Current Status and Historical Trends of Selected Estuarine and Coastal Habitats in the Corpus Christi Bay National Estuary Program Study Area

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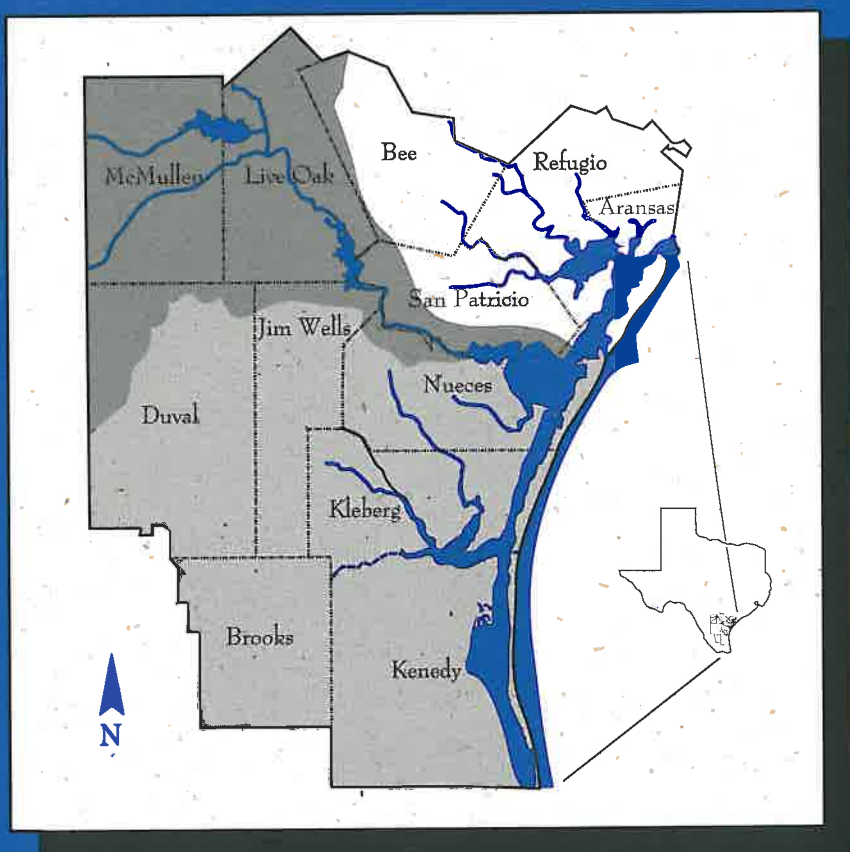

Corpus Christi Bay National Estuary Program
CCBNEP-29 · July 1998

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CORPUS CHRISTI BAY NATIONAL ESTUARY PROGRAM

The Corpus Christi Bay National Estuary Program (CCBNEP) is a four-year, community based effort to identify the problems facing the bays and estuaries of the Coastal Bend, and to develop a long-range, Comprehensive Conservation and Management Plan. The Program's fundamental purpose is to protect, restore, or enhance the quality of water, sediments, and living resources found within the 600 square mile estuarine portion of the study area.

The Coastal Bend bay system is one of 28 estuaries that have been designated as an **Estuary of National Significance** under a program established by the United States Congress through the Water Quality Act of 1987. This bay system was so designated in 1992 because of its benefits to Texas and the nation. For example:

- Corpus Christi Bay is the gateway to the nation's sixth largest port, and home to the third largest refinery and petrochemical complex. The Port generates over $1 billion of revenue for related businesses, more than $60 million in state and local taxes, and more than 31,000 jobs for Coastal Bend residents.
- The bays and estuaries are famous for their recreational and commercial fisheries production. A study by Texas Agricultural Experiment Station in 1987 found that these industries, along with other recreational activities, contributed nearly $760 million to the local economy, with a statewide impact of $1.3 billion, that year.
- Of the approximately 100 estuaries around the nation, the Coastal Bend ranks fourth in agricultural acreage. Row crops -- cotton, sorghum, and corn -- and livestock generated $480 million in 1994 with a statewide economic impact of $1.6 billion.
- There are over 2600 documented species of plants and animals in the Coastal Bend, including several species that are classified as endangered or threatened. Over 400 bird species live in or pass through the region every year, making the Coastal Bend one of the premier bird watching spots in the world.

