bermudagrass
Spergularia echinosperma	brittleseed sandspurry	*Dactyloctenium aegyptium*	Egyptian grass
Bromus catharticus	rescuegrass	*Dichanthium annulatum*	Kleberg's bluestem
Chloris canterai var. *canterai*	Paraguayan windmill grass	*Digitaria bicornis*	Asian crabgrass
Chloris gayana	Rhodes grass	*Parapholis incurva*	curved sicklegrass
Digitaria sanguinalis	hairy crabgrass	*Paspalum dilatatum*	dallisgrass
Eragrostis barrelieri	Mediterranean lovegrass	*Pennisetum ciliare*	buffelgrass
Lolium perenne	perennial ryegrass	*Medicago polymorpha*	bur clover
Polypogon monspeliensis	annual rabbitsfoot grass	*Melilotus albus*	white sweet-clover
Sorghum halepense	Johnson grass	*Melilotus indicus*	annual yellow sweetclover
Leucaena leucocephala	white leadtree	*Nicotiana glauca*	tree tobacco
Lantana camara	largeleaf lantana	*Citrullus colocynthis*	colocynth
Anagallis arvensis	scarlet pimpernel	*Citrullus lanatus* var. *citroides*	watermelon
Tribulus terrestris	puncturevine	*Tamarix chinensis*	five-stamen tamarisk
Cucumis melo	cantaloupe	*Tamarix gallica*	French tamarisk
Tamarix aphylla	Athel tamarisk	*Tamarix ramosissima*	salt cedar
Tamarix canariensis	Canary Island tamarisk	*Schinus terebinthifolius*	Brazilian peppertree
Echinochloa crus-galli	barnyard grass	*Nerium oleander*	oleander
Chenopodium album	lambsquarters	*Casuarina equisetifolia*	beach sheoak

Threats and Stressor Factors

Threats to the park's terrestrial vegetative communities include human traffic (pedestrian and vehicle), oil and gas exploration and development, drought, altered fire regime, and insects and disease. Both pedestrian and vehicle traffic can destroy dune vegetation and impact soils, which can affect species composition and create harsher microenvironments for remaining plants (McAtee and Drawe 1974). Traffic also decreases aboveground and root production, as well as plant cover and diversity, with reductions in cover related to the intensity and type of traffic (McAtee and Drawe 1981). Plant communities in areas with heavy traffic are typically in earlier successional stages than those in similar undisturbed areas (McAtee and Drawe 1981).

Fire was likely a natural and common historic occurrence on Padre Island. However, fires would have become less frequent after human settlement, particularly with the introduction of grazing, which reduces the fine fuels necessary to carry fire. Since the establishment of PAIS and cessation of grazing, plant litter accumulation (Photo 4) and wildfire occurrence in these areas of litter build-up have become a problem for NPS staff (Drawe and Kattner 1978). Fires that occur in areas with excess built-up fuel can be particularly threatening to park resources and visitors. Research suggests that prescribed burning may be helpful in decreasing litter accumulation and wildfire risk, without harming the park's terrestrial vegetative communities (Drawe and Kattner 1978, Lonard et al. 2004).

Photo 4. A grassland in PAIS with heavy litter accumulation due to lack of fire (photo by Shannon Amberg, SMUMN GSS).

Oil and gas development is one of the greatest threats to the park's natural resources (NPS 1996). According to the park's most recent oil and gas management plan (NPS 2001), vegetation disturbance due to drilling pad, access road, and other construction is predicted to impact 45-101 ha (113-250 ac) of PAIS over the next 20 years. The two mapped live oak mottes have been designated as sensitive resources, and no disturbance will be allowed within 152 m (500 ft) of the mottes (NPS 2001). Carls et al. (1990) analyzed the vegetation around oil and gas development sites and access roads in PAIS, and determined that the greatest impacts on vegetation were hard surfacing of sites and alteration of site elevation (given the low relief of the island's ecosystem). A total of 18.6 ha were disturbed by 24 drilling/processing sites and 8.9 ha by 17 access roads at the time of the Carls et al. (1990) survey. The secondary dunes and vegetated flats were the most impacted habitat in the park, with 17 oil and gas sites affecting this vegetation. The primary dunes habitat was impacted by only three sites (Carls et al. 1990). Vegetation communities could also be impacted by potential oil, gas, and other hazardous substance leaks or spills (NPS 2001).

<u>Data Needs/Gaps</u>
There are many data needs related to the park's terrestrial vegetative communities. These include a more in-depth plant species inventory (e.g., species lists by plant community), the current and historic coverage of grassland and dune vegetation, the extent of non-native plant species within the park, and how these non-natives are impacting native communities and ecological processes (e.g., fire, erosion). Data are also needed regarding bare ground coverage within the park's vegetative communities. A survey of 91 vegetation field plots in the park during the summer of

2012 may provide some of this information (Photo 5); an analysis of this work has not yet been published (Arnie Peterson, GULN Vegetation Mapping Coordinator, e-mail communication, 9 November 2012). Further information regarding the isolated oak mottes would also be useful. Potential research topics include change in motte extent over time, genetic status (e.g., are the individual mottes genetically unique and, if so, could they hybridize?) (Cooper et al. 2005), and factors threatening their continued existence.

Photo 5. A vegetation sampling transect through a PAIS grassland (NPS photo).

Overall Condition

Native Species Richness

The project team defined the *Significance Level* for native species richness as a 3. A total of 115 native species have been confirmed in the park's terrestrial vegetative communities by the sources discussed in this assessment. There is no evidence that species richness has changed during the past several decades; however, these habitats have not been sampled since the early 2000s. Due to this lack of recent data, a *Condition Level* was not assigned for this measure.

Percent Coverage of Grassland and Dune Vegetation

The project team defined the *Significance Level* for percent coverage of grassland and dune vegetation as a 3. A comparison of landcover (Laine and Ramsey 1998) and surficial geology (NPS 2007) data suggest that overall terrestrial vegetative cover has increased in PAIS over time. However, since surficial geology mapping did not specifically separate grassland and dune vegetation, any changes in the relative percentage of these two cover types cannot be determined (*Condition Level* = N/A). In the absence of disturbance, grasslands may replace dune vegetation over time.

Percent of Bare Ground

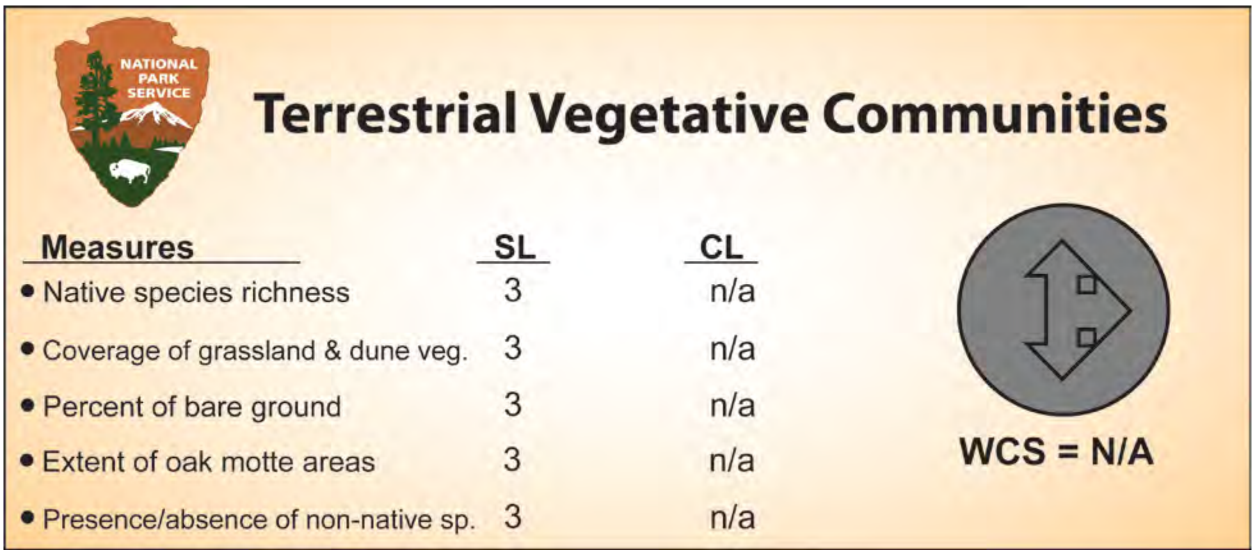
The project team defined the *Significance Level* for percent of bare ground as a 3. Very little information is available regarding bare ground coverage within the park's terrestrial vegetative communities. Therefore, a *Condition Level* could not be assigned for this measure.

Extent of Oak Motte Areas

The project team defined the *Significance Level* for extent of oak motte areas as a 3. Only two oak mottes have been mapped within the park and information on their extent is very limited. A *Condition Level* could not be assigned at this time.

Presence vs. Absence of Non-Native Species
The project team defined the *Significance Level* for presence vs. absence of non-native species as a 3. While 48 non-native species have been confirmed within PAIS boundaries, their locations (e.g., presence in specific community types) and extents have not been studied. As a result, a *Condition Level* was not assigned for this measure.

Weighted Condition Score
A *Weighted Condition Score* was not calculated for PAIS terrestrial vegetative communities, as *Condition Levels* were not assigned for any of the measures. The current condition and trend of this component is unknown.



Sources of Expertise
Wade Stablein, Biological Technician, PAIS

Arnie Peterson, Vegetation Mapping Coordinator, GULN

James Lindsay, Chief of Science and Resource Management, PAIS

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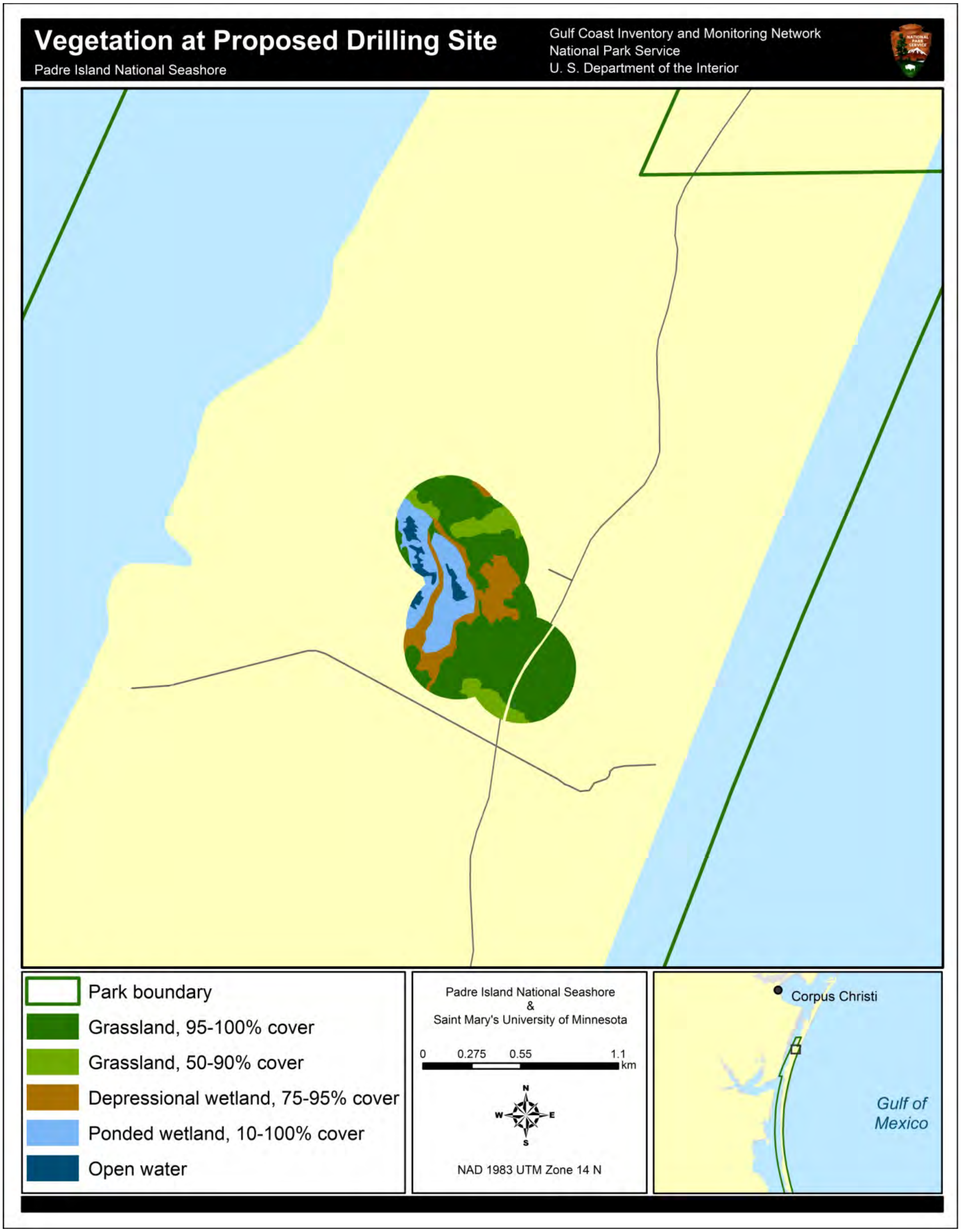


Plate 2. Example of a vegetation map created for an energy development proposal (Boss Operating Company 2007).

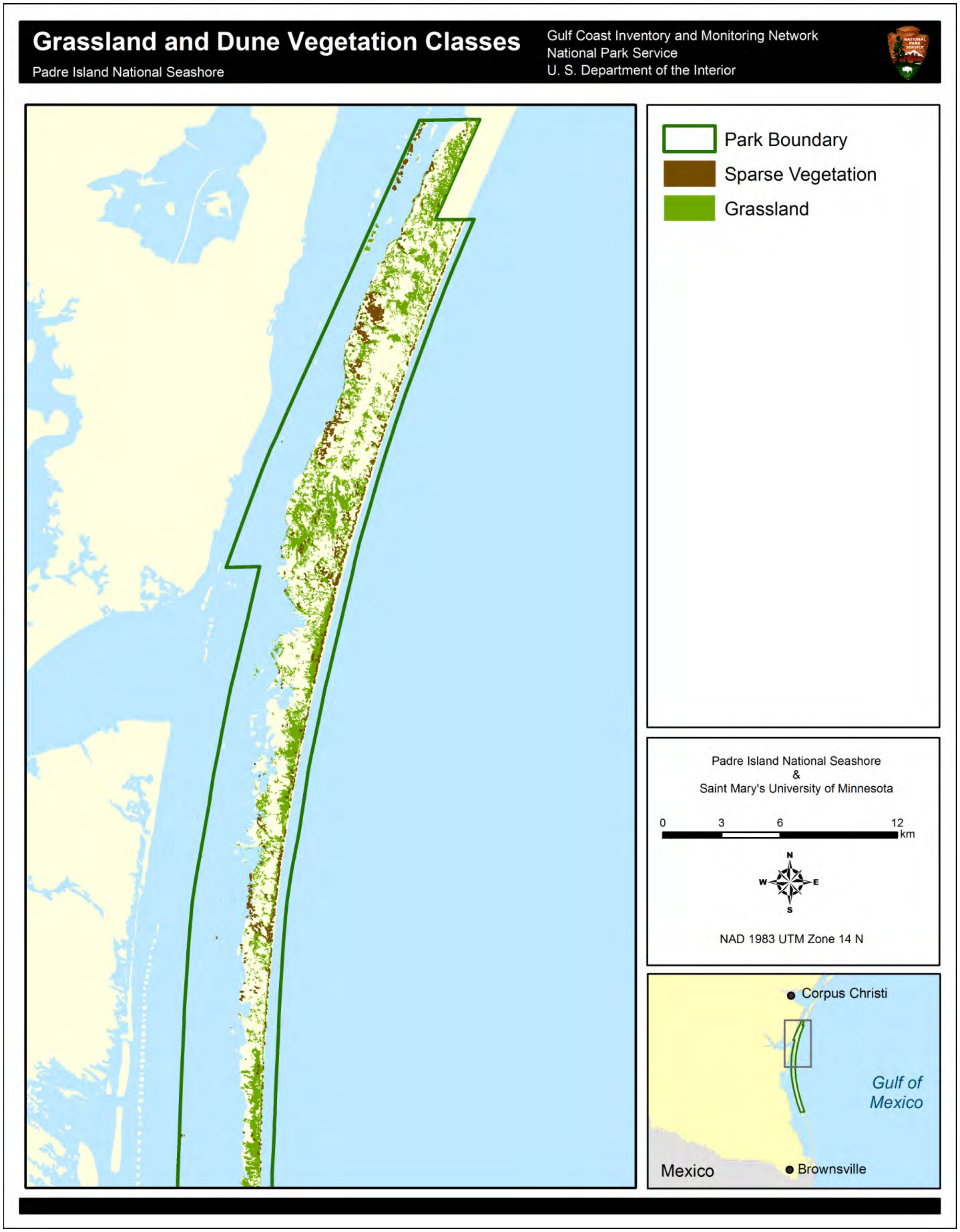


Plate 3. Extent of grassland and dune (sparse) vegetation in the northern half of PAIS (Laine and Ramsey 1998).

Plate 4. Extent of grassland and dune (sparse) vegetation in the southern half of PAIS (Laine and Ramsey 1998)

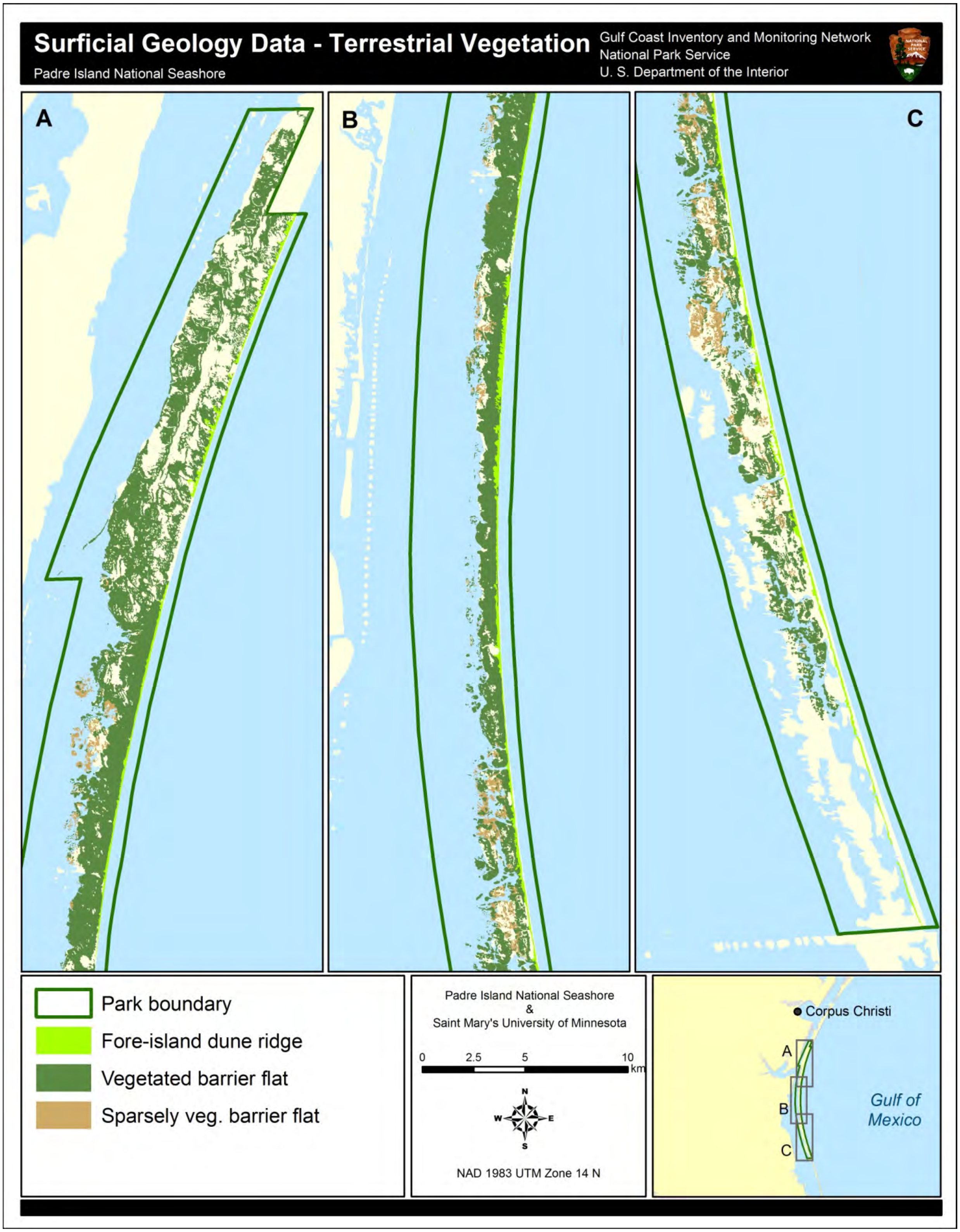


Plate 5. Extent of terrestrial vegetation mapping units, according to NPS surficial geology data (NPS 2007)

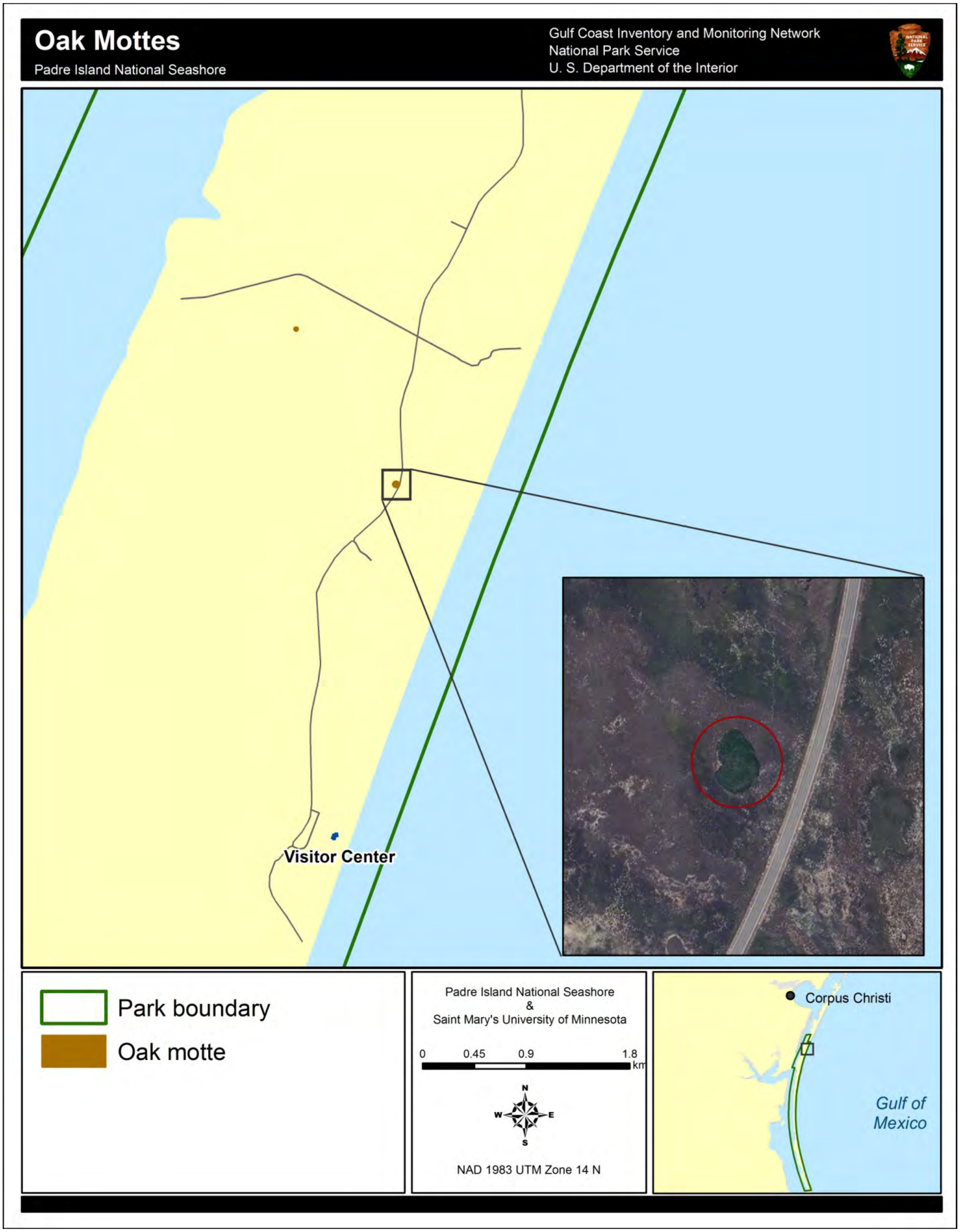


Plate 6. Mapped oak motte locations in the northern portion of PAIS, with an inset showing an aerial photo of one of the mottes.

4.2 Algal Mats of Mud Flats (Wind Tidal Flats)

Description

The wind tidal flats found in PAIS represent a unique habitat; instead of being formed by the tides, these areas are cyclically flooded and exposed in response to wind processes (Withers and Tunnell 1998). The wind tidal flats ecosystem is the second largest ecosystem in the park, spanning 21.7% (11,447 ha [28,287 ac]) of the park's land (NPS 2013). The wind tidal flats in the Laguna Madre are vulnerable due to their proximity to the GIWW because it puts them at a higher risk for petroleum contamination, which would adversely affect algae productivity, waterfowl, and commercial fisheries in the area (Withers 1993).

Photo 6. Dry Algal mats on mud flats in PAIS (Photo by Shannon Amberg, SMUMN GSS).

Blue-green algae (more appropriately referred to as Cyanobacteria) are a group of photosynthetic bacteria that are the primary producers on the flats. Globally, cyanobacteria account for 20-30% of the Earth's photosynthetic productivity (Pisciotta et al. 2010).

Some parts of the wind tidal flats are frequently inundated by water from the Laguna Madre. In these areas, extensive algal mats are often observed. A large accumulation of blue-green algae is referred to as an algal mat. These mats cover a majority of the soil on the wind-tidal flats in the park, and can look like foam, scum, or a layer of film floating on water or soil surfaces. The thickness of these mats varies; in some areas, the algal mat is thick enough to trap hydrogen sulfide gas, which is released from the soil. Pores then form in the soil, causing the surface of the soil to rise (USDA et al. 2005).

The algal mats on these flats contribute the majority of productivity within the estuary, making them important feeding grounds for shorebirds; over 20 species of shorebirds (e.g., red knots [*Calidris canutus*]) occupy the flats seasonally (Withers and Tunnell 1998). Other birds utilize this habitat as well, including the federally protected piping and snowy plovers (*Charadrius melodus*, *C. alexandrinus*), reddish egret (*Egretta rufescens*), white-tailed hawk (*Buteo albicaudatus*), and peregrine falcon (*Falco peregrinus*) (Withers and Tunnell 1998). Benthic invertebrates inhabit the algal mat and provide the link between the primary producers and the consumers (Cooper et al. 2005). Plate 7 displays the extent of wind-tidal flats in PAIS (USGS 2009).

Measures

- Extent of algal mats
- Density and richness of benthic macroinvertebrates

Reference Conditions/Values

The reference condition for the algal mats on tidal flats in PAIS would be the extent of algal mats and the density and richness of benthic macroinvertebrates that occupy the algal mats found at the Nine-mile Hole tidal flats, just south of the land-cut tidal flats.

Data and Methods

Withers (1993) conducted a study on abundance and distribution of benthic macroinvertebrates on a blue-green algal flat along the northern boundary of PAIS. The algal flat was divided into four microhabitats: intertidal, wet, dry or damp areas, and open water. Macroinvertebrates were sampled in three of the four microhabitats twice a month between 1991 and 1992. The open water microhabitat was not sampled for macroinvertebrate abundance or distribution.

Withers (1996) studied the macroinvertebrates of several tidal flats on the Laguna Madre side of PAIS. From November 1995 to March 1996, macroinvertebrate communities were studied at two former drilling sites south of Malaquite Beach to explore the impact of drilling and restoration activities on these organisms. Withers (1996) looked at diversity and density at the restored sites and in nearby control areas.

Withers (1998) investigated the biological productivity of three southerly wind-tidal flats in PAIS between 1997 and 1998. The study included taking core samples from each wind-tidal flat to determine the density of benthic macroinvertebrates. The three flats were located at Yarborough Pass, Dunn Ranch, and at Mile Marker 45. Samples were collected from Yarborough Pass between November 1997 and March 1998. The Dunn Ranch site was sampled between December 1997 and February 1998, and the Mile Marker 45 site was sampled between December 1997 and April 1998.

Laine (1998) created a landcover classification for PAIS, which included wind tidal flats. Each landcover class description matches guidelines set by the National Vegetation Classification System (NVCS). Twelve general class descriptions were used, including wind tidal flat. A three-part map was created using a total of 479 randomly sampled points to classify landcover within PAIS.

Gilbeaut (2010) conducted a study on the transition of estuarine wetland habitat caused by sea-level rise. GIS models were used to measure the loss of tidal flats on Mustang Island and North Padre Island (north of PAIS). A digital elevation model (DEM) was used for elevation reference. The model created estuarine wetland habitat types, which includes tidal flats, based on elevation. The models allow for the adjustment of elevation of the island to simulate sea level rise.

Current Condition and Trend

<u>Extent of Algal Mats</u>

Laine (1998)
Laine (1998) classified 11,298 ha (27,918.40 ac); 21.75% of the National Seashore) as wind tidal flats in PAIS. Algal mats likely do not cover the entire extent of the wind tidal flats, but will only occur in these areas within the park. The flats that become infrequently inundated by wind action are ideal habitat for algal mats. Plate 7 displays the extent of wind tidal flats in PAIS according to Lain (1998).

Withers (1998)
Withers (1998) studied two tidal flat sites (Yarborough Pass, Dunn Ranch) with extensive algal mats covering the surface. The third site (Mile Marker 45) was said to have little algal covering on the surface that still becomes inundated. Some algal mats were also present on the dry areas of Mile Marker 45. Plate 7 displays the approximate locations of Withers' (1998) tidal flats sites along the Laguna Madre.

Gilbeaut (2010)
Gilbeaut (2010) concluded that Mustang Island lost approximately 57% of its tidal flat habitat between 1950 and 2004. As a result of sea-level rise, the low tidal flats became open water during inundation periods. Open water is unsuitable for the growth of blue-green algal mats because algal mats require high levels of light penetration to grow and light levels are reduced in deeper water. While this study may not have been in PAIS, the wind tidal flats around both Padre and Mustang Islands are vulnerable to many of the same factors. It is probable that PAIS wind-tidal flats experienced similar changes during this time.

<u>Density and Richness of Benthic Macroinvertebrates</u>
The macroinvertebrate community of PAIS is discussed in detail in Chapter 4.10 of this document. For this assessment, only a discussion of the studies that sampled the wind tidal flats is included.

Withers (1993)
Withers (1993) documented 38 macroinvertebrate taxa (including tanaids, insects, and polychaetes) in the algal mat/wind tidal flat area on the park's northern boundary (Appendix C). Of the three sampling areas in the study (damp/dry, wet, intertidal), the intertidal sampling area had the highest species richness value (31 sp.), while the damp/dry sampling area had the lowest observed species richness (15 sp.) (Appendix C).

Density ranged greatly throughout the three microhabitats, and throughout the year (0 – 70,000/m^2). The intertidal and wet sampling locations had the greatest density values (reaching 70,000 organisms/m^2), while the damp sampling location only had a peak density of 16 organisms/m^2 (Figures 2a, 3a, and 4a in Withers 1993). Tanaids showed the highest density in all three sampling locations (Withers 1993).

Withers (1996)
Withers (1996) explored the distribution of macroinvertebrates at two former oil and gas development sites that had been restored (See Plate 7). At the Texaco site, six species were found

within the restored area, six in an adjacent control area, and four within tire tracks (Withers 1996, Appendix D). Only insects were found in tire tracks and no mollusks were found at the site. At Yarborough Pass, 27 macroinvertebrate species occurred in the restored area, 13 in the control area, and only six within tire tracks (Withers 1996). Nearly all species found at the control and tire track locations were also present in the restored area (Appendix D).

Withers (1996) noted low densities of most macroinvertebrates at two tidal flats south of Malaquite Beach. On average, less than one polychaete, tanaid, and amphipod were detected per 5.4 x 5 cm sediment core from the Texaco site. Insect larvae were slightly more common, reaching a density of 1.2 per core at control sites in November (Withers 1996). Densities were higher at Yarborough Pass. Peak mean monthly insect density was 15 organisms per core and peak tanaid density was around 100 organisms per core. Polychaete, amphipod, and mollusk densities never exceeded four organisms per core (Withers 1996).

Withers (1998)
Withers (1998) collected 31 species representing four phyla from three tidal flats in 1998. The Yarborough Pass tidal flat had the highest species richness value (25 sp.), while the Dunn Ranch and Mile Marker 45 tidal flats had 14 and 13 species, respectively (Appendix E).

The highest density of benthic macroinvertebrates was recorded at Mile Marker 45. Thirteen species were recorded at this site, and the density was given for the two most abundant phyla of benthic macroinvertebrates. Polychaete density peaked in February at this site with approximately 1,300 organisms/m^2, while mollusk density peaked in March 1998 with approximately 250 organisms/m^2.

Twenty-five macroinvertebrate species were observed at the Yarborough Pass site. Polychaete and tanaid densities peaked in two separate months, as peak polychaete densities were about 350 organisms/m^2 and 550 organisms/m^2 for January and March, respectively; tanaid densities were the highest in January and March with approximate densities of 11,000 organisms/m^2 and 15,000 organisms/m^2, respectively. Dunn Ranch had the lowest density during the study, as polychaete and tanaid densities did not exceed 60 organisms/m^2 for any of the days sampled. The insect density peaked in January with about 190 organisms/m^2. Most macroinvertebrate densities seemed to peak in March, perhaps due to a spring flooding of the tidal flats.

<u>Threats and Stressor Factors</u>
There are several threats to the park's algal mats on mud flats (wind tidal flats). PAIS staff identified seven stressors that have occurred or are presently occurring in the park. Those stressors include off-road vehicle (ORV) and boat disturbances, marine debris, oil/contaminant spills, oil and gas exploration and development, sea-level rise, sedimentation, impaired water quality and/or quantity (water quality is discussed in detail in Chapter 4.14 of this report), and desiccation of the wind tidal flats (a natural process).

Off-road vehicle disturbance is a major stressor to the wind-tidal flats in PAIS. Tire tracks create ditches and trenches that alter the surface hydrology of the wind-tidal flats (NPS 2013). Vehicles can compact soil and cause other habitat destruction on the sensitive beaches and tidal flats of PAIS. This can impact macroinvertebrate communities, as shown in Withers (1996), where fewer species were found in tire tracks than in restored and control areas. The wind-tidal flats are inundated as a result of northerly winds across the Laguna Madre, which, when flooded, allows blue-green algae mats to grow. The trenches caused by ORVs prevent the natural flow of water across the wind-tidal flats (NPS 2012). These algal communities are fragile and very static, often taking a long time to heal after vehicular disturbance (Photo 7). As an example of how static these areas of PAIS are, damage from vehicular traffic seen in aerial photographs taken in the1930s and 1940s is still apparent in modern satellite imagery (Stablein, written communication, 13 May 2013). Further complicating this threat is the fact that there are no known methods for restoration once these communities are damaged (Stablein, written communication, 13 May 2013).

Photo 7. Inundated wind-tidal flats with ORV tire tracks (Photo by Shannon Amberg, SMUMN GSS).

Marine debris can cause light attenuation, deplete oxygen, and alter physical habitat by changing its structure. Marine debris has caused habitat degradation by harming (e.g., smothering, fragmenting), “habitat forming species” such as the algal mats; this process may result in reduced macroinvertebrate populations (Donohue et al. 2001, Asoh et al. 2004, Chiappone et al. 2005, as cited by EPA 2011, p. 9). Algal mats also require shallow waters with a low degree of light attenuation, so increased light attenuation may stop algal mats from forming (NPS 2012). This may also reduce the density and richness of macroinvertebrates that inhabit the algal mats.

Oil spills and oil/gas exploration and development can be a threat to the algal mats on the mud flats in PAIS. Oil spills may cause habitat degradation and poor water quality, and exposure to oil can cause mortality among bivalves, amphipods, and polychaetes (Withers and Tunnell 1998). Oil and gas drilling sites have also altered suitable habitat. According to Carls et al. (1990), drilling sites have affected the elevation near wind tidal flats. If the change in elevation were to cause the flats to flood unevenly or not flood in areas, this could cause a reduction of extent of algal mats in these drier areas.

Sea-level rise poses a threat to the algal mats on wind tidal flats because it may cause permanent inundation if it were to exceed the aggradation rates (Morton and Holmes 2009). According to Glick et al. (2007), sea level rise will cause the extent of wind-tidal flats to decrease, and as a result the extent of algal mats will also decrease due to loss of suitable habitat. Sedimentation may be a threat to algal mats on PAIS. Aggradation is a natural process of sediment accumulation caused by wave action; however, over time this process may cause the area of wind tidal flats to decrease due to increased elevation. Tidal flats decreased in area in the Laguna Madre/Corpus Christi Bay region between the 1950s and 1980; most of the lost tidal flats were replaced by open water or seagrass beds (Withers and Tunnell 1998).

Poor water quality can negatively affect algal mats and the organisms that inhabit them. Water with elevated levels of nitrogen and phosphorous can be harmful to aquatic organisms such as macroinvertebrates (USGS 2013). Eutrophication is a result of excess nutrients in the water, and it can cause harmful algal blooms (red tide) and deplete dissolved oxygen levels, which threaten fish and macroinvertebrate populations (USGS 2013). Drastic declines in mollusk, echinoderm, crustacean, and polychaete populations have been noted in the Gulf of Mexico following red tides (Dupont and Coy 2008).

Data Needs/Gaps

There are limited data for the extent of algal mats on wind-tidal flats and the density and richness of macroinvertebrates in PAIS. Laine (1998) and Withers (1998) are more than 10 years old, and therefore outdated. While the Gilbeaut (2010) study is current, it only focuses on the wind-tidal flats of Mustang Island, which is north of PAIS. Withers (1993, 1996, 1998) conducted a short-term study on benthic invertebrates occurring in the wind-tidal flats. According to Withers (1998, p. 32), short-term studies of benthic macroinvertebrate communities "tend to be inadequate for proper characterization." The macroinvertebrate studies that have occurred in and near PAIS have typically provided single-year "snapshots" of the community at particular locations, which have not been revisited over time. Resampling the sites discussed in this assessment would provide insight into whether or not the macroinvertebrate community has changed over time (i.e., changes in diversity, density, etc.). Longer-term studies of several years would also provide a more detailed picture of the park's macroinvertebrate populations.

Overall Condition

Extent of Algal Mats

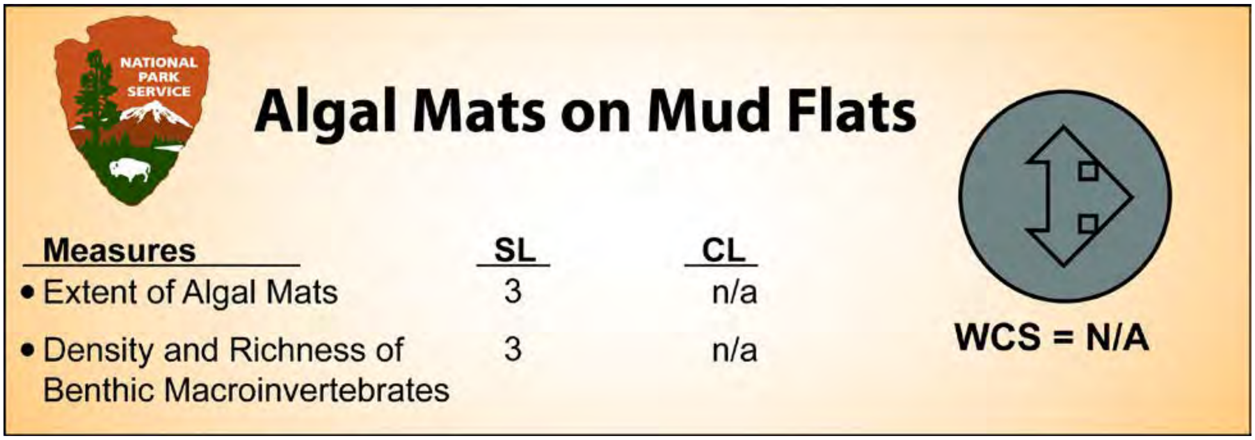
The project team defined the *Significance Level* for extent of algal mats as a 3. It is difficult to get an exact extent of algal mats from the Withers (1998) study; however, if algal mats occupy most of the wind-tidal flats identified in the Laine (1998) document, the algal mats may cover approximately 21% of the park. Gilbeaut (2010) executed a GIS model that estimated a 57% loss in tidal flat extent on Mustang Island between 1950 and 2004, which may mean that the tidal flats in PAIS also suffered a similar loss. There are no studies that give the exact extent of the algal mats on the wind-tidal flats in PAIS. As a result, a *Condition Level* could not be determined for this measure.

Density and Richness of Benthic Macroinvertebrates

The *Significance Level* for density and richness of benthic macroinvertebrates is a 3. As described in the macroinvertebrates assessment (Chapter 4.10), a *Condition Level* could not be assigned for this measure because of a lack of current data. The historic data collected by Withers (1993, 1996, 1998) could be used as a baseline of comparison for future condition assessments.

Weighted Condition Score

The *Weighted Condition Score* for algal mats on mud flats was not calculated due to a lack of current data for all measures.



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James Lindsay, Chief of Science and Resource Management, PAIS

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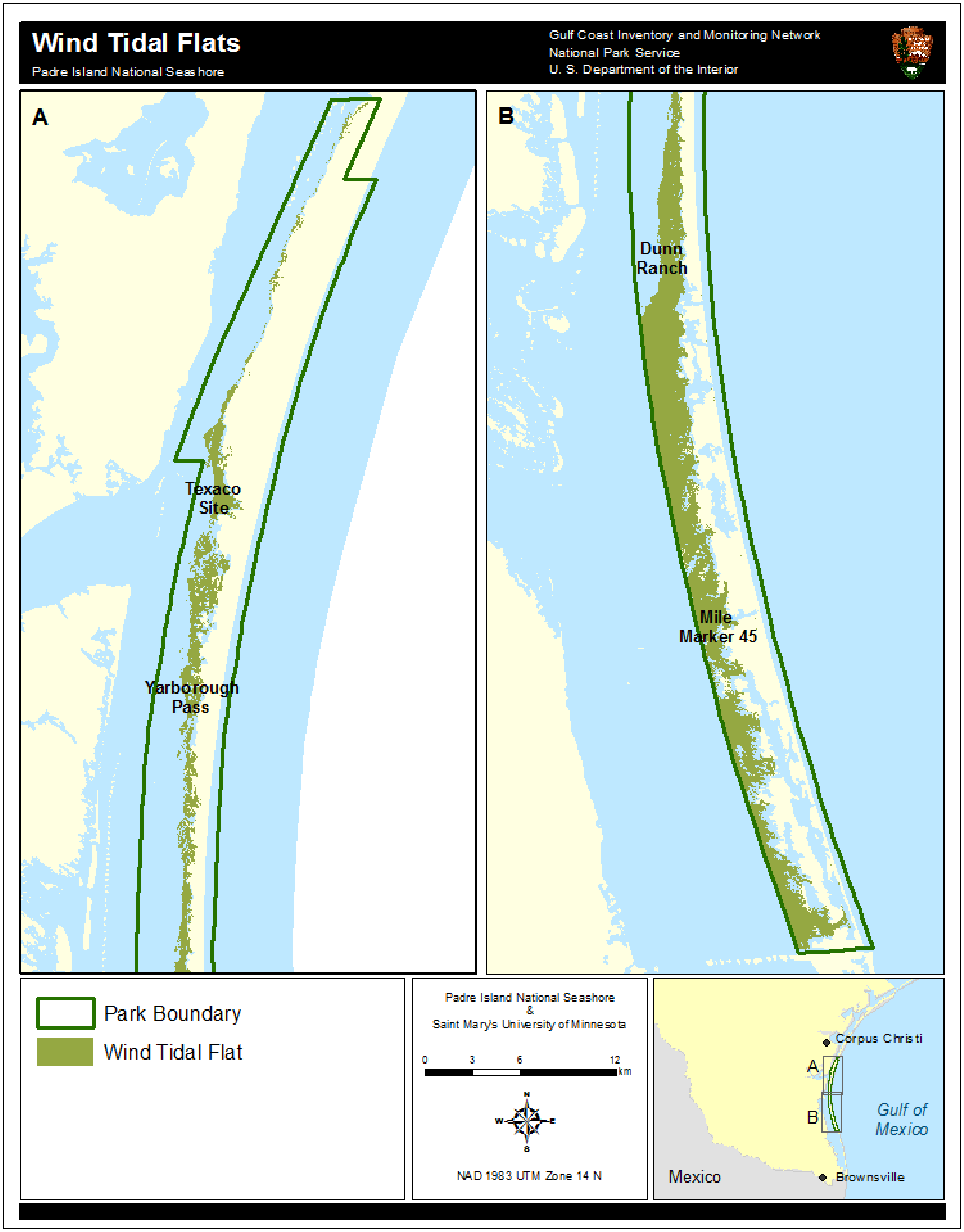


Plate 7. The extent of wind tidal flats in PAIS (USGS 2009), and the approximate locations of Withers' (1996,1998) tidal flats sites along the Laguna Madre.

4.3 Seagrass Community

Description

Seagrass communities are ecologically important because they provide food and protection to marine mammals, birds, fish, and invertebrates, including redhead ducks, red drum (*Sciaenops ocellatus*), and green sea turtles (*Chelonia mydas*) (Handley et al. 2007). According to Blair and White (1997), seagrass communities are also considered ecological indicators of estuarine water quality because they are sensitive to factors such as nutrient loading and eutrophication.

Photo 8. Seagrass bed in the Laguna Madre (Photo by Dr. Ken Dunton, http:// www.texasseagrass.org).

PAIS is located on the southeastern coast of Texas, in the western portion of the Gulf of Mexico. Over 50% of the U.S. seagrass distribution and approximately 5% of the world's seagrass distribution occurs in the Gulf of Mexico (Green and Short 2003, as cited by Handley et al. 2007). The most widespread seagrass beds in the western Gulf of Mexico are found in the Laguna Madre (Onuf 1996). The Laguna Madre supports a variety of seagrass species, including turtle grass, manatee grass, star grass (*Halophila engelmannii*), widgeon grass, and shoal grass (Onuf 2007).

Measures

- Species composition
- Percent cover
- Canopy height

Reference Conditions/Values

Historical accounts indicate that seagrass beds/meadows covered nearly the entire lagoon bottom of the lower Laguna Madre in 1965 (Onuf 2007). However, data recording the changes to the community over time are very limited. A long-term monitoring strategy has been recently (2011) initiated by the GULN through a task agreement with researchers at the University of Texas Marine Science Institute (UTMSI) in Port Aransas, Texas. This will provide insight on current community condition; however, several years of data will be needed to determine condition trends. There is debate among seagrass experts on what characterizes a "healthy" seagrass community and what changes in communities over time may suggest about the community's ability to persist and thrive (Wilson and Dunton 2011). Thus, no reference condition has been defined for the seagrass community in the Laguna Madre in PAIS. The comprehensive survey efforts by GULN could serve as a reference condition for future research efforts.

Data and Methods

Onuf (2007) documented seagrass status and trends in the Laguna Madre. Sampling in the lower Laguna Madre consisted of 22 east-west transects that were set at 0.6 m (2 ft) intervals. Sampling in the upper Laguna Madre consisted of transects set at 0.3 to 1.5 m (1 ft to 5 ft) intervals and perpendicular to the long axis of the lagoon. Four sediment core samples were retrieved from each transect. The study documented species present in each core. Earlier survey source maps were digitized for an analysis of historical trends. Figure 4 displays the two segments of the Laguna Madre.

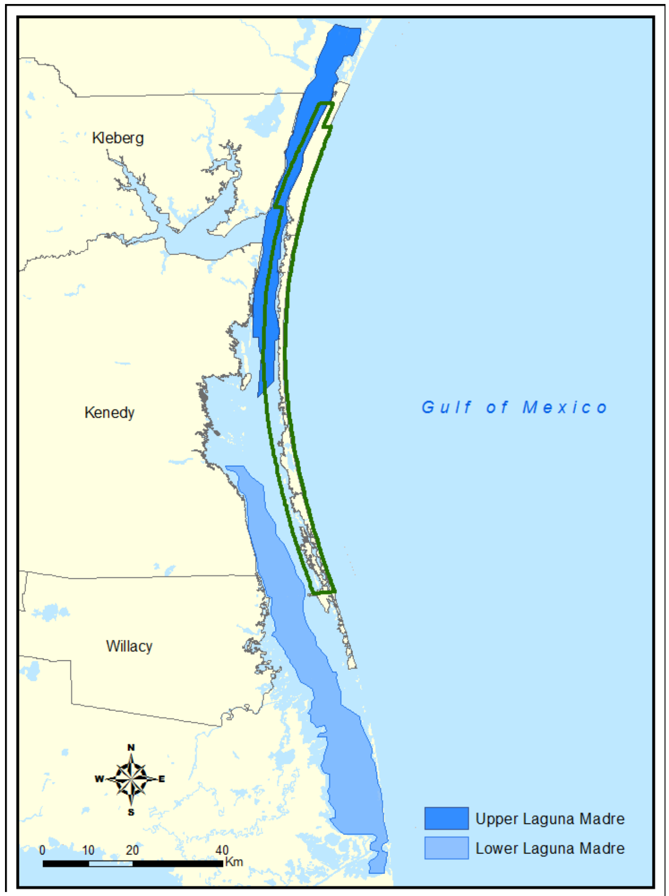


Figure 4. Upper and Lower Laguna Madre in relation to PAIS (Onuf 2007).

Wilson and Dunton (2011) surveyed areas near PAIS as part of a monitoring program for seagrass in Texas. Sampling station locations were distributed among three estuary systems, including the Laguna Madre, which was separated into two segments, Upper Laguna Madre (ULM) and Lower Laguna Madre (LLM). The LLM sampling sites were all located just outside of the park boundaries. Observational data was obtained through field surveys and displayed using GIS to analyze the relationships between study parameters and seagrass habitat.

Current Condition and Trend

<u>Species Composition</u>

Onuf (2007) documented several changes in seagrass community composition since 1965. Species composition has been dynamic, with the historically dominant species (shoal grass) being replaced by manatee grass and turtle grass. By 1998, shoal grass coverage was at just 46%. Turtle grass dominated the southern portion of the lower Laguna Madre, with fringes of shoal grass along the shore and west side of the lagoon. Shoal grass was also present in the middle region of the lower Laguna Madre, where it dominated the shore area. Manatee grass was found at both the north and south ends of the lower Laguna Madre, splitting around the deep bare areas. The upper Laguna Madre's vegetative area only covered 63% of the permanently flooded areas. Shoal grass was the dominant species with 92% coverage in the vegetated area. Manatee grass was found on the north end of the basin, covering 6% of the vegetated area. Star grass was confined to the deep fringe or mid region of the lagoon; it covered 1% of the basin. Widgeon grass, also covering only 1%, was only located in the shallow flats by the GIWW. Table 9 displays the species composition in the lower and upper Laguna Madre in 1998.

Table 9. Seagrass species composition (in hectares) and percent cover of vegetated areas in the lower and upper Laguna Madre in 1998 (Onuf 2007).

	Lower Laguna Madre		Upper Laguna Madre	
Seagrass Species	**Area (Hectares)**	**Percent Cover**	**Area (Hectares)**	**Percent Cover**
Shoal grass	21,118	45.7%	20,553	91.6%
Manatee grass	12,861	27.9%	1,452	6.5%
Turtle grass	11,132	24.1%	N/A	0%
Star grass	1,063	2.3%	307	1.3%
Widgeon grass	N/A	0%	132	0.6%
Total Vegetated	**46,174**	**100%**	**22,444**	**100%**

Wilson and Dunton (2011) documented slightly different seagrass compositions for the two sections of the Laguna Madre. There were five and six seagrass species identified in the lower and upper Laguna Madre, respectively. The seagrass composition in the upper Laguna Madre consists of shoal grass, manatee grass, turtle grass, widgeon grass, and star grass. Unlike the upper basin, there is no star grass present in the lower Laguna Madre. The lower Laguna Madre contains shoal grass, manatee grass, turtle grass, and widgeon grass. Table 10 displays the seagrass compositions (represented by mean percent coverage) in both sections of the Laguna Madre.

Table 10. Seagrass species composition, in the lower and upper Laguna Madre in 2011, represented by mean percent coverage (Wilson and Dunton 2011).

Seagrass Species	**Lower Laguna Madre**	**Upper Laguna Madre**
Shoal grass	25.5 ± 35.7%	60.9 ± 36.9%
Manatee grass	1.4 ± 7.6%	13.6 ± 26.1%
Turtle grass	18 ± 33.4%	0.1 ± 0.6%
Widgeon grass	0.6 ± 3.5%	0.3 ± 1.9%
Star grass	N/A	0.3 ± 1.5%
Total Vegetated	**45.9 ± 40%**	**75.2 ± 30.9%**

Percent Cover

Onuf (2007) documented changes in seagrass coverage since 1965. The lower Laguna Madre has lost vegetative area over the years. In 1965, it was reported that nearly the entire lagoon floor of the lower Laguna Madre was composed of seagrasses. There was an approximate 21% decrease in seagrass cover between the 1960s and 1970s. In 1998, the percent cover of seagrass in the lower and upper Laguna Madre was 67% and 63%, respectively. The percent cover of vegetated bottoms in Laguna Madre as a whole has decreased by 4%, between 1965 and 1998. Bare areas in the lower lagoon have increased from 9,181 ha to 22,761 ha between the 1960s and 1998. The bare area in the upper basin has decreased from 20,826 ha to 12,950 ha between the 1960s and 1998.

Table 11 displays the coverage (in hectares) and percent cover in the lower and upper Laguna Madre.

Table 11. Total coverage (in hectares) and percent cover of bare and vegetated bottoms in the lower and upper Laguna Madre in 1998 (Onuf 2007).

Cover Type	Lower Laguna Madre	Upper Laguna Madre
Bare	22,761 (33%)	12,950 (36. 6%)
Total Vegetated	46,174 (67%)	22,444 (63.4%)
Total	**68,935**	**35,394**

Wilson and Dunton (2011) recorded the percent cover of seagrass in the Laguna Madre. The mean percent cover for upper and lower Laguna Madre was 75.2 ± 30.9% and 45.9 ± 40.0%, respectively. Approximately 32% of the sampling stations recorded less than 10% seagrass coverage in the lower Laguna Madre. In the upper Laguna Madre, there were approximately 10 sampling stations (6.9%) that recorded less than 10% seagrass coverage. There were roughly 48 stations in the lower basin that recorded areas devoid of vegetation; only seven stations in the upper basin recorded areas with no vegetation.

Canopy Height

Wilson and Dunton (2011) documented canopy heights in the lower and upper Laguna Madre. Recorded canopy heights ranged between 3 and 51 cm. Mean canopy heights were 15.7 ± 9.8 cm and 20.1 ± 8.8 cm in the lower and upper Laguna Madre, respectively. Greater canopy heights in the lower Laguna Madre seem to be concentrated in the bottom portion of the basin; greater canopy heights were dispersed throughout the upper Laguna Madre. This difference may have occurred because the lower Laguna Madre has a higher percent of areas with no vegetation, which may count against the average canopy height. It is important to note that canopy height varies among seagrass species, which makes it difficult if not impossible to determine the health of the seagrasses through gross canopy height alone.

Threats and Stressor Factors

The park has identified several potential threats to the park's seagrass communities, including light attenuation, unbalanced physiochemical water quality parameters, nutrient loading in the estuary, oil and gas exploration and development, and hazardous materials.

Light attenuation or reduction in water transparency is a stressor on seagrass communities, since they require a certain amount of light to grow. According to Duarte et al. (2004), reduced water transparency is a primary cause of seagrass loss. Reduced water transparency could be caused by nutrient loading or turbidity. The extent of water transparency can also limit the depth at which seagrass grows (Dunton 2010, FDEP 2011). Bare areas in the lagoon may cause a negative feedback loop because non-vegetated areas are unstable and apt to resuspension of sediment caused by wind-driven waves; this can lead to a decline in seagrass area by preventing future growth in these areas (Onuf 1994, as cited by Teeter 2002). Light attenuation or reduction in transparency/clarity can be caused by a number of factors, some having short-term effects and others having long-term or extended effects. Dredging and channel construction cause sediments to become suspended and allow little light through to the plants; however, most suspended sediments settle in a short amount of time (Pulich et al. 1997). It is believed that nutrient enrichment/loading is another stressor to seagrass, as it encourages algal blooms (phytoplankton)

(Pulich et al. 1997) This algae may grow on the surface of seagrass leaves causing shading from available light (Martha Segura, written communication, 11 April 2013). Algal blooms have the ability to cause light attenuation in a short time period, and they can remain in an area for a long period. An algal bloom called a brown tide was recorded in the upper Laguna Madre between 1990 and 1995. According to Onuf (1996), there was a significant reduction in seagrass biomass between 1991 and 1993. Additional research has also shown that seagrass communities are adversely affected by unrelenting brown tide events (Pulich et al. 1997, as cited by Cooper et al. 2005).

Excess total suspended solids (TSS) and chlorophyll A are threats to seagrass because they reduce water clarity. Total suspended solids are mostly sediments that become resuspended by processes such as wind and waves. Chlorophyll A levels represent the abundance of phytoplankton present (Dunton 2012). Reduced water clarity puts a strain on seagrass photosynthesis (EPA 2012). Seagrass depth can be limited by even low levels of TSS (Burd and Dunton 2000, as cited by Teeter 2002).

According to Handley et al. (2004), the health of seagrass beds is dependent on water quality. Imbalances in water quality parameters, including dissolved oxygen (DO), pH, temperature, and salinity can cause stress on seagrass beds. Some seagrass species are less tolerant to water quality fluctuations than others. Manatee grass is rather intolerant to saline fluctuations, restricting it to the upper Laguna Madre because of its low saline variation (Wilson and Dunton 2011). Species composition shifts have also been known to occur as a result of water quality imbalances (Cooper et al. 2005).

Nutrient loading is a threat resulting from human population growth and development near the coast. A surplus of nutrients causes an imbalance and favors fast-growing organisms, such as phytoplankton and macroalgae (Dunton 2010). The high nutrient concentrations can also cause a shift in vegetation, typically favoring widgeongrass and seaweeds (Fourqurean and Rutton 2003, as cited by Dunton 2010).

Oil and gas exploration and development is another threat caused by anthropogenic activity. The risk of chemical spills increases in areas with oil and gas development, such as barge traffic in the GIWW or offshore oil rigs. Oil could possibly be carried into the Laguna Madre by currents, winds, or storms that follow a spill (SDWF 2012). If oil comes in contact with seagrass beds, it can become trapped in the sediment and kill the seagrass (STC 1995).

Prop scarring also threatens the seagrass communities. Boat propellers can physically damage seagrass leaves and roots or even uproot the plants (TPWD 2012). Most prop scarring occurs in shallow waters (< 1 m) which are favorable for seagrasses (PAIS 2001). According to Martin (2008), prop scarring is an increasing threat in the PAIS area due to increased recreational boating as a result of coastal population growth.

Data Needs/Gaps

There are limited long-term data on seagrass in PAIS. While current data exist, long-term studies are not available. The imagery used by Wilson and Dunton (2011) is outdated (from 2004) and could cause inconsistencies, so updated imagery is recommended for future seagrass mapping. The long-term monitoring program to assess trends in seagrass community composition by the

GULN through the University of Texas Marine Science Institute in Port Aransas will provide substantial insight into how the community is changing over time. The 2012 data from this relatively young monitoring effort was not yet available at the time this assessment was developed, but would provide further insight into the current condition of seagrass communities in the Laguna Madre.

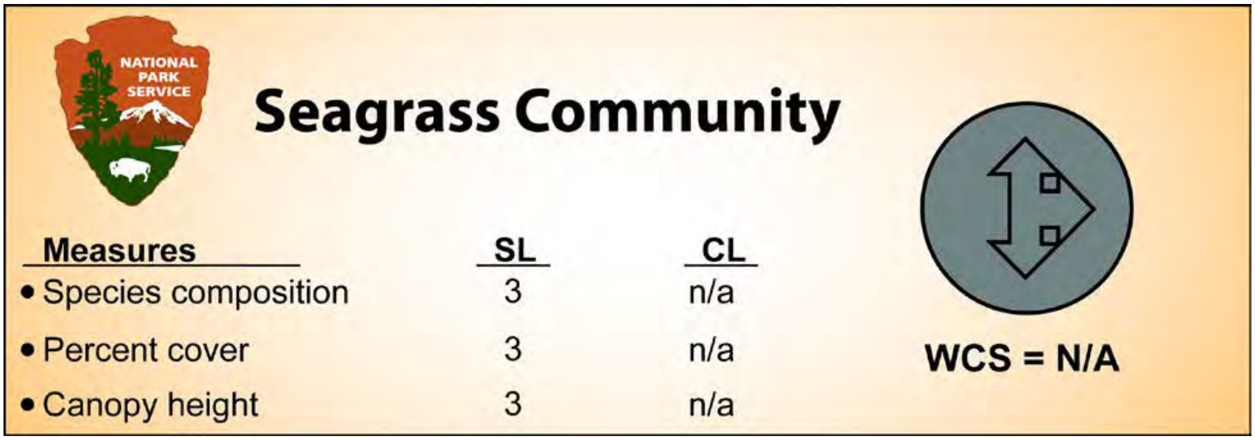
<u>Overall Condition</u>

Species Composition
The project team defined the *Significance Level* for species composition as a 3. The species compositions in both sections of the Laguna Madre have been shifting since the mid 1960s. Shoal grass, for example, has decreased by approximately 31,000 ha (76,603 ac) in the lower basin, but has increased approximately 8,000 ha (19,768 ac) in the upper basin. It is not clear if the shift in species composition is an indication of degrading health of the system or a natural phenomenon. It should be noted that even though the species composition has been shifting, all of the seagrass species that are expected to be in the Laguna Madre are still there (Martha Segura, written communication, 11 April 2013). More research is needed to understand this. Due to the reference condition being undefined, a *Condition Level* was not assigned for this measure.

Percent Cover
The *Significance Level* for percent cover is a 3. The percent cover has been changing in both the upper and lower Laguna Madre over the last few decades. In the 1960s, the bottom of the lower Laguna Madre was almost entirely covered with seagrass beds. Wilson and Dunton (2011) discovered that approximately 32% and 7% of the sampling stations recorded less than 10% seagrass coverage in the lower and upper Laguna Madre, respectively. Wilson and Dunton (2011) specify that it is currently difficult to determine if the seagrass community in the Laguna Madre is actually expanding or contracting at this time based on limited comprehensive field evaluations over time. However, they note that 2011 data compared to delineations of seagrass habitat by NOAA in 2004 and 2007 indicate that many seagrass beds are in decline. Further monitoring would provide a more complete understanding of any change over time. Due to the reference condition being undefined and the lack of data to determine trends over time, a *Condition Level* was not assigned for this measure.

Canopy Height
The project team defined the *Significance Level* for this measure as a 3. According to Wilson and Dunton (2011), seagrass community canopy heights ranged from 3 to 51 cm (1.18 to 20.1 in) throughout the lagoon. The average canopy height was greater in the upper lagoon basin (20.1 ± 8.8 cm) than in the lower lagoon basin (15.7 ± 9.8 cm). As was previously mentioned, canopy height varies among seagrass species, which makes it difficult if not impossible to determine the health of the seagrasses through gross canopy height alone. With the absence of a reference condition, and the variability in canopy heights between different species and communities, a *Condition Level* was not assigned for this measure.

Weighted Condition Score
A *Weighted Condition Score* for the PAIS seagrass community could not be calculated at this time due to an undefined reference condition and limited data on the characteristics and condition of the seagrass community in the Laguna Madre adjacent to PAIS.



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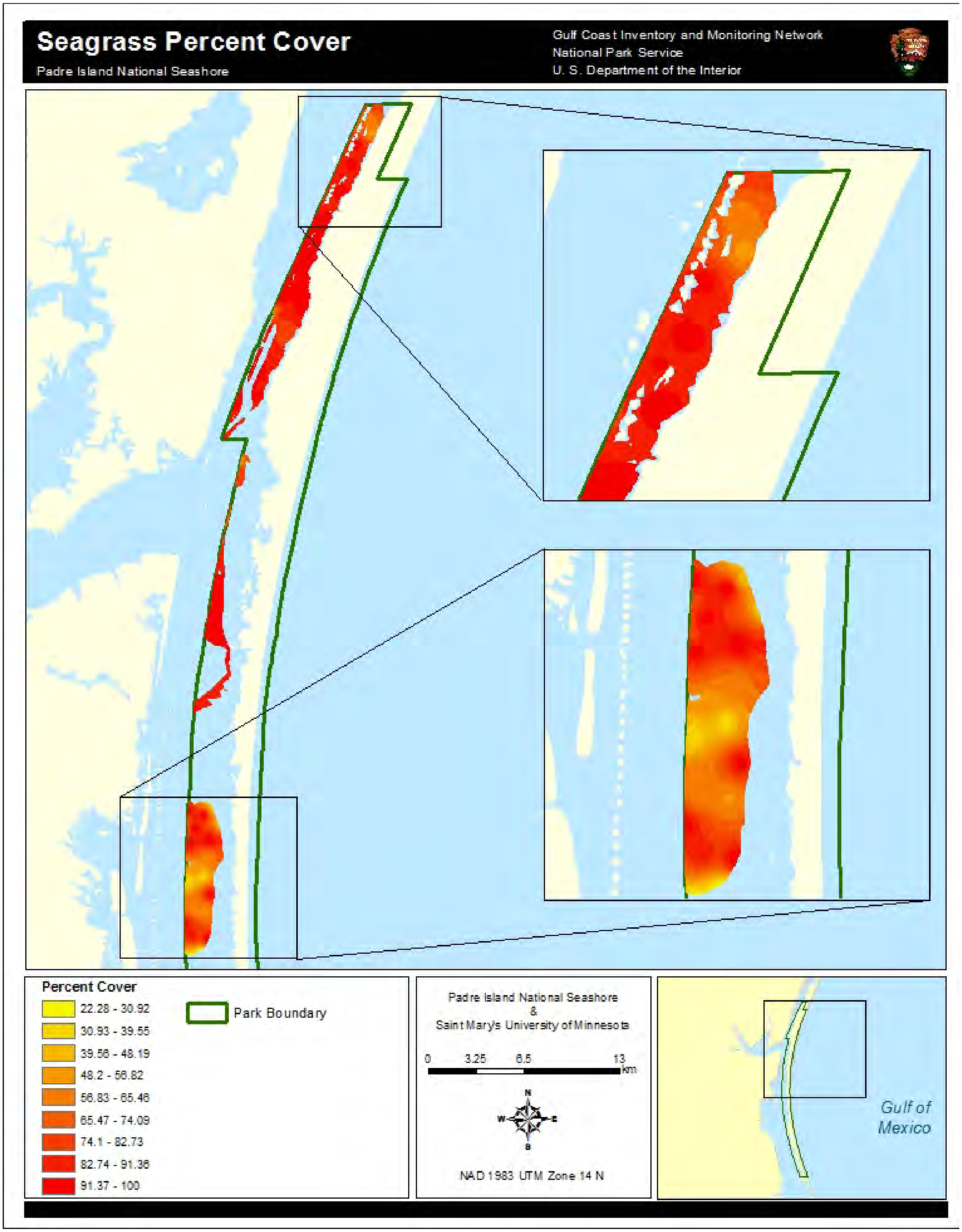


Plate 8. Percent cover of all seagrass in PAIS (Wilson and Dunton 2011).

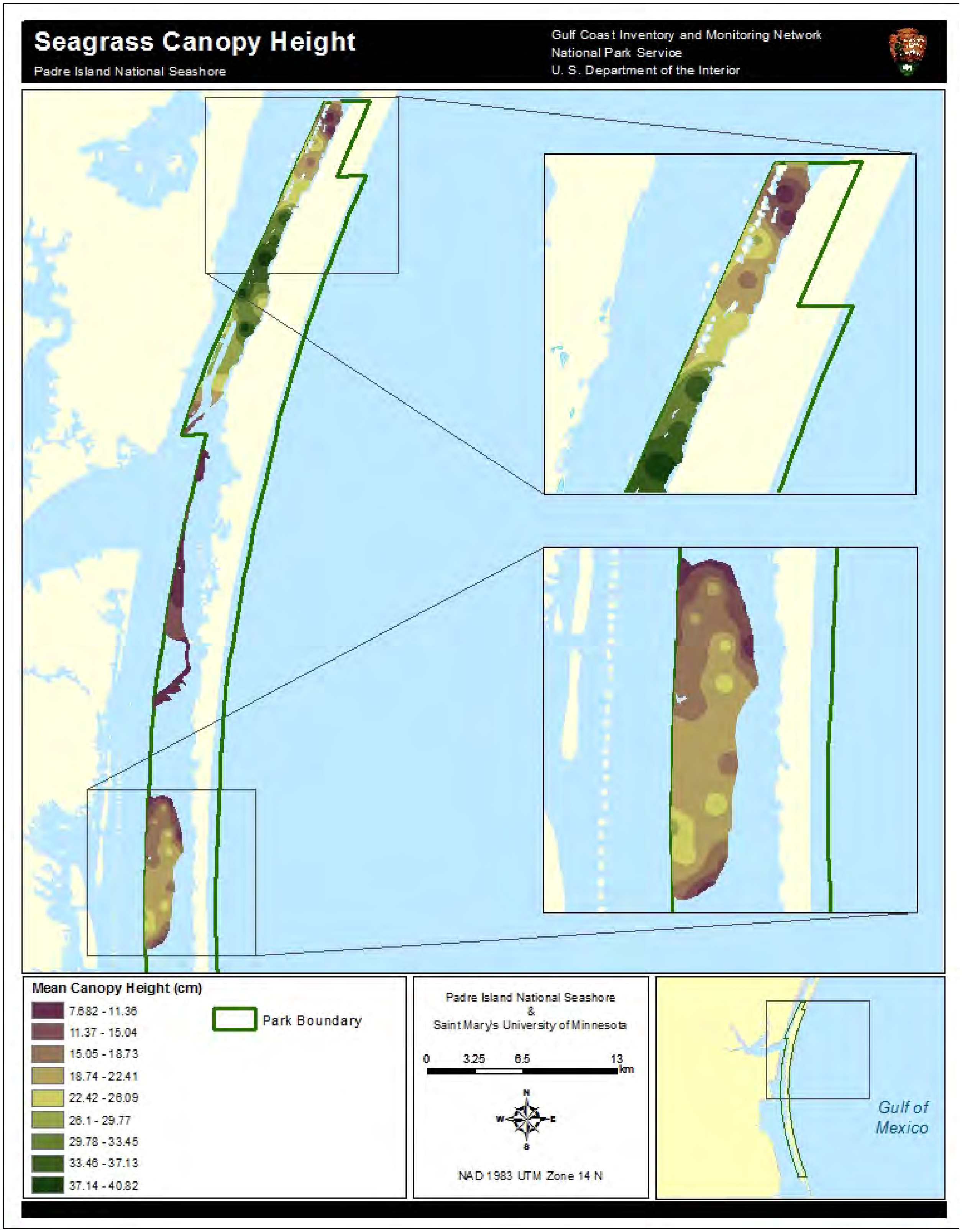


Plate 9. Mean canopy height (cm) of all seagrass in PAIS (Wilson and Dunton 2011).

4.4 Emergent Wetland and Pond Communities

Description

The inland areas of PAIS, between the Gulf dunes and Laguna Madre beaches, support wetlands and freshwater ponds that are vital to the island's wildlife. These areas provide habitat for aquatic invertebrates, fish, amphibians, and waterfowl, as well as a water source for other birds and mammals (Photo 9; NPS 1996, White et al. 2006). On barrier islands such as Padre Island, wetlands and ponds form in flat areas left behind migrating dunes. These low-lying areas, scoured by wind and sand, are called deflation flats or troughs (Hunter et al. 1972, as cited in Weise and White 1980). Wetlands and ponds are more common in the north and central portions of PAIS, where precipitation is slightly higher than in the south, allowing wetlands to hold water for most of the year (Weise and White 1980, NRCS 2007).

Photo 9. Waterfowl on Pond B along Park Road 22 (photo by Shannon Amberg, SMUMN GSS).

Vegetation around the lowest emergent wetlands typically includes southern cattail (*Typha domingensis*), spikerushes, (*Eleocharis* spp.), common threesquare (*Schoenoplectus pungens)*, seashore paspalum (*Paspalum vaginatum*), coastal waterhyssop (*Bacopa monnieri*), and sweetscent (*Pluchea odorata* var. *odorata*). Species common in slightly higher wetlands with less frequent standing water are cordgrass (*Spartina* spp.), flatsedges (*Cyperus* spp.), bushy seaoxeye (*Borrichia frutescens*), paspalum (*Paspalum* spp.), largeleaf pennywort (*Hydrocotyle bonariensis*), and frog fruit (*Phlya* sp.) (White et al. 2006). Additional wetland species noted in PAIS include starrush whitetop, marsh fimbry (*Fimbristylis castanea*), rushes (*Juncus* spp.), and smartweed (*Polygonum* sp.) (Drawe et al. 1981, White et al. 2006).

Measures

- Extent
- Native species composition
- Wetland/pond elevation

Reference Conditions/Values

Since little is known about the island's wetlands and ponds, a reference condition has not been established. The ephemeral nature of many of the park's wetlands and a lack of historic information make this difficult to determine.

Data and Methods

Descriptions of the park's ecological communities, including wetlands, from the 1970s and early 1980s were found in Baccus et al. (1977), Weise and White (1980), and Drawe et al. (1981). In 1989-1990, Sissom et al. (1990) completed a baseline survey of three ponds in PAIS. They sampled chemical and physical parameters and surveyed both the flora and fauna around these ponds. The first landcover classification for the park was completed by Laine and Ramsey (1998), and provides information on the extent of wetland vegetation in PAIS. Laine and Ramsey (1998) followed classification and interpretation protocols developed by NOAA C-CAP and used map descriptions that fit NVCS guidelines.

White et al. (2006) studied the status of wetlands on south Texas barrier islands, which included PAIS. They compared aerial photos from the 1950s, 1979, and 2002-2004 to identify changes in wetland extent over time. National Wetland Inventory (NWI) GIS data from the USFWS provides wetland information for the park. USFWS interpreted color infrared aerial imagery from the 1990s to generate this data. It provides an indication of the prevalence and distribution of wetland types (according to the Cowardin et al. 1979 classifications) throughout the park. In 2007, the NPS created a surficial geology GIS map for PAIS, based primarily on 2003 aerial photography (NPS 2012). Map classifications are loosely based on land cover and include four classes that could be considered wetlands and/or ponds (NPS 2007). This map and associated data are considered the most up-to-date and accurate information regarding wetland and pond distribution in PAIS.

Since little data exist for wetland/pond elevation, SMUMN GSS analysts used ArcGIS to determine the approximate elevations (above sea level) of wetlands and ponds throughout PAIS. First, a set of points was created by using the centroid of each NWI wetland polygon (one point per polygon), ensuring that points were actually inside their respective polygons. Then, elevations for each point were extracted from a 30 m (98 ft) DEM created as part of a NOAA Tsunami Inundation Gridding Project (Taylor et al. 2008). Finally, the point elevations were spatially joined to the NWI wetland polygons, resulting in an elevation attribute within the wetland polygon layer.

Current Condition and Trend

<u>Extent</u>

According to NWI GIS data, approximately 2,298.9 ha (5,681 ac) or just over 4% of the park is classified as palustrine (non-tidal) wetland (Table 12, Plate 10). The majority of this wetland area (2,205 ha) supports persistent emergent vegetation (PEM1).

Table 12. Major National Wetland Inventory (NWI) classifications (Cowardin 1979) by area in PAIS.

NWI Code	NWI Description	Total wetland area (ha)
PEM1A	Palustrine, emergent, persistent, temporary flooded	992.3
PEM1C	Palustrine, emergent, persistent, seasonally flooded	1,040.8
PEM1F	Palustrine, emergent, persistent, semipermanently flooded	169.5
PEM1Khs	Palustrine, emergent, persistent, artificially flooded, diked/impounded	2.6
PUBF	Palustrine, unconsolidated bottom*, semipermanently flooded	4.5
PUBKx	Palustrine, unconsolidated bottom, artificially flooded, excavated	0.9
PUSA	Palustrine, unconsolidated shore, temporary flooded	45.8
PUSC	Palustrine, unconsolidated shore, seasonally flooded	42.5
	Total	**2,298.9**

*Areas classified as "unconsolidated bottom" or "unconsolidated shore" have <30% vegetative cover

White et al. (2006) found that their North Padre Island study area supported more palustrine marsh (356 ha) than any other island studied. The extent of palustrine marsh on North Padre fluctuated over time, decreasing from the mid-1950s to 1979 (275 ha to 258 ha), and then increasing between 1979 and the early 2000s. Losses between the 1950s and 1979 were attributed primarily to replacement by uplands, although some area was lost to migrating dunes (White et al. 2006).

The 1998 landcover classification project (Laine and Ramsey 1998) identified three landcover classes that could include inland wetlands or ponds: inland water, emergent wetland, and unconsolidated shore. These classes are described by Laine and Ramsey (1998, p. 6) as follows

- Inland water - Semipermanent areas of standing freshwater that are found parallel to the foredune ridge along the interior of the island. Depending on depth, vegetation may consist of species such as largeleaf pennywort.

- Emergent wetland - Shallow depressions that are inundated with freshwater from rain events or saltwater from tropical storms. These areas are vegetated with bulrush, cattails, black willow, gulfdune paspalum, and largeleaf pennywort.

- Unconsolidated Shore - Areas adjacent to washover channels and inland water areas consisting of fine sands with little to no vegetation. If vegetation is present, it is sparse with species such as cattails or bulrush.

The last two classes (emergent wetland and unconsolidated shore), however, were not separated into estuarine and palustrine systems. Therefore, the extent of inland/palustrine wetlands cannot be precisely determined from these data. These extents are shown in Table 13 and Plate 11, but it should be noted that, with the exception of the inland water class, these extents are overestimates.

Table 13. Area of map classes that contain wetland and pond communities, according to GIS landcover data (Laine and Ramsey 1998)

Map class	Area (Ha)
Inland water	947.3
Emergent wetland*	7,882.9
Unconsolidated shore*	2,613.3

*These classes include both inland (palustrine) and shore (estuarine) communities, and therefore overestimate inland wetland and pond community coverage.

The 2007 PAIS surficial geology map includes several wetland and pond mapping units: temporarily flooded brackish to fresh marsh, seasonally flooded brackish to fresh marsh, semipermanently flooded brackish to fresh marsh, and water. According to GIS data, these four map units together cover 2,614 ha (6,459.6 ac) of the park. The area of each map unit is presented in Table 14 and Plate 12.

Table 14. Area of wetland and pond mapping units, according to surficial geology GIS data (NPS 2007).

Map unit	Area (Ha)
Temporarily flooded brackish to fresh marsh	549.8
Seasonally flooded brackish to fresh marsh	1,266.2
Semipermanently flooded brackish to fresh marsh	599.6
Water	198.5
Total	2,614.1

Native Species Composition

While several sources have described the plant species characteristic of the park's wetland and pond communities, a comprehensive study of wetland species composition is not available. Drawe et al. (1981) sampled 10 vegetation transects in PAIS in 1972-1973. They divided the island into five habitat types; while wetlands were not identified as a specific habitat, two of the habitat types (salt marsh and salty sands) were described as inundated to the point that sampling was not possible during four of the six study seasons (Drawe et al. 1981). These two habitat types likely included the park's wetland and pond communities. A list of plant species identified in the salt marsh and salty sands communities is presented in Table 15. More species may be present but were not documented because of inaccessibility due to standing water during the majority of sampling periods.

Table 15. Vascular plants documented in the salt marsh and salty sands habitats of PAIS (Drawe et al. 1981). Some scientific and common names were updated to match those accepted by the Integrated Taxonomic Information System (ITIS).

Scientific name	Common name	Salt marsh	Salty sands
Hydrocotyle bonariensis	water pennywort	x	
Juncus marginatus	grassleaf rush	x	
Sisyrinchium sagittiferum	spearbract blue-eyed grass	x	
Salicornia bigelovii	dwarf saltwort		x
Blutaparon vermiculare	silverhead	x	x
Sesuvium portulacastrum	shoreline seapurslane		x
Limonium carolinianum	lavender thrift		x
Heliotropium curassavicum var. *curassavicum*	salt heliotrope	x	
Heterotheca subaxillaris	camphorweed		x
Erigeron procrumbens	Corpus Christi fleabane		x
Conoclinium betonicifolium	betonyleaf thoroughwort	x	
Rhynchospora colorata	starrush whitetop	x	
Eleocharis geniculata	Canada spikesedge	x	
Eleocharis montevidensis	spike sedge; sand spikerush		x
Fimbristylis castanea	marsh fimbry	x	x
Schoenoplectus pungens var. *longispicatus*	common threesquare	x	
Croton capitatus	hogwort		x
Croton glandulosus	sand croton		x
Croton punctatus	gulf croton		x
Spiranthes vernalis	spring lady's tresses	x	
Eragrostis secundiflora	red lovegrass	x	
Paspalum monostachyum	gulfdune paspalum	x	
Spartina patens	saltmeadow cordgrass		x
Sporobolus virginicus	seashore dropseed	x	x
Phyla nodiflora	frog fruit	x	
	Total	**15**	**13**

During their survey of three ponds in PAIS, Sissom et al. (1990) documented all vascular plant species within 60 m (200 ft) of the ponds. Across all three ponds, Sissom et al. (1990) recorded 46 native and three non-native species (Appendix F). Sissom et al. (1990) also sampled algae in the ponds and obtained fungal species lists from another researcher studying these organisms in the three ponds. Fungal samples were found on foam, live and decaying plant matter, and other organic debris in the ponds. These algal and fungal species lists are also included in Appendix G and Appendix H. A total of 27 algal and 32 fungal taxa were identified (Sissom et al. 1990).

Additional species reported in PAIS wetlands but not recorded by Drawe et al. (1981) or Sissom et al. (1990) are listed in Table 16. All together, just over 70 native plant species have been documented in PAIS wetland and pond communities.

Table 16. Additional plant species documented in PAIS wetlands (White et al. 2006).

Scientific name	Common name	Scientific name	Common name
Schoenoplectus californicus	California bulrush	*Chloracantha spinosa*	spiny chlorocantha
Paspalum vaginatum	seashore paspalum	*Panicum* spp.	panicgrasses
Spartina spartinae	gulf cordgrass	*Andropogon glomeratus*	bushy blustem
Borrichia frutescens	bushy seaoxeye	*Cynodon dactylon**	bermudagrass

* indicates non-native species

Wetland/Pond Elevation

The presence of freshwater in the park's wetlands and ponds is largely determined by the elevation of the wetland or pond and the depth of the underlying groundwater table at any given time of the year (Stablein, phone communication, 29 August 2012). As groundwater levels fluctuate, the elevation of a wetland or pond can help managers predict whether the feature will contain water; water bodies at higher elevations are more likely to dry up if groundwater levels drop, while those at lower elevations continue to hold water. To date, the only published wetland/pond elevation data available for the park are from Sissom et al. (1990)'s three study ponds. The elevations at the deepest points of Ponds A, B, and C were 3.5 m (11.6 ft), 2.5 m (8.1 ft), and 3.1 m (10.3 ft) respectively (Sissom et al. 1990).

SMUMN GSS analysts used a DEM to determine the approximate elevations of wetlands and ponds throughout PAIS (see Plate 13 Plate 14). Analysis of the resulting elevation data shows that nearly 75% of wetlands and ponds in PAIS are between 2 and 4 m (6.6-13.1 ft) in elevation (Figure 5). However, the total wetland/pond area is more widely distributed between 1 and 5 m (3.3-16.4 ft) in elevation (Figure 6).

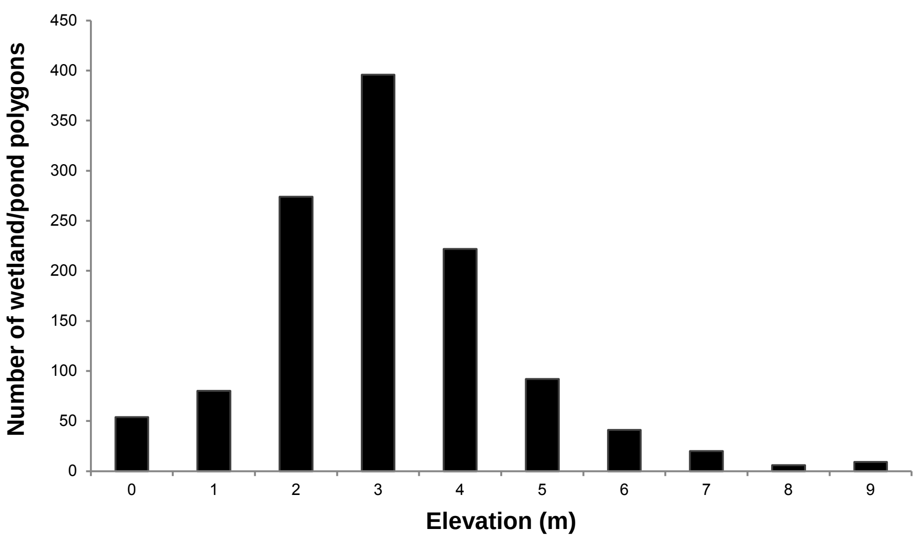


Figure 5. Number of wetlands and ponds in PAIS by elevation.

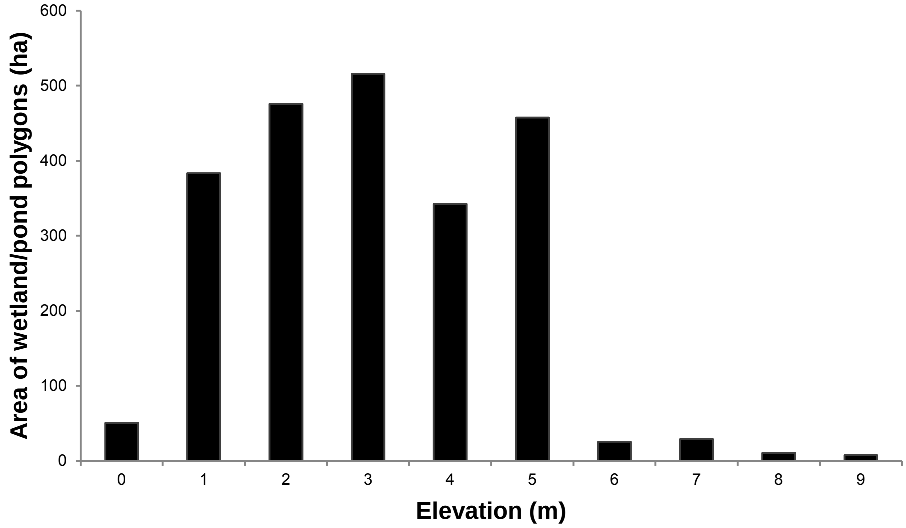


Figure 6. Wetland and pond area in PAIS by elevation.

Threats and Stressor Factors

Threats to the park's wetlands and ponds include non-native plant species, oil and gas exploration and development, drought, sand migration, storm surge, and saltwater inundation. Non-native plants, such as giant reed (*Arundo donax*), threaten to outcompete native species for limited resources in wetland areas, eventually replacing the natives. Aggressive native species, such as common reed (*Phragmites* sp.), may also threaten wetland species diversity (one known *Phragmites* location in the park is shown in Plate 10). Extreme weather events, including droughts and hurricanes, can negatively impact the wetlands and ponds of PAIS. Hurricanes are one of the greatest concerns for the park's ecological communities, as their effects can be devastating (Cooper et al. 2005). On average, the Texas coast is struck by 0.67 storms per year, or approximately two storms every 3 years (Weise and White 1980). Storm surge is perhaps one of the most significant threats associated with hurricanes. These waters erode and transport large amounts of sediment and can even breach the dunes, allowing saltwater to reach inland areas of the island (Weise and White 1980). High winds, during hurricanes and at other times, have the potential to blow sand from the dunes and beaches into wetlands and ponds; this sand could eventually accumulate and reduce the wetland or pond's capacity to hold water. For example, Sissom et al. (1990) reported that one of their study ponds was filling with sand and would eventually be converted to a marsh.

According to NPS (1996, p. 19), "Oil/natural gas exploration and production pose a greater threat to the natural resources of Padre Island National Seashore than any other type of activity that takes place in or near the park." Incidents such as hydrocarbon spills, improper drilling mud disposal, and sump discharges can have long-term cumulative effects on the park's groundwater. Groundwater is shallow at PAIS and any contamination has the potential to impact wetland and pond communities (NPS 1996).

Data Needs/Gaps

Cooper et al. (2005) identified several data needs for wetlands and ponds at PAIS. These include how wetlands have changed over time, if any wetlands have become degraded and are in need of restoration, and how or if park development and oil/gas exploration are affecting wetlands and surface water regime. A more comprehensive native plant survey specific to the park's wetlands and ponds would also be helpful in assessing community condition. Repeated analysis of wetland/pond elevation in the future will help determine if any changes (i.e., sedimentation and filling of wetlands) are occurring over time.

<u>Overall Condition</u>

Extent
The project team assigned this measure a *Significance Level* of 3. The extent of wetland and pond communities in PAIS varies greatly depending on moisture availability (e.g., precipitation). While NWI and NPS surficial geology data provide some indication of wetland extent within PAIS, it is not enough to assess the current condition of this measure. White et al. (2006)'s assessment of barrier island wetlands suggests that palustrine marsh area on North Padre Island has remained relatively stable over time. However, the most recent imagery used in their assessment was 2002-2004, which is nearly a decade ago. As a result of a lack of comparable information over time, a *Condition Level* was not assigned.

Native Species Composition
The species composition measure was also assigned a *Significance Level* of 3. Wetland and pond native species composition has not been comprehensively surveyed. The available information is limited, both temporally and spatially. As a result, a *Condition Level* could not be determined for this measure.

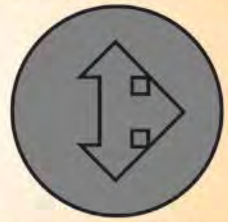
Wetland/Pond Elevation
This measure was assigned a *Significance Level* of 3. Prior to this assessment, published elevation data was only available for three ponds in the park at one point in time (Sissom et al. 1990). SMUMN GSS analysts used a DEM to create a GIS data layer with the approximate elevations of wetlands and ponds throughout PAIS. This information may be used as a baseline for future assessments, but at this time there is not enough data to determine a *Condition Level* for this measure.

Weighted Condition Score

A *Weighted Condition Score* was not calculated for PAIS emergent wetland and pond communities, since *Condition Levels* could not be determined for any of the measures.

Emergent Wetland and Pond Communities

Measures	SL	CL
• Extent	3	n/a
• Native species composition	3	n/a
• Wetland/pond elevation	3	n/a



WCS = N/A

Sources of Expertise

Wade Stablein, Biological Technician, PAIS

Joe Meiman, Hydrologist, GULN

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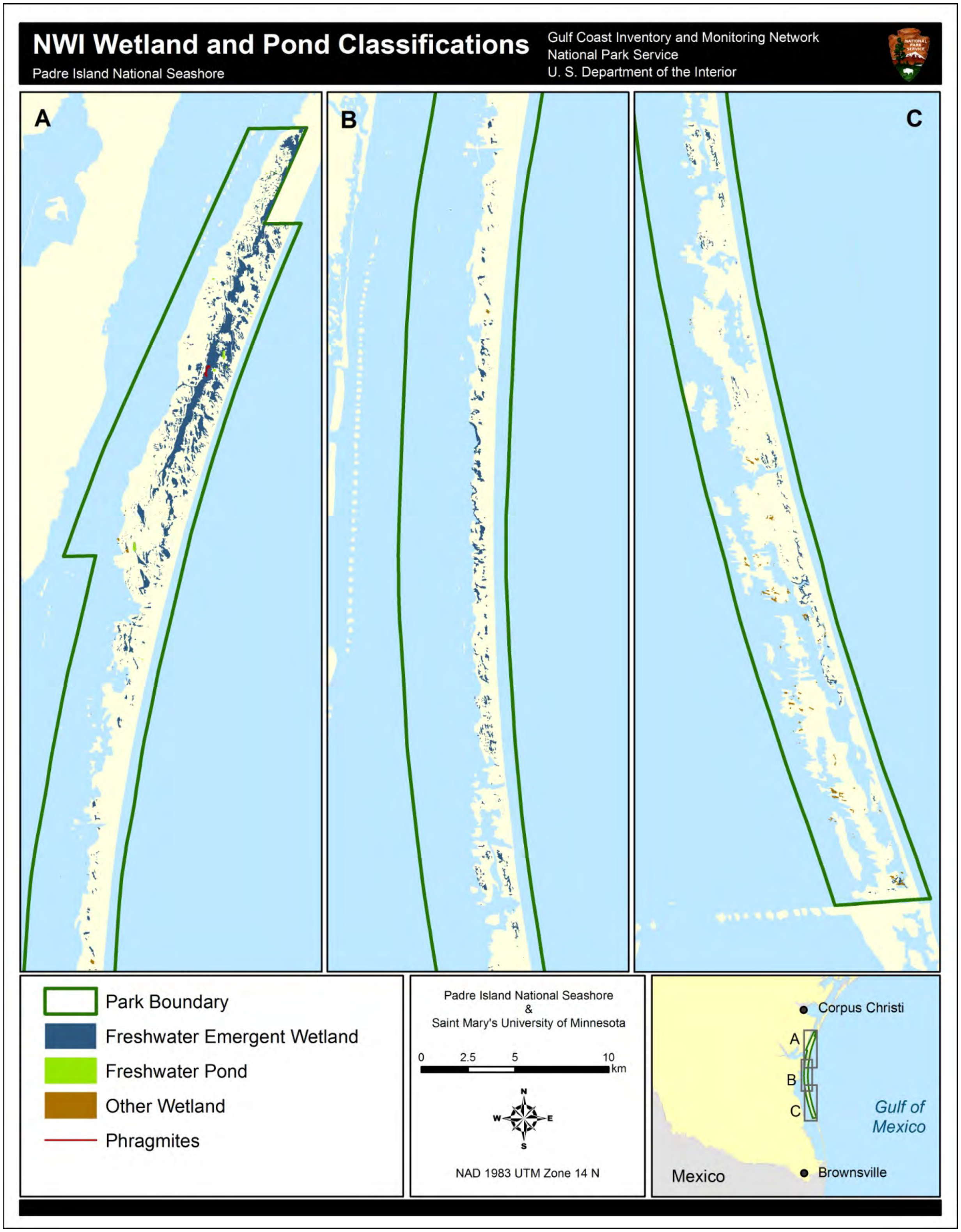

Plate 10. Wetlands and ponds in PAIS according to NWI data (USFWS 2012). The location of a potentially problematic *Phragmites* stand is also shown in the far left map.

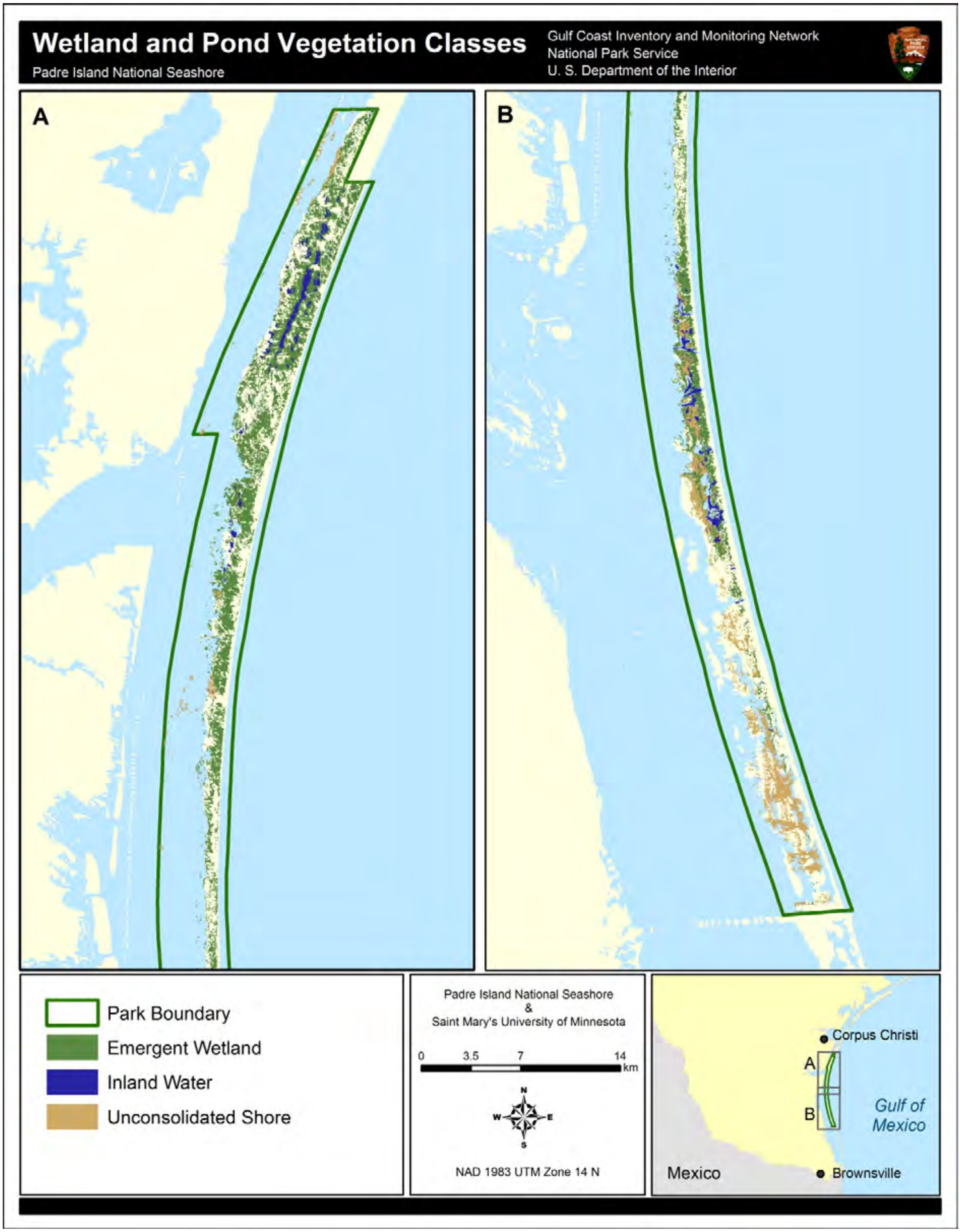

Plate 11. Extent of wetland and pond vegetation classes in PAIS according to Laine and Ramsey (1998). The emergent wetland and unconsolidated shore classes include both estuarine and palustrine areas and therefore overestimate the true extent of inland/palustrine wetlands.

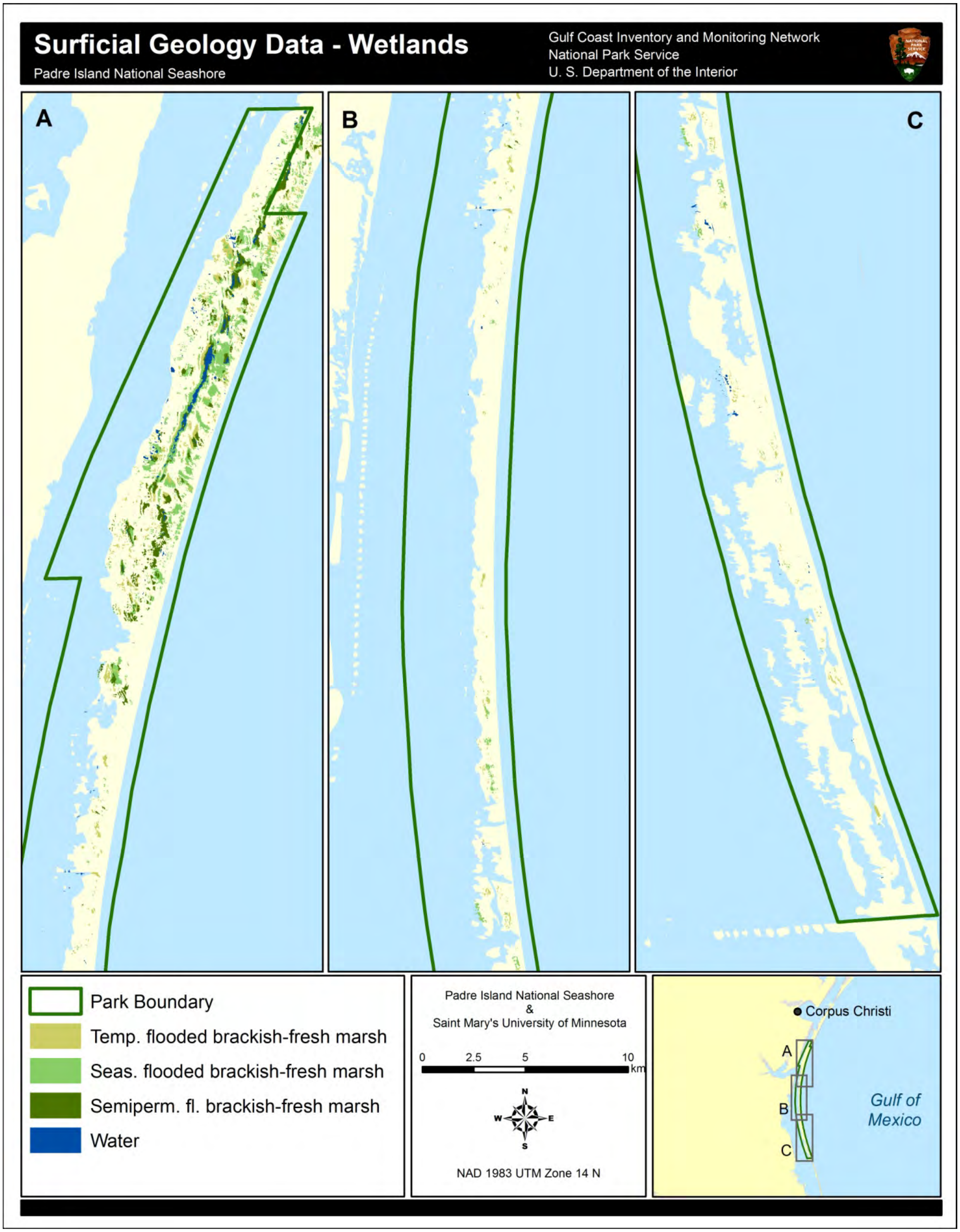

Plate 12. Extent of wetland and pond mapping units, according to NPS surficial geology data (NPS 2007). Temp. = temporarily, Seas. = seasonally, Semiperm. = semipermanently.

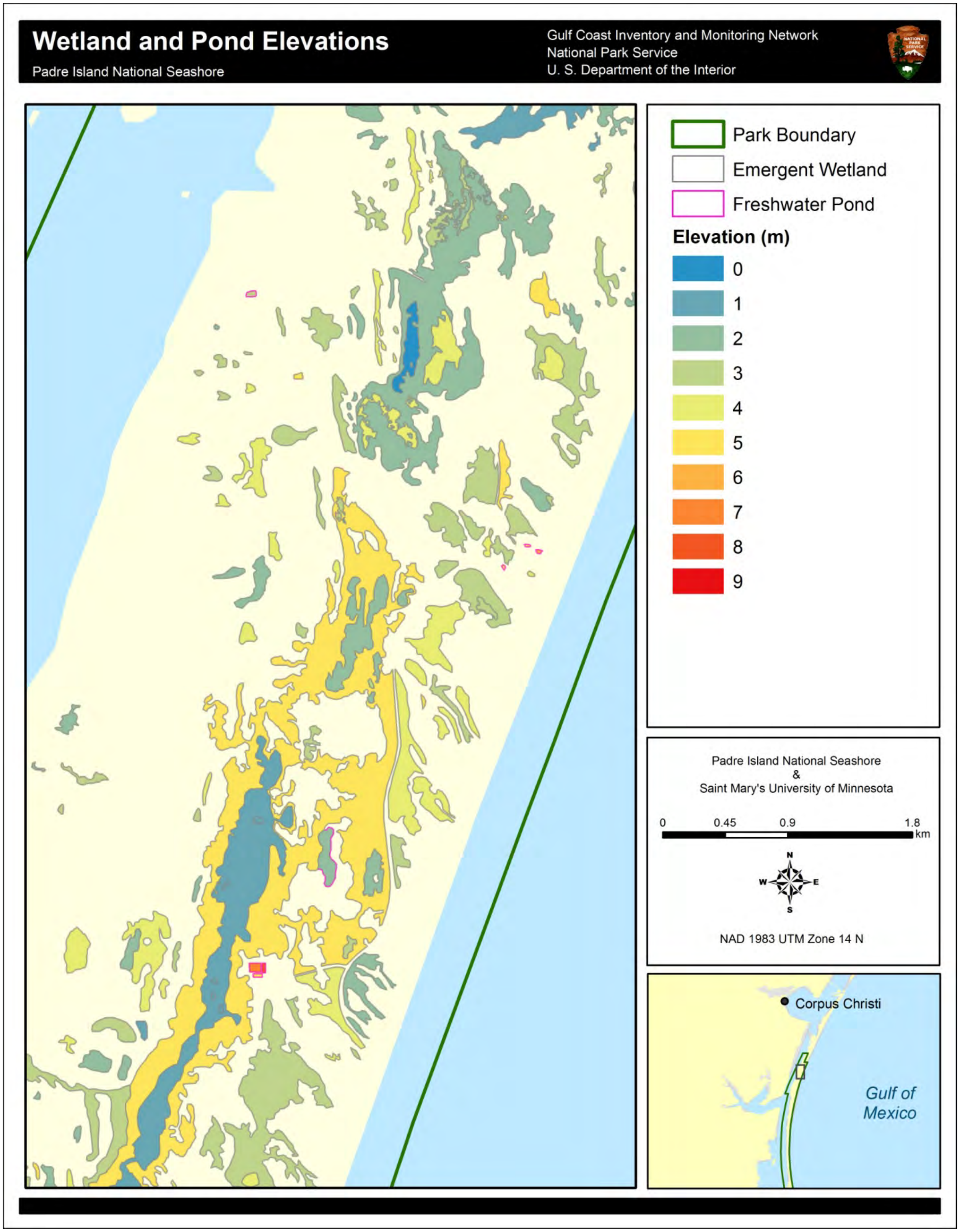

Plate 13. Sample map showing approximate wetland and pond elevations in a northern portion of PAIS.

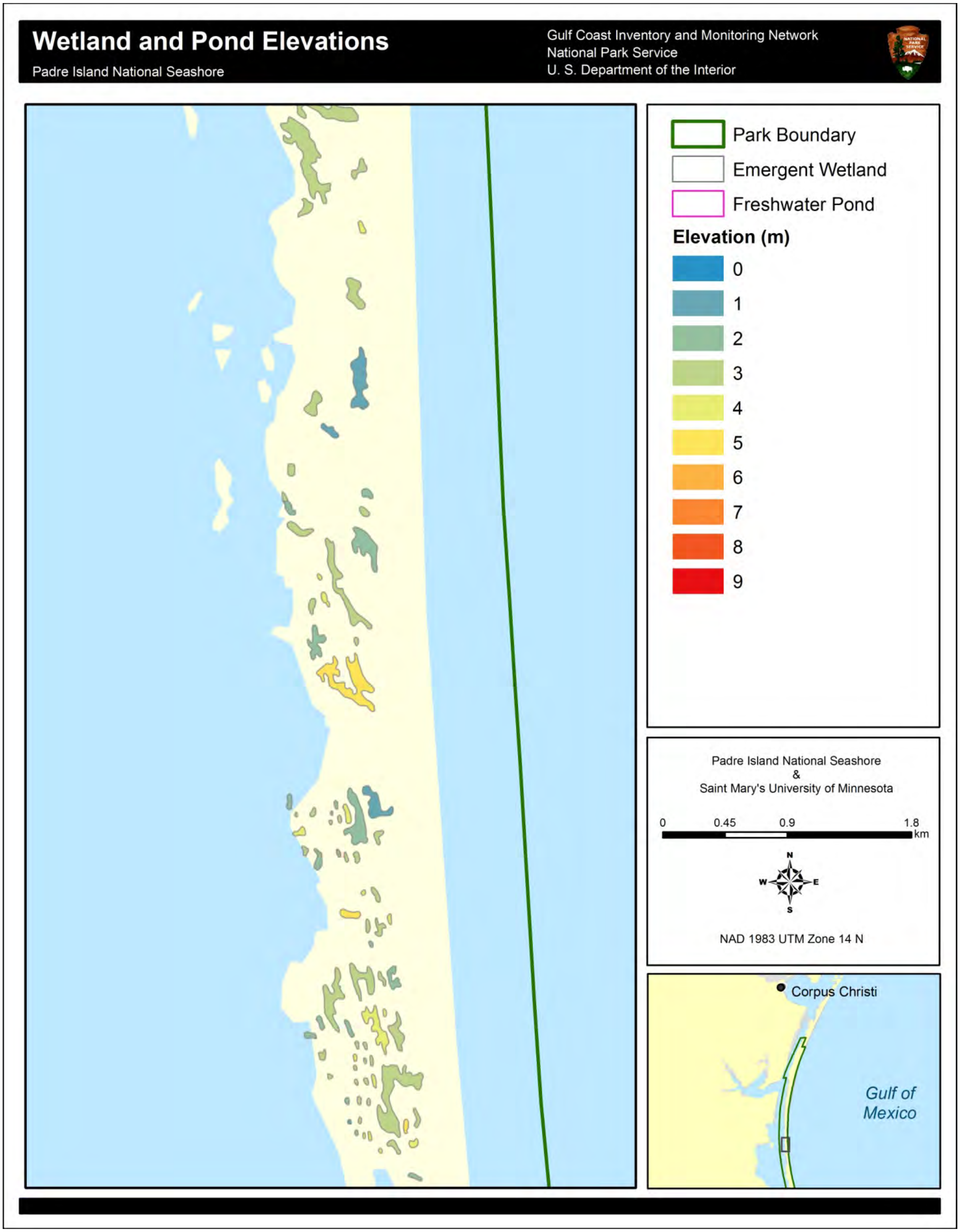

Plate 14. Sample map showing approximate wetland elevations in a central portion of PAIS.

4.5 Migratory Bird Species

Description

Bird populations often act as excellent indicators of an ecosystem's health (Morrison 1986, Hutto 1998, NABCI 2009). Birds are often highly visible components of ecosystems, and bird communities typically reflect the abundance and distribution of other organisms with which they co-exist (Blakesley et al. 2010). Migratory birds serve as excellent ecological indictors because a disturbance adversely affecting any of the habitats used by these species (e.g., stopover, wintering, or breeding habitats) can cause declines in populations and a decrease in species' reproductive success (Hilty and Merenlender 2000, Zöckler 2005).

Photo 10. Reddish egrets (photo by Joel Reynolds, USFWS).

The unique ecosystems and physical formations of the Gulf and Laguna Madre coasts in PAIS provide bird species with ideal stopover and overwintering habitats (Chaney et al. 1993a), and represent a vital area for many migratory bird species in North and South America. The American Bird Conservancy (ABC) has identified PAIS as a Globally Important Bird Area. In order to be listed as a Globally Important Bird Area, a site must, during some part of the year, contain habitat that supports:

1. A significant population of an endangered or threatened species;
2. A significant population of a U.S. WatchList species;
3. A significant population of a species with a limited range, or
4. A significantly large concentration of breeding, migrating or wintering birds, including waterfowl, seabirds, wading birds, raptors or landbirds (ABC 2010).

In addition to being listed as a Globally Important Bird Area by the ABC, PAIS has also been identified by the Western Hemisphere Shorebird Reserve Network (WHSRN) as a part of the Laguna Madre, a Site of International Importance (WHSRN 2009). Criteria for being listed as a Site of International Importance include:

1. At least 100,000 shorebirds annually, or
2. At least 10% of the biogeographic population of a species (WHSRN 2009).

PAIS has confirmed the presence of more than 350 species of birds, of which approximately 40% are migratory species (NPS 2013b). PAIS is located along one of the major migration flyways in North America (Figure 7), and many species, such as the red knot and the black tern (*Chlidonias niger*), pass through the park on their way from wintering grounds in the south to breeding grounds in the north. PAIS acts as an important over-wintering area for several migratory species, such as the ruby-crowned kinglet (*Regulus calendula*) and the black-bellied plover (*Pluvialis squatarola*), as these species spend the winter months along PAIS's coastlines before returning to their breeding grounds in the spring. Migratory birds that nest in the park include the long-billed curlew (*Numenius americanus*), as well as least tern (*Sternula antillarum*) and Wilson's plover (*Charadrius wilsonia*), both which nest along the tidal flats.

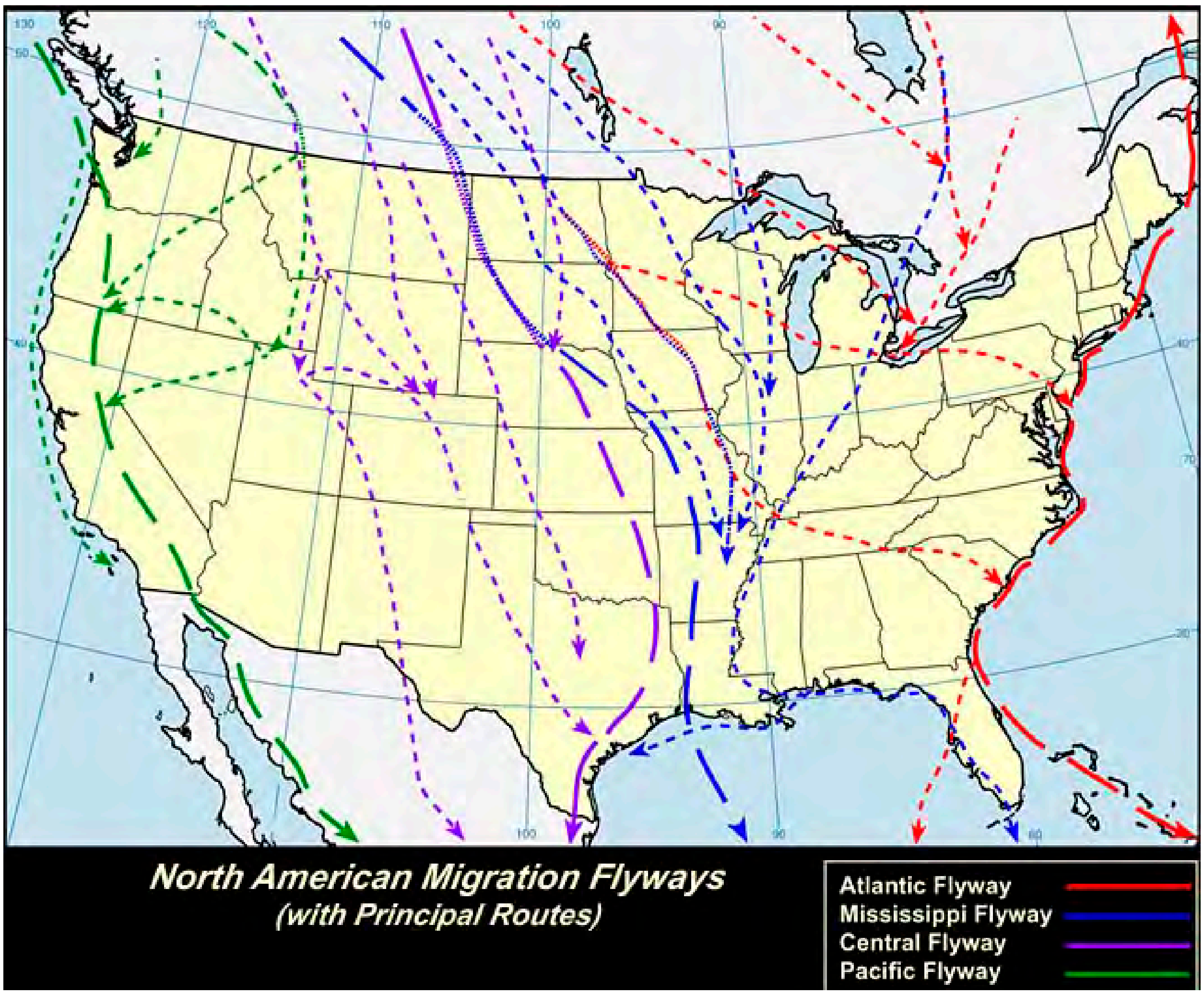

Figure 7. Major North American migratory flyways. PAIS is located at a bottleneck of the Central and Mississippi Flyways (NPS 2013b).

One of the more iconic overwintering species is the redhead. Seventy-five percent of the global redhead populations overwinter in the Laguna Madre (Weller 1964, Roetker 2003, James 2006), and the overwintering birds are almost entirely dependent upon shoalgrass rhizomes. The overwintering redheads also utilize the three freshwater ponds found in the interior of the park. PAIS is also home to several species of conservation concern, such as the piping plover, reddish egret (Photo 10), wood stork (*Mycteria americana*), and swallow-tailed kite (*Elanoides forficatus*); these species are listed as threatened or endangered by the state of Texas or by the USFWS (NPS 2013c). Two migratory species in PAIS, the red knot and Sprague's pipit (*Anthus spragueii*), are candidate species for federal protection and listing under the Endangered Species Act.

Long-distance migratory species are highly informative indicator species, as their overall health depends on several different ecosystems. Global Christmas Bird Count (CBC) data indicate significant declines in migratory bird numbers in recent years (Peterjohn and Sauer 1999, Vicerky and Herkert 2001). The red knot is one of the park's longest distance migrants, as it migrates south to the park from its circumpolar breeding habitats; the coastal red knot habitat in PAIS is among the highest quality habitats for this species in Texas (Stablein, written communication, 13 May 2013). There are six recognized subspecies of red knots, and it is likely that PAIS is home to the *C. c. rufa* and *C. c. roselaari* subspecies, with the *C. c. rufa* subspecies being the most commonly observed (Stablein, written communication, 13 May 2013). Monitoring of long distance migratory species populations (such as the red knot) as they pass through or overwinter in PAIS may help managers to develop a better understanding of the overall health of not only the PAIS ecosystem, but also the other ecosystems that these bird species rely on.

Measures

- Neotropical species abundance and diversity
- Raptor abundance
- Waterfowl abundance

Reference Conditions/Values

A reference condition for migratory bird species in PAIS has not been defined. No annual monitoring of these groups of birds occurs in the park, and a contemporary baseline survey could be used to define condition. There are limited contemporary and historic data for this component, and no reference condition was used in the assessment of condition for this component.

Data and Methods

While there have been several bird surveys in the park (see Chaney et al. 1993a, 1993b, 1995a, 1995b; Ginter 2004; Lawson 2009), these surveys did not identify any Neotropical migrants and their results are not discussed here. Chapter 4.6 uses and summarizes the data from these surveys when appropriate.

The NPS Certified Bird Species List (NPS 2013a) (Appendix I) for PAIS was used for this assessment; this list represents all of the bird species confirmed as present in the park. For this component, only bird species considered migratory were included. SMUMN GSS removed resident and colonial waterbird species from this list, as these groups are discussed separately in Chapters 4.6 and 4.7 of this document.

The Christmas Bird Count conducted in PAIS was part of the International Christmas Bird Count, which started in 1900 and is coordinated internationally by the Audubon Society. The

PAIS CBC was conducted annually from 1974-1990. Multiple volunteers surveyed a 24-km (15-mi) diameter on one day, typically between 14 December and 5 January. The center point of the 24-km diameter was 27.3333ºN, -97.3333ºW (Plate 15). Unlike the surveys that occur during the breeding season (such as the North American Breeding Bird Survey [BBS]), the CBC surveys overwintering and resident birds that are not territorial and singing. The total number of species and individuals were recorded each year. Recently, a new CBC circle was established with a center point located in the center of 9-mile Hole. Staff members of the NPS, TPWD, USFWS, CBBEP, National Audubon Society, Texas A&M University – Corpus Christi, and volunteers from the public perform this CBC in the winter. Data from this new CBC are not yet available from the National Audubon Society.

Chapman (1984) investigated the effects of the 1979 IXTOC I oil spill on the coastal bird species of Mustang and Padre Islands. One of the survey areas (area B) was located within PAIS, and extended from Malaquite Beach in the north, to Mansfield Channel in the south. From October 1980 to June 1981, bird censuses were conducted from a four-wheel drive vehicle that was driven along the beaches, and only birds on the beaches were counted (i.e., no flying or swimming birds were counted). Stops were made every 16 km (10 mi), and researchers were allowed 15 minutes to scan the area for birds that may have been missed from the vehicle.

Blacklock et al. (1998) mist-netted and banded Neotropical migrants in PAIS during the 1998 spring migration. Net locations were near the PAIS ranger station and near a wetland and dune habitat along Bird Island basin. Blacklock et al. (1998) also investigated Neotropical migrant habitat use in the park by setting up line-transects in three habitat types: dunes, wetlands, and grasslands. These transects were surveyed throughout the 1998 spring migration.

Seegar et al. (2012) summarized the annual peregrine falcon migration survey on South Padre Island in 2012. South Padre Island is one of the major overwintering areas for the Arctic peregrine falcon (*F. p. tundrius*), and surveys, banding, and blood sample collections have occurred during migration (spring and fall) in the area for over 50 years. The long-term objectives of the South Padre Island surveys are:

- Monitoring population trends and migration phenology through band returns and sightings;
- Maintaining a banded population to continue this monitoring;
- Sampling blood from captured individuals for DNA level genetic analyses to identify the regional make-up of the Padre migrants;
- Identifying migratory pathways, breeding areas and critical wintering areas for the migrant Padre population through band returns and locations of radio marked falcons tracked by satellite (Seegar et al. 2012, p. 2).

Surveys in the spring of 2012 spanned from 10-24 April, while fall surveys in 2012 were from 25 September to 23 October. The southern boundary of the survey area was near the northern end of U.S. Highway 100, while the northern boundary was the Mansfield Channel. Despite the fact that these surveys did not take place in PAIS, the results reported by Seegar et al. (2012) likely apply to the park due to the extremely close proximity of the two areas.

Survey participants used all-terrain vehicles (ATVs) to survey the study area from dawn to dusk, and recorded time, species, age, sex, location, and activity when falcons were sighted (Seegar et al. 2012). When a falcon was sighted in an area that allowed a safe, successful trapping effort, researchers would make a capture attempt. If a falcon was successfully captured, it was banded (U.S. Geological Survey [USGS] bands), had 2 mL of blood withdrawn, and had an axillary feather sample taken; a full description of banding protocol is available in Seeger et al. (2012).

Current Condition and Trend

<u>Neotropical Species Abundance and Diversity</u>
Nearctic-Neotropic migrants, hereafter Neotropical migrants, are bird species that breed in the temperate latitudes of the U.S. and Canada, but migrate to the tropical latitudes of Central and South America in the winter months (Figure 8, TPWD 2013). Stotz et al. (1996) estimate that approximately 420 bird species are classified as Neotropical migrants, and 333 of these species have been recorded in Texas (TPWD 2013). TPWD (2013) estimates that nearly half of all the documented bird species in Texas are Neotropical migrants.

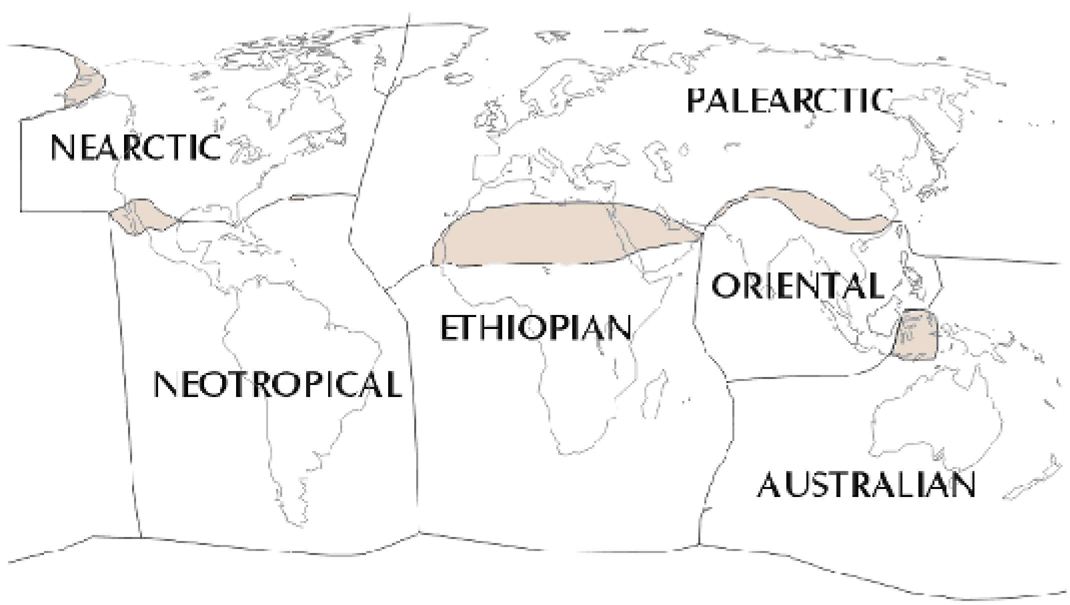

Figure 8. Zoogeographic regions of the world; shaded areas represent transition areas between regions (TPWD 2013).

PAIS is located in a unique area, as it lies very close to the perceived boundary between the Nearctic and Neotropical zoogeographic regions. Because of this, several Neotropical nesting species (e.g., great kiskadee [*Pitangus sulphuratus*]) also call PAIS home. For this measure of the assessment, however, only Neotropical migrant species will be discussed. TPWD (2013) has identified all Neotropical migrant species that are known to occur in Texas, and Appendix I indicates which of these species are present in PAIS.

NPS Certified Species List

The NPS Certified Bird Species List (accessible from: https://irma.nps.gov/App/Species/Search) confirms the presence of 370 bird species within PAIS. Of the 370 species identified, 216 species are identified as migratory species, and 127 species are Neotropical migrants (Appendix I).

PAIS Christmas Bird Count (1974-1990)

The Christmas Bird Count conducted in PAIS was part of the International Christmas Bird Count, which started in 1900 and is coordinated internationally by the Audubon Society. The PAIS CBC was conducted annually from 1974-1990. Multiple volunteers surveyed a 24-km (15-mi) diameter on one day, typically between 14 December and 5 January. Unlike the surveys that occur during the breeding season (such as the North American BBS), the CBC surveys overwintering and resident birds that are not territorial and singing. The total number of species and individuals were recorded each year. Recently, a new CBC circle was established with a center point located in the center of 9-mile Hole. Staff members of the NPS, TPWD, USFWS, CBBEP, National Audubon Society, Texas A&M University – Corpus Christi, and volunteers from the public perform this CBC in the winter. Data from this new CBC are not yet available from the National Audubon Society. SMUMN GSS adjusted the yearly data for these surveys in order to only display the observed Neotropical migrants (Table 17). The highest number of observed individuals occurred during the 1975-76 survey when 527 individuals were observed (Table 17). The 1974-75 survey had the highest number of observed species (14) (Figure 9).

Table 17. Number of Neotropical migrant individuals observed on the PAIS Christmas Bird Count from 1974-1990. Data retrieved from http://audubon2.org/cbchist/count_table.html.

Species	1974-75	1975-76	1976-77	1977-78	1978-79	1979-80	1980-81	1981-82	1982-83	1983-84	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90
semipalmated plover	31	1		22	22			23	22		1			2	2	
Wilson's plover					5				3							
black-bellied plover	88	138	21	108	137	11	9	109	83	45	69	20	127	187	58	13
red knot	25	279	9	92	289	1		75	21	4	129				19	
white-rumped sandpiper											4					
least sandpiper	185	56	113	103	38	14	69	160	158	3	25		10		69	
semipalmated sandpiper	6			3												
whimbrel		1														
Wilson's phalarope		4														
solitary sandpiper	2				1						1					
indigo bunting		1														
Cassin's sparrow	9	7	2	8			1	2					1			1
Lincoln's sparrow	21	7	18	33	1	21	6	2	23	12	16		13	30		
barn swallow													1			
gray catbird	1		1				1									
yellow-throated warbler						1	9				1					
black-throated green warbler	2															
palm warbler	1												1			
orange-crowned warbler	30	28	15	48		9	23						5			
house wren	12	5	18	7		2	3						5			1
common nighthawk	1															
Total	**414**	**527**	**197**	**424**	**493**	**59**	**121**	**371**	**310**	**64**	**246**	**20**	**163**	**219**	**148**	**15**

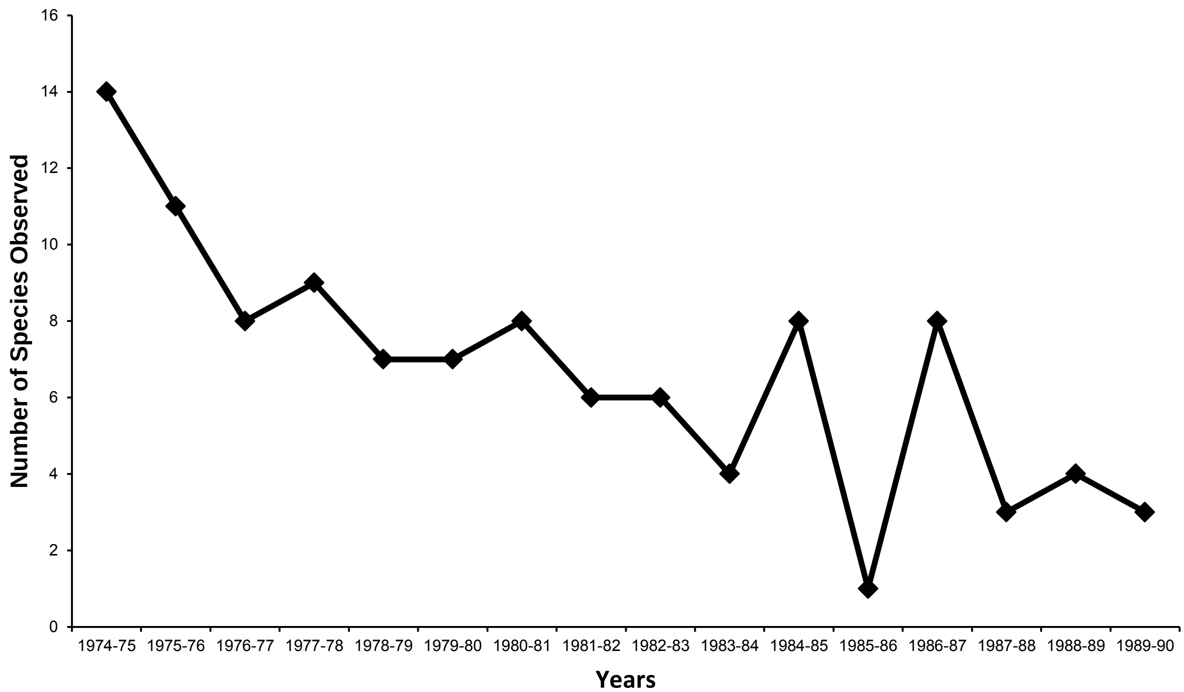

Figure 9. Number of Neotropical migrant species observed on the PAIS Christmas Bird Count from 1974-1990. Data retrieved from http://audubon2.org/cbchist/count_table.html.

There was a considerable degree of variation in the number of observed Neotropical migrant species and individuals throughout the duration of the PAIS CBC (Table 17, Figure 9). The CBC data available for these species can only be interpreted with caution, as count data are largely dependent upon the effort of the observers and may not always provide an accurate depiction of a species' abundance in PAIS.

Chapman (1984)

Chapman (1984) surveyed the Padre and Mustang Island areas to investigate the effect that the IXTOC oil spill had on the coastal bird population. The study area of this project stretched from Aransas Pass in the north to Brazos Santiago Pass in the south. All of PAIS was included in the survey area, although the number of species identified during the survey was not isolated to specific regions. Because of this, the species observed during this survey must be analyzed and interpreted with caution.

Similar to the transformations made to the CBC data for this assessment, the Chapman (1984) data were organized to include only the Neotropical migrant species that were observed. After re-organization, Chapman (1984) reported nine Neotropical migrants, most of which were sandpiper or plover species (Table 18). No abundance or diversity data were reported for these species.

Table 18. Neotropical migrant species observed during the Chapman (1984) coastal bird surveys.

Species
semipalmated plover
Wilson's plover
black-bellied plover
upland sandpiper
red knot
pectoral sandpiper
Baird's sandpiper
least sandpiper
buff-breasted sandpiper

Blacklock et al. (1998)

Banding and survey efforts during the 1998 spring migration identified 447 Neotropical migrant birds of 53 different species (Table 19). Five species (indigo bunting, northern waterthrush, Lincoln's sparrow, Swainson's thrush, and the gray catbird) accounted for more than 50% of the captured birds (Table 19). Blacklock et al. (1998) indicated that there were not significant differences in species abundance between the dune or wetland habitats, although more individual birds were netted in the wetland habitats.

Table 19. Neotropical migrant species and abundance results from the Blacklock et al. (1998) surveys and banding efforts.

Common Name	# of Individuals	Common Name	# of Individuals
yellow-billed cuckoo	1	ovenbird	3
blue grosbeak	4	northern waterthrush	64
painted bunting	10	American redstart	2
indigo dunting	75	Tennessee warbler	13
rose-breasted grosbeak	6	blue-winged warbler	1
black-headed grosbeak	1	Nashville warbler	17
dickcissel	5	Canada warbler	2
Lincoln's sparrow	37	hooded warbler	7
barn swallow	3	Wilson's warbler	1
northern rough-winged swallow	1	scarlet tanager	5
hooded oriole	1	summer tanager	10
Baltimore oriole	18	house wren	1
orchard oriole	9	veery	3
gray catbird	29	gray-cheeked thrush	7
bay-breasted warbler	3	Swainson's thrush	34
cerulean warbler	1	wood thrush	1
yellow-throated warbler	2	eastern wood-pewee	2
blackburnian warbler	1	least flycatcher	3
chestnut-sided warbler	2	Acadian flycatcher	4
yellow warbler	22	great crested flycatcher	2
blackpoll warbler	3	eastern kingbird	2
black-throated green warbler	4	warbling vireo	16
worm-eating warbler	2	red-eyed vireo	9
yellow-breasted chat	11	Chuck-will's-widow	1
black-and-white warbler	7	lesser nighthawk	1
Kentucky warbler	5	common highthawk	1
prothonotary warbler	1		

Blacklock et al. (1998) also refers to a 1997 banding survey that was similar to the 1998 banding efforts; however, the 1997 summary report is not on file at PAIS and a hard or digital copy of the report has not been located. Despite this, Blacklock et al. (1998, p. 2) states that: “transect data from the present study [1998] strongly support the conclusions from the 1997 study that burned areas do not receive nearly as much use by Neotropical migrants as unburned habitats.” Blacklock et al. (1998) also suggests that Neotropical migrants likely favor the wetland habitats in the park, but that enough evidence to make that conclusion was not yet available.

<u>Raptor Abundance</u>

The NPS Certified Species List (NPS 2013a) identifies 11 migratory raptor species as present in the park (Table 20). Unfortunately, few studies have focused exclusively on raptors in PAIS, and the studies that have focused on this avian group have dealt almost exclusively with the peregrine falcon. As an important over-wintering site for the Arctic peregrine falcon, surveys of this species in PAIS during the spring and fall allow researchers to monitor population trends, migratory characteristics, contaminants, and diseases (Seegar et al. 2012).

Table 20. Migratory raptor species identified on the NPS Certified Species List (NPS 2013a).

Scientific Name	Common Name
Accipiter cooperii	Cooper's hawk
Accipiter striatus	sharp-shinned hawk
Buteo jamaicensis	red-tailed hawk
Buteo lineatus	red-shouldered hawk
Buteo platypterus	broad-winged hawk
Buteo swainsoni	Swainson's hawk
Elanoides forficatus	swallow-tailed kite
Ictinia mississippiensis	Mississippi kite
Cathartes aura	turkey vulture
Coragyps atratus	black vulture
Falco peregrinus	peregrine falcon

During the spring 2012 survey, Seegar et al. (2012) recorded 301 peregrine falcon sightings and captured 37 birds during 145 survey hours in the field. The sighting rate for spring 2012 (20.76 birds/10 survey hours) was among the highest recorded during recent years, and was higher than the 18-year average (17.53 ± 4.16 birds/10 survey hours) (Figure 10). Seven of the captured birds had been previously banded in the Padre Island area, and one bird was a migrant from the Maryland coast (Seegar et al. 2012).

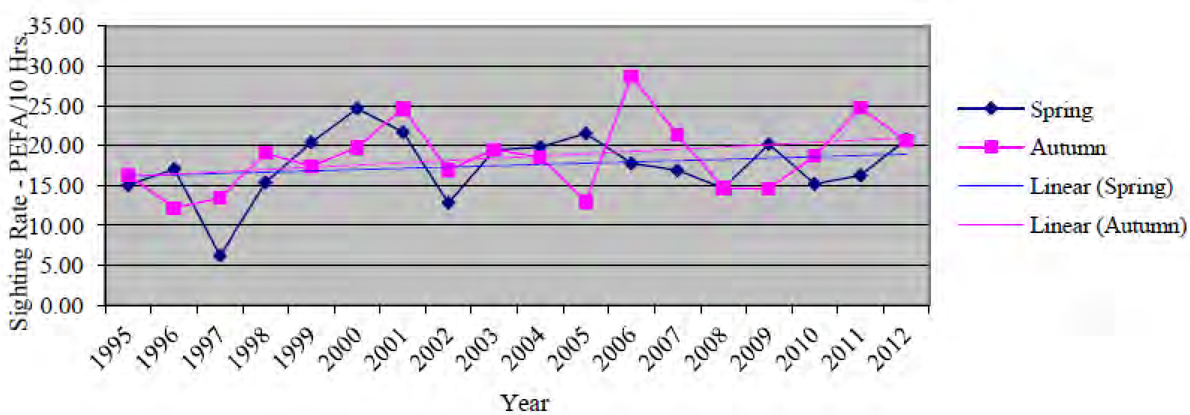

Figure 10. Padre Island peregrine falcon survey sighting rates from 1995-2012 (PEFA = peregrine falcon). Solid lines represent trend lines for the fall and spring surveys (figure reproduced from Seeger et al. 2012).

The fall 2012 peregrine falcon survey resulted in 1,002 observations and 228 captures during 484 survey hours in the field (Seegar et al. 2012). Only seven of the captured individuals had been previously banded (all were Padre Island area bands). The sighting rate for fall 2012 (20.70 birds/10 survey hours) was higher than the 19-year average (18.73 ± 4.37 birds/10 survey hours) for fall sightings (Figure 10).

Waterfowl Abundance

Very few studies have focused specifically on the migratory waterfowl population of PAIS. Several of the aforementioned bird studies (e.g., Chapman 1984; Chaney et al 1993b, 1995b; CBC data) have documented the presence of waterfowl species during their monitoring. The species that have been observed in the park during these monitoring efforts are reported in Table 21.

Table 21. Waterfowl species observed in PAIS during several avian monitoring reports.

Species	NPS (2013)	Chapman (1984)	Chaney et al. (1993b)	Chaney et al. (1995b)	CBC
mottled duck	X	X	X	X	X
northern pintail	X	X	X	X	X
blue-winged teal	X	X	X	X	X
northern shoveler	X		X	X	X
gadwall	X	X	X	X	X
American wigeon	X	X	X	X	X
canvasback	X	X		X	X
redhead	X	X	X	X	X
lesser scaup	X	X	X	X	X
bufflehead	X	X	X	X	X
red-breasted merganser	X	X	X	X	X
fulvous whistling duck [B]	X		X		
black-bellied whistling duck [B]	X		X		
greater white-fronted goose	X		X		X
snow goose	X		X		X
green-winged teal	X	X	X		X
common goldeneye	X		X		X
mallard	X	X			X
long-tailed duck (oldsquaw) [A]	X	X			X
surf scoter	X	X			X
Canada goose	X				X
wood duck [B]	X				X
cinnamon teal	X				X
ring-necked duck	X				X
greater scaup	X				X
black scoter	X				X
hooded merganser	X				X
ruddy duck	X				X
American black duck	X				
Ross's goose	X				
Harlequin Duck [A]	X				
white-winged scoter	X				

[A] = Vagrant species
[B] = Migratory species

The CBC efforts in the park (from 1974-1990) were the only source of abundance data for many waterfowl species in PAIS. While this data is now outdated, it does provide some context for what the historic migratory baseline values may be for the identified species. The results from the CBC efforts are outlined in Table 22.

Table 22. Waterfowl abundance as recorded on the PAIS CBC from 1974-1990.

Species	1974-75	1975-76	1976-77	1977-78	1978-79	1979-80	1980-81	1981-82	1982-83	1983-84	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90
greater white-fronted goose	19	171	27	5		138	58	8	8	7			109			
snow goose	1217	1830	5930	1664	1272	2659	2959	2354	553	578	729	1685	354	260	226	101
Canada goose	1690	844	2227	547	6	421	2290	405	30	82		5	373	6	47	252
wood duck			2										4			
gadwall	90	167	164	105	23	349	665	54	3	91	3	21	253	19	92	
American wigeon	5115	281	110	417	343	180	408	50	43	11	14	5	101		29	21
mallard	6	39	109	77	84	89	53	148	5	2	8	24			1	
mottled duck	128	99	361	246	150	182	102	216	33	57	35	109	54		50	2
blue-winged teal	21	13	121	40	85	302	70	100	31	4	8	20	5		2	
cinnamon teal	7	2	5	11		10	3	1				17				
northern shoveler	340	330	216	568	326	635	674	462	59	327	331	54	551	44	58	41
northern pintail	14266	6165	14346	3140	2813	4835	8290	932	2306	8293	2170	1630	924	199	1849	1372
green-winged teal	577	473	285	596	58	1003	387	246	180	600	23	95	162	53	3	
canvasback	13	9	1	13		16	5			11	46	8	4		8	3
redhead	20044	7551	10934	4210	6606	14724	2564	5951	1946	1112	8669	4856	627	776	4921	304
ring-necked duck		1				13	1			4						1
greater scaup									11		1				2173	
lesser scaup	8085	6073	12990	5001	4856	2210	6547	3753	3006		56	632	233	278	1156	733
surf scoter	3										1					
black scoter			2													
long-tailed duck (oldsquaw)						4										
bufflehead	926	372	1202	246	354	1030	406	249	288	243	184	153	223	139	141	261
common goldeneye		55	74	5					3			3			1	
hooded merganser	4	2	16	10		1	37	3	6							
red-breasted merganser	50	1	124	159	36	83	22	23	3	4	24				9	7
ruddy duck	40	36	130	81	343	813	118	8	10	57	10	41	4		4	1
Total	**52641**	**24514**	**49376**	**17141**	**17355**	**29697**	**25659**	**14963**	**8524**	**11483**	**12312**	**9358**	**3981**	**1774**	**10770**	**3099**

During the CBC efforts, there were three species that dominated in terms of annual abundance: the northern pintail, redhead, and the lesser scaup (*Aythya affinis*). These species accounted for almost 75% of all individuals observed during the PAIS CBC. There was a considerable amount of annual variation in these species (and all species observed during the CBC) (Table 22), and as mentioned previously, CBC data must be interpreted with caution as these data are dependent upon the number of researchers participating in the count, the skill-base of the researchers, and the level of effort displayed by the researchers.

As displayed in the CBC data (Table 22), the redhead is a prominent species in PAIS during the winter months. Large congregations of redheads (approximately 75% of the global population) overwinter in the Laguna Madre, as the Laguna holds large amounts of shoalgrass; shoalgrass comprises 70-92% of the overwintering redhead's diet (Koenig 1969, McMahan 1970, Cornelius 1977, Marsh 1979, Woodin 1996, James 2006). With such a large concentration of a single species in a single location foraging on a specific food, management efforts can be very focused.

Redhead populations have been increasing annually since the 1980s (James 2006); Wilkins and Otto (2002) indicated that breeding redhead populations reached near record numbers in the early 2000s. There is concern whether the Laguna Madre can support the ever-growing redhead population, as shoalgrass populations in the Laguna are heavily impacted by several threats:

1. Heavy foraging in previous winters by redheads and other waterfowl species;

2. Active dredging of the GIWW, which increases turbidity and can bury shoalgrass communities;

3. Altered salinity regime in the Laguna, primarily stemming from runoff and freshwater input;

4. Propeller scarring from both recreational and commercial vessels (James 2006).

While the global redhead population appears to be of low concern, their continued presence in PAIS and the Laguna Madre is not as clear. Aggregations of wintering redheads have been known to abandon historic wintering areas when submerged aquatic vegetation populations become depleted (this has been documented in the Chesapeake Bay [Perry et al. 1981] and in the Laguna Madre de Tamaulipas, Mexico [Saunders and Saunders 1981]). Managers of PAIS and agencies that operate in the Laguna should pay close attention to any trends in both the abundance of wintering redheads and the population of shoalgrass in the Laguna.

<u>Threats and Stressor Factors</u>

Migratory bird species face deteriorating habitat conditions along their migratory routes and wintering grounds. Most of the birds that breed in the United States spend winters in the Neotropics (MacArthur 1959); deforestation rates in these wintering grounds have occurred at an annual rate up to 3.5% (Lanly 1982). While forest and habitat degradation does occur in the United States, it does not approach the level of degradation seen in the tropics (WRI 1989). Furthermore, Robbins et al. (1989) supported the suggestion that deforestation in the tropics has a more direct impact on Neotropical migrant populations than deforestation and habitat loss in the United States.

Grassland degradation is also an issue for migratory birds in the PAIS area, as less than 1% of the original coastal grasslands of the Texas coast is considered to be in pristine condition (Smeins et al. 1991). Lawson (2009) reports a significant portion of the remaining pristine coastal grasslands in Texas is located in PAIS. Nationwide, over 97% of the native grasslands in the United States have been lost, primarily due to land conversion to agricultural fields (NABCI 2011).

As urban areas continue to develop and grow, modern alterations to the landscape often foster competition between native and non-native bird species. Human-made structures may fragment a landscape and reduce its continuity; often as these changes occur, non-native bird species are able to inhabit the areas. Marzluff (2001, pp. 26-28) states that,

> The most consistent effects of increasing settlement were increases in non-native species of birds, increases in birds that use buildings as nest sites (e.g., swallows and swifts), increases in nest predators and nest parasites (brown-headed cowbirds [*Molothrus ater*]), and decreases in interior- and ground-nesting species.

Being located along two major migratory routes, PAIS is frequently home to migratory “fallout” events. Fallout is when migratory birds descend to the ground in large numbers following a disturbance of some kind. While exhaustion is one of the most common causes of fallout, many factors can influence a species’ migration pattern and cause fallout events. Examples of these factors include food availability (Niles et al. 1996), the presence of a large desert (Berthold 1993) or open body of water (Alerstam 1990), topographic features (Berthold 1993, Bishop 1997), or weather events (Alerstam 1990, Niles et al. 1996).

In PAIS, weather-related fallout events are the most common, as hurricanes and strong thunderstorms may occur along the coast during migratory periods. Spring fallout events in Texas typically occur after strong, fast-moving cold-fronts move across the coast and into the Gulf of Mexico during the middle of the day (HAS 2013). The heavy rain and wind that accompany these cold fronts force migratory birds to the ground to avoid exhaustion. Migratory species that reach PAIS via a transoceanic flight (across the Gulf of Mexico) typically avoid periods of unfavorable weather, and large-scale movements often coincide with favorable wind conditions (Richardson 1976, Williams et al. 1977, Williams 1985, Moore et al. 1995, Butler 2000), whereas birds migrating over landmasses tend to ground when wind and weather conditions deteriorate (Butler 2000).

While extreme weather events such as hurricanes, tropical storms, and severe thunderstorms represent a significant threat to PAIS’s migratory birds, drought is also a source of stress for migratory birds. Drought is a major threat to most of the natural resources in PAIS. Not only do periods of drought remove many sources of standing water in PAIS (particularly the Bird Island Basin area), but these periods also affect availability of food for migratory birds. Drought may reduce forage items such as insects and plant species (Smith 1982), and could lead to starvation for many breeding birds in the park. Drought could also interrupt or alter the migratory patterns of species (Zeng 2003, Dai et al. 2004, Gordo 2007).

Human disturbance is a common threat to animal populations across the planet, and in the PAIS area, one of the more pressing issues is oil and gas exploration and development. These operations often fragment the landscape, and the traffic and human activity associated with the sites may further disrupt the bird species in the area. Oil and gas extraction has taken place on Padre Island since before the park's establishment in 1961 (Lawson 2009). Seventy oil/gas operations occurred within the administrative boundaries of the park between 1951 and 1981 (NPS 2005). The number of active operations in PAIS has declined since that era, and as of March 2013, there were six active pads within the park and 11 active wells. Two more pads are scheduled for restoration in the future, and only two operators (soon to be one operator) are active in the park (Stablein, written communication, 13 May 2013). While no new wells are being planned, exploration and development could occur at any time.

Data Needs/Gaps

Prior to 2013, there was no annual monitoring program for the land birds (whether migratory, resident, or raptor species) in PAIS. However, the GULN is beginning both a wintering and breeding landbird survey that will document both migratory and resident bird species. The establishment of these annual bird surveys and the resumption of the CBC efforts will likely provide the park with survey results that would be descriptive for both the resident and migratory species of the park. PAIS's location provides managers with a unique opportunity to survey several unique species during the migratory periods, and long-term trend data would allow for a greater understanding of the health of not only PAIS's habitat, but also the breeding and wintering areas for Neotropic migrants. Point counts will provide more detail regarding the breeding bird population of the park. The migratory bird population in PAIS serves as an excellent indicator of the entire park's health, and routine winter area search surveys will provide managers with a better understanding of health of both the migratory bird population and the many PAIS ecosystems.

No formal survey for migratory raptors exists in the park. It is likely that raptors could be surveyed in conjunction with Neotropical migrants in the park; results of these surveys could be assessed as a separate measure (i.e., raptor population) or the raptors could be merged and analyzed as part of the Neotropical migrant measure.

Overall Condition

Neotropical Species Abundance and Diversity

The project team defined the *Significance Level* for Neotropical species abundance and diversity as a 3. Because of its location along two major migratory flyways, PAIS is home to hundreds of different species that are not widely distributed in the U.S. There are not enough historic baseline data to assign this measure a *Condition Level*. Continuation/resumption of the Blacklock et al. (1998) survey would allow managers to detect any trends and to better understand species abundance and diversity in the park, although these surveys would need to be replicated for several years to have meaningful data.

Raptor Abundance
The *Significance Level* for raptor abundance is a 3. PAIS likely represents a high-priority area for migratory raptor species, especially the peregrine falcon. However, there are no established raptor monitoring programs in the park, and there is not enough historic baseline data to assign this measure a *Condition Level*. Creation of annual surveys would allow managers to detect any trends and to better understand the species composition and abundance in the park.

Waterfowl Abundance
The *Significance Level* for waterfowl abundance was defined as a 3. The abundant coastline and wetland habitats in the park serve as important wintering and stopover grounds for migratory waterfowl, especially the redhead. However, there is no contemporary abundance data for this measure, and a *Condition Level* cannot be assigned at this time. Monitoring of the overwintering species and the health of their forage species' populations will be essential in accurately defining the condition of this measure in the future. Special attention should be given to the overwintering redheads in the Laguna Madre, as this group represents a substantial percentage of the global population.

Weighted Condition Score
A *Weighted Condition Score* for PAIS's migratory bird species was not assigned. Few data exist regarding the abundance and diversity of the park's Neotropical migrants or raptor species. The establishment of annual surveys in the park would allow these measures to be accurately assessed in the future.

Migratory Bird Species

Measures	SL	CL
• Neotropical Species Abundance and Diversity	3	n/a
• Raptor Abundance	3	n/a
• Waterfowl Abundance	3	n/a

WCS = N/A

Sources of Expertise
Wade Stablein, Biological Technician, PAIS

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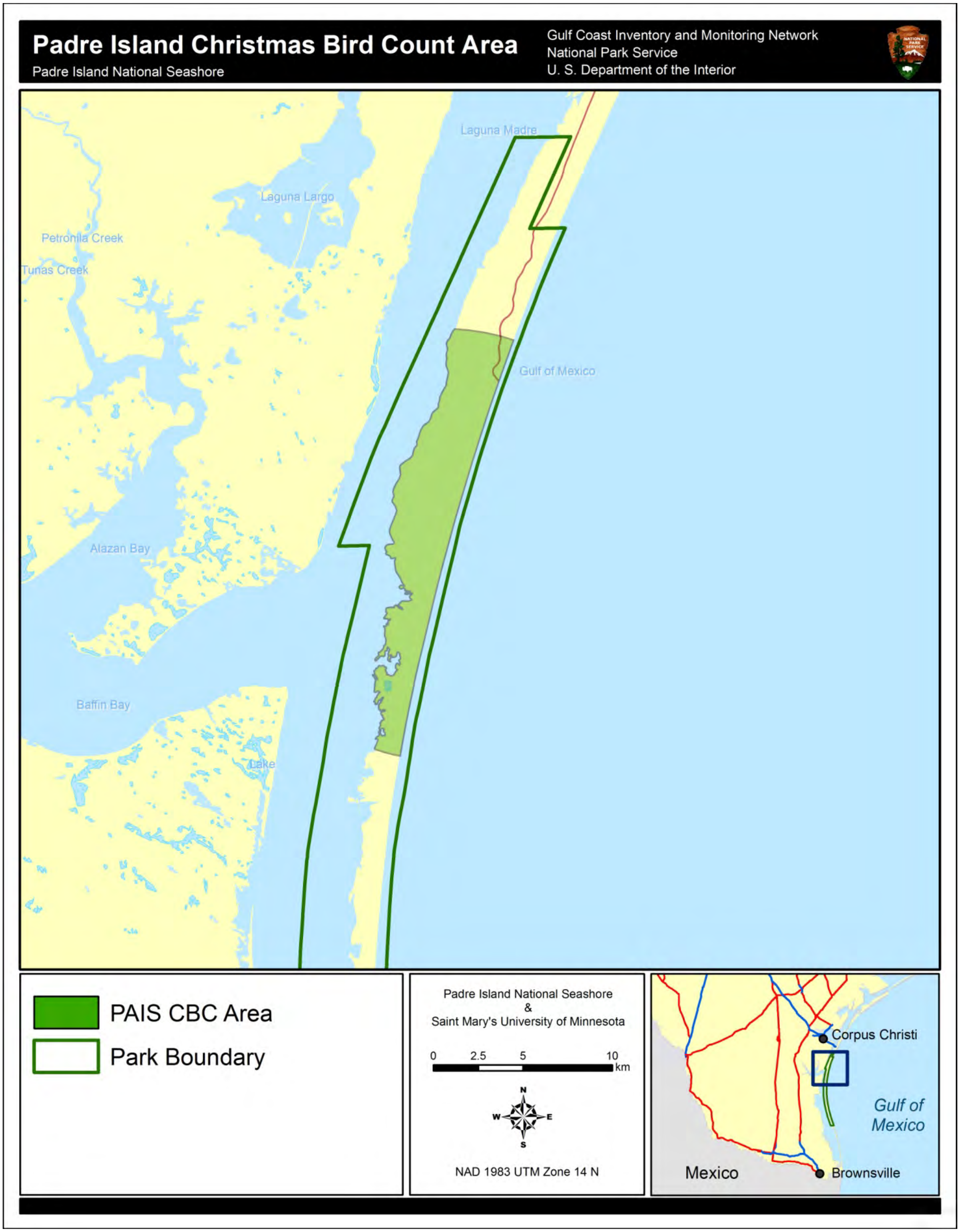

Plate 15. PAIS Christmas Bird Count survey area (1974-1990).

4.6 Resident Bird Species

Description

Resident bird species are birds that remain in one area throughout the year and do not migrate (Mettke-Hofmann et al. 2009). Unlike migratory birds, trends in resident bird species' populations are likely due to changes occurring in their immediate habitat or ecosystem, and (in theory) it is possible to study all of their population processes directly throughout the year (Koskimies 1989).

Excluding migratory species and colonial waterbirds (which are discussed in Chapters 4.5 and 4.7, respectively), NPS (2013) identifies 67 resident bird species in PAIS; these include waterfowl, raptors, shorebirds, and passerine species. Several of the resident species in the park, such as the northern pintail and the black-necked stilt (*Himantopus mexicanus*, Photo 11), are dependent upon the coastal wetlands/shorelines, while other species, such as the eastern meadowlark, rely on the grasslands of the park's interior.

Photo 11. Black-necked stilt (TPWD photo).

While migratory and colonial waterbird species often overshadow the resident bird species of PAIS, this particular assemblage of birds may serve as a valuable ecological indicator, as they are year-round residents of the park, and their health and abundance are dependent solely upon PAIS ecosystems. As previously stated in this report, PAIS has been identified as both a Globally Important Bird Area (ABC 2010), and as part of the Laguna Madre, a Site of International Importance (WHSRN 2009). Monitoring of the resident bird populations in PAIS may help managers to protect the vital bird habitats present in the park.

Measures

- Species abundance and diversity
- Species distribution
- Raptor abundance

Reference Conditions/Values

A reference condition for resident bird species in PAIS has not been defined. No annual monitoring of these birds occurs in the park, and a contemporary baseline survey could be used to define condition. There are limited contemporary and historic data for this component; therefore, no reference condition was used in the assessment of condition for this component.

Data and Methods

This component focuses exclusively on the resident bird species of the park, and does not discuss any migratory or colonial waterbird species (these species are discussed in Chapter 4.5 and Chapter 4.7 of this document, respectively). A species was classified as a resident bird based on the NPS Certified Bird Species List (NPS 2013, Appendix J), and by using the species' life history traits and established range as described by the Cornell University Lab of Ornithology's All About Birds online database (http://www.allaboutbirds.org).

The Christmas Bird Count conducted in PAIS was part of the International Christmas Bird Count, which started in 1900 and is coordinated internationally by the Audubon Society. The PAIS CBC was conducted annually from 1974-1990. Multiple volunteers surveyed a 24-km (15-mi) diameter on one day, typically between 14 December and 5 January. The center point of the 24-km diameter was 27.3333ºN, -97.3333ºW (Plate 16). Unlike the surveys that occur during the breeding season (such as the North American BBS), the CBC surveys overwintering and resident birds that are not territorial and singing. The total number of species and individuals were recorded each year. Recently, a new CBC circle was established with a center point located in the center of 9-mile Hole. Staff members of the NPS, TPWD, USFWS, CBBEP, National Audubon Society, Texas A&M University – Corpus Christi, and volunteers from the public perform this CBC in the winter. Data from this new CBC are not yet available from the National Audubon Society.

Chapman (1984) investigated the effects of the 1979 IXTOC I oil spill on the coastal bird species of Mustang and Padre Islands. All of PAIS was included in the survey area, although the number of species identified during the survey was not isolated to specific regions. Because of this, the species observed during this survey must be analyzed and interpreted with caution. From October 1980 to June 1981, bird censuses were conducted from a four-wheel drive vehicle that was driven along the beaches, and only birds on the beaches were counted (i.e., no flying or swimming birds were counted). Stops were made every 16 km (10 mi), and researchers were allowed 15 minutes to scan the area for birds that may have been missed from the vehicle. Only resident bird species that were observed are reported in this component.

EcoServices, Inc. conducted annual bird surveys along both the Gulf and Laguna Madre beaches from 1992-1995 (Chaney et al. 1993a, b, 1995a, b). These surveys focused on identifying protected bird species and determining the abundance and distribution of these species (Chaney et al. 1993b). The results of the surveys were summarized annually and released as internal NPS documents. At the midpoint of the project, more funds became available and the surveys were expanded to include all bird species (not just protected species). Data regarding protected species were collected in July 1992, and from October to April of 1992-93; data for all species were collected in July 1992 and from January to April of 1993. Unfortunately, much of the data collected in this report has been lost, as the only known physical copy has been lost. The data and information that were available from these studies are reported here, and were adjusted for this component to only include resident bird species in PAIS.

Current Condition and Trend

Species Abundance and Diversity

NPS Certified Species List

The NPS Certified Bird Species List (accessible from: https://irma.nps.gov/App/Species/Search) confirms the presence of 370 bird species within PAIS. Of the 370 species, 67 are identified as resident species (Appendix J).

PAIS Christmas Bird Count (1974-1990)

The most abundant data source for resident bird species' abundance was PAIS's annual CBC, which ran continuously from 1974 through 1990; this survey was discontinued in 1990 and has not been resumed in the years following. SMUMN GSS adjusted the yearly data for these surveys in order to display only the observed resident species (Appendix K). The highest number of observed individuals occurred during the 1977-78 survey when 5,835 individuals were observed (Appendix K). This survey year featured an unusually high number of American coots (*Fulica americana*) (900 individuals), as well as the highest number of northern bobwhite (*Colinus virginianus*) individuals (240) recorded during the PAIS CBC. The 1974-75 and 1975-76 surveys had the highest number of observed species with 41 (Figure 11).

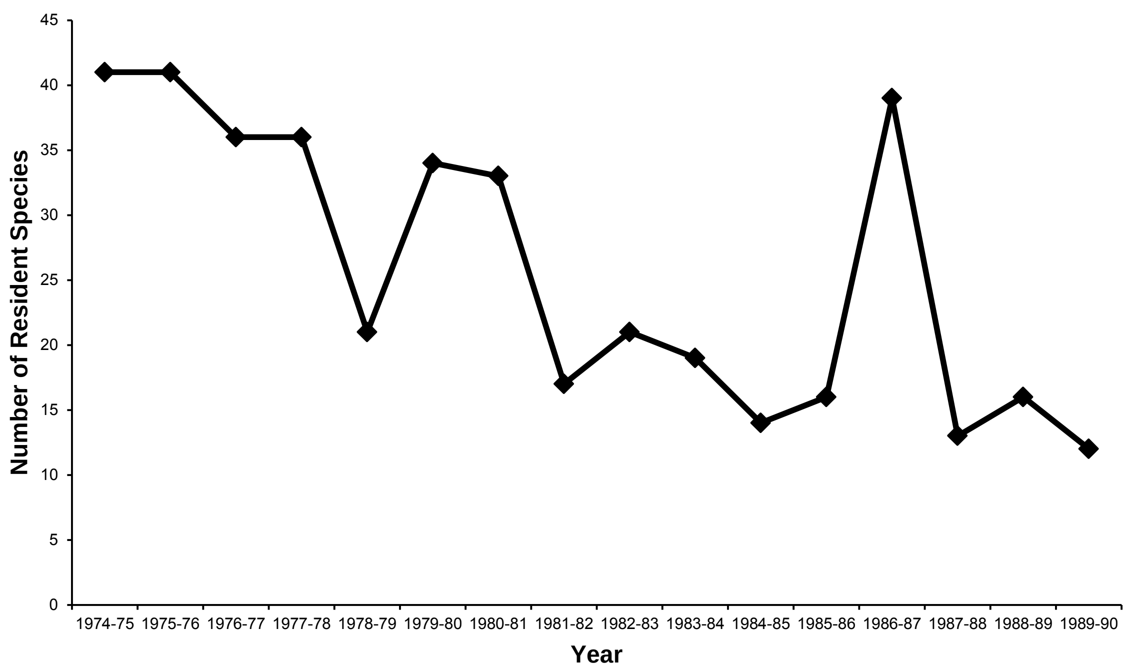

Figure 11. Number of resident bird species observed on the PAIS Christmas Bird Count from 1974-1990. Data retrieved from http://audubon2.org/cbchist/count_table.html.

Five resident bird species were responsible for over 70% of the individuals observed during the PAIS CBC; these species were the American coot, mourning dove (*Zenaida macroura*), red-winged blackbird (*Agelaius phoeniceus*), eastern meadowlark, and the brown-headed cowbird (Appendix K). The red-winged blackbird was observed every year during the CBC, and was the most numerous of all the resident bird species, with more than 10,000 observations over the course of the park's CBC (Appendix K).

There was a considerable degree of variation in the number of observed resident bird species and individuals throughout the duration of the PAIS CBC (Appendix K, Figure 11). The CBC data available for these species can only be interpreted with caution, as count data are largely dependent upon the effort and number of the observers, and may not always provide an accurate depiction of a species' abundance in PAIS.

Chapman (1984)

The data presented in Chapman (1984) were organized to include only the resident species that were observed. After re-organization, Chapman (1984) reported 10 resident bird species (Table 23). No abundance or diversity data were reported for these species.

Table 23. Resident bird species observed during the Chapman (1984) coastal bird surveys.

Scientific Name	Common Name
Tachybaptus dominicus	least grebe
Podilymbus podiceps	pied-billed grebe
Buteo albicaudatus	white-tailed hawk*
Falco sparverius	American kestrel*
Colinus virginianus	northern bobwhite
Fulica americana	American coot
Haematopus palliatus	American oystercatcher
Charadrius alexandrinus	snowy plover
Charadrius vociferus	killdeer
Eremophila alpestris	horned lark

* Indicates a raptor species

Chaney et al. (1993a, b; 1995a, b)

The 1993 and 1995 surveys of the Gulf and Laguna Madre coasts of PAIS resulted in the observation of 17 resident bird species (Table 24). Eleven species were observed during the Gulf surveys, and 13 species were observed on the Laguna Madre surveys (Table 24); only three species (snowy plover, turkey vulture [*Cathartes aura*], and American kestrel [*Falco sparverius*]) were observed on all four surveys. No abundance or diversity estimates were reported by Chaney et al. (1993a, b; 1995a, b).

Table 24. Resident bird species observed during the 1993 and 1995 surveys of the Gulf and Laguna Madre coasts (Chaney et al. 1993a, b; 1995a, b).

		Gulf		Laguna Madre	
Scientific Name	**Common Name**	**Chaney et al. (1993a)**	**Chaney et al. (1995a)**	**Chaney et al. (1993b)**	**Chaney et al. (1995b)**
Dendrocygna bicolor	fulvous whistling-duck	X		X	
Buteo jamaicensis	red-tailed hawk*	X			
Charadrius alexandrinus	snowy plover	X	X	X	X
Cathartes aura	turkey vulture*	X	X	X	X
Falco sparverius	American kestrel*	X	X	X	X
Colinus virginianus	northern bobwhite	X			
Dendrocygna autumnalis	black-bellied whistling-duck			X	
Podilymbus podiceps	pied-billed grebe			X	X
Fulica americana	American coot			X	X
Eremophila alpestris	horned lark		X	X	X
Sturnella magna	eastern meadowlark			X	X
Charadrius vociferus	killdeer		X	X	X
Buteo albicaudatus	white-tailed hawk*		X		X
Molothrus ater	brown-headed cowbird		X		
Quiscalus mexicanus	great-tailed grackle		X		
Haematopus palliatus	American oystercatcher				X
Polyborus plancus	crested caracara*				X

* Indicates a resident raptor species

<u>Species Distribution</u>

Few data exist regarding the distribution of resident bird species in PAIS. The bird surveys that have documented distribution have been focused on migratory shorebirds (Chapman 1984), colonial waterbirds (TCWS 2011a, b), or priority shorebird species (Chaney et al. 1993a, b; 1995a, b). Further complicating analyses, the Chaney et al. (1993a; 1995a, b) documents have been lost or damaged in the years following completion. Without these complete documents, an accurate summary of the data is not possible.

Chapman (1984)

Chapman (1984) surveyed the coastal shorebird population of the park, and did not record many resident bird species (Table 23); this study focused only on the beach habitat zones of the park (Figure 12). Because of this, the conclusions reached in this report must be interpreted with caution as they do not apply to all of the resident bird population, nor do they apply to all of the habitat types in PAIS.

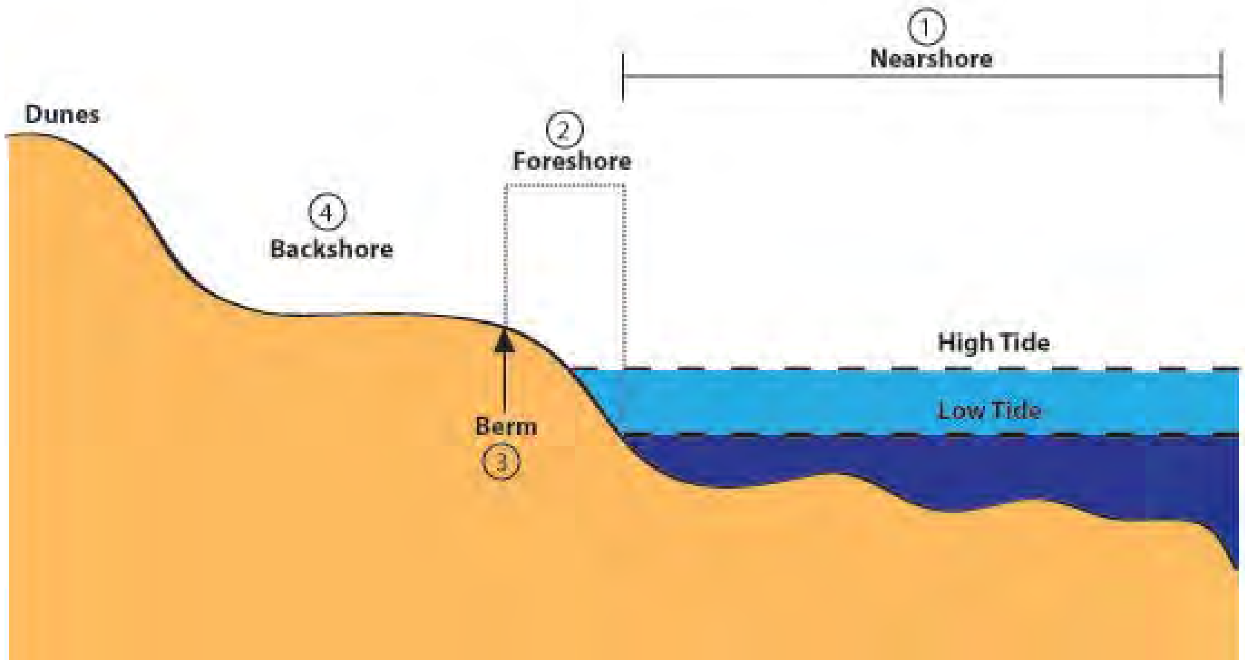

Figure 12. The habitat zones used to classify bird distribution in Chapman (1984).