The CCBNEP is gathering new and historical data to understand environmental status and trends in the bay ecosystem, determine sources of pollution, causes of habitat declines and risks to human health, and to identify specific management actions to be implemented over the course of several years. The 'priority issues' under investigation include:

- altered freshwater inflow
- declines in living resources
- loss of wetlands and other habitats
- bay debris
- degradation of water quality
- altered estuarine circulation
- selected public health issues

The **COASTAL BEND BAYS PLAN** that will result from these efforts will be the beginning of a well-coordinated and goal-directed future for this regional resource.

STUDY AREA DESCRIPTION

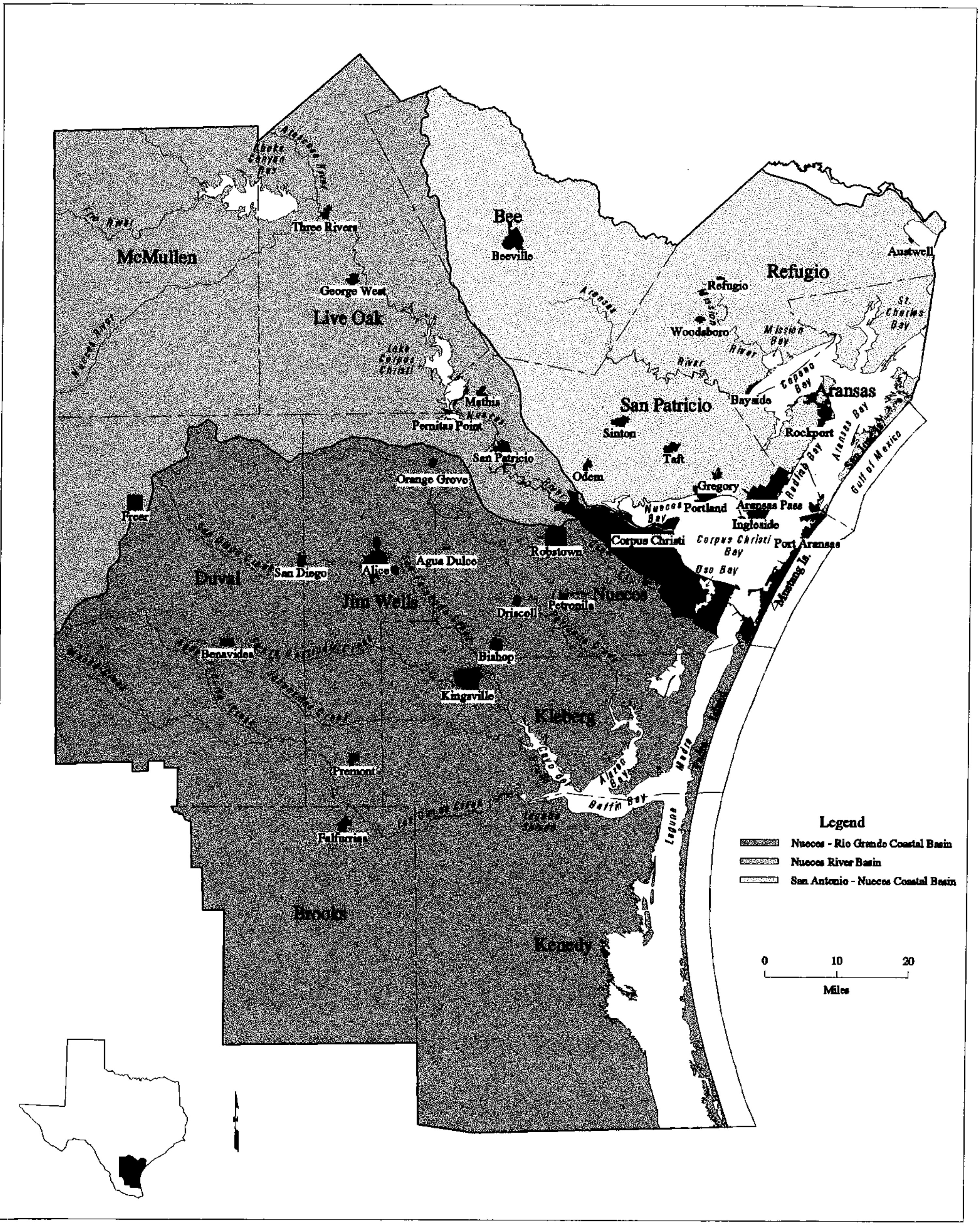
The CCBNEP study area includes three of the seven major estuary systems of the Texas Gulf Coast. These estuaries, the Aransas, Corpus Christi, and Upper Laguna Madre are shallow and biologically productive. Although connected, the estuaries are biogeographically distinct and increase in salinity from north to south. The Laguna Madre is unusual in being only one of three hypersaline lagoon systems in the world. The study area is bounded on its eastern edge by a series of barrier islands, including the world's longest -- Padre Island.

Recognizing that successful management of coastal waters requires an ecosystems approach and careful consideration of all sources of pollutants, the CCBNEP study area includes the 12 counties of the Coastal Bend: Refugio, Aransas, Nueces, San Patricio, Kleberg, Kenedy, Bee, Live Oak, McMullen, Duval, Jim Wells, and Brooks.

This region is part of the Gulf Coast and South Texas Plain, which are characterized by gently sloping plains. Soils are generally clay to sandy loams. There are three major rivers (Aransas, Mission, and Nueces), few natural lakes, and two reservoirs (Lake Corpus Christi and Choke Canyon Reservoir) in the region. The natural vegetation is a mixture of coastal prairie and mesquite chaparral savanna. Land use is largely devoted to rangeland (61%), with cropland and pastureland (27%) and other mixed uses (12%).

The region is semi-arid with a subtropical climate (average annual rainfall varies from 25 to 38 inches, and is highly variable from year to year). Summers are hot and humid, while winters are generally mild with occasional freezes. Hurricanes and tropical storms periodically affect the region.

On the following page is a regional map showing the three bay systems that comprise the CCBNEP study area.



Corpus Christi Bay National Estuary Program Study Area

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LIST OF ACRONYMS

CCBNEP	Corpus Christi Bay National Estuary Program
CCMP	Comprehensive Conservation and Management Plan
EPA	U.S. Environmental Protection Agency
GIS	Geographic Information System
GIWW	Gulf Intracoastal Waterway
GLO	Texas General Land Office
LSU	Louisiana State University
MOSS	Map Overlay and Statistical Subsystem
NRCS	Natural Resources Conservation Service
NWI	National Wetlands Inventory
PINS	Padre Island National Seashore
SCS	Soil Conservation Service
TCWS	Texas Colonial Waterbird Society
TNRCC	Texas Natural Resource Conservation Commission
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

ACKNOWLEDGMENTS

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We are very grateful to David Dall and Jim Dick (USFWS) for providing NWI 1950's and 1990's aerial photographs for analysis of wetland trends in the CCBNEP area.

Special thanks go to Catherine Blair (TPWD) who was involved in GIS analysis during early phases of the project, and to Suzanne Dilworth (Center for Coastal Studies) for fieldwork and figure preparation. Thanks also to staff of the Bureau of Economic Geology including Susan Lloyd for assistance in manuscript preparation, and to David Stephens, Kerza Prewitt, and Jennifer Hughes, under the direction of Joel Lardon, for figure preparation.