Among the bird species that frequent the beach habitat, Chapman (1984) found that the foreshore region (Figure 12) of the beaches at PAIS supported the highest concentration of birds, while the backshore (which is almost always dry) was the least used habitat. Perhaps more importantly, Chapman (1984) noted that birds were not uniformly distributed along the beaches, and that three factors affected the distribution of birds in the study area:

1. Beach substrate composition;
2. The presence of storm-tidal passes;
3. The location of tar mats, fresh tar balls, or mousse (Chapman 1984, p. 30).

Big Shell and Little Shell Beaches had noticeably lower numbers of bird species and individuals (Chapman 1984). This trend was likely due to the unique shell-hash substrate of these two beaches; most of the survey area in Chapman (1984) consisted of a fine-sand substrate. The shell-hash substrate supports low numbers of invertebrates and other important forage species for shorebirds, which is probably why these beaches were poorly represented in the survey.

Raptor Abundance

There have been no studies in PAIS that focused exclusively on the park's resident raptor population. Several studies have observed resident raptor species, however, and these results are summarized below.

NPS Certified Species List

The NPS Certified Bird Species List confirms the presence of 13 native raptor species within PAIS (Table 25). The white-tailed hawk is listed as a threatened species by the State of Texas (TPWD 2013), while the aplomado falcon, is federally and state-listed as an endangered species (TPWD 2013).

Table 25. Resident raptor species in PAIS (NPS 2013).

Scientific Name	Common Name	State Status	Federal Status
Buteo albicaudatus	white-tailed hawk	T	
Buteo jamaicensis	red-tailed hawk		
Buteo lineatus	red-shouldered hawk		
Elanus leucurus	white-tailed kite		
Parabuteo unicinctus	Harris' hawk		
Cathartes aura	turkey vulture		
Coragyps atratus	black vulture		
Falco femoralis	aplomado falcon	E	E
Falco sparverius	American kestrel		
Polyborus plancus	crested caracara		
Athene cunicularia	burrowing owl		
Bubo virginianus	great horned owl		
Tyto alba	barn owl		

T = Threatened
E = Endangered

PAIS Christmas Bird Count (1974-1990)

The CBC was the only data source that recorded abundance values for each survey, and 1,947 individual resident raptors from nine species were observed during the CBC in PAIS from 1974-1990 (Table 26). Only the white-tailed hawk was observed during every year of the CBC, while the turkey vulture was the most abundant raptor species (Table 26). The inaugural CBC (1974-1975) resulted in the highest number of raptor species observed (nine), while the 1979-80 and 1980-81 surveys resulted in the highest number of observed raptor individuals (Table 26).

Table 26. Resident raptor species observed during the PAIS CBC (1974-1990). Data retrieved from http://audubon2.org/cbchist/count_table.html.

Species	1974 -75	1975 -76	1976 -77	1977 -78	1978 -79	1979 -80	1980 -81	1981 -82	1982 -83	1983 -84	1984 -85	1985 -86	1986 -87	1987 -88	1988 -89	1989 -90
black vulture	14	2		4		12	2		2	5			4	2		
turkey vulture	149	40	50	107	5	242	261	14	29	14		29	73		42	
Harris's hawk	4					11	3						5			
white-tailed hawk	11	6	10	13	4	14	20	6	2	1	8	5	6	5	7	4
red-tailed hawk	11	5	1	15	1	16	12	2	2	1	5	1	4		1	
crested caracara	3	7	4	10		12	20		1			2	2		2	
American kestrel	68	31	42	68	11	82	91	30	30		11	6	25	16	6	22
great horned owl	2	1	3	5			2		1				2		1	
burrowing owl	2		1						1							

Chapman (1984)
Only two raptor species (the white-tailed hawk and American kestrel) were observed during the Chapman (1984) survey (Table 23). No abundance data were recorded.

Chaney et al. (1993a, b; 1995a, b)
Five resident raptor species were observed during both the Gulf and Laguna coast bird surveys (Chaney et al. 1993a, b; 1995a, b; Table 24). Only the turkey vulture and the American kestrel were observed during both of the Gulf and Laguna Madre surveys (1993, 1995). The red-tailed hawk (*Buteo jamaicensis*) was only observed on the Gulf coast, while the crested caracara was only observed on the Laguna Madre coast (Table 24).

Threats and Stressor Factors
Because resident bird species do not migrate, they are entirely dependent upon the PAIS ecosystem for their sustenance. As a result, stressors on the PAIS landscape become stressors to the resident bird population; a decline in the resident bird population is likely indicative of a much larger issue occurring on the island. Currently, the major threats facing the PAIS resident bird population include human disturbance (e.g., oil and gas exploration/development, habitat alteration/loss), invasive and non-native species, predation, and drought.

Human disturbance exists in many forms in PAIS, with boating, fishing, vehicle travel on the Gulf beach, and wildlife viewing all being popular visitor activities. However, several sources of human disturbance come from sources not tied to visitor activity, such as commercial boat traffic on the GIWW and oil exploration and developments in the park. These represent significant threats to the resident birds. The GIWW supports some of the heaviest industrial water traffic in the world (DOI 1989), and there are currently six active drilling pads within the park and 11 active wells. Two more pads are scheduled for restoration in the future (pending funding), and only one operator is active in the park (Stablein, written communication, 13 May 2013). While no new wells are being planned, exploration and development could occur at any time. The establishment of additional oil sites, coupled with the increase in vehicle and foot traffic, could fragment or eliminate several habitat areas of the park's resident birds.

Drought represents a major threat to the resident bird population of the park. Periods of drought often reduce the water levels in critical bird habitats such as Bird Island Basin and the freshwater ponds on the island. Drought may also reduce the availability of prey or forage species (Smith 1982).

Data Needs/Gaps
Prior to 2013, there was no annual monitoring program for the land birds (whether migratory, resident, or raptor species) in PAIS. However, the GULN is beginning both a wintering and breeding landbird survey that will document both migratory and resident bird species. The establishment of these annual bird surveys and the resumption of the CBC efforts will likely provide the park with survey results that would be descriptive for both the resident and migratory species of the park. Point counts will provide more detail regarding the breeding bird population of the park. The resident bird population in PAIS serves as an excellent indicator of the entire park's health, and routine winter area search surveys will provide managers with a better understanding of the health of both the resident bird population and the many PAIS ecosystems.

Overall Condition

Species Abundance and Diversity
The project team defined the *Significance Level* for this measure as a 3. However, there are not enough historic or contemporary abundance data to assign this measure a *Condition Level*.

Species Distribution
The project team defined the *Significance Level* for species distribution as a 3. Very few studies have focused on the distribution of the resident bird species in the park. Without this descriptive data, an assessment of condition for this measure is not possible; therefore, a *Condition Level* was not assigned.

Raptor Abundance
The *Significance Level* for raptor abundance is a 3. No raptor-specific survey has been conducted in the park, and the only records for this group come from sightings reported in various shorebird and waterbird surveys. Until baseline abundance data for this measure are obtained, a *Condition Level* cannot be assigned.

Weighted Condition Score
A *Weighted Condition Score* for PAIS's resident bird species was not assigned. Few data exist regarding the abundance, diversity, or distribution of the park's resident birds; the establishment of annual surveys in the park would allow these measures to be accurately assessed in the future.

Resident Bird Species

Measures	SL	CL
• Species Abundance and Diversity	3	n/a
• Species Distribution	3	n/a
• Raptor Abundance	3	n/a

WCS = N/A

Sources of Expertise
Wade Stablein, Biological Technician, PAIS

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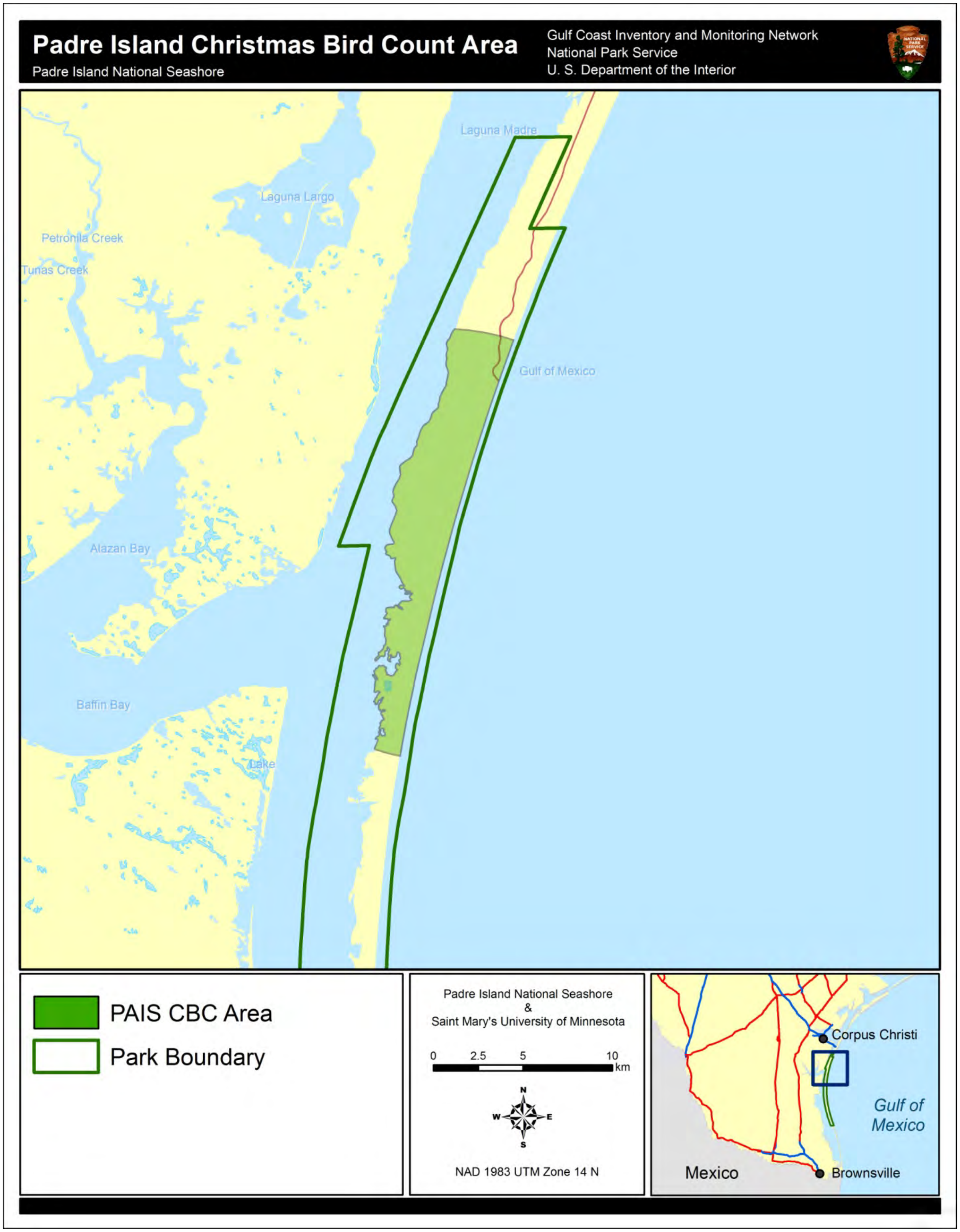

Plate 16. PAIS Christmas Bird Count survey area (1974-1990).

4.7 Colonial Waterbirds

Description

Colonial waterbirds are a unique group of bird species that gather in large numbers to nest at a specific location during the breeding season (Buckley and Buckley 1979, Kushlan 1986). These colony sites may consist of several unique species; waterbirds typically observed at these colonies include herons, gulls, terns, pelicans, egrets, and many others. Table 27 lists those families classified as waterbirds according to the Patuxent Wildlife Research Center's Waterbird Monitoring Partnership (USGS 2001). For the purpose of this assessment, only species that are listed in Table 27 are discussed in this component.

Table 27. Families of waterbirds as defined by the USGS Patuxent Wildlife Research Center's Waterbird Monitoring Partnership (USGS 2001).

Family	Species
Pelecanidae	pelicans
Phalacrocoracidae	cormorants
Ahhingidae	darters
Fregatidae	frigatebirds
Ardeidae	herons, egrets, bitterns
Threskiornithidae	ibises, spoonbills
Laridae	gulls, terns, skimmers

PAIS is home to two very unique coastal ecosystems, both of which are used by the park's waterbirds. On the east side of Padre Island is the Gulf of Mexico (Gulf) shoreline, while the west side of the island is bordered by the Laguna Madre. The Gulf shoreline is comprised of firmly packed white sand and is bordered by a narrow dune ridge. The Gulf coast provides important foraging and staging grounds for birds, especially during the migratory period. However, few, if any, waterbird colonies exist on the Gulf coast beach (TCWS 2011a, 2011b).

Photo 12. Brown pelicans (*Pelecanus occidentalis*) flying along the Gulf coast of PAIS (Photo by Shannon Amberg, SMUMN GSS).

The Laguna Madre is a hypersaline lagoon that can be 1.5 to 3 times as salty as the ocean, and is a very sensitive ecosystem (NPS 2012). Unlike the turbulent nature of the Gulf coast, the Laguna Madre has hardly any flow of sediments. Beginning in 1942, the U.S. Army Corps of Engineers (USACE) began extending the GIWW within the Laguna Madre from Corpus Christi, Texas to the Mexican border (Chaney et al. 1978). To allow for navigation throughout the GIWW, the channel needed to be dredged to a depth of 3.7 m (12 ft) and a width of 38.1 m (125 ft) (Chaney et al. 1978). Dredge material was frequently disposed of along land banks; however, there were several instances in the Laguna Madre where this disposal method was not possible. According to Chaney et al. (1978, p. 10), "For those channels that pass through deep water areas, dredged material is deposited in sub-aqueous banks; but in shallow bays or lagoons, the deposits commonly form emergent domes, or islands."

Within PAIS boundaries, there are 11 man-made dredge spoil islands in the Laguna Madre that have acted as nesting islands for colonial waterbird species (Island 614-344 is discussed in this document, but is located just outside of the park boundary) (Plate 17). Several of these islands support over 1,000 birds of many different species. For many species (e.g., American white pelican and black skimmer), the colony sites in PAIS represent >25% of their coast-wide populations (TCWS 2011a). Annual monitoring of these colonies provides PAIS managers with valuable information regarding the health of these unique bird populations.

Measures

- Species abundance and diversity
- Species distribution
- Nesting success

Reference Conditions/Values

A reference condition for colonial waterbirds in PAIS has not been defined. Although there are no NPS-initiated waterbird surveys, the TCWS has monitored the rookery islands of the park for the past 36 years. While there is a high degree of variability in annual abundance, yearly comparisons to the 36-year average for each colony island may serve as an appropriate reference condition for some measures.

Data and Methods

The NPS Certified Bird Species List (NPS 2013a) (Appendix L) for PAIS was used for this assessment; this list represents all of the confirmed bird species present in the park. For this component, only bird species considered colonial waterbirds (as defined in Table 27 and Appendix L) were included. SMUMN GSS removed migratory and resident species from this list, as these species are discussed separately in Chapters 4.5 and 4.6 of this document.

Chapman (1984) investigated the effects of the 1979 IXTOC I oil spill on the coastal bird species of Mustang and Padre Islands. One of the survey areas (area B) was located within PAIS, and extended from Malaquite Beach in the north, to Mansfield Channel in the south. From October 1980 to June 1981, bird censuses were conducted from a four-wheel drive vehicle that was driven along the beaches, and only birds on the beaches were counted (i.e., no flying or swimming birds were counted). Stops were made every 16 km (10 mi), and researchers were allowed 15 minutes to scan the area for birds that may have been missed from the vehicle.

EcoServices Annual Bird Surveys (1992-95)
EcoServices conducted annual bird surveys along both the Gulf and Laguna Madre beaches from 1992-1995 (Chaney et al. 1993a, b, 1995a, b). These surveys were summarized annually and released as internal documents to the NPS. Although the surveys on the Gulf likely only identified non-breeding colonial waterbirds, their observations are reported in this document. Chaney et al. (1993a) was the first of these annual surveys, and monthly bird surveys were completed along the Gulf beach of PAIS from September 1992 to August 1993. The survey area included the beach areas of the park from Mansfield Channel north to the upper end of the closed beach area, for a total length of 103 km (64 mi). A total of 51,205 birds of 56 species were identified during the study; of those species identified, 22 were colonial waterbirds. Only the results that applied to the waterbirds of PAIS are reported in this component.

Chaney et al. (1993b, p. 1) continued the surveys, and focused the study to "determine the abundance and distribution of protected bird species within the mudflats bordering the Laguna Madre shoreline from Yarborough Pass to Mansfield Channel." This section of the park does not contain any rookeries, and it is likely that only foraging or vagrant colonial waterbirds were observed in these areas (Stablein, written communication, 11 April 2013). At the midpoint of the project, more funds became available and the surveys were expanded to include all bird species (not just protected species). Data regarding protected species were collected in July 1992, and from October to April of 1992-93; data for all species were collected in July 1992, and from January to April of 1993. Unfortunately, much of the data collected in this report has been lost, as the only known physical copy has been lost.

Chaney et al. (1995a) replicated the bird surveys of Chaney et al. (1993a), surveying the Gulf beach from October 1994 through September 1995. This study utilized a similar methodology as its predecessor, and recorded 36,697 birds of 52 species. Similarly, Chaney et al. (1995b) replicated the bird surveys conducted on the Laguna Madre coast that were completed by Chaney et al. (1993b). These surveys were completed monthly from August 1994 to August 1995, and recorded 66,895 birds of 93 species; 25 species were identified as colonial waterbirds. Unfortunately, much of the data collected in these reports has been lost, as the only known physical copies have been damaged/lost.

The TCWS is made up of Audubon Texas, CBBEP, Texas A&M University – Kingsville, Texas General Land Office, Texas Parks & Wildlife Department (TPWD), The Nature Conservancy, USFWS, the NPS, and various volunteers. TPWD has taken on the responsibility of being the point of contact for managing and accessing data, until a better way of managing and serving the data is identified and managed. According to TPWD (2013), the mission of the TCWS is to "monitor, promote research, and inform management of colonial waterbird populations in Texas." Annual surveys are conducted at each of the 12 dredge spoil islands that have historically supported breeding colonial waterbirds. Surveys for some islands date back to 1973, while other islands had initial surveys conducted as recently as 2003. TCWS provides annual regional reports for the upper, central, and lower coasts of Texas (TCWS 2011a, b); PAIS is located on both the central and lower coasts, and the data for the park are split into two separate summary reports.

For data regarding the extent and cover of the spoil islands, Laine and Ramsey (1998) completed a landcover classification for the park which provides information on the extent of various vegetation communities and non-vegetated areas on PAIS spoil islands based on mid-1990s aerial photography. Laine and Ramsey (1998) followed classification and interpretation protocols developed by the NOAA C-CAP program and used map descriptions that fit NVCS guidelines. In 2007, the NPS created a surficial geology GIS map for PAIS, based primarily on 2003 aerial photography (NPS 2012b). Map classifications are loosely based on land cover and divide spoil island communities into two classes: vegetated spoil mound and barren spoil mound (NPS 2007).

Current Condition and Trend

The colonial waterbirds that nest in the park are heavily dependent upon the unique dredge spoil islands and do not nest on the mainland of PAIS. According to surficial geology GIS data (NPS 2007), the total area of the spoil islands (vegetated and barren spoil mounds) within the PAIS boundary (based on 2003 aerial imagery) is just under 490 ha (1,208 ac). However, this includes some spoil deposits on Padre Island itself. Using 2009 aerial imagery and the ArcGIS measure tool, SMUMN analysts estimated the area of the 18 islands studied by Chaney et al. (1978). The total area of all islands was approximately 80 ha (197.7 ac), a 6 ha (14.9 ac) reduction from the 1970s total (Chaney et al. 1978).

The availability of mineral earth or bare ground is important for many species of ground-nesting sea and shorebirds. No data have been published regarding the overall percentages of vegetative cover and bare ground on the park’s spoil islands. According to the park’s surficial geology GIS data, vegetated spoil mound covers approximately 440 ha (1087 ac) or nearly 90% of the park’s spoil islands (total area = 490 ha [1,211 ac]) (NPS 2007). The barren spoil mound class covers approximately 49 ha (121 ac) or around 10% of the total spoil island area (NPS 2007). However, bare ground patches do occur within the vegetated spoil mound class; the size of these areas and, therefore, overall percentages of vegetative cover and bare ground, have not been measured.

The 1998 landcover classification (Laine and Ramsey 1998) identified three vegetated cover classes on spoil mounds: emergent wetland, grassland, and sparse vegetation. The emergent wetland and grassland classes make up 33 ha (81.5 ac) and 186 ha (460 ac) of the spoil mounds, respectively (Laine and Ramsey 1998; Plate 18). These numbers include some spoil mounds on Padre Island, not just the separate spoil islands in the Laguna Madre. The sparse vegetation class covers 155 ha of the spoil mounds, but it is unknown what percent of this landcover class is actually vegetated.

A fourth class identified on the 1998 landcover classification (Laine and Ramsey 1998) was unconsolidated shore, described as “consisting of fine sands with little to no vegetation” (Laine and Ramsey 1998, p. 6). According to landcover GIS data, unconsolidated shores make up approximately 162 ha of the park’s spoil mounds. However, this includes some spoil mound on Padre Island as well as the separate spoil islands. The 155 ha (383 ac) of spoil mounds covered with sparse vegetation, as discussed above, likely includes substantial patches of bare ground (Laine and Ramsey 1998; Plate 18).

Species Abundance and Diversity

NPS Certified Bird Species List

The NPS Certified Bird Species List (NPS 2013a) contains 43 colonial waterbird species belonging to seven different families (Appendix L). This list, however, does not allow for an analysis of annual abundance or diversity, as no data are collected. This list simply represents a synthesis of confirmed reports of bird species occurring within PAIS boundaries.

Chapman (1984)

Chapman (1984) documented the seasonal abundance of coastal bird populations along the Texas Gulf coast. The maximum abundance values for all coastal bird species occurred during the spring and fall migration periods, with peak abundance occurring in the fall of 1980 (186 birds/km) (Chapman 1984). Chapman (1984) did not focus specifically on colonial waterbirds, although 10 colonial waterbird species were identified during the surveys. These species, along with their estimated abundance values, are displayed in Table 28.

Table 28. Average monthly abundance and diversity of colonial waterbirds in PAIS from October 1980 to June 1981. Data represents mean birds per km (± standard deviation). Data modified from Chapman et al. (1984).

	Month									
Species	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**Monthly Average**
royal tern	1.4 (1.1)	2.4 (1.6)	1.5 (0.9)	1.1 (0.1)	3.6 (0.9)	1.6 (0.2)	7.8 (1.7)	4.5 (2.3)	3.4 (1.5)	**3.03**
Caspian tern	1 (0.6)	1.8 (1.3)	0.2 (0.2)	---	---	0.2 (0.1)	0.1 (0.0)	---	0.1 (0.0)	**0.57**
Forster's tern	0.8 (0.8)	1.8 (1.0)	1 (0.7)	1.7 (0.3)	4.4 (1.5)	0.3 (0.3)	0.1 (0.0)	---	---	**1.44**
sandwich tern	0.3 (0.1)	0.5 (0.5)	0.5 (0.5)	0.1 (0.1)	0.1 (0.1)	0.4 (0.3)	3.8 (1.4)	0.8 (0.5)	1.3 (1.2)	**0.87**
least tern	---	---	---	---	---	---	1.7 (0.5)	2.2 (0.6)	1.3 (0.2)	**1.73**
black tern	---	---	---	---	---	---	---	0.9 (0.9)	2.2 (2.2)	**1.55**
laughing gull	7.1 (3.3)	4.8 (1.9)	3.7 (1.8)	2.3 (0.8)	2.6 (0.8)	11.8 (5.8)	12 (0.4)	9.3 (0.5)	9.1 (2.8)	**6.97**
herring gull	0.2 (0.1)	0.9 (0.2)	1.1 (0.3)	1.1 (0.1)	2 (0.7)	1.7 (0.3)	1.5 (0.8)	0.1 (0.1)	---	**1.08**
ring-billed gull	2.4 (0.5)	5 (2.3)	4.5 (2.7)	4.3 (0.6)	6.2 (2.2)	5 (3.4)	1 (0.1)	0.1 (0.1)	---	**3.56**
great blue heron	0.5 (0.3)	0.3 (0.0)	0.3 (0.1)	0.1 (0.1)	0.2 (0.1)	---	0.1 (0.0)	0.1 (0.1)	0.1 (0.1)	**0.21**
# of species	**8**	**8**	**8**	**7**	**7**	**7**	**9**	**8**	**7**	**7.67**

Chapman (1984) found the abundance of colonial waterbirds to be higher during the fall and spring months, with most species experiencing a notable drop in abundance during the winter season (Table 28). A few notable examples of this trend are the royal tern (increased from 1.6 birds/km in March, to 7.8 birds/km in April), and the laughing gull (increased from 2.6 birds/km in February, to 11.8 birds/km in March) (Table 28). With only one calendar year surveyed by Chapman (1984), it is impossible to detect any trends in abundance. Density values for all coastal birds were reported in Chapman et al. (1984), but as this component of the NRCA focuses only on colonial waterbird species, the reported density values in Chapman et al. (1984) would be inaccurate.

Chaney et al. (1993a, 1995a) (Gulf Coast Surveys)

Chaney et al. (1993a, 1995a) investigated avian usage of PAIS's Gulf beach; Chaney et al. (1993a) surveyed the beach from 1992-93, while Chaney et al. (1995a) surveyed the beach from 1994-95. Species observed on the Gulf coast are assumed to be using the coast for foraging or migration, as no nesting colonies are present on the Gulf side of PAIS (Stablein, written communication, 11 April 2013).

During the 1992-93 survey of the Gulf beach, Chaney et al. (1993a) observed 22 colonial waterbird species (Table 29). A total of 14,210 colonial waterbird individuals were observed during the survey (Table 30). However, prior to February 1993 only "protected" bird species were counted; resident gull and tern species were not counted for the duration of the survey (an estimated 11,200 black terns were observed, but not reported, in September 1992). Because of these discrepancies, the total number of birds reported in Table 29 and Table 30 are not true reflections of how many birds may have used the Gulf beach for the 1992-93 season. No diversity estimates were calculated by Chaney et al. (1993a).

Table 29. Colonial waterbird species observed on the Gulf coast and the Laguna Madre during the 1993-94 and 1994-95 surveys.

Common Name	Gulf		Laguna Madre	
	Chaney et al. (1993a)	**Chaney et al. (1995a)**	**Chaney et al. (1993b)**	**Chaney et al. (1995b)**
brown pelican	X	X	X	X
double-crested cormorant	X	X	X	X
great blue heron	X	X	X	X
snowy egret	X	X	X	X
little blue heron	X	X	X	X
tricolored heron	X	X	X	X
reddish egret	X	X	X	X
cattle egret	X	X	X	X
yellow-crowned night heron	X	X	X	X
laughing gull	X		X	
ring-billed gull	X	X	X	X
herring gull	X	X	X	X
lesser black-backed gull	X			
gull-billed tern	X	X	X	X
Caspian tern	X	X	X	X
royal tern	X	X	X	X
sandwich tern	X	X	X	X
common tern	X	X	X	X
Forster's tern	X	X	X	X
least tern	X	X	X	X
black tern	X	X	X	X
black skimmer	X	X	X	X
American white pelican			X	X
neotropic cormorant		X	X	X
great egret			X	X
green-back heron (green heron)			X	
black-crowned night-heron			X	
white ibis		X	X	X
white-faced ibis			X	
roseate spoonbill			X	X
Franklin's gull			X	
magnificant frigatebird		X		
Totals	**22**	**23**	**30**	**25**

Table 30. Abundance of colonial waterbirds during the 1993-94 survey on the Gulf coast. Dates on the left side of the dotted line (Sept 1993 – Jan 1994) represent the period that documented only priority bird species in the park. Dates after the dotted line represent the survey period when all species were recorded, not just priority species (Chaney et al. 1993a).

	Month												
Species	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Total**
brown pelican	24	69	233	26	12	304	91	19	70	15	32	84	978
magnificent frigatebird												3	3
double-crested cormorant		62	181	830	222	109	114	1					1,519
great blue heron	2						1	1	6	4	1	16	31
little blue heron								6	8	2		1	17
tricolored heron							2	1	9				12
reddish egret	1	24	10	3							2		40
reddish egret white		1	1	1									3
cattle egret							32	114	284			11	441
yellow-crowned night-heron							2					1	3
royal tern		1											1
common tern								3					3
Forster's tern									12				
least tern	1,405	1					21	1,348	840	646	957	988	6,206
black tern		1						1	223	823	1,477	2,428	4,953
Total	**1,432**	**159**	**425**	**860**	**234**	**413**	**263**	**1,494**	**1,452**	**1,490**	**2,469**	**3,532**	**14,210**

Chaney et al. (1995a) surveyed the Gulf beach in PAIS monthly from October 1994 to September 1995. Twenty-three colonial waterbird species were observed during the monthly surveys (Table 29); however, the physical report has been lost in the years following its completion, and alternate copies of the report have not been located. Because of this, an accurate summary and analysis of the data from this research is not possible.

Chaney et al. (1993b, 1995b) Laguna Madre Surveys

Chaney et al. (1993b) surveyed the Laguna Madre side of Padre Island from July 1992 to April 1993. The survey methods largely replicated the survey efforts of Chaney et al. (1993a) on the Gulf side of the island. However, much of the report has been damaged or lost in the years since its completion, and a full analysis of the results is not possible at this time. All that can accurately be reported from the incomplete document are the 30 species of colonial waterbirds observed during the monthly surveys (Table 29).

Chaney et al. (1995b) surveyed the Laguna Madre side of Padre Island from August 1994 to August 1995. Similar to Chaney et al. (1993b, 1995a), the final report is damaged and does not have complete data to report on. All that can accurately be reported is that 25 colonial waterbird species were observed on the Laguna side of the island during the survey period (Table 29).

Texas Colonial Waterbird Society Annual Monitoring

The TCWS annually surveys the islands of PAIS and records abundance based on the estimated number of breeding pairs for each species observed on the islands. In this section, islands 614-341a, b, c, and d are reported on as though they constitute a single island (as was done in NPS 2013a); the same procedure was used for islands 614-342a, and b. Plate 19-Plate 26 present the 2011 abundance data in relation to the 36-year average for each of the eight islands surveyed.

Of the nine islands surveyed in 2011, four had zero nesting colonial waterbirds (614-341, Plate 19; 614-344, Plate 22: 614-346, Plate 24; 614-347, Plate 25). Island 614-345 had the highest number of breeding pairs (780). However, 740 of those pairs were American white pelicans; the other species that were observed on the island were observed in lower numbers than their historical average (Plate 23).

When the TCWS survey results were summarized for the entire park, seven of the 22 identified colonial waterbird species exhibited a positive percent change in breeding pair abundance when comparing 2011 park-wide survey results to the previous 36-year average (Table 31). Twelve colonial waterbirds exhibited a negative percent change in breeding pair abundance, and three species (brown pelican, Forster's tern [*Sterna forsteri*], and sooty tern [*Sterna fuscata*]) were not observed frequently enough to determine a trend (trends were only determined for species that averaged $\geq$ 1 breeding pair/year) (Table 31).

Table 31. Average annual abundance of breeding birds in PAIS, 2011 abundance values, and the overall percent change observed in 2011 compared to the average abundance of the species. Italicized entries were not observed frequently enough to determine trend.

Species	Park-wide avg # of breeding pairs	2011 # of breeding pairs	% Change
white pelican	130.86	740	465
brown pelican	*0.77*	*20*	*n/a*
great blue heron	5.39	19	252
great egret	5.89	0	-100
snowy egret	13.02	3	-77
little blue heron	3.12	1	-68
tricolored heron	17.49	3	-83
reddish egret	9.04	10	11
cattle egret	111.92	0	-100
black crowned night heron	2.38	0	-100
white ibis	1.32	0	-100
white-faced ibis	13.59	0	-100
roseate spoonbill	15	0	-100
laughing gull	389.02	252	-35
gull-billed tern	14.01	60	328
Caspian tern	8.3	81	876
royal tern	46.9	14	-70
sandwich tern	49.01	16	-67
Forster's tern	4.24	67	1,481
least tern	*0.96*	*0*	*n/a*
sooty tern	*0.18*	*0*	*n/a*
black skimmer	16.29	135	729

The Caspian tern (*Sterna caspia*) and the black skimmer exhibited the highest percentage increase in abundance in 2011, with the Caspian tern increasing 876% and the black skimmer increasing by 729% (Table 31). The American white pelican had the highest increase in terms of number of estimated breeding pairs observed in 2011 (740 breeding pairs observed), up 609 pairs (465%) from the 36-year average (Table 31). The 740 breeding pairs of American white pelicans were observed on island 614-345 (commonly referred to as “Pelican Island”, Photo 13) and were the only colony of breeding pelicans observed during the TCWS (2011a) survey of the central coast of Texas.

Photo 13. American white pelican nesting colony on Pelican Island (614-345) in the Laguna Madre (image from TCWS 2011a).

Several species typically observed in PAIS (e.g., cattle egret [*Bubulcus ibis*], roseate spoonbill [*Ajaia ajaja*], and white-faced ibis [*Plegadis chihi*]) were not recorded during the 2011 survey. Aside from these species, the tricolored heron [*Egretta tricolor*] (-83%) and the snowy egret [*Egretta thula*] (-77%) exhibited the largest percent decrease in breeding pair abundance.

The laughing gull was observed more than any other colonial waterbird during the TCWS surveys (Table 31, Plate 19-Plate 26). However, breeding pair abundance values for the species in PAIS were lower in 2011 compared to the 36-year historical average, down 137 pairs (-35%; Table 31). TCWS (2011a) reported a similar trend during 2011 surveys of the central coast of Texas. Laughing gull abundance values were lower along the central coast in 2011, down 7,649 pairs (-22%) compared to the 8-year historic average, and down 8,099 pairs from 2010 (-22%; Figure 13).

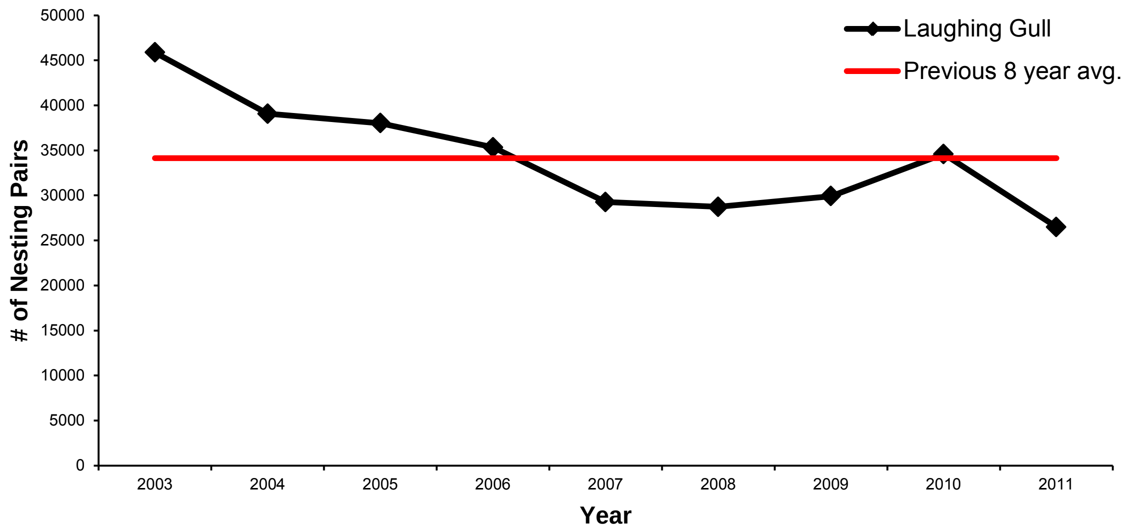

Figure 13. Laughing gull abundance on the central coast of Texas from 2003-2011 (TCWS 2011a).

<u>Species Distribution</u>

Beaches along islands have several distinct zones, each characterized by unique features. Bird species will utilize these zones for feeding, staging, and breeding, with some zones being favored more than others. Chaney et al. (1993a, p. 4) defined five habitat zones when recording their species-specific observations:

1. Nearshore – feeding or resting in or over the water close to shore;

2. Foreshore – feeding or loafing in the bare, wet area of the beach from the water line (swash zone) to the berm;

3. Berm – feeding or loafing on the first ridge of sand and debris caused by the high tide, usually dry above and wet underneath;

4. Backshore – a usual loafing area of dry sand and debris between the berm and the vegetated foredune ridge;

5. Aerial – groups of birds flying north or south that were obviously migrating, usually offshore.

A visual representation of these habitat types was presented previously in Figure 12. Chapman et al. (1984) used similar terminology in their assessment of bird distribution, simplifying the number of habitat types to only foreshore, backshore, and berm.

Chapman et al. (1984)

Chapman et al. (1984) found that most of the birds in the study area were concentrated along the foreshore region (Zone 2 on Figure 12) (Figure 14). This area was used primarily as a feeding and loafing area for several species, with the majority of species congregating near the high-tide swash line (Chapman et al. 1984). The dry backshore (Zone 4 on Figure 12) was the least used habitat type (Figure 14). This zone was frequented most by shorebirds foraging on garbage and food left by human campers. Note that the data in Figure 14 includes all bird species observed during Chapman et al. (1984)'s bird surveys; colonial waterbird distribution was not isolated by the authors.

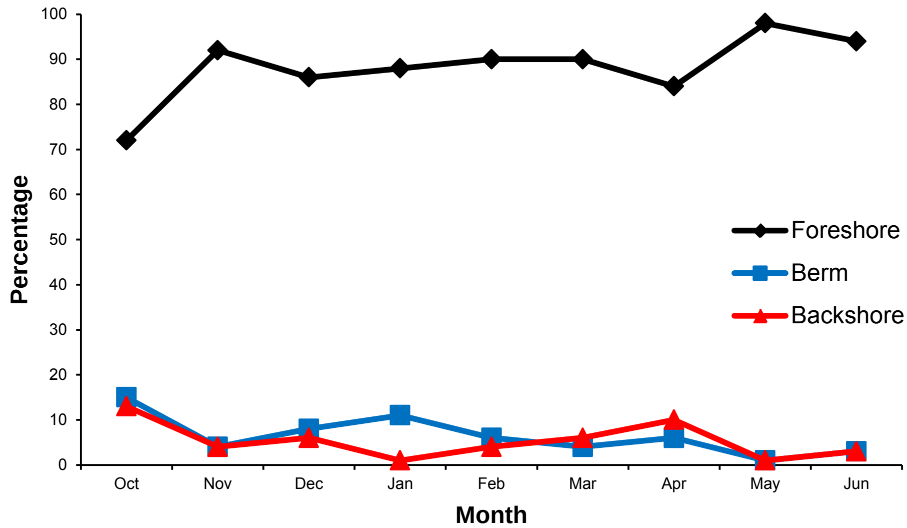

Figure 14. Distribution of bird species along the Gulf beach as reported by Chapman et al. (1984).

Along the length of the barrier islands surveyed in Chapman et al. (1984), birds were not evenly distributed, as several beaches exhibited low bird abundance throughout the study. Two of these areas, Big Shell Beach and Little Shell Beach, were located in PAIS; the shell substrate of these beaches had low-density prey species populations that could not support foraging colonial waterbirds. No birds were observed breeding on the beaches monitored during the study.

Chaney et al. (1993a) (Gulf Coast Surveys)

Although Chaney et al. (1993a) did not focus on colonial waterbirds, the report did find some overall trends in distribution along the island. Along the entire survey of the open beach area (the portion of PAIS that begins in the north at North Beach and ends at Mansfield Channel in the south), Chaney et al. (1993a) found that the distribution of birds was uneven. The areas of the Gulf beach with large shell substrate (e.g., Big Shell Beach – Mile 17.1-28.8) had fewer birds present than areas of the beach with washover channels. Washover channels are not permanent, but appeared to be selected by shorebirds for feeding, nesting, and roosting.

Chaney et al. (1993a) only reported the species distribution for protected species, and a complete analysis of colonial waterbird distribution is not possible. However, five colonial waterbird species were identified as protected and their distribution data is presented in Table 32.

Table 32. Distribution of protected colonial waterbird species during the 1993-94 bird surveys of the PAIS Gulf beach; habitat types are defined in text, and in Figure 14. (Chaney et al. 1993a).

	Habitat Type					
Species	**1**	**2**	**3**	**4**	**5**	**Total**
brown pelican	410	462	3		103	978
reddish egret	28	14	1			43
least tern	169	4,207	1,576	254		6,206
double-crested cormorant	675	844				1,519
black tern	399	4,106	388	41	19	4,953
Total	**1,681**	**9,633**	**1,968**	**295**	**122**	**13,699**

Brown pelicans appeared to favor the nearshore and foreshore habitats, and Chaney et al. (1993a) notes that they were among the easiest species to identify in flight, perhaps indicating why they have the highest abundance in the aerial habitat type (Table 32). Similarly, double-crested cormorants (*Phalacrocorax auritus*) were only found in the nearshore and foreshore habitat types (Table 32). Overall, the most individuals were identified in the foreshore habitat (9,633 individuals); the least tern and the black tern accounted for 86% of the observations in this habitat type (Table 32). No birds were observed breeding on the coasts surveyed by Chaney et al. (1993a)

Texas Colonial Waterbird Society Annual Monitoring

The TCWS survey data allow for the distribution measure to be analyzed in a variety of ways (e.g., island species richness, island abundance). When looking at the species richness averages of each island (i.e., on average, how many species of colonial waterbirds are found at an island in a given year), the 614-341 island group had the highest value (12 species/year). Island 614-346 exhibited the lowest species richness value over the 36-year period (2.21 species/year). The majority of the TCWS surveyed islands (five out of eight islands [62.5%]) exhibited a decrease in species richness in 2011; including each individual sub island from the 614-341 and 614-342 sub groups, eight of the 12 islands (66.7%) exhibited a decline in species richness.

The 614-341 island group had the highest average number of breeding bird pairs (4,573; Figure 15), and the highest recorded number of breeding pairs in one breeding season (15,341 in 1978; Figure 15). However, since 2008, only 13 breeding pairs have been observed on the island group (NPS 2013a). Island 614-346 had the lowest average number of breeding bird pairs (17.4), and has not had any nesting birds observed on the island since 2006 (NPS 2013a); Plate 24 reveals that much of the island is now submerged or has eroded away.

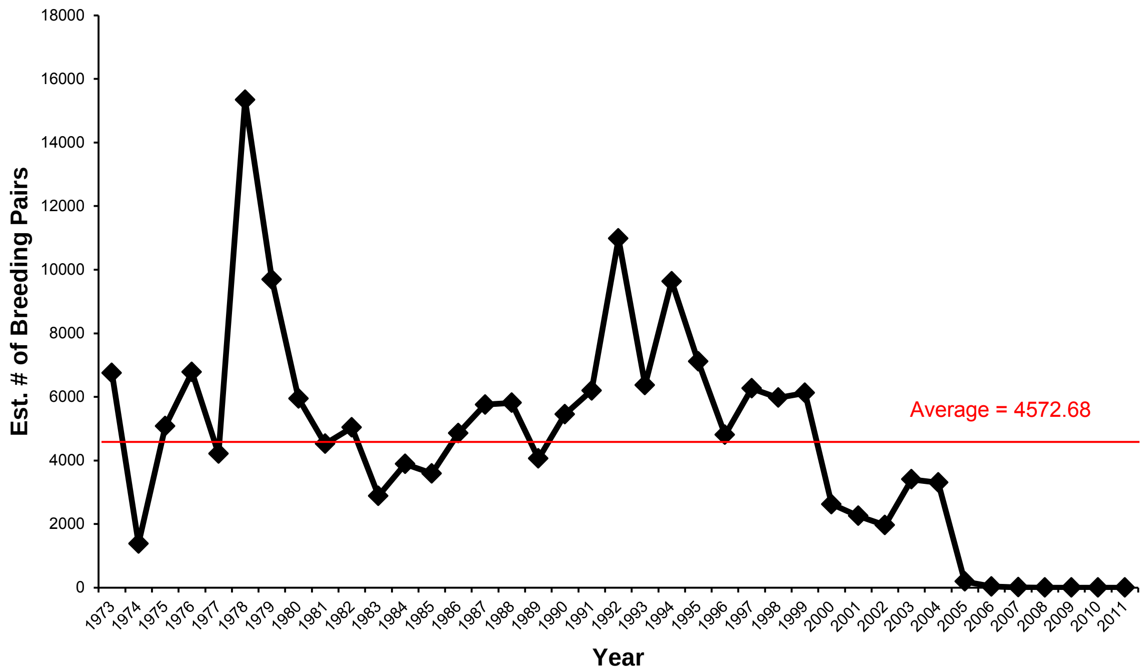

Figure 15. Est. number of breeding pairs (all species) observed at the island group 614-341 from 1973-2011 (NPS 2013a).

American white pelicans have only been observed breeding on two islands in the park (614-341 and 614-345). Island 614-345 is commonly referred to as Pelican Island, due to the large numbers of pelicans that have bred on the island in the past. 2011 marked the largest number of breeding pelicans for this island (740 pairs). Similarly, the brown pelican has only been observed breeding on the 614-342 island group; the breeding abundance of brown pelicans in PAIS is substantially lower when compared to the American white pelican. Cattle egrets have been observed breeding on islands 614-360, 614-345, and 614-341, with island 614-341 supporting the largest group of breeding cattle egrets in the park, averaging almost 379 pairs a year (Plate 19).

Laughing gulls are the most abundant colonial waterbird in the park, and have been observed breeding on all of the surveyed islands in the park (Plate 19-Plate 26). While they are distributed across the spoil islands in the park, laughing gulls have occurred in the highest numbers at the island 614-341 cluster (36-year average = 3,163; Plate 19). Other species that have been observed breeding on all of the surveyed islands include the tricolored heron, gull-billed tern (*Sterna nilotica*), Caspian tern, royal tern, Forster’s tern, and the black skimmer.

<u>Nesting Success</u>

Nesting success is typically defined as the mean number of young fledged for each nesting attempt, although Erwin and Custer (1982) suggest that it may be more desirable to estimate the number of young fledged to each nesting female. In PAIS, there have been no estimates of colonial waterbird nesting success; without these data, an assessment of current condition is not possible for this measure.

Threats and Stressor Factors

Several threats exist for the colonial waterbird population in PAIS. These threats range from global threats like climate change, sea level rise, and subsidence, to more local threats such as erosion and wind farm developments.

One threat to the colonial waterbird populations of PAIS are wind farms and future wind farm developments in south Texas. Wind turbines are suspected to be a direct cause of mortality in bird species, as the rotating blades on a wind turbine can strike flying birds. The extent to which mortalities occur in bird species is likely dependent upon several factors, namely the species of birds in the area, the height of the turbine (i.e., higher turbines lead to more mortalities), and the elevation of the wind farm above sea level (de Lucas et al. 2008). Elevation equates to larger diameter for the turbine's rotor; the larger the rotor, the faster the tip speed, even at slow rotations per minute.

Recent efforts to develop alternative energy sources have resulted in more wind farm development across the planet (de Lucas et al. 2008). However, the exact effect that these wind farms have on birds is still poorly understood. Some studies have found that wind farms are responsible for no more mortalities than other human-made structures (e.g., buildings, communication towers) (Osborn et al. 2000), while other studies have found that turbines are responsible for unusually high numbers of bird mortalities (Smallwood and Thelander 2007).

Two onshore wind energy developments have occurred in Kenedy County, Texas, on the 93,078 ha (230,000 ac) Kenedy Ranch. This ranch lies across the Laguna Madre from the park, just a few kilometers west of the park boundary. One of these developments, the 283 megawatt (MW) Gulf Wind Farm, developed by Babcock and Brown but sold to Pattern Energy Group in 2010, is located across approximately 2,954 ha (7,300 ac) of the John G. and Marie Stella Kenedy Memorial Foundation portion of the Kenedy Ranch. The Gulf Wind Farm project consists of 118 Mitsubishi turbines. The other wind energy development on the Kenedy Ranch is the 404 MW Peñascal (I and II) Wind Project, which operates on the John G. Kenedy Jr. Charitable Trust property. The Peñascal Wind Project consists of 168 Mitsubishi MHI 92 wind turbines, each with a capacity of 2.4 MW. This project was completed in April 2010 by Iberdrola, and continues to be owned and operated by Iberdrola (Stablein, written communication, 10 May 2013).

Another onshore wind energy project occurring near PAIS is Los Vientos (I and II) Wind Energy Project, located approximately 24 km (15 mi) southwest of the park in Willacy County, Texas. This 400 MW development is owned by Duke Energy Renewables, and consists of 171 turbines made up of 84 Mitsubishi 2.4 MW turbines and 87 Siemens 2.7 MW turbines. This large project was scheduled for completion in December 2012, but continues to be developed and was nearing completion in March 2013. One other notable wind project occurring within the park's general vicinity is the 200 MW Magic Valley Wind Farm, constructed by Blattner Energy, and operated by E.ON. The Magic Valley Wind Farm is located 8 km (5 mi) east of Raymondville, TX, or 40 km (25 mi) west of PAIS, and is made up of 112 Vesta 1.8 MW turbines, whose output is contracted to local energy producer, AEP (Stablein, written communication, 10 May 2013).

To the north of PAIS is the Papalote Creek Wind Farm. Completed in December 2010, this 380 MW onshore project is made up of 196 turbines. The first phase consisted of 109 Vestas 1.65

MW turbines, online in the fall of 2009, followed up by 87 Siemens 2.3 MW turbines a little over one year later (Stablein, written communication, 10 May 2013).

Two proposals for large offshore (from the park) wind farms have been submitted over the past 6 years; however, one of these proposed developments was abandoned (Stablein, written communication, 10 May 2013). Superior Renewable Energy began plans for one of these offshore developments in 2003, but after Babcock and Brown acquired Superior in 2006, and some preliminary planning and public scoping in 2006, the project was soon dropped. In 2011, Baryonyx Corporation proposed a development of offshore turbines, which included large turbines directly east of the park's visitor center; however, these plans have been changed to relocate the proposed site further south (Stablein, written communication, 10 May 2013). The park has agreed to join the USACE in co-authoring the environmental impact statement (EIS) for this development. It is believed that the original proposed locations were not carried forward due to conflict with air space designated to the U.S. Navy. Moving turbines further south off South Padre Island includes potential for shared air space with the approved development of SpaceX launch zone, Boca Chica Beach in Cameron County, Texas.

While not currently being constructed in the U.S., the latest turbines are now larger than 7.0 MW; the diameter of the turbine's rotor can be more than 165 m (541 ft), with hub heights as tall as 110 to 120 m (361-394 ft). Offshore turbines are quickly approaching more than 200 m (656 ft) in total height. It is expected within a few years that offshore turbines will be generating at least 10.0 MW, have rotors up to 180 m (590 ft) in diameter, and hub heights as tall as 150 m (492 ft). Installation of hundreds of these offshore turbines is possible within 8 km (5 mi) of the park in the Gulf of Mexico waters (Stablein, written communication, 10 May 2013).

Another threat to the park's colonial waterbirds are fire ants (*Solenopsis geminata, S. invicta*) that were accidentally brought to the U.S. on a shipping vessel from South America, and have since spread rapidly across the southeastern U.S. (Wetterer and Moore 2005). These ant species are well-known predators of bird hatchlings, and ground nesting bird species are particularly vulnerable. Many colonial waterbird species are ground nesters, and the presence of fire ants on nesting islands represents a significant threat. Fire ants on dredge spoil islands in the Laguna Madre have previously been found to have significant impacts on the breeding success of several colonial waterbird species, particularly the snowy egret, laughing gull, and great blue heron (*Ardea herodias*) (Mrazek 1974). Monitoring of fire ant abundance on islands that support large waterbird colonies may help to explain potential decreases in abundance, changes in distribution, or a change in reproductive success.

Human disturbance represents a significant threat to colonial waterbird species, as these species are particularly vulnerable to human intrusion (Manuwal 1978). Recreational activities, such as boating, fishing, and wildlife viewing have the potential to flush waterbirds from their nests, leaving their young/eggs vulnerable. With the GIWW passing near several of the nesting colonies, boat traffic represents a significant threat to these islands. Any human interaction at the islands during nesting season could result in nest abandonment, and a dramatic reduction in nesting success. Furthermore, human disturbance in the form of oil spills and marine debris also represent significant threats to the survival and reproduction of colonial waterbirds. Several man-made structures (e.g., pilings and signage) in the Laguna Madre often serve as excellent perch locations for raptor species, and may result in increased raptor abundance and predation on colonial waterbirds.

The primary mammalian predators of nesting colonies are likely coyotes and raccoons (*Procyon lotor*). These predators likely gain access to the nesting islands by swimming or wading across from the Texas mainland or from an adjacent barrier island (Coste and Skoruppa 1989). Islands that support nesting colonial waterbirds are most at risk to raccoons and coyotes if they are in close proximity to large islands or to the mainland of Texas; low water levels also facilitate predator's access to the colonies (Coste and Skoruppa 1989). Coyotes are the largest documented predators in PAIS that are able to successfully inhabit the barrier islands in Texas (Snodgrass 1997), and have been documented hunting or scavenging along the small spoil islands of the Laguna Madre (Frey and Jones 2008). Raccoons are opportunistic predators, and frequently forage for insects, herptiles, small birds, and nuts/fruits. Raccoons have proven to be major predators on Virginia barrier island populations of colonial waterbirds (Erwin et al. 2001), and the establishment of large raccoon populations on lands adjacent to colonial waterbird nesting colonies could have significant impacts on the nesting success of these species.

Coste and Skoruppa (1989) documented the bird colonies along the Texas coast that were experiencing disturbance from mammalian predators. Several of the identified colonies were located in or near PAIS, and the primary predators observed were raccoons and coyotes. Table 33 displays the name and approximate location of the colonies, how accessible they are to predators, and how successful potential predator control efforts may be if instituted. These data are nearly 25 years old, and care should be taken when interpreting the table, as several factors may have changed in the years since the report.

Table 33. Predation accessibility and pressure for several historic colonial waterbird nesting colonies in the PAIS region (Coste and Skoruppa 1989).

Colony Name	Class	Longitude	Latitude	Predator Accessibility	Predators Present	Potential for Predator Control?
Mkr 37 Spoil (NM75) W of GIWW	1	27°33'	-97°17'	Medium	Coyotes/Raccoons	Fair
North of Bird Island (NM 87-91)	1	27°32'	-97°17'	Medium	Coyotes/Raccoons	Fair
North Bird Island	3	27°31'	-97°17'	High	Coyotes/Raccoons	Poor
West Side Spoil Islands	3	27°30'	-97°17'	High	Cats/Coyotes	Poor
South Bird Island	1	27°30'	-97°18'	High	Coyotes	Poor
South of South Bird Is.	1	27°29'	-97°19'	Low	Badger/Coyote	Good
Mkr 103-117 spoil (NM 207-221)	1	27°18'	-97°24'	Medium	Raccoons	Fair
South Baffin Bay Islands (4 islands)	1	27°15'	-97°24'	3 islands are high, 1 island is low	Coyotes	3 islands are poor, 1 island is good
Mkr 87 (178) Diked Spoil	1	27°27'	-97°23'	Medium	Coyotes/Raccoons	Fair
Spoil from cut east of Potrero Grande	3	27°06'	-97°26'	High	Coyotes/Raccoons/Rabbits	Poor
Spoil east of Potrero Cortado	3	27°04'	-97°26'	High	Coyotes/Raccoons	Poor
South Land Cut - North Section	1	26°47'	-97°27'	Medium	Coyotes	Fair
South Land Cut - South Section	1	26°47'	-97°27'	Medium	Coyotes	Fair
Mansfield Odd Spoil	1	26°39'	-97°23'	Medium	Coyotes/Raccoons	Poor
NE Mansfield Intersection	1	26°34'	-97°24'	Low	Coyotes/Raccoons	Good
SW Mansfield Intersection	1	26°33'	-97°25'	Medium	Coyotes/Raccoons	Fair
Green Hill Spoil Island	1	26°30'	-97°23'	Medium	Coyotes/Raccoons	Fair
Mansfield Channel Spoil West section	2	26°33'	-97°23'	High	Raccoons	Poor
Green Island	1	26°24'	-97°19'	Medium	Raccoons	Fair

Class 1: Site is essential for continued breeding by one or a few species with narrow habitat requirements, highly restricted distribution, or low abundance in Texas. Alternatively, the site is highly desirable for a diverse assemblage of colonial waterbirds, important to a few species with somewhat specialized nesting requirements and restricted range in Texas, or an important component of a bay system nesting complex.

Class 2: Site is important to only a few nesting pairs of species with broad distribution.

Class 3: Site has minimal or no known current use for waterbird breeding but is important for consideration in management to stimulate future breeding.

Non-native plants were introduced to some spoil island communities by people who built cabins on the islands prior to park establishment (NPS 2001), and represent a major threat to nesting colonial waterbirds in the park. Examples of non-native plants documented on park spoil islands include oleander, Brazilian peppertree, saltcedar, and bermudagrass (Chaney et al. 1978, NPS 1996). Bufflegrass is also present on several of the spoil islands, and, like many of the other non-native plant species, often prevents the bare-ground or mineral earth nesting colonial species (e.g., black skimmers and tern species) from establishing nests on the spoil islands.

Erosion in the PAIS area is a significant concern for colonial waterbirds, as some islands in the area that used to support rookeries and colonies have completely eroded away (Coste and Skoruppa 1989). No data have been gathered on erosion or accretion rates around the park's spoil islands. However, anecdotal information indicates that many of these islands are eroding (Smith 2002, Chaney and Blacklock 2005). In a study of Laguna Madre rookery islands, Smith (2002) identified two spoil islands within PAIS (identified as LM 63A and Marker 81 [referred to in this component as 614-345]) that had lost area to erosion between 1975 and 1995. Marker 81 (island 614-345) spoil island was approximately 1.7 ha (4.2 ac) in size during the 1970s (TCWS 1982), but was measured at just 1.1 ha (2.8 ac) in 1986 (Coste and Skoruppa 1989). The landcover of this island is shown in Figure 16. The bare ground that once provided habitat for ground-nesting birds has become intertidal flats, no longer suitable for nesting (Smith 2002).

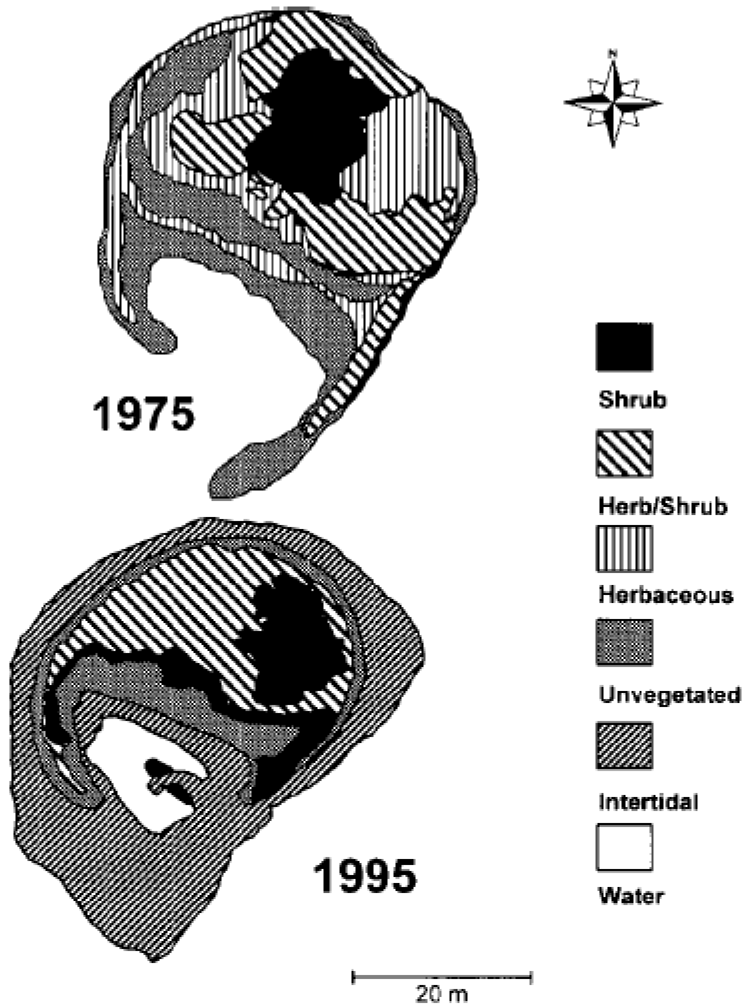

Figure 16. Change in vegetative cover on Marker 81 (referred to in this component as island 614-345) spoil island in PAIS (Smith 2002). Note that large areas that were vegetated are now intertidal, meaning they are at least temporarily under water, due to erosion.

<u>Data Needs/Gaps</u>

Continued monitoring of the colonial waterbird colonies is needed to observe future trends and patterns in the breeding species of the park. Although difficult to obtain in colonial nesting species, a survey or estimate of nesting success for nesting species would also help managers to better understand recruitment into the regional and global populations.

In addition to the annual waterbird colony surveys, monitoring of the erosion rates on the nesting islands may be beneficial to managers. Erosion rates in the past few decades have elevated, as is represented in Figure 16. Heavy boat traffic in the Laguna, paired with the unstable nature of the dredge spoil put these islands at high risk. Although knowing erosion rates may be beneficial to managers, whether or not the NPS can take preventative/reactive actions to this threat is a much larger issue. The dredge spoil islands represent some of the last remaining breeding habitat for colonial waterbird species, as the creation of the GIWW and development along the Laguna has displaced many of the birds from their natural habitat (i.e., natural islands). The spoil islands pre-date the park by almost 15 years, and could be considered a historic component of the park

(James Lindsay, email communication, 25 March 2013). While the islands are not a natural feature of the landscape, PAIS managers are essentially tasked to ensure that the colonial waterbird species do not pass into regional extirpation. It may be worthwhile for PAIS managers to investigate potential avenues to add material to rookery islands within the park; James Lindsay indicated (email communication, 25 March, 2013) that the USFWS and the State of Texas are pursuing BP restoration funds to add material to rookery islands in the Laguna (including islands within PAIS).

Overall Condition

Species Abundance and Diversity
The project team defined the *Significance Level* for this measure as a 3. The TCWS datasets have documented the abundance of colonial waterbirds in the Laguna Madre for over 30 years. This data provides useful information to analyze trends in the overall colonial waterbird population and in individual species. As displayed in Table 31, over half of the observed species (12 out of 22) exhibited a decline in breeding pair abundance in 2011. Three species that were observed in PAIS frequently during the TCWS surveys (cattle egret, roseate spoonbill, and white-faced ibis) were not observed breeding in the park in 2011. The most numerous colonial waterbird during the course of the TCWS surveys has been the laughing gull. However, 2011 abundance numbers declined 35 percent compared to the 36-year average; this trend was reported throughout the central coast of Texas (TCWS 2011a). The 2011 results, combined with the numerous threats that these populations face on the dredge spoil islands in the park, warranted a *Condition Level* of 2 for the species abundance and diversity measure.

Species Distribution
Species distribution was assigned a *Significance Level* of 3. The unique landscape of PAIS has been largely shaped by natural events and occurrences; however, the natural islands and habitat in the Laguna Madre that are typically utilized by colonial waterbirds have been developed by humans or degraded by human activity. The only suitable nesting locations for colonial waterbirds in the park are found on man-made dredge spoil islands. The TCWS has actively monitored the breeding locations of colonial waterbirds for over 30 years, and the park has a substantial data set that allows researchers and managers to see where species have typically nested (and in what numbers) throughout the years. Because of issues like erosion, predation, and sea-level rise, the stability of the colonial waterbird populations on these dredge spoil islands is of moderate concern to managers; a *Condition Level* of 2 was assigned to the measure of species distribution.

Nesting Success
The project team defined the *Significance Level* for nest success as a 3. However, no studies have documented the nesting success of colonial waterbirds in PAIS, and a *Condition Level* was not assigned.

Weighted Condition Score
The *Weighted Condition Score* for PAIS's colonial waterbirds is 0.667, which is on the borderline of moderate and high concern. After analysis of the historic data, and the threats and stressors that are likely to affect the dredge spoil islands in the near future, SMUMN GSS determined that the moderate concern designation was most appropriate at this time. It is

important to note that because of its borderline Weighted Condition Score, it will be important for PAIS managers to closely monitor the condition of these species in the future. Further degradation of the breeding islands or declines in the breeding pair abundance values may dictate a future designation of high concern.

Sources of Expertise

James Lindsay, Chief of Science and Resource Management, PAIS

Wade Stablein, Biological Technician, PAIS

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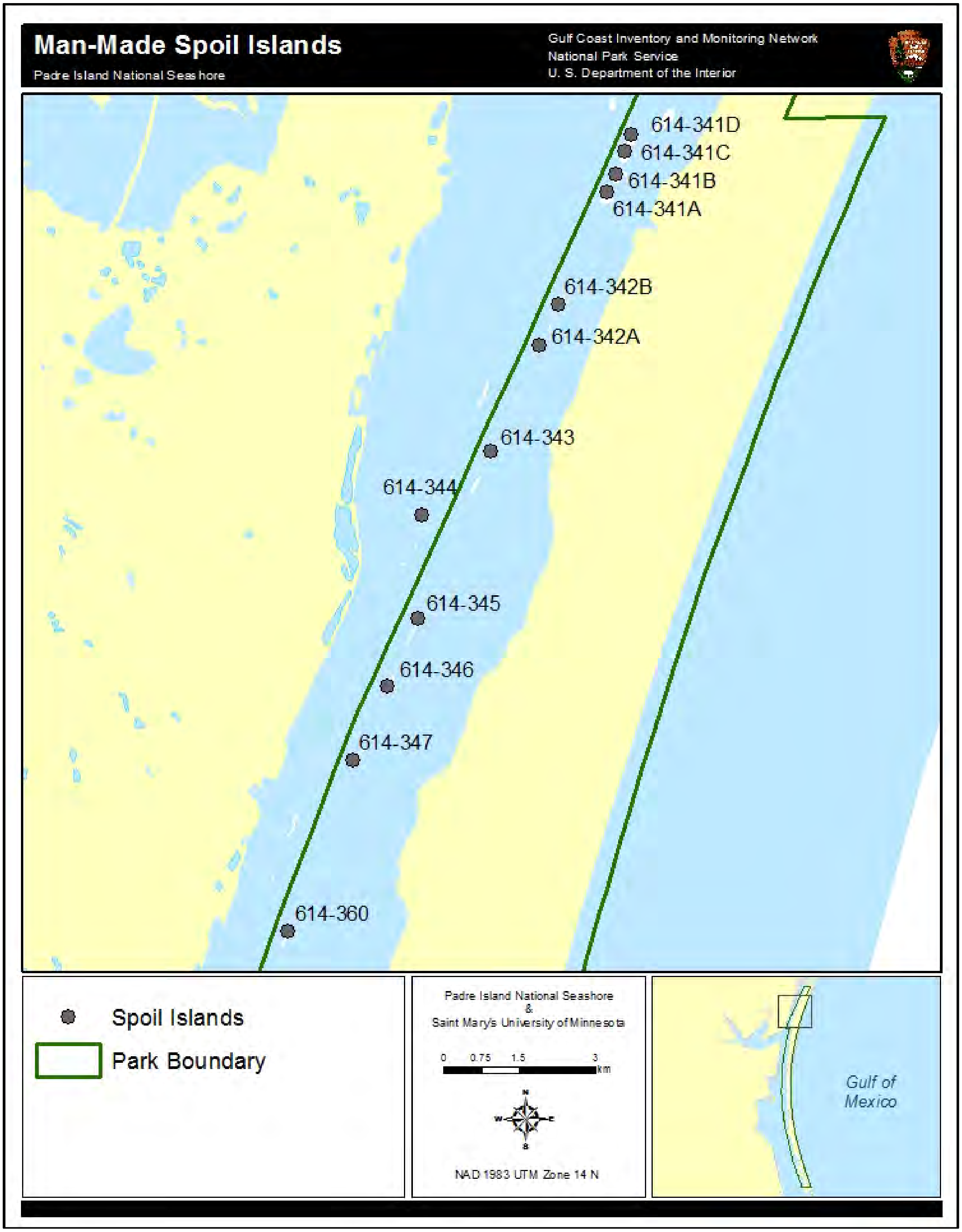


Plate 17. Location of the 12 dredge spoil islands used by nesting colonial waterbirds in PAIS.

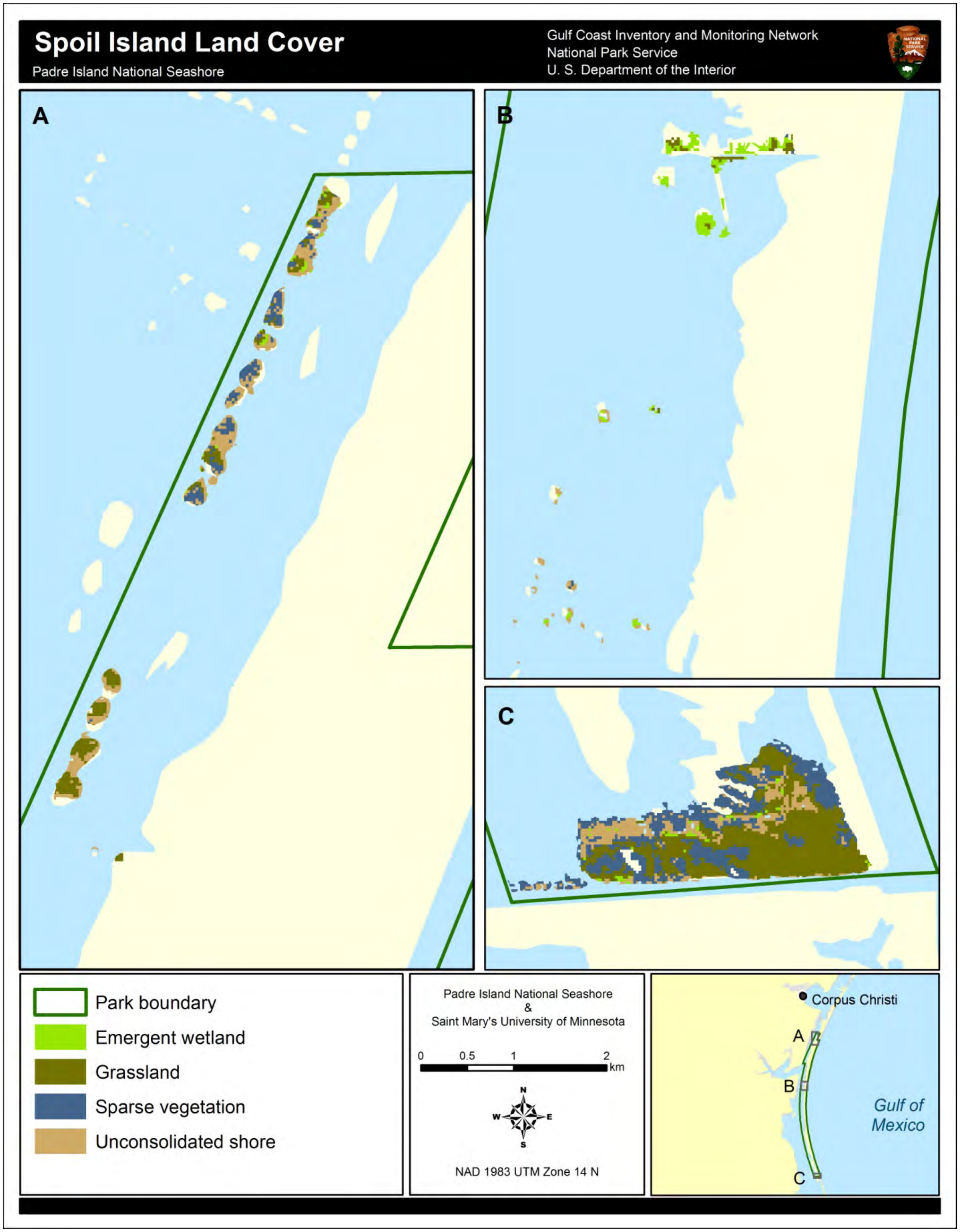
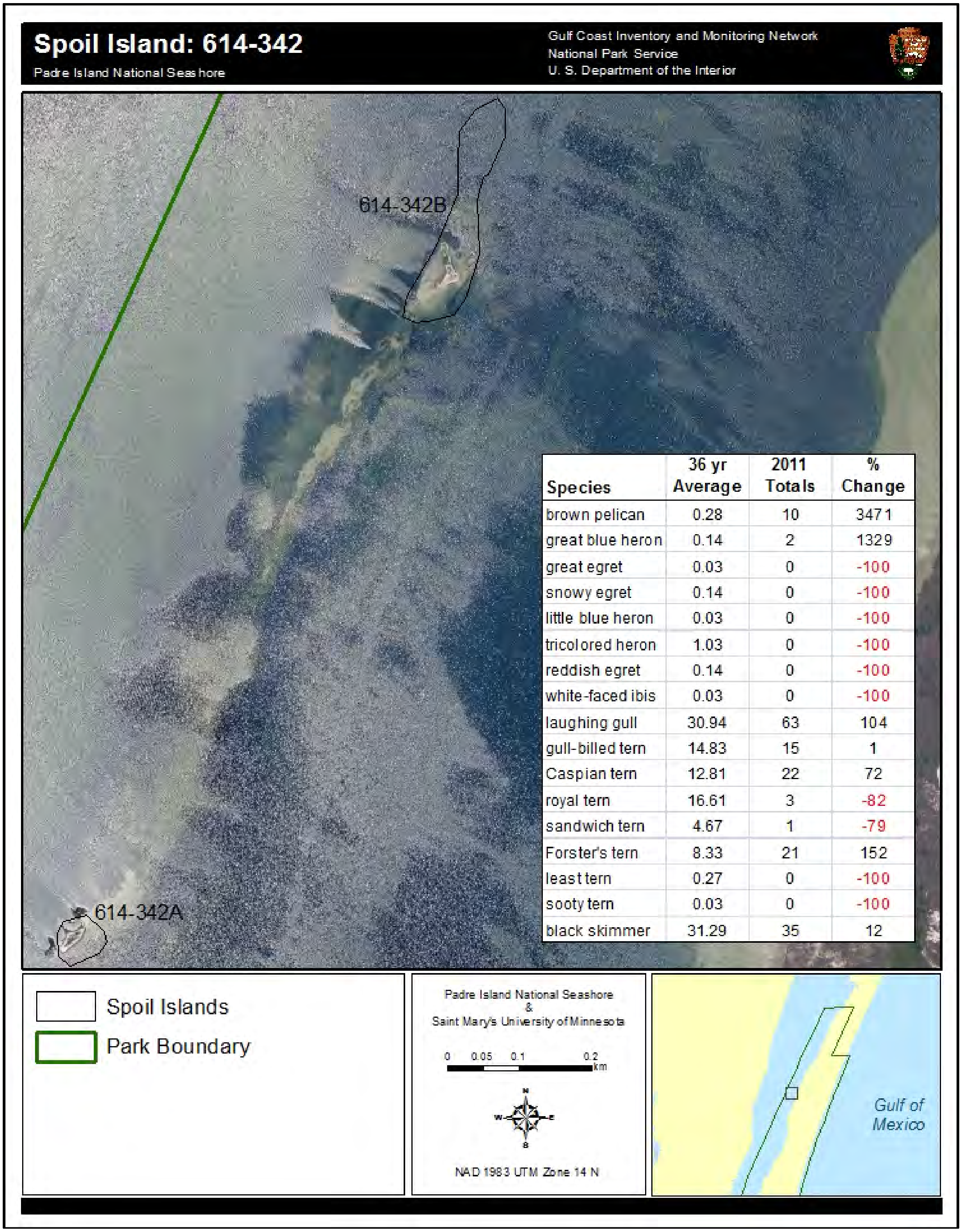


Plate 18. Land cover of PAIS' spoil mounds (Laine and Ramsey 1998).

Species	36 yr Average	2011 Totals	% Change
white pelican	13.95	0	-100
great blue heron	30.08	0	-100
great egret	27.12	0	-100
snowy egret	83.32	0	-100
little blue heron	12.26	0	-100
tricolored heron	94.79	0	-100
reddish egret	41.61	0	-100
cattle egret	378.79	0	-100
black crowned night heron	9.8	0	-100
white ibis	2.98	0	-100
white-faced ibis	69.33	0	-100
roseate spoonbill	54.42	0	-100
laughing gull	3162.68	0	-100
gull-billed tern	19.42	0	-100
Caspian tern	11.18	0	-100
royal tern	342.88	0	-100
sandwich tern	306.65	0	-100
Forster's tern	0.29	0	-100
least tern	0.21	0	-100
sooty tern	0.42	0	-100
black skimmer	4.34	0	-100

Plate 19. Dredge spoil island 614-341 in PAIS. These islands were identified as a single unit in TCWS reporting, but are shown as four sub islands in this plate.



Species	36 yr Average	2011 Totals	% Change
brown pelican	0.28	10	3471
great blue heron	0.14	2	1329
great egret	0.03	0	-100
snowy egret	0.14	0	-100
little blue heron	0.03	0	-100
tricolored heron	1.03	0	-100
reddish egret	0.14	0	-100
white-faced ibis	0.03	0	-100
laughing gull	30.94	63	104
gull-billed tern	14.83	15	1
Caspian tern	12.81	22	72
royal tern	16.61	3	-82
sandwich tern	4.67	1	-79
Forster's tern	8.33	21	152
least tern	0.27	0	-100
sooty tern	0.03	0	-100
black skimmer	31.29	35	12

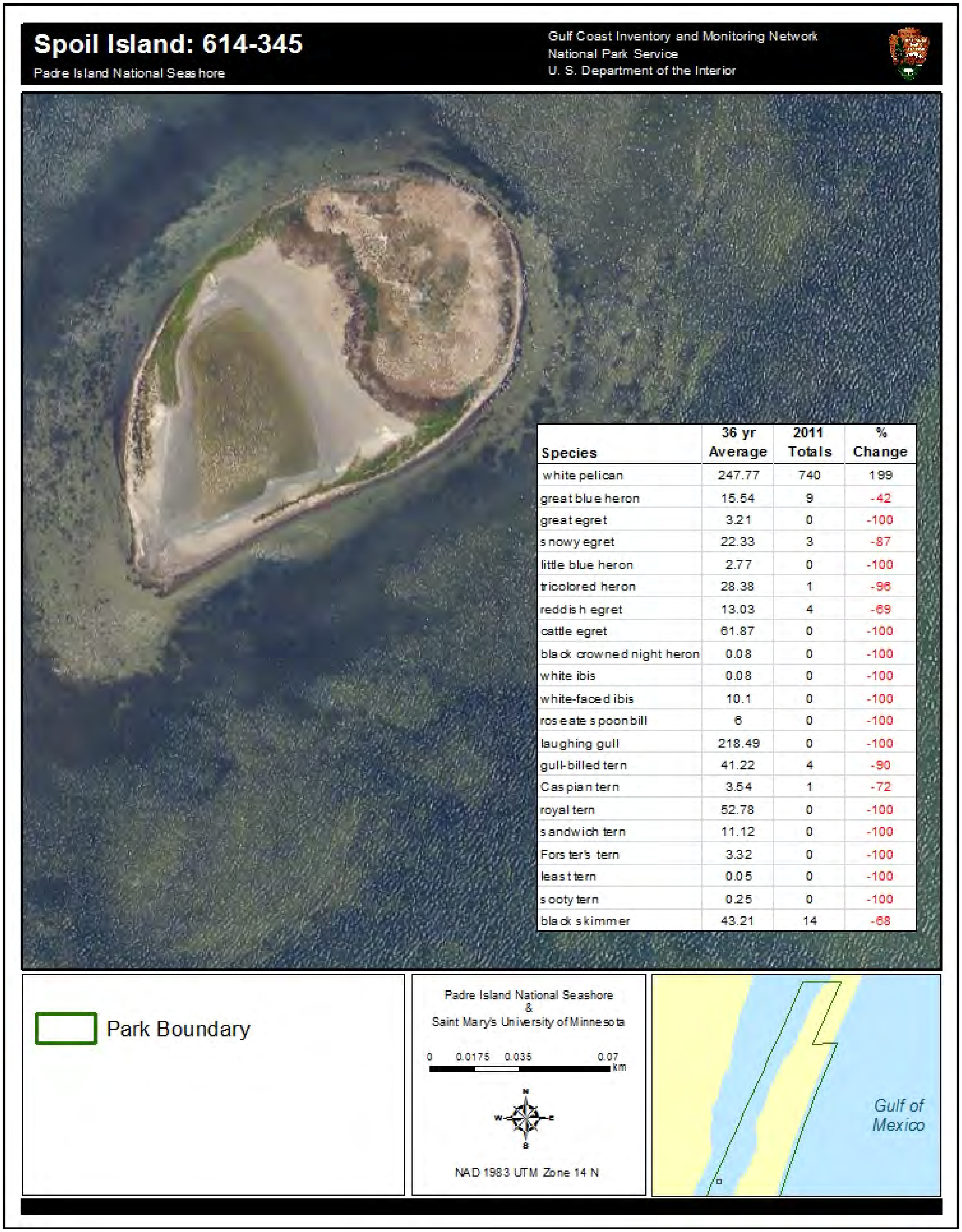
Plate 20. Dredge spoil island 614-342 in PAIS. These islands were identified as a single unit in TCWS reporting, but are shown as two sub islands in this plate.

Species	36 yr Average	2011 Totals	% Change
great blue heron	0.29	0	-100
great egret	0.03	0	-100
snowy egret	3.6	0	-100
little blue heron	0.49	0	-100
tricolored heron	12.31	0	-100
reddish egret	4.26	2	-53
white-faced ibis	1.03	0	-100
laughing gull	138.1	58	-58
gull-billed tern	16.03	0	-100
Caspian tern	18.6	2	-89
royal tern	0.16	0	-100
sandwich tern	0.09	0	-100
Forster's tern	6.85	0	-100
least tern	0.2	0	-100
black skimmer	11.56	0	-100

Plate 21. Dredge spoil island 614-343 in PAIS.

Species	36 yr Average	2011 Totals	% Change
great blue heron	0.03	0	-100
great egret	0.03	0	-100
tricolored heron	0.15	0	-100
laughing gull	55.28	0	-100
gull-billed tern	14.39	0	-100
Caspian tern	1.56	0	-100
royal tern	0.91	0	-100
Forster's tern	0.06	0	-100
least tern	4.06	0	-100
sooty tern	0.03	0	-100
black skimmer	32.33	0	-100

Plate 22. Dredge spoil island 614-344 in PAIS.

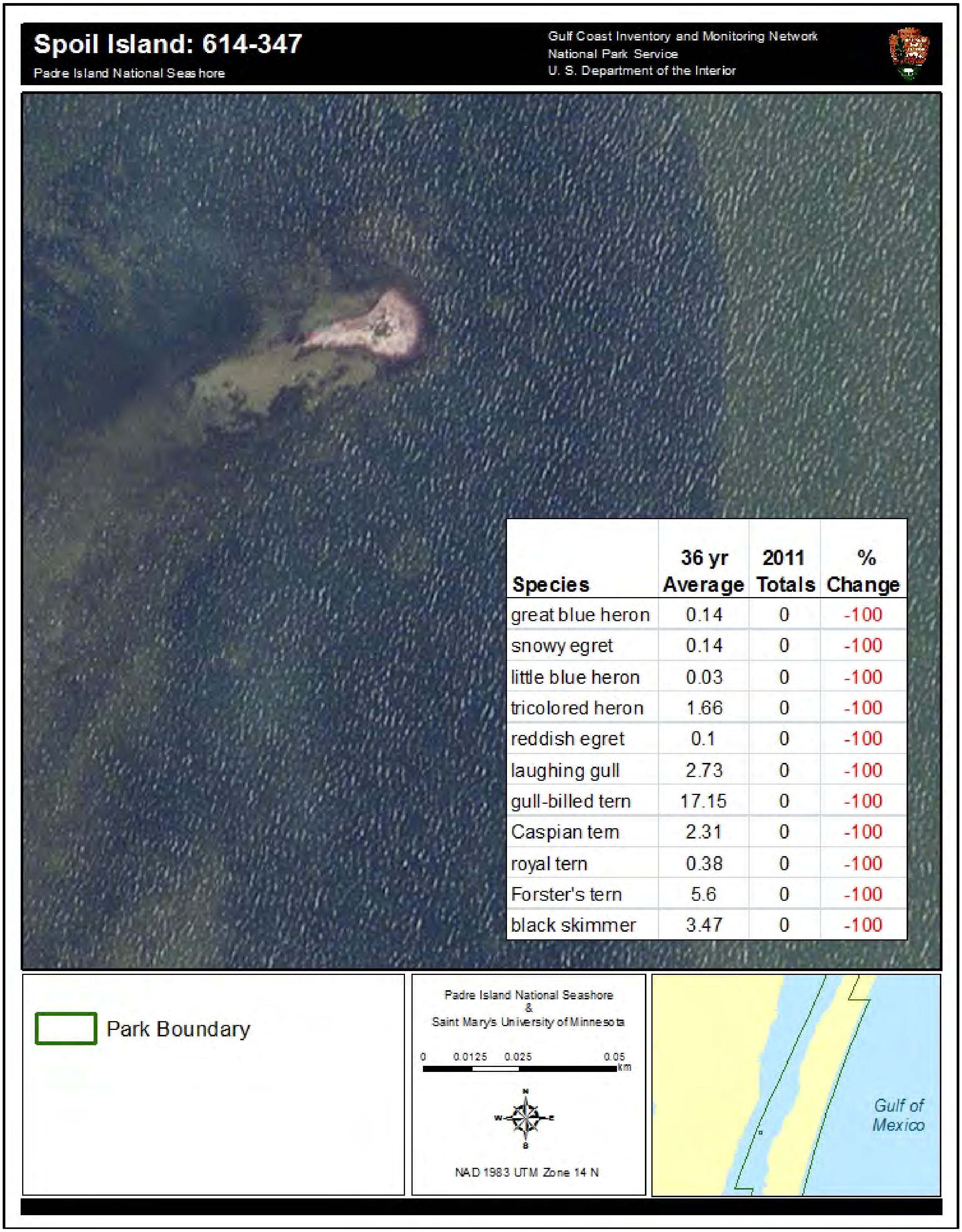


Species	36 yr Average	2011 Totals	% Change
white pelican	247.77	740	199
great blue heron	15.54	9	-42
great egret	3.21	0	-100
snowy egret	22.33	3	-87
little blue heron	2.77	0	-100
tricolored heron	28.38	1	-96
reddish egret	13.03	4	-69
cattle egret	61.87	0	-100
black crowned night heron	0.08	0	-100
white ibis	0.08	0	-100
white-faced ibis	10.1	0	-100
roseate spoonbill	6	0	-100
laughing gull	218.49	0	-100
gull-billed tern	41.22	4	-90
Caspian tern	3.54	1	-72
royal tern	52.78	0	-100
sandwich tern	11.12	0	-100
Forster's tern	3.32	0	-100
least tern	0.05	0	-100
sooty tern	0.25	0	-100
black skimmer	43.21	14	-68

Plate 23. Dredge spoil island 614-345 in PAIS.