CURRENT STATUS AND HISTORICAL TRENDS OF SELECTED ESTUARINE AND COASTAL HABITATS IN THE CORPUS CHRISTI BAY NATIONAL ESTUARY PROGRAM STUDY AREA

EXECUTIVE SUMMARY

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Introduction

Wetland and associated aquatic habitats are essential biological components of the Corpus Christi-Aransas Bays estuarine systems. Understanding the spatial and temporal distribution of these habitats is critical for effective protection and management. This report presents results of an investigation to determine status and trends of wetlands, intertidal flats, riparian woodlands, shorelines, and dredged-material rookery islands in the CCBNEP area. The investigation, sponsored by the CCBNEP and funded by EPA and TNRCC, was a cooperative effort between the Bureau of Economic Geology, TPWD, and Texas A&M University–Corpus Christi.

Methods

The study area for this investigation encompasses primarily the Corpus Christi-Aransas Bay System, extending from the Mesquite Bay Quandrangle southward to upper Laguna Madre (Fig. I.). Counties include Refugio, Aransas, San Patricio, and Nueces, and parts of Calhoun and Kleberg. Status and trends of wetlands in the study area were determined by using a GIS to analyze the distribution of wetlands mapped on aerial photographs taken in the 1950's, 1979, and 1992. Maps and digital files were provided by the USFWS. Wetlands were mapped in accordance with the classification by Cowardin et al. (1979), in which wetlands were classified by system (marine, estuarine, riverine, palustrine, lacustrine), subsystem (reflective of hydrologic conditions), and class (descriptive of vegetation and substrate). Maps for 1979 and 1992 were additionally classified by subclass (subdivisions of vegetated classes only), water-regime, and special modifiers. Upland habitats were delineated on 1979 maps using a modified Anderson et al. (1976) land-use classification system.

Field sites were examined as part of the effort to characterize wetland plant communities and define wetland map units in the study area. Topographic surveys were conducted along several transects. Rookery islands composed of dredged material were also investigated.

Shorelines were classified, mapped, and digitized in order to differentiate shores that have been artificially hardened by riprap, seawalls, and other human structures from natural and other nonhardened shores. Shorelines were mapped using low altitude aerial videotape surveys and recent aerial photographs.