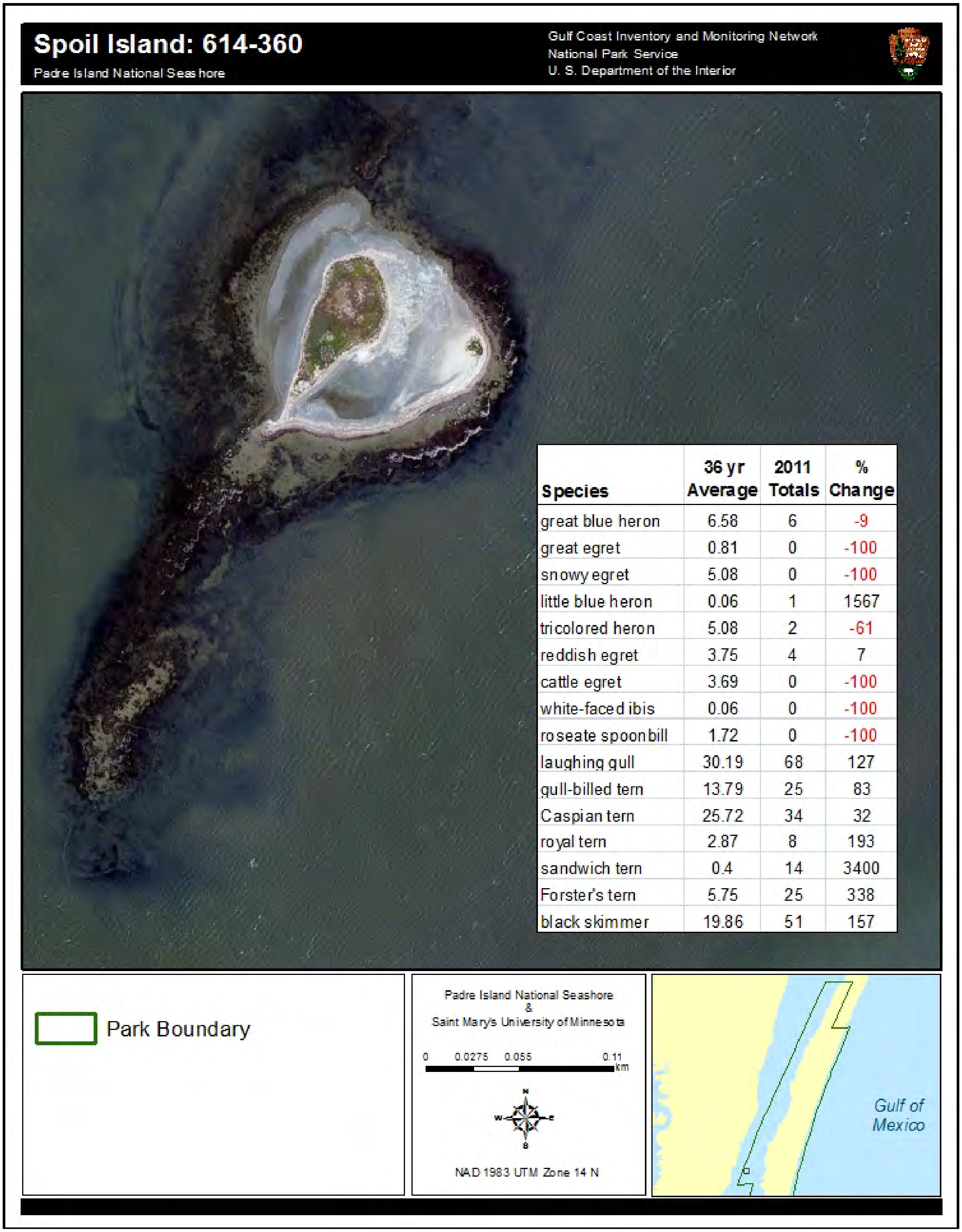
Species	36 yr Average	2011 Totals	% Change
snowy egret	0.03	0	-100
tricolored heron	0.76	0	-100
reddish egret	0.51	0	-100
laughing gull	2.13	0	-100
gull-billed tern	5.43	0	-100
Caspian tern	2.62	0	-100
royal tern	0.97	0	-100
Forster's tern	4.26	0	-100
black skimmer	0.67	0	-100

Plate 24. Dredge spoil island 614-346 in PAIS.



Species	36 yr Average	2011 Totals	% Change
great blue heron	0.14	0	-100
snowy egret	0.14	0	-100
little blue heron	0.03	0	-100
tricolored heron	1.66	0	-100
reddish egret	0.1	0	-100
laughing gull	2.73	0	-100
gull-billed tern	17.15	0	-100
Caspian tern	2.31	0	-100
royal tern	0.38	0	-100
Forster's tern	5.6	0	-100
black skimmer	3.47	0	-100

Plate 25. Dredge spoil island 614-347 in PAIS.



Species	36 yr Average	2011 Totals	% Change
great blue heron	6.58	6	-9
great egret	0.81	0	-100
snowy egret	5.08	0	-100
little blue heron	0.06	1	1567
tricolored heron	5.08	2	-61
reddish egret	3.75	4	7
cattle egret	3.69	0	-100
white-faced ibis	0.06	0	-100
roseate spoonbill	1.72	0	-100
laughing gull	30.19	68	127
gull-billed tern	13.79	25	83
Caspian tern	25.72	34	32
royal tern	2.87	8	193
sandwich tern	0.4	14	3400
Forster's tern	5.75	25	338
black skimmer	19.86	51	157

Plate 26. Dredge spoil island 614-360 in PAIS.

4.8 Coyotes

Description

Coyotes (Photo 14) are highly adaptive, top-level predators found throughout the continental United States (Bekoff and Gese 2003). They are widespread across Texas and are reported as the most common native large carnivore in southeastern Texas (Schmidly 2004). There are 19 recognized subspecies of coyote, and PAIS is home to the lower Rio Grande subspecies (*Canis latrans microdon*). Coyotes are documented as the largest predator in PAIS able to successfully inhabit the barrier islands of Texas (Snodgrass 1997). They have been observed frequently traversing the coastal grasslands and prairies throughout the park (Frey and Jones 2008).

Photo 14. Coyote (*Canis latrans*) (USGS photo).

Dog-like in appearance, coyotes have thick, grayish fur and a long, bushy tail (Bekoff 1977). The size of adult coyotes varies by gender (males are typically larger) and geographic region, but an average adult coyote has a body length of about 1-1.5 m (3.28-4.92 ft) (Hall and Kelson 1959, Bekoff 1977, Bekoff and Gese 2003). They are primarily active in early evening and at night, but are also sporadically active during the day (Bekoff 1977).

Coyotes are opportunistic predators, and prey species will vary depending on fluctuations in prey base abundance (Bekoff 1977, Windberg and Mitchell 1990, Bekoff and Gese 2003). In southern Texas, coyotes have been observed preying upon rabbits, rodents, fruit, insects, and carrion (TPWD 2012a). In PAIS, coyotes have been observed hunting or scavenging along the beaches, mudflats, and occasionally on the small spoil islands in the Laguna Madre (Frey and Jones 2008). They are known to eat several species of mammals (mostly rodents), birds, reptiles, fish, crabs, insects, fruits, and seeds (Snodgrass 1997).

Measures

- Population density
- Distribution

Reference Conditions/Values

The ideal reference condition is population densities and distribution prior to the intensive grazing and settlement of North Padre Island that occurred during the late 1800s through 1971. There is very little historic information that identifies coyote population parameters on Padre Island during this time.

Data and Methods

Very little historic information quantifies coyote densities or distribution for the reference period. Bailey (1905) reported the presence of coyotes on Padre Island and other nearby barrier islands in the late 1800s and early 1900s, but did not characterize densities or specific distribution of coyotes on the island. Few studies document the status or health of coyote populations in PAIS up to present times. The studies that do exist are primarily biological inventories of the park, and only address the presence/absence of species rather than describe distribution or population densities.

Frey and Jones (2008) examined mammal populations in the coastal prairie ecosystem of PAIS. The objectives of the research were to 1) conduct a baseline inventory of small mammals present in the park, 2) describe the habitat associations of small mammal populations, 3) determine factors that structure small mammal populations in the park, and 4) characterize patterns in species diversity and community structure. Standardized Sherman trap transects were utilized to evaluate small mammal presence on the island, while sign (scat, tracks, etc.), direct observation, and motion-sensing cameras were used to document the presence of larger mammals, including coyotes.

Current Condition and Trend

Population Density

No current estimate of population density exists for coyotes in PAIS. Density of coyote populations is likely to be largely dependent upon food and habitat availability. Snodgrass (1997) noted that coyotes on barrier islands, such as PAIS, tend to be more solitary than coyotes on the mainland because of the seasonal or limited availability of mammalian prey items.

Frey and Jones (2008) recorded locations of coyote observations during a survey of small mammals in PAIS, but did not specifically quantify densities through intensive trapping. Based on the number of coyotes observed, Frey and Jones (2008) suggested that coyote densities appeared high in PAIS, although additional species-specific trapping studies are needed to quantify this observation.

Distribution

Very little research investigating coyote distribution in PAIS has been completed to date. Frey and Jones (2008) documented the presence and relative distribution of coyotes in PAIS by mapping coyote sightings during the 2005 through 2007 field seasons. Locations of all coyote sightings, both by direct researcher observation or images captured on motion-sensing cameras, were mapped to determine presence throughout the park; coyote sign (i.e., scat and tracks) was also documented when encountered.

Ninety-one of 214 images from motion-sensing cameras placed throughout the park documented coyotes. During the Frey and Jones (2008, p. 74) inventory, researchers stated that they “frequently saw coyote tracks traversing transects of Sherman traps, adjacent to mudflats, along the beach, and on most small islands in the Laguna Madre”. Figure 17 shows the trap locations where coyotes were documented in the park. However, it could not be verified if individual coyote observations were unique individuals or if some individuals were observed repeatedly during the study. Likewise, the distance that individuals traveled throughout the park was not determined.

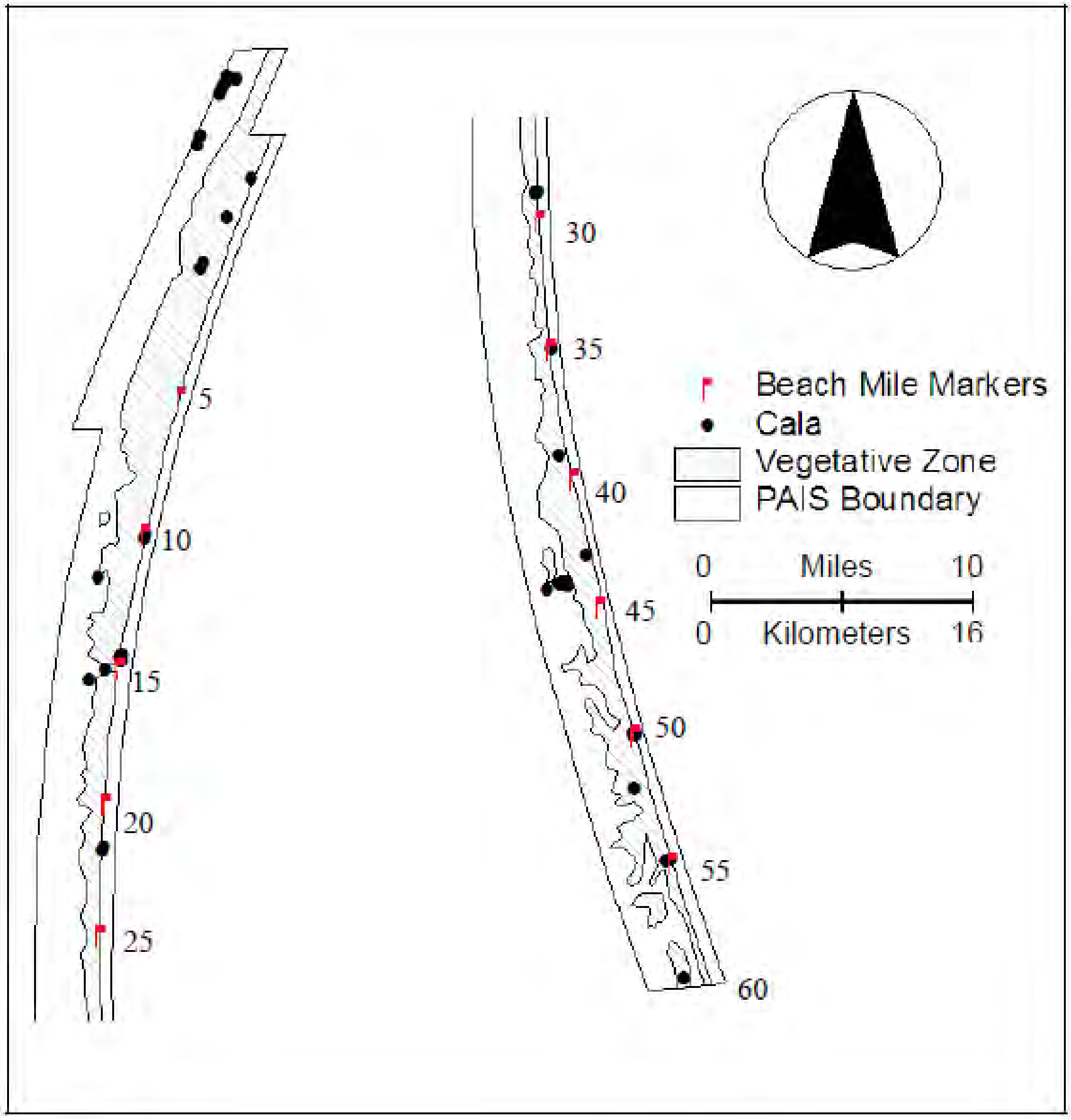


Figure 17. Trapping locations where coyotes were documented within PAIS (Frey and Jones 2008). The section to the left shows locations from the northern boundary of the park to beach mile 28.5. The section on the right shows locations from beach mile 28.5 to the southern boundary of the park. Cala = *Canis latrans*.

Threats and Stressor Factors

Outbreaks of harmful algal blooms (HABs), specifically red tides, have been identified as a threat to coyote populations in PAIS, particularly when events are sustained. HABs arise when annual blooms of naturally occurring microscopic algae grow out of control. The algae in red tides is made up of the dinoflagellate *Karenia brevis* and is found primarily in the Gulf of Mexico (NOAA 2012b). *K. brevis* produces a neurotoxin, known as brevetoxin, which at high concentrations can affect the central nervous systems of fish, shellfish, birds, and marine and terrestrial mammals, as well as sicken people who eat contaminated molluscan shellfish (NOAA 2012a, TPWD 2012b). When temperature, salinity, and nutrients reach certain levels in the Gulf of Mexico, exponential increases in *K.brevis* algae occur (TPWD 2012b). While the precise combination of factors that cause a red tide event is not clear, it is believed that high temperatures in addition to lack of rainfall and wind play a significant role in overgrowth of red tide algae (TPWD 2012b). In 2009, PAIS experienced a sustained red tide event that also coincided with an extended drought period for the region. During this time, a number of coyotes in the park were observed displaying symptoms of neurological problems, such as ataxia (loss of coordination) and partial paralysis of limbs; at least 12 coyotes were discovered dead during and in the weeks following this event, all of which were determined to have died from brevetoxin poisoning.

Drought is also a threat to the coyote population in PAIS as periods of drought remove many sources of water, as well as significantly affect the availability of prey items. Starvation during crashes of prey sources may be a substantial mortality factor for coyotes across their range (Bekoff and Gese 2003).

Coyotes are susceptible to a wide variety of diseases and parasites (Bekoff 1977). External parasites, such as various species of fleas, ticks, lice, and internal parasites, such as cestodes, roundworms, intestinal worms, hookworms, whipworms, heartworms, pinworms, thorny-headed worms, and coccidia fungus have been known to affect coyotes across the extent of their range (Bekoff 1977). Diseases such as tularemia, distemper, rabies, and bubonic plague also are documented in coyote populations (Beckoff 1977). Disease and parasitic outbreaks within a small population can hinder recruitment of young and overall population sustainability.

Human activity has been identified as a leading cause of death in adult coyotes (Windberg et al. 1985, Gese et al. 1989, Windberg 1995). A possible threat to coyote populations in PAIS is coyote-human conflicts, including collisions with vehicles while crossing roadways. Another possible impact is the habituation of coyotes to humans, particularly in park settings where refuse stations and visitor supplies are associated with opportunistic food sources. In the last 7 years, a total of five coyotes have died as a result of collision with vehicles on park roads; two or three individuals have had to be removed as a result of habituation to humans (Stablein, email communication, 29 November 2012). Historically, poaching of coyotes for pelts or reduction of large predators in the area has been a threat to coyote populations. Although coyotes within PAIS are protected from hunting, poaching or hunting that occurs outside of park boundaries may affect the health of the population in the park.

Data Needs/Gaps

An investigation into the current coyote population density and distribution is needed for PAIS. In addition, assessments detailing disease prevalence or impacts and reproductive success would provide valuable insights into population conditions in the park. Without this information, an assessment of current condition of the coyote population is not possible.

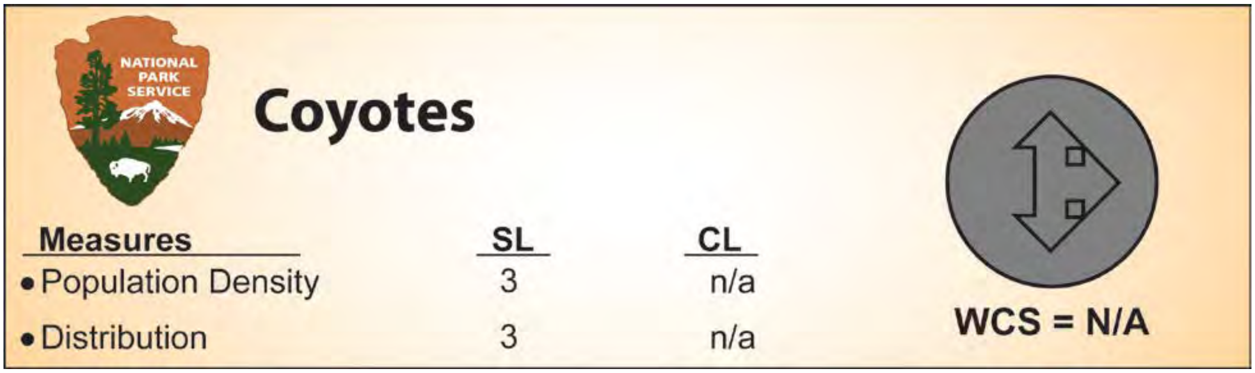
Overall Condition

Population Density

The project team defined the *Significance Level* for population density as a 3. However, due to the lack of data regarding this measure, a *Condition Level* was not assigned.

Distribution
The project team defined the *Significance Level* for distribution as a 3. Very limited data exist for coyote distribution in PAIS; thus, a *Condition Level* was not assigned to this measure.

Weighted Condition Score
Information regarding the coyote population at PAIS is not available at this time. Without detailed information regarding the population density and distribution of coyotes in the PAIS area, a *Weighted Condition Score* cannot be assigned.



Sources of Expertise
Wade Stablein, Biological Technician, PAIS

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4.9 Small Mammals

Description

Twenty-four terrestrial mammals are known to inhabit PAIS (NPS 2012a, GULN 2010). With the exception of white-tailed deer, coyote, and the non-native nilgai (a rare occurrence in the park), all mammals in the park are considered small mammals. While the majority of native mammals in PAIS are rodents, the small mammal population also includes rabbits, moles, bats, opossums, and armadillos (NPS 2012a). The primary habitats utilized by the small mammal population of the park include grasslands, vegetated dune communities, and wetlands/semi-permanent ponds (NPS 2012b).

Photo 15. Spotted ground squirrel (*Spermophilus spilosoma*) (TPWD photo).

While visitors do not often observe small mammals, several of these species (rodents in particular) make up important components of the park's ecosystem. Rodents serve as the primary food source for avian predators, reptiles, and larger mammal species (e.g., coyote, gray fox [*Urocyon cinereoargenteus*], and badger (Sieg 1987). The black rat and the house mouse are two non-native small mammals introduced to the U.S. in the 18th century (Raun 1959) that have been identified in PAIS (NPS 2012a). These species, although uncommon in the park, compete with native rodents for food resources and burrows where they do occur.

Photo 16. Hispid cotton rat (*Sigmodon hispidus*) (TPWD photo).

Measures

- Species diversity and abundance
- Distribution
- Density

Reference Conditions/Values

The ideal reference condition for this component is species diversity and abundance and population densities and distribution prior to the intensive grazing and settlement of North Padre Island that occurred during the late 1800s through 1971. Unfortunately, little to no data exist for this time period. Future assessments of condition may need to use more contemporary data as a baseline for trend and condition comparisons.

Data and Methods

Bailey (1905) conducted a biological survey of Texas. This survey described the ranges and distributions of native species in relation to "life zones" located throughout Texas. The four main life zones identified were the Lower Austral Zone (including the Lower Sonoran Zone), Upper Austral Zone (including the Upper Sonoran Zone), Transition Zone, and Canadian Zone. Mammal species were only addressed for the Upper and Lower Austral Zones; PAIS was located in the Lower Austral Zone.

Raun (1959) compiled an annotated checklist of mammals for Mustang and Padre Islands. The checklist included terrestrial and marine mammals recorded on the islands and in adjacent waters. It was nearly 20 years before another mammalian checklist was compiled in the PAIS area, as Baker and Rabalais (1975) compiled a checklist of mammals found within PAIS, including terrestrial and marine mammals, in 1975. Species abundance in PAIS was recorded as possible, rare, uncommon, fairly common, or common in the park.

Baccus (1977) investigated how recreational use of the beaches and dunes influence the flora and fauna of PAIS. Objectives included correlating the distribution and diversity of mammals with vegetation patterns to determine which rodent species may be indicators of habitat degradation. Sampling occurred at four main sites (Notraf, Vetraf, Pedtraf, and Shell) (Figure 18). The four sites were selected based on levels of disturbance, which include no vehicle traffic (Notraf), limited four-wheel traffic (Shell), mostly pedestrian traffic (Pedtraf), and unrestricted vehicle traffic (Vehtraf). Three stations were established at each site for sampling small mammals, each spaced 6 m (20 ft) apart. Three lines were set, one at each station, with 25 Sherman live traps per line. Sampling data included species name, sex, station location, transect number, site, and date captured. There were a total of 1,800 trap nights for all four study sites (450 trap nights per site).

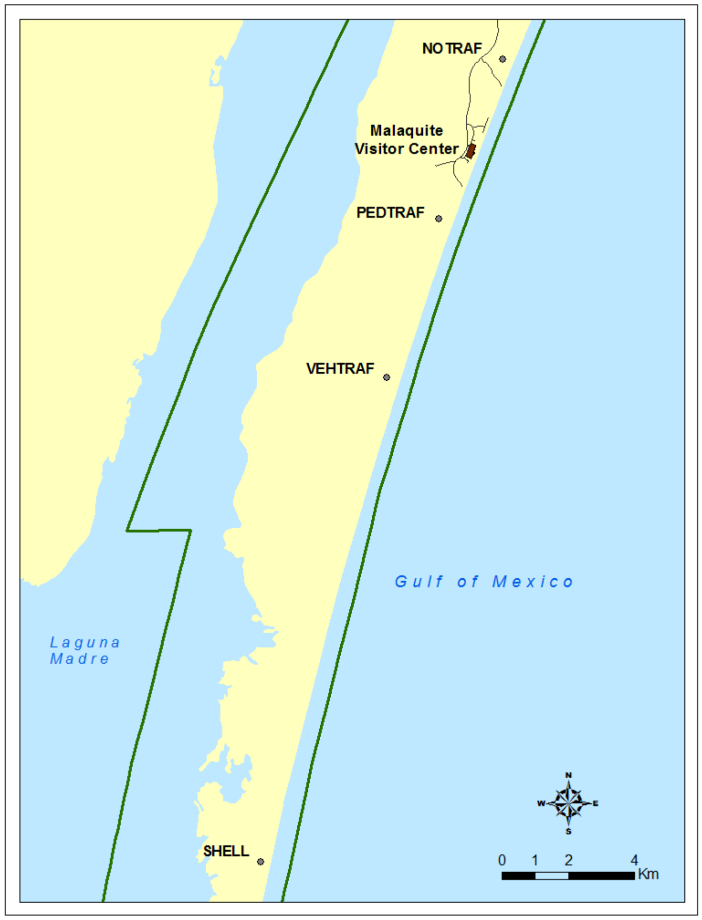

Figure 18. Locations of the four main sampling sites used during the Baccus (1977) study in PAIS.

Segers (1984) studied the ecology of ground squirrels (*Spermophilus* sp.), including spotted ground squirrels, from 1976 through 1977. The study area was approximately 3.2 km (1.9 mi) north of PAIS and was comprised of four vegetation zones: active dunes, deflation flat (trough where sand erosion is stabilized by moisture), herbaceous area, and saturated depression. One hundred live traps were laid in a 4.4 hectare grid behind the island’s foredune ridge. The traps were checked twice a day for two consecutive days every week.

Harris (1988) compiled a list of mammals found in PAIS during an inventory between June and December 1984. Traps were set in 18 locations within the northernmost 10 km (6.2 mi) of park, and were used to capture and identify small mammals; museum records were referenced for species not observed during the course of the inventory. Museum vouchers included species found in PAIS as well as on Mustang Island.

Frey and Jones (2008) conducted an extensive 2-year survey of mammals within PAIS, Mustang Island, and other small islands in the Laguna Madre. This study utilized literature, museum queries, and field surveys to determine the mammals found in PAIS. The field survey was conducted between May 2005 and March 2007. Trapping was done in the summer of 2005, 2006, and the fall of 2006. Live trapping methods utilized Sherman traps, pitfall traps, mist nets, Hart traps, motion-sensor photography, and Tomahawk traps. Figure 19 shows all trapping locations in the study. The survey divided PAIS into three latitudinal sections (North Beach, Closed Beach, South Beach), and longitudinally divided the park into six zones: beach, foredune, interdune, primary dune, interior, interior dune, laguna matrix.

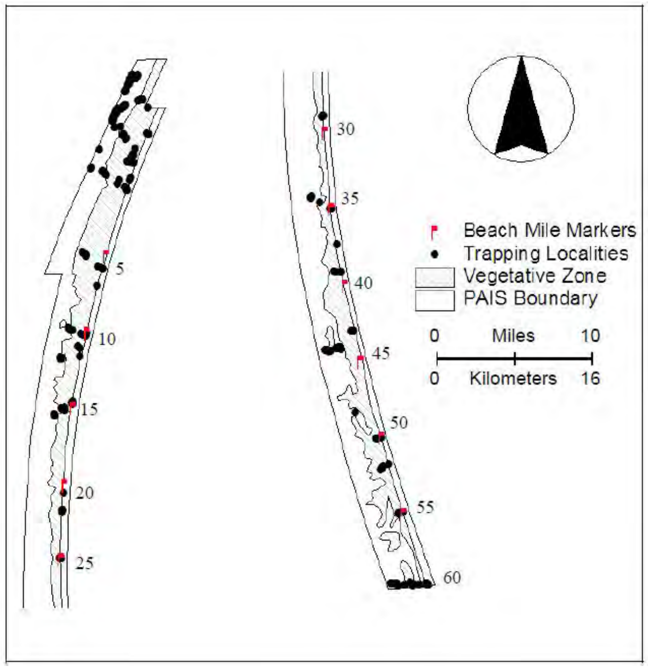

Figure 19. Locations of mammal trap transects during the Frey and Jones (2008) survey in PAIS.

Current Condition and Trend

<u>Species Diversity and Abundance</u>

Small mammal diversity is a measure that takes into consideration both species richness and the relative abundance of different species. Often, the Shannon-Wiener species diversity index (H') is used to represent this measure; when properly calculated, this index can "… determine the uncertainty that an individual picked at random will be of a given species" (UC 2012, p. L 5-2). The equation for the Shannon-Wiener diversity index is listed below.

$$H' = -\sum_{i=1}^{s}(p_i)(\ln p_i)$$

p_i = proportion of individuals of species (i) in a community (=n_i/N; where n_i is the number of individuals of a given species and N is the total number of individuals in a sample) (UC 2012).

The diversity index will result in an H' value that will typically be between 0 and 4; a value of 0 indicates a community that displays low/no species complexity, while a value of 4 indicates a community of high species complexity. For this measure, only studies that surveyed small mammals and recorded the number of individuals in a survey were included.

Bailey (1905) reported 15 species of small mammals (representing six orders) from Padre Island or nearby Mustang Island; nine of the 15 mammals were from the order Rodentia. Two of the species (the hispid cotton rat and the northern pygmy mouse [*Baiomys taylori*]) were not explicitly reported on the two islands, but their distribution area included PAIS and Mustang Island. Although abundance values were not provided for all of the mammals, a general description of abundance was provided for a few of the identified species. The Brazilian free-tailed bat (*Tadarida brasiliensis*) was said to be common, the Gulf coast kangaroo rat was recorded as probably common, and the Tamaulipan hog-nosed skunk (*Conepatus leuconotus*) was said to occur occasionally. All the small mammal species documented by Bailey (1905) on the islands are displayed in Appendix M.

Raun (1959) recorded 17 small mammal species (representing five orders) on Padre and Mustang Islands; the order Rodentia represented the majority (10 spp.) of the small mammals observed. Raun (1959) recorded only the presence of species, and no surveys or formal estimates of abundance were completed. Appendix M displays the small mammals present on the Raun (1959) mammal checklist of Padre and Mustang Islands.

Baker and Rablais (1975) recorded 31 small mammal species (representing seven orders) in PAIS; no specific estimates of abundance were created, however. A number of the species (12) were only recorded as a "possible presence" on Padre Island. Seven species were considered uncommon, five species were fairly common, and six species were considered common in PAIS. The six species considered common in the park were the spotted ground squirrel, Mexican ground squirrel (*Spermophilus mexicanus parvidens*), black-tailed jackrabbit, Texas pocket gopher, Gulf coast kangaroo rat, and hispid cotton rat. The Tamaulipan hog-nosed skunk was stated to have a former range that extended into the area, but its occurrence in PAIS was thought to be highly improbable at the time of the Baker and Rablais (1975) study. Appendix M displays the small mammals documented on the Baker and Rablais (1975) checklist and their status in PAIS.

Baccus (1977) documented 10 small mammals (representing four orders) during a Padre Island study in 1976. Five rodent species inhabited the beaches and dunes in PAIS, including the Gulf coast kangaroo rat, spotted ground squirrel, hispid cotton rat, fulvous harvest mouse (*Reithrodontomys fulvescens*), and northern pygmy mouse. The marsh rice rat (*Oryzomys palustris texensis*) was another rodent known to inhabit the islands, but it was not observed during the study. The other mammal species observed are presented in Appendix M. The site with vehicle traffic (Vetraf) showed lower species diversity than the other three study sites; it had a diversity value of 0.951. This may be due to reduced vegetation cover. The dominant species found at the Vetraf site was the spotted ground squirrel. The two sites with the highest diversity had no traffic (Notraf) or only pedestrian traffic (Pedtraf), and they had diversity values of 1.382 and 1.425, respectively (Table 34).

Table 34. Shannon-Wiener Diversity Indices for rodent species of the four main sampling sites in PAIS (Baccus 1977).

	Sampling Sites			
	NOTRAF	**PEDTRAF**	**VETRAF**	**SHELL**
Diversity (H)	1.382	1.425	0.951	1.359
Evenness (e)	2.295	2.039	1.9445	1.993
Richness (d)	1.791	2.449	1.661	2.532
Number of Species	4	5	3	5

Harris (1988) identified 27 small mammal species that were recorded during previous inventories or studies in the park; however, only nine species from seven orders were captured or observed during the survey in 1984. The most diverse order was Rodentia, and the rodent species captured included the spotted ground squirrel, Texas pocket gopher, Gulf coast kangaroo rat, marsh rice rat, and northern pygmy mouse. According to Harris (1988), the eastern pipistrelle (*Sylvilagus floridanus*) had only been documented by Zehner (1985), and was not observed during this study. A list of the other mammals captured during this study can be found in Appendix M.

Frey and Jones (2008) reported 21 small mammal species that are present or probably present in PAIS. The species represent seven orders, with the order Rodentia being the most diverse. A striped skunk was observed during the study, but the report did not specify if it was inside PAIS. Only three species were listed as probably present in the park. Those species were the white-nosed coati (*Nasua narica*), eastern pipestrelle, and Virginia opossum. These mammals were not documented in the park during the survey, but have been seen north of the park or recorded in previous studies. Abundance estimates were not created, but Frey and Jones (2008) indicated that the hispid cotton rat was the most common species trapped during the study. The Texas pocket gopher was commonly observed throughout the park's terrestrial zones, while the northern pygmy mouse, fulvous harvest mouse, house mouse, and American badger were said to be in low abundance or uncommon. Appendix M displays all of the small mammals recorded during the inventory.

GULN (2010) summarized 20 small mammal species that are currently present or probably present in PAIS, based on the NPS Certified Species List. The list does not estimate abundance or diversity, however. The mammals identified in the summary represent seven orders, with the order Rodentia being the most diverse. Other orders include Carnivora, Cingulata, Chiroptera, Didelphidae, Lagomorpha, and Soricomorpha. Only three species were listed as probably present in the park. Those species were the white-nosed coati, eastern pipestrelle, and Virginia opossum. Appendix M displays all of the small mammals recorded during the inventory. The NPS Certified Species List (NPS 2012) has remained unchanged since this summary, accounting for 20 small mammals that are listed as probably present or present in PAIS.

Distribution

Limited data exist for the distribution of small mammals across PAIS. Baccus (1977) reported that all of the mammals observed inhabited the beaches and dunes in PAIS. The Gulf coast kangaroo rat and spotted ground squirrel seemed to prefer the open or sparsely vegetated areas, while the other species preferred areas with denser vegetative cover. Most of the species documented were found at the sampling site with no traffic (Notraf site). No marsh rice rats were collected during the study, but they are known to inhabit marshy areas with grasses and sedges.

Table 35 displays the small mammals observed at the four main sites of the study (refer back to Figure 18 for site locations).

Table 35. Small mammal species collected in PAIS (Baccus 1977).

Common Name	Notraf	Pedtraf	Vetraf	Shell
eastern mole	X			
black-tailed jack rabbit	X	X		
spotted ground squirrel	X	X	X	X
Padre Island pocket gopher	X	X	X	X
Gulf coast kangaroo rat	X	X	X	X
fulvous harvest mouse		X		X
northern pygmy mouse	X	X		X
hispid cotton rat	X	X	X	X
badger	X			

Density

Currently, there are limited data regarding density of small mammals in PAIS. Segers (1984) calculated the density of the spotted ground squirrel population just north of PAIS on Padre Island between 1976 and 1977. The mean density of the population was 1.5 animals per hectare. The highest densities of spotted ground squirrels (3.2 and 2.3 animals per ha) occurred in August and September of 1976, respectively.

Threats and Stressors

There are several threats to the park's small mammal population, and PAIS staff identified eight stressors that have occurred or are presently occurring in the park. Those stressors include invasive species, drought, erosion, predation, flooding and inundation, oil and gas development, marine debris (hazardous materials), and management actions.

The anthropogenic threats to small mammals include oil and gas development, marine debris, management actions, and invasive species. Oil and gas development can adversely affect small mammals in several ways. Small mammals could be killed during the drilling process; increased mortality could also result from vehicle collisions due to increased traffic (BLM 1981). Another anthropogenic threat to small mammals is hazardous marine debris. One of the largest environmental issues in the Gulf of Mexico is marine debris (EPA 1993). According to EPA (1993), injuries and deaths of animals as a result of debris have been increasing over the years. Small mammals could ingest or get entangled in beached debris (e.g., tar balls, plastic particles, fishing line), which may cause suffocation or predation due to entanglement. Invasive species also threaten the small mammals of PAIS through competition for resources. Invasive species do not have natural predators when introduced to a new environment. This allows them to out-compete native mammals for resources (e.g., food, shelter) and even prey on other native species (Pimentel et al. 2005). The Norway rat (*Rattus norvegicus*), for example, is an opportunistic feeder and feeds on the best quality food that is available (Major 2004). Invasive rat species have been known to eat native invertebrates and other vertebrates (e.g., birds, eggs) (Pimentel et al. 2005).

The natural threats to the small mammals on PAIS are drought, flooding and inundation, erosion, and predation. Drought is a stressor to the island's small mammals because precipitation is a significant source of freshwater input on barrier islands. There are only a few freshwater ponds in PAIS that serve as a source of fresh water; these ponds also double as a source of food for small mammals that prey on aquatic life found in those ponds (Gilbert et al. 2012). Flooding and inundation can cause significant stress to small mammals. Inundation usually occurs on the tidal flats as a result of wind action, but large storm events have caused nearly the entire island to be flooded in the past (Hice and Schmidly 2002). Flooding and inundation can destroy habitats, uproot vegetation, and cause mortality to many small mammals. According to Hice and Schmidly (2002), flooding and inundation can result in the need for mammals to recolonize after waters recede. Some may have had to swim to the Texas mainland; being in the open for long periods of time could increase the risk of predation. Erosion may cause stress to the burrowing small mammals in PAIS. Erosion is a common and necessary process on barrier islands due to wave action and the Gulf current. Increased erosion may put mammals such as the eastern mole, Texas pocket gopher, and black-tailed jackrabbit at risk by causing mounds to collapse into burrows. If erosion causes a burrow to collapse, these mammals may become more susceptible to predation while digging another burrow. Small mammals are preyed upon by several animals including coyotes, foxes, and raptors. Most rodents, however, have high productivity rates, which can aid the survival of the population even with predation (Sieg 1987).

<u>Data Needs/Gaps</u>
Small mammal species richness has been well documented over the past 100 years. Species found in PAIS have been documented by Bailey (1905), Raun (1959), Baker and Rablais (1975), Baccus (1977), Harris (1988), Frey and Jones (2008), GULN (2010), and NPS (2012a); however, abundance, diversity, distribution, and density data are largely absent for PAIS. The establishment of a baseline small mammal survey that could be repeated routinely to document species richness and abundance would provide managers with meaningful information that can be used for future assessments of condition.

<u>Overall Condition</u>

Species Diversity and Abundance
The project team defined the *Significance Level* for species diversity and abundance as a 3. While several inventories and reports have documented the small mammal species that are present in PAIS, very few studies have documented species diversity or abundance. Without contemporary estimates of these measures, an assessment of condition is not possible. For this reason, a *Condition Level* was not assigned for this measure.

Distribution
The project team defined the *Significance Level* for distribution as a 3. There are historic reports of distribution by vegetation or habitat type, but some of these studies were conducted outside of the park. Baccus (1977) reported that all of the terrestrial mammals recorded were found in the beach or dune habitat, but this was not in PAIS nor is it current data. A current study on distribution within the park is necessary to make a proper assessment. As a result, a *Condition Level* was not assigned for this measure.

Density
The density measure was assigned a *Significance Level* of 3. There are limited data for density of small mammals in PAIS. Segers (1984) recorded densities of spotted ground squirrels north of PAIS; this study is 20 years old and needs to be replicated within park boundaries to determine the current density of the species. The density of other small mammals would be necessary to assess the current condition for this measure. Because of this data gap, a *Condition Level* for this measure was not assigned.

Weighted Condition Score
A *Weighted Condition Score* for small mammals in PAIS was not assigned because none of the measures had known *Condition Levels*.

Small Mammals

Measures	SL	CL
• Diversity and Abundance	3	n/a
• Distribution	3	n/a
• Density	3	n/a

WCS = N/A

Sources of Expertise
Wade Stablein, Biological Technician, PAIS

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4.10 Macroinvertebrates

Description

Macroinvertebrates are often used as biological indicators in assessing overall aquatic ecosystem health (EPA 2012). Their presence or absence may reflect ecosystem integrity or disturbances that can affect higher trophic levels (Rocha 1995, Segura et al. 2007). Along the Texas coast, macroinvertebrates are an important food source for shorebirds, fish, and other wildlife (Withers and Tunnell 1988, Rocha 1995). Species abundance and diversity, distribution, and density of macroinvertebrates in aquatic systems is one of the GULN Vital Signs, chosen to represent the overall health and condition of the park's natural resources (Segura et al. 2007). Macroinvertebrate indicator species can range from sensitive species, such as caddisflies (Trichoptera) and Unionids (freshwater mussels of the family Unionidae, also known as naiads) to the much more tolerant midge (Diptera) and aquatic worm (Oligochaeta) species.

Photo 17. A ghost crab at PAIS (photo by Shannon Amberg, SMUMN GSS).

The aquatic and beach environments of PAIS are generally harsh (e.g., high salinity, pounding waves) and dynamic (e.g., tidal surges) (Parker 1959, Rocha 1995). The macroinvertebrates that inhabit these communities must be able to adapt to these extreme conditions. The Laguna Madre, due to its lack of water exchange with other water bodies, is typically hypersaline with high summer water temperatures (30-35 °C) (Parker 1959). The dominant aquatic macroinvertebrate taxa found in PAIS include crustaceans, polychaete worms, and shelled mollusks (Rocha 1995, Withers et al. 2004). Burrowing invertebrates, such as the ghost crab (*Ocypode quadrata*) (Photo 17), are common on beaches, while bivalve mollusks (e.g., clams) are frequently found in intertidal areas and the Laguna Madre (Parker 1959, Rocha 1995). Additional macroinvertebrate species include echinoderms (e.g., sand dollars), cnidarians (e.g., jellyfish), and gastropods (Parker 1959, Rocha 1995, Withers et al. 2004).

Measures

- Distribution
- Density
- Species diversity and abundance

Reference Conditions/Values

A park-wide reference condition has not been defined for the macroinvertebrate community. The condition of the community at the time of park establishment would be an appropriate reference condition, but no information is available from this time. The data and information presented here could be used as a baseline for future assessments.

Data and Methods

Macroinvertebrates have been sampled in several habitats in and around PAIS. The earliest work by Parker (1959) occurred in the Laguna Madre. Based on analyses of aquatic macroinvertebrate samples from 121 stations throughout the Laguna Madre, Parker (1959) identified five unique environments, three of which occur along PAIS: open hypersaline lagoon, enclosed hypersaline lagoon, and a small amount of "hypersaline lagoon influenced by adjacent lower-salinity bay" near the northern boundary (p. 2148). During the mid-1970s, Rabalais (1976) created a checklist of crab species found at PAIS and their general habitat.

Throughout the 1990s, Withers (1993, 1996, 1998) studied the macroinvertebrates of several tidal flats on the Laguna Madre side of PAIS. From October 1991 to September 1992, Withers (1993) sampled benthic macroinvertebrates twice a month on an algal flat along the park's northern boundary. A species list was generated, as well as density and distribution (damp, wet, or intertidal microhabitats) information. From November 1995 to March 1996, Withers (1996) studied the macroinvertebrate communities at two former drilling sites south of Malaquite Beach to explore the impact of drilling and restoration activities on these organisms. Withers (1996) looked at diversity and density at the restored sites and in nearby control areas. Finally, Withers (1998) sampled macroinvertebrates on three wind-tidal flats in PAIS from November 1997 through March 1998. Density and diversity data from this study were compared to similar sites from Withers' previous studies (1993 and 1996).

Also in the early 1990s, Rocha (1995) studied benthic invertebrates on the Gulf of Mexico beaches of PAIS. Four transects, stretching from the backshore to subtidal areas (e.g., sandbars and troughs), were sampled monthly from October 1992 to September 1993 (Plate 27). In addition to generating a species list and characterizing species distribution along the transects, species density and diversity were also calculated (Rocha 1995).

Limited data regarding inland aquatic macroinvertebrates at PAIS were available from Sissom et al. (1990), who completed a biological inventory of three ponds in the park (Plate 27). Macroinvertebrate sampling included species richness and monthly density data from September 1989 to August 1990.

Current Condition and Trend

<u>Distribution</u>

Several studies have explored the distribution of macroinvertebrate species within a particular environment (e.g., beaches, tidal flats). Parker (1959) identified three separate aquatic environments in the portion of the Laguna Madre that borders PAIS: open hypersaline lagoon, enclosed hypersaline lagoon, and saline lagoon influenced by a lower salinity bay. The distribution of macroinvertebrates across these three environments is shown in Table 36. Only three bivalve species were found in all three environments, while 10 species were found in just one environment (Parker 1959).

Table 36. Macroinvertebrate species collected in three Laguna Madre environments that border PAIS (Parker 1959). Only species captured alive are included here; any species collected only as shells have been omitted.

Species	Open hypersaline	Enclosed hypersaline	Low salinity, bay influenced
Gastropods (Snails/Slugs)			
Crepidula glauca convexa	x		
Cerithidea variable		x	
Nassarius vibex	x		x
Bittium varium	x		
Mitrella lunata	x		
Odostomia bisuturalis		x	x
Bivalves (Mussels)			
Brachidontes citrinus	x	x	
Amygdalum papyri	x		
Laevicardium mortoni	x		x
Macoma brevifrons	x		
Mactra fragilis	x		x
Pseudocyrena floridana	x		
Anomalocardia cuneimeris	x	x	x
Mulinia lateralis	x	x	x
Tellina tampaensis	x	x	x
Crassostrea virginica			x
Lyonsia floridana hyaline			x
Phacoides pectinatus			x
Crustaceans (Crabs/Shrimp)			
Callinectes sapidus	x		x
Total	**14**	**6**	**11**

Withers (1993) reported the distribution of benthic macroinvertebrates within damp, wet, and intertidal microhabitats on an algal flat. Microhabitats were divided based on water depth; intertidal areas contained 2-4 cm of water, wet areas up to 2 cm, and damp areas generally had no standing water but were wet just below the ground surface. Ten macroinvertebrate species were found in all three microhabitats (Withers 1993, Table 37). Twenty-two species were found in just one microhabitat, most often the intertidal areas. However, several insect families occurred only in the damp microhabitat (Withers 1993). Withers (1996) explored the distribution of macroinvertebrates at two former oil and gas development sites that had been restored (Plate 27). At the Texaco site, six species were found within the restored area, six in an adjacent control area, and four within tire tracks (Withers 1996, Table 37). Only insects were found in tire tracks and no mollusks were found at the site. At Yarborough Pass, 26 macroinvertebrate species occurred in the restored area, 14 in the control area, and only six within tire tracks (Withers 1996). Nearly all species found at the control and tire track locations were also present in the restored area. Withers (1998) sampled three tidal flats on the western side of the park: two algal flats (Dunn Ranch and Yarborough Pass) and one sandflat (Mile Marker 45) (Plate 27). Taxa found at all three sites included several polychaetes (segmented worms), one bivalve (*Anomalocardia auberiana*), a tanaid crustacean (*Hargeria rapax*), and two dipteran families (Dolichopodidae and Canaceidae) (Table 37). Amphipod crustaceans occurred at both algal flats, but not at the Mile Marker 45 sandflat. Nemerteans (ribbon worms) were recorded only at Yarborough Pass (Withers 1998).

Table 37. Distribution of benthic macroinvertebrates on tidal flats during three studies by Withers (1993, 1996, 1998). For Withers (1993), D = damp, W = wet, and I = intertidal. For Withers (1996), Rs = restored, C = control (no known oil/gas disturbance), and TT = in tire tracks.

Species	Withers 1993	Withers 1996		Withers 1998		
		Texaco site	Yarborough Pass	Yarborough Pass	Dunn Ranch	Mile Marker 45
Phylum Nemertea	W,I		Rs,C	x		
Phylum Annelida, Class Polychaeta						
Arenicola cristata	W					
Axiothella mucosa	I					x
Capitella capitata	D,W,I			x	x	x
Capitomastus aciculatus	W,I					
Chone duneri	I					
Demonax micropthalmus	I		Rs	x	x	x
Dorvillea rubra	I					
Eteone heteropoda	D,W,I		Rs	x	x	x
Exogone dispar	I		Rs			
Haploscoloplos foliosus	D,W,I		Rs,C,TT	x		x
Laeonereis culveri				x		
Polydora ligni	I					
Polydora spp.		C	Rs,C	x		
Prionospio cristata	I					
Prionospio heterobranchia	I		Rs	x		
Prionospio pinnata			Rs,C			
Marphysa regalis				x		
Melinna maculata				x		x
Nainereis laevigata			Rs		x	x
Nereis riisei				x	x	
Sabella sp. A	I		Rs	x		
Spio pettibonniae			Rs			
Streblospio benedicti			Rs			
Syllis cornuta	D,W,I		Rs			
Capitellidae			Rs			
Maldanidae			TT			
Phylum Mollusca, Class Bivalvia						
Amygdalum papyrium	W		Rs,C			
Anomalocardia auberiana	W,I		Rs,C	x	x	x
Bulla striata	D,I					
Mulinia lateralis	D,W,I					
Tellina tampaensis	I			x		x
Tellina sp.			Rs			
Phylum Arthropoda						
Subphylum Chelicerata						
Spiders	W,I					
Subphylum Crustacea						
Corophium acherusicum		Rs,C	Rs,C		x	
Corophium louisianum	D,W,I		Rs,C	x		
Grandidierella bonnieroides				x		
Gammarus mucronatus			Rs	x		
Hargeria rapax	D,W,I	Rs,C	Rs,C,TT	x	x	
Orchestia grillus				x		
Oxyurostylis smithii	I					
Sphaeroma quadridentatum				x		
Subphylum Hexapoda, Class Insecta						
Berosus sp.		Rs,TT				
Bledius sp.	D,W			x		
Canaceidae	D,W,I	Rs,C,TT	Rs	x	x	x

Table 37. Distribution of benthic macroinvertebrates on tidal flats during three studies by Withers (1993, 1996, 1998). For Withers (1993), D = damp, W = wet, and I = intertidal. For Withers (1996), Rs = restored, C = control (no known oil/gas disturbance), and TT = in tire tracks (continued).

Species	Withers 1993	Withers 1996		Withers 1998		
		Texaco site	Yarborough Pass	Yarborough Pass	Dunn Ranch	Mile Marker 45
Carabidae	D					
Ceratopogonidae	D,W,I	Rs,C	Rs,C,TT	x	x	
Dolichopodidae	D,W,I	Rs,C,TT	Rs,C,TT	x	x	x
Empidiae	I					
Ephydridae			C			
Hemiptera (nymph)					x	
Homoptera	I					
Hydrophilidae (larvae)					x	x
Leuctridae sp.	W					
Melyridae	D		Rs,C			
Nabidae		TT	TT			
Pteromalidae	I					
Saldidae	D					
Scelionidae	I					
Staphylinidae (larvae)					x	x
Tipulidae				x		
Subphylum Hexapoda, Class Entognatha						
Cyphoderus sp.	I					
Phylum Platyhelminthes						
Turbellaria			Rs,C			

Rocha (1995) divided Gulf beaches into three regions (supra-, inter-, and subtidal) and nine zones within these regions. The distribution of benthic macroinvertebrates within these zones is presented in Table 38. Figure 20, created by Rocha (1995), shows the distribution of dominant macroinvertebrates among the three regions of the Gulf beaches. Rocha (1995) characterized the supratidal or backshore region as a rove beetle-ghost crab (*Bledius*-*Ocypode*) community. The intertidal region was divided among two communities: a haustoriid amphipod-spionid polychaete (*Haustorius*-*Scolelepis*) community in higher subzones and a bivalve-mole crab (*Donax*-*Emerita*) community in lower subzones (Rocha 1995). Due to high species diversity but low abundance, the subtidal community was difficult to classify. Previous researchers had identified the region as a ghost shrimp-bivalve- haustoriid amphipod (*Callichirus*-*Donax*- Haustoriidae) community (Hill and Hunter 1976, as cited in Rocha 1995). While ghost shrimp (*Callichirus islagrande*) were not detected by Rocha (1995) due to their deep burrowing behavior, observations of abundant burrow holes suggested that they were an important species in the subtidal community. Other common species included a polychaete (*Lumbrineris impatiens*), haustoriids (*Haustorius* sp.), bivalves (*Donax* sp.), and several crustaceans (Table 38). The subtidal zone also supported echinoderms, cnidarians, and gastropods (Rocha 1995).

Table 38. Distribution and abundance (number of individuals) of benthic macroinvertebrates by zone along Gulf beaches within PAIS (Rocha 1995). UBS – upper backshore, MBS – mid backshore, HS – high intertidal, MS – mid intertidal, LS – low intertidal, T1 – first trough, B1 – first sandbar, T2 – second trough, B2 – second sandbar.

	Supratidal		Intertidal			Subtidal			
Taxa	**UBS**	**MBS**	**HS**	**MS**	**LS**	**T1**	**B1**	**T2**	**B2**
Phylum Cnidaria									
Scyphozoan polyp			1		1	42	5	71	
Phylum Nemertea			1				1		
Phylum Annelida, Class Polychaeta									
Scolelepis squamata	2		597	357	247	41	10	25	22
Dispio uncinata			2	1		1	7	6	8
Polydora ligni						2			
Onuphis eremita oculata						1	4		2
Magelona riojai					1	3		1	1
Owenia fusiformis						1	2		
Nereididae sp.								1	
Nephtys picta				4	6	6	16	19	21
Lumbrineris impatiens	30	1	92	276	557	966	933	706	341
Phylum Arthropoda									
Subphylum Crustacea									
Callichirus islagrande					1				
Isocheles wurdemanni							4	1	3
Emerita benedicti	2		168	169	116	38	34	32	30
Emerita portoricensis			17	54	28			2	
Lepidopa websteri				1		1	1	1	3
Callinectes sapidus								1	1
Austinixa chacei			14	63	89	54	52	161	45
Pinnixa chaetopterana					2			6	
Bowmaniella brasiliensis					12	1	7	7	14
Metamysidopsis swifti							1		1
Oxyurostylis smithi			48	10	10	4	2	4	
Ancinus depressus		1	27	26	44	158	165	73	63
Lepidactylus triarticulatus						2			
Acanthohaustorius sp.					2				2
Protohaustorius bousfieldi						2	2	2	0
Haustorius sp.	14	518	2,300	194	182	556	352	556	301
Corophium sp.					4	12	8	6	3
Talorchestia sp.						4	2		
Tanaid (unidentified)	10	6				2			
Subphylum Hexapoda									
Bledius sp.	1	97							
Dipteran larvae				34	1				

Table 38. Distribution and abundance (number of individuals) of benthic macroinvertebrates by zone along Gulf beaches within PAIS (Rocha 1995). UBS – upper backshore, MBS – mid backshore, HS – high intertidal, MS – mid intertidal, LS – low intertidal, T1 – first trough, B1 – first sandbar, T2 – second trough, B2 – second sandbar (continued).

	Supratidal		**Intertidal**			**Subtidal**			
Taxa	**UBS**	**MBS**	**HS**	**MS**	**LS**	**T1**	**B1**	**T2**	**B2**
Phylum Mollusca									
Class Bivalvia									
Anadara ovalis								2	
Donax texasianus			2	52	117	46	43	80	133
Donax variabilis	6		181	1,138	482	128	158	153	126
Donax spat			731	89	321	77	30	41	41
Class Gastropoda									
Hastula salleana				2		1	1		3
Oliva sayana						1			
Polinices duplicatus							1		
Phylum Echinodermata									
Ophiophragmus moorei				1		15	13	35	17
Mellita quinquiesperforata									3

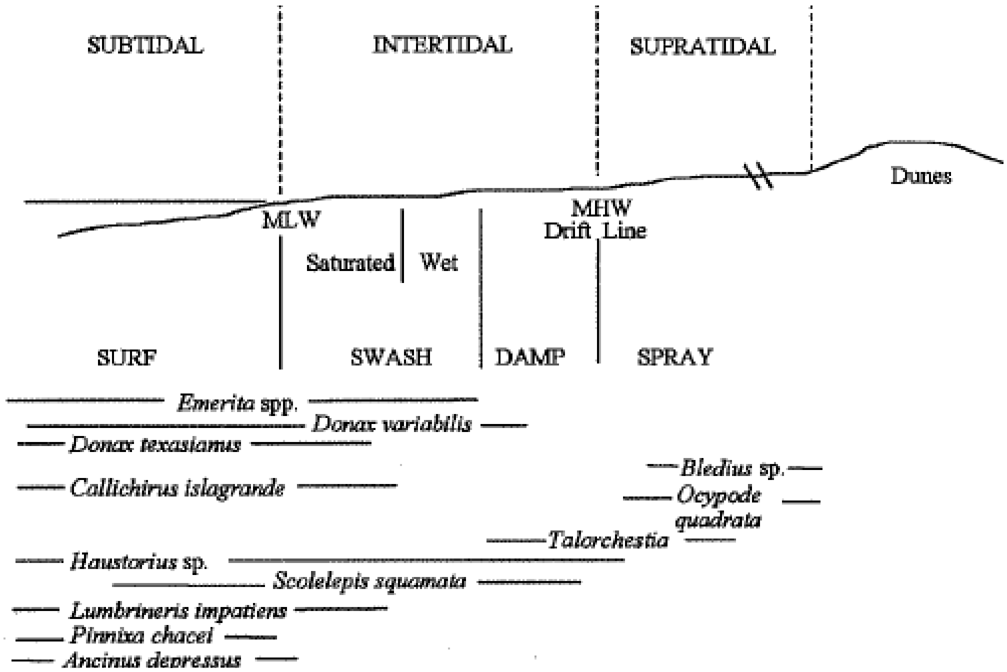

Figure 20. Distribution of dominant macroinvertebrate taxa along the Gulf beaches of PAIS. Name placement indicates the zone with highest abundance while lines show overall distribution (Rocha 1995). MLW = mean low water, MHW = mean high water.

Density

Macroinvertebrate density data are available for PAIS Gulf beaches, tidal flats, and inland ponds. On an algal flat along the park's northern boundary, Withers (1993) found that densities were highly variable throughout the year, ranging from 0 to 70,000 organisms/m^2. Of the three microhabitats sampled, densities were lowest at the damp sites, peaking around 16,000 organisms/m^2 (Withers 1993). Densities reached 70,000 organisms/m^2 at both the wet and intertidal areas. Tanaids showed the highest densities in all three microhabitats (Withers 1993).

Withers (1996) noted low densities of most macroinvertebrates at two tidal flats south of Malaquite Beach. On average, less than one polychaete, tanaid, and amphipod were detected per 5.4 x 5 cm sediment core from the Texaco site. Insect larvae were slightly more common, reaching a density of 1.2 per core at control sites in November (Withers 1996). Densities were higher at Yarborough Pass. Peak mean monthly insect density was 15 organisms per core and peak tanaid density was around 100 organisms per core. Polychaete, amphipod, and mollusk densities never exceeded four organisms per core (Withers 1996).

Rocha (1995) calculated mean macroinvertebrate densities for each of the four Gulf study locations as well as by beach zone, averaging across all four locations (Table 39). Total macroinvertebrate density was highest at Closed Beach and decreased at each site heading south. This may indicate a sediment grain size influence, as Closed Beach has finer sands and the more southerly beaches contain more coarse sediments and shell fragments (Rocha 1995). Jansson (1967, as cited in Rocha 1995) previously suggested that grain size distribution influences water content, circulation, and oxygen availability, which then impact macroinvertebrate community structure. Grain size and shape may also simply influence the suitability of beach habitat for burrowing organisms (Stablein, written communication, 3 February 2013). Of the three beach zones, the intertidal area supported the highest densities, followed by the subtidal zone, and the backshore with much lower densities (Table 39). Crustacean and mollusk densities were also highest in the intertidal zone while polychaetes peaked in the subtidal zone. Rocha (1995) also noticed seasonal patterns in macroinvertebrate density. At all four sites, the highest densities were recorded primarily during the summer (June-August), with the subtidal zone showing the greatest seasonal variability. Crustacean densities were highest in January and June while polychaetes peaked during the warmer months, beginning in April (Rocha 1995).

Table 39. Mean benthic macroinvertebrate density (per m^2) by study site and by major beach zone (across all study sites) (Rocha 1995).

	Crustaceans	Polychaetes	Molluscs	Total
Study site				
Closed Beach	1,374	349	703	2,426
Mile 15	229	552	544	1,325
Mile 25	324	453	182	959
Mile 45	295	462	53	810
Beach zone				
Backshore	451	41	32	524
Intertidal	796	482	713	1,991
Subtidal	482	520	177	1,179

Rocha (1995) also compared densities from this study to prior sampling efforts at Closed Beach (Shelton and Robertson 1981, Vega 1988). Rocha's (1995) densities were lower than previous findings (Table 40); however, Rocha attributes this to differences in methodology (e.g., size of sampling equipment) rather than actual change over time.

Table 40. Comparison of mean macroinvertebrate densities (#/m^2) between three sampling efforts at Closed Beach, PAIS (Rocha 1995).

	Shelton and Robertson (1981)	Vega (1988)	Rocha (1995)
Overall mean	3,980	4,900	2,450
Highest month	6,616 (June)	11,660 (May)	7,560 (June)

Sissom et al. (1990) calculated crustacean densities based on monthly samples from three PAIS ponds (Table 41). Densities ranged from approximately 200 to over 20,000 organisms per liter of pond water. Pond A showed the highest mean and maximum densities; Pond B had the lowest mean density while Pond C produced the lowest minimum density (Sissom et al. 1990).

Table 41. Crustacean macroinvertebrate density (log of total number per liter of pond water) for three ponds within PAIS (Sissom et al. 1990). The months that maximum and minimum values occurred are given in parentheses.

	Mean	Minimum	Maximum
Pond A	4.04	3.30 (Apr.)	4.33 (Sept.)
Pond B	3.45	3.04 (Oct.)	4.22 (Apr.)
Pond C	3.61	2.3 (Dec.)	4.21 (Apr.)

Species Diversity and Abundance

In the earliest study of macroinvertebrates in or near PAIS, Parker (1959) reported 19 live species in the Laguna Madre waters bordering the park: 12 bivalves, six gastropods, and one crustacean (see Table 36). Of the three environments sampled within the Laguna, the open hypersaline lagoon showed the highest diversity with 14 species, but macroinvertebrates were most abundant in the enclosed hypersaline lagoon, where the number of living individuals per sample "outnumbered all of the other individuals in the rest of the Laguna Madre" (Parker 1959, p. 2147).

In a study of an algal flat on the northern edge of PAIS, Withers (1993) documented 38 total taxa. Diversity was highest in the intertidal habitat (31 taxa) and lowest in damp habitats (15 taxa) (see Table 37). Withers (1996) recorded seven and 29 taxa on two tidal flats south of Malaquite Beach. The abundance of these organisms, ranging from rare (<3 per sample core) to abundant (>25 per sample core), were also reported (Table 42). The majority of taxa were classified as rare, while only one crustacean (*Hargeria rapax*) was considered abundant. Withers (1998) collected a total of 29 species at three tidal flats in the park. The algal flat at Yarborough Pass was most diverse with 25 species, while Mile Marker 45 and Dunn Ranch yielded 13 and 14 species respectively (see Table 37). According to Withers (1998), this may be because northerly Laguna Madre flats are generally more diverse, with diversity typically decreasing as distance from Aransas Pass (near Corpus Christi) increases. Some research suggests that species richness on tidal flats may increase with proximity to seagrass meadows (Withers 1994). Regarding macroinvertebrate abundance, Withers (1998) noted that mollusks appear to be more abundant in locations with little to no algal cover.

Table 42. Abundance of macroinvertebrate taxa recorded by Withers (1996) at two sites within PAIS. A = abundant (average >25/core when present), C = common (11-25/core when present), U = uncommon (3-10/core when present), R = rare (<3/core when present), * = found in only core during study.

Species	Texaco Site	Yarborough Pass
Phylum Nemertea		R
Phylum Annelida, Class Polychaeta		
Eteone heteropoda		R
Exogone dispar		R
Polydora spp.	R*	R
Prionospio heterobranchia		R
Prionospio pinnata		R
Nainereis laevigata		R
Demonax micropthalmus		R
Sabella sp. A		R
Haploscoloplos foliosus		U-R
Spio pettibonniae		R*
Streblospio benedicti		R*
Syllis cornuta		R*
Capitellidae		R*
Maldanidae		R*
Phylum Mollusca, Class Bivalvia		
Amygdalum papyrium		R
Anomalocardia auberiana		R
Tellina sp.		R*
Phylum Arthropoda		
Subphylum Crustacea		
Corophium acherusicum		R
Corophium louisanum		U-R
Gammarus mucronatus		R*
Hargeria rapax	R	A
Subphylum Hexapoda		
Berosus sp.	R	
Canaceidae	R	R*
Ceratopogonidae	R	R-C
Dolichopodidae	R	R
Ephydridae		R*
Melyridae		R
Nabidae	R*	R*
Phylum Platyhelminthes		
Turbellaria		R

In a study of the park's Gulf beaches, Rocha (1995) documented 40 total taxa from six phyla (see Table 38). Crustaceans were most diverse with 19 species, while polychaetes and mollusks contributed nine and six species respectively (Rocha 1995). Across all sample sites, subtidal zones supported the highest species diversity, as shown by Shannon's diversity index (H′) (Table 43). Crustaceans were also most abundant, comprising 41% of all individuals collected. Polychaetes made up 32% of individuals sampled and mollusks 25%. Cnidarians, nemerteans, and echinoderms were uncommon (Rocha 1995). The number of individuals of each species collected is presented in Table 38.

Table 43. Benthic macroinvertebrate species richness and diversity by beach zone (Rocha 1995). See Table 38 and Figure 20 for zone definitions and locations.

	Supratidal		**Intertidal**			**Subtidal**			
	UBS	**MBS**	**HS**	**MS**	**LS**	**T1**	**B1**	**T2**	**B2**
Number of species	7	5	15	18	21	28	27	26	24
Species diversity (H')	0.96	0.73	1.99	2.55	2.81	2.52	2.42	2.75	3.01

Sissom et al. (1990) identified just six species in a study of three inland ponds within the park, primarily crustaceans (Table 44). Only one mollusk, the razor clam (*Tagelus plebeius*), was found in just one of the three ponds, although the population there was large (Sissom et al. 1990).

Table 44. Macroinvertebrate species documented by Sissom et al. (1990) in three PAIS ponds.

Scientific name	**Common name**	**Pond A**	**Pond B**	**Pond C**
Mollusca				
Tagelus plebeius	razor clam			x
Crustacea				
Paleomonetes sp.	grass shrimp	x	x	x
Cladocera spp.	water fleas	x		
Ostracoda spp.	seed shrimp	x	x	x
Copepoda spp.	copepods	x	x	x
Nematoda	roundworms	x (Nov. & July)	x (April only)	x (April only)

<u>Threats and Stressor Factors</u>

Threats to the park's macroinvertebrates include vehicle disturbance on beaches and tidal flats, habitat loss (e.g., flooding on tidal flats), soil compaction, harmful algal blooms (e.g., red tide), hazardous material spills, and alterations of water quality and/or hydrology. Vehicles can compact soil and cause other habitat destruction on the sensitive beaches and tidal flats of PAIS. This can impact macroinvertebrate communities, as shown in Withers (1996), where fewer species were found in tire tracks than in restored and control areas. Habitat loss is also caused by inundation of tidal flats, likely due to sea level rise (Withers and Tunnell 1998). Tidal flats decreased in area in the Laguna Madre/Corpus Christi Bay region between the 1950s and 1980; most of the lost tidal flats were replaced by open water or seagrass beds (Withers and Tunnell 1998).

Macroinvertebrate populations are threatened by contaminants from oil and gas development and transport in and around PAIS (Rocha 1995, Withers 1996). For example, exposure to oil can cause mortality among bivalves, amphipods, and polychaetes (Withers and Tunnell 1998). Harmful algal blooms, such as red and brown tides, can also impact macroinvertebrates. The dinoflagellate in red tides produces a neurotoxin which can affect an animal's nervous system, potentially causing paralysis (NOAA 2012). Drastic declines in mollusk, echinoderm, crustacean, and polychaete populations have been noted in the Gulf of Mexico following red tides (Dupont and Coy 2008).

<u>Data Needs/Gaps</u>

According to Withers (1998, p. 32), short-term studies of benthic macroinvertebrate communities “tend to be inadequate for proper characterization.” The macroinvertebrate studies that have occurred in and near PAIS have typically provided single-year “snapshots” of the community at particular locations, which have not been revisited over time. Resampling the sites discussed in this assessment would provide insight into whether or not the macroinvertebrate community (diversity, density, etc.) has changed over time. Longer-term studies of several years would also provide a more detailed picture of the park’s macroinvertebrate populations. Additional data needs include further information on macroinvertebrate dispersal dynamics, colonization, and community succession (Withers and Tunnell 1998). Population recruitment should also be monitored over wider stretches of park shoreline (Stablein, written communication, 3 February 2013). This information would provide not only a better understanding of the macroinvertebrate community, but also the wildlife populations that rely on them as a food source.

<u>Overall Condition</u>

Distribution

The project team defined the *Significance Level* for distribution as a 3. While some macroinvertebrate distribution information is available for various locations within PAIS, studies have generally occurred for just one year and have not been repeated at these locations over time. In addition, all available data was collected over a decade ago. Therefore, it is not possible to determine if change is occurring or to assess current condition at this time. A *Condition Level* was not assigned.

Density

The density measure was assigned a *Significance Level* of 3. As with distribution information, data for this measure are limited and do not allow for condition assessment. As a result, a *Condition Level* could not be assigned.

Species Diversity and Abundance

The project team defined the *Significance Level* for this measure as a 3. While available data indicates some patterns in species diversity across various habitats within PAIS (Withers 1993, 1998, Rocha 1995), the lack of comparable data over time prevents an assessment of current condition and trend (*Condition Level* = n/a).

Weighted Condition Score

A *Weighted Condition Score* could not be calculated for macroinvertebrates at PAIS, as the current condition of all three measures is unknown.

Macroinvertebrates

Measures	SL	CL
• Distribution	3	n/a
• Density	3	n/a
• Species diversity & abundance	3	n/a

WCS = N/A

Sources of Expertise

Wade Stablein, Biological Technician, PAIS

Martha Segura, I & M Program Coordinator, GULN

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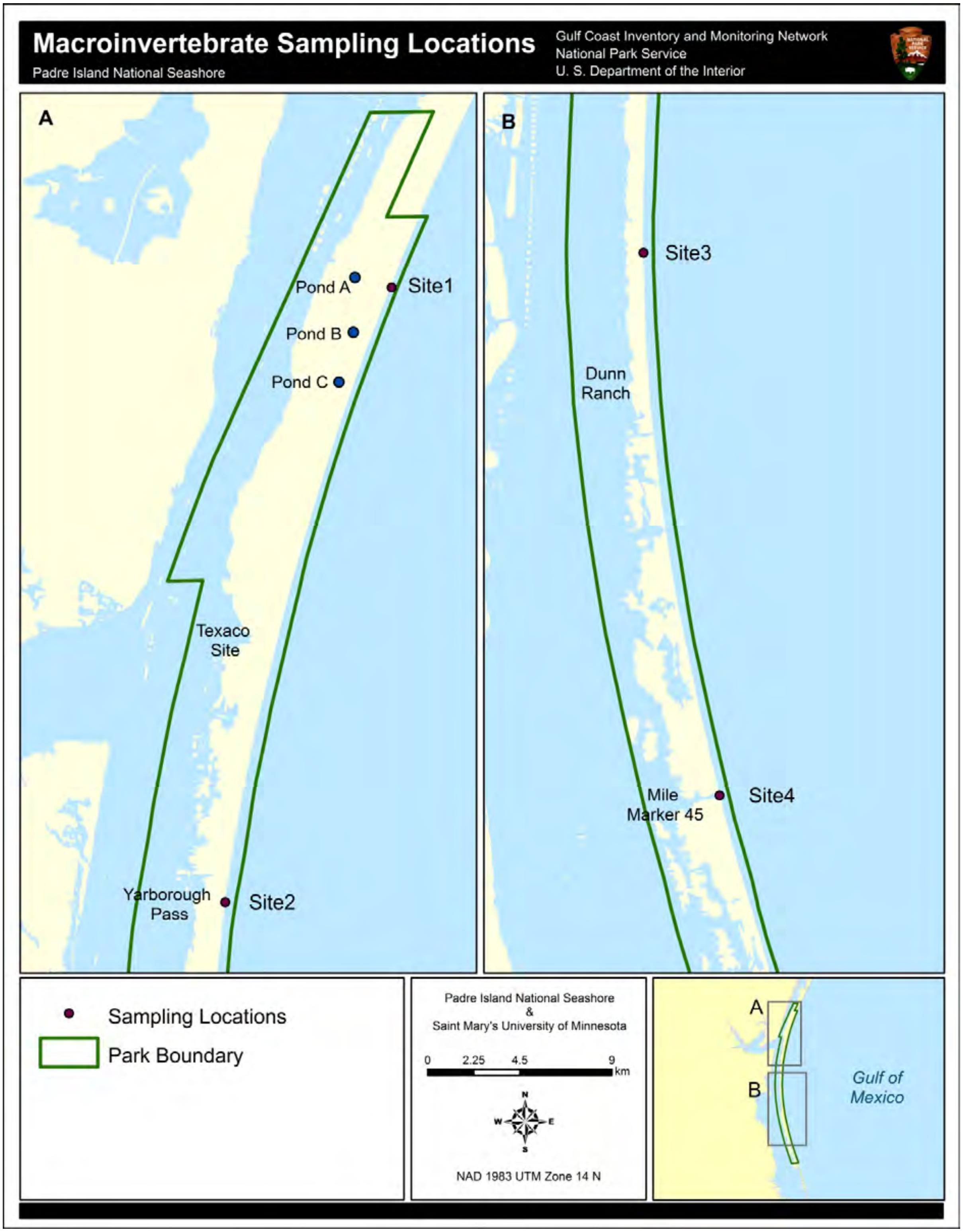


Plate 27. Transect locations for Rocha's (1995) Gulf beaches (Sites 1-4) and approximate locations of Withers' (1996,1998) tidal flats sites along the Laguna Madre. The approximate locations of ponds sampled by Sissom et al. (1990) are also shown.

4.11 Reptiles

Description

PAIS provides habitat for a variety of reptiles, including snakes, lizards, turtles, and alligators. Snakes are the most diverse reptile group in PAIS, with 15 species documented in the park. There have been six lizard species documented in PAIS, two of which are the documented non-native species in the park: the Mediterranean house gecko (*Hemidactylus turcicus*), and the six-lined racerunner (*Aspidoscelis sexlineatus*).

The park is also home to the American alligator (NPS 2012). Four turtle species are found in PAIS, including the federally endangered Kemp's Ridley sea turtle (*Lepidochelys kempi*). Chapter 4.14 provides a detailed discussion of the condition of sea turtles in PAIS. Reptiles play an important role in the food chain, as some species serve as both predator and prey species (ESI 2011). Reptiles may also play a role in seed dispersal and act as pollinators for various plant species (TPWD 2012).

Measures

- Species abundance and diversity
- Species distribution
- Reproductive success
- Sex ratio

Reference Conditions/Values

The ideal reference condition for reptiles in PAIS would be the condition of reptile populations on Padre Island prior to the intensive cattle ranching and grazing that began in the late 1880s and lasted until 1971. However, very little information is available from this historical period. The most comprehensive description of reptiles on the island comes from an inventory by Duran (2004). This description is used as the reference condition for this assessment.

Photo 18. Texas scarlet snake (*Cemophora coccinea lineri*) (Photo from Duran 2004).

Data and Methods

Duran (2004) conducted an inventory of reptiles and amphibians in PAIS between 2002 and 2003. Major sampling efforts were focused on 17 different sites across grassland, wetland, wetland-grasslands, sparse vegetation, and dune habitats. Trapping methods included funnel-type minnow traps and drift-fence arrays; other inventory methods were visual encounters, auditory surveys, and road surveys. Many of the observations are linked with GPS points to get a general distribution in PAIS. During interpretation of Duran's (2004) data, SMUMN GSS combined the western (*Sistrurus catenatus tergeminus*) and desert massasauga (*S. c. edwardsii*) observations. For this assessment, these species are identified as 'massasauga.'

Current Condition and Trend

Species Abundance and Diversity

Duran (2004) observed 22 species in PAIS, three of which were non-native or introduced: the six-lined racerunner, Mediterranean house gecko, and the American Alligator. This inventory excluded sea turtles due to an ongoing sea turtle monitoring program within the park (Duran 2004). NPS (2012b) listed a total of 25 species of reptiles present in PAIS, including snakes, lizards, turtles, tortoises, and alligators (Table 45). This list does not include one species mentioned by Duran (2004), the Texas indigo snake (*Drymarchon corais erebennus*); this species was noted as an unusual historical museum specimen and was not observed in the park during inventory. Duran (2004) noted the possible occurrence of two other species that were not observed during the study: the lined snake (*Tropidoclonion lineatum*) and the southern earless lizard (*Holbrookia lacerata subcaudalis*). These two species are documented by museum vouchers that indicate their presence in PAIS.

Table 45. Reptiles found in PAIS as documented by NPS (2012b). Bolded species were documented in the 2003 herpetological inventory (Duran 2004).

Scientific Name	Common Name
Agkistrodon piscivorus leucostoma	western cottonmouth
Alligator mississippiensis	American alligator
Arizona elegans arenicola	Texas glossy snake
Aspidoscelis sexlineatus	six-lined racerunner
Caretta caretta	loggerhead sea turtle
Cemophora coccinea lineri	Texas scarlet snake
Chelydra serpentina serpentina	common snapping turtle
Coluber constrictor oaxaca	Mexican racer
Crotalus atrox	western diamondback rattlesnake
Elaphe emoryi	Great Plains rat snake
Eumeces obsoletus	Great Plains skink
Hemidactylus turcicus	Mediterranean house gecko
Heterodon platirhinos	eastern hognose snake
Holbrookia propinqua propinqua	keeled earless lizard
Lampropeltis triangulum annulata	Mexican milksnake
Lepidochelys kempi	Kemps Ridley sea turtle
Masticophis flagellum testaceus	western coachwhip
Nerodia rhombifer	diamondback water snake
Ophisaurus attenuatus	western slender glass lizard
Scincella lateralis	ground skink
Sistrurus catenatus	massasauga
Tantilla gracilis	flathead snake
Thamnophis marcianus marcianus	checkered garter snake
Thamnophis proximus orarius	Gulf Coast ribbon snake
Trachemys scripta elegans	red-eared slider

Duran (2004) noted the keeled earless lizard (*Holbrookia propinqua propinqua*) as the most common reptile species in PAIS; this species has a Natural Heritage vulnerability status in the state (Cooper et al. 2005). Duran (2004) identified the western slender glass lizard (*Ophisaurus attenuatus*), western coachwhip (*Masticophis flagellum testaceus*), and the six-lined racerunner as common species in the park. Several species observed during the survey are dependent on the permanent ponds on the northern side of PAIS, including the red-eared slider (*Trachemys scripta elegans*), diamondback water snake (*Nerodia rhombifer*), checkered garter snake (*Thamnophis marcianus*), and the Gulf coast ribbon snake. The Texas scarlet snake was observed once during this survey, which was the first sighting of the species in PAIS; this snake is a state endangered species that has only been reported 10 times in its natural range (Duran 2004). Duran (2004) also identified the western diamondback rattlesnake as a potential conservation concern for PAIS due to few instances of live individuals observed and the number of dead individuals observed.

Photo 19. Keeled earless lizard (Photo from Duran 2004).

Species Distribution

Duran (2004) provides species distributions for 21 reptiles found in PAIS; a distribution was not provided for the Texas glossy snake. While the distribution was not defined for this species, Duran (2004) noted that grasslands are a documented habitat for the Texas glossy snake.

The identified distributions of the 21 species in Duran (2004) varied. Some reptile species were found throughout the park, including the six-lined racerunner, western coachwhip, and keeled earless lizard. The western diamondback rattlesnake was uncommon during the inventory, but observations spanned both the northern and southern borders of the park. Two species were only trapped in trap 10, located in the middle of PAIS (see Plate 28). These species were the eastern hognose snake (*Heterodon platirhinos*) and the Texas scarlet snake. The Texas indigo snake, a species not observed during the inventory, was documented in 1985 near the Malaquite visitor center on the northern end of the seashore (Duran 2004). The Mexican racer (*Coluber constrictor oaxaca*) was only observed north of the park entrance in dune habitat.

Duran (2004) found a majority of the reptile species were distributed throughout the northern half of the park. An American alligator was observed by the waste water treatment facility, which is located at the northern end of PAIS. Duran (2004) believed it must have been released near the area because PAIS is not native habitat for this species. Jim Lindsay (Pers. Comm.) clarified the alligator washed up on the beach in PAIS after a major storm and was placed in Pond C. It later moved to the sewage treatment pond and grew quite large. Thus, around 2007, it was captured and given to the zoo in San Antonio. Some reptiles are distributed in the northern half of the park due to dependence on permanent freshwater ponds, such as the red-eared slider, diamondback water snake, checkered garter snake, massasauga (*Sistrurus catenatus*), and gulf coast ribbon snake. The Mediterranean gecko was mostly observed on buildings including the ranger station and visitor center. The flathead snake (*Tantilla gracilis*), ground skink (*Scincella lateralis*), Mexican milk snake (*Lampropeltis triangulum annulata*), Great Plains rat snake (*Pantherophis emoryi*), Great Plains skink (*Eumeces obsoletus*), and western slender glass lizard were found in traps in the northern half of the park. The Great Plains skink was also found in trap 17 at the southern end of the park.

<u>Reproductive Success</u>
Currently, no data are available that characterize the reproductive success of reptiles in PAIS.

<u>Sex Ratio</u>
Currently, no data are available that characterize sex ratio in PAIS reptile populations.

<u>Threats and Stressor Factors</u>
PAIS staff identified a number of threats to reptiles in the park, including flooding and salt-water inundation of wetlands and ponds, erosion, human disturbance, vehicle strikes, hazardous materials such as chemical spills (hazmat), extended drought, predation, habitat loss, disease, and oil and gas development.

Many threats and stressors to reptiles in the park can be categorized as anthropogenic. Park infrastructure and development increases the incidence of vehicle strikes on roads and leads to fragmentation or loss of habitat (NPS 2001). Reptiles may also be struck by vehicles traveling along the beaches or along the gravel roads that run through the grasslands and mudflat areas of the park. Oil and gas development within the park may result in additional habitat loss. Explosive charges detonated during gas exploration and drilling efforts may cause injury or death to burrowing reptiles (NPS 2001). The risk of chemical spills also increases in areas with oil and gas development.

The Gulf of Mexico currents continually carry and deposit marine debris and trash onto the PAIS beaches. Sources of this trash include the shrimping industry, offshore oil platforms, and debris from storm activity (Cappiello 2003). According to a nationwide survey in 1993, PAIS had more trash than any other NPS unit along the U.S. coast (Cappiello 2003). Along with that distinction, PAIS is also the only NPS unit to have its own hazmat team (Cappiello 2003). The debris and pollution on land and in the water can result in suffocation, sickening, or strangulation of reptiles.

Very few reptile species are salt tolerant. Most reptiles cannot survive in seawater, so saltwater inundation of wetlands and ponds in PAIS can be a substantial stressor (Karraker 2007). Reptiles inhabiting the southern seashore may be at a higher risk than those on the northern seashore of PAIS due to the relative sea level rise and erosion rates occurring in the southern end of the park. According to White et al. (2007), the southern seashore has been eroding at a rate of 1.2 to 2.4 m/year (3.0 to 7.9 ft/year). White et al. (2007) also stated that between 1949 and 1999, the relative sea level had risen at a rate of 3.38 mm/year.

Natural stressors for reptiles include drought, predation, and disease. Reptiles use ponds to remain cool when temperatures become too hot. Some species of reptiles are more dependent on ephemeral and permanent ponds, and may become stressed during drought periods. Reptiles that persist in PAIS seem better adapted to such conditions, yet are still susceptible during extended periods of drought.

Although disease in the reptile population has not been investigated in depth in PAIS, diseases could pose a significant threat to the park population of reptiles should they spread through the region. Ranavirus infections are known to impact amphibian populations by causing death in larvae or recently metamorphosed individuals in the park (Stablein, written communication, 22 October 2012); diseases affecting reptiles have not been researched or documented in PAIS to date.

<u>Data Needs/Gaps</u>
Very little information is available that characterizes reptile population parameters in PAIS. Duran (2004) describes only the abundance and diversity of species observed. Additionally, this survey is nearly a decade old. Current and long-term annual or biannual monitoring efforts would provide information necessary to determine trends in population sizes or diversity, reproductive success, and population structure (sex ratio). Prevalence of disease in reptiles in the park is not well understood. Periodic monitoring for detection of disease would help managers understand possible threats to populations in the park. Annual monitoring of the populations in the park will allow for a more accurate assessment of population condition.

<u>Overall Condition</u>
A number of species of snakes, lizards, and turtles have been documented in PAIS; however, there is no established annual herpetological monitoring in the park, and very little information characterizing reptile populations is currently available. While the NPS has a record of confirmed species in the park, this list does not allow for estimates of abundance, reproductive success, or other population parameters. Thus, it is not possible to assess the condition of reptiles in PAIS at this time.

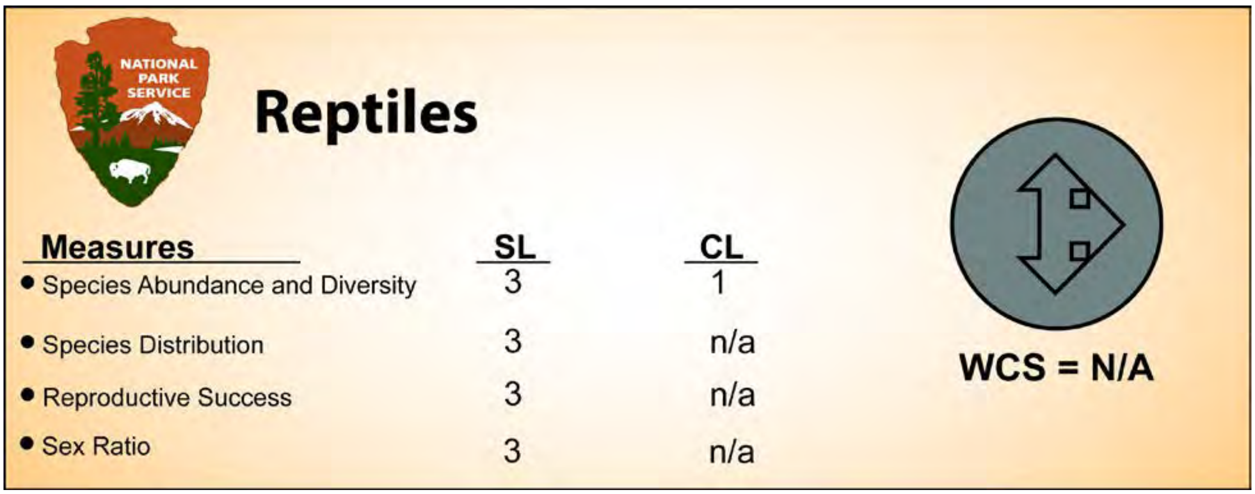
Species Abundance and Diversity
The project team defined the *Significance Level* for species abundance and diversity as a 3. Duran (2004) documented 22 species of reptiles in PAIS, some of which were more common or abundant than others (such as the keeled earless lizard and western coachwhip). Because a historical reptile inventory of PAIS does not exist, it is not possible to determine how diversity and abundance of reptile species may have changed over time. Several species present in the park are considered to be of conservation concern due to rarity or restriction of range. As a result, the measure was assigned a *Condition Level* of 1 or of low concern.

Species Distribution
The project team defined the *Significance Level* for species distribution as a 3. Limited data are available that characterize reptile species distributions in PAIS. Therefore, it is not possible to assign a *Condition Level* for this measure.

Reproductive Success
The project team defined the *Significance Level* for reproductive success as a 3. There are no available data characterizing the reproductive success of reptiles in PAIS. Because of this data gap, a *Condition Level* for this measure was not assigned.

Sex Ratio
The project team defined the *Significance Level* for sex ratio as a 3. There are no available data characterizing the sex ratio of reptiles in PAIS. Because of this data gap, a *Condition Level* for this measure was not assigned.

Weighted Condition Score
A *Weighted Condition Score* for reptiles in PAIS was not assigned because >50% of the measures had unknown *Condition Levels*.



Sources of Expertise
Wade Stablein, Biological Technician, PAIS

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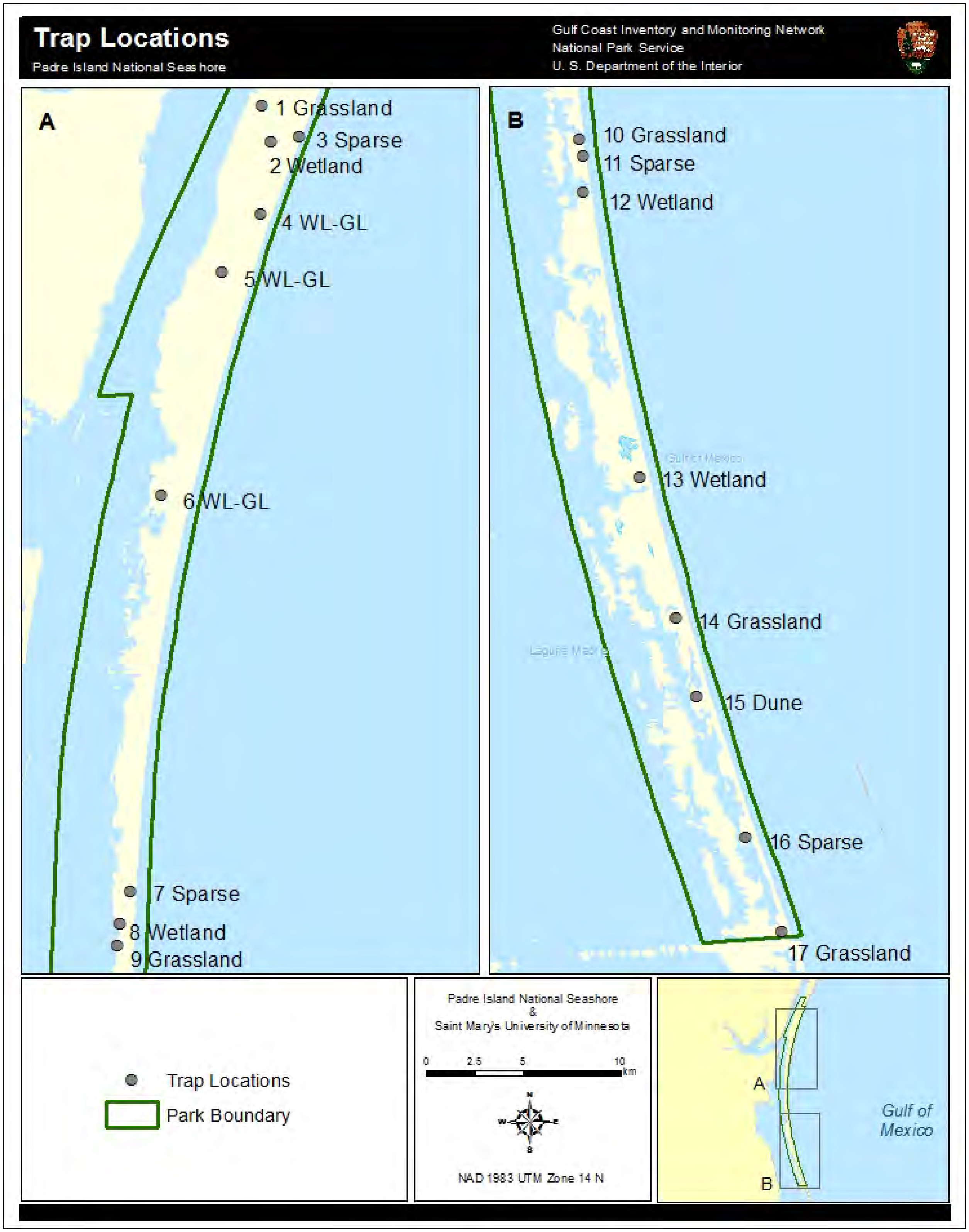

Plate 28. Trap locations used during 2002-2003 inventory of reptiles and amphibians in PAIS (Duran 2004).

4.12 Sea Turtles

Description

Five species of sea turtles have been documented nesting at PAIS: the leatherback (*Dermochelys coriacea*), green (*Chelonia mydas*), Kemp's ridley (Photo 20), hawksbill (*Eretmochelys imbricata*), and loggerhead (*Caretta caretta*). All of these species are federally listed as either threatened or endangered (NPS 2012). Additionally, PAIS waters provide important marine habitat for these species. Nearshore waters of the Gulf of Mexico in and adjacent to the park are used by various life stages and species for dispersal, foraging, and migration. Waters of the Mansfield Channel are used by various species to travel between the Gulf of Mexico and the Laguna Madre, and by juvenile green and hawksbill turtles for foraging and resting. Waters of the Laguna Madre are also used for foraging, primarily by juvenile green turtles.

Photo 20. Kemp's ridley sea turtle (NPS photo).

Sea turtles are considered keystone species, meaning the species plays a critical role in ecological community structure and its impact is greater than expected based on relative abundance or biomass (Mills et al. 1993). Sea turtles also help maintain marine ecosystems. For instance, green sea turtles graze on seagrass, which prevents overgrowth and increases seagrass productivity (Wilson et al. 2010). Hawksbill sea turtles feed on marine sponges, which normally out-compete coral species, and thus allow new coral species to colonize and grow (Wilson et al. 2010). Leatherback sea turtles consume large amounts of jellyfish daily, which helps regulate jellyfish populations. Loggerhead sea turtles prey on crustaceans; their feeding behavior of crushing and consuming the crustaceans' shells helps increase nutrient recycling on the ocean bottom (Wilson et al. 2010).

The Kemp's ridley sea turtle is the smallest species of sea turtle that inhabits the Gulf of Mexico, and is the most critically endangered sea turtle species in the world (NMFS, USFWS, and SEMARNAT 2011). Nearly all nesting is limited to beaches on the western coast of the Gulf of Mexico, with the majority of nests occurring in Tamaulipas and Veracruz, Mexico (NMFS, USFWS, and SEMARNAT 2011). Nesting also occurs regularly along coastal Texas, particularly along Padre Island and including PAIS (NMFS, USFWS, and SEMARNAT 2011). Kemp's ridley nests comprise a majority of the documented sea turtle nests within the park, and PAIS supports more Kemp's ridley nests than any other single location in the United States (Shaver 1999, 2005a). Populations sharply declined in the Gulf of Mexico in the mid-1900s, primarily due to overharvesting of adults for meat and leather by commercial fishers and harvesting of eggs believed to be an aphrodisiac; incidental capture in fishing and shrimping nets is also believed to have caused impacts to populations (Shaver 1987, Caillouet et al. 1996).

Reintroduction and monitoring efforts along the Gulf beach of Padre Island National Seashore (Imprinting and Headstarting program) started in 1978 (Shaver 2005a). Each summer from 1978-1988, a collection of Kemp's ridley eggs from Rancho Nuevo, Tamaulipas, Mexico, where the majority of Kemp's ridley turtles have historically nested, were transported to the incubation facility in PAIS in an effort to bolster population numbers and form a secondary breeding colony of this native species there (Shaver 1987, 1990, 1992a, 2005a, b).

Measures

- Number of nests per year
- Number of hatchlings released per year
- Diversity

Reference Conditions/Values

The reference conditions for the sea turtles in PAIS are the established management objectives for nesting success and population growth within park boundaries for each species of sea turtle present in the park. The objectives established by the U.S. National Marine Fisheries Service (NMFS) and USFWS recovery plans for each species provide context on the overall goals for species recovery and population growth along the Gulf coast. These plans are used to understand potential reference conditions or target management objectives for each species present and nesting within PAIS.

<u>Kemp's Ridley Sea Turtle</u>

The NMFS, USFWS, and SEMARNAT (2011) bi-national recovery plan for the Kemp's ridley sea turtle describes the beaches along the Texas coast as the second most vitally important nesting grounds for this species behind the beaches of the Tampaulipas and Veracruz region in Mexico. Kemp's ridley nesting has increased in Mexico since the mid-1980s and in Texas since the mid-1990s. The Kemp's Ridley Recovery Plan reported that the number of nests found was increasing at 12-18% per year and projected that this rate of increase would continue for the next several years (NMFS, USFWS, and SEMARNAT 2011). However, the numbers of nests found both in Mexico and Texas plateaued from 2009-2013 and fell short of those projections from 2010-2013. About 55-65% of Kemp's ridley nests found in Texas are located on North Padre Island, and about 50-55% of all Kemp's ridley nests in the U.S. are located on beaches within PAIS (NMFS, USFWS, and SEMERNAT 2011).

Park waters are also used by Kemp's ridleys of various life stages. Since 1980, sea turtles found stranded (i.e., washed ashore or floating sick, weakened, or dead) at PAIS have been documented by PAIS staff and volunteers in conjunction with the national Sea Turtle Stranding and Salvage Network (STSSN) (Shaver 1998, 1999). Incidental capture in shrimp trawls has been a threat to sea turtles in Texas waters (Caillouet et al. 1996, Shaver 2005a) and the seasonal closure of nearshore Gulf of Mexico waters in and adjacent to the park (out to 5 nautical miles) established by TPWD has aided with conservation efforts in south Texas (Lewison et al. 2003). Nearshore Gulf of Mexico waters provide vital habitat for adult female and male Kemp's ridley turtles during the nesting season and during migration between foraging areas in the northern Gulf of Mexico and nesting areas in Texas and Mexico (Shaver et al. 2005, 2013; Shaver and Rubio

2008). The only observation of Kemp's ridleys mating in Texas waters was in the Mansfield Channel (Shaver 1992b).

Management of the Kemp's ridley sea turtle population in PAIS is a high priority because of its secondary breeding colony status. Objectives for the population in the park are based on the number of nests located and protected each year and number of hatchlings successfully incubated and released each year. The target management action is to continue to protect nests and release hatchlings to contribute to the recovery of the species, so that hopefully someday it can be removed from the threatened and endangered species list.

Green Sea Turtle

Green sea turtles are a global species with nesting and foraging grounds found all over the world. South Texas coastal waters provide important foraging habitat for this species, particularly for juveniles (Shaver 1994, 2000). In fact, the Laguna Madre and South Texas jetty systems (including the Mansfield Channel at PAIS) are among the most important developmental habitats for juvenile green turtles in the western Gulf of Mexico (Shaver 1994, 2000). Based on increases in observations of green turtles swimming in park waters and stranding on park beaches, it is apparent that the green turtle population has increased dramatically in south Texas in recent years (Shaver 2000, 2012, 2013). Although most nesting grounds for the Atlantic population of green sea turtles are located in Florida, Mexico, and Central and South America, PAIS and South Padre Island have documented several nests since the first recorded nest at PAIS in 1987 (Shaver 1989, 2012, 2013). From 2002-2013, between one and 13 nests have been confirmed in PAIS each year, but some nests may have been missed due to nesting later in the season after main nest patrolling efforts were concluded (Shaver 2012, 2013; Donna Shaver, Chief, Division of Sea Turtle Science and Recovery, PAIS, email communication, 23 August 2013). The number of juveniles found in Texas waters far exceeds the production of hatchlings from Texas beaches; the likely origin for juveniles inhabiting Texas waters is Mexico, Florida, or the Caribbean (Anderson et al. 2013). The reference condition for green sea turtles in PAIS is a management target of maintaining each season the average number of nests confirmed in the park over the last decade.

Loggerhead Sea Turtle

Loggerhead sea turtles nest from Texas to as far north as Virginia on the east coast of the U.S., with the vast majority of nesting occurring on the Florida coast (NMFS and USFWS 2008). Several loggerhead nests are found on PAIS beaches most years, and over the last 10 years the number of nests documented has ranged from 0-12 nests per year (Shaver 2012, 2013; Shaver, email communication, 23 August 2013). Some nests may go undetected due to nesting season extending past the main nest patrolling season. Various life stages of loggerheads have been documented stranded at PAIS and use nearshore Gulf of Mexico waters inside and adjacent to the park (Shaver 1998, 1999; Bjorndal et al. 2001, Bowen et al. 2004). The reference condition for loggerhead sea turtles in PAIS is a management target of maintaining each season the average number of nests confirmed in the park over the last decade.

Leatherback Sea Turtle

Leatherback sea turtles are found worldwide, but their primary nesting grounds in the Atlantic Ocean are located mainly in the Caribbean and northern coast of South America, although some nests have been documented in Florida and the Gulf of Mexico coastline in Mexico (NMFS and

USFWS 1992). Leatherback nests have only been confirmed in Texas at PAIS. In 2008, a leatherback nest was documented at PAIS (Shaver 2009); this nest represents the only time the species has been recorded nesting in the state since the 1930s (NPS 2013b; Shaver, email communication, 23 August 2013). Thus, the reference condition for leatherback turtles in PAIS is occasional sightings of adults and infrequent or rare incidence of nesting in the park.

<u>Hawksbill Sea Turtle</u>

Hawksbill sea turtles are found primarily in the Gulf of Mexico and the Caribbean. Primary nesting locations in the U.S. include Puerto Rico, the Virgin Islands, and the coast of Florida (NMFS and USFWS 1993). The first hawksbill turtle nest recorded on the Texas coast was documented at PAIS in 1998 (Shaver 1999b) and it remains the only documented hawksbill nest on Texas coastline (NPS 2013a). Their occurrence at PAIS is infrequent with only one documented case of nesting. However, park waters of the Gulf of Mexico and Mansfield Channel are used by juvenile hawksbill turtles and observations of stranded or captured individuals are noted when they occur (Shaver 1999b, 1999c, 2000; Bowen et al. 2007). Thus, the reference condition for hawksbill turtles in PAIS is occasional sightings of individuals and rare incidence of nesting in the park.

Data and Methods

Shaver (2013) summarizes data on recorded Kemp's ridley sea turtle nests located along the Texas Coast from 1978 to 2012, which is based on the monitoring efforts of Dr. Donna Shaver at the Sea Turtle Recovery Project at PAIS. Eggs from most confirmed nests from North Padre Island northward on the Texas coast are transported to an incubation facility in PAIS, where they are hatched. Eggs from some nests found at the southern end of PAIS are transported to large screen enclosures called corrals. Hatchlings from the incubation facility and corrals are released on the beach at PAIS and allowed to crawl into the Gulf of Mexico and go free. The nesting records include year observed, number of nests, number of eggs, and number of hatchlings released.

Annual turtle nesting and stranding reports are produced as part of an on-going incubating and nesting monitoring program at PAIS (Shaver 2005a, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013). These reports detail the efforts of several organizations and participants, including NPS, USFWS, Animal Rehabilitation Keep (ARK) in Port Aransas, TX, Sea Turtle, Inc., Texas A&M University at Galveston, TPWD, STSSN, and others. During the main sea turtle nesting season (April to mid-July), these groups patrol Gulf of Mexico beaches in search of nesting Kemp's ridley turtles and sea turtle nests. Several thousand kilometers of beach along the Texas coast are patrolled each year as part of this effort. Nests are also found as a result of reports from others working on the beach or the public. Patrollers identify species, locate and examine nests, relocate eggs from a majority of nests to an incubation facility or corral, and document any turtle strandings during each season. Hatchlings are also released from the incubation facility and corrals and their releases are documented. Sea turtle strandings occur year-round. Stranded sea turtles are located during nesting patrols, while PAIS staff members and volunteers conduct other functions on the beach, and in response to reports from visitors.

Current Condition and Trend

Number of Nests

Shaver (2013) reports a total of 1,384 Kemp's ridley sea turtle nests were documented between 1996 and 2012. Patrolling for nests and protection efforts began at PAIS in 1986, but were limited for the first decade (NMFS, USFWS, and SEMARNAT 2011). Patrolling and protection efforts began on other Texas beaches south of PAIS in 1999, and began north of North Padre Island in following years. This limited patrol coverage may be a reason for the small number of nests that were found and reported before patrols became comprehensive. The number of nests increased significantly between 1996 and 2012. Table 46 displays the number of Kemp's ridley nests found on the Texas coast; most of these nests were taken to the incubation facility or corrals in Texas for protection from predation and other threats.

Table 46. Number of Kemp's ridley sea turtle nests located along the Texas coast, 1996-2012 (Shaver 2013).

Year	Number of Nests
1996	6
1997	9
1998	13
1999	16
2000	12
2001	8
2002	38
2003	19
2004	42
2005	50
2006	102
2007	128
2008	195
2009	197
2010	141
2011	199
2012	208

Annual reports by Shaver (2005-2013) summarize data on the number of confirmed turtle nests recorded across several years of patrolling along the Texas coast. Four sea turtle species were observed throughout the last nine years (2004-2012) of patrolling efforts, including Kemp's ridley, green, loggerhead, and leatherback sea turtles. Table 47 displays the reported nest numbers for three of the four turtle species documented along the Texas coast and within PAIS. The total number of Kemp's ridley nests has increased from 2004-2012, with the exception of 2010. NMFS, USFWS, and SEMARNAT (2011), the bi-national recovery plan for the Kemp's ridley sea turtle, reports a total of 911 Kemp's ridley nests documented along the Texas coast from 2002 and 2010. There were several green and loggerhead sea turtle nests during the years of reports. NMFS and USFWS (2008) reports an average of 906 loggerhead nests documented in the northern Gulf of Mexico recovery unit between 1995 and 2004, an area that includes the Texas coast and PAIS beaches; however, very few of these are confirmed in Texas or PAIS annually.

Table 47. The total number of Kemp's ridley, green, and loggerhead sea turtle nests confirmed in PAIS and along the Texas coast, 2004-2012 (Shaver 2012, 2013).

	Kemp's ridley		Green		Loggerhead	
Report Year	**In PAIS**	**Total Texas**	**In PAIS**	**Total Texas**	**In PAIS**	**Total Texas**
2004	22	42	1	1	1	1
2005	27	50	4	4	2	3
2006	64	102	2	2	1	2
2007	73	128	2	3	4	6
2008	93	195	4	5	1	3
2009	117	197	1	1	0	0
2010	74	141	5	5	9	9
2011	117	199	6	3	0	0
2012	106	209	6	8	1	5

NPS (2013a) also summarizes hawksbill nesting activity along the Texas coast based on a report by Shaver (1999b). The first hawksbill nest to be reported and confirmed in PAIS occurred in 1998 (Shaver 1999b); since then, no hawksbill nests have been confirmed in Texas (NPS 2013a). Only one confirmed leatherback turtle nest has been confirmed along the Texas coast in recent years, which was documented in PAIS in 2008 (Shaver 2009).

Number of Hatchlings Released

Annual reports by Shaver (2005-2013) summarize data on the total number of turtle eggs collected along the Texas coast and hatchlings reared and released from the incubation facility at PAIS and corrals in Texas from 2004-2012 (Note that reports are authored the year following the calendar year of survey efforts). Table 48 displays the total number of eggs collected and hatchlings released for three turtle species observed during the 2004-2012 monitoring seasons. A total of 118,916 Kemp's ridley eggs were recorded in nests along the Texas coast and 99,746 hatchlings were released from the PAIS incubation facility and corrals in Texas between 2004 and 2012. A few eggs are found broken each year during egg collection and are not transported for incubation; the broken eggs are included in the annual totals. Likewise, a total of 3,985 green sea turtle eggs were recorded, from which 3,076 hatchlings were successfully released. Finally, a total of 3,211 loggerhead eggs were recorded, with 2,525 hatchlings successfully released into the Gulf of Mexico. In 2008, one leatherback nest was recorded; however, none of the six eggs hatched.

Table 48. The total number of Kemp's ridley, green, and loggerhead sea turtle eggs recorded in nests that were collected and taken to the PAIS incubation facility or Texas corrals and total number of hatchlings released to the Gulf of Mexico, 2004-2012 (Shaver 2005-2013). This includes the few eggs found broken upon collection of nests.

	Kemp's ridley		Green		Loggerhead	
Report Year	Total Number of Eggs	Total Released	Total Number of Eggs	Total Released	Total Number of Eggs	Total Released
2004	3,928	3,298	113	105	90	88
2005	4,700	3,402	428	380	221	117
2006	9,717	7,475	300	189	263	190
2007	12,565	10,594	341	298	638	579
2008	17,933	15,819	547	496	367	333
2009	17,518	14,506	137	130	0	0
2010	13,584	11,983	642	529	1,070	881
2011	18,904	16,092	613	499	0	0
2012	20,067	16,577	864	450	562	337

Based on Shaver (1999b), NPS (2013a) summarized data on the number of hawksbill turtle eggs collected and hatchlings released from PAIS. The one hawksbill nest recorded at PAIS in 1998 contained 140 eggs, of which 132 hatchlings were released into the Gulf of Mexico.

Diversity and Distribution

Nests and stranded individuals of all five species have been confirmed at PAIS since 1998 (Shaver 1989, 1994, 1998, 1999b, 1999c, 2000, 2005a, 2005b, 2006-2013; Shaver and Rubio 2008; Shaver et al. 2013). Park beaches are used for nesting and park waters are used for dispersal, foraging, and migration.

Shaver serves as Texas Coordinator of the STSSN and her annual reports summarize stranded sea turtles and sea turtle nests recorded in Texas. In these reports, distribution is not specifically stated for PAIS, apart from whether the nests were observed within PAIS or at some other location along the Texas Coast. However, distribution of stranded sea turtles has been recorded in conjunction with the STSSN since 1980; data are aggregated by Shrimp Statistical Zone and posted on the NOAA website (http://www.sefsc.noaa.gov/species/turtles/strandings.htm). Locations of sea turtle nests found at PAIS have been recorded since the mid-1980s. Distribution data for green and Kemp's ridley turtles have also been recorded through satellite tracking (Shaver 2000, Shaver and Rubio 2008, Shaver et al. 2013).

Kemp's ridley and green turtles are the most numerous and widespread species at the park, whereas the leatherback is the least numerous and widespread. Nesting by Kemp's ridley and loggerhead turtles occurs along the entire Gulf of Mexico beachfront. In contrast, nesting by green and leatherback turtles is concentrated on Big Shell and Little Shell beaches. Strandings of all five species occur along the entire Gulf of Mexico beachfront of PAIS. The green turtle is the most numerous species in the Laguna Madre and Mansfield Channel, but occasionally the other four species are found there too.

According to NMFS and USFWS (1992), there were 77 hawksbill turtle observations along the Texas coast between 1972 and 1984; however, it is not indicated whether any of these observations were specific to PAIS. These were likely stranded individuals. Hawksbills are found stranded at PAIS annually, and a large portion of those 77 were likely from PAIS. Most of the hawksbills stranded at PAIS are juveniles. Juvenile hawksbills were also captured during directed capture netting conducted at the Mansfield Channel during the 1990s (Shaver 2000). Only one hawksbill has been recorded nesting in PAIS, which occurred in 1998 (Shaver 1999b, as summarized by NPS 2013a). There have been no documented observations of this species nesting before or after this time.

<u>Threats and Stressor Factors</u>
There are several threats to sea turtles in the park. PAIS park staff members have identified seven anthropogenic and four natural threats that have occurred or are presently occurring in the park: beach driving, boat traffic, oil spills, dredging, poaching, commercial and recreational fishing, marine debris, extreme weather events, harmful algal blooms, predation, and disease.

A majority of the threats to sea turtles in the park are anthropogenic. Marine debris is a serious threat to sea turtles in PAIS. Sea turtles can become entangled, ingest debris, and be smothered by floating and non-floating debris (Plotkin and Amos 1990, NOAA 2006). Entanglements have been reported for all five species found in or near PAIS (Plotkin and Amos 1990). Photo 21 illustrates how entanglement could decrease turtle mobility. Some sea turtle species (e.g., loggerhead, leatherback) may be more vulnerable to debris ingestion because marine debris may resemble their natural prey (Tomas et al. 2002). For example, floating plastic bags may be mistaken for jellyfish (a prey species), which results in many mortalities caused by the ingestion of or suffocation with plastic. However, Kemp's ridley, green, and hawksbill turtles, especially small individuals, also consume marine debris (Shaver 1991, Shaver and Plotkin 1998). Commercial and recreational fishermen are largely responsible for discarding marine debris and accidentally snagging and drowning turtles in shrimp nets (Plotkin and Amos 1990). Beach driving is another anthropogenic threat to sea turtles. In Texas outside of PAIS, adult loggerhead and Kemp's ridley turtles have been crushed and killed by passing vehicles, as have hatchling Kemp's ridleys that were on their way to the sea (Shaver, email communication, 23 August 2013). Oil spills are also a threat to sea turtles. These spills can affect turtles at every stage of life, but tend to be more damaging at earlier life stages (Milton et al. 2003). According to Milton et al. (2003), petroleum hydrocarbons bind to lipids, which occur in high concentrations in young turtles. If oil contamination reaches a nest and alters the gas exchange, nest temperature, and sand moisture, it will cause an increase in mortality of the embryos (Milton et al. 2003). If oil reaches foraging grounds turtles can ingest the oil incidentally when aiming to consume flora or fauna there. Oil spills can also suffocate seagrass and other benthic organisms, which are important food sources for sea turtles (NMFS and USFWS 1991). According to NMFS and USFWS (1991), a 3-month hopper dredging operation

Photo 21. Hawksbill sea turtle entangled in rope (NPS photo).

is to blame for the mortality of about 100 green sea turtles. Water recreation, in particular boating, is a common threat to sea turtles, and coastal development may increase boat traffic near PAIS. Injuries caused by propellers or colliding with boats may result in the stranding and death of sea turtles. According to NMFS and USFWS (1991), there were 111, 175, and 179 stranded turtles with propeller or collision injuries each year from 1986 to 1988 in the Gulf of Mexico. Those numbers accounted for less than 10% of the total number of stranded turtles documented in the Gulf of Mexico and Atlantic (NMFS and USFWS 1991). Poaching is a potential threat to sea turtles in PAIS. It is illegal to harvest eggs as well as juvenile and adult sea turtles from U.S. beaches and waters, but harvesting still occurs (NMFS and USFWS 1991, 1992, 1993, 2008; NMFS, USFWS, and SEMARNAT 2011). In the past, some sea turtle species were popular items in culinary dishes (NMFS and USFWS 1991). Between 1983 and 1989, 28 arrests were made for possession of whole turtles and turtle parts (NMFS and USFWS 1991).

The natural threats to sea turtles include extreme weather events, harmful algal blooms, predation, and disease. Every few years, severe cold fronts affect south Texas and cause hypothermic stunning of green turtles, primarily in south Texas bays and passes (Shaver 2000). Hypothermic stunning during these periods of freezing air temperatures is the most significant threat to green turtles in Texas waters (Shaver 2000). If green turtles are not quickly found during these events and transported to rehabilitation facilities, they will succumb due to exposure or predation. These hypothermic stunning events can involve hundreds of green turtles found at the park, many of which are located alive. Pike and Stiner (2007) suggest that seasonal tropical storms can adversely affect the reproductive season of sea turtles, as well as threaten turtles at various life stages. For instance, eggs and hatchlings seem to be most vulnerable to exposure due to limited or no mobility. Seasonal storms can cause high tides and salt-water inundation of turtle nests, disrupting the oxygen exchange among the turtle eggs (Pike and Stiner 2007). High tides can also occur at other times that are not associated with storm events. High tides can erode the beach, removing sand on top of the nest and sometimes washing the eggs out to sea. The salt-water can also cause the loss of water within the egg, which could result in decreased hatching success. Some sea turtle species may be affected more than others by seasonal weather events, in that some species nest during times with higher incidence of extreme events (Pike and Stiner 2007). For example, leatherback sea turtles lay their eggs earlier in the nesting season before the peak of the storm season and, thus, the nests may be less affected by weather events; conversely, green sea turtle reproductive success may be more affected due to nesting later in the summer, during peak tropical storm and hurricane season (Pike and Stiner 2007). However, efforts to protect eggs in the PAIS incubation facility and south Texas corrals have mitigated substantial, potential recruitment losses due to extreme weather events.

Harmful algal blooms (HAB) may pose a threat to sea turtles, although blooms have not been documented as being a substantial problem in PAIS. Algal blooms become harmful when they release toxins, causing such issues as respiratory and neurological problems (EPA 2012). HABs can also cause low-oxygen zones and block out sunlight, resulting in fishkills and dying seagrass, both of which are important food sources for some sea turtle species (EPA 2012). The longer HABs persist, the more these events can adversely affect the surrounding habitat and organisms.

Predation is a threat to sea turtles in PAIS; however, predation rates decrease as turtles grow and mature. Nest depredation seems to be the most common form of predation on sea turtles. The main predators of eggs and hatchlings on the beach at PAIS include raccoons, coyotes, skunks, badgers, ghost crabs, and ants (NMFS and USFWS 1991; NMFS, USFWS, and SEMARNAT 2011). Seabirds and a variety of fish typically prey on hatchlings and young turtles. Larger, mature turtles experience less predation, but according to NMFS and USFWS (1991), tiger sharks have been observed preying upon adult green sea turtles.

Photo 22. Green turtle with fibropapillomatosis (Photo by Keuper-Bennett and Bennett 2011).

Disease is the last acknowledged natural threat to sea turtles in PAIS. One disease that has been observed on green sea turtles in the park is fibropapilloma; a condition causing growths or tumors on the turtles' soft tissues (Tristan et al. 2010). Photo 22 illustrates the growths that occur on green turtles affected by fibropapillomatosis. This disease can occur both externally and internally (Arthur et al. 2007). Normally this condition is not fatal, but if the growths occur on the eyes, mouth, and flippers they can negatively affect feeding and mobility (Tristan et al. 2011).

Data Needs/Gaps

Current and long-term data are available for the number of nests, number of hatchlings released, and species diversity. Sea turtle distribution in PAIS is summarized in publications (Shaver 1994, 2000; Shaver and Rubio 2008; Shaver et al. 2013) and the NOAA website reporting locations of stranded turtles documented by the STSSN (http://www.sefsc.noaa.gov/species/turtles/strandings.htm). Monitoring efforts focus on the Kemp's ridley sea turtle, with less attention focused on the other four species of sea turtle documented in the park. This is because of the long-term, bi-national, multi-agency program to form a secondary nesting colony at PAIS, the critically endangered status of the species over the years of this program, and importance of PAIS beaches to nesting Kemp's ridley turtles (i.e., more Kemp's ridley nests are located at PAIS than at any other location in the U.S.). Less nesting conservation efforts have been focused on the other species because far fewer of their nests have been confirmed each year versus those confirmed for the Kemp's ridley turtle. Continued annual monitoring of the populations in the park will allow for accurate assessment of population conditions in the future. Regarding work with sea turtles in the marine environment and work with stranded sea turtles, more effort has been undertaken with green turtles than any other species due to their numerical dominance and propensity for stranding alive in large events.

Overall Condition

Number of Nests

The project team defined the *Significance Level* for number of nests as a 3. Shaver (2013) documented several years of nesting data collected along the Texas coast, including nests documented in PAIS. The number of confirmed nests for Kemp's ridley sea turtles each season increased at approximately 12-18% per year from the mid-1990s through 2009, but plateaued from 2009 through 2013. The increasing trend in Kemp's ridley nests was mostly likely the result of the incubating, release, and monitoring research program on-going since 1978; protection efforts on the nesting beaches in Mexico; and protections in the marine environment including mandatory use of Turtle Excluder Devices (TEDs) and the seasonal area closure for shrimp trawling off south Texas established by TPWD in 2000. Monitoring and study must be continued to identify long-term trends and examine potential impacts to nest numbers from the Deepwater Horizon Oil Spill. Additionally, protection efforts must be continued to help restore the species. There is a slight increase in the number of loggerhead and green turtle nests found at PAIS in recent years. Very few nests of the leatherback and hawksbill turtles have been documented at PAIS. Thus, a *Condition Level* of 2 was assigned to this measure.

Number of Hatchlings Released
The *Significance Level* for number of hatchlings released is a 3. Shaver (2013) documented several years of nesting data collected along the Texas coast. Most eggs from confirmed nests are transported to an incubation facility in PAIS or south Texas corrals. Hatchlings are released to the wild and guarded during release. Hatchling success is higher for eggs protected in the incubation facility and corrals than for eggs left at nesting sites to hatch. The number of Kemp's ridley turtle eggs recorded and resulting hatchlings released into the wild has been increasing for over a decade. For loggerhead and green sea turtles, the number of eggs brought for protected care and hatchlings released is more variable from year to year, which is likely influenced to some degree by the low number of nests (from 0-13) documented each season at PAIS and the nesting habits and season of the species. These species tend to nest every three years whereas Kemp's ridleys tend to nest every other year. Also, these species nest later in the year when detection efforts are more limited. Thus, the measure was assigned a *Condition Level* of 2.

Diversity and Distribution
The project team defined the *Significance Level* for diversity and distribution as a 3. Shaver (1989, 1999b, 2000, 2009, 2012, 2013) has documented five species of sea turtle in PAIS, some of which were more common or abundant than others (e.g., Kemp's ridley and green sea turtles). Several species present in the park are of conservation concern due to rarity or restriction of range. Thus, a *Condition Level* of 2 was assigned to this measure.

Weighted Condition Score
A *Weighted Condition Score* of 0.667 was calculated for sea turtles in PAIS, meaning the component is of moderate concern with a stable trend. This is due primarily to the rarity and conservation concern of sea turtle populations along the Texas Gulf coastline.

Sea Turtles

Measures	SL	CL
• Number of Nests	3	2
• Number of Hatchlings Released	3	2
• Diversity and Distribution	3	2

WCS = 0.667

Sources of Expertise

Dr. Donna Shaver, Chief, Division of Sea Turtle Science and Recovery, Texas Coordinator, Sea Turtle Stranding and Salvage Network, PAIS

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4.13 Amphibians

Description

PAIS is suitable habitat for a small variety of amphibians, which may be due to the Laguna Madre acting as a barrier to the mainland. Amphibians act as key indicator species as they are especially susceptible to ecological changes due to their permeable skin (Smith and Keinath 2007). Any toxins that have been absorbed by amphibians can be spread throughout the ecosystems if infected amphibians are consumed by other animals (Smith and Keinath 2007). Amphibians require access to freshwater at all life stages, and wet seasons are essential for the survival of many species in PAIS (Schmidly et al. 1996); most of the amphibian species in PAIS have been found near ephemeral ponds (Cooper et al. 2005). Adequate water sources are necessary for successful reproduction; without water sources, amphibians can go years without a successful breeding event (Dayton 2005).

Measures

- Species abundance and diversity
- Species distribution
- Reproductive success
- Age class structure

Photo 23. Green tree frog (*Hyla cinerea*) (Photo by Duran, taken in 2003 herpetological inventory for PAIS).

Reference Conditions/Values

The ideal reference condition for amphibians in PAIS would be the condition of amphibian populations on Padre Island prior to the intensive cattle ranching and grazing that began in the late 1880s and lasted until 1971. However, very little information is available from this historical period. The most comprehensive description of amphibians on the island comes from an inventory by Duran (2004). This description is used as the reference condition for this assessment.

Data and Methods

Duran (2004) conducted an inventory of reptiles and amphibians in PAIS between 2002 and 2003. Major sampling efforts were focused on 17 different sites across grassland, wetland, wetland-grasslands, sparse vegetation, and dune habitats (see Plate 29 for trapping locations in the park). Trapping methods included funnel-type minnow traps and drift-fence arrays; other inventory methods were visual encounters, auditory surveys, and road surveys. Other than a few isolated reports, little research has been devoted to amphibians in PAIS (Cooper et al. 2005).

Current Condition and Trend

Species Abundance and Diversity

NPS (2012) lists a total of five species of amphibians in PAIS, all of which are anurans and native to PAIS. Duran (2004) documented seven anuran species in PAIS: Rio Grande leopard frog (*Lithobates berlandieri*), green tree frog, Hurter's spadefoot toad, spotted chorus frog, Woodhouse's toad (*Anaxyrus woodhousii*), and a species of narrow-mouthed toad (*Gastrophryne sp.*) that was not able to be identified with certainty. According to Duran (2004), the tadpoles found seemed to be integrated between the eastern and Great Plains narrow-mouthed toad. The green tree frog was the most abundant amphibian species encountered during the survey, as several green tree frogs were spotted at every sample site with permanent or semi-permanent water (Duran 2004). According to Duran (2004), the Woodhouse's toad is an unusual observation in PAIS due to the species' distribution being located several hundred kilometers north. Table 49 displays the amphibian species currently confirmed in PAIS and encountered during the Duran (2004) survey.

Table 49. Amphibians that have been confirmed in PAIS (NPS 2012, Duran 2004). Species scientific names were updated if necessary using Integrated Taxonomic Information System (ITIS 2012).

Scientific Name	Common Name	Frequency of Occurrence Duran study 2002-2003
Anaxyrus woodhousii	Woodhouse's toad	Common*
Hyla cinerea	green tree frog	Common
Pseudacris clarkii	spotted chorus frog	Rare*
Lithobates berlandieri	Rio Grande leopard frog	Common
Scaphiopus hurterii	Hurter's spadefoot	Common
Gastrophryne sp.+	Species of narrow-mouthed toad	Rare*

*denotes species that were first accounts within the park during the Duran 2004 study.

+ species unable to be identified with certainty by Duran 2004; does not occur in the certified species list for PAIS.

Species Distribution

The majority of anuran species in the PAIS ecosystem depend on ephemeral pools created by large rain events for breeding (Dayton et al. 2004). The distribution of anurans found in PAIS shows very little variation.

All anuran species are heavily concentrated in the northern half of the park (Duran 2004; see Plate 30), likely due to the greater likelihood of ephemeral ponding in this part of the park rather than higher sampling effort during inventory (Stablein, written communication, 19 October 2012). The Duran (2004) inventory documented several observations for all amphibian species known to occur in PAIS. The Woodhouse's toad and Rio Grande leopard frog were the only two amphibian species to be observed on the southern end of the park. Both species were found near or at trap 14, which was located in a grassland habitat (see Plate 30). Presence of the narrow-mouthed toad species is limited to specimens recorded near Park Road 22 on Mustang Island (observation location does not show up on Plate 30because it is north of the northern park boundary).

Reproductive Success

Currently, there are no data regarding reproductive success of amphibians in PAIS. Without established annual surveys and monitoring programs, this measure cannot be assessed.

Age Class Structure

There are also no data regarding age class structure in PAIS. Without established annual surveys and monitoring programs, this measure cannot be assessed.

Threats and Stressor Factors

According to Stuart et al. (2004), amphibians are generally more threatened than birds and mammal species. There are several threats to amphibians in the park. PAIS park staff have identified 10 stressors that have occurred or are presently occurring in the park: saltwater inundation, human disturbance, vehicle strikes, hazardous materials such as chemical spells (hazmat), drought, predation, habitat loss, disease, and oil and gas development.

Many threats can be categorized as anthropogenic. Humans negatively impact amphibians and their habitat by constructing roads and by drilling wells for oil and gas development. Amphibians cannot quickly escape construction areas and can be struck by vehicles when on the roads and beaches (PAIS 2001). The risk of chemical spills also increases in areas with oil and gas development.

Pollution in the air, on land, and in the water can result in compromised health, suffocation, and strangulation of amphibians. The gulf currents that historically brought in natural items and wood debris from ship wrecks now bring in trash items that are tossed into the ocean by the shrimping industry and off shore oil industries; trash tossed into rivers that flow into the Laguna and Gulf also accumulates in PAIS (Cappiello 2003). According to a nationwide survey in 1993, PAIS had the most trash of any NPS unit along the U.S. coast; as a result, it is the only NPS unit to have its own hazmat team (Cappiello 2003).

Many amphibians are salt intolerant and cannot survive in sea water; salt-water inundation of PAIS may therefore prove to be another threat (Karraker 2007). The amphibians inhabiting the southern seashore may be at a higher risk than those on the northern seashore of PAIS due to the relative sea level rise and erosion rates. According to White et al. (2007), the southern seashore has been eroding at a rate of 1.2 to 2.4 m/year (3.9 to 7.9 ft/year). White et al. (2007) stated that between 1949 and 1999, relative sea level had risen at a rate of 3.38 mm/year on the southern shore.

Natural stressors for amphibians are drought, predation, and disease. Amphibians require a freshwater source throughout each stage of life. If drought were to occur, the small number of freshwater pools in PAIS could dry up, causing the amphibians on the island to become more vulnerable. According to Duran (2004), amphibians found on the mainland of Texas near PAIS (but not on the island) may lack drought survival mechanisms.

Chytrid fungus, specifically *Batrachochytrium dendrobatidis*, is a chytrid pathogen of amphibians that could potentially affect amphibian populations in PAIS. The pathogen has been identified as the cause of severe population declines on several continents, including North America (Piotrowski et al. 2004). Amphibians infected by *B. dendrobatidis* develop chytridiomycosis, an infectious non-hyphal zooporic fungus that causes roughening and reddening of the skin, convulsions, ulcers and hemorrhages, and sporadic death. Not all amphibians infected with *B. dendrobatidis* develop chytridiomycosis or die; environmental factors, such as pH of the environment, drought, and temperature at time of infection, may affect mortality rates. Some research indicates that the fungus growth is inhibited by high temperatures (28 °C or 82 °F) and exposure of infected individuals to high temperatures may kill the fungus (Woodhams et al. 2003). Also, ranaviruses have been associated with die-offs of amphibians and reptiles in over 25 states and more than 20 species of amphibians and turtles in the U.S. (USGS 2012). Mortality due to ranaviruses occurs mostly in larval amphibians, true frogs, and chorus frogs. Infected individuals may exhibit subtle or severe hemorrhages in ventral skin, often appearing as an irregular rash; onset of illness is sudden and often affects most individuals in a wetland (up to or exceeding 90%) (USGS 2012). Neither disease has been detected in PAIS to date, but may greatly impact amphibian populations if diseases are transmitted to the island.

Data Needs/Gaps

There are limited data on amphibians in PAIS. The 2004 Duran inventory only describes the abundance, diversity, and possible distribution of most of the species observed, and is now outdated. A more current study and long-term monitoring of amphibians are needed to assess any trends within the park. The Gulf Coast Network has plans to initiate a long-term monitoring program of amphibians in the park in the near future.

Overall Condition

PAIS is home to a small variety of amphibians in the area due to the Laguna Madre acting as a barrier to the mainland. However, because there have been no annual herpetological surveys in the park, a quantitative condition evaluation of amphibians in PAIS cannot be completed at this time. While the NPS has a record of confirmed species in the park, this list does not include estimates of current species richness or diversity, which were the NPS-specified measures for amphibians in PAIS. Annual monitoring of the populations in the park will allow for a more accurate assessment of these parameters.

Species Abundance and Diversity

The project team defined the *Significance Level* for species abundance and diversity as a 3. There is a lack of diversity on the island, but this measure does not appear to be of particular concern for those species that do occur in PAIS. However, long-term monitoring data may prove beneficial to managers. This measure was assigned a *Condition Level* of 0 or no concern.

Species Distribution

The project team defined the *Significance Level* for species distribution as a 3. There are limited distribution data for PAIS, but this measure does not appear to be of particular concern at this time. Long-term monitoring of amphibian distribution may prove beneficial to managers. This measure was also assigned a *Condition Level* of 0 or of no concern.

Reproductive Success

The project team defined the *Significance Level* for reproductive success as a 3. There are no data for reproductive success of amphibians in PAIS. Because of this data gap, a *Condition Level* for this measure was not assigned.

Age Class Structure
The project team defined the *Significance Level* for age class structure as a 3. There are no data for age class structure of amphibians in PAIS. Because of this data gap, a *Condition Level* for this measure was not assigned.

Weighted Condition Score
A *Weighted Condition Score* for amphibians in PAIS was not assigned because 50% of the measures had unknown *Condition Levels*.

Amphibians

Measures	SL	CL
• Species Abundance and Diversity	3	0
• Species Distribution	3	0
• Reproductive Success	3	n/a
• Age Class Structure	3	n/a

WCS = N/A

Sources of Expertise
Wade Stablein, Biological Technician, PAIS

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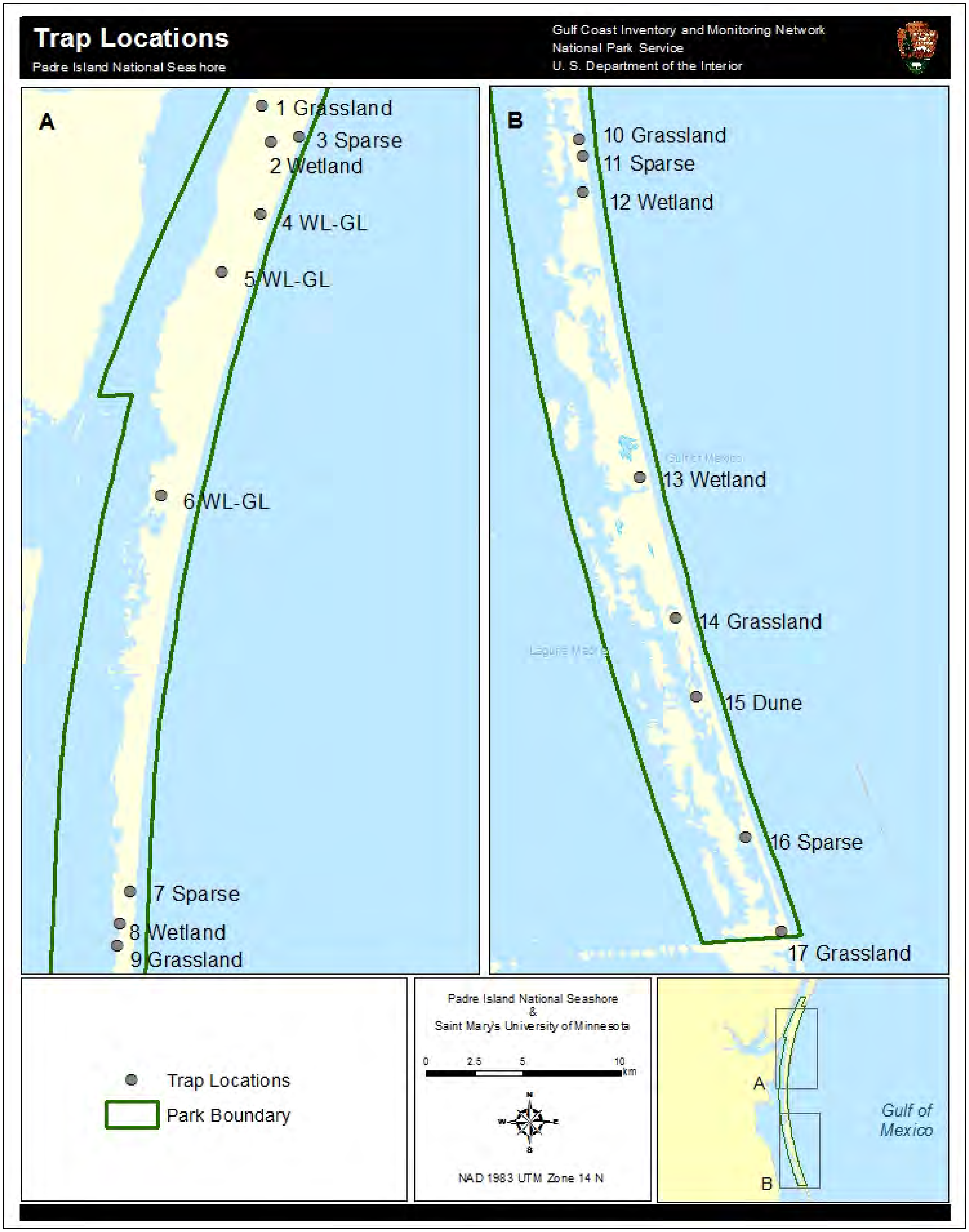

Plate 29. Trapping locations used during the 2002-2003 PAIS inventory (Duran 2004). The locator map displays the extents that the traps occurred.

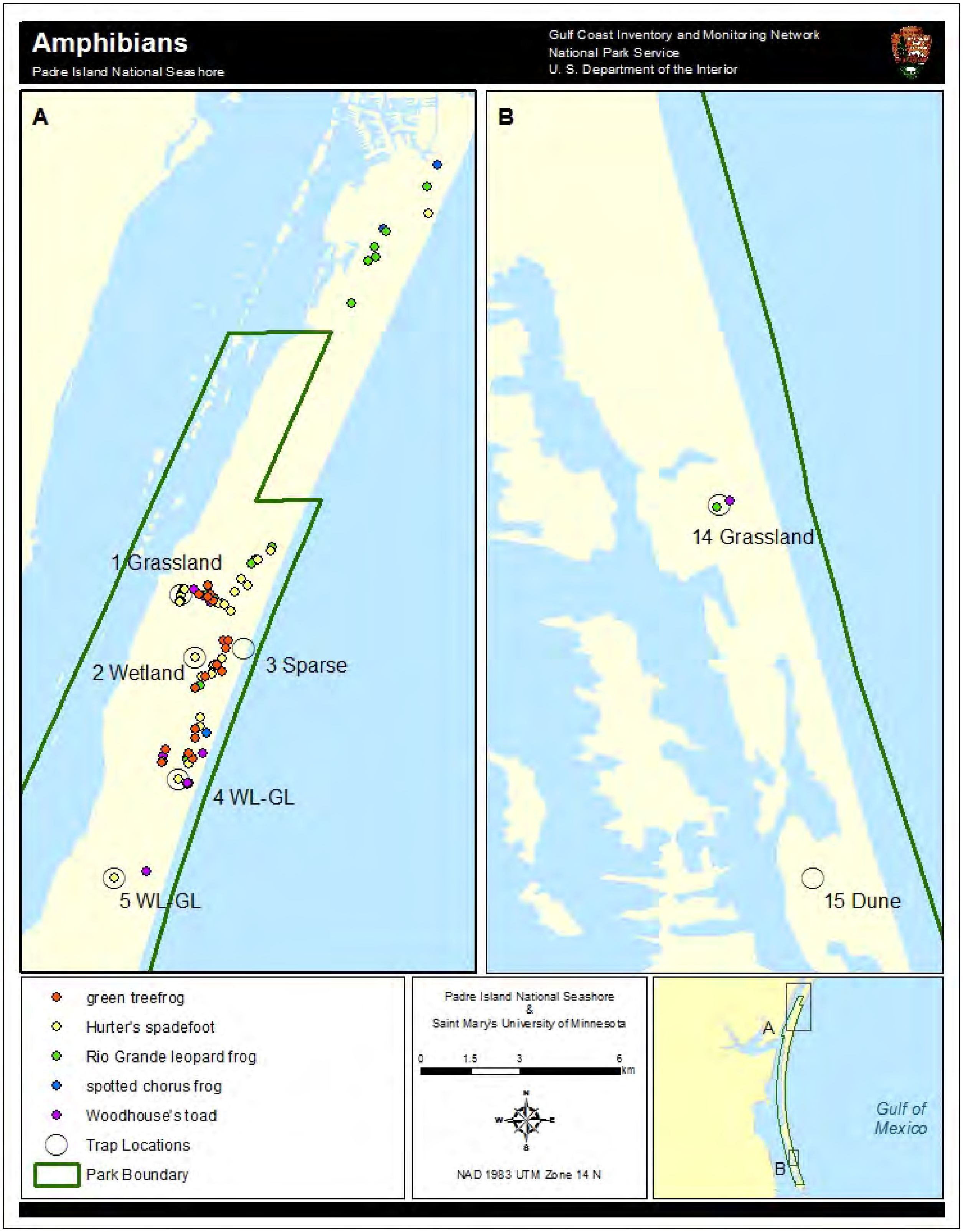

Plate 30. Amphibian species found during the 2002-2003 PAIS inventory (Duran 2004). Location of narrow-mouthed toad is not included in the map because no GPS locations were recorded.

4.14 Water Quality

Description

Good water quality is essential to a healthy aquatic ecosystem. Many organisms (e.g., plant communities, animals) rely on balanced and stable water quality measures to survive and thrive (NPS 2012a). Water quality is a Vital Sign for parks in the GULN. Dissolved oxygen, temperature, pH, salinity, turbidity, and nutrients are core water quality measures identified by PAIS staff as important for understanding condition of water quality in the park.

Photo 24. The Gulf of Mexico shore along PAIS (NPS photo).

PAIS is bordered by the Gulf of Mexico on the east (Photo 24) and the Laguna Madre on the west, which separates the barrier islands from mainland Texas. The Laguna Madre is a hypersaline lagoon that can be one and a half to three times as salty as the ocean, and is a highly sensitive and important ecosystem (NPS 2012b). The Laguna Madre is divided into two halves (upper and lower) and covers approximately 665,936 ha (1,645,563 ac) (Chapman and Wallace 2009). PAIS also supports several freshwater ponds in the northern part of the park, which typically hold water year-round with the exception of particularly dry years.

The Laguna Madre, the Gulf of Mexico, the freshwater ponds, wetlands, and the vast number of acres that become ephemeral ponds after significant rain events on the island provide critical habitat for a variety of plants and animals important to PAIS ecology, such as shoal grass, sea turtles, fishes, various avian species, and amphibians.

Measures

- Dissolved oxygen
- Temperature
- pH
- Salinity
- Turbidity
- Nutrients (including total phosphorus, nitrate-nitrite, orthophosphate, and ammonia)

Dissolved Oxygen

Dissolved oxygen (DO) is critical for organisms that live in water. Fish and zooplankton filter out or “breathe” dissolved oxygen from the water to survive (USGS 2010). Generally, oxygen enters water from the atmosphere, through transpiration by aquatic plants, or through ground water discharge. In the Laguna Madre, the largest source of DO is due to transpiration by vast seagrass meadows that readily produce oxygen, especially with increased levels of sunlight. DO transpiration by seagrasses slows down at night (diurnal fluctuation in levels) and especially in winter months, as grasses go into senescence from late October to March (seasonal fluctuation in levels), when water temperatures and daylight hours decrease (Joe Meiman, GULN and CUPN Hydrologist, written communication, 14 March 2013). As the amount of DO drops, it becomes more difficult for water-based organisms to survive (USGS 2010). The concentration of DO in a water body is closely related to water temperature; cold water holds more DO than does warm water (USGS 2010). Thus, DO concentrations are subject to seasonal fluctuations as low temperatures in the winter and spring allow water to hold more oxygen, and warmer temperatures in the summer and fall cause water to hold less oxygen (USGS 2010).

Temperature

Water temperature greatly influences water chemistry and the organisms that live in aquatic systems. Not only can it affect the ability of water to hold oxygen, water temperature also affects biological activity and growth within water systems (USGS 2010). All aquatic organisms, from fish to insects to zoo- and phytoplankton, have a preferred or ideal temperature range for existence (USGS 2010). As temperature increases or decreases too far past this range, the number of individuals and species able to live there eventually decreases. In addition, higher temperatures allow some compounds or pollutants to dissolve more easily in water and they can be more toxic to aquatic life (USGS 2010).

pH

pH is a measure of the level of acidity or alkalinity of water and is measured on a scale from 0 to 14, with 7 being neutral (USGS 2010). Water with a pH of less than 7.0 indicates acidity, whereas water with a pH greater than 7.0 indicates alkalinity. Aquatic organisms have a preferred pH range that is ideal for growth and survival (USGS 2010). Chemicals in water can change the pH and harm animals and plants living in the water; thus, monitoring pH can be useful for detecting natural and human-caused changes in water chemistry (USGS 2010).

Salinity

Salinity is the measure of dissolved salts in water; it is usually stated in parts per thousand (ppt) (EPA 2006). Salinity levels can affect other water quality measures, including dissolved oxygen. The higher the salinity in a body of water, the lower the amount of oxygen it can hold (EPA 2006). The level of salinity also controls the types of organisms (plants and animals) that can survive in the body of water. Some species, such as shoal grass, can withstand higher levels of salinity, but other species only tolerate lower salinity levels (EPA 2006).

Turbidity

Turbidity assesses the amount of fine particle matter (e.g., clay, silt, plankton, microscopic organisms, or finely divided organic or inorganic matter) that is suspended in water by measuring the scattering effect that solids have on light passing through water (USGS 2010). For instance, the more light that is scattered, the higher the turbidity measurement will be. The suspended materials that make water turbid can absorb heat from sunlight, increasing the water temperature in waterways and reducing the concentration of dissolved oxygen in the water (USGS 2010). The scattering of sunlight by suspended particles decreases photosynthesis by plants and algae, which contributes to decreased DO concentrations in the water (USGS 2010). Suspended particles also irritate and clog the gill structures of many fish and amphibians, making it difficult to thrive (USGS 2010).

<u>Nutrients</u>

Nutrients are essential for plant and animal growth. Nitrogen and phosphorus are particularly important for aquatic life, but a surplus can cause negative effects. Organisms can also be affected by chemical and biological processes that change the form of the nutrient and transfer it to or from water, soil, biological organisms, and the atmosphere. Nitrogen has different forms including ammonia and nitrate. Ammonia is a compound that occurs when dissolved nitrogen combines with hydrogen in natural water. The number of hydrogen atoms determines if the water will be ionic or unionized; the former is more toxic to fish than the latter. Nitrate is a compound that occurs when dissolved nitrogen combines with oxygen in natural water. Both ammonia and nitrate are very water-soluble and easily transferred though groundwater and streams. Phosphates are compounds of dissolved phosphorus in combination with oxygen and hydrogen. Phosphate compounds are moderately soluble and less mobile then nitrates; however, they tend to bond well with soil particles, and can be transported though erosion (Mueller and Helsel 2009).

Reference Conditions/Values

The reference condition for PAIS's water quality is the Texas Commission on Environmental Quality (TCEQ) water quality criterion for surface waters in Texas. Table 50 displays water quality parameter standards set by the TCEQ. The TCEQ (2002) water quality criteria for saltwater and estuary systems serves as the reference condition for nutrient conditions in the Laguna Madre and Gulf of Mexico (Table 51).

Table 50. Texas Commission on Environmental Quality standards for surface-water quality (TCEQ 2010).

Water Quality Measure	TCEQ Standards
Dissolved Oxygen	> 4.5 mg/L (Laguna Madre marine waters); 5.0 mg/L (freshwater)
Temperature	< 95°F (35°C) Laguna Madre marine waters; N/A for freshwater on barrier islands
pH	6.5 – 8.5 (marine waters) or 9.0 (freshwater)
Salinity	N/A
Turbidity	N/A
Nutrients	See Table 2

Table 51. TCEQ 2002 water quality criteria for nutrients in saltwater estuaries in PAIS (TCEQ 2002, as cited in Withers et al. 2004).

Nutrients	TCEQ Saltwater (Estuaries) Standards
Ammonia-N (mg/L)	0.1
Nitrate+Nitrite-N (mg/L)	0.26
Orthophosphate (mg/L)	0.16
Total Phosphorous (mg/L)	0.22
Chlorophyll a (µg/L)	11.5

Data and Methods

General Baseline Inventory

In 2003, the NPS published results of surface-water quality data retrievals for PAIS using six EPA national databases: Storage and Retrieval (STORET) water quality database management system, River Reach File (RF3), Industrial Facilities Discharge (IFD), Drinking Water Supplies (DRINKS), Water Gages (GAGES) and Water Impoundments (DAM) (NPS 2003). The retrieval resulted in 210,665 observations for various parameters at 257 monitoring stations operated by the NPS, USGS, EPA, and Texas Natural Resource Conservation Commission from 1941 to 1998. A number of stations (73) were found within the park; however, only three of these stations (PAIS 0119, PAIS 0016, PAIS 0080) yielded long-term records (NPS 2003) (Plate 31). PAIS 0080 (named Laguna Madre Estuary Line 125) is located in the Laguna Madre at Yarborough Pass. PAIS 0016 (named Laguna Madre Estuary Line 194 Site 01) is located in PAIS along the GIWW in the Laguna Madre just north of Baffin Bay. PAIS 0119 (named Laguna Madre Estuary Line 053 Site 1) is located in the Laguna Madre directly west of Dagger Hill. The water quality parameters measured at these sites include DO, temperature, pH, turbidity, and various nutrients. Data were collected from these stations only several times per year or intermittently over several years. As a result, these data points represent a snapshot in time and are difficult to use in determining trends over time or current condition of water quality parameters. This inventory used EPA standards for water quality to determine exceedances, which are noted as results from this inventory are presented.

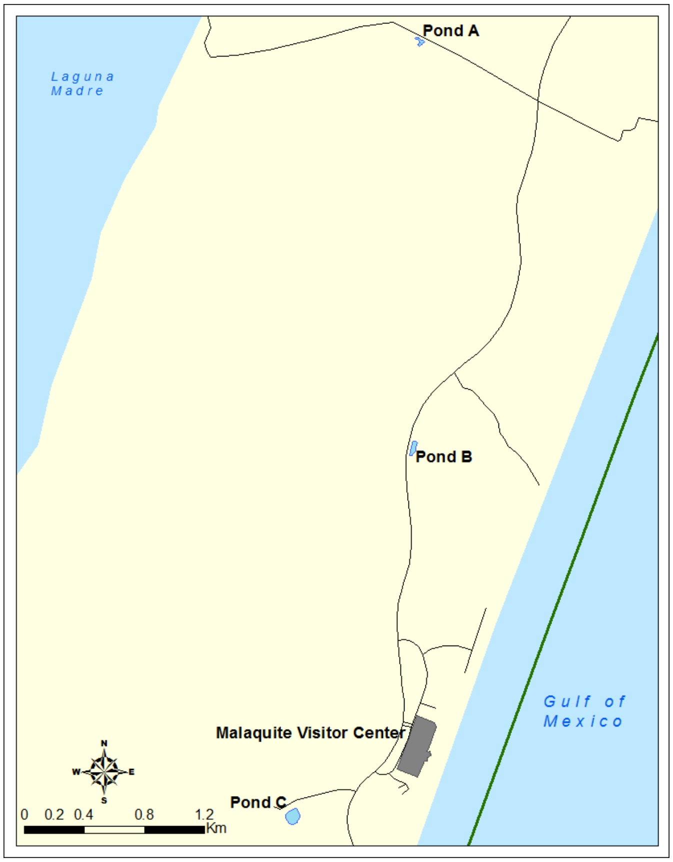

Figure 21. Location of the three freshwater ponds in PAIS.

Freshwater ponds and groundwater

Sissom et al. (1990) conducted a baseline study of three ponds in PAIS from September 1989 through August 1990. The three freshwater ponds were surveyed on or near the 15th of each month, at which time samples were taken with the intention of detecting possible contaminants, such as inorganic nutrients and heavy metals. Water quality parameters, including temperature, turbidity, oxygen, salinity, and pH were also measured. Because only one sample was taken in each pond per month, the data points represent a snapshot view of water quality in the ponds at one point in time. Figure 21 shows the locations of the three freshwater ponds in PAIS. Photo 25 shows Pond B in early winter.

Photo 25. Pond B located near PAIS Park Headquarters (seen in the background). The freshwater ponds in PAIS provide crucial habitat for many species of waterfowl that migrate through the region (Photo by Shannon Amberg, SMUMN GSS).

Based on historical data, NPS (1996) describes the near surface groundwater in the park as a lens of freshwater approximately 9 m (30 ft) thick that overlays brackish saltwater. This lens is approximately 3 km (2 mi) in width and is recharged mostly by precipitation events and less commonly by saltwater wave surges. It is believed the groundwater flows easterly from the Laguna Madre toward the Gulf of Mexico (NPS 1996), although the hydrology of the area has not been assessed completely.

Gulf of Mexico and Laguna Madre

An inventory of water quality for the Gulf of Mexico's surface waters at PAIS has not been conducted to date (NPS 1996, Wade Stablein, Pers. Comm.).

Nicolau (2005) collected monthly grab samples from six sites in the Laguna Madre between 2003 and 2005. A total of six sampling locations were used to collect data: three sites in the upper Laguna Madre and three sites in the lower Laguna Madre. Water quality parameters examined in this study included water temperature, DO, and salinity measures. A suite of nutrients (ammonia, nitrate+nitrite, orthophosphate, total phosphate, chlorophyll-a) were also recorded at each sampling site.

Wilson and Dunton (2011) surveyed areas near PAIS as part of a monitoring program for seagrass in Texas; water quality measures were recorded, including DO, pH, and salinity. Leaf tissues were also collected and analyzed from each station with a vegetated bottom. Only one species of seagrass (shoal grass) was analyzed for nutrient levels. Sampling station locations were distributed among three estuary systems, including the Laguna Madre, which was separated into two segments, ULM and LLM. The LLM sampling sites were all located just outside the park boundary. A 2012 summary report of repeat survey efforts is anticipated to be available soon, but was not available at the time this assessment was developed; however, various maps and figures featuring 2012 summary data were available and are included in this document where appropriate.

The NPS (2012c) NPSTORET database was accessed to query data for two stations located in the Laguna Madre near PAIS. The stations, located at Baffin Bay and Bird Island, report on observations for various nutrients, including nitrogen, nitrite, nitrate, ammonia, phosphorus, and orthophosphate. Many of the nutrient observations were recorded as “present” but less than the quantification limit; some were recorded as a specific numeric value. Samples are collected on a monthly basis.

NPS (2013) provides real-time data collected via data loggers installed at two TCEQ water quality monitoring stations in the Laguna Madre: one located at Baffin Bay (TCEQ Surface Water Quality Management Station 13444) and another located at Bird Island (TCEQ Station 13445). Water quality samples drawn at these stations are collected approximately monthly. GULN initiated an effort to monitor water quality conditions continuously (in real-time) in the Laguna Madre to better understand the dynamics of water quality in the hypersaline lagoon. This called for the installation of data loggers that would capture observations every 15 minutes, rather than occasionally. The intent of the effort is to gather data that may be used to model the dynamics of the system and which environmental factors affect various water quality conditions (e.g., weather events, diurnal or seasonal patterns, isolated disturbance events such as dredge activity). Water quality parameters observed in this effort include DO, salinity, turbidity, water temperature, and pH. Data collection began in 2008 and continues through the present; however, most of the data are in raw form and have yet to be analyzed in great detail. Data presented here represent very preliminary analyses to provide a snapshot of the interactions and complexities of water quality conditions in the system.

Plate 31 displays the locations for the long-term monitoring stations featured in NPS (2003), NPS (2012c) NPSTORET database, and the NPS (2013) GULN monitoring effort on the Laguna Madre.

Current Condition and Trend

<u>Dissolved Oxygen</u>
Sissom et al. (1990) documented dissolved oxygen in the three freshwater ponds in PAIS. DO observations in Pond A ranged from 3.60 to 12.0 mg/L; one exceedance (3.60 mg/L) occurred in August 1990. Pond B had dissolved oxygen values ranging from 5.40 to 10.60 mg/L; no exceedances were recorded during sampling. DO observations in Pond C ranged from 5.40 to 10.0 mg/L; no exceedances were recorded in Pond C during sampling.

Table 52 displays the dissolved oxygen values (mg/L) observed in the three ponds in PAIS during sampling from September 1989 through August 1990.

Table 52. Dissolved oxygen values (mg/L) for three freshwater ponds located in PAIS, September 1989 through August 1990 (Sissom et al. 1990). Exceedances are denoted with bold red text.

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Pond A	9.60	9.30	7.40	8.40	5.40	7.80	5.60	12.0	8.60	7.65	7.0	**3.60**
Pond B	10.40	6.60	9.0	8.40	5.40	9.30	10.0	7.20	6.20	10.6	7.30	5.60
Pond C	9.30	7.40	6.0	6.0	5.40	6.20	6.40	5.80	8.0	7.45	8.0	10.0

NPS (2003) reported 91 dissolved oxygen observations collected at three monitoring stations within the park. Of these, eight observations (all from one station location) exceeded the EPA threshold of 4.5 mg/L for marine systems. Table 53 displays the DO values from each station.

Table 53. Summary of dissolved oxygen observations (mg/L) from three water quality stations in the Laguna Madre in PAIS, including minimum, maximum, and mean values, and number of exceedances (NPS 2003).

Station	Time Period	Number of Observations	Minimum	Maximum	Mean	Exceedances
PAIS0016	1968-1974	30	4.9	9.3	6.6	0
PAIS0080	1968-1978	32	0.0	10.9	5.1	8
PAIS0119	1968-1982	29	4.6	14.4	7.1	0

Wilson and Dunton (2011) recorded 282 DO measurements from the lower Laguna Madre and 142 observations from the upper Laguna Madre. Of these observations, a total of 10 in the lower Laguna Madre and 58 in the upper Laguna Madre were found to be below the TCEQ threshold considered to be protective of marine aquatic life (>4.5 mg/L). Dissolved oxygen levels varied greatly in both sections of the Laguna Madre across observations, which may be due to interactions with salinity, water temperature, and respiration of marine plants. Water temperature and respiration also vary diurnally, which would create a diurnal affect in DO saturation as well. Table 54 displays the DO values for the upper and lower Laguna Madre collected by Wilson and Dunton (2011). Plate 32 graphically represents DO values in the Laguna Madre based on 2011 and 2012 survey results.

Table 54. DO observations collected in the lower and upper Laguna Madre in 2011, including minimum, maximum, and mean values (mg/L) (Wilson and Dunton 2011).

Laguna Madre Section	Number of Observations	Minimum	Maximum	Mean
Lower Laguna Madre	282	2.37	10.98	7.17
Upper Laguna Madre	142	1.34	10.64	5.33

Nicolau (2005) reported the Laguna Madre as an impaired water body for depressed dissolved oxygen levels, as is documented in the 2002 Texas Clean Water Act 303(d) listing. However, it is very difficult to assess trends in dissolved oxygen levels due to the complex interactions of many factors that affect DO in a hypersaline environment, some of which result in large DO fluctuations during the diurnal cycle.

Preliminary analysis of one year (August 2008 to August 2009) of NPS (2013) dissolved oxygen data from the Baffin Bay and Bird Island loggers is presented in Figure 22. DO levels appear to fluctuate diurnally, seasonally, and possibly as a result of isolated events, such as storms or disturbances. The daily fluctuation in DO concentration appears larger during the summer months and is less pronounced during winter months; this is largely a function of transpiration from seagrass meadows, which transpire large amounts of oxygen during summer months when daylight hours are long and water temperatures are warmer, but produce much less DO as seagrass meadows go into senescence during winter months when water temperatures are cooler and daylight hours are decreased. Further analysis is needed to understand which factors affect fluctuations in DO levels in the Laguna Madre. The greatest daily DO fluctuation recorded in 2008 occurred at the Bird Island data logger, in which DO ranged from 1.1 mg/L to 11.8 mg/L. Figure 22 clearly shows that DO levels frequently drop below the TCEQ threshold considered protective of marine aquatic life in the Laguna Madre (4.5 mg/L). This appears to occur more often in the warmer summer months than in the cooler winter months.

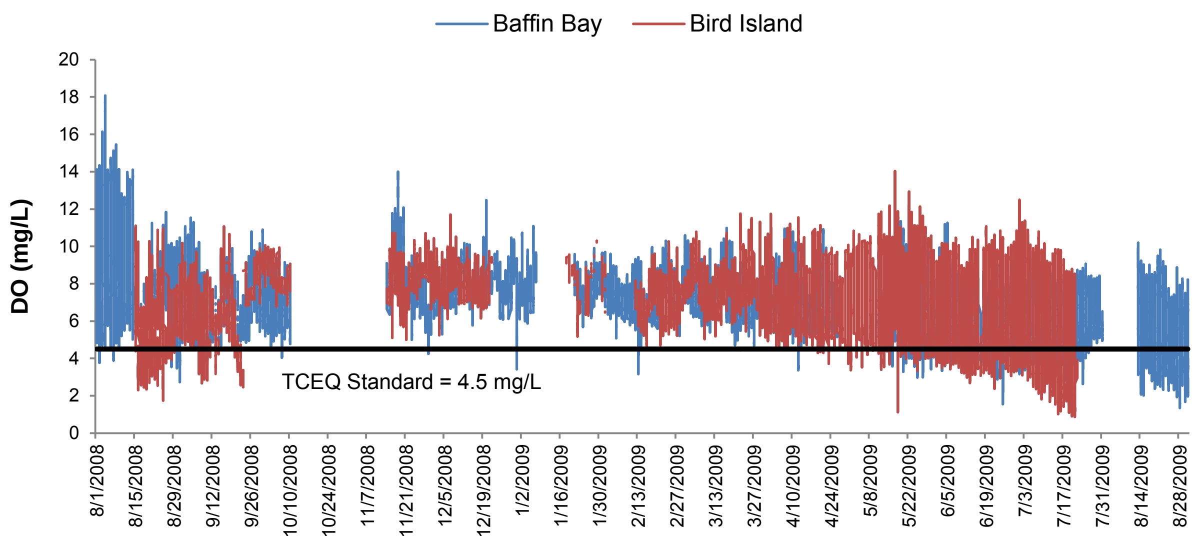

Figure 22. Fluctuations in daily DO observations at Baffin Bay and Bird Island data loggers in the Laguna Madre in PAIS, August 2008 through August 2009 (NPS 2013).

<u>Temperature</u>

Sissom et al. (1990) reported temperature measurements from the three freshwater ponds in PAIS from September 1989 through August 1990. Temperatures in Pond A during sampling ranged from 13.0 to 33.0 °C. Temperature observations in Pond B ranged from 12.0 to 35.0 °C, while temperatures in Pond C ranged from 12.0 to 33.0°C. For all three ponds, the lowest temperatures were observed during winter months and the highest temperatures were observed in summer and early fall. Table 55 displays monthly temperatures (°C) across the three ponds in PAIS from September 1989 through August 1990.

Table 55. Water temperature values (°C) for three freshwater ponds located in PAIS, September 1989 through August 1990 (Sissom et al. 1990).

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Pond A	33.0	30.0	19.0	13.0	16.0	13.0	26.0	29.0	30.0	29.5	30.0	33.0
Pond B	32.0	30.0	20.0	12.0	18.0	15.0	24.5	29.0	31.0	32.0	28.0	35.0
Pond C	31.0	30.0	20.0	12.0	17.0	15.0	24.0	31.0	31.0	32.5	29.0	33.0

NPS (2003) documented a total of 93 water temperature observations at monitoring stations in the Laguna Madre in PAIS between 1968 and 1982. No exceedances were recorded at these stations during the period of data collection. Because the data are not continuous, it is difficult to determine any trends in water temperature that may have occurred during this time. Table 56 displays the summary characteristics of water temperature observations from the three monitoring stations in the Laguna Madre in PAIS.

Table 56. Summary of water temperature observations (°C) from three water quality stations in the Laguna Madre in PAIS, including minimum, maximum, mean values, and exceedances (NPS 2003).

Station	Time Period	Number of Observations	Minimum	Maximum	Mean	Exceedances
PAIS0016	1968-1974	32	23.4	29.2	26.4	0
PAIS0080	1968-1978	32	17.7	29.8	24.7	0
PAIS0119	1968-1982	29	12.5	31.1	25.1	0

Nicolau (2005) calculated monthly water temperature averages for 24 consecutive months for three stations in the upper Laguna Madre and three stations in the lower Laguna Madre between August 2003 and July 2005. Water temperature at the upper Laguna Madre stations ranged from 13.9 to 31.7 °C. Figure 23 displays monthly average water temperatures at three sampling locations in the upper Laguna Madre in PAIS between 2003 and 2005. Water temperatures at the lower Laguna Madre sampling locations ranged from 13.5 to 30.7 °C. Figure 24 displays monthly average water temperatures at the three sampling locations in the lower Laguna Madre in PAIS between 2003 and 2005. For both upper and lower Laguna Madre, the warmest water temperatures occurred in late summer and early fall months and the coolest water temperatures occurred in winter months.

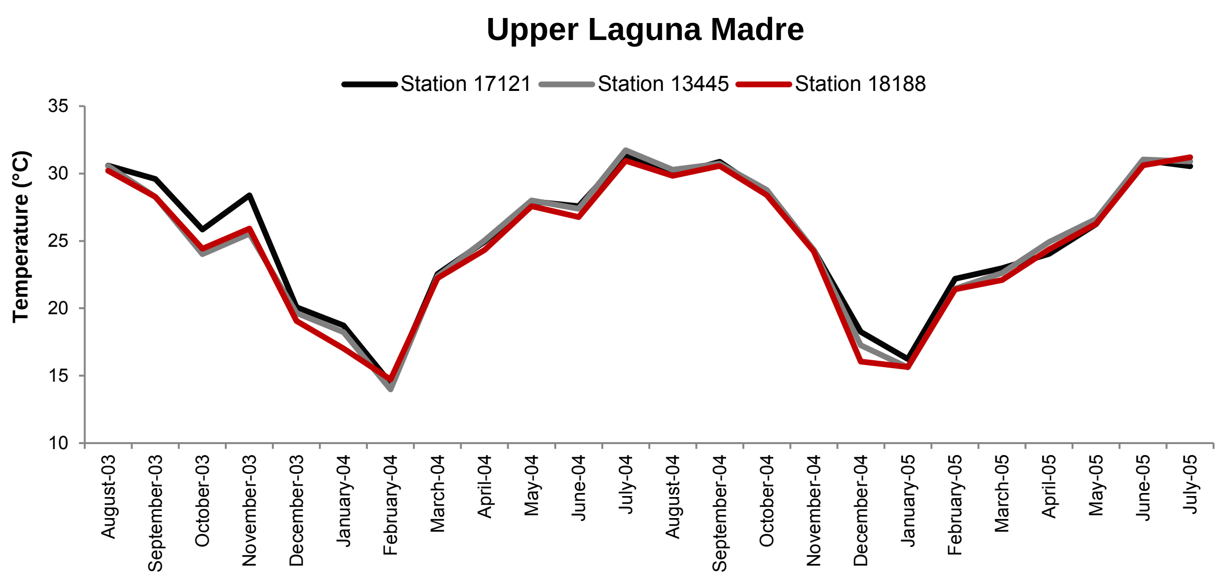

Figure 23. Average monthly water temperatures (°C) at three sampling locations in the upper Laguna Madre in PAIS between 2003 and 2005 (Nicolau 2005).

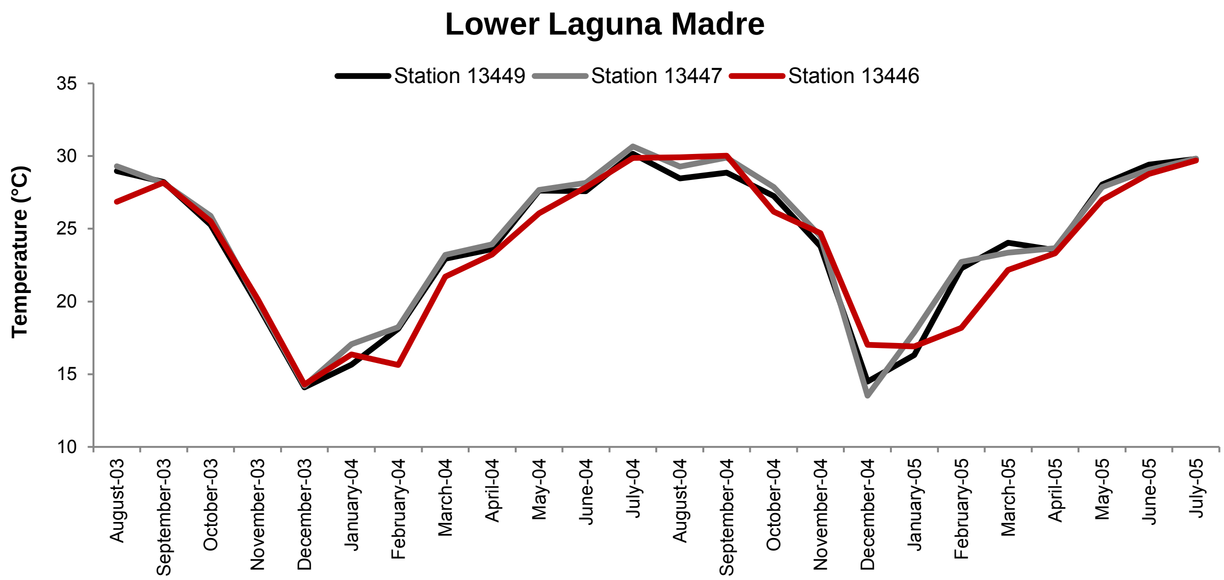

Figure 24. Average monthly water temperatures (°C) at three sampling locations in the lower Laguna Madre in PAIS between 2003 and 2005 (Nicolau 2005).

Preliminary analysis of one year (August 2008 to August 2009) of NPS (2013) data on water temperatures at the Baffin Bay and Bird Island loggers in Laguna Madre is presented in Figure 25. Water temperatures fluctuate daily and seasonally with rising and falling ambient temperatures. There is a clear, but not unexpected, annual pattern of lower water temperatures in the cooler winter months and higher water temperatures in the warmer summer months. It is not clear how weather events affect daily or periodic water temperature fluctuations and more analysis is needed to understand how such changes in water temperature alters other water quality parameters, such as dissolved oxygen. During summer months, water temperatures can reach as high as 35 °C (95 °F), but fall as low as 10 °C (50 °F) during the winter months. In the analysis of temperatures from August 2008 through August 2009, only two records exceeded the TCEQ standard with a measurement of 35.15 °C (95.3 °F) and 35.1 °C (95.2 °F), occurring on 4 August and 8 August 2008, respectively.

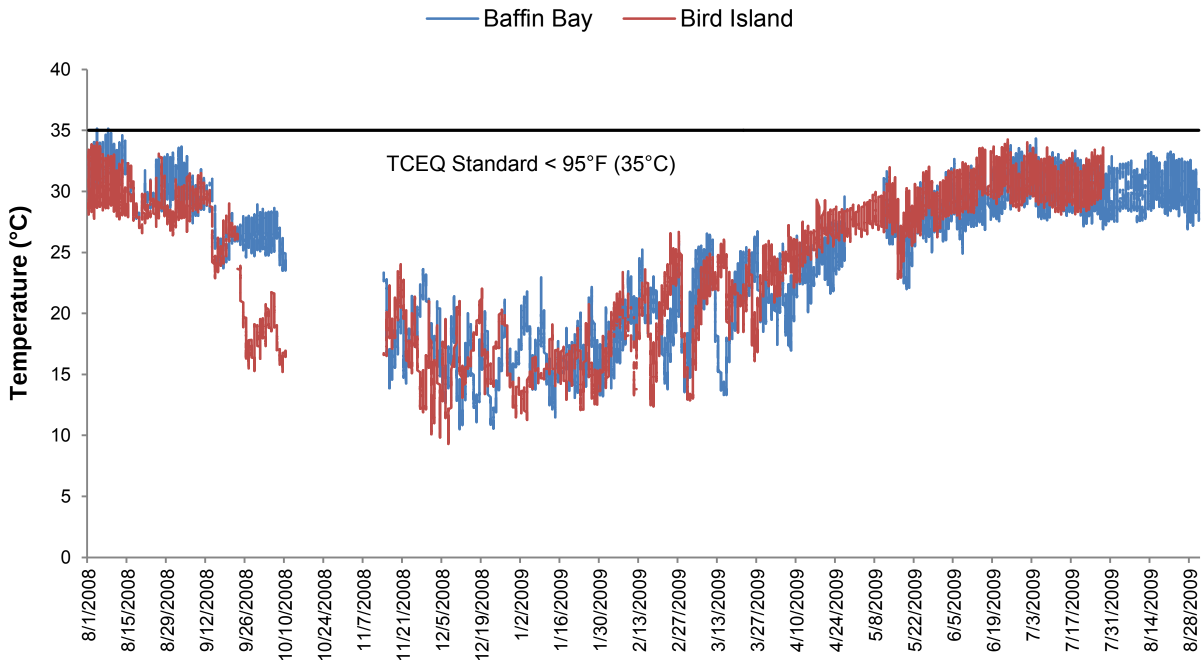

Figure 25. Fluctuations in daily water temperature (°C) observations from Baffin Bay and Bird Island data loggers in the Laguna Madre in PAIS, August 2008 through August 2009 (NPS 2013).

<u>pH</u>

Sissom et al. (1990) documented seasonal averages for pH in the three main freshwater ponds in PAIS. Pond A had a pH range from 8.13 to 8.46; there were no exceedances of the TCEQ standard considered protective of freshwater aquatic life (9.0 for freshwater) recorded at this pong during sampling. pH in Pond B ranged from 7.7 to 9.8; one exceedance (9.8) occurred in the month of September during sampling. Pond C had a pH range from 8.2 to 9.2; one exceedance (9.2) occurred in the month of September during sampling. Table 57 shows pH values for each month during the study across the three freshwater ponds in PAIS.

Table 57. pH values for three freshwater ponds located in PAIS, September 1989 through August 1990 (Sissom et al. 1990). Exceedances are denoted by bolded red text.

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Pond A	8.8	8.5	8.1	8.2	8.0	8.2	8.5	8.5	8.3	8.5	8.4	8.2
Pond B	**9.8**	8.6	8.5	7.7	8.0	8.5	8.5	8.6	8.4	8.5	8.6	8.3
Pond C	**9.2**	8.3	8.5	8.5	8.4	8.2	8.4	8.4	8.5	8.5	8.3	8.3

NPS (2003) documented a total of 92 pH observations collected at monitoring locations in the Laguna Madre in PAIS between 1968 and 1982. A total of 15 observations exceeded the upper limits of the EPA threshold considered protective of marine aquatic life (6.5 to 8.5 standard units): nine observations at PAIS0080 and six observations at PAIS0119. Across the three monitoring locations, pH ranged from 7.5 to 8.7. Due to the intermittent nature of these data, it is not possible to determine a trend in pH values over time. Table 58 shows the summary characteristics of pH observations from the three PAIS stations in the Laguna Madre.

Table 58. Summary of pH observations from three water quality stations in the Laguna Madre in PAIS, including minimum, maximum, and mean values, and number of exceedances (NPS 2003).

Station	Time Period	Number of Observations	Minimum	Maximum	Mean	Exceedances
PAIS0016	1968-1974	33	7.5	8.4	8.1	0
PAIS0080	1968-1978	30	7.8	8.7	8.3	9
PAIS0119	1968-1982	29	7.8	8.7	8.3	6

Wilson and Dunton (2011) recorded 285 pH observations in the lower Laguna Madre and 143 observations in the upper Laguna Madre during sampling in 2011. A total of 27 observations exceeded the upper limit of the TCEQ standard considered protective of marine aquatic life: 17 observations in the lower Laguna Madre and 10 observations in the upper Laguna Madre. Table 59 displays a summary of pH observations collected from the upper and lower Laguna Madre during sampling by Wilson and Dunton (2011). Plate 33 graphically represents pH values in the Laguna Madre as a result of recent monitoring efforts (2011 and 2012).

Table 59. Summary of pH observations from the upper and lower Laguna Madre, including minimum, maximum, and mean values collected in 2011 (Wilson and Dunton 2011).

Laguna Madre Section	Number of Observations	Minimum	Maximum	Mean	Exceedances
Lower Laguna Madre	285	7.50	9.04	8.09	17
Upper Laguna Madre	143	6.99	8.84	7.96	10

Preliminary analysis of one year (August 2008 to August 2009) of NPS (2013) data on pH from the Baffin Bay and Bird Island loggers in the Laguna Madre is presented in Figure 26. None of the pH measurements exceeded the TCEQ standard range. Initial analysis of data suggests that pH varies widely both diurnally and seasonally. For instance, in the snapshot of data from 2008 shown in Figure 26, pH levels appear to be lower and fluctuate less during the cooler winter months, but variability increases substantially during the warmer summer months. Further analysis is needed to understand the effect of bio-chemical changes in the Laguna Madre as temperature changes diurnally and seasonally.

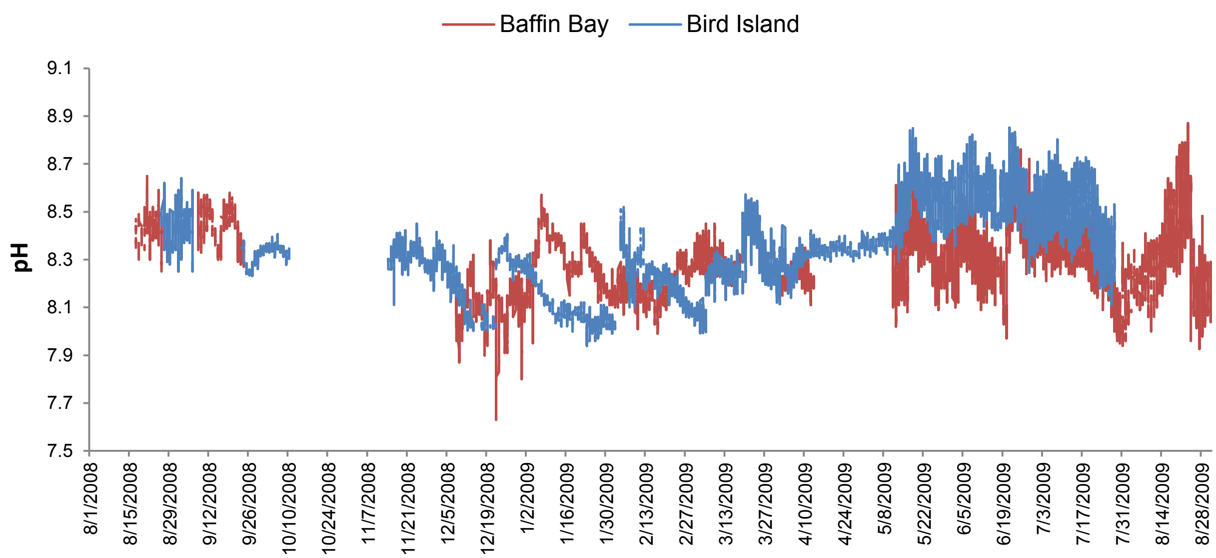

Figure 26. Fluctuations in daily pH observations from Baffin Bay and Bird Island data loggers in the Laguna Madre in PAIS, August 2008 through August 2009 (NPS 2013).

Salinity

Sissom et al. (1990) documented salinity values from three ponds in PAIS during a sampling effort in 1989 and 1990. Salinity in Pond A ranged from 0.12 to 0.64 ppt. Salinity in Pond B ranged from 0.12 to 2.5 ppt; all but one observation (2.5 ppt in August 1990) fell well below 1.0 ppt. It is not clear what occurred in August 1990 to substantially increase the salinity level in Pond B over all other months of sampling. Salinity observations in Pond C were substantially higher overall than the other two ponds, with observations ranging from 10.5 to 19.8 ppt. Of the three ponds, Pond C is located the closest to the Gulf of Mexico. Sissom et al. (1990) speculated several theories for increased salinity in Pond C, including increased levels are 1) due to higher incidence of wash-over of saltwater from the Gulf of Mexico during storm events, 2) leaching from salt deposits in the substrate of the island, or 3) salt entering the pond from groundwater coming in through the substrate from the bay. Regardless of how the salt entered the pond, Sissom et al. (1990) refers to it as a brackish environment rather than freshwater. Table 60 displays salinity observations (ppt) for the three ponds in PAIS from September 1989 through August 1990.

Table 60. Salinity values (ppt) for three freshwater ponds located in PAIS, September 1989 through August 1990 (Sissom et al. 1990).

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Pond A	0.48	0.64	0.64	0.32	0.32	0.36	0.24	0.24	0.2	0.2	0.12	0.3
Pond B	0.80	0.40	0.20	0.22	0.20	0.12	0.18	0.20	0.18	0.20	0.15	2.5
Pond C	14.60	12.0	14.0	16.5	18.0	19.80	10.5	12.0	11.80	14.0	15.30	19.0

Nicolau (2005) calculated monthly salinity averages for 24 consecutive months for three stations in the upper Laguna Madre and three stations in the lower Laguna Madre between August 2003 and July 2005. Salinity levels at the upper Laguna Madre stations ranged from 25 to 50 ppt, with most observations measured between 25 and 40 ppt. Figure 27 displays monthly average salinity values at three sampling locations in the upper Laguna Madre in PAIS from 2003 to 2005. Salinity values at the lower Laguna Madre sampling locations were found to be overall more variable than those values of the upper Laguna Madre, with some salinity values recorded as being quite low (range across sampling locations was 6.09 to 44.71 ppt). Figure 28 displays monthly average salinity values at the three sampling locations in the lower Laguna Madre between 2003 and 2005.

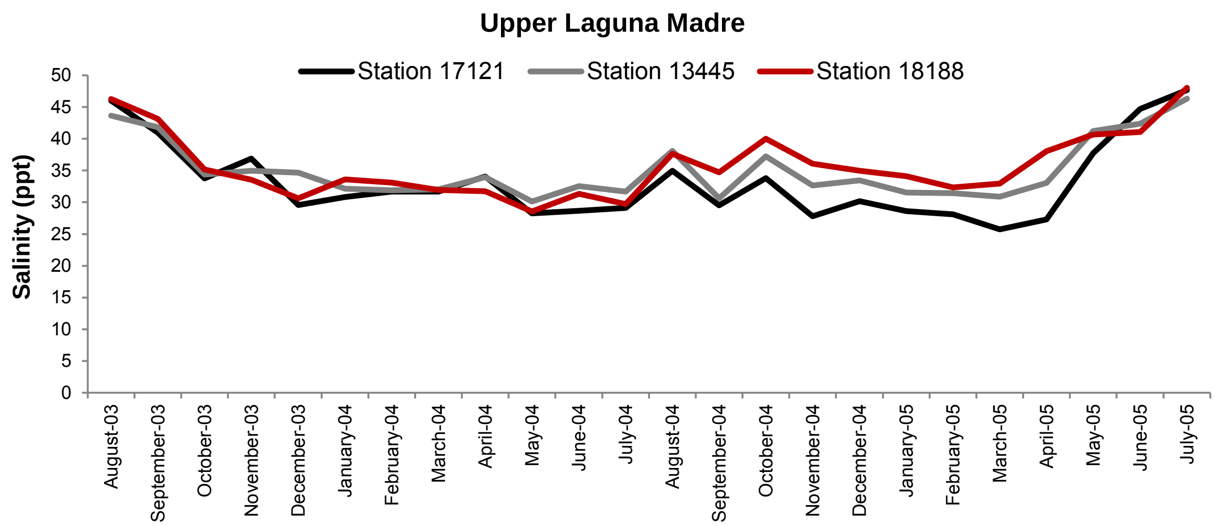

Figure 27. Average monthly salinity values (ppt) from three water quality stations in the Laguna Madre, August 2003 through July 2005 (Nicolau 2005).

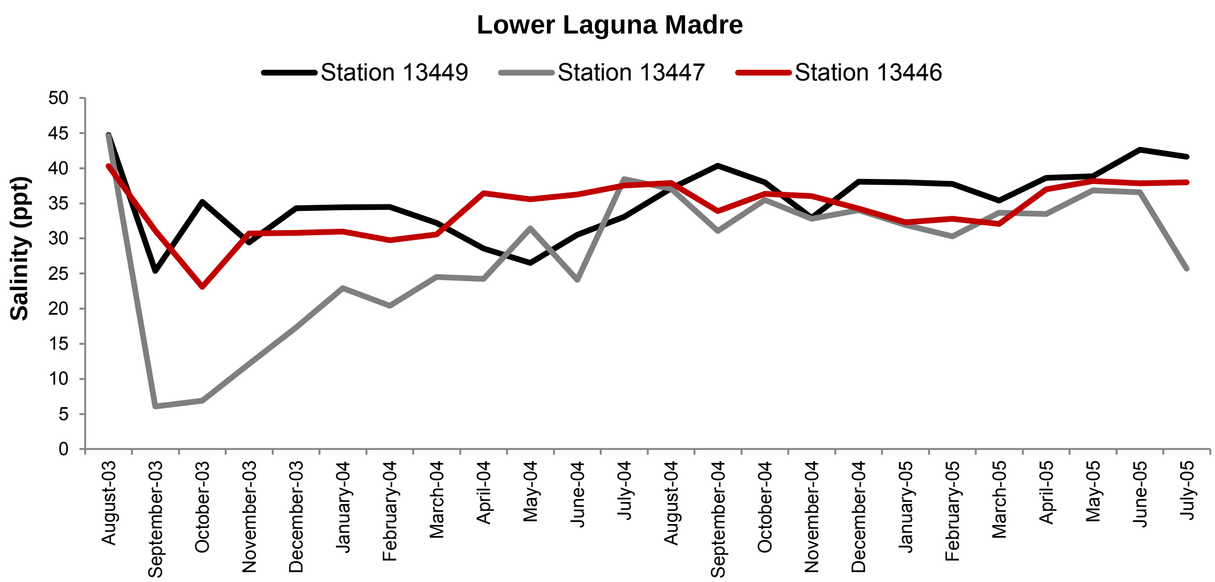

Figure 28. Average monthly salinity values (ppt) from three stations in the lower Laguna Madre in PAIS, August 2003 through July 2005 (Nicolau 2005).

Wilson and Dunton (2011) recorded 284 salinity observations in the lower Laguna Madre and 142 observations in the upper Laguna Madre during sampling in 2011. The salinity in the lower

Laguna Madre ranged from 30.82 to 55.64 ppt; salinity levels were much more varied in the upper Laguna Madre, ranging from 7.43 to 74.20 ppt. Table 61 displays a summary of salinity observations from the upper and lower Laguna Madre in 2011. Plate 34 graphically represents salinity values in the Laguna Madre as a result of recent monitoring efforts (2011 and 2012).

Table 61. Summary of salinity observations from the upper and lower Laguna Madre, including minimum, maximum, and mean values collected in 2011 (Wilson and Dunton 2011).

Laguna Madre Section	Number of Observations	Minimum	Maximum	Mean
Lower Laguna Madre	284	30.82	55.64	41.64
Upper Laguna Madre	142	7.43	74.20	49.32

Preliminary analysis of one year (August 2008 to August 2009) of NPS (2013) data on salinity from the Baffin Bay and Bird Island loggers in the Laguna Madre is presented in Figure 29. Salinity in the Laguna Madre appears to have increased steadily from mid-summer 2008 through mid-summer 2009, showing a numeric increase of around 15 to 20 ppt across the year at both sampling locations. Further analysis is necessary to understand what other factors may be contributing to the overall increase in salinity, as well as which factors have a dynamic relationship with salinity in the lagoon that influence changes daily, seasonally, or across several years. For instance, drought may contribute substantially to increased salinity over time, as evaporation rates exceed rates of precipitation, thus concentrating salts in the lagoon system. Precipitation records were not considered in conjunction with these data during this preliminary analysis, but would be pertinent in understanding trends in salinity during more in-depth analysis of the dataset.

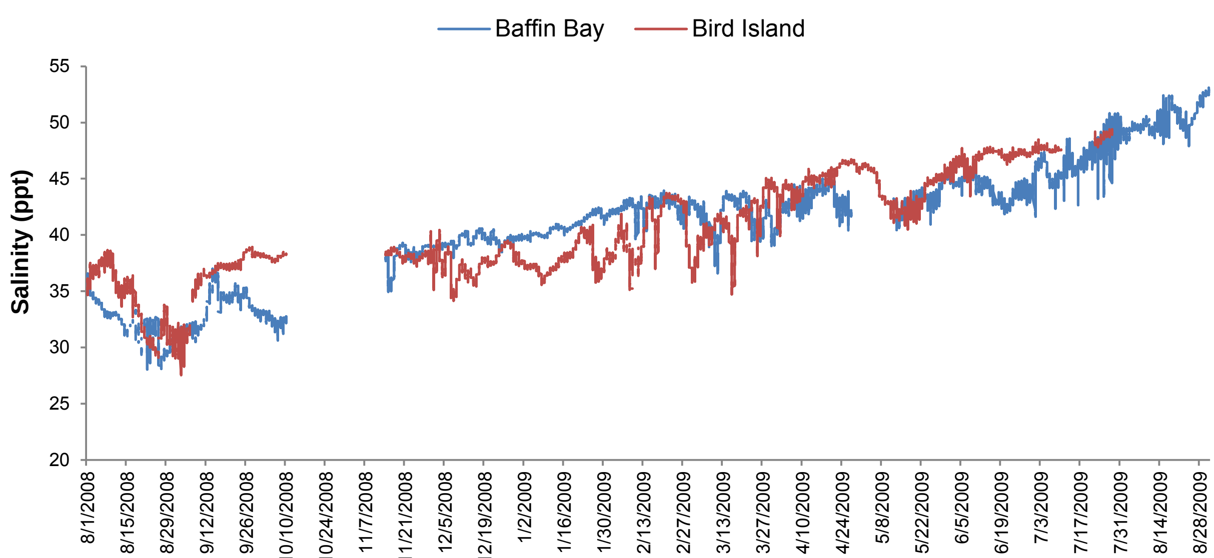

Figure 29. Fluctuations in daily salinity values (ppt) from Baffin Bay and Bird Island data loggers in the Laguna Madre in PAIS, August 2008 through August 2009 (NPS 2013).

<u>Turbidity</u>

Sissom et al. (1990) documented turbidity levels from the three main freshwater ponds in PAIS. Turbidity in Pond A ranged from 10.0 to 70.0 NTU; highest turbidity measurements in Pond A appeared to occur in spring to early summer months, perhaps due to the effects of increased precipitation. Due to blue green algae present in Pond B nearly all year, turbidity levels consistently measured higher than the other ponds. During sampling, Pond B turbidity ranged from 25 to 190 NTU; turbidity decreases when water temperatures drop or the pond freezes during winter months, but increases again after it thaws in the spring. Turbidity observations in Pond C ranged from 0 to 20 NTU during sampling. Table 62 displays turbidity observations at the three ponds in PAIS from September 1989 through August 1990.

Table 62. Turbidity observations (NTU) for three freshwater ponds located in PAIS, September 1989 through August 1990 (Sissom et al.1990).

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Pond A	12.0	18.0	29.0	10.0	15.0	25.0	42.5	70.0	65.0	33.0	20.0	20.0
Pond B	110.0	90.0	180.0	190.0	25.0	90.0	93.0	138.0	101.0	144.0	140.0	155.0
Pond C	18.0	14.0	10.0	5.0	2.0	18.0	20.0	30.0	3.0	20.0	0.0	0.0

NPS (2003) reported 21 turbidity observations collected at three monitoring stations in the Laguna Madre in PAIS from 1974 to 1976. No exceedances were observed among the PAIS stations (standard used is 50 NTU). Table 63 displays the turbidity records from the three PAIS stations.

Table 63. Summary of turbidity observations (NTU) from three water quality stations in the Laguna Madre in PAIS, including minimum, maximum, and mean values, and number of exceedances (NPS 2003).

Station	Time Period	Number of Observations	Minimum	Maximum	Mean	Exceedances
PAIS0016	1974-1974	6	8	16	10	0
PAIS0080	1974-1976	13	4	28	12.4	0
PAIS0119	1974-1974	2	4	4	4	0

NPS (2013) has documented continuous turbidity levels as well as a number of turbidity events from 2008 through 2012 (data are still recorded currently). Turbidity can be affected by a number of factors including weather events, recreation activities, shipping or marine vehicle travel through the lagoon, etc. Waters with increased turbidity can become difficult for plant and animal life to thrive in. Trends in turbidity are not presented here as more analysis is needed. However, based on preliminary analysis of data from August 2008 through August 2009, data suggest that spikes in turbidity can be short- (a few hours) or long-lived (several days or weeks) in the Laguna Madre. Three large spikes in turbidity were recorded at the Bird Island station in the lagoon between August 2008 and August 2009. Figure 30 shows an example of a relatively long-lasting turbidity spike that occurred near the Bird Island logger between 30 August 2008 and 5 September 2008. Figure 31 shows the largest of three short-lived turbidity spikes captured at the Bird Island station on 25 June 2009. The largest of the three spikes measured at 804 NTU, while subsequent spikes were much lower; this series of spikes lasted approximately seven hours. Further analysis is needed to understand which factors contribute to spikes in turbidity in addition to overall consistent turbidity conditions.

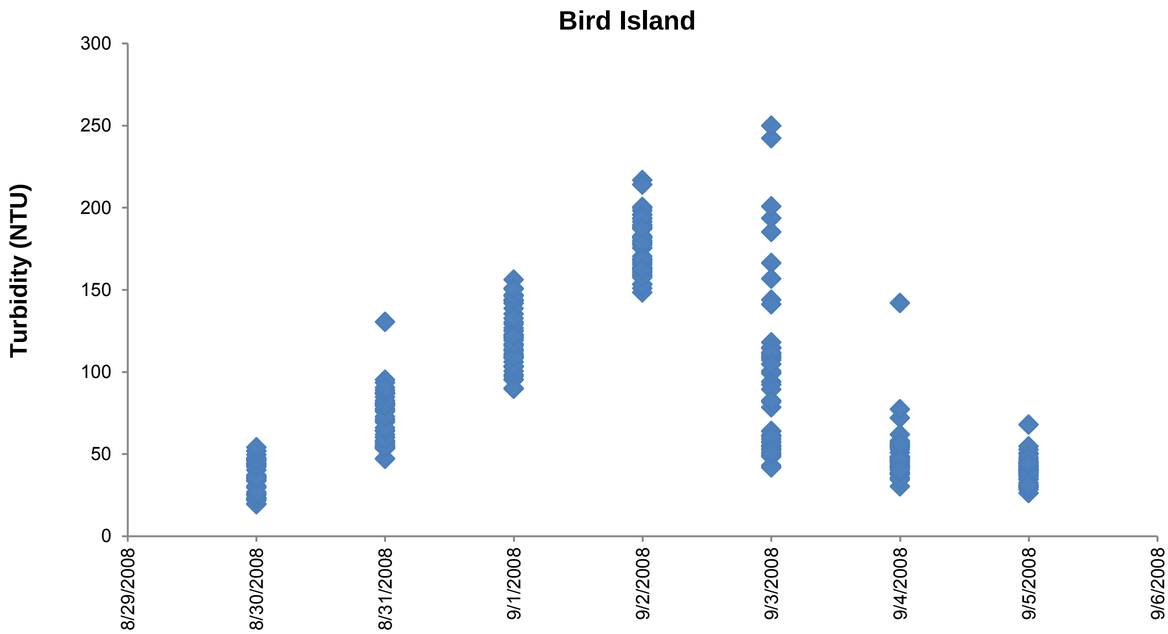

Figure 30. Turbidity event lasting several days captured at the Bird Island data logger in the Laguna Madre in PAIS between 30 August and 5 September 2008 (NPS 2013). Data points represent observations taken throughout each day.

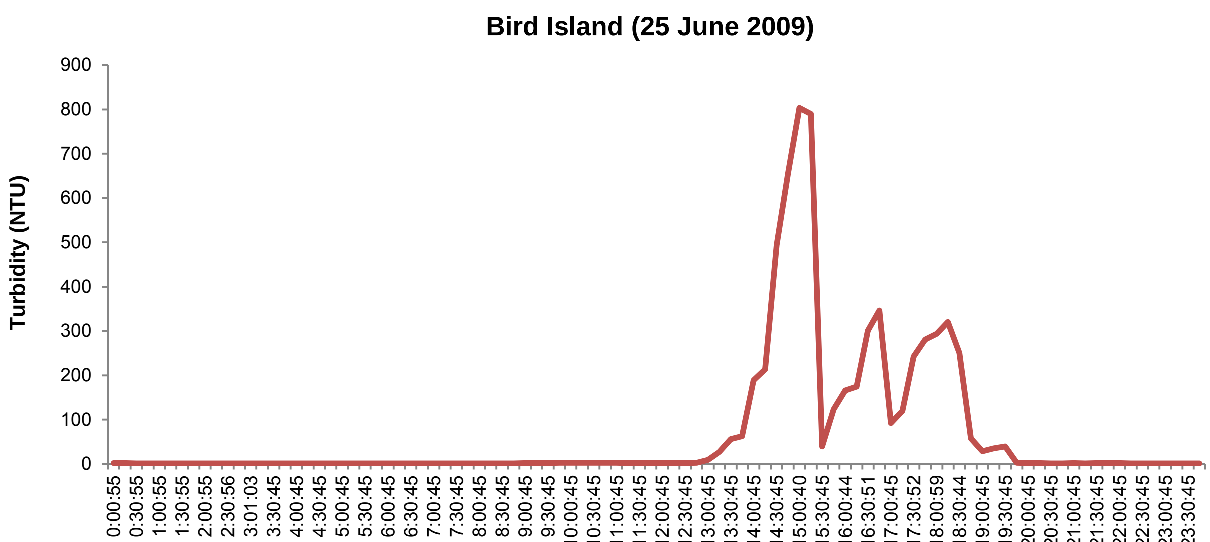

Figure 31. Short-term spike in turbidity (approximately 7 hours) as captured at the Bird Island data logger in the Laguna Madre in PAIS on 25 June 2009 (NPS 2013).

Nutrients

Nicolau (2005) studied levels of six different nutrients at six monitoring stations in the upper and lower Laguna Madre from August 2003 through August 2005. A total of 48 observations were recorded at three monitoring stations in the upper Laguna Madre, in which 16 water samples were collected at each location and analyzed for nutrients. Likewise, 48 observations were recorded at three monitoring stations in the lower Laguna Madre, with 16 water samples collected at each site and analyzed for nutrients over the two year sampling period. Table 64 displays summary characteristics of water samples analyzed for five nutrients in the upper and lower Laguna Madre. Concentrations of chlorophyll-a were elevated at all three monitoring stations in the upper Laguna Madre in 50% (Station 17121) to 75% (Stations 13445 and 18188) of samples collected, totaling 31 exceedances of the TCEQ threshold (11.5 µg/L) out of 48 samples collected. All other nutrients in the upper Laguna Madre were within the range deemed acceptable for protection of marine aquatic life, with the exception of total phosphate which exceeded the upper limits in two samples (one at Station 13445 and one at Station 17121). Samples from the lower Laguna Madre reflect similar results, in that chlorophyll-a exceeded the upper limits of the TCEQ threshold in 19 of 48 samples (approximately 40% of samples); 10 of the exceedances occurred at Station 17121 and 9 occurred at station 18188. Samples collected at Station 17121 revealed elevated levels of all nutrients under investigation at least once and up to four times during the two-year period when samples were collected.

Table 64. Nutrient ranges and exceedances from six water sampling locations in the upper and lower Laguna Madre in PAIS, August 2003 and August 2005 (Nicolau 2005). Note: samples were not collected from November 2004 through February 2005.

Upper Laguna Madre						
	Station 13445		Station 17121		Station 18188	
Nutrient	**Range**	**Exceeded**	**Range**	**Exceeded**	**Range**	**Exceeded**
Ammonia (mg/L)	<0.02-0.03	0	<0.02-0.05	0	<0.02-0.06	0
Nitrate+Nitrite (mg/L)	<0.02-<0.04	0	<0.02-<0.04	0	<0.02-<0.04	0
Orthophosphate(mg/L)	<0.04-0.08	0	<0.04	0	<0.04	0
Total Phosphate(mg/L)	0.03-0.24	1	0.04-0.24	1	0.04-0.13	0
Chlorophyll-a (µg/L)	1.8-30.5	12	0.08-40.5	7	8.1-58.6	12
Lower Laguna Madre						
	Station 13445		Station 17121		Station 18188	
Nutrient	**Range**	**Exceeded**	**Range**	**Exceeded**	**Range**	**Exceeded**
Ammonia (mg/L)	<0.02-0.06	0	<0.02-0.15	2	<0.02-0.06	0
Nitrate+Nitrite (mg/L)	<0.04-0.04	0	<0.04-0.88	4	0.02-0.06	0
Orthophosphate(mg/L)	0.02-<0.04	0	0.02-0.18	1	0.02-0.07	0
Total Phosphate (mg/L)	0.03-0.08	0	<0.06-0.27	1	0.04-0.17	0
Chlorophyll-a (µg/L)	0.8-5.3	0	4.4-87.5	10	2.0-36.4	9

NPS (2012c) NPSTORET provided monthly nutrient data collected from October 2010 to November 2012 at two monitoring locations in the Laguna Madre, one at Baffin Bay and the other at Bird Island. The database includes observations for ammonia, nitrate+nitrite, orthophosphate, total phosphorus, and chlorophyll-a. Nearly all records included in the query report nutrients present and at levels less than the quantification limit, which means they are within the acceptable threshold considered protective of marine aquatic life. A few observations provide actual numeric values, of which nearly all were within the acceptable limits for nutrients in a marine ecosystem. The exception to this are observations of chlorophyll-a in October and

November 2012 at both Bird Island and Baffin Bay data loggers; observations at Baffin Bay in October and November 2012 were 27.2 and 24.0 µg/L, while observations at Bird Island were 12.0 and 17.5 µg/L, respectively. These observations all exceed the TCEQ threshold considered protective of marine aquatic life (11.5 µg/L).

Threats and Stressor Factors

Oil and gas exploration and development are a major threat to water quality in PAIS. There are six active oil pads in the park, and a total of 11 wells that are active. Two more pads are scheduled for restoration in the near future, and no new wells are planned for the near future (Stablein, written communication, 14 May 2013). If any leaks or spills occurred near the shoreline or inundation zone, it could result in contaminated water in the Laguna Madre. Boat traffic and dredging activity can result in re-suspension of material, which increases turbidity; high turbidity levels can negatively affect aquatic organisms such as fish and seagrass species.

Another threat to the park's water quality, from a public health standpoint, is tied in with high levels of *E. coli* and fecal coliform bacteria that are found in runoff after high rain events. Potential sources of fecal contaminants include the numerous state-approved fishing cabins in the Laguna Madre (most of the cabins are floating in the Laguna) (Stablein, written communication, 14 May 2013). These cabins are mandated to contain their human waste and have it pumped out; however, it is certainly possible that some of these cabins will dump their waste directly into the Laguna. To check for fecal contamination, PAIS tests the water near areas of high visitor use six times a week; three samples are taken from the Malaquite Visitor Center area, and three samples are taken from the Bird Island windsurfing area.

Natural events such as hurricanes and tropical storms can cause major inundations, which can adversely affect water quality in PAIS. Storms can cause changes in turbidity and salinity. According to Steward et al. (2006), waves and wind can cause erosion and re-suspend sediment, causing increased turbidity. Strong wind and wave action from storms will only worsen the erosion in the park that has been caused by the practice of brush clearing. Storms can also cause decreased salinity levels that can remain low for months, depending on the extent of the storm (Steward et al. 2006). Furthermore, rivers that once reached the Laguna Madre no longer do, primarily due to high water demands in the area. During periods of drought, there may be times when the salinity becomes very high, as the cycle of tides coming in and water evaporating out of the Laguna will elevate the salinity of the remaining water.

Hurricanes and storms can also adversely affect fish and seagrass species. The loss or depletion of seagrass can be a stressor on water quality. Seagrass communities help create a stable lagoon bottom (Moore 2004), which may lead to overall lower turbidity levels. Seagrass also absorbs nutrients and oxygenates water, resulting in improved water quality (TPWD 2011); loss of seagrass beds could cause an increase in nutrients in the water column.

Although algae are natural components of marine and fresh water systems, excessive growth of algae can become a significant threat to users of water bodies and the ecological balance and health of a system. Algae that have grown excessively dense, some species of which can be toxic in high biomass blooms (i.e., HABs), can impact water quality by altering the quantity and quality of light in the water column. This, in turn, can affect benthic flora and fauna that depend on light to thrive (EPA 2013, USGS 2013). Excessive blooms can accumulate as a layer of thick scum or a mat on the water surface, which upon decomposing, can stimulate hypoxia (high rates of oxygen consumption that result in very low dissolved oxygen levels) and lead to degradation or mortality of fish, shellfish, and invertebrate communities, as well as degrade aquatic plant habitats (EPA 2013). Algal toxins in HABs can cause mortality in terrestrial animals or waterbirds that use affected water sources (USGS 2013). Likewise, recreational users of water bodies affected by HABs can become ill from exposure to the cyanobacteria and toxins they create. The red tide that occurs in the Gulf of Mexico is of primary concern to PAIS managers. This brevetoxin has caused deaths among the resident coyotes in the park, and has contributed to the death of visitor's dogs as well (Stablein, written communication, 14 May 2013).

Brown tides (*Aureoumbra lagunensis*) also occur in the park, although more commonly in the Laguna Madre. Nutrient loading caused by winter freezes (i.e., fish kills from freezing weather) and heavy rain events result in runoff from agricultural fields on the mainland reaching the Laguna. Brown tides typically occur after a winter freeze and the associated fish kill from that freeze (Stablein, written communication, 14 May 2013). Population growth in the lower Laguna Madre may result in higher levels of runoff, and this runoff may also contribute to brown tide events. Brown tide events in high concentrations and densities may block out sunlight in the water and prevent seagrass colonies from receiving the necessary sunlight to survive (TPWD 2013).

Data Needs/Gaps

A number of data sources are available that speak to water quality in PAIS (either for the freshwater ponds or the Laguna Madre), but many of these datasets are outdated, short-term in nature, or intermittent in nature of collection. These circumstances make it difficult to understand the current conditions of water quality in the park-managed waters and how conditions may have changed over time. Data presented in NPS (2003) also used EPA standards for comparisons to determine exceedances, which are less conservative than TCEQ water quality standards commonly used for water quality assessment in Texas. Observations reported in NPS (2003) include only the date of observation and minimum, maximum, mean, and median values; individual records of observation are not included. This makes it impossible to know with certainty the total number of observations that met or exceeded TCEQ standards in addition to exceeding EPA standards. Wilson and Dunton (2011) provide data that are much more current for several water quality measures, but each sampling location provides only one data record per measure.

The NPS (2013) dataset is continuous and contains almost four full years of observations for DO, temperature, pH, salinity, and turbidity. Observations are collected every 15 minutes, 365 days a year (with the exception of some small data gaps), beginning in August 2008 to current. However, analysis of these data is in the very preliminary stages as of current and offers little insight into current condition for this assessment. Upcoming analysis of this dataset should prove to be highly valuable to understanding recent trends in water quality in the Laguna Madre, especially the complexities of the relationships among various water quality parameters and the other factors that have an influence on water quality.

Overall, consistent water quality sampling would provide PAIS managers with better insight into current water quality conditions (freshwater and marine) in the park. GULN has undertaken a consistent monitoring effort in the Laguna Madre, but there is nothing in place for Gulf of

Mexico waters or the freshwater ponds in the park. Consistent monitoring for these water features in addition to the Laguna Madre would, in the future, begin to illustrate trends in water quality that may be occurring over time.

<u>Overall Condition</u>

Dissolved Oxygen
The project team defined the *Significance Level* for dissolved oxygen as a 3. Nicolau (2005) restated that the Laguna Madre was considered impaired under the 2002 Texas Clean Water Act 303(d) list because of the depressed dissolved oxygen levels; however, this listing is outdated and NPS (2013) data suggest that Laguna Madre DO levels fluctuate diurnally and seasonally. Wilson and Dunton (2011) found average DO levels to be within the acceptable limits for protection of marine organisms. For the small segment of NPS (2013) data that were analyzed preliminarily, DO levels in the Laguna Madre overall are well within the range considered acceptable for marine aquatic life. There is not enough recent, long-term data analyzed to date that would help determine the current condition of DO levels in the freshwater ponds in PAIS. A *Condition Level* of 1 was assigned for dissolved oxygen, meaning it is of low concern in the park.

Temperature
The project team defined the *Significance Level* for temperature as a 3. Sissom et al. (1990) recorded one measurement from Pond B that exceeded the TCEQ temperature standard; however, these data are more than 20 years old. NPS (2003) and Nicolau (2005) did not record any exceedances in Laguna Madre water temperatures. Preliminary analysis of NPS (2013) data from August 2008 to August 2009 showed just two temperature measurements in the Laguna Madre in August 2008 that exceeded TCEQ standards for marine water temperature; however, more recent data have yet to be analyzed. Therefore, a *Condition Level* was not assigned at this time.

pH
The project team defined the *Significance Level* for pH as a 3. Sissom et al. (1990) recorded two pH exceedances from the freshwater Ponds B and C. NPS (2003) did not record any pH exceedances in the Laguna Madre. Wilson and Dunton (2011) recorded only two exceedances from two upper Laguna Madre sampling stations. Preliminary analysis of NPS (2013) data revealed no pH exceedances in the Laguna Madre PAIS from August 2008 to August 2009; however, more recent data have yet to be analyzed. A *Condition Level* of 0, meaning pH is of no concern, was assigned at this time.

Salinity
The project team defined the *Significance Level* for salinity as a 3. Sissom et al. (1990) recorded salinity levels for the three permanent ponds in PAIS; only Pond C had salinity measurements over 1 ppt (10.5 – 19.8 ppt). Nicolau (2005) observed salinity levels that ranged between 25 and 50 ppt in the Laguna Madre, which is considered a moderate salinity level. Saltwater fish and seagrass can still thrive under these conditions. Wilson and Dunton (2011) recorded several salinity measurements above 50 ppt in the upper Laguna Madre, with a mean salinity of 49.3 ppt. The highest salinity observation recorded was 74.2 ppt. The NPS (2013) data displayed a trend in increasing water salinity from August 2008 to August 2009; however, observations during that

time did not exceed 50 ppt. Further analysis of the NPS (2013) data is needed to understand recent and current trends in salinity of the Laguna Madre. Thus, a *Condition Level* of 2 was assigned for salinity, meaning salinity is of moderate concern.

Turbidity
The project team defined the *Significance Level* for turbidity as a 3. Turbidity in the freshwater ponds was found to be within TCEQ standards protective of freshwater aquatic life with the exception of Pond B, which consistently sustains high turbidity due to blue-green algae colonies. Turbidity in the Laguna Madre can vary diurnally and seasonally due to weather conditions and temperature, and sporadically due to isolated disturbances. Preliminary analysis of the NPS (2013) dataset from August 2008 to August 2009 revealed several instances of turbidity spikes at Baffin Bay and Bird Island in the Laguna Madre, some that persisted for several days and some that lasted for just a few hours. There are more consistent turbidity spikes at the Baffin Bay logger, which may be the result of more boat traffic. Further analysis of the NPS (2013) data is needed to understand recent and current trends in turbidity of the Laguna Madre, and the factors that influence it. A *Condition Level* of 1 was assigned at this time, meaning turbidity is of low concern.

Nutrients
The project team defined the *Significance Level* for nutrients as a 3. Nicolau (2005) found that four of five nutrients studied in the Laguna Madre fell within the acceptable limits for protection of marine aquatic life; the exception was Chlorophyll-a, which exceeded TCEQ limits in 65% of samples collected in the upper Laguna Madre and 40% of samples collected in the lower Laguna Madre from August 2003 to August 2005. NPS (2012c) NPSTORET data report most observations with nutrient levels below the quantifiable limit, with the exception of chlorophyll-a, which were found to exceed TCEQ standards in October and November 2012. Thus, a *Condition Level* of 1 was assigned, meaning nutrients are of low concern.

Weighted Condition Score
The *Weighted Condition Score* for water quality in PAIS was calculated as 0.333, meaning the current condition is of moderate concern. A trend in water quality could not be determined at this time.

Water Quality

Measures	SL	CL
• Dissolved Oxygen	3	1
• Temperature	3	n/a
• pH	3	0
• Salinity	3	2
• Turbidity	3	1
• Nutrients	3	1

WCS = 0.333

Sources of Expertise

Joe Meiman, Hydrologist, GULN

Wade Stablein, Biological Technician, PAIS

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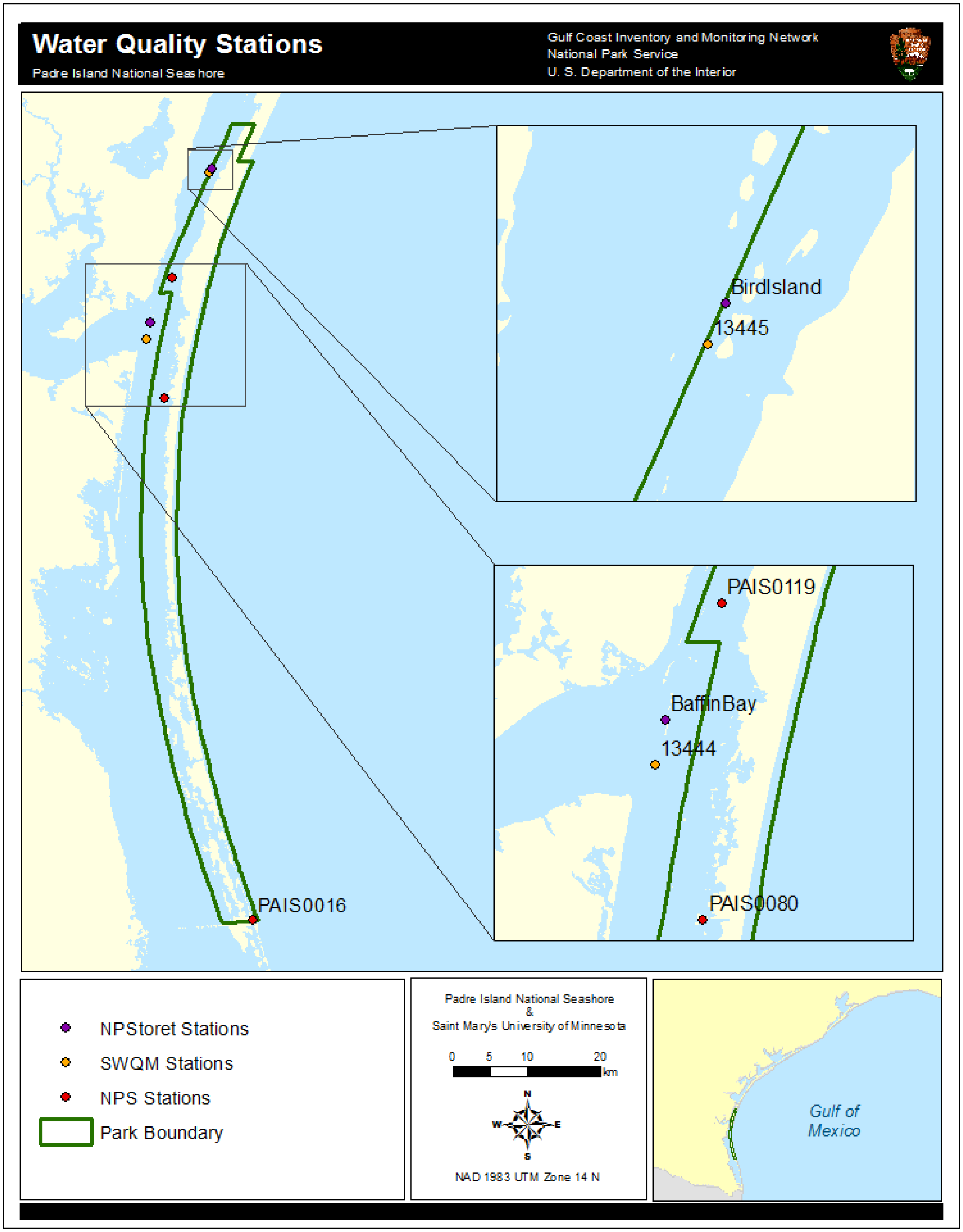

Plate 31. Locations of the long-term water quality sampling stations featured in NPS (2003), NPS (2012c) NPSTORET database, and the NPS (2013) Gulf Network monitoring effort on the Laguna Madre in PAIS. Purple markers indicate stations used in the NPS (2012c) data query; Yellow markers indicate TCEQ SWQM stations where NPS (2013) data are collected; Red markers indicate stations queried for the NPS (2003) baseline water quality inventory.

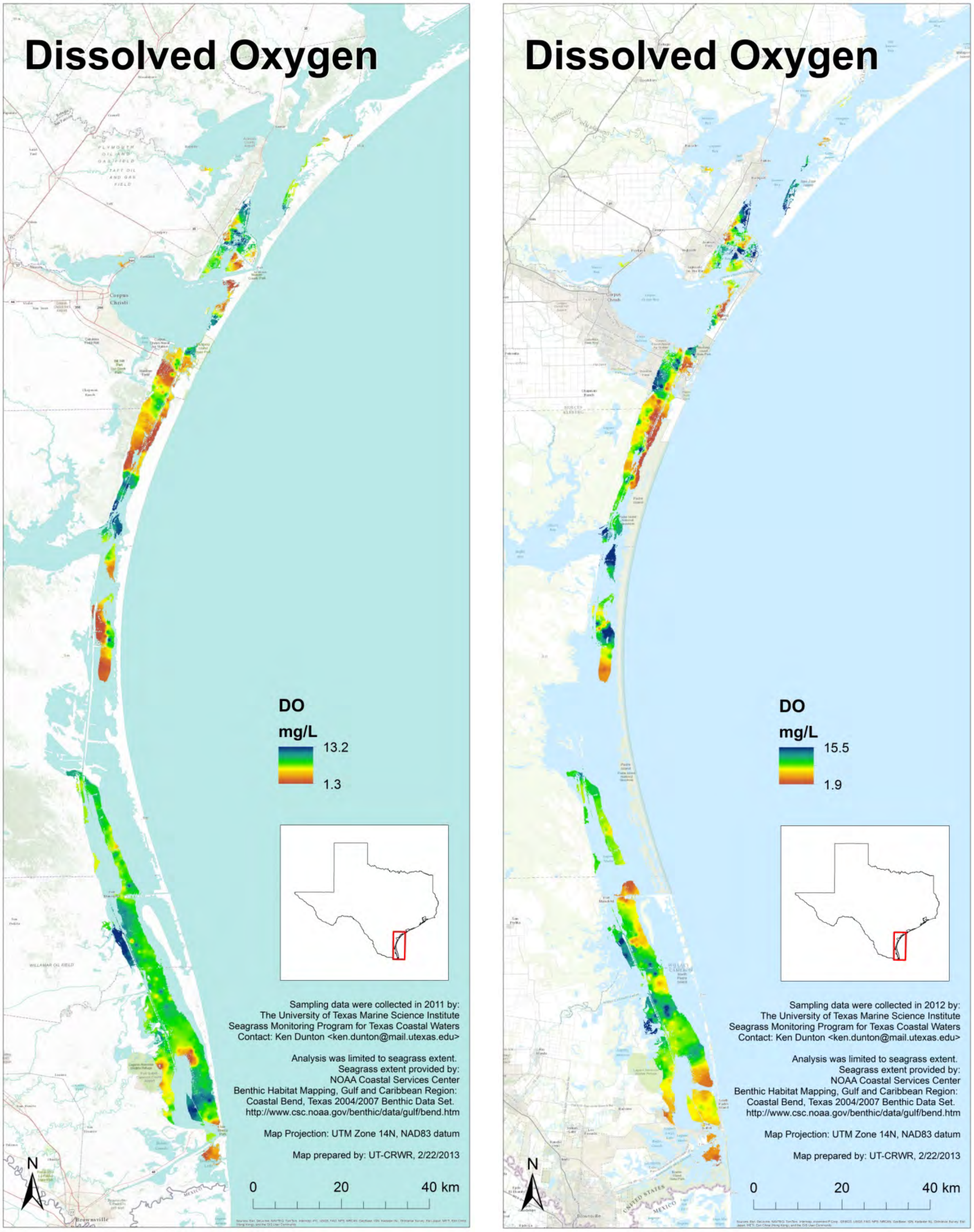

Plate 32. Dissolved oxygen values in the Laguna Madre from 2011 (left) and 2012 (right) based on monitoring surveys conducted by Wilson and Dunton (2012).

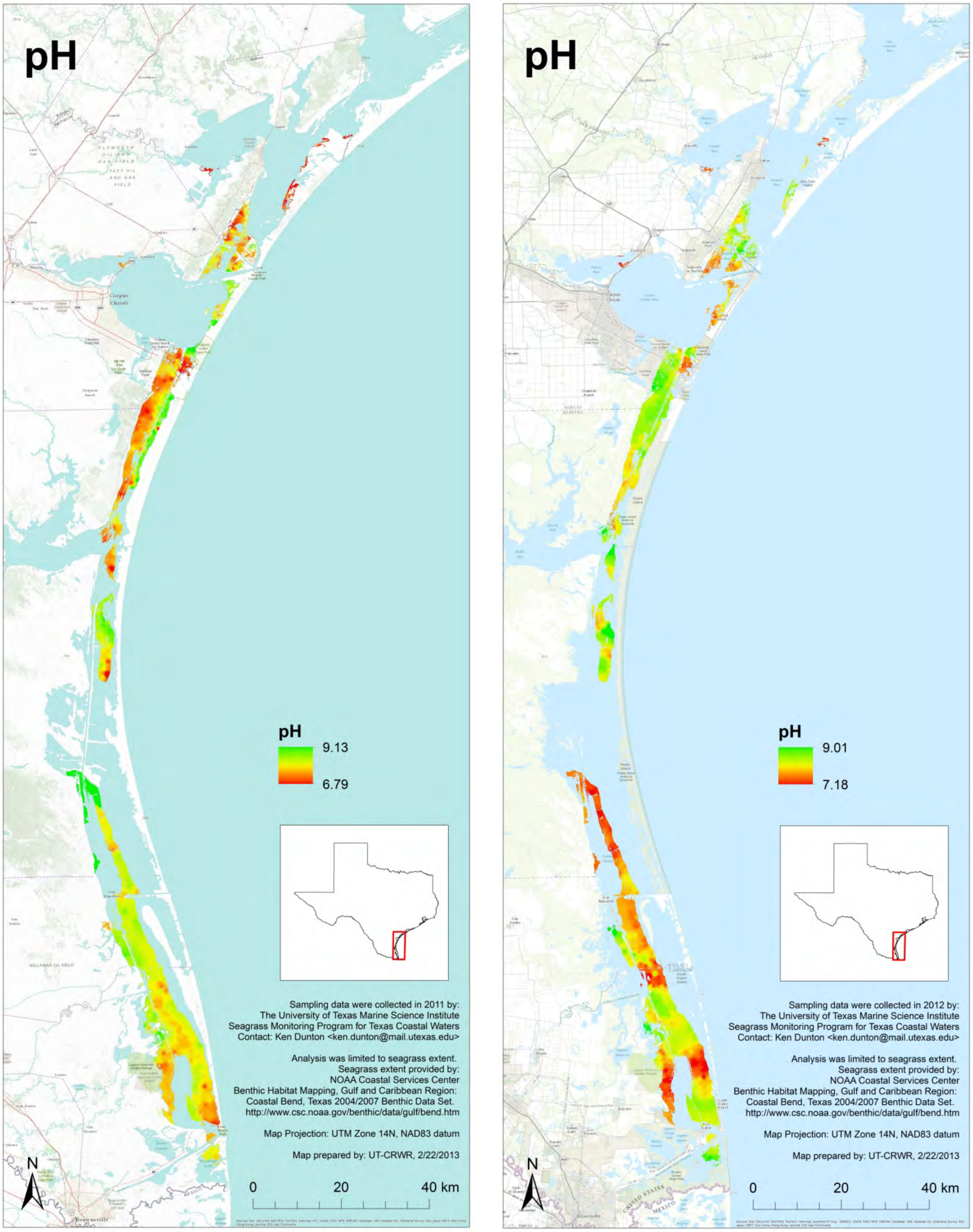

Plate 33. pH values in the Laguna Madre from 2011 (left) and 2012 (right) based on monitoring surveys conducted by Wilson and Dunton (2012).

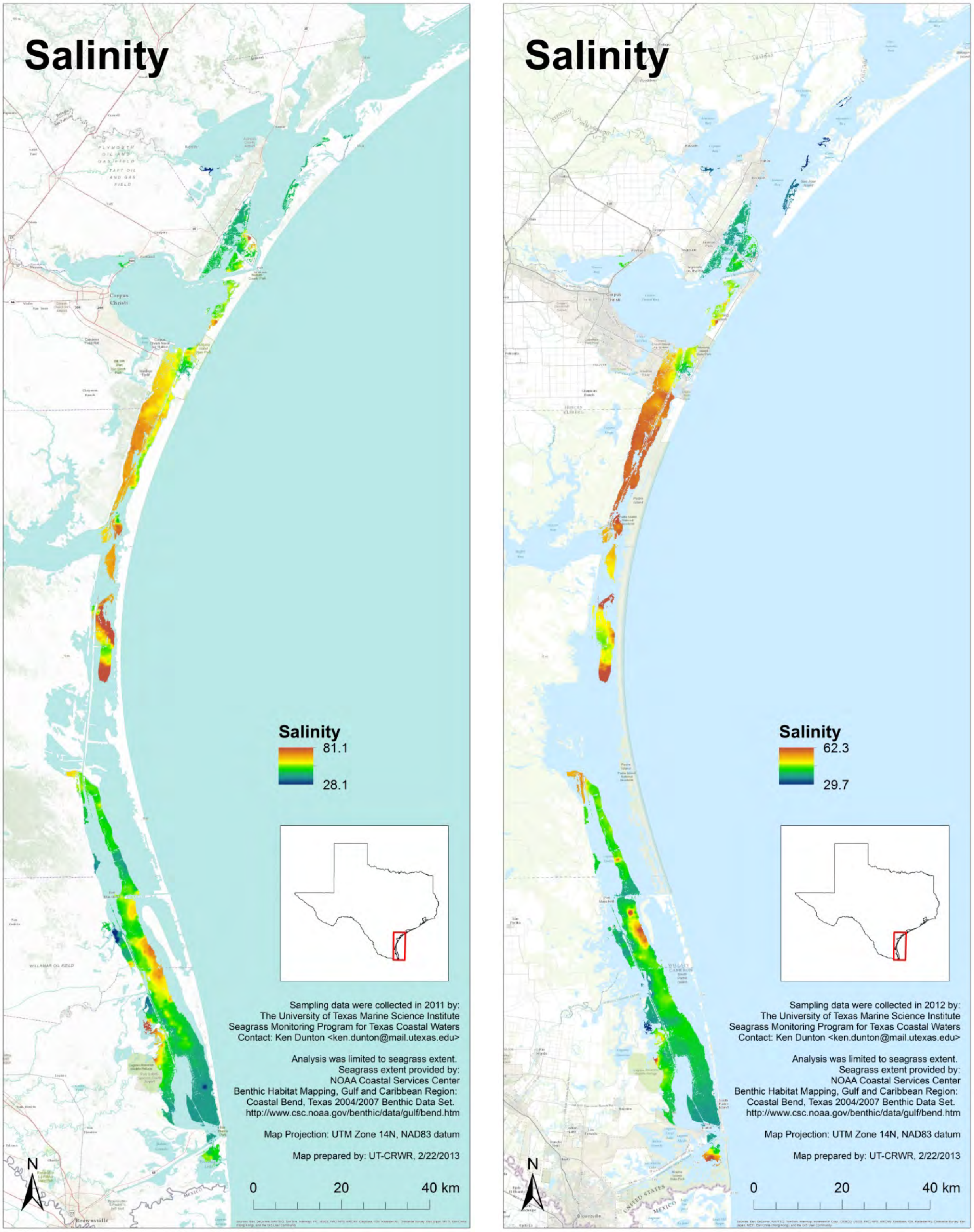

Plate 34. Values in the Laguna Madre from 2011 (left) and 2012 (right) based on monitoring surveys conducted by Wilson and Dunton (2012).

4.15 Air Quality

Description

Air pollution can significantly affect natural resources and their associated ecological processes. Consequently, air quality in parks and wilderness areas is protected and regulated through the 1916 Organic Act and the Clean Air Act of 1977 (CAA) and the CAA's subsequent amendments. The CAA defines two distinct categories of protection for natural areas, Class I and Class II airsheds. Class I airsheds receive the highest level of air quality protection as offered through the CAA; only a small amount of additional air pollution is permitted in the airshed above baseline levels. For Class II airsheds, the increment ceilings for additional air pollution above baseline levels are slightly greater than for Class I areas and allow for moderate development (EPA 2008a). PAIS is designated as a Class II airshed.

Measures

- Nitrogen deposition
- Sulfate deposition
- Mercury deposition/concentration
- Ozone concentration
- Particulate matter ($PM_{2.5}$)
- Visibility

Atmospheric Deposition of Nitrogen and Sulfur

Nitrogen and sulfur oxides are emitted into the atmosphere primarily through the burning of fossil fuels, industrial processes, and agricultural activities (EPA 2008b). While in the atmosphere, these emissions form compounds that may be transported long distances and settle out of the atmosphere in the form of pollutants such as particulate matter (e.g., sulfates, nitrates, ammonium) or gases (e.g., nitrogen dioxide, sulfur dioxide, nitric acid, ammonia) (EPA 2008b, NPS 2008). Atmospheric deposition can be in wet (i.e., pollutants dissolved in atmospheric moisture and deposited in rain, snow, low clouds, or fog) or dry (i.e., particles or gases that settle on dry surfaces as with windblown dusts) form (EPA 2008b). Deposition of sulfur and nitrogen can have significant effects on ecosystems, including acidification of water and soils, excess fertilization or increased eutrophication, changes in the chemical and physical characteristics of water and soils, and accumulation of toxins in soils, water, and vegetation (NPS 2008, reviewed in Sullivan et al. 2011a and 2011b). The native vegetation in the semi-arid and grassland plant communities in PAIS is considered sensitive to excess nitrogen and acidic deposition (Sullivan et al. 2011c, 2011d).

Mercury

Sources of atmospheric mercury include fuel combustion and evaporation (especially coal-fired power plants), waste disposal, mining, industrial sources, and natural sources such as volcanoes and evaporation from mercury-enriched soils, wetlands, and oceans (EPA 2008b). Mercury deposited into rivers, lakes, and oceans can accumulate in various aquatic species, resulting in exposure to wildlife and humans (EPA 2008b). PAIS supports several freshwater ponds that are important habitat for a variety of wildlife, especially migrating waterfowl and waterbirds.

Ozone

Ozone occurs naturally in the earth's atmosphere where, in the upper atmosphere, it protects the earth's surface against ultraviolet radiation (EPA 2008b). However, it also occurs at the ground level (i.e., ground-level ozone) where it is created by a chemical reaction between nitrogen oxides and volatile organic compounds (VOCs) in the presence of heat and sunlight (NPS 2008). Ozone is also one of the most widespread pollutants affecting vegetation and human health in the U.S. (NPS 2008). Considered phytotoxic, ozone can cause significant foliar injury and growth effects for sensitive plants in natural ecosystems (EPA 2008a, NPS 2008). Specific effects include reduced photosynthesis, premature leaf loss, and reduced biomass, and prolonged exposure can increase vulnerability to insects and diseases or other environmental stressors (NPS 2008). At high concentrations, ozone can aggravate respiratory and cardiovascular diseases in humans, reduce lung function, cause acute respiratory problems, and increase susceptibility to respiratory infections (EPA 2008b, EPA 2010a); this could be a concern for visitors and staff engaging in aerobic activities in the park, such as hiking.

Particulate Matter (PM) and Visibility

Particulate matter (PM) is a complex mixture of extremely small particles and liquid droplets suspended in the atmosphere. Fine particles ($PM_{2.5}$) are those smaller than 2.5 micrometers in diameter (EPA 2009). Particulate matter largely consists of acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles (EPA 2008a, EPA 2009). Fine particles are a major cause of reduced visibility (haze) in many national parks and wildernesses (EPA 2010b). $PM_{2.5}$ can be directly emitted from sources such as forest fires, or they can form when gases emitted from power plants, industries, and/or vehicles react with air (EPA 2009, EPA 2010b). Particulate matter either absorbs or scatters light. As a result, the clarity, color, and distance seen by humans decreases. Water in the atmosphere causes particles like nitrates and sulfates to expand, increasing their light-scattering efficiency (EPA 2010b). $PM_{2.5}$ is also a concern for human health as these particles can easily pass through the throat and nose and enter the lungs (EPA 2008b, EPA 2009, EPA 2010b). Short-term exposure to these particles can cause shortness of breath, fatigue, and lung irritation (EPA 2008b, EPA 2009).

Reference Conditions/Values

The NPS Air Resources Division (ARD) developed an approach for rating air quality conditions in national parks, based on the current NAAQS, ecosystem thresholds, and visibility improvement goals (Table 65) (NPS 2010a). Assessment of current condition of nitrogen and sulfur atmospheric deposition is based on wet (rain and snow) deposition. Ozone condition is based on the NAAQS standard of 75 parts per billion (ppb) (an annual fourth-highest daily maximum 8-hr concentration, averaged over 3 years). Visibility conditions are assessed in terms of a Haze Index, a measure of visibility (termed deciviews) that is derived from calculated light extinction and represents the minimal perceptible change in visibility to the human eye (NPS 2010a). Finally, NPS ARD recommends the following values for determining air quality condition (Table 65). The "good condition" metrics may be considered the reference condition for PAIS.

Table 65. National Park Service Air Resources Division air quality index values (NPS 2010a).

Condition	Ozone concentration (ppb)	Wet Deposition of N or S (kg/ha/yr)	Visibility (dv*)
Significant Concern	≥76	>3	>8
Moderate Condition	61-75	1-3	2-8
Good Condition	≤60	<1	<2

*a unit of visibility proportional to the logarithm of the atmospheric extinction (TCEQ 2012); one deciview represents the minimal perceptible change in visibility to the human eye.

Data and Methods

Monitoring in the Park
There is no active on-site monitoring of air quality parameters at PAIS.

NPS Data Resources
Although data on air quality parameters are not actively collected within park boundaries, data collected at several regional monitoring stations for various parameters can be used to estimate air quality conditions in PAIS. NPS ARD provides estimates of ozone, wet deposition of nitrogen and sulfur, and visibility that are based on data interpolations from all air quality monitoring stations operated by NPS, EPA, various states, and other entities, averaged over the most recent five years (e.g., 2006-2010). These estimates are available from the Explore Air website (NPS 2012) and are used to evaluate air quality conditions. On-site or nearby data are needed for a statistically valid trends analysis, while a five-year average interpolated estimate is preferred for the condition assessment.

Other Air Quality Data Resources
The National Atmospheric Deposition Program–National Trends Network (NADP) database provided annual average summary data for nitrogen and sulfur concentration and deposition in the southern coastal Texas region. Monitoring site TX39, located in Corpus Christi, Texas, is approximately 24 km (15 mi) north of PAIS. Although no longer operational, this site provided deposition data for the region from 2002 through 2006. There are no active NADP mercury monitors near PAIS.

The EPA Air Trends database provides annual average summary data for ozone concentrations near PAIS. Ozone concentrations are collected at monitoring site number 48-355-0025, located in Corpus Christi, Texas approximately 32 km (20 mi) northwest of PAIS. The site is operated by the Texas Commission on Environmental Quality and has actively collected data from January 1990 through April 2012 (EPA 2012). The Air Trends database also provided data for particulate matter concentrations ($PM_{2.5}$) from a monitoring site near PAIS. The Corpus Christi Huisache monitoring site (ID 48-355-0032), located approximately 32 km (20 mi) northwest of PAIS, has actively collected data from January 2000 through March 2012. Results from monitors located within 16 km (10 mi) from parks are generally considered to be representative of park conditions (Ellen Porter, NPS Air Resources Division Air Quality Specialist, phone communication, 25 October 2012). Data recorded at monitors beyond this distance from parks may represent regional conditions, but may not be representative of actual park conditions.

The Clean Air Status and Trends Network (CASTNet) provides summaries of the composition of nitrogen and sulfur deposition in various regions around the U.S. Similarly, the Interagency Monitoring of Protected Visual Environments Program (IMPROVE) actively monitors visibility conditions in Class I airsheds across the U.S. However, the nearest CASTNet and IMPROVE monitoring sites are located in Big Bend National Park, approximately 675 km (420 mi) west of PAIS. This distance and the variations among terrain make it difficult to extrapolate data accurately; thus, data from these monitoring stations were not considered in this assessment.

Special Air Quality Studies

Sullivan et al. (2011a) assessed the relative sensitivity of national parks to the potential effects of acidification caused by acidic atmospheric deposition from nitrogen and sulfur compounds. The relative risk for each park was assessed by examining three variables: the level of exposure to emissions and deposition of nitrogen and sulfur; inherent sensitivity of park ecosystems to acidifying compounds (N and/or S) from deposition; and level of mandated park protection against air pollution degradation (i.e., Wilderness and Class I). The outcome was an overall risk assessment that estimates the relative risk of acidification impacts to park resources from atmospheric deposition of nitrogen and sulfur (Sullivan et al. 2011a). Using the same approach, Sullivan et al. (2011b) assessed the sensitivity of national parks to the effects of nutrient enrichment by atmospheric deposition of nitrogen. The outcome was an overall risk assessment that estimates the relative risk to park resources of nutrient enrichment from increased nitrogen deposition.

Current Condition and Trend

Atmospheric Deposition of Nitrogen and Sulfur

Five-year interpolated averages of total nitrogen (from nitrate and ammonium) wet deposition and total sulfur (from sulfate) wet deposition are used to estimate condition for deposition; using a five-year average smoothes out annual variations in precipitation, such as heavy precipitation one year versus drought conditions in another. The current 5-year average (2006-2010) estimates total wet deposition of nitrogen in PAIS at 2.5 kg/ha/yr, while total wet deposition of sulfur is 2.3 kg/ha/yr (NPS 2012). Relative to the NPS ratings for air quality conditions (see Table 65 for ratings values), atmospheric deposition of both nitrogen and sulfur falls into the *Moderate Concern category*. However, several factors are considered when rating the condition of atmospheric deposition, including effects of deposition on different ecosystems (NPS 2010a). Based on the NPS process for rating air quality conditions, ratings for parks with ecosystems considered potentially sensitive to nitrogen or sulfur deposition typically are adjusted up one condition category. In general, semi-arid ecosystems are considered to be sensitive to increased levels of nitrogen and sulfur, as acidification and nutrient enrichment can cause shifts in native species composition and allow encroachment of exotic species and grasses (reviewed in Sullivan et al. 2011a and 2011b). PAIS comprises semi-arid vegetation communities, which may be at risk from increased deposition, particularly nitrogen. Thus, the condition for deposition of nitrogen and sulfur in PAIS are considered to be of *Significant Concern*.

Figure 32 shows the annual average concentrations of sulfate, nitrate, and ammonium recorded in Corpus Christi, Texas, the NADP monitor nearest to PAIS (approximately 24 km north of the park).

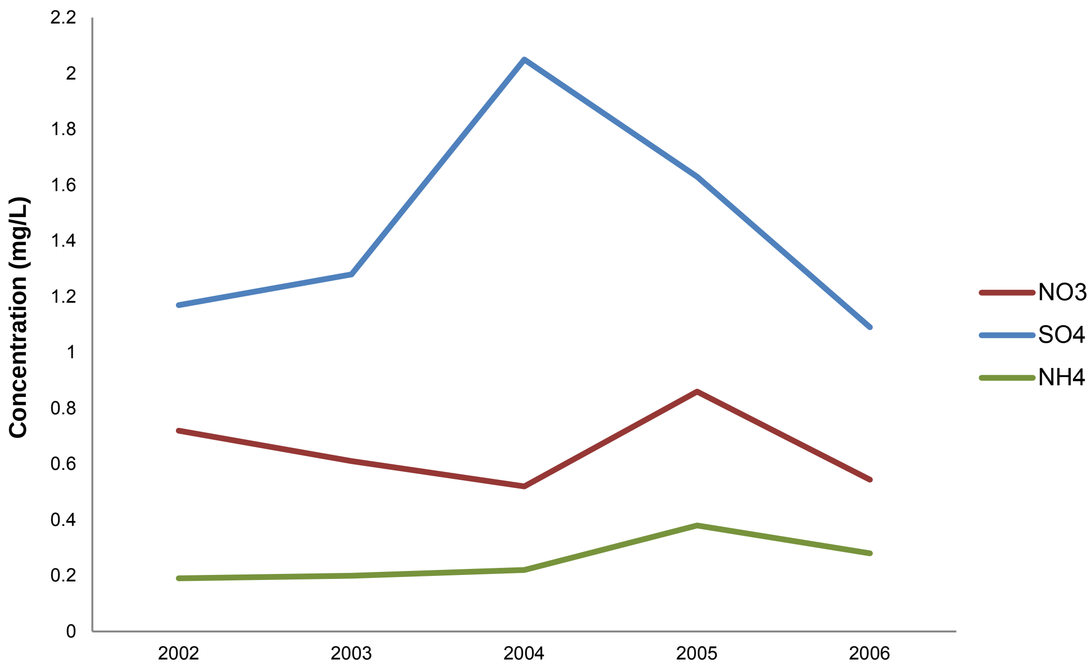

Figure 32. Annual average concentrations of sulfate (SO_4), nitrate (NO_3), and ammonium (NH_4) in precipitation (mg/L) in Corpus Christi, Texas, 2002-2006 (NADP monitoring site TX39, located approximately 24 km north of PAIS) (Source: NADP 2012). Note: Ammonium (NH_4) is included because it adds significantly to total nitrogen deposition.

Relative risk of acidification and nutrient enrichment of ecosystems was assessed by examining exposure to nitrogen deposition and acidification, inherent sensitivity of park ecosystems, and mandates for park protection. Sullivan et al. (2011c) ranked PAIS as having moderate exposure to acidifying (nitrogen and sulfur) pollutants, very low ecosystem sensitivity to acidification, and moderate park protection due to its Class II airshed status. The ranking of overall risk from acidification due to acid deposition was low relative to other parks (Sullivan et al. 2011c). In a separate examination, Sullivan et al. (2011b) used the same approach to assess the sensitivity of national parks to nutrient enrichment effects from atmospheric nitrogen deposition relative to other parks. PAIS was ranked as having moderate risk for nitrogen pollutant exposure, moderate ecosystem sensitivity, and moderate park protection mandates (Class II airshed). The ranking of overall risk of effects from nutrient enrichment from atmospheric nitrogen deposition was moderate relative to other parks (Sullivan et al. 2011d).

Atmospheric Deposition of Mercury

To date, no monitoring data are available for mercury deposition or concentration in PAIS. The nearest monitoring station is located in Gregg County, TX, approximately 731 km (455 mi) northeast of the park. It is not appropriate to interpolate from stations that far from the park.

Ozone Concentration

The NAAQS standard for ground-level ozone is the benchmark for rating current ozone conditions within park units. In 2008, the standard was strengthened from 80 ppb to 75 ppb, based on the annual 4th highest daily maximum 8-hour concentration, averaged over 3 years. The condition of ozone in NPS park units is determined by calculating the 5-year average of the fourth-highest daily maximum of 8-hour average ozone concentrations measured at each monitor within an area over each year (NPS 2010a). The current 5-year average (from 2006-2010) for PAIS indicates an average ground-level ozone concentration of 67.1 ppb (NPS 2012), which falls under the *Moderate Concern* category based on NPS guidelines.

A portable ozone monitor was also used to collect ozone concentration data within PAIS during 2007 and 2008. The fourth-highest daily maximum 8-hour concentrations for those years were 65.0 and 75.0 ppb, respectively. Long-term data that characterize ozone concentrations within the park do not exist. However, ozone concentrations are monitored daily by TCEQ in Corpus Christi, TX, approximately 32 km (20 mi) northwest of PAIS. Although results from this monitor may not be representative of ozone concentrations within PAIS, they can be considered to represent concentrations in the region of the park. Figure 33 illustrates the trend in annual fourth-highest daily maximum 8-hour values from 1995 to 2012; these are presented with both the old and revised national standards to provide perspective on acceptable versus potentially harmful ozone conditions in the region. Measurements within the last seven years appear to be well within the updated NAAQS standard considered to be protective of human health.

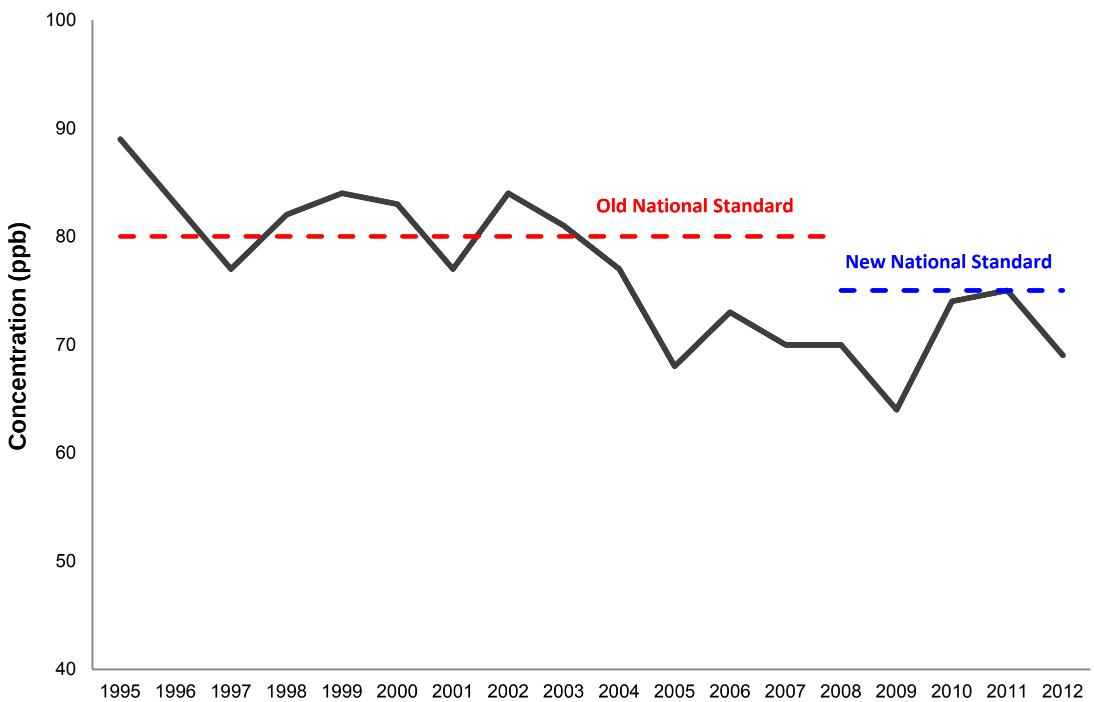

Figure 33. Annual 4th highest 8-hour maximum ozone (O_3) concentrations (ppb) in the PAIS region, 1995-2012 (Source: EPA 2012). Note: Site 48-355-0026 is the monitor located in Corpus Christi, Texas, approximately 32 km (20 mi) northwest of PAIS. Prior to 2008, the NAAQS ozone standard was 0.08 ppm (80 ppb) (shown in red); in March 2008, the standard was amended to 0.075 ppm (75 ppb) (shown in blue).

Kohut (2004) assessed ozone concentrations in the GULN and the risk of injury to plant species that are sensitive to sustained ozone exposure. Data from 1995-1999 indicate ozone concentrations in PAIS during this time frequently exceeded 60 ppb each year and occasionally exceeded 80 ppb each year. Concentrations exceeded 100 ppb rarely, although one year catalogued 16 hours above this threshold; at these levels, it is possible for vegetation to sustain injury. Sensitive plant species begin to experience foliar injury when exposed to ozone concentrations of 80-120 ppb/hour for extended periods of time (8 hours or more); however, the levels of exposure experienced in PAIS are not likely to cause foliar damage (Kohut 2004). Overall, the risk of foliar injury from ozone is low (Kohut 2004). Smooth cordgrass (*Spartina alterniflora*) is identified in PAIS as a plant species that is sensitive to elevated ozone levels (Kohut 2004).

Particulate Matter ($PM_{2.5}$)

The NAAQS standard for $PM_{2.5}$ is a weighted annual mean of 15.0 $\mu g/m^3$ or 35 $\mu g/m^3$ in a 24-hour period over an average of 3 years (EPA 2010b). Particulate matter concentrations, monitored at two different stations in the PAIS region, are available from 2000 through 2012. Weighted annual average $PM_{2.5}$ concentrations in the PAIS region have been relatively stable since 2000, fluctuating between 9 and 11 $\mu g/m^3$ (Figure 34). All measurements are well within the EPA standards for levels that are protective of human health; concentrations on the haziest days contribute to occasional impaired visibility in the park.

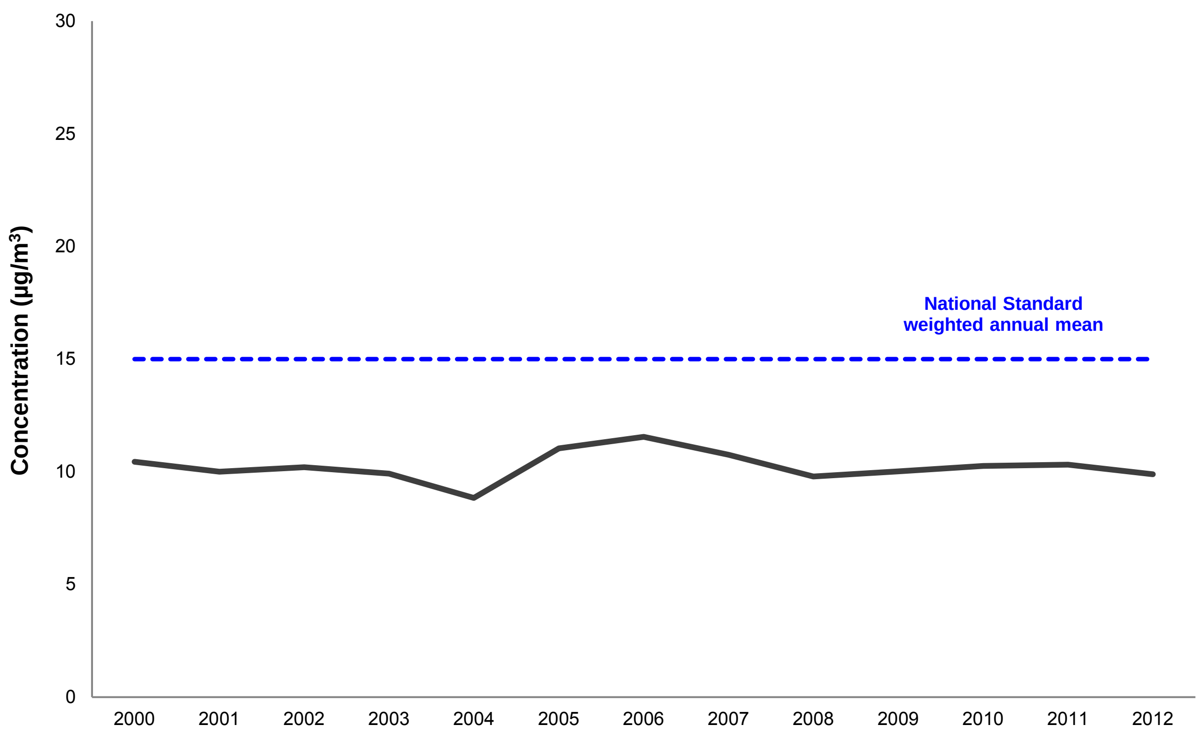

Figure 34. Annual particulate matter ($PM_{2.5}$) concentrations (weighted annual mean) near PAIS, 2000-2012 (EPA 2012). Note: Corpus Christi Huisache monitoring site (ID 48-355-0032) is located approximately 32 km (20 mi) northwest of PAIS.

Visibility

Visibility impairment occurs when airborne particles and gases scatter and absorb light; the net effect is called “light extinction,” which is a reduction in the amount of light from a view that is returned to an observer (EPA 2003). In response to the mandates of the CAA of 1977, federal and regional organizations established IMPROVE in 1985 to aid in monitoring of visibility conditions in Class I airsheds. The goals of the program are to 1) establish current visibility conditions in Class I airsheds; 2) identify pollutants and emission sources causing the existing visibility problems; and 3) document long-term trends in visibility (NPS 2010b). Visibility in PAIS is often naturally impaired by water vapor fog from the Gulf of Mexico; however, it may at times be impaired by atmospheric particulate matter.

The most current 5-year average (2006-2010) estimates average visibility in PAIS to be 9.1 dv above average natural visibility conditions (NPS 2012). This falls into the *Moderate Concern* category for NPS air quality condition assessment.

The clearest and haziest 20% of days each year are also examined for parks (NPS 2012), as these are the measures used by States and EPA to assess progress towards meeting the national visibility goal. Conditions measured near 0 dv are clear and provide excellent visibility, and as dv measurements increase, visibility conditions become hazier. The most current 5-year average (2006-2010) estimates visibility at PAIS at 8.9 dv on the 20% clearest days and 20.5 dv on the 20% haziest days (NPS 2012).

Threats and Stressor Factors

Park managers have identified a number of threats and stressors to air quality in PAIS. These include the aerosolized toxins of harmful algal blooms, land use activities within and adjacent to the park (particularly oil and gas exploration, emissions from development), vehicle emissions from nearby highway/roads and traffic along the beaches where driving is permitted, emissions from nearby urbanized areas, and smoke from grassland fires in and around the park.

Outbreaks of HABs, specifically red tides, have been identified as a threat to air quality and visitor respiration, particularly when events are sustained. HABs arise when annual blooms of the naturally occurring microscopic algae *Karenia brevis* grow out of control (NOAA 2012b). *K. brevis* produces a potentially fatal neurotoxin, known as brevetoxin, which at high concentrations can affect the central nervous systems of fish, shellfish, birds, and marine and terrestrial mammals, as well as cause respiratory problems in people exposed to the aerosols or sicken people who eat contaminated molluscan shellfish (NOAA 2012a, TPWD 2012b). Inhaled aerosolized red tide toxins can cause eye and nasal irritation, wheezing, difficulty breathing (similar to asthma), and a persistent nonproductive cough (Fleming et al. 2007).

Nitrogen deposition results from nitrogen oxides in vehicle emissions, power plants, and other combustion sources, and ammonia from agricultural activities and fires. In ecosystems adapted to naturally low amounts of nitrogen (such as semi-arid systems and grasslands), increased nitrogen deposition can alter plant communities and reduce diversity (Sullivan 2011b). Higher nitrogen levels favor certain plant species, like fast-growing invasive species, at the expense of native forbs and shrubs (Sullivan 2011b). Sulfur emissions and particulate matter often originate from such sources as coal-fired power plants, petroleum refining, and chemical processing operations, many of which are located in central, southern and coastal Texas, as well as northern Mexico. Prevailing seasonal winds may carry these emissions into PAIS.

Data Needs/Gaps

There are monitors in nearby Corpus Christi, TX that provide particulate matter and ozone concentration data as both daily and annual average summaries for the region. However, for data to be considered representative of park conditions, monitors should be within 16 km (10 mi) of the park; these active monitors are approximately 30 km (20 mi) from the northern part of PAIS. Additionally, the nearest active NADP monitor that provides annual averages for nitrogen and sulfur deposition is locate in Beeville, Texas, approximately 136 km (84 miles) northwest of PAIS headquarters; an inactive NADP monitor in Corpus Christi provided data from 2002-2006. Finally, the nearest CASTNet and IMPROVE sites, which monitor acid deposition and visibility respectively, are located in Big Bend National Park, over 800 km northwest of PAIS. Periodic or consistent monitoring of nitrogen and sulfur deposition and visibility would help managers better understand the local air quality conditions in and around PAIS.

Overall Condition

Nitrogen Deposition

The *Significance Level* for atmospheric deposition of nitrogen was defined as a 3. Minimal annual data have been collected intermittently (2002-2006) at a monitor approximately 30 km (20 mi) north of the park and is not enough to determine local or regional trends in deposition rates and concentrations over time. However, Sullivan et al. (2011b, 2011d) and NPS (2010a) rate the semi-arid and grassland ecosystems in PAIS as moderately sensitive to nutrient enrichment by nitrogen deposition and at moderate risk of exposure to the pollutant. Overall risk is ranked as moderate relative to other parks. Likewise, current interpolated estimates for nitrogen deposition are considered to be of moderate to significant concern based on NPS criteria for rating air quality when factoring in the sensitivity of the ecosystem. Deposition of nitrogen is of significant concern (*Condition Level* = 3).

Sulfate Deposition

The *Significance Level* for atmospheric deposition of sulfate was defined as a 3. Minimal annual data have been collected intermittently (2002-2006) at a monitor approximately 30 km (20 mi) north of the park and is not enough to determine local or regional trends in deposition rates and concentrations over time. Sullivan et al. (2011a, 2011c) rate the sensitivity of semi-arid and grassland ecosystems in PAIS to acidification by sulfur deposition and other acids as very low and at moderate risk of pollutant exposure. Overall risk is ranked low relative to other parks. Current interpolated estimates for sulfate deposition fall into the moderate to significant concern category based on NPS criteria for rating air quality when factoring in sensitivity of the ecosystem. Deposition of sulfate is of moderate concern (*Condition Level* = 2).

Deposition/concentration of Mercury

The project team defined the *Significance Level* for mercury concentration as a 3. No data are available to summarize mercury deposition/concentration rates in or near PAIS. Because there is no record of mercury deposition/concentration for much of south and western Texas, it is not possible to determine a *Condition Level* for this measure.

Ozone Concentration

The *Significance Level* for ozone concentration was defined as a 3. Current average ground-level ozone concentrations fall into the moderate concern category based on NPS criteria for rating air quality condition. Annual 4th highest 8-hour maximum concentrations (1993 through 2012) indicate a declining trend since 1995, but with fluctuations between 65 and 75 ppb in the last six years. All measurements, including those taken in the park in 2007 and 2008, are within EPA standards protective of human health. GULN (2004) suggests the risk of foliar injury from ozone is low for the park. Therefore, the *Condition Level* for ozone concentration is a 1, of low concern.

Particulate Matter Concentration ($PM_{2.5}$)
The *Significance Level* for concentration of fine particulate matter ($PM_{2.5}$) was defined as a 3. Trends in $PM_{2.5}$ concentrations near PAIS have been relatively stable over the last 12 years and are well within the EPA standards for levels that are protective of human health. The *Condition Level* for $PM_{2.5}$ is a 1, of low concern.

Visibility
The *Significance Level* for visibility was defined as a 3. Current interpolated average visibility estimates for PAIS fall into the moderate concern category based on NPS criteria. However, no data are collected at the park, and the nearest visibility monitor is over 676 km (420 mi) west of the park; this makes it difficult to determine average conditions or trends in visibility conditions in PAIS. The *Condition Level* for visibility could not be determined.

Weighted Condition Score
The *Weighted Condition Score* (WCS) for the air quality component is 0.583, indicating the condition is of moderate concern. The trend was determined to be stable.

Sources of Expertise
Ellen Porter, Biologist, NPS Air Resources Division

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4.16 Dark Night Skies

Description

A lightscape is a place or environment characterized by the natural rhythm of the sun and moon cycles, clean air, and of dark nights unperturbed by artificial light (NPS 2007). The NPS directs each of its units to preserve, to the greatest extent possible, these natural lightscapes (NPS 2006). Natural cycles of dark and light periods during the course of a day affect the evolution of species and other natural resource processes such as plant phenology (NPS 2006, 2012a). Several species require darkness to hunt, hide their location, navigate, or reproduce (NPS 2012a). In addition to the ecological importance of dark night skies, park visitors expect skies to be free of light pollution and allow for star observation.

PAIS is located on the southern Texas coast and is affected by light pollution from nearby cities, most notably Corpus Christi, Texas (primarily in northern PAIS); and Brownsville, Texas (the southern reach of PAIS) (NPS 2012b). Figure 35 illustrates the approximate levels of artificial sky brightness against the natural sky brightness in southeastern Texas (NPS 2012b).

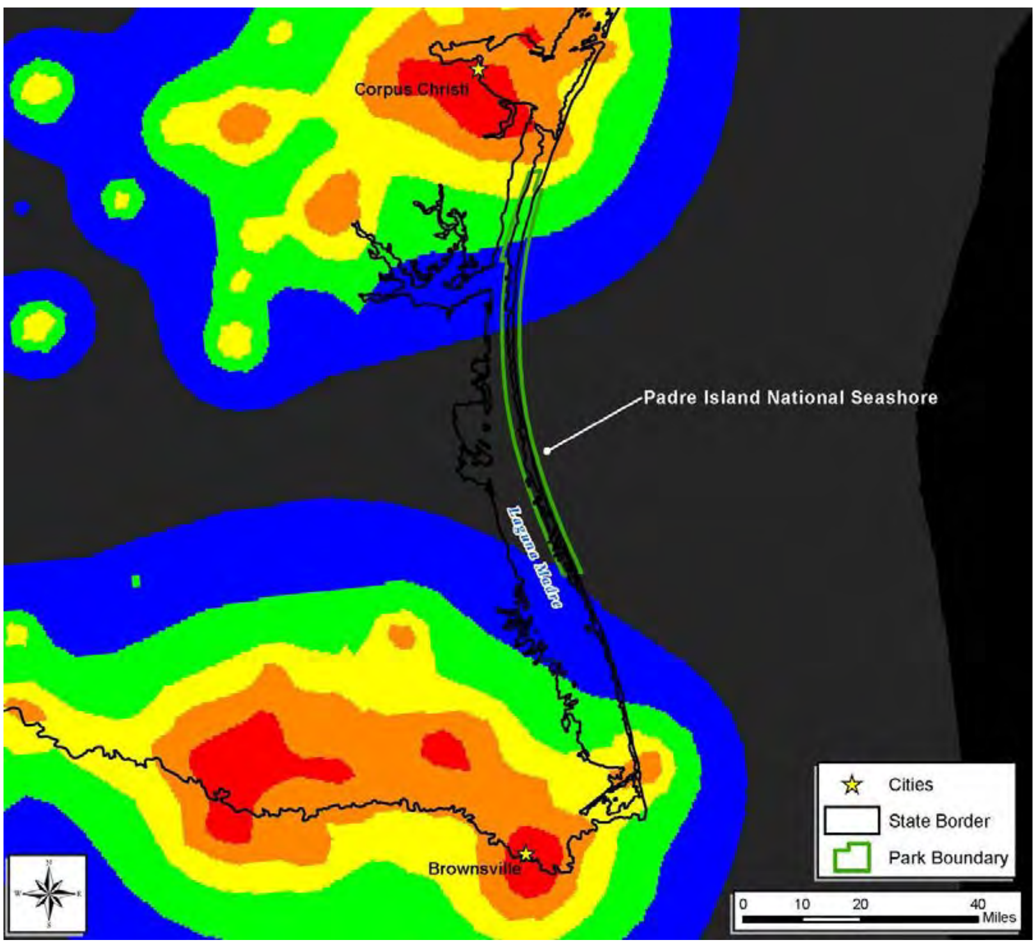


Figure 35. Artificial sky brightness in southeastern Texas (NPS 2012b). Red indicates higher incidence of artificial brightness while blue indicates less artificial brightness.

Measures

During site visits, the NPS Night Sky Team (NST) collects data for a suite of measures in order to define the current condition of dark night skies in a park unit. The suite of measures that the NST typically uses on a visit includes:

- Sky luminance over the hemisphere in high resolution (thousands of measurements comprise a data set), reported in photometric luminance units (V magnitudes per square arc second or milli-candela per square meter) or relative to natural conditions, often shown as a sky brightness contour map of the entire sky. V magnitude is a broadband photometric term in astronomy, meaning the total flux from a source striking a detector after passing through a "Johnson-Cousins V" filter. It is similar to the "CIE photopic" broadband function for wavelengths of light to which the human eye is sensitive (Bessell 1990);

- Integrated measures of anthropogenic sky glow from selected areas of sky that may be attributed to individual cities or towns (known as city light domes), reported in milli-Lux of hemispheric illuminance or vertical illuminance;

- Integration of the entire sky illuminance measures, reported either in milli-Lux of total hemispheric (or horizontal) illuminance, milli-Lux of anthropogenic hemispheric (or horizontal) illuminance, V-magnitudes of the integrated hemisphere, or ratio of anthropogenic illuminance to natural illuminance;

- Vertical illuminance from individual (or groups of) outdoor lighting fixtures at a given observing location (such as the Wilderness boundary), in milli-Lux;

- Visual observations by a human observer, such as Bortle Class and Zenithal limiting magnitude;

- Integrated synthesized measure of the luminance of the sky within 50 degrees of the Zenith, as reported by the Unihedron Sky Quality Meter, in V magnitudes per square arc second;

Reference Conditions/Values

The reference condition for this resource is defined in terms of sky luminance and illuminance at the observer's location from anthropogenic sources as follows:

> No portion of the sky background brightness exceeds natural levels by more than 200 percent, and the sky brightness at the Zenith does not exceed natural Zenith sky brightness by more than 10 percent. The ratio of anthropogenic hemispheric illuminance to natural hemispheric illuminance from the entire night sky does not exceed 20 percent. The observed light from a single visible anthropogenic source (light trespass) is not observed as brighter than the planet Venus (0.1 milli-Lux) when viewed from within any area of the park designated the naturally dark zone (Dan Duriscoe, NPS Night Sky Team, pers. comm., 2011).

Achieving this reference condition for preserving natural night skies is well summarized in the NPS Management Policies (2006) as follows in section 4.10: “The Service will preserve, to the greatest extent possible, the natural lightscapes of parks, which are natural resources and values that exist in the absence of human-caused light.”

Implementing this directive in PAIS requires that facilities within the park and local communities that utilize outdoor lighting meet outdoor lighting standards that provide for the maximum amount of environmental protection while meeting human needs for safety, security, and convenience. This means that outdoor lights within the park produce zero light trespass beyond the boundary of their intended use, be of an intensity that meets the minimum requirement for the task (but does not excessively exceed that requirement), be of a color that is toward the yellow or orange end of the spectrum to minimize sky glow, and be controlled intelligently (preventing unnecessary dusk to dawn bright illumination of areas).

Data and Methods

Data were collected in PAIS at two locations in 2009 by Wade Stablein and Teresa Jiles, NPS Night Sky Team Research Associate. One location was near Big Shell Beach, while the other was near the Bird Island Boat Ramp (Plate 35). Data were collected for a suite of measures during this visit, and a description of some of these measures is provided below.

Anthropogenic light in the night environment can be very significant, especially on moonless nights. Unshielded lamps mounted on tall poles have the greatest potential to cause light pollution, since light directly emitted by the lamp has the potential to follow an unobstructed path into the sky or the distant landscape. This type of light spill has been called glare, intrusive light, or light trespass (Narisada and Schreuder 2004). The dark-adapted human eye will see these individual light sources as extremely bright points in a natural environment. These sources also have the potential to illuminate the landscape, especially vertical surfaces aligned perpendicular to them, often to a level that approaches or surpasses moonlight. The brightness of such objects may be measured as the amount of light per unit area striking a “detector” or a measuring device, or entering the observer’s pupil. This type of measure is called illuminance (Ryer 1997).

Illuminance is measured in lux (metric) or foot-candles (English), and is usually defined as luminous flux per unit area of a flat surface (1 lux = 1 lumen / m^2). However, different surface geometries may be employed, such as a cylindrical surface or a hemispheric surface. Integrated illuminance of a hemisphere (summed flux per unit area from all angles above the horizon) is a useful, unbiased metric for determining the brightness of the entire night sky. Horizontal and vertical illuminance are also used; horizontal illuminance weights areas near the Zenith much greater than areas near the horizon, while vertical illuminance preferentially weights areas near the horizon, and an azimuth of orientation must be specified.

Direct vertical illuminance from a nearby anthropogenic source will vary considerably with the location of the observer, since this value varies as the inverse of the square of the distance from light source to observer (Ryer 1997). Therefore, measures of light trespass are usually made in sensitive areas (such as public campgrounds).

Anthropogenic light which results in an upward component will be visible to an observer as “sky glow.” This is because the atmosphere effectively scatters light passing through it. The sky is blue in daytime because of Rayleigh scattering by air molecules, which is more effective for light of shorter wavelengths. For this reason, bluish light from outdoor fixtures will produce more sky glow than reddish light. Larger particles in the atmosphere (aerosols and water vapor droplets) cause Mie scattering and absorption of light, which is not as wavelength-dependent and is more directional. When the air is full of larger particles, this process gives clouds their white appearance and produces a whitish glow around bright objects (e.g., the sun and moon). The pattern of sky glow as seen by a distant observer will appear as a dome of light of decreasing intensity from the center of the city on the horizon. As the observer moves closer to the source, the dome gets larger until the entire sky appears to be luminous (Garstang 1989).

Light propagated at an angle near the horizon will be effectively scattered, and the sky glow produced will be highly visible to an observer located in the direction of propagation. Predictions of the apparent light dome produced by a sky glow model demonstrate this (Luginbuhl et al. 2009). Light reflected off surfaces (e.g., a concrete road or parking area) becomes visible light pollution when it is scattered by the atmosphere above it, even if the light fixture has a “full cutoff” design and is not visible as glare or light trespass to a distant observer. For this reason, the intensity and color of outdoor lights must be carefully considered, especially if light-colored surfaces are present near the light source.

Light domes from many cities, as they appear from a location within Joshua Tree National Park, are shown in Figure 36 and Figure 37, as a grayscale and in false color. This graphic demonstrates that the core of the light dome may be tens or hundreds of times brighter than the extremities. A logarithmic scale for sky luminance and false color are commonly used to display monochromatic images or data with a very large dynamic range, and are used extensively in reports of sky brightness by the NST.

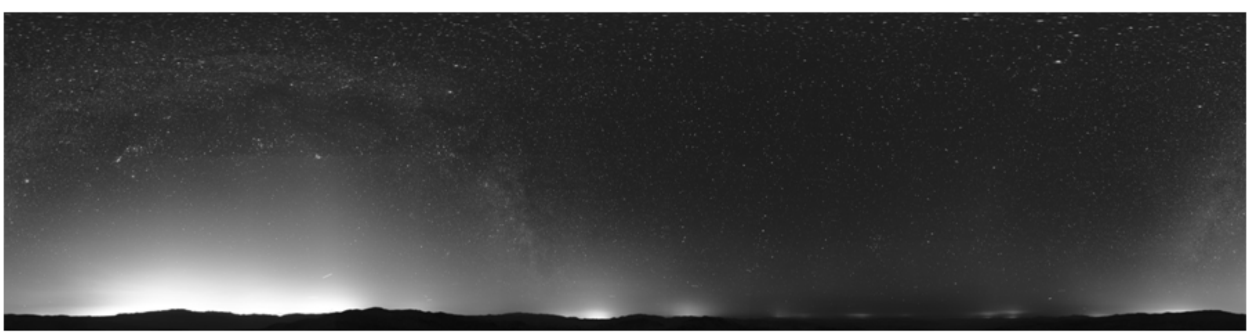


Figure 36. Grayscale representation of sky luminance from a location in Joshua Tree National Park (Figure provided by Dan Duriscoe, NPS Night Sky Team).

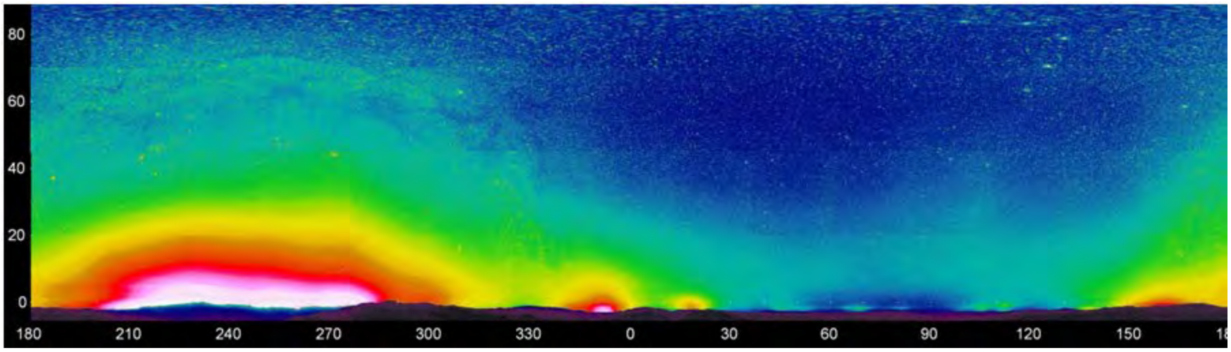


Figure 37. False color representation of Figure 2 after a logarithmic stretch of pixel values (Figure provided by Dan Duriscoe, NPS Night Sky Team).

The brightness (or luminance) of the sky in the region of the light domes may be measured as the number of photons per second reaching the observer for a given viewing angle, or area of the sky (such as a square degree, square arc minute, or square arc second). The NST utilizes a digital camera with a large, dynamic range, monochromatic charge-coupled device (CCD) detector and an extensive system of data collection, calibration, and analysis procedures (Duriscoe et al. 2007). This system allows for the accurate measurement of both luminance and illuminance, since it is calibrated on standard stars that appear in the same images as the data and the image scale in arc seconds per pixel is accurately known. Sky luminance is reported in astronomical units of V-magnitudes per square arc second, and in engineering units of milli-candela per square meter. High resolution imagery of the entire night sky reveals details of individual light domes that may be attributed to anthropogenic light from distant cities or nearby individual sources. These data sets may be used for both resource condition assessment and long-term monitoring.

Figure 36 and Figure 37 contain information on natural sources of light in the night sky as well as anthropogenic sources. The appearance of the natural night sky may be modeled and predicted in terms of sky luminance and illuminance over the hemisphere, given the location, date, time, and the relative brightness of the natural airglow (the so-called “permanent aurora” which varies in intensity over time) (Roach and Gordon 1973). The NST has constructed such a model, and uses it in analysis of data sets to remove the natural components. This results in a more accurate measure of anthropogenic sky glow (Figure 38). Figure 37 represents “total sky brightness” while Figure 38 displays “anthropogenic sky glow” or “net light pollution.” This is an important distinction, especially in areas where anthropogenic sky glow is of relatively low intensity.

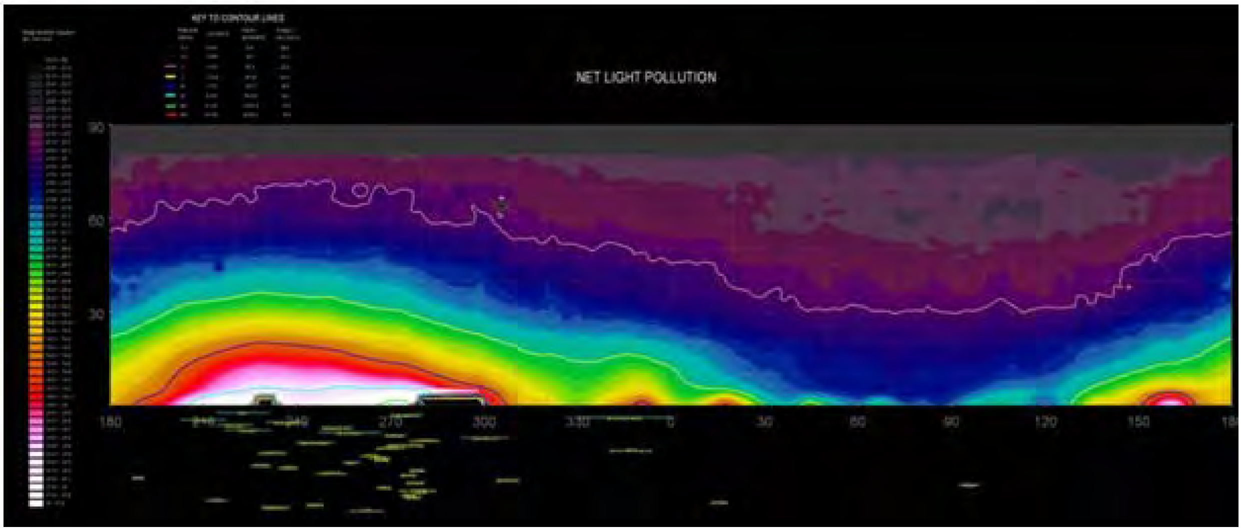


Figure 38. Contour map of anthropogenic sky glow at a location in Joshua Tree National Park, analogous to Figure 37 with natural sources of light subtracted (Figure provided by Dan Duriscoe, NPS Night Sky Team).

The accurate measurement of both anthropogenic light in the night sky and the accurate prediction of the brightness and distribution of natural sources of light allows for the use of a very intuitive metric of the resource condition - a ratio of anthropogenic to natural light. Both luminance and illuminance for the entire sky or a given area of the sky may be described in this manner (Hollan 2008). This so-called "light pollution ratio" is unitless and is always referenced to the brightness of a natural moonless sky under average atmospheric conditions, or, in the case of the NST data, the atmospheric conditions determined from each individual data set.

The reference conditions for anthropogenic sky luminance were identified as no more than 200 percent brighter than natural conditions in *any* area of the sky and no more than 10 percent brighter at the Zenith. These values correspond to light pollution ratios of 2.0 and 0.1, respectively. The NST has obtained values of 50-100 for this measure at the core of city light domes seen from several areas administered by the NPS, including Lake Mead National Recreation Area, Saguaro National Park, and Colorado National Monument (NPS Night Sky Team, unpublished data). This is because these NPS areas are very close to the cities of Las Vegas, Nevada; Tucson, Arizona; and Grand Junction, Colorado, respectively.

A quick and accurate method of quantifying sky brightness near the Zenith is the use of a Unihedron Sky Quality Meter. The Unihedron Sky Quality Meter is a single-channeled hand-held photometric device. A single number in magnitudes per square arc second is read from the front of the device after its photodiode and associated electronics are pointed at the Zenith and the processor completes its integration of photon detection. Because the meter is relatively inexpensive and easy to use, a database of measures has grown since its introduction (see http://unihedron.com/projects/darksky/database/index.php). The NST produces values from each data set as both a synthesized value derived from the high-resolution images and by hand-held measures with a Unihedron Sky Quality Meter. The performance of the Sky Quality Meter has been tested and reviewed by Cinzano (2005). While fairly accurate and easy to use, the value it produces is biased toward the Zenith. Therefore, the robustness of data collected in this manner is limited to areas with relatively bright sky glow near the Zenith, corresponding to severely light polluted areas. While not included in the reference condition, a value of about 21.85 would be considered “pristine”, providing the Milky Way is not overhead and/or the natural airglow is not unusually bright when the reading is taken.

Visual observations are important in defining sky quality, especially in defining the aesthetic character of night sky features. A published attempt at a semi-quantitative method of visual observations is described in the Bortle Dark Sky Scale (Bortle 2001). Observations of several features of the night sky and anthropogenic sky glow are synthesized into a 1-9 integer interval scale, where class 1 represents a “pristine sky” filled with easily observable features and class 9 represents an “inner city sky” where anthropogenic sky glow obliterates all the features except a few bright stars. Bortle Class 1 and 2 skies possess virtually no observable anthropogenic sky glow (Bortle 2001).

Another visual method for assessing sky quality is Zenithal Limiting Magnitude (ZLM), which is the apparent brightness or magnitude of the faintest star observable to the unaided human eye, which usually occurs near the Zenith. This method involves many factors, the most important of which is variability from observer to observer. A ZLM of 7.0-7.2 is usually considered “pristine” or representing what should be observed under natural conditions; observation of ZLM is one of the factors included in the Bortle Dark Sky Scale. Zenith Limiting Magnitude is often referenced in literature on the quality of the night sky, and is the basis for the international “Globe at Night” citizen-scientist program (see http://www.globeatnight.org/index.html). The NST has experimented with the use of this observation in predicting sky quality, and has found that it is a much coarser measure and prone to much greater error than accurate photometric measures over the entire sky. For these reasons, it is not included in the reference conditions section.

Current Condition and Trend

The NPS Night Sky Team (NST) visited PAIS in March 2009, and measured the quality of the park’s night skies at two locations: Big Shell Beach and the Bird Island Boat Ramp (Plate 35).

Big Shell Beach

Data were collected from Big Shell Beach on the night of 30 March 2009; monitoring began at 4:27 AM, and lasted until 6:37 AM. Important statistics from these data are presented in Table 66.

Table 66. Sky quality photometric report for Big Shell Beach, 30 March 2009 (NPS 2012c).

PARK:	Padre Island NS
SITE NAME:	Big Shell
LONGITUDE:	-97.38006
LATITUDE:	27.04985
ELEVATION (m):	7
DATE (UT):	March 29, 2009
TIME START (UT):	4:27:58
DATA QUALITY:	excellent

EQUIPMENT:	IMG3, 50mm f/2, 6084		
OBSERVERS:	T Jiles, W Stablein		
AIR TEMP (°F):	63		
REL HUMID (%):	56		
WIND SP (mph):	1.5		
CCD TEMP (°C):	-20		
EXP (seconds):	14		
BORTLE CLASS:	3	**ZLM:**	6.47

SKY BRIGHTNESS DATA

	Time (UT)	**Extinction coefficient** (mag/air-mass)	**Std Err Y Extinction Stars** (mags)	**Zenith** (mag/sq arc-sec)	**Whole Sky** (mags)	**Sky Above 20° Altitude** (mags)	**Brightest** (mag/sq arc-sec)	**Darkest** (mag/sq arc-sec)
1st Start	4:27:58			21.60				
End	4:51:04	0.238	0.033	21.64	-7.69	-6.73	17.91	21.81
2nd Start	5:21:04			21.66				
End	5:44:09	0.233	0.026	21.66	-7.64	-6.70	17.96	21.84
3rd Start	6:14:07			21.66				
End	6:37:12	0.226	0.030	21.67	-7.61	-6.67	17.99	21.87

According to Teresa Jiles (NPS, NST), the night of 30 March 2013 was

> Clear, calm and dry, especially for this coastal site. This site [Big Shell] has a view due east where sea turtle nesting occurs every mid to late spring. The view to the west, southwest is King Ranch where there are flashing red lights from wind turbines and a grass fire that lessened with intensity as the night waned, smoke drifted south. A bright green light near the naval base is unshielded and very intense, but does not make it to the east beach.

A contour map of night sky brightness in fisheye projection (Figure 39), and a panoramic projection of the anthropogenic sky glow (Figure 40) were created from the data gathered during the NST visit.

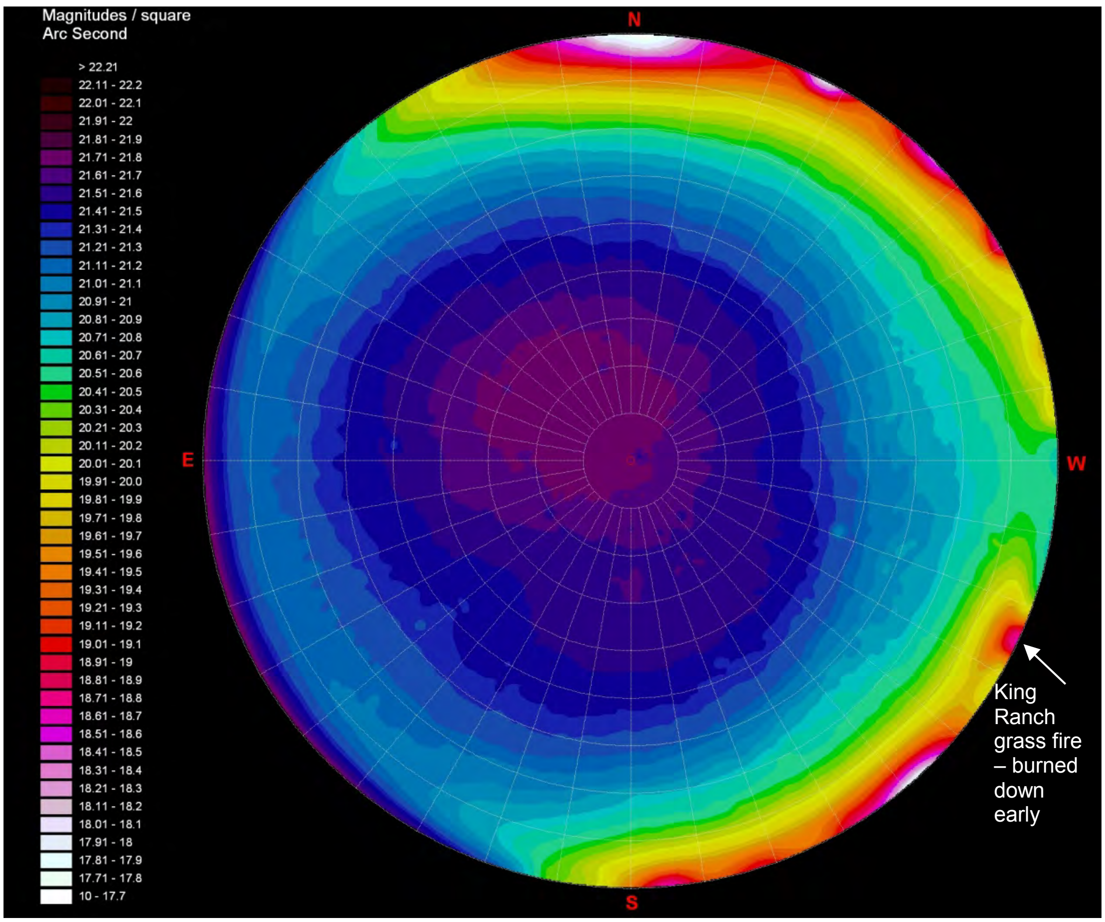


Figure 39. Contour map of sky brightness in fisheye projection, Big Shell Beach, 30 March 2009. The sky dome to the north is Corpus Christi, TX, while King Ranch's sky glow is visible in the southwest.

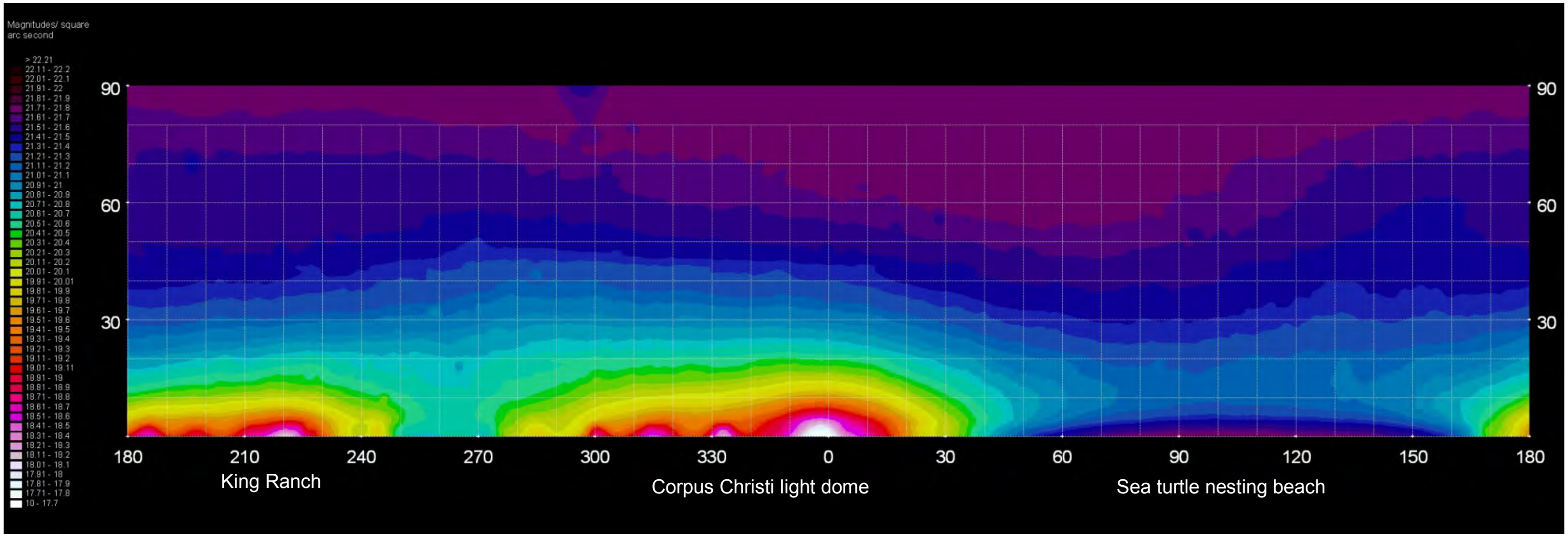


Figure 40. Anthropogenic light measured at Big Shell Beach, 30 March 2009, in panoramic projection.

As is seen in Figure 39 and Figure 40, light glow is visible at the Big Shell site from both the King Ranch area and from Corpus Christi to the north. This site was the darkest of the two visited by the NST, partially due to the fact that this location is 32 km (20 mi) further south than Bird Island and consequently further away from the bright lights of Corpus Christi. Big Shell had a ZLM of 6.47, and was classified as a Bortle Class 3 sky, which is indicative of a ‘rural sky’ (some light pollution visible on the horizon, clouds are illuminated at the horizon, but are dark overhead).

Bird Island Boat Ramp

Data were collected from the Bird Island Boat Ramp on the night of 30 March 2009; monitoring began at 5:32 AM, and lasted until 6:29 AM. Important statistics from these data are presented in Table 67.

Table 67. Sky quality photometric report for Bird Island Boat Ramp, 30 March 2009 (NPS 2012d).

PARK:	Padre Island	**EQUIPMENT:**	IMG3, 50mm f/2, 6084		
SITE NAME:	Bird Island Boat Ramp	**OBSERVERS:**	T Jiles, W Stablein		
LONGITUDE:	-97.30969	**AIR TEMP (°F):**	68		
LATITUDE:	27.47332	**REL HUMID (%):**	66		
ELEVATION (m):	1	**WIND SP (mph):**	8		
DATE (UT):	March 30, 2009	**CCD TEMP (°C):**	-20		
TIME START (UT):	5:32:04	**EXP (seconds):**	12		
DATA QUALITY:	fair	**BORTLE CLASS:**	4	**ZLM:**	5.8

SKY BRIGHTNESS DATA

	Time (UT)	**Extinction coefficient** (mag/air-mass)	**Std Err Y Extinction Stars** (mags)	**Zenith** (mag/sq arc-sec)	**Whole Sky** (mags)	**Sky Above 20° Altitude** (mags)	**Brightest** (mag/sq arc-sec)	**Darkest** (mag/sq arc-sec)
1st Start	5:32:04			20.76				
End	5:53:29	0.438	0.049	20.86	-8.91	-7.81	16.04	20.98
2nd Start	6:08:17			20.98				
End	6:29:43	0.34	0.042	20.84	-8.89	-7.75	16.09	21.04

According to Teresa Jiles, on the night of 30 March this site had low clouds near the horizon that distorted the Corpus Christi light dome that was located due north. The light from Corpus Christi spills onto the west coastal waters at the Bird Island Boat Launch site, and the coastal waters reflect the light up, making the sky appear brighter.

As was done at the Big Shell site, a contour map of night sky brightness in fisheye projection (Figure 41), and a panoramic projection of the anthropogenic sky glow (Figure 42) were created from the data gathered during the NST visit. The NST also compared Figure 41 to two other parks: the North Rim of Grand Canyon National Park (which has some of the darkest night skies in the NPS; Figure 43), and the Santa Monica Mountains National Recreation Area (which has some of the brightest night skies in the NPS; Figure 44).

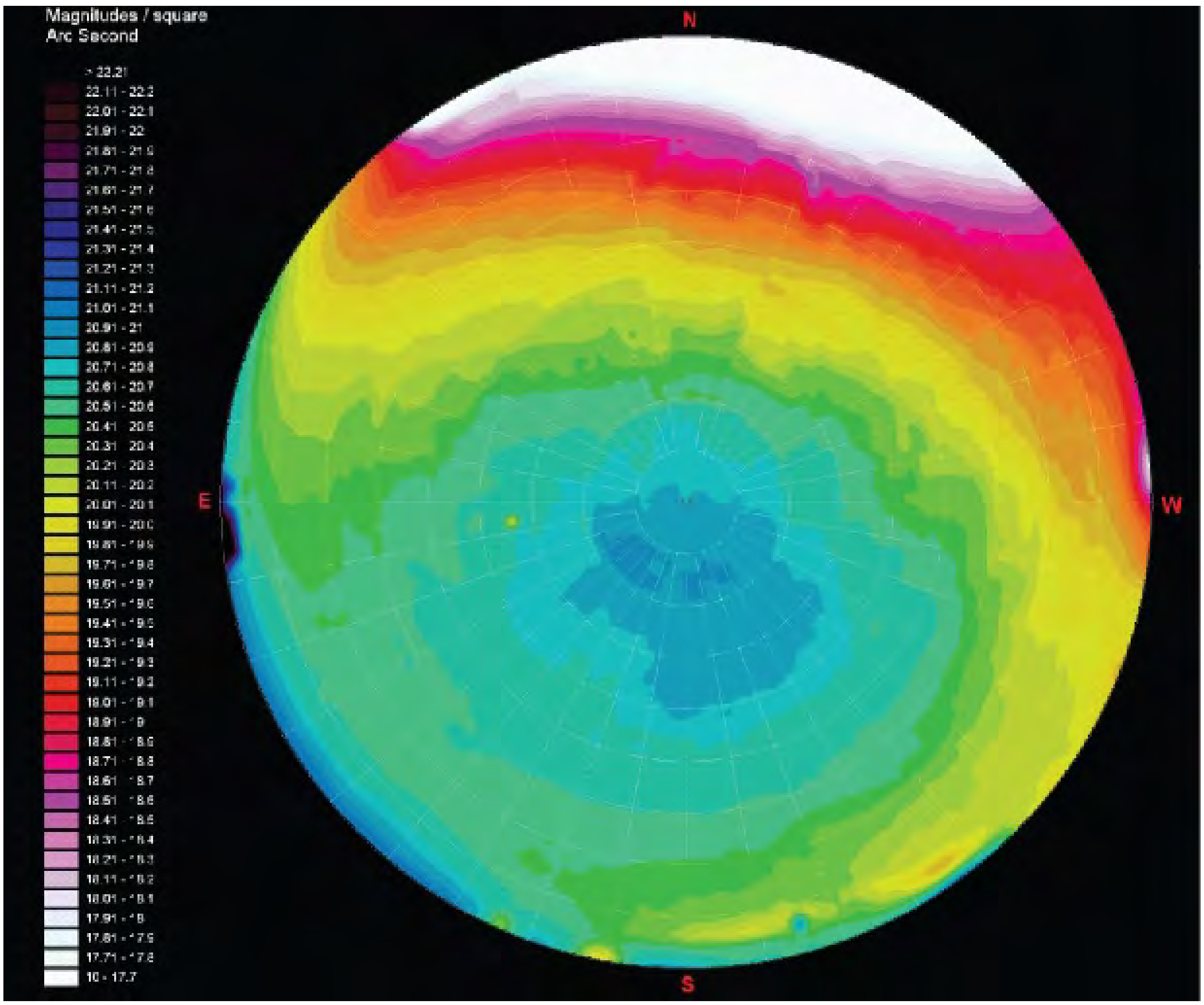


Figure 41. Contour map of sky brightness in fisheye projection, Bird Island Boat Ramp, 30 March 2009. The sky dome to the north is Corpus Christi, TX.

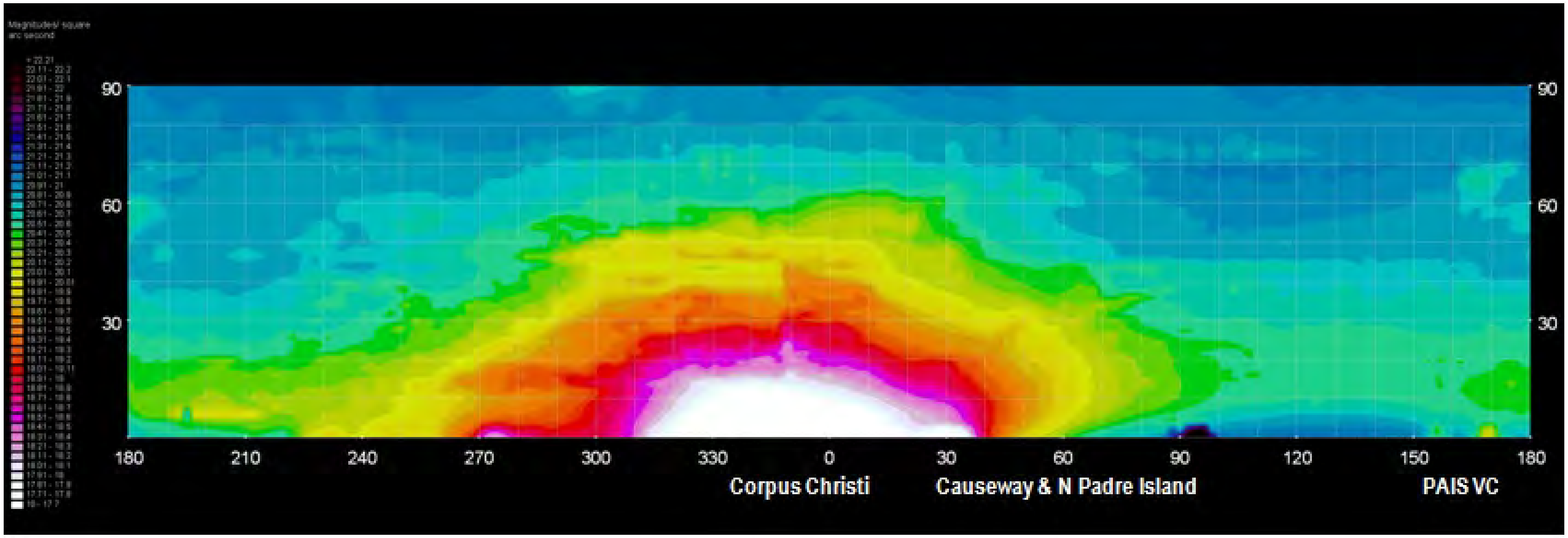
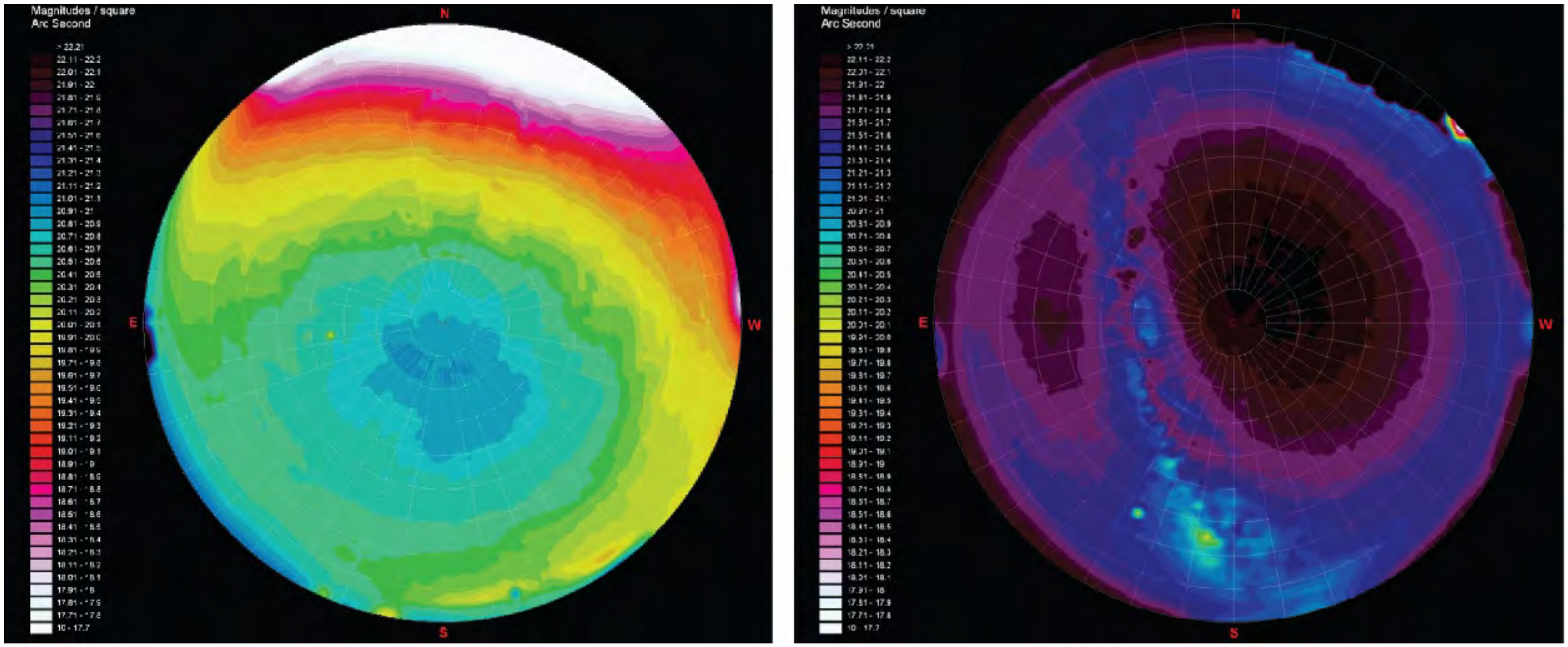


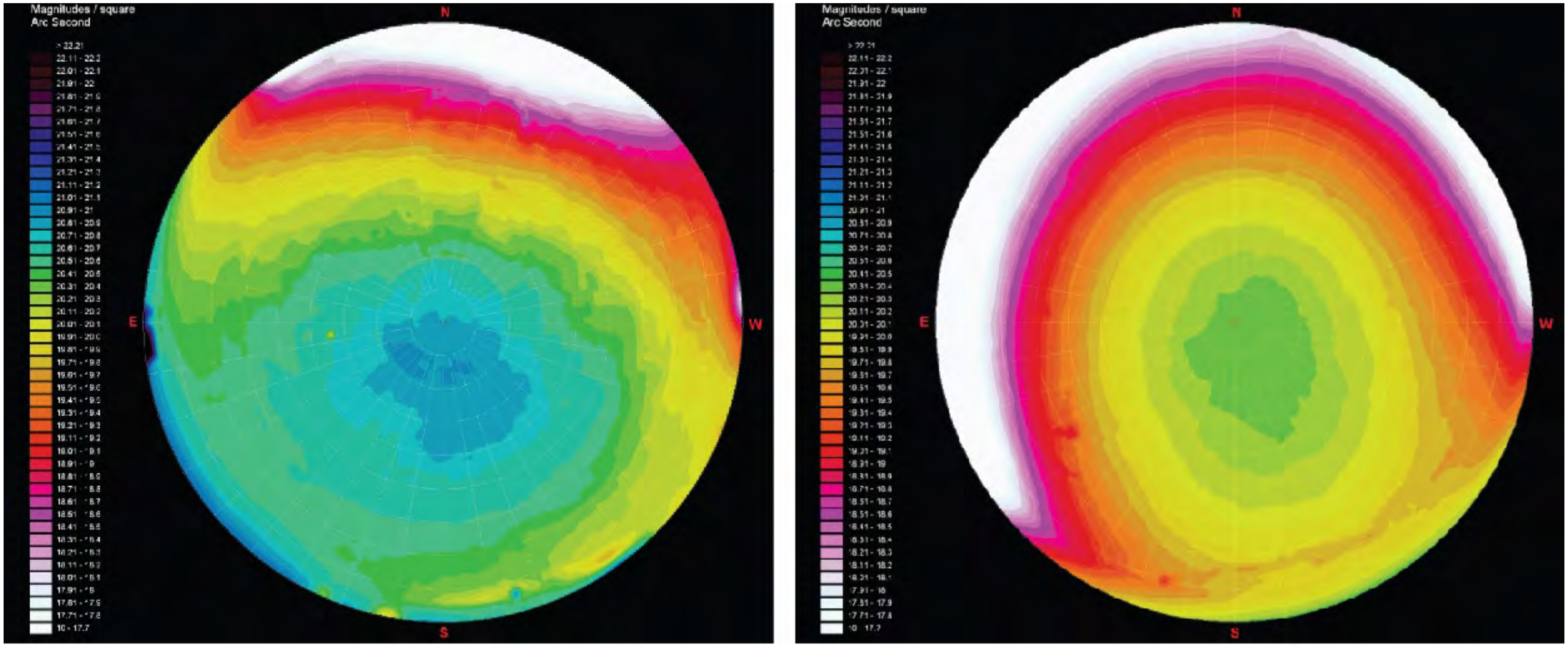
Figure 42. Anthropogenic light measured at Bird Island Boat Launch, 30 March 2009, in panoramic projection.



Bird Island Boat Launch

North Rim of Grand Canyon National Park

Figure 43. Contour map of sky brightness in fisheye projection; Bird Island Boat Ramp on the left, and the North Rim of Grand Canyon National Park on the right.



Bird Island Boat Launch

Santa Monica Mountains National Recreation Area

Figure 44. Contour map of sky brightness in fisheye projection; Bird Island Boat Ramp on the left, and Santa Monica Mountains National Recreation Area on the right.

Compared to the Big Shell NST sampling site, the Bird Island Boat Ramp is significantly brighter (Figure 45). Bird Island had a ZLM of 5.8 (compared to 6.47 at Big Shell), and was classified as a Bortle Class 4 sky (indicative of a 'suburban transition' area, with light pollution domes visible in various directions over the horizon; Bortle 2001). Bird Island is closest to the north end of the park's boundary, and is also closer to North Padre Island and Corpus Christi than Big Shell. The water at the Bird Island Boat Ramp site reflects much of the light from the Corpus Christi area into the thin cloud layers that are typically seen at night, making the sky seem very bright (NPS 2012c, d).

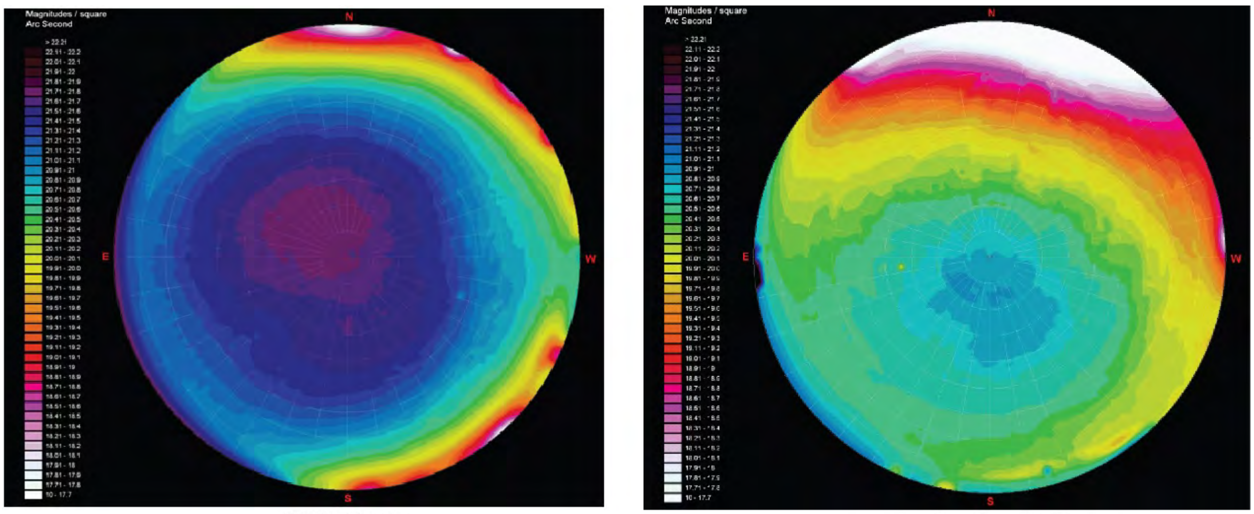


Figure 45. Contour map of sky brightness in fisheye projection; Big Shell Beach on the left, and Bird Island Boat Launch on the right.

<u>Threats and Stressor Factors</u>

As a barrier island situated between two major U.S. cities (Brownsville, TX; and Corpus Christi, TX), PAIS is threatened by the light pollution from theses cities. However, PAIS is in a unique region of the U.S. and faces some non-typical threats to the quality of the dark night skies. Oil and gas extraction has taken place on Padre Island since before the park's establishment in 1961 (Lawson 2009), and over 70 oil and gas operations operated in PAIS between 1951-1981 (NPS 2005). Currently, only six active pads and 11 active wells occur within the park (Stablein, written communication, 13 May 2013).

These oil and gas operations use heavy machinery and result in an increase of vehicular traffic in the park. The lights that are used with these operations will likely detrimentally affect the quality of the dark night skies in the park. Furthermore, the new light bulbs that are used on several of the automobiles travelling through the park (specifically the bright blue bulbs) are very bright and have an effect on the overall quality of night skies to observers in their vicinity (Lindsay, interview, 31 December 2011).

Another unique threat to the dark night skies in PAIS are recreational lights from fishing vessels in the Laguna Madre and the Gulf of Mexico. The lights attached to both recreational and commercial fishing boats, although not excessively bright, do contribute a small amount of light pollution at the horizon.

Air transparency affects night sky quality. Estimates of optical depth or b_ext from PM10 air monitoring stations correlate well with this effect. Haze and smoke will reduce contrast and dim light from the night sky, resulting in a loss of detail and character in the Milky Way, and a reduction in the number of stars seen by the observer, particularly near the horizon. These effects are reduced by higher altitude observations. However, pristine night sky quality may only be truly observed when pristine air quality exists above the observer.

<u>Data Needs/Gaps</u>

A draft plan for natural lightscape management in PAIS, which includes zoning the park area to indicate where outdoor lighting is required and where the naturally dark zones occur, would greatly benefit park managers and researchers. Light trespass measurements should be taken at the boundary of the naturally dark zones close to park developments and close to Corpus Christi. In this manner, it may be determined if standards for environmental protection are being met. While monochromatic and color digital photographs provide qualitative information, calibrated photometry is required to make a definitive judgment of the resource condition.

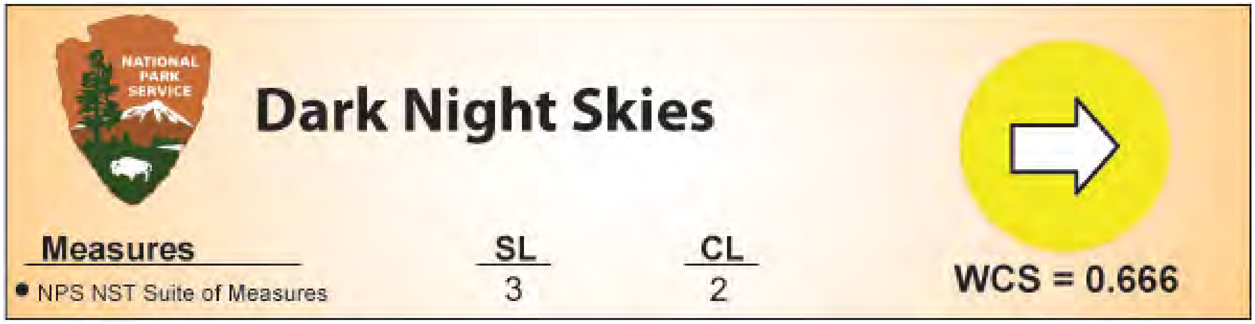
Continued measurement of the entire sky brightness condition should occur on a periodic basis, about once every 5 years, with Big Shell Beach and Bird Island Boat Ramp as the preferred observing sites, in order to track external threats.

<u>Overall Condition</u>

The northern region of PAIS (Bird Island Boat Ramp) has noticeable light pollution originating from nearby Corpus Christi; this region also has elevated levels of light pollution reflecting off of the coasts and low-lying clouds. Big Shell Beach is located further south of the Bird Island Boat Ramp, and it has lower levels of light pollution, although the Corpus Christi and King Ranch light domes arre still visible (Figure 45). No survey of the night sky has been completed in the southern portion of the park; Figure 35 suggests that this region may be at the northern boundary of the artificial sky brightness that originates from Brownsville, TX, although this is only speculation based on a simulated map.

While the number of oil and gas developments has decreased in recent years (and no new developments are currently being planned), the nearby cities of Brownsville and Corpus Christi continue to grow and contribute anthropogenic light trespass to the PAIS night sky. The data used in this assessment were collected in 2009, and significant change in the levels of light trespass and the size of the light domes in the night sky may have occurred. Due to the bright night skies observed at the Bird Island Boat Ramp, and the presence of noticeable light domes at Big Shell Beach, a *Condition Level* of 2 was assigned for the NPS suite of night sky measures.

Weighted Condition Score
The *Weighted Condition Score* for dark night skies at PAIS is 0.666, indicating this component is of moderate concern.



Sources of Expertise
National Park Service Night Sky Team: Dan Duriscoe, Chad Moore, Teresa Jiles, Jeremy White, and Robert Meadows

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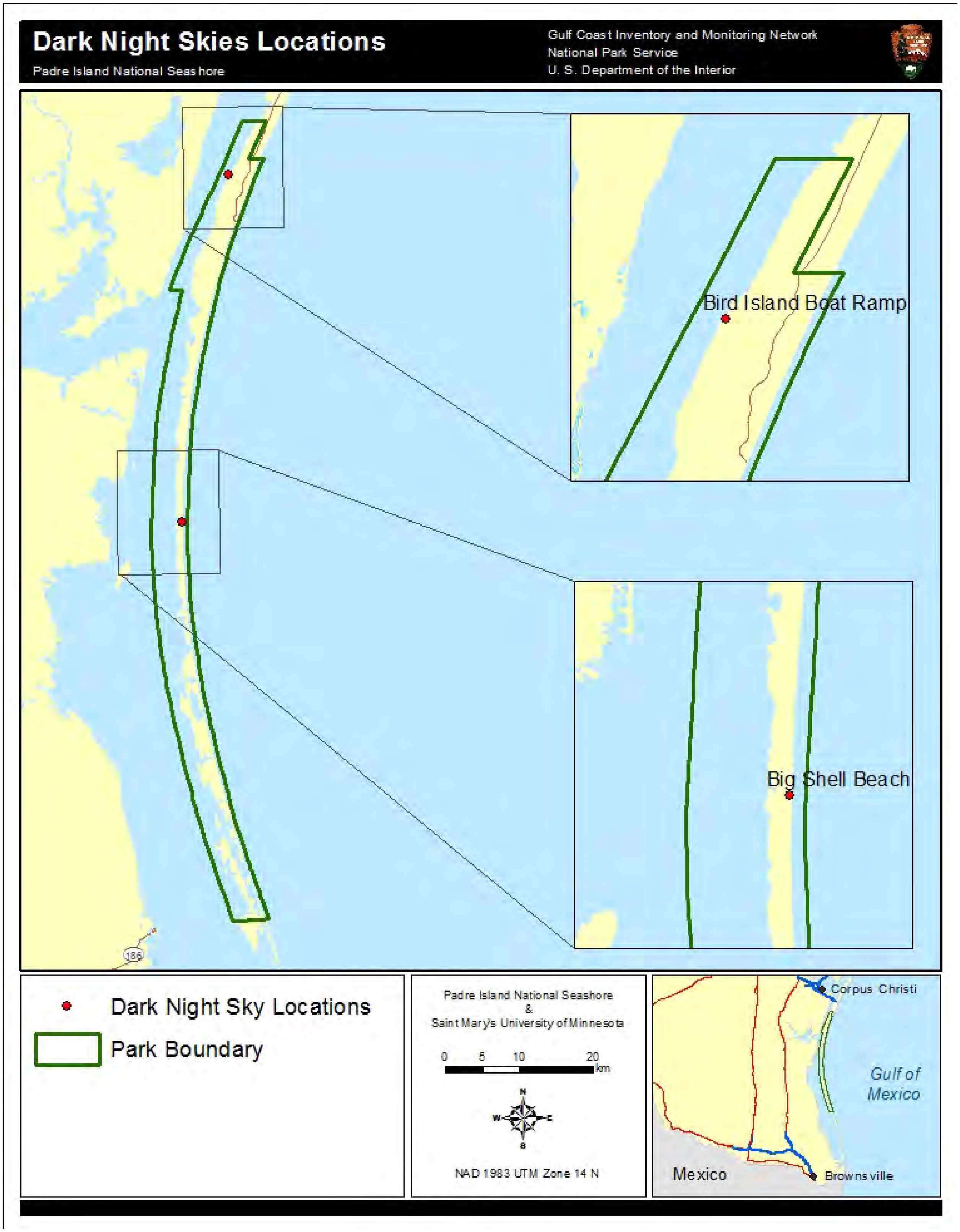

Plate 35. Dark night sky sampling locations within PAIS; both sites were surveyed on 30 March 2009.

4.17 Coastal Dunes and Beaches

Description

Barrier islands consist of a complexity of geological formations (KellerLynn 2010). Back beaches form the wet or swash zone along the shoreline, while the fore beach defines the area of coppice or emergent dunes. Adjacent to the fore beach is the fore-island dune ridge, which is the first significant rise in elevation from the beach zone. Behind the fore-island dune ridge are stabilized and active blowout dunes (KellerLynn 2010). These are dynamic features, in that they change frequently under the powerful influence of consistent offshore winds, tides, wave action, weather patterns, and storm events (Weise and White 1980, KellerLynn 2010, USGS 2013). In PAIS, these geologic features are a primary aspect of what makes the park unique; the beach and dune zones create important habitat for a variety of animal species, as well as recreational opportunities for visitors.

Weise and White (1980) detail the geology of PAIS. They describe a shore zone, which consists of the beaches adjacent to the water’s edge, and emergent dunes, which are located immediately behind the shore zone (Photo 26). The beaches along the seashore are the source of sand that form and build the emergent and fore-island dunes (Weise and White 1980). Wave action deposits sand and sediment on the beaches, which are dried, picked up, and carried inland by steady offshore winds. The sands are deposited and trapped by vegetation, creating fore-island and back-island dunes (Weise and White 1980, USGS 2013).

Photo 26. Emergent dunes in PAIS (left); beach zone adjacent to the water’s edge in PAIS (right) (Photos by Shannon Amberg, SMUMN GSS).

Established fore-island dunes, created mostly through wind-blown sand deposited behind the shore, typically form the first and highest dune ridge behind the shore zone (Weise and White 1980, USGS 2013) (Photo 27). These dunes run parallel to the beach and shoreline and often are covered at least partially with vegetation, which acts to catch more sand as it is carried inland, as well as stabilize the dunes from erosion that may result from light or moderate winds (Weise and White 1980, USGS 2013).


Photo 27. View of the fore-island dune ridge as seen from the Gulf beach in PAIS (left); atop the fore-island dune ridge looking south down the length of the fore-island ridge parallel to the beach (right) (Photos by Shannon Amberg, SMUMN GSS).

Back-island dunes are located behind the fore-island dune ridge, and typically tend to be lower in height than the fore-island dunes and support a significantly higher density of vegetation cover (USGS 2013). However, what used to be the tallest dunes in PAIS (until recently eroded by recreational impact, including Green Hill) are all located behind the fore-island dune ridge (Lindsay, pers. communication, 12 July 2013). Active dunes, in contrast, have little to no vegetation, allowing the dune sands to move freely across the island with predominant winds (USGS 2013). Photo 28 shows examples of vegetated back-island dunes (stabilized dunes) and active blowout dunes in PAIS. Figure 46 shows a cross-section of the geomorphologic features of PAIS, depicting beach and dune formations moving from the Gulf side (east) toward the Laguna Madre (west).


Photo 28. An active blowout dune in the northern part of PAIS (left); vegetated back-island dunes, or stabilized dunes, as viewed from the grasslands in the northern part of PAIS (right) (Photos by Shannon Amberg, SMUMN GSS).

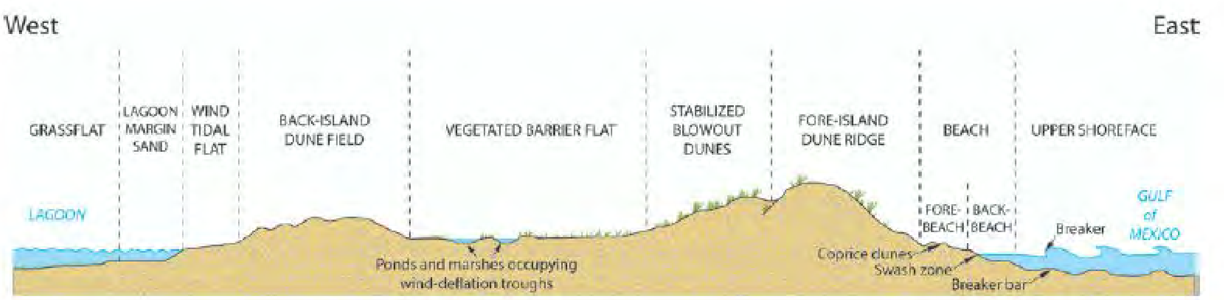

Figure 46. Geomorphologic formations of Padre Island National Seashore, showing the major zones in land formation across a barrier island (KellerLynn 2010).

Wind is the dominant process in the creation of barrier islands and shaping the shoreline and land features at PAIS (KellerLynn 2010). In turn, predominant winds drive ocean currents and create waves that transport sediments and deposit or erode materials onto the beaches along the shoreline (KellerLynn 2010). Longshore Gulf currents, converging at 27° latitude also influence island development by carrying sediment toward the island, where it is easily deposited onto beaches by wind generated wave and tidal action (KellerLynn 2010).

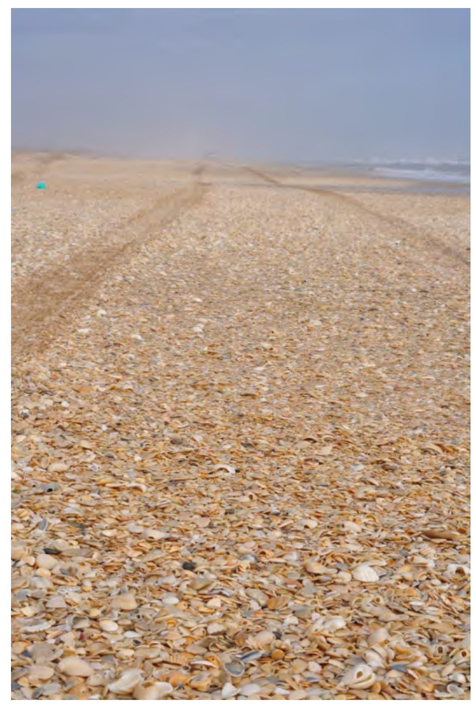

Photo 29. Big Shell Beach at PAIS (Photo taken by Shannon Amberg, SMUMN GSS).

The sediment that makes up a majority of the dunes and beaches in PAIS is fine sand, which becomes coarser in composition from the north to the south boundary of the seashore (KellerLynn 2010). Shell and shell fragments (shell hash) are also a common component in beach composition in PAIS. Specifically, as much as 80% of beach composition consists of shells, occurring primarily at the convergence zone of the longshore (the Yucatan and Texas longshore) currents at Little Shell and Big Shell beaches, where the collision of these currents suspends materials and deposits them on shore (Weise and White 1980, KellerLynn 2010). Photo 29 shows the predominantly shell composition of Big Shell Beach in PAIS.

Persistent blowing sands are ubiquitous in PAIS and the rate of sand and sediment migration across the island is such that maintenance of permanent roads and walkways (moving piled sand off the roads) is quite frequent (KellerLynn 2010).

Measures

- Annual change in shoreline position
- Rate of change in dune elevation (emergent, fore-island dune and back-island dunes)
- Rate of dune migration
- Rate of sand deposition/erosion (for beaches, emergent, fore-island dunes, and back-island dunes)

Reference Conditions/Values

Barrier islands and eolian dune systems are highly dynamic geomorphological features that undergo near constant change due to the influence of winds, waves, ocean currents, tidal action, storm events, and erosion and accretion of materials (KellerLynn 2010). The constant state of fluctuation and change for these geomorphic features is a natural process, periodically migrating landward or accreting along the shoreline. PAIS was primarily established to protect much of Padre Island from further development, and to ensure the natural barrier island features, and the dynamic processes that create them, could be left uninhibited. Because of the dynamic nature of the environment and constant change the coastal beaches and dunes undergo as a natural process, it was decided that a reference condition was unnecessary for this component. However, measures have been designated to track the rate of change and movement over time for the barrier island features.

Data and Methods

Nearly all studies at PAIS or along the Gulf coast of Texas focus on the dynamics and mechanics of the eolian dune (built by wind and water) and barrier island systems versus documenting change in dune structure and migration or shoreline position over time. Morton (1977) described the causes and mechanics of shoreline change on the Texas Gulf coast, including those factors that contribute most to beach erosion. Weiner (1982) documented the impact of predominant winds and weather patterns on oblique dune elevations and migration across the barrier island and how these changes vary seasonally. Hummel and Kocurek (1984) discussed the rate of dune migration during 1 year of mapping, and how migration direction is affected seasonally by predominant winds and weather patterns. Kocurek et al. (1992) documented various phases (constructive and destructive) of dune development, and found that deposition and accumulation of sands for dune building is dependent upon airflow patterns, sand supply, and moisture levels occurring seasonally. Dahl and Goen (1974) determined the importance of native vegetation in capturing blowing sands and stabilizing and building the foredune ridge.

The NPS completed a Geologic Resources Inventory (GRI) for PAIS in 2010 (compiled by KellerLynn 2010). The purpose of the GRI was to provide park managers with baseline information on geologic resources and increase understanding of the processes that influence geomorphology in the park. The goal of this GRI was to provide PAIS managers with sound geologic information that may be used in resource management decision-making, as ecosystems within PAIS are fundamentally shaped by the geology of the eolian beach and dune systems. The PAIS GRI describes the geomorphology of the area of North Padre Island within park boundaries and discusses its importance in creating unique ecosystems along the Texas coast. The GRI also discusses in depth various geologic issues or threats and stresses to geomorphological processes in the park that may require management attention (KellerLynn 2010).

Some studies have documented rates of shoreline change, dune migration, and materials deposition or erosion. Gibeaut et al. (2001) provides data regarding more recent shoreline position. Gibeaut et al. (2001) is a summary report of long-term rates of shoreline change along the Texas Gulf Coast shoreline. The area of study spans the coastline from Aransas Pass to the north boundary of PAIS, including Mustang and North Padre Islands. Gibeaut et al. (2001) did not study shoreline change within PAIS. This study used airborne LiDAR (Light Detection and Ranging) surveys to map the shoreline from Aransas Pass to the north boundary of PAIS; mapping occurred on 21 September 2000. Four passes were made by an aircraft at an altitude of 750 m (2,460 ft) and imagery data were captured extending approximately 500 m (1,640 ft) inland from the seashore. The data identified shoreline, foredunes, secondary dunes, and oceanfront structures. From the LiDAR data points, a DEM with a 1.5 m by 1.5 m grid was constructed and used to determine the current shoreline position; this shoreline was deemed an order of magnitude more accurate in position than earlier mapping using aerial photography. Historical shorelines were mapped on vertical aerial photographs (scale of 1:24,000 or larger) in 1937, 1956/58/59, 1965/69, 1974, and 1990/95. These were scanned and digitized in ArcView GIS software, then exported and analyzed by the Shoreline Shape and Projection Program (SSAP) developed by the Bureau of Economic Geology at The University of Texas at Austin. Historical shoreline position was compared to shoreline position as of September 2000. Linear regression modeling was used to calculate the average annual rate of shoreline change over time. Results are presented in the Current Condition and Trend section below.

In a report from the Bureau of Economic Geology at the University of Texas at Austin, Paine et al. (2011) characterize long-term rates of shoreline change along the Gulf Coast of Texas from 1930 through 2007. The Texas coastline was divided into three segments (Upper Texas Coast, Central Texas Coast, and Lower Coast/Padre Island). Rates of shoreline change were calculated through 2007 using shoreline positions depicted in topographic charts from the 1800s, aerial photography (1930-2007), ground surveys using GPS (mid-1990s), and an airborne LiDAR survey (conducted in 2000). Net rates of change were calculated for 11,731 sites, spaced 50 m apart, along the Texas Gulf of Mexico shoreline (535 km [332 mi]). Net shoreline change is discussed in the Current Conditions and Trend section below.

The Harte Research Institute at Texas A&M University – Corpus Christi has collected updated shoreline positions along the Texas coast (since Paine et al. 2011 and Gibeaut et al. 2001); however, new shoreline rates of change have not been calculated yet (Diana Del Angel, Coastal Geoscientist, pers. comm., 29 July 2013).

Pendleton et al. (2004) provide a coastal vulnerability assessment of PAIS to rising sea levels. Using a coastal vulnerability index, the authors characterized relative vulnerability to future sea-level rise for the PAIS Gulf of Mexico shoreline. The coastal vulnerability index ranks geomorphology, regional coastal slope, rate of relative sea-level rise, rate of change along shorelines, mean tidal range, and mean significant wave height in terms of their physical contribution to coastal change related to sea-level rise. Taken into consideration in this approach is the coastal system's natural ability to adapt to changing environmental conditions in conjunction with its susceptibility to such change. The index provides a quantitative measure of vulnerability to sea-level rise, although this is a relative measure. The assessment highlights the regions in PAIS where the physical effects of future sea-level rise may be greatest; these are discussed in the threats and stressors section below.

The GULN is working to establish a monitoring program to assess rates of change in materials deposition and erosion along the shoreline and in the dunes of PAIS using LiDAR technology and volumetric change analyses.

Current Condition and Trend

Annual Change in Shoreline Position

Early studies show that shoreline change along the Texas coast is a highly dynamic and complex process. According to Morton (1977), shoreline change along the Texas Gulf coast is caused by a complex interaction of multiple factors, including climate, available sediments, coastal processes, conditions of relative sea level rise, and various human activities. Although the retreat pattern of barrier islands toward the mainland is a natural occurrence, the author identified jettied inlets and navigation channels as the greatest detractors of available sediment (sediment sink), depriving natural processes of the sediment necessary for beach deposition and building; this may speed up the natural movement of the island toward the mainland. Morton (1977) suggested that rates of erosion and total length of eroding shoreline on the Texas coast have increased since historical documentation; data collected by Morton suggest this has been due to human impacts and sea level rise. It is further suggested that most of the Texas coastline would continue a natural retreat pattern toward the mainland.

Gibeaut et al. (2001) determined that the shoreline position between Aransas Pass and the north boundary of PAIS has been retreating since the 1930s, when the first aerial photos of the shoreline were taken. Plate 36 shows the location of Aransas Pass relative to the north boundary of PAIS; this stretch of shoreline between Aransas Pass and PAIS was the focus of Gibeaut et al.'s (2001) shoreline position study. Figure 47 shows the trend in shoreline position change along the stretch of shoreline studied from the 1930s through 2000. There are some areas of variability in change, which are likely caused by human alterations such as jetties, piers and seawalls, dredging, or other development activities.

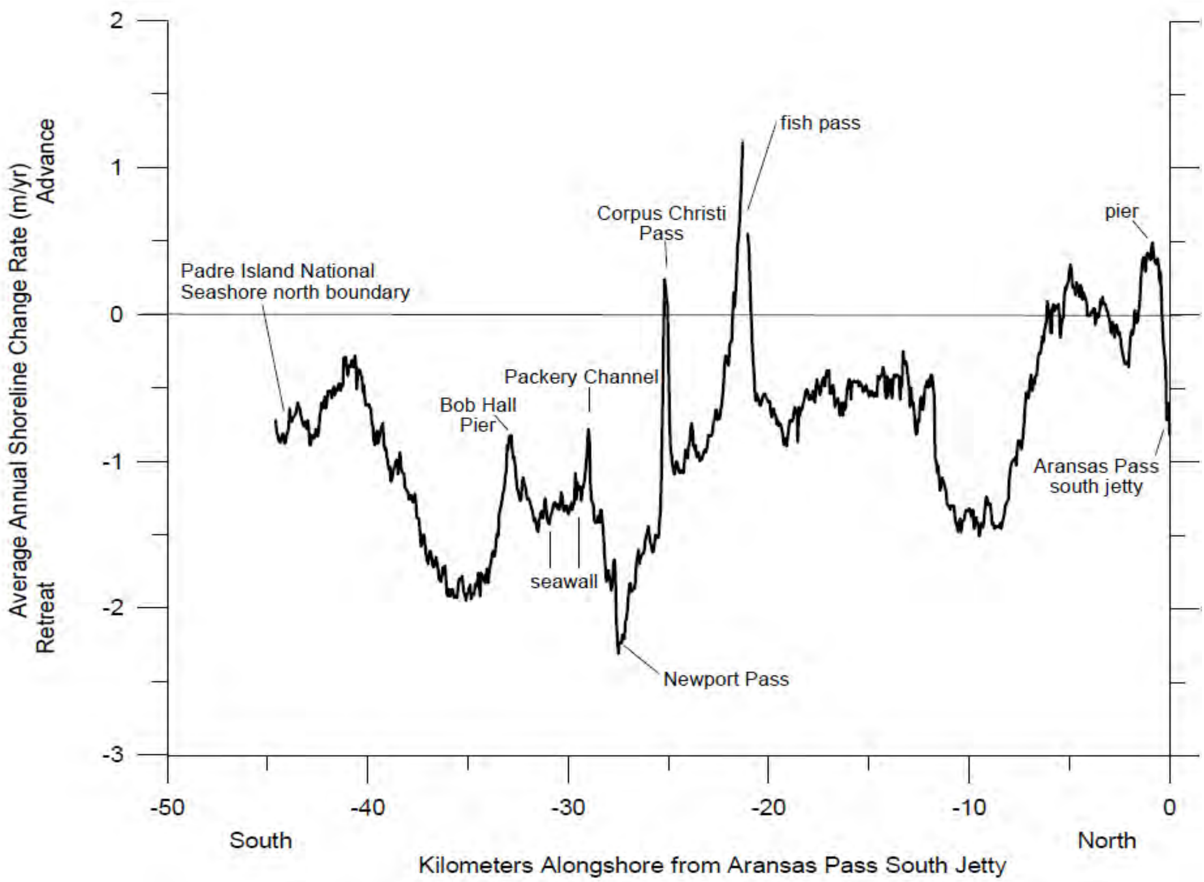

Figure 47. Average annual change in shoreline position (m/yr) from Aransas Pass to the north boundary of Padre Island National Seashore (reproduced from Gibeaut et al. 2001).

Paine et al. (2011) calculated the long-term average rate of change for Texas Gulf of Mexico shoreline position between the 1930s (some images dated back to the late 1800s) and 2007 to be 1.24 m of net retreat per year. Of 11,731 sites evaluated along the entire Texas coastline, net retreat was found at 9,830 (more than 80%) sites. The Lower Coast segment, comprised primarily of Padre Island, is largely undeveloped except for concentrated development at the northern and southern ends of the island. This segment encompasses 183 km (114 mi) of shoreline, which is classified primarily as a sandy barrier island with a well-developed eolian dune system along most of its length (Paine et al. 2011). Rates of change for shoreline position were calculated across 3,663 sites along the lower coast segment. Figure 48 shows the calculated net change in shoreline position for the Lower Texas Coast segment including PAIS. Despite Padre Island's location in a longshore drift convergent zone, net shoreline retreat (toward the mainland) was found at 84% of sites. Shoreline change at individual sites ranged from an advancement of 3.2 m/yr to retreat at 7.5 m/yr (Paine et al. 2011). Locations where advancing shoreline was detected included the segments (approximately 5 km in length) adjacent to the north and south jetties at Brazos Santiago Pass (south of PAIS), a segment near Little Shell Beach within PAIS (approximately 15 km [9 mi] long), and a stretch (approximately 5 km [3 mi] long) in the northern part of PAIS in central Kleberg County (Paine et al. 2011). The authors report that many locations with the highest rates of net shoreline retreat on Padre Island occur south of PAIS toward the southern end of the barrier island. Overall, PAIS is one of the areas of lower Texas coastline where the least amount of shoreline retreat is occurring; however, within PAIS, where retreat is occurring, the highest rates were measured along an 8 km (5 mi) stretch north of the Mansfield Channel jetties (>3 m/yr). Paine et al. (2011) conclude that engineering structures have affected shoreline position significantly in certain locations, namely jetties that are associated with shipping and boater access channels. These calculations will be updated using new LiDAR survey results captured in spring 2012.

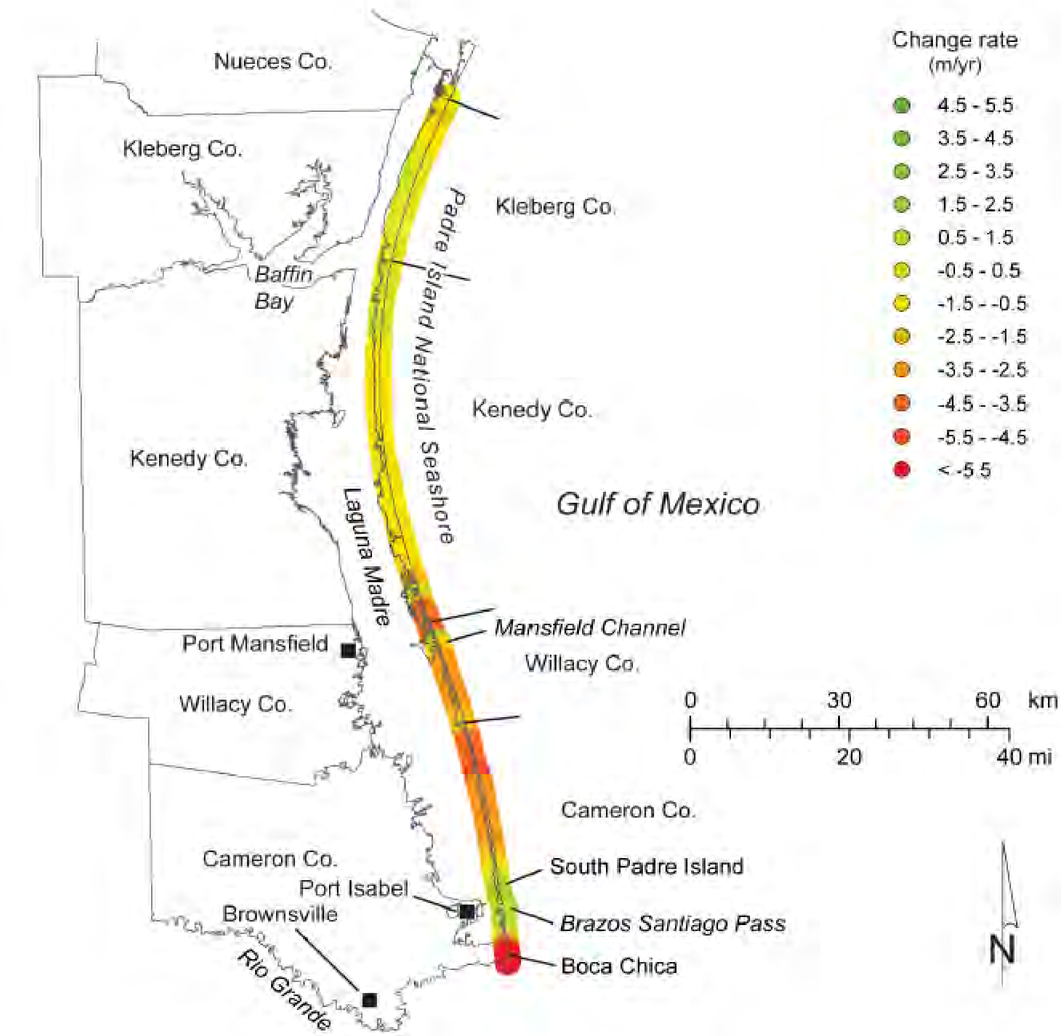

Figure 48. Net rates of long-term change in shoreline position for the lower Texas Gulf of Mexico, including PAIS, calculated from shoreline positions from 1930 through 2007 (Paine et al. 2011).

PAIS managers have observed accretion and erosion throughout the seashore over the years. In particular, the shoreline in the northern one-third of the park has been accreting over time. During the time when cattle ranching occurred on the island, sediments were carried out into the Laguna Madre, extending the island toward the mainland. When cattle were removed from the island, and as vegetation recovered, sand transport declined substantially, causing the Laguna Madre shoreline to erode quickly. Additionally, waves generated by boating and shipping traffic on the GIWW may be adding to the incidence of erosion along the Laguna Madre shoreline (Lindsay, personal communication, 29 July 2013).

Rate of Change in Dune Elevation

Weiner (1982) described that, depending on predominant wind patterns and season, oblique dunes on South Padre Island can change in elevation significantly. During early spring (March) and early fall (October), variable wind patterns and direction tend to flatten the dunes, while predominant winds that persist in a general direction during the summer and winter months build oblique dunes throughout the season.

LiDAR data as recent as 2012 do exist for PAIS, but dune elevations have not been extracted and analyzed yet to estimate elevation for the features within PAIS. These data could be compared to older or future LiDAR surveys to understand how features change over time.

Houser and Mathew (2011) studied the variability of dune height and extent on South Padre Island and the influence of sediment supply and foreshore and shoreline morphology. Using LiDAR data collected in 2000 and 2005, the authors characterized the alongshore variation in dune morphology and identified how dune height and extent are related to shoreline shape, potential for sediments to be transported, and sediment availability. The authors concluded that dune morphology (height and extent) is a result of both transport potential of sediments and sediment availability. For instance, the authors note that the largest dunes on South Padre Island are found where the beach is intermediate width but with a large supply of sediment available for transport on the backshore and foreshore areas. They argue that dune elevation and extent are a function of both transport potential and volume of sediment available for transport.

Rate of Dune Migration

Rates of dune migration for active dunes can vary yearly, but average rates can be determined by examining the position of specific dunes on aerial photographs or satellite imagery captured across several years (Weise and White 1980, USGS 2013). No recent studies have focused on rates of dune migration across the barrier island. LiDAR data as recent as 2012 do exist for PAIS, but current dune positions and degree of migration over time have not been extracted and calculated yet for the features within the park.

It appears that dune feature migration varies, depending on annual or seasonal wind patterns. Weiner (1982) found that, from April through September, during prevailing onshore winds, oblique dunes migrate northwestward. During times of high velocity wind events in the winter, dunes can migrate rapidly southward, while frequent changes in wind pattern and direction during the early spring and early fall months can cause dunes to flatten (Weiner 1982). Active (transgressive) dunes on South Padre Island were found to migrate up to 5-15 m/year (16-49 ft/year) during mapping completed in 2005 through 2009 (Diana Del Angel, Coastal Scientist, Harte Research Institute, pers. comm. 15 July 2013). Catastrophic weather events, such as hurricanes or tropical storms, have less long-term effect on dune migration than do the predominant winds and long-term weather patterns (Weiner 1982). Dahl and Goen (1974) found that foredunes with well-established vegetation prevented sand migration into the backdune areas of the island.

Hummel and Kocurek (1984) mapped interdune areas of the back-island dunes on North Padre Island over the course of 1 year. They described the back-island dune areas as young (about 100 years old) and consisting of persistent oblique dunes up to 6 m (19.7 ft) high and areas of sheet sand. Hummel and Kocurek (1984) found that, over 1 year of mapping, sand transport on the island was shown to be highly complex and cyclical. The dune field and individual dunes showed a net migration of approximately 15 m/year (49 ft/year) to the northwest overall, but are seasonally affected by varying weather frontal systems and wind direction. In winter, sands are shifted to expand the interdune area, while in summer, sands shift from the interdune area and build back-island dunes in size (Hummel and Kocurek 1984).

Rate of Sand Deposition/Erosion

Kocurek et al. (1992) documented that back-island dune fields on Padre Island go through seasonal changes, both destructive and constructive, in which they are reduced to nearly a flat surface during the winter months and reform again in the spring and summer months. Deposition of dry materials initially depends on weight and roughness of the materials, lowering the capacity of transport as elements become heavier and rougher. The building and survival of dunes depends on predominant and secondary airflow patterns, sand supply, advanced stage of development, and overall size (Kocurek et al. 1992). Dunes ultimately grow at the expense of transporting sand away from the interdune flats; however, moisture and damp surfaces allow increased and sustained accumulation on interdune flats. Kocurek et al. (1992) describe the Padre Island dune fields as representative of an eolian system where interdune flats expand and accumulate sands during periods of water table rise and constrict when the water table is static or falls.

Dahl and Goen (1974) conducted a 5-year study examining an experimental fore-island dune stabilization with native grasses. The authors found that native vegetation, particularly grasses, helped to stabilize and build the fore-island dune ridge through capture of blowing sands. Plots planted with native grasses captured 2-2.5 times more sand than dune areas with limited or no vegetation. Total sand accumulation in the unplanted areas was well-below the accumulation in the experimental planting areas.

Threats and Stressor Factors

Although erosion and sand transport is a natural dynamic in the barrier island and eolian dune systems, a number of factors can impact dune and beach integrity in PAIS. These include drought, vegetation loss, hurricanes, storm surges, high tide events, various forms of human disturbance, restriction of available sediments, and relative sea-level rise.

Drought and Loss of Vegetation

Vegetation plays a key role in trapping windblown sands to build and stabilize dunes along the fore-island dune ridge and preventing sand migration into back-island areas (Weise and White 1980). Sparsely vegetated dunes are more susceptible to breaching by heavy winds and strong storm surges. Sand and sediment not stabilized by vegetation is easily transported across the island, toward and into the mud flats, bays, and lagoon. Barrier islands are the first land feature in the path of storm surges (from hurricanes or tropical storms) and a well-developed and stabilized vegetated fore-island dune ridge is an important defense against inundation and destruction for the mainland. Loss of vegetation would compromise the stability and integrity of the fore-island dune ridge, reducing the barrier island's ability to dissipate large amounts of wave and water current energy (Weise and White 1980, USGS 2013).

Hurricanes, Storm Surges, and High Tides

Tropical storms and hurricanes have a long history of impacting the Texas Gulf of Mexico coastline (Paine et al. 2011). Barrier islands along the Texas Gulf coast are the first land feature in the path of approaching hurricanes and the accompanying storm surges (KellerLynn 2010). NOAA historical accounts indicate a total of 64 hurricanes and 56 tropical storms have made landfall along the Texas coastline between 1850 and 2010; an average of four hurricanes and four tropical storms hit the Texas coast every decade (Roth 2010).

Scientists have determined two primary influences in the erosion potential of hurricanes and tropical storms: storm surge height and duration. The longer the seas are elevated above normal along the coastlines during a storm event, the more likely it is that sediment is eroded from the beach and redistributed (Paine et al. 2011). Heavy winds and high tides, which accompany severe storm events, can cut into fore-island dunes, overwashing into and inundating low-lying areas or carrying sands and sediment back to the beaches and out into the Gulf (Weise and White 1980, KellerLynn 2010). During particularly strong storm events, winds and storm surges can carry sands to the back side of the barrier island and into the Laguna Madre, redistributing the sands across the island. Where vegetation is sparse, the fore-island dune ridge is not well developed and the force of wind and waves from strong storms and surges can create gaps or breaks in the ridge. Subsequently, sand is blown or washed into the back island area, forming blowout dunes and back-island active dunes that migrate toward the lagoon and deposit sediment into the lagoon, unless stabilized by vegetation (Weise and White 1980). Big storm events accelerate the natural erosion and deposition processes on a barrier island, changing beaches and dune features in ways that would typically take months or even years under normal conditions (Weise and White 1980, KellerLynn 2010, Paine et al. 2011).

In an assessment of the effect of Hurricane Allen on South Padre barrier island vegetation, Judd and Sides (1983) found that the percent cover of backshore zone vegetation following the hurricane was only 11% of what it was along line transects prior to the hurricane. Foredunes were found to be completely flattened by the storm. Low-growing plant species with shallow root systems were most vulnerable to dislodge and transportation by storm surge waters, whereas taller, grass-like species persisted. Loss of vegetative cover makes dunes susceptible to erosion and sands vulnerable to wind transport lagoon-ward.

The Harte Research Institute at Texas A&M University at Corpus Christi recently developed a Storm Susceptibility index for the Texas coast. This index identifies the theoretical level of protection that beaches and fore-island dune features provide against storm surge and erosion that would result from a tropical storm or hurricane event. This index may be able to provide managers with information on which areas are more likely to overwash during storm events of varying magnitudes (Del Angel, pers. communication, 29 July 2013).

Human Disturbance (including vehicle traffic, recreation in dunes, and oil and gas drilling)

PAIS is unique in that most of the seashore's beaches (approximately 101 km [63 mi]) are open to motor vehicle traffic; only just over 7 km (4.5 mi) of beach are off limits to beach driving (between the North Beach and South Beach access roads, including Malaquite Beach)

(KellerLynn 2010). Over the years, exploring the seashore by driving along the beaches has become a common and popular occurrence (KellerLynn 2010). Various studies in the 1970s and 1980s investigated the impacts of recreational driving on the dune and beach environments. KellerLynn (2010) summarizes many observed impacts, including: inhibiting shoreline accretion, increasing shoreline erosion and instability during storms, lowering dune elevation and changing dune form, reducing vegetation height, destroying vegetation and destabilizing dunes, changing distribution of beach and coppice dune fauna and invertebrates (e.g., ghost crabs, sea turtles, and birds), impacting benthic invertebrate populations, and negatively affecting the natural rebuilding capacity of fore-island dunes and coppice dunes between major storm events.

McAtee and Drawe (1981) documented damage to beach and fore-island dune vegetation on North Padre Island and PAIS caused by vehicle and pedestrian traffic. Damage was also compounded by weather (i.e., drought or heavy rains), salinity, and evaporation. Blum and Jones (1985) found that the density and complexity of vegetation on fore-island dunes on North Padre Island varied based on the amount of vehicular and pedestrian traffic experienced at different study sites. Sites sustaining greater amounts of traffic exhibited decreased density and complexity of vegetation.

Baccus et al. (1977) found a significant difference in diversity of floral composition between dune areas experiencing heavy versus light recreational traffic. Similarly, beaches experiencing heavier traffic exhibited higher incidence of impact (i.e., erosion, sand displacement, damage to vegetation) than those with less visitation. Baccus et al. (1977) goes on to suggest the dune and beach capacity to entrap blowing sands is substantially compromised when vegetation is damaged or destroyed.

Houser et al. (2013) used LiDAR data to determine if beach driving contributed to differences in beach and dune morphology between areas of open access and areas where driving is restricted. The authors found that beach driving in PAIS does not affect fore-island dune height or volume, but does significantly decrease the elevation of the crest and base of dunes compared to sections of beach where driving is restricted. Beach driving was not found to contribute to net loss of sediment, but driving on the beach does make fore-island dunes more susceptible to scarping and overwash during tropical storms and hurricanes (Houser et al. 2013).

Oil and gas development occurs within PAIS under special permits for drilling. Despite many precautions taken and mitigative measures in place to prevent potential spills and accidental leaks, the presence of such activity presents a threat to the geology, groundwater, and sensitive habitats of the park. Daily traffic to and from oil and gas drilling sites is limited to a maximum number of trucks per day and driving at or below 40 km/hr (25 mi/hr) to reduce potential for erosion or other damage to features, vegetation, or fauna (KellerLynn 2010).

Activities Restricting the Flow of Sediments

Activities such as off-shore sand mining, dredging in the Laguna Madre, channels and jetties, and dams on rivers can deprive the Gulf shores of sediment and sands that are crucial for beach and dune building. Two artificial channels, the Mansfield Channel and Brazos Santiago Pass, were created through Padre Island to connect the Gulf of Mexico to the Laguna Madre (KellerLynn 2010). Mansfield Channel marks the southern boundary of PAIS; it is a maintained pass that is used for shipping traffic and recreational access from the lagoon to the Gulf.

Mansfield Channel is lined with rock jetties that extend approximately 500 m (1,640 ft) out into the Gulf. These jetties cause inshore sediments to bypass the near shore or littoral zone and disrupt the transport ofsediments along the long shore (Jeffrey Bracewell, GIS specialist, pers. Comm., 29 July 2013). Sediment becomes trapped on the south side of the Mansfield Channel and jetty, building the beach out to the end of the jetty. The beach on the north side of the jetty erodes at a rate that requires renourishment every few years (Lindsay, pers. Comm., 29 July 2013). Any sediment that moves past the south jetty is 550 m (1,800 ft) out in the Gulf. Flow from Mansfield Channel pushes the sediment even further out into the Gulf; it may take as much as 40 km (25 mi) of northerly travel in the Gulf for the sediment to move back to shore (Lindsay, pers. Comm., 29 July 2013). Photo 30 shows the influence of the Mansfield Channel jetties on the transport of sediment into the Gulf and along the shoreline.

Photo 30. Imagery of Mansfield Channel jetties at the southern boundary of PAIS shows the flow of sediments through the channel and away from the littoral nearshore zone (Source: Google maps imagery https://maps.google.com, 2013).

Sediment is periodically dredged from the Mansfield and Brazos Santiago passes to keep the channels deep enough for boating and barge traffic to pass safely. Dredging removes materials that would typically flow through the channels and potentially deposit onto beaches by way of currents or storm events. Dredging also occurs on the GIWW.

Relative Sea Level Rise

Climate models predict that by 2100, global sea level will rise approximately 0.35 m (0.23 to 0.47 m) (IPCC 2007). Impacts to shorelines can include erosion, saltwater inundation of wetlands and groundwater aquifers, threats to cultural, historic and natural resources, and threats to infrastructure. Rising sea levels also contribute to shoreline retreat via submergence (through inundation of low-lying areas) and increasing the incidence of retreat by physical erosion (from currents and wave action) (Paine et al. 2011). Paine et al. (2011) summarize the most recent relative sea-level rise rates for coastal Texas; the highest rates of rise (>5 mm/year) are occurring at gauge sites along the upper and central Texas coast (Galveston, Sabine Pass, and Rockport), while the lowest rates (1.93 mm/year) are occurring near Port Mansfield. Gauges at Port Isabel, north Padre Island, and Freeport have calculated rates of sea-level rise between 3.48 and 4.35 mm/year (Paine et al. 2011).

Pendleton et al. (2004) estimate the overall vulnerability of PAIS to sea level rise as very high for the entire shoreline, specifically the tidal range. However, the actual vulnerability varies along the shoreline. For instance, 17% of the Gulf shoreline at PAIS is determined to have very high vulnerability, 28% has high vulnerability, 29% has moderate vulnerability, and 26% has what is categorized as low vulnerability (Pendleton et al. 2004). The authors determined areas most highly vulnerable are those that currently have the highest occurrence of overwash and the highest rates of shoreline change. Those areas considered vulnerable are more susceptible to shoreline erosion, saltwater intrusion into groundwater, inundation of wetlands, and damage to infrastructure (Pendleton et al. 2004).

NOAA's National Water Level Observation Network has been monitoring sea level rise with tide stations for over 150 years. Changes in mean sea level (MSL) have been computed at 128 long-term water level stations using a minimum span of 30 years of observations at each location. Measurements are averaged by month to remove the effects of phenomena such as storm surges and compute an accurate linear sea level trend. Based on data from 1948 through 2012, sea level rise in the Padre Island region (both north and south islands) is recorded at approximately 0-6 mm/year or 0-2 ft/century (NOAA 2013). Three monitoring stations in the North/South Padre Island region have recorded data on sea level rise over the last century: Station 8779750 at South Padre Island, Station 8778490 at Port Mansfield, and Station 8774770 at Rockport, Texas. Trends in mean annual sea level rise are presented below.

The mean sea level trend calculated for conditions at the South Padre Island, TX station is an increase of 3.48 mm/year (+/- 0.75 mm/year), based on monthly mean sea level data from 1958 to 2006 (Figure 49). This is equivalent to a change of 1.14 ft in 100 years (NOAA 2013). The mean sea level trend calculated for conditions at the Port Mansfield, Texas station is an increase of 1.93 mm/year (+/- 0.97 mm/year), based on monthly mean sea level data from 1963 to 2006 (Figure 50). This is equivalent to a rise of 0.63 ft in 100 years (NOAA 2013). The mean sea level trend calculated for conditions at the Rockport, Texas station (north of Padre Island) is an increase of 5.16 mm/year (+/- 0.67 mm/year), based on monthly mean sea level data from 1948 to 2006 (Figure 51). This is equivalent to a rise of 1.69 ft in 100 years (NOAA 2013). It is noted that a portion of apparent sea level rise may be due to subsidence of land due to unconsolidated deltaic sediments that make up the barrier island system (Lindsay, pers. Comm., 29 July 2013).

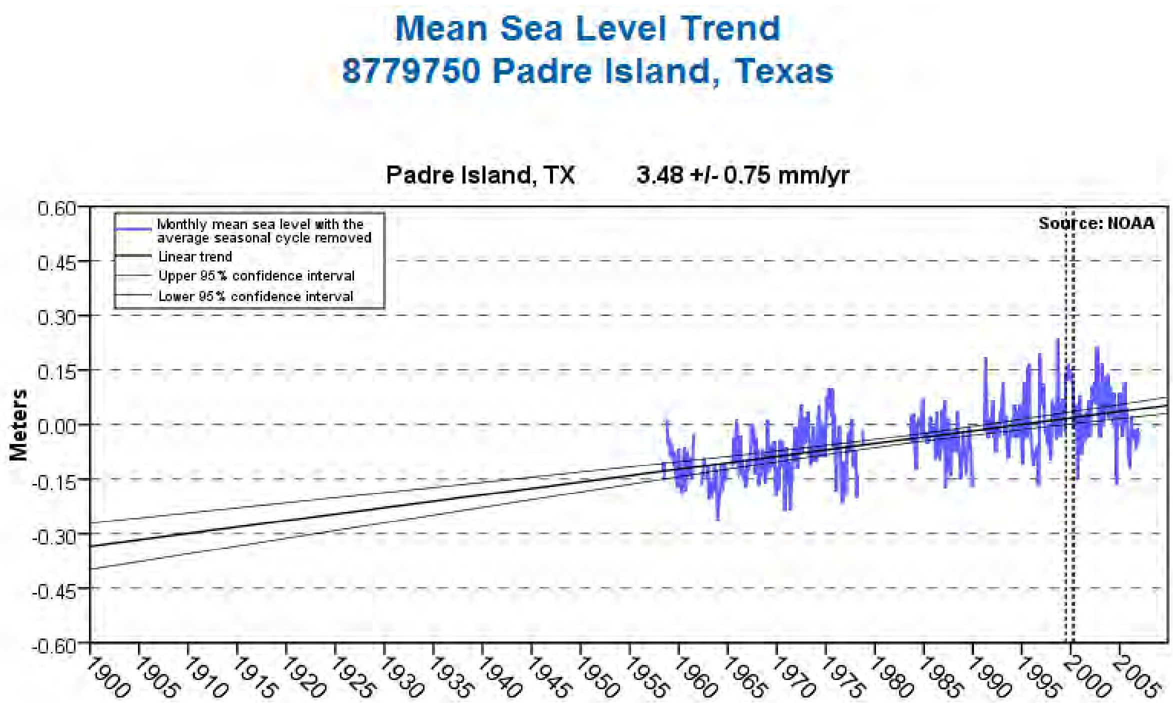

Figure 49. Trend in mean sea level rise recorded at Padre Island, TX, 1958 to 2006 (NOAA 2013).

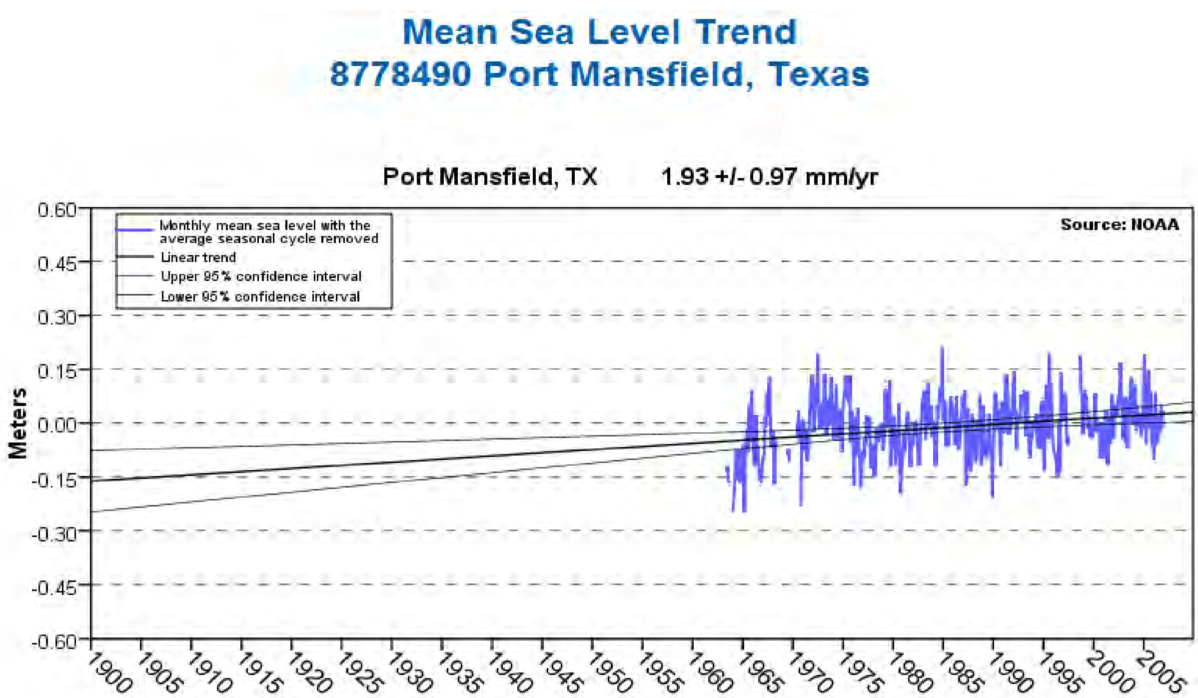

Figure 50. Trend in mean sea level rise recorded at Port Mansfield, TX, 1963 to 2006 (NOAA 2013).

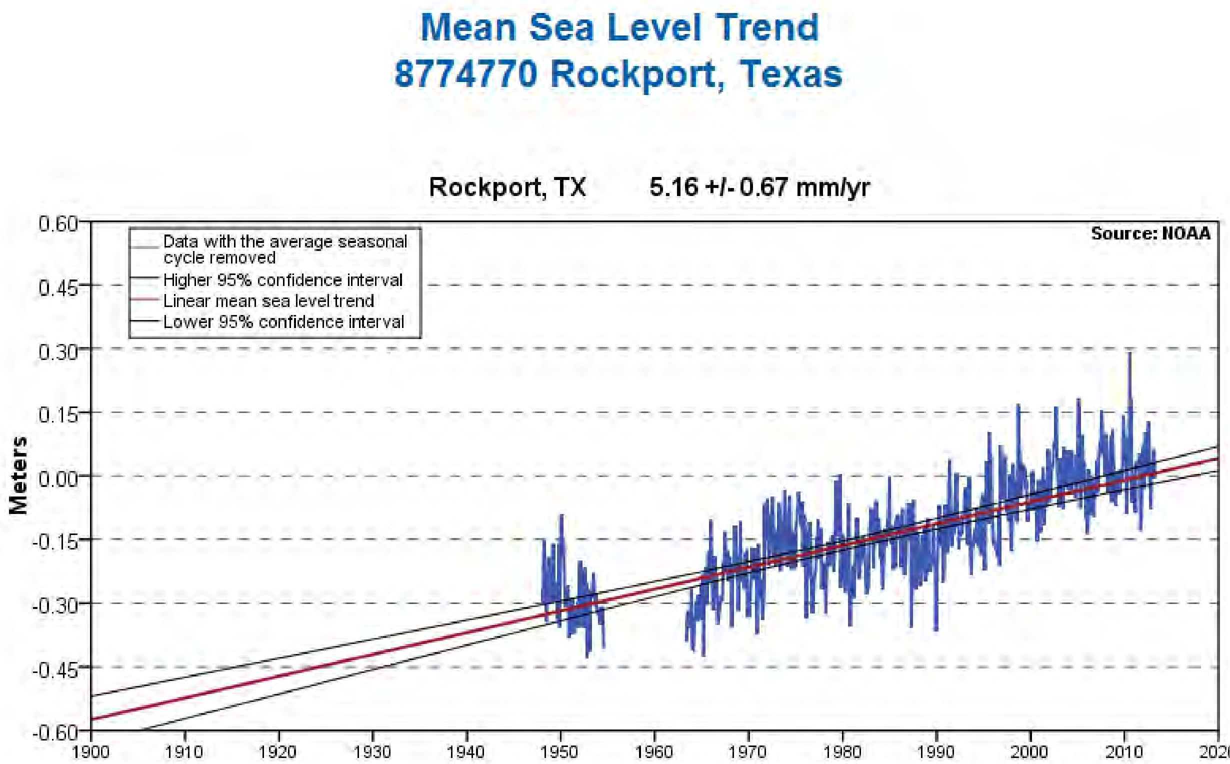

Figure 51. Trend in mean sea level rise recorded at Rockport, TX, 1948-2006 (NOAA 2013).

Data Needs/Gaps

Recent LiDAR (2012) imagery, available from the Bureau of Economic Geology, captures data for the shoreline and dunes (water's edge to approximately 200-300 m in from the shoreline) along Padre Island but does not capture data for the entire barrier island (center parts of the island). It is possible these data may be used to estimate dune migration within PAIS, but may not capture the patterns of those features greater than 300 meters from the shoreline. Information on dune elevation and shoreline position could be extracted and compared with older shoreline position analyses and dune elevation data to provide managers with a more complete picture of change over time. Current analyses for shoreline position change include calculations through 2007 for PAIS and 2011 for north of the park.

Consistent annual monitoring of changes in shoreline position and dune migration across the island would help park managers understand the rate of change occurring within the park on a seasonal and yearly basis, as well as what effects storm events and tidal surges may have on these features. Available imagery or LiDAR data and GIS analysis and comparison to earlier images can be quite useful in estimating change in eolian features and shoreline position in the park over time. A longer-term study of sand deposition/erosion would help managers understand the average rate at which materials are moved, deposited, and eroded by wind and wave actions, ultimately providing understanding of the implications for long-term integrity of the beaches and dune system. Benchmarks have been installed along the PAIS shoreline in 2012 and will be used to determine erosion and accretion rates in the near future and long-term.

Overall Condition

Annual Change in Shoreline Position
The project team defined the *Significance Level* for annual change in shoreline position as a 3, as an indication of loss or gain of material. Analysis of recent LiDAR data compared to historical imagery and aerial photos indicates shoreline position change is variable along the PAIS shoreline (both the Gulf of Mexico and the Laguna Madre). Paine et al. (2011) found a few locations in the northern part of PAIS and at the southern boundary have experienced significant advancement in shoreline position, while a few locations have also experienced significant retreat. Overall, with the exception of several sites experiencing high net retreat or advancement, net shoreline position change seems relatively stable (Paine et al. 2011). While shoreline position change is a natural process in barrier islands, engineered structures, such as jetties and channels, are documented to influence the transport of sediments that build beaches and dunes (Paine et al. 2011). Thus, a *Condition Level* of 2 was assigned, indicating moderate concern.

Rate of Change in Dune Elevation
The project team defined the *Significance Level* for rate of change in dune elevation as a 3. Recent LiDAR data are available for 2012, but dune elevation information has not yet been extracted or calculated for PAIS. Thus, a *Condition Level* was not assigned.

Rate of Dune Migration
The project team defined the *Significance Level* for rate of dune migration as a 3. Recent LiDAR data are available for dune migration, but have not yet been extracted or calculated for PAIS. Thus, a *Condition Level* was not assigned.

Rate of Sand Deposition/Erosion
The project team defined the *Significance Level* for rate of sand deposition/erosion as a 3. Limited information exists that focuses sand deposition/erosion on Texas barrier islands and in PAIS; however, this information is outdated. Thus, a *Condition Level* was not assigned.

Weighted Condition Score
Although LiDAR data do exist that could characterize the current condition of the measures, information has not yet been extracted from the dataset or analyzed for these measures. Thus, the Condition Level for several measures could not be determined. A *Weighted Condition Score* could not be calculated with Condition Levels undetermined for a majority of the measures.

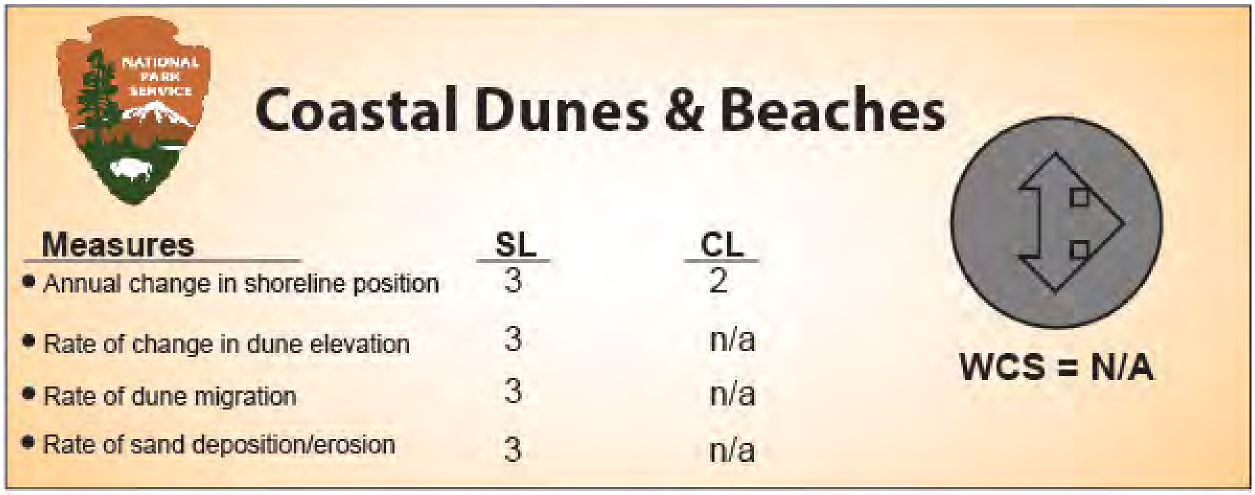

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Plate 36. Location of NOAA sea level rise monitoring stations relative to PAIS.

Chapter 5 Discussion

Chapter 5 provides an opportunity to summarize assessment findings and discuss the overarching themes or common threads that have emerged for the featured components. The data gaps and needs identified for each component are summarized and the role these play in the designation of current condition is discussed. Also addressed is how condition analysis relates to the overall natural resource management issues of the park.

5.1 Component Data Gaps

The identification of key data and information gaps is an important objective of NRCAs. Data gaps or needs are those pieces of information that are currently unavailable, but are needed to help inform the status or overall condition of a key resource component in the park. Data gaps exist for most key resource components assessed in this NRCA. Table 68 provides a detailed list of the key data gaps by component. Each data gap or need is discussed in further detail in the individual component assessments (Chapter 4).

Table 68. Identified data gaps or needs for the featured components in PAIS.

Component	Data Gaps/Needs
Terrestrial Vegetative Communities	➢ Comprehensive species inventory ➢ Assessment of current and historic coverage of grassland and dune vegetation ➢ Assessment of non-native plant species extent and distribution, and how non-native species are impacting native communities ➢ Assessment of prevalence of bare ground coverage in the park ➢ Study of oak motte extent, genetic status, factors affecting existence
Algal Mats on Mud Flats (Wind tidal flats)	➢ Current mapping of extent of algal mats within park boundaries ➢ Long-term surveys of benthic invertebrates or resampling of locations that have been sampled in previous study efforts
Seagrass Community	➢ Continuation of long-term monitoring effort to assess trends in species composition and distribution of seagrass beds within park boundaries
Emergent Wetland and Pond Communities	➢ Assessment of how wetlands have changed over time (in size, quality) and contributing factors to such change ➢ Comprehensive native plant survey specific to wetlands and ponds ➢ Repeated analysis of wetland/pond elevation to monitor trends in sedimentation or filling over time
Migratory Bird Species	➢ Establishment of an annual monitoring program to build a long-term data set on populations ➢ Establish formal survey for migratory raptors
Resident Bird Species	➢ Establishment of annual monitoring program or breeding bird survey ➢ Resuming Christmas Bird Count (CBC) efforts
Colonial Waterbirds	➢ Continued monitoring to determine trends in breeding populations ➢ A survey or estimate of nesting success ➢ Monitoring rate of erosion on islands used as primary nesting habitat

Table 68. Identified data gaps or needs for the featured components. (continued)

Component	Data Gaps/Needs
Coyotes	➢ Study of current coyote population density and distribution ➢ Estimation of reproductive success on the barrier island ➢ Assessment of disease prevalence
Small Mammals	➢ Assessment of species abundance, diversity, distribution and density throughout the park ➢ Establishment of annual small mammal survey
Macroinvertebrates	➢ Resampling of previous study sites to build longer-term data sets ➢ Long-term monitoring of species composition and population recruitment ➢ Assessment of dispersal dynamics, colonization, community succession
Reptiles	➢ Current and long-term monitoring to assess population sizes and diversity, reproductive success, and sex ratio ➢ Assessment of disease prevalence
Sea Turtles	➢ Continued annual monitoring of populations in the park
Amphibians	➢ Current survey to identify species within the park and long-term monitoring to determine trends in populations
Water Quality	➢ Establish monitoring program for freshwater ponds in the park ➢ Continued water quality sampling for the standard parameters in the Laguna Madre
Air Quality	➢ Consistent monitoring of nitrogen and sulfur deposition, ozone concentration, mercury deposition, particulate matter concentration and visibility within park boundaries
Dark Night Skies	➢ Draft plan for natural lightscape management showing areas where outdoor lighting are required and where naturally dark zones occur ➢ Periodic light trespass measurements into naturally dark zones to see how development outside park boundaries may be affecting conditions within the park and near park edges ➢ Calibrated photometry data to define dark night skies condition
Coastal Dunes and Beaches	➢ Annual or seasonal monitoring of changes in shoreline position and dune migration lagoonward ➢ Monitoring of impacts to shoreline and fore-island dune ridge from storm surges and hurricanes ➢ Long-term study of sand deposition/erosion from wave action and wind patterns

Many of the park's data needs involve establishing monitoring programs, as a number of the park's components have either outdated data or lack data all together. Many of the components analyzed in this report lacked enough data to facilitate long-term trend analyses.

Annual or consistent monitoring programs of some manner would establish a history of data records for most of the featured components or would repeat previous survey efforts in which current information could be compared to historic data and observations. This would help managers determine any changes in resource condition over time.

Sensitive terrestrial communities, such as the park's grassland and wetland vegetation and algal mats, are in need of up-to-date, comprehensive surveys of species and extent, as well as an investigation on how these communities have changed under the influence of non-native species advance, human impacts and disturbance, and weather changes. Several populations of terrestrial faunal species, such as reptiles, amphibians, and small mammals, are in need of contemporary data that describe population characteristics, diversity, and abundance. Since PAIS is an important stopover for many species of migratory birds, as well as habitat for numerous species of resident birds, the establishment of monitoring efforts for assessing population trends seems necessary. The components that describe environmental quality (i.e., air quality, water quality, dark night skies) are in need of expanded and more consistent monitoring efforts. In particular, for air and water quality, managers would benefit from more consistent sampling efforts (both in timing and methodology) within the park, as these initiatives would provide valuable insights into trends occurring seasonally and annually. Some of these needs are now being addressed through recently implemented GULN monitoring efforts with water quality in the Laguna Madre; however, data analyses are in beginning stages.

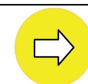
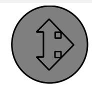
5.2 Component Condition Designations

The conditions assigned to each resource component featured in Chapter 4 are presented in Table 69 (definitions of condition graphics are located in Figure 52 following Table 69). It is important to remember that the graphics represented are simple symbols for the overall condition and trend assigned to each component. Because the assigned condition of a component (as represented by the symbols in Figure 52) is based on a number of factors and an assessment of multiple literature and data sources, it is strongly recommended that the reader refer back to each specific component assessment in Chapter 4 for a detailed explanation and justification of the assigned condition. Condition designations for some components are supported by existing datasets and monitoring information and/or the expertise of NPS staff, while other components lack historic data, a clear understanding of reference conditions (i.e., what is considered desirable or natural), or even current information.

Table 69. Summary of current condition and condition trend for featured PAIS NRCA components. Higher Weighted Condition Scores indicate higher concern.

Component	WCS	Condition
Biological Composition		
Ecological communities		
Terrestrial Vegetative Communities	N/A	
Algal Mats on Mud Flats	N/A	
Seagrass Communities	N/A	
Emergent Wetland and Pond Communities	N/A	
Wildlife and other Biotics		
Birds		
Migratory Birds	N/A	
Resident Birds	N/A	
Colonial Waterbirds	0.667	
Mammals		
Coyotes	N/A	
Small Mammals	N/A	
Macroinvertebrates		
Macroinvertebrates	N/A	
Herpitiles		
Reptiles	N/A	
Sea Turtles	0.667	
Amphibians	N/A	
Environmental Quality		
Water Quality	0.333	
Air Quality	0.583	

Table 70. Summary of current condition and condition trend for featured PAIS NRCA components. Higher Weighted Condition Scores indicate higher concern.

Component	WCS	Condition
Dark Night Skies	0.667	
Physical Characteristics		
Geomorphology		
Coastal Dunes and Beaches	N/A	

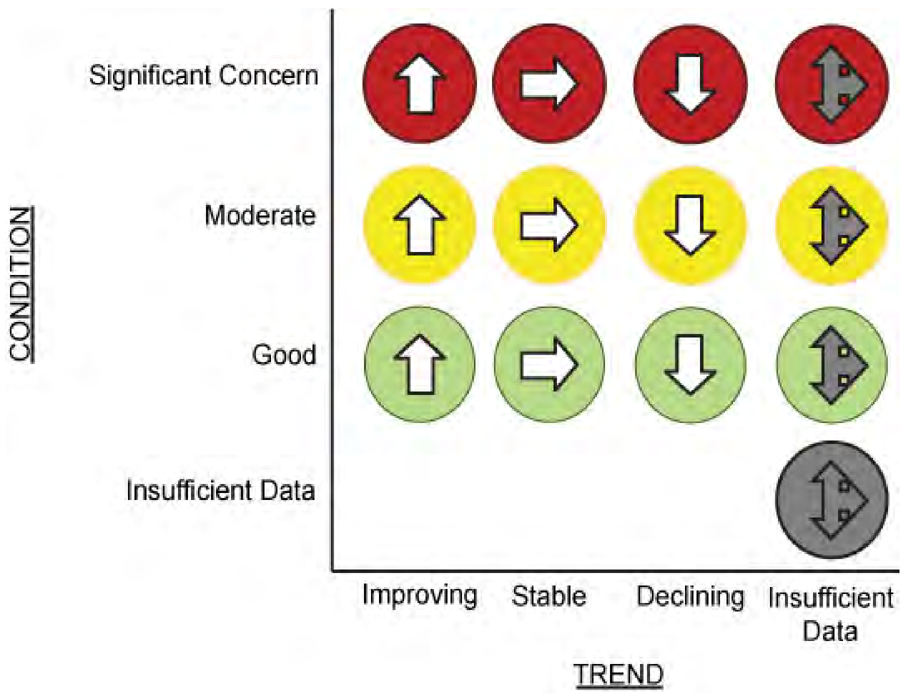


Figure 52. Symbols used for individual component assessments with condition or concern designations along the vertical axis and trend designations along the horizontal.

Of the 17 components featured in this assessment, 12 did not have sufficient data available to designate current condition. For featured components with available data and limited knowledge gaps, the resource conditions assigned varied. In total, five components had sufficient available data to determine current condition, all of which were assessed as being of moderate concern. These were colonial waterbirds, sea turtles, water quality, air quality, and dark night skies.

Four of the five components had enough available data or information to determine a trend in resource condition. Sea turtles, air quality, and dark night skies all had stable trends, while colonial waterbirds was determined to have a declining trend in resource condition.

5.3 Park-wide Condition Observations

Despite the great variety in vegetation and physical features within PAIS's boundaries, many of the resources discussed in this report are interrelated and share similar management concerns (e.g., data gaps, threats from outside the park).

Ecological Communities

PAIS comprises several unique ecological communities that are vital resources for the park, providing habitat for wildlife and performing critical ecological functions. These communities include the terrestrial vegetation (grasslands and dune vegetation) that covers much of the island, emergent wetland and pond communities, seagrass beds in the Laguna Madre, and the algal mats/mud flats occurring along the leeward side of PAIS. These unique communities are also among the most visible to park visitors exploring the different parts of the island. Limited research has been conducted on many of the ecological communities within the park and, due to a lack of available data and information (both recent and historic for comparison), current condition could not be assessed for the featured ecological communities.

Wildlife and other Biotics

A diversity of wildlife species or groups were featured in nine distinct components within this assessment, including both migratory and resident birds, colonial waterbirds, reptiles and amphibians, coyotes, small mammals, and sea turtles. Due to a lack of available recent and historical data and information, current condition and trend could not be determined for seven of the nine faunal components. Many of these components have had limited or sporadic monitoring or survey efforts completed in the park over the last several decades. The notable exceptions are colonial waterbirds and sea turtles. A local conservation group collects annual data on colonial waterbird populations in the Laguna Madre, which is then made available to PAIS managers for their records. Sea turtle nests and hatchling emergence is monitored annually for the five species that occur in PAIS; specifically, much data exists regarding the endangered Kemp's ridley, as species nesting and hatchling success is closely monitored in PAIS and carefully handled by biologists because of its status as a high conservation priority. Establishing regular monitoring efforts for the remaining featured components would fill many data gaps in understanding the condition of other wildlife and biotic populations in the park and the interrelationships that exist among species and habitats.

Environmental Quality

Environmental quality is important in maintaining healthy functioning ecosystems. The quality of air and water in an ecosystem can substantially affect the health of terrestrial and aquatic organisms that occur within parks. The park's air and water quality are currently of moderate concern; air quality has a stable trend, while trends for water quality could not be determined due to insufficient history of data. Nitrogen and sulfate deposition are at least a moderate concern regarding PAIS air quality, primarily due to the sensitivity of semi-arid and grassland ecosystems to acidification and/or nutrient enrichment from these pollutants. Water quality is on the low end of the moderate concern category, due primarily to concern about salinity levels in the Laguna Madre. Preliminary analysis of data for most measures of water quality are within established thresholds and elicit low concern at this time; however, more analyses are needed to understand trends over time and interrelationships of water quality parameters.

The park's dark night skies resource is also currently of moderate concern, with a stable trend. Light pollution from the mainland and developed areas of North Padre Island impact the dark night skies quality. However, rate of development outside park boundaries is currently slow or limited, which is helping to preserve dark sky quality presently.

Park-wide Threats and Stressors

Several threats and stressors influence the condition of multiple resources throughout PAIS. These include energy development (e.g., oil, gas, and wind), extreme weather events (e.g., hurricanes, tropical storms, and drought), relative sea level rise, and human impacts (e.g., recreation and development outside of the park).

Energy development within PAIS and in the area around the park would potentially affect the park's dark night skies, air quality, ecological communities, and certain biotics such as bird populations or small mammals. Oil drilling currently occurs within the park and, although these operations are carefully permitted, transportation traffic to and from the oil pads can damage sensitive grassland species or impact wildlife along beaches and dunes. Likewise, accidental spills of oil or other chemicals at drilling sites could damage important grassland habitats and associated wildlife, as well as contaminate groundwater. Oil platforms in the Gulf of Mexico are also visible from PAIS beaches. Spills at these development sites could adversely affect the beach environment and terrestrial and marine organisms that use the shoreline along PAIS. Wind energy development is occurring in the Laguna Madre and on the mainland of Texas and is directly visible from PAIS. These sites could pose a risk to migrating or resident bird populations as well as detract from the park's viewscape.

Hurricanes and tropical storms strike the Gulf coast of Texas at an average rate of 0.67 storms per year, or approximately two storms every 3 years; most of these weather events occur between late spring and early fall, with prime storm activity occurring from August through October (Weise and White 1980). When wind velocities reach 119 km/hr (74 mi/hr), tropical storms become categorized as hurricanes; the most severe hurricanes have sustained winds in excess of 322 km/hr (200 mi/hr) (Weise and White 1980). Heavy winds and high tides that accompany severe storm events can cut into fore-island dunes, overwashing into and inundating low-lying areas with saltwater or carrying sands and sediment back to the beaches and out into the Gulf (Weise and White 1980, KellerLynne 2010). Big storm events accelerate the natural erosion and deposition processes on a barrier island, changing beaches and dune features in ways that would typically take months or even years under normal conditions (Weise and White 1980, KellyLynn 2010).

Sea-level rise is a significant concern for PAIS. Pendleton et al. (2004) estimate the overall vulnerability of PAIS to sea level rise as very high for the entire shoreline, specifically the tidal range. However, the actual vulnerability varies along the shoreline, with approximately 35% of the PAIS shoreline rated as having very high or high vulnerability. Impacts to shorelines can include erosion, saltwater inundation of wetlands and groundwater aquifers, threats to cultural, historic and natural resources, and threats to infrastructure. Sea-level rise poses a particular threat to the algal mats on the wind tidal flats as it would cause permanent inundation if it were to exceed the rates at which sediment is deposited on the the flat (Morton and Holmes 2009). Thus, the extent of wind-tidal flats would decrease, limiting the extent of algal mats and leading to a loss of suitable habitat for macroinvertebrate populations and many species of birds.

Most of PAIS's beaches are open to motor vehicle traffic (approximately 101 km) with very few restrictions (approximately 7 km of beach is off limits to vehicles). Research over the last several decades has determined a number of observed impacts from such recreational driving, including encouraging shoreline erosion and inhibiting accretion of sediments onto shore, damaging beach and dune vegetation, impacting wildlife and benthic communities, destabilizing dunes, and negatively affecting the rebuilding capacity of coppice and fore-island dunes (KellerLynn 2010), and increasing susceptibility to overwash (Houser et al. 2013). Pedestrian traffic on the dunes can be impacting as well, destroying dune vegetation and impacting soils. In addition to catching new blowing sediments picked up from the beaches, vegetation stabilizes the dunes in the middle of the island and prevents sands and sediments from blowing away and migrating lagoonward. Pedestrian and motor vehicle traffic can damage above ground plant structure, as well as root systems, leading to sparser coverage and higher incidence of bare ground and wind erosion. By far, vehicle and pedestrian traffic is most damaging to the extremely sensitive algal mats and mud flat ecosystem. Scars and trenches made from passing vehicles can take months, years, or longer to heal, disrupting water flow across the flats and jeopardizing sensitive macroinvertebrate communities that populate the system and serve as a main food source for many wading bird species.

Overall Conclusions

PAIS is a very unique and diverse park that supports a variety of unique ecological communities and wildlife populations. The diversity in PAIS's communities ranges from grassland, to beaches and sand dunes, to wetlands and tidal flats, to hypersaline lagoon. Visitors to PAIS have the opportunity to view unique landscapes and eolian dune geology, as well as wildlife ranging from very small native rodents to bands of migrating, resident or colonial nesting birds, to larger mammals such as deer and coyote.

This assessment serves as a review and summary of available data and literature for featured natural resources in the park. The information presented here may serve as a baseline against which any changes in condition of components in the future may be compared. Unfortunately, many of the components analyzed here were not assigned an overall condition due to data gaps; some of these needs are being addressed by recently implemented GULN monitoring programs, which will provide valuable information for condition assessment in the near future. In order for PAIS managers to better understand the health, integrity, and trends of these valuable resources, additional research is needed for the specified components identified in this document.

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Appendices

Appendix A. Native plant species documented in PAIS.

Scientific Name	Common Name	Baccus 1977	Drawe et al. 1981	Carls et al. 1991	Nelson et al. 2000	Lonard et al. 2004
Amaranthus greggii	Gregg's amaranth	x			x	
Ambrosia psilostachya	Cuman ragweed	x			x	
Andropogon glomeratus	bushy bluestem			x		
Asclepias oenotheroides	zizotes milkweed		x		x	
Baptisia bracteata	longbract wild indigo					x
Cenchrus spinifex	coastal sandbur	x	x		x	x
Chamaecrista fasciculata var. *fasciculata*	partridge pea	x	x	x	x	x
Chamaesyce bombensis	Dixie sandmat	x	x			
Chamaesyce cordifolia	heartleaf sandmat	x				x
Chamaesyce serpens	matted sandmat			x		
Commelina erecta	whitemouth dayflower	x			x	x
Croptilon divaricatum	slender scratchdaisy	x				
Croptilon rigidifolium	stiffleaf scratchdaisy					x
Croton capitatus	hogwort	x				
Croton glandulosus	sand croton	x				x
Croton punctatus	gulf croton	x	x	x	x	
Cyperus echinatus	globe flatsedge					x
Cyperus esculentus	yellow nutsedge	x				
Cyperus retroflexus	oneflower flatsedge	x				
Digitaria arenicola	sand crabgrass					x
Digitaria cognata	Carolina crabgrass	x		x		
Eleocharis sp.	spikerush			x		
Eragrostis secundiflora	red lovegrass	x		x		
Eragrostis spectabilis	purple lovegrass	x	x			
Erigeron procumbens	Corpus Christi fleabane	x				
Euthamia leptocephala	bushy goldentop					x
Fimbristylis castanea	marsh fimbry	x				
Galactia canescens	hoary milkpea	x				x
Helianthus debilis	cucumberleaf sunflower	x				
Heliotropium racemosum	coastal plain heliotrope	x				
Heterotheca subaxillaris	camphorweed	x		x	x	x
Houstonia subviscosa	nodding bluet				x	
Hydrocotyle bonariensis	water pennywort	x		x	x	x
Indigofera miniata	coastal indigo	x	x		x	
Ipomoea imperati	beach morning-glory	x	x	x	x	x
Ipomoea pes-caprae	bayhops		x		x	
Oenothera drummondii	beach evening primrose	x	x	x	x	
Panicum amarum	bitter panicgrass	x		x	x	x
Panicum capillarioides	slender panicgrass		x		x	

Scientific Name	Common Name	Baccus 1977	Drawe et al. 1981	Carls et al. 1991	Nelson et al. 2000	Lonard et al. 2004
Paspalum monostachyum	gulfdune paspalum	x	x	x	x	x
Paspalum setaceum	thin paspalum	x	x	x	x	x
Paspalum vaginatum	seashore paspalum		x			
*Pennisetum ciliare**	buffelgrass				x	
Phlox drummondii	annual phlox		x			
Phlox glabrifolia	Rio Grande phlox	x				
Phyla nodiflora	frog fruit; turkey tangle fogfruit			x	x	
Physalis cinerascens var. *spathulifolia*	smallflower groundcherry		x		x	x
Physalis viscosa	starhair groundcherry	x		x		
Rayjacksonia phyllocephala	camphor daisy			x		
Rhynchosia americana	American snoutbean		x		x	x
Rhynchosia minima	least snoutbean				x	
Sabatia arenicola	sand rose gentian	x				
Schizachyrium scoparium var. *littorale*	shore little bluestem	x		x	x	x
Schoenoplectus pungens var. *longispicatus*	common threesquare			x		
Senecio riddellii	Riddell's ragwort	x			x	x
Senecio spartioides	broom-like ragwort		x			
Sesuvium portulacastrum	shoreline seapurslane	x			x	
Spartina patens	saltmeadow cordgrass	x	x		x	
Spiranthes vernalis	spring lady's tresses				x	
Sporobolus pyramidatus	Madagascar or whorled dropseed			x		
Sporobolus tharpii	Tharp's dropseed				x	
Sporobolus virginicus	seashore dropseed	x	x		x	
Stillingia sylvatica	queen's-delight		x			
Trichoneura elegans	Silveus' grass	x				
Triplasis purpurea	purple sandgrass					x
Uniola paniculata	seaoats	x	x	x	x	x
Urochloa ciliatissima	fringed signalgrass	x	x			
Vaseyochloa multinervosa	Texasgrass	x				x
	Total	**41**	**23**	**21**	**31**	**24**

* indicates a non-native species

Appendix B. Plant species documented in interior/grassland habitats (Drawe et al. 1981 [low coastal sands and shoregrass flats]; Carls et al. 1991 [secondary dunes & vegetated flats]; Nelson et al. 2000 [barrier flat]; Lonard et al. 2004 [vegetated flats]). Some scientific and common names were updated to match those accepted by the Integrated Taxonomic Information System (ITIS).

Scientific Name	Common Name	Drawe et al. 1981	Carls et al. 1991	Nelson et al. 2000	Lonard et al. 2004
Acacia farnesiana	sweet acacia			x	
Agalinis maritima	saltmarsh false foxglove		x	x	
Ambrosia psilostachya	Cuman ragweed	x	x	x	
Andropogon glomeratus	bushy bluestem	x	x	x	x
Aristida longespica var. *geniculata*	slimspike threeawn	x	x		
Asclepias oenotheroides	zizotes milkweed	x		x	
Baptisia bracteata	longbract wild indigo	x	x	x	x
Batis maritima	turtleweed			x	
Blutaparon vermiculare	silverhead	x	x	x	
Borrichia frutescens	bushy seaoxeye			x	
Buchnera americana	American bluehearts			x	
Calylophus serrulatus	yellow sundrops	x	x		
Cenchrus echinatus	southern sandbur	x			
Cenchrus spinifex	coastal sandbur	x		x	
Chamaecrista fasciculata	partridge pea	x	x	x	
Chamaesyce bombensis	Dixie sandmat	x			
Chamaesyce cordifolia	heartleaf sandmat				x
Chamaesyce serpens	matted sandmat		x		
Cirsium horridulum	yellow thistle				x
Commelina erecta var. *angustifolia*	whitemouth dayflower	x	x	x	
Conoclinium betonicifolium	betonyleaf thoroughwort	x	x	x	x
Coreopsis tinctoria	golden tickseed				
Croptilon divaricatum	slender scratchdaisy	x			
Croton capitatus var. *lindheimeri*	Lindheimer’s hogwort			x	
Croton glandulosus	sand croton				x
Croton punctatus	gulf croton	x			
Cyperus rotundus	nutgrass		x		
Cyperus echinatus	globe flatsedge			x	
Dalea emarginata	wedgeleaf prairie clover	x			
Dichanthelium sp.	rosette grass		x		
Dichanthelium acuminatum	tapered rosette grass				x
Dichanthelium sabulorum var. *thinium*	hemlock rosette grass	x		x	
Dichanthelium sphaerocarpon var. *sphaerocarpon*	roundseed panicgrass	x			
Digitaria cognata	Carolina crabgrass		x		
Eleocharis sp.	spikerush		x		
Eleocharis geniculata	Canada spikesedge	x			

Scientific Name	Common Name	Drawe et al. 1981	Carls et al. 1991	Nelson et al. 2000	Lonard et al. 2004
Eleocharis montevidensis	spike sedge; sand spikerush	x			
Eragrostis secundiflora	red lovegrass	x	x		
Eragrostis secundiflora ssp. *oxylepis*	red lovegrass			x	
Eragrostis spectabilis	purple lovegrass	x			
Erigeron procumbens	Corpus Christi fleabane	x	x	x	
Eupatorium compositifolium	yankeeweed				x
Eustachys petraea	pinewoods fingergrass	x	x		
Eustoma exaltatum	catchfly prairie gentian		x		
Fimbristylis caroliniana	Carolina fimbry			x	
Fimbristylis castanea	marsh fimbry	x	x	x	x
Flaveria brownii	Brown's yellowtops			x	
Gaillardia pulchella	Indian blanket	x	x		
Galactia canescens	hoary milkpea		x		
Heliotropium curassavicum var. *curassavicum*	salt heliotrope	x	x		
Heterotheca subaxillaris	camphorweed	x	x		
Hydrocotyle bonariensis	water pennywort	x	x	x	x
Indigofera miniata	coastal indigo	x	x	x	
Ipomoea imperati	beach morning-glory		x		
Ipomoea pes-caprae	bayhops	x			
Iva angustifolia	narrowleaf marsh elder		x	x	
Juncus sp.	rushes			x	x
Limonium carolinianum	lavender thrift	x	x	x	
Linum alatum	winged flax	x			
Lythrum alatum var. *lanceolatum*	winged lythrum			x	
Lythrum californicum	California loosestrife		x		
Mimosa latidens	Kairn's sensitive-briar	x	x		
Monanthochloe littoralis	shoregrass	x			
Oenothera drummondii	beach evening primrose	x	x		
Opuntia macrorhiza	twistspine pricklypear			x	x
Panicum amarum	bitter panicgrass		x		
Panicum amarum var. *amarulum*	coastal or bitter panicgrass	x			
Panicum capillarioides	slender panicgrass			x	
Paspalum monostachyum	gulfdune paspalum	x	x	x	x
Paspalum plicatulum	brownseed paspalum				x
Paspalum setaceum	thin paspalum	x	x	x	
Paspalum vaginatum	seashore paspalum	x			
Phlox drummondii	annual phlox		x		
Phyla nodiflora	frog fruit; turkey tangle fogfruit	x	x	x	
Physalis cinerascens var. *spathulifolia*	smallflower groundcherry	x		x	
Physalis viscosa	starhair groundcherry		x		
Polygala alba	white milkwort	x	x	x	

Scientific Name	Common Name	Drawe et al. 1981	Carls et al. 1991	Nelson et al. 2000	Lonard et al. 2004
Polygala incarnata	procession flower		x		
*Polypogon monspeliensis**	annual rabbitsfoot grass	x			
Quercus fusiformis	Texas live oak			x	
Rayjacksonia phyllocephala	camphor daisy	x	x	x	
Rhynchosia americana	American snoutbean	x	x	x	x
Rhynchosia minima	least snoutbean	x		x	
Rhynchospora colorata	white-top sedge	x			
Sabatia arenicola	sand rose gentian	x		x	
Salicornia bigelovii	dwarf saltwort	x			
Salix nigra	black willow			x	
Samolus ebracteatus	limewater brookweed		x	x	
Schizachyrium scoparium var. *littorale*	shore little bluestem		x	x	x
Schoenoplectus pungens var. *longispicatus*	common threesquare	x	x	x	
Sesuvium portulacastrum	shoreline seapurslane	x	x		
Sisyrinchium biforme	wiry blue-eyed grass		x	x	
Sisyrinchium sagittiferum	spearbract blue-eyed grass	x			
Spartina patens	saltmeadow cordgrass	x	x	x	
Spiranthes vernalis	spring lady's tresses	x	x	x	
Sporobolus pyramidatus	Madagascar or whorled dropseed	x			
Sporobolus tharpii	Tharp's dropseed	x			
Sporobolus virginicus	seashore dropseed	x	x	x	
Stemodia lanata	gray-woolly twintip	x		x	x
Stillingia sylvatica	queen's-delight	x			
Tidestromia lanuginosa	wooly tidestromia			x	
Tragia sp.	noseburn		x		
Uniola paniculata	seaoats	x	x	x	
Yucca treculeana	Don Quixote's lace			x	
	Total	**61**	**52**	**52**	**17**

* indicates a non-native species

Appendix C. List of macroinvertebrate species and respective microhabitat types observed during a study of PAIS between 1991 and 1992 (Withers 1993).

Species	Damp	Wet	Intertidal
Phylum Nemertea		X	X
Phylum Annelida			
Class Polychaeta			
Arenicola cristata		X	
Axiothella mucosa			X
Capitella capitata	X	X	X
Capitomastus aciculatus		X	X
Chone duneri			X
Demonax micropthalmus			X
Dorvillea rubra			X
Eteone heteropoda	X	X	X
Exogone dispar			X
Haploscoloplos foliosus	X	X	X
Polydora ligni			X
Prionospio cristata			X
Prionospio heterobranchia			X
Sabella sp. A			X
Syllis cornuta	X	X	X
Phylum Mollusca			
Class Bivalvia			
Amygdalum papyrium		X	
Anomalocardia auberiana		X	X
Bulla striata	X		X
Mulinia lateralis	X	X	X
Tellina tampaensis			X
Phylum Arthropoda			
Subphylum Chelicerata			
Spiders		X	X
Subphylum Crustacea			
Corophium louisianum	X	X	X
Hargeria rapax	X	X	X
Oxyurostylis smithii			X
Subphylum Hexapoda,			
Class Insecta			
Bledius sp.	X	X	
Canaceidae	X	X	X
Carabidae	X		
Ceratopogonidae	X	X	X

Species	Damp	Wet	Intertidal
Dolichopodidae	X	X	X
Empidiae			X
Homoptera			X
Leuctridae sp.		X	
Melyridae	X		
Pteromalidae			X
Saldidae	X		
Scelionidae			X
Subphylum Hexapoda,			
Class Entognatha			
Cyphoderus sp.			X
Total Number of Species	**15**	**18**	**31**

Appendix D. List of macroinvertebrate species observed at two former oil and gas development sites that have been restored in PAIS (Withers 1996).

	Texaco site			Yarborough Pass		
Species	Restored	Control	Tire Tracks	Restored	Control	Tire Tracks
Phylum Nemertea				X	X	
Phylum Annelida						
Class Polychaeta						
Demonax micropthalmus				X		
Eteone heteropoda				X		
Exogone dispar				X		
Haploscoloplos foliosus				X	X	X
Polydora spp.		X		X	X	
Prionospio heterobranchia				X		
Prionospio pinnata				X	X	
Nainereis laevigata				X		
Sabella sp. A				X		
Spio pettibonniae				X		
Streblospio benedicti				X		
Syllis cornuta				X		
Capitellidae				X		
Maldanidae						X
Phylum Mollusca						
Class Bivalvia						
Amygdalum papyrium				X	X	
Anomalocardia auberiana				X	X	
Tellina sp.				X		
Phylum Arthropoda						
Subphylum Crustacea						
Corophium acherusicum	X	X		X	X	
Corophium louisianum				X	X	
Gammarus mucronatus				X		
Hargeria rapax	X	X		X	X	X
Subphylum Hexapoda,						
Class Insecta						
Berosus sp.	X		X			
Canaceidae	X	X	X	X		
Ceratopogonidae	X	X		X	X	X
Dolichopodidae	X	X	X	X	X	X
Ephydridae				X		
Melyridae				X	X	
Nabidae			X			X

Species	Texaco site			Yarborough Pass		
	Restored	Control	Tire Tracks	Restored	Control	Tire Tracks
Phylum Platyhelminthes						
Turbellaria				X	X	
Total Number of Species	**6**	**6**	**4**	**27**	**13**	**6**

Appendix E. List of macroinvertebrate species observed at three southerly wind-tidal flats in PAIS between 1997 and 1998 (Withers 1998).

Species	Yarborough Pass	Dunn Ranch	Mile Marker 45
Phylum Nemertea	x		
Phylum Annelida			
Class Polychaeta			
Axiothella mucosa			x
Capitella capitata	x	x	x
Demonax micropthalmus	x	x	x
Eteone heteropoda	x	x	x
Haploscoloplos foliosus	x		x
Laeonereis culveri	x		
Polydora spp.	x		
Prionospio heterobranchia	x		
Marphysa regalis	x		
Melinna maculata	x		x
Nainereis laevigata		x	x
Nereis riisei	x	x	
Sabella sp. A	x		
Phylum Mollusca			
Class Bivalvia			
Anomalocardia auberiana	x	x	x
Tellina tampaensis	x		x
Phylum Arthropoda			
Subphylum Crustacea			
Corophium acherusicum		x	
Corophium louisianum	x		
Grandidierella bonnieroides	x		
Gammarus mucronatus	x		
Hargeria rapax	x	x	
Orchestia grillus	x		
Sphaeroma quadridentatum	x		
Subphylum Hexapoda			
Class Insecta			
Bledius sp.	x		
Canaceidae	x	x	x
Ceratopogonidae	x	x	
Dolichopodidae	x	x	x
Hemiptera (nymph)		x	
Hydrophilidae (larvae)		x	x
Staphylinidae (larvae)		x	x
Tipulidae	x		
Total Number of Species	**25**	**14**	**13**

Appendix F. Vascular plants within 60 m (200 ft) of the three ponds sampled at PAIS (Sissom et al. 1990).

Scientific name	Common name	Pond A	Pond B	Pond C
Hydrocotyle bonariensis	water pennywort	x		
Asclepias oenotheroides	zizotes milkweed		x	
Cirsium horridulum	yellow thistle	x		
Croptilon divaricatum	slender scratchdaisy			x
Erigeron procumbens	Corpus Christi fleabane		x	
Gaillardia pulchella	Indian blanket	x		
Heterotheca pilosa	golden aster			x
Heterotheca subaxillaris	camphorweed	x	x	
Iva angustifolia	narrowleaf marsh elder	x	x	
Pluchea odorata var. *odorata*	sweetscent		x	
*Cyperus rotundus**	flatsedge; nutgrass		x	
Rhynchospora colorata	white-top sedge		x	
Eleocharis montevidensis	spike sedge		x	
Fimbristylis castanea	marsh fimbry			x
Schoenoplectus americanus	American bulrush	x		
Croton capitatus	hogwort			x
Croton glandulosus	sand croton			x
Croton punctatus	gulf croton	x		
Chamaesyce cordifolia	heart-leaf sandmat			x
Chamaesyce maculata	spotted sandmat			x
Baptisia bracteata	longbract wild indigo	x		
Chamaecrista fasciculata	partridge pea		x	
Galactia canescens	hoary milkpea			x
Indigofera miniata	coastal indigo	x		
Sesbania vesicaria	bladder pod	x		
Eustoma exaltatum	catchfly prairie gentian		x	
Triadenum virginicum	St. John's wort		x	x
Sisyrinchium biforme	wiry blue-eyed grass		x	
Plantago rhodosperma	redseed plantain			x
Andropogon glomeratus	bushy bluestem		x	
Cenchrus spinifex	coastal sandbur			x
*Dactyloctenium aegyptium**	Egyptian grass			x
Eragrostis secundiflora	red lovegrass		x	
Eustachys petraea	finger grass		x	
Leptochloa fusca ssp. *fascicularis*	bearded sprangletop	x		
Paspalum setaceum	thin paspalum	x	x	
*Pennisetum ciliare**	buffelgrass	x		
Schizachyrium scoparium	little bluestem		x	
Setaria parviflora	yellow bristlegrass	x		
Sporobolus pyramidatus	Madagascar dropseed			x
Polygala incarnata	pink milkwort	x		
Eriogonum multiflorum	wild buckwheat			x

Scientific name	Common name	Pond A	Pond B	Pond C
Samolus ebracteatus	limewater brookweed		x	x
Agalinis maritima	saltmarsh false foxglove		x	
Bacopa monnieri	coastal water hyssop		x	
Buchnera americana	American bluehearts	x		
Physalis viscosa	ground cherry	x		
Typha domingensis	narrow-leaf cattail	x		
Phyla nodiflora	frog fruit	x		
	Total	**19**	**20**	**15**

* indicates non-native species

Appendix G. Algae documented in three PAIS ponds by Sissom et al. (1990).

Genus	Pond A	Pond B	Pond C
Cyanophyta (blue-green algae)			
Polycystis	x	x	x
Oscillatoria	x	x	x
Coelosphaerium	x	x	x
Rhaphidiopsis	x	x	x
Merismopedia	x	x	
Chroococcus	x	x	x
Spirulina	x	x	
Chlorophyta (green algae)			
Dictyosphaerium	x	x	
Pediastrum	x	x	x
Protococcus	x	x	x
Crucigenia	x	x	
Botryococcus	x	x	x
Spirogyra	x	x	
Microspora	x		
Zygnema	x		
Tribonema	x		
Selenastrum	x	x	
Scenedesmus	x		
Desmidium	x		
Hydrocera	x		
Staurastrum	x	x	x
Cosamarium	x		x
Closterium	x		x
Tetemorus	x		
Penium	x		
Ankistrodesmus		x	
Evastrum		x	
Total	**25**	**17**	**11**

Appendix H. Fungal species documented in three PAIS ponds by Florence Oxley (Sissom et al. 1990).

Taxa	Pond A	Pond B	Pond C
Cladosporium	x	x	x
Altenaria	x	x	x
Cephalosporium	x	x	x
Curvularia		x	x
Fusarium	x	x	x
Drechslera	x	x	x
Nigrospora	x	x	x
Aspergillus	x	x	x
Phoma	x	x	x
Penicillium	x	x	x
Ascochyta	x		x
Macrophoma	x	x	
Didymosphaenia maritima	x		
Didymosphaenia enalia		x	
Leptosphaeria discors	x		
Leptosphaeria oraemaris	x		
Leptosphaeria australiensis	x		
Leptosphaeria marina		x	
Epicoccum	x	x	x
Pithomyces	x	x	x
Eurotiales	x	x	
Pestalotia	x	x	x
Rhizopus		x	
Tetraploa			
Pleospora		x	
Stagnospora		x	
Myrothecium		x	
Trichoderma		x	
Candelabrella		x	
Humicola			x
Stachybotrys			x
Bipolaris			x
Total	**19**	**23**	**17**

Appendix I. Neotropical migrant species that are confirmed in PAIS (NPS 2013a, TPWD 2013).

Scientific Name	Common Name
Anas cyanoptera	cinnamon teal
Anas discors	blue-winged teal
Chaetura pelagica	chimney swift
Amazilia yucatanensis	buff-bellied hummingbird
Archilochus alexandri	black-chinned hummingbird
Archilochus colubris	ruby-throated hummingbird
Buteo platypterus	broad-winged hawk
Buteo swainsoni	Swainson's hawk
Elanoides forficatus	swallow-tailed kite
Ictinia mississippiensis	Mississippi kite
Pandion haliaetus	osprey
Charadrius semipalmatus	semipalmated plover
Charadrius wilsonia	Wilson's plover
Himantopus mexicanus	black-necked stilt
Pluvialis dominica	American golden plover
Pluvialis squatarola	black-bellied plover
Mycteria americana	wood stork
Falco columbarius	merlin
Falco peregrinus	peregrine falcon
Actitis macularia	spotted sandpiper
Arenaria interpres	ruddy turnstone
Bartramia longicauda	upland sandpiper
Calidris alba	sanderling
Calidris bairdii	Baird's sandpiper
Calidris canutus	red knot
Calidris fuscicollis	white-rumped sandpiper
Calidris himantopus	stilt sandpiper
Calidris mauri	western sandpiper
Calidris melanotos	pectoral sandpiper
Calidris minutilla	least sandpiper
Calidris pusilla	semipalmated sandpiper
Limnodromus griseus	short-billed dowitcher
Limosa haemastica	Hudsonian godwit
Numenius phaeopus	whimbrel
Phalaropus tricolor	Wilson's phalarope
Tringa flavipes	lesser yellowlegs
Tringa melanoleuca	greater yellowlegs
Tringa solitaria	solitary sandpiper
Tryngites subruficollis	buff-breasted sandpiper
Coccyzus americanus	yellow-billed cuckoo

Scientific Name	Common Name
Coccyzus erythropthalmus	black-billed cuckoo
Crotophaga sulcirostris	groove-billed ani
Gallinula galeata	common gallinule
Porphyrula martinica	purple gallinule
Guiraca caerulea	blue grosbeak
Passerina ciris	painted bunting
Passerina cyanea	indigo bunting
Pheucticus melanocephalus	black-headed grosbeak
Spiza americana	dickcissel
Polioptila caerulea	blue-gray gnatcatcher
Ammodramus savannarum	grasshopper sparrow
Melospiza lincolnii	Lincoln's sparrow
Spizella passerina	chipping sparrow
Hirundo pyrrhonota	cliff swallow
Hirundo rustica	barn swallow
Progne subis	purple martin
Riparia riparia	bank swallow
Stelgidopteryx serripennis	northern rough-winged swallow
Icterus bullockii	Bullock's oriole
Icterus cucullatus	hooded oriole
Icterus galbula	Baltimore oriole
Icterus spurius	orchard oriole
Dumetella carolinensis	gray catbird
Dendroica castanea	bay-breasted warbler
Dendroica cerulea	cerulean warbler
Dendroica dominica	yellow-throated warbler
Dendroica fusca	blackburnian warbler
Dendroica magnolia	magnolia warbler
Dendroica nigrescens	black-throated gray warbler
Dendroica palmarum	palm warbler
Dendroica pensylvanica	chestnut-sided warbler
Dendroica petechia	yellow warbler
Dendroica striata	blackpoll warbler
Dendroica tigrina	Cape May warbler
Dendroica virens	black-throated green warbler
Geothlypis trichas	common yellowthroat
Helmitheros vermivorus	worm-eating warbler
Icteria virens	yellow-breasted chat
Limnothlypis swainsonii	Swainson's warbler
Mniotilta varia	black-and-white warbler
Oporornis formosus	Kentucky warbler
Oporornis philadelphia	mourning warbler

Scientific Name	Common Name
Parula americana	northern parula
Protonotaria citrea	prothonotary warbler
Seiurus aurocapillus	ovenbird
Seiurus motacilla	Louisiana waterthrush
Seiurus noveboracensis	northern waterthrush
Setophaga ruticilla	American redstart
Vermivora celata	orange-crowned warbler
Vermivora chrysoptera	golden-winged warbler
Vermivora peregrina	Tennessee warbler
Vermivora pinus	blue-winged warbler
Vermivora ruficapilla	Nashville warbler
Wilsonia canadensis	Canada warbler
Wilsonia citrina	hooded warbler
Wilsonia pusilla	Wilson's warbler
Piranga ludoviciana	western tanager
Piranga olivacea	scarlet tanager
Piranga rubra	summer tanager
Troglodytes aedon	house wren
Catharus fuscescens	veery
Catharus minimus	gray-cheeked thrush
Catharus ustulatus	Swainson's thrush
Hylocichla mustelina	wood thrush
Contopus borealis	olive-sided flycatcher
Contopus virens	eastern wood-pewee
Empidonax alnorum	alder flycatcher
Empidonax flaviventris	yellow-bellied flycatcher
Empidonax minimus	least flycatcher
Empidonax traillii	willow flycatcher
Empidonax virescens	Acadian flycatcher
Myiarchus cinerascens	ash-throated flycatcher
Myiarchus crinitus	great crested flycatcher
Tyrannus forficatus	scissor-tailed flycatcher
Tyrannus tyrannus	eastern kingbird
Tyrannus verticalis	western kingbird
Vireo bellii	Bell's vireo
Vireo flavifrons	yellow-throated vireo
Vireo flavoviridis	yellow-green vireo
Vireo gilvus	warbling vireo
Vireo olivaceus	red-eyed vireo
Vireo philadelphicus	Philadelphia vireo
Vireo griseus	white-eyed vireo
Caprimulgus carolinensis	Chuck-will's-widow

Scientific Name	Common Name
Caprimulgus vociferus	whip-poor-will
Chordeiles acutipennis	lesser nighthawk
Chordeiles minor	common nighthawk

Appendix J. Resident bird species identified on the PAIS Certified Species List (NPS 2013).

Scientific Name	Common Name
Aix sponsa	wood duck
Dendrocygna autumnalis	black-bellied whistling-duck
Dendrocygna bicolor	fulvous whistling-duck
Amazilia yucatanensis	buff-bellied hummingbird
Buteo albicaudatus	white-tailed hawk
Buteo jamaicensis	red-tailed hawk
Buteo lineatus	red-shouldered hawk
Elanus leucurus	white-tailed kite
Parabuteo unicinctus	Harris' hawk
Ixobrychus exilis	least bittern
Charadrius alexandrinus	snowy plover
Charadrius vociferus	killdeer
Haematopus palliatus	American oystercatcher
Cathartes aura	turkey vulture
Coragyps atratus	black vulture
Falco femoralis	aplomado falcon
Falco sparverius	American kestrel
Polyborus plancus	crested caracara
Podilymbus podiceps	pied-billed grebe
Tachybaptus dominicus	least grebe
Columba livia	rock dove
Columbina inca	Inca dove
Columbina passerina	common ground-dove
Zenaida macroura	mourning dove
Chloroceryle americana	green kingfisher
Geococcyx californianus	greater roadrunner
Colinus virginianus	northern bobwhite
Meleagris gallopavo	wild turkey
Fulica americana	American coot
Rallus elegans	king rail
Rallus longirostris	clapper rail
Eremophila alpestris	horned lark
Cardinalis cardinalis	northern cardinal
Cardinalis sinuatus	pyrrhuloxia
Corvus cryptoleucus	Chihuahuan raven
Aimophila cassinii	Cassin's sparrow
Ammodramus maritimus	seaside sparrow
Arremonops rufivirgatus	olive sparrow
Chondestes grammacus	lark sparrow
Agelaius phoeniceus	red-winged blackbird

Scientific Name	Common Name
Icterus gularis	Altamira oriole
Molothrus aeneus	bronzed cowbird
Molothrus ater	brown-headed cowbird
Quiscalus mexicanus	great-tailed grackle
Sturnella magna	eastern meadowlark
Lanius ludovicianus	loggerhead shrike
Mimus polyglottos	northern mockingbird
Toxostoma curvirostre	curve-billed thrasher
Toxostoma longirostre	long-billed thrasher
Baeolophus atricristatus	black-crested titmouse
Passer domesticus	house sparrow
Auriparus flaviceps	verdin
Sturnus vulgaris	European starling
Campylorhynchus brunneicapillus	cactus wren
Thryomanes bewickii	Bewick's wren
Thryothorus ludovicianus	Carolina wren
Turdus migratorius	American robin
Pitangus sulphuratus	great kiskadee
Pyrocephalus rubinus	Vermilion flycatcher
Tyrannus couchii	Couch's kingbird
Melanerpes aurifrons	golden-fronted woodpecker
Picoides scalaris	ladder-backed woodpecker
Nyctidromus albicollis	common pauraque
Phalaenoptilus nuttallii	common poorwill
Athene cunicularia	burrowing owl
Bubo virginianus	great horned owl
Tyto alba	barn owl

Appendix K. Resident bird species observed on the PAIS CBC from 1974-1990.

Species	1974-75	1975-76	1976-77	1977-78	1978-79	1979-80	1980-81	1981-82	1982-83	1983-84	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90
wood duck			2										4			
wild turkey		6				71	36						53			
northern bobwhite	50	101	175	240	79	17	54	40	21	18		7	26	12	8	34
least grebe			3		4	21				3					4	1
pied-billed grebe	5	42	46	16	35	87	7	45		16	2	3	8	3		
black vulture	14	2		4		12	2		2	5			4	2		
turkey vulture	149	40	50	107	5	242	261	14	29	14		29	73		42	
Harris's hawk	4					11	3						5			
white-tailed hawk	11	6	10	13	4	14	20	6	2	1	8	5	6	5	7	4
red-tailed hawk	11	5	1	15	1	16	12	2	2	1	5	1	4		1	
crested caracara	3	7	4	10		12	20		1			2	2		2	
American kestrel	68	31	42	68	11	82	91	30	30		11	6	25	16	6	22
clapper rail		1			1											
king rail	3															
American coot	3	264	365	900	355	1,459	33	26		179	1	268	200			
snowy plover	31	34	10	12	14	19	7	49	32	1	30		17	15		1
killdeer	373	131	86	141	93	73	176	80	41	20	21	39	53	8	11	9
mourning dove	745	280	348	615	15	278	444	42	2	29	117	4	213	1	24	8
Inca dove		6		7												
common ground-dove	6	9	14	4		2							7			
greater roadrunner	9	5	5	5		5	3						4			
great horned owl	2	1	3	5			2		1				2		1	
burrowing owl	2		1						1							
common pauraque		2														
golden-fronted woodpecker	3		1	11		3							12			
ladder-backed woodpecker	2	3		3		2	1						2			
Vermillion flycatcher	3	4	1	3			2									

Species	1974-75	1975-76	1976-77	1977-78	1978-79	1979-80	1980-81	1981-82	1982-83	1983-84	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90
Couch's kingbird													1			
loggerhead shrike	68	50	158	58	2	60	79	8	12	6		6	25	4	1	5
horned lark	109	85	30	36	62	87	67	71	18	18	16	45	14		15	
black-crested titmouse	3												3			
verdin	1	2														
cactus wren		1	1			2							1			
Carolina wren		2			1											
Bewick's wren	2	2		7		1	1						7			
American robin	449	82	209			2	179		8	4		1	137	1		
northern mockingbird	195	54	56	37		31	19				1	2	48			
long-billed thrasher	7	30	40	12		2	2						7			
curve-billed thrasher	9	19	3	5		4	6						1			
European starling	13		15	9									9		20	
olive sparrow	2	3								2						
Cassin's sparrow	9	7	2	8			1	2					1			1
lark sparrow	35	81	82	38	1		4		2				9			
seaside sparrow				6					2		3			20		
northern cardinal	106	41	94	133		54	49						71			
pyrrhuloxia	31	66	166	99		46	20						22			
red-winged blackbird	606	1,184	495	1,513	796	1,636	965	387	721	452	16	714	552	13	22	253
eastern meadowlark	471	454	660	742	591	734	455	574	269	267	331		430	192	86	150
great-tailed grackle	1	29	27	43	9	54	66	38	4	7	2	25	362		5	15
brown-headed cowbird	520	1120	281	835	2	184	89	1	1	40			424			
house sparrow	15	46	39	75	9	31										
Total	**4149**	**4338**	**3525**	**5835**	**2090**	**5354**	**3176**	**1415**	**1201**	**1083**	**564**	**1157**	**2844**	**292**	**255**	**503**

Appendix L. Colonial waterbird species that have been identified in PAIS, and appear on the NPS Certified Species List (NPS 2013).

Family	Scientific Name	Common Name
Anhingidae	*Anhinga anhinga*	anhinga
Ardeidae	*Ardea alba*	great egret
Ardeidae	*Ardea herodias*	great blue heron
Ardeidae	*Botaurus lentiginosus*	American bittern
Ardeidae	*Bubulcus ibis*	cattle egret
Ardeidae	*Egretta caerulea*	little blue heron
Ardeidae	*Egretta rufescens*	reddish egret
Ardeidae	*Egretta thula*	snowy egret
Ardeidae	*Egretta tricolor*	tricolored heron
Ardeidae	*Nyctanassa violacea*	yellow-crowned night-heron
Ardeidae	*Nycticorax nycticorax*	black-crowned night-heron
Fregatidae	*Fregata magnificens*	magnificent frigatebird
Laridae	*Chlidonias niger*	black tern
Laridae	*Larus argentatus*	herring gull
Laridae	*Larus atricilla*	laughing gull
Laridae	*Larus californicus*	California gull
Laridae	*Larus delawarensis*	ring-billed gull
Laridae	*Larus fuscus*	lesser black-backed gull
Laridae	*Larus glaucoides*	Iceland gull
Laridae	*Larus hyperboreus*	glaucous gull
Laridae	*Larus marinus*	great black-backed gull
Laridae	*Larus occidentalis*	western gull
Laridae	*Larus pipixcan*	Franklin's gull
Laridae	*Larus thayeri*	Thayer's gull
Laridae	*Rissa tridactyla*	black-legged kittiwake
Laridae	*Rynchops niger*	black skimmer
Laridae	*Sterna anaethetus*	bridled tern
Laridae	*Sterna antillarum*	least tern
Laridae	*Sterna caspia*	Caspian tern
Laridae	*Sterna forsteri*	Forster's tern
Laridae	*Sterna fuscata*	sooty tern
Laridae	*Sterna hirundo*	common tern
Laridae	*Sterna maxima*	royal tern
Laridae	*Sterna nilotica*	gull-billed tern
Laridae	*Sterna sandvicensis*	sandwich tern
Pelecanidae	*Pelecanus erythrorhynchos*	American white pelican
Pelecanidae	*Pelecanus occidentalis*	brown pelican
Phalacrocoracidae	*Phalacrocorax auritus*	double-crested cormorant

Family	Scientific Name	Common Name
Phalacrocoracidae	*Phalacrocorax brasilianus*	neotropic cormorant
Threskiornithidae	*Ajaia ajaja*	roseate spoonbill
Threskiornithidae	*Eudocimus albus*	white ibis
Threskiornithidae	*Plegadis chihi*	white-faced ibis
Threskiornithidae	*Plegadis falcinellus*	glossy ibis

Appendix M. Summary of small mammal species present or probably present within PAIS.

Scientific Name	Common Name	Bailey (1905)	Raun (1959)	Baker and Rabalais (1975)	Baccus (1977)	Harris (1988)	Frey and Jones (2008)	GULN (2010)	NPS (2012a)
Baiomys taylori	northern pygmy mouse	X		X_{UC}	X	X	X	X	X
Chaetodipus hispidus	hispid pocket mouse			X_{P}					
Conepatus leuconotus texensis	Tamaulipan hog-nosed skunk	X	X	X_{HI}					
Cryptotis parva berlanieri	least shrew			X_{P}					
Dasypus novemcinctus	nine-banded armadillo	X		X_{UC}			X	X	X
Didelphis virginiana	Virginia opossum			X_{P}		X	X	X	X
Dipodomys compactus	Gulf coast kangaroo rat	X		X_{C}	X	X	X	X	X
Dipodomys ordi compactus	Ord kangaroo rat		X						
Geomys personatus	Texas pocket gopher	X	X	X_{C}	X	X	X	X	X
Lasiurus borealis borealis	red bat			X_{P}					
Lasiurus intermedius	northern yellow bat	X	X	X_{P}					
Lasiurus seminolus	seminole bat			X_{P}					
Lepus californicus	black-tailed jack rabbit	X	X	X_{C}	X	X	X	X	X
Mephitis mephitis varians	striped skunk			X_{UC}			X		
Mus musculus	house mouse*		X	X_{FC}			X	X	X
Myocastor coypus	nutria								
Nasua narica	white-nosed coati						X	X	X
Nycticeius humeralis	evening bat			X_{P}					
Onychomys leucogaster	northern grasshopper mouse		X	X_{FC}			X	X	X
Oryzomys palustris	marsh rice rat	X	X	X_{FC}	X	X	X	X	X
Perognathus flavus	Baird’s pocket mouse								
Perognathus leucopus	white-footed mouse	X	X	X_{P}					
Perognathus merriami	Merriam’s pocket mouse	X	X	X_{UC}					
Pipeistrellus subflavus	eastern pipistrelle			X_{P}			X	X	X
Procyon lotor	common raccoon		X	X_{FC}			X	X	X
Rattus norvegicus	Norway rat*								
Rattus rattus	black rat*			X_{UC}			X	X	X
Reithrodontomys fulvescens	fulvous harvest mouse	X	X	X_{UC}	X		X	X	X
Scalopus aquaticus	eastern mole	X	X		X	X	X	X	X
Sigmodon hispidus	hispid cotton rat	X	X	X_{C}	X		X	X	X
Spermophilus mexicanus	Mexican ground squirrel			X_{C}					
Spermophilus spilosoma	spotted ground squirrel	X	X	X_{C}	X	X	X	X	X
Spilogale putorius indianola	eastern spotted skunk			X_{P}					
Sylvilagus floridanus	eastern cottontail		X	X_{P}					

Scientific Name	Common Name	Bailey (1905)	Raun (1959)	Baker and Rabalais (1975)	Baccus (1977)	Harris (1988)	Frey and Jones (2008)	GULN (2010)	NPS (2012a)
Tadarida brasiliensis	Brazilian free-tailed bat	X		X_{FC}		X	X	X	X
Taxidea taxus	badger		X	X_{UC}	X		X	X	X
Urocyon cinereoargenteus	common gray fox			X_{P}			X	X	X

*exotic/non-native species

Relative abundance from Baker and Rabalais (1975) P= possible, UC = uncommon, FC = fairly common, C = common, HI = highly improbable.

NPS 613/123431, January 2014

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