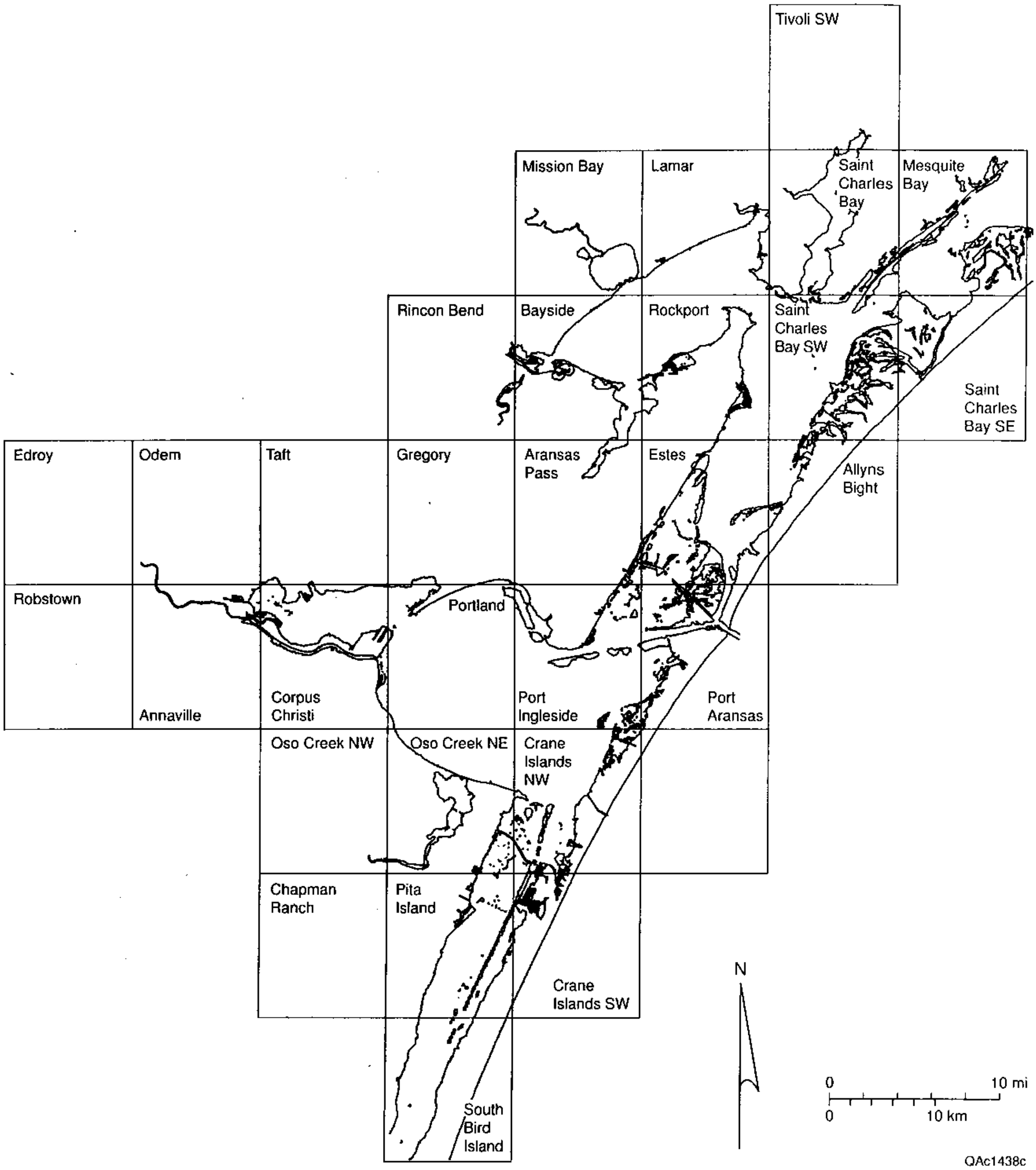

Figure I. Study area defined by 30 USGS 7.5-minute quads

Current Status: 1992

Based on the 1992 NWI data, wetlands and aquatic habitats are dominated by an estuarine system that encompasses about 161,000 ha (398,000 acres) (Table I) in the 29 7.5-minute quadrangles that make up the study area (excluding South Bird Island quadrangle) (Fig. I).

Major estuarine and palustrine habitats include salt, brackish, and fresh marshes, riparian woodlands (including forested and scrub-shrub wetlands), intertidal flats, and estuarine open water/subtidal aquatic beds. Vegetated wetlands (marshes, scrub-shrub, and forested wetlands) have a total area of about 48,400 ha (119,595 acres), or about 11 percent of all habitats (Fig. II). Marshes, or estuarine and palustrine emergent wetlands, cover about 47,100 ha (116,385 acres), representing almost 97 percent of vegetated wetlands. Riparian woodlands, which include forested and scrub/shrub wetlands (1,270 ha) within the major fuvial-deltaic systems (Nueces, Aransas-Chiltipin, and Mission Rivers), have a total area of about 1,820 ha (4,500 acres), with the largest area (828 ha, or 2,045 acres) occurring in the Nueces River valley.

Table I. Areal extent of wetland systems and uplands in study area

System	Area (ha)	Area (acres)	Percent of Study Area
Estuarine	161,069	398,000	37
Palustine	26,580	65,678	6
Lacustrine	4,740	11,712	1
Riverine	255	630	<1
Marine (excludes marine open water)	716	1,768	<1
Total	193,358	477,788	44
Uplands	245,162	605,795	56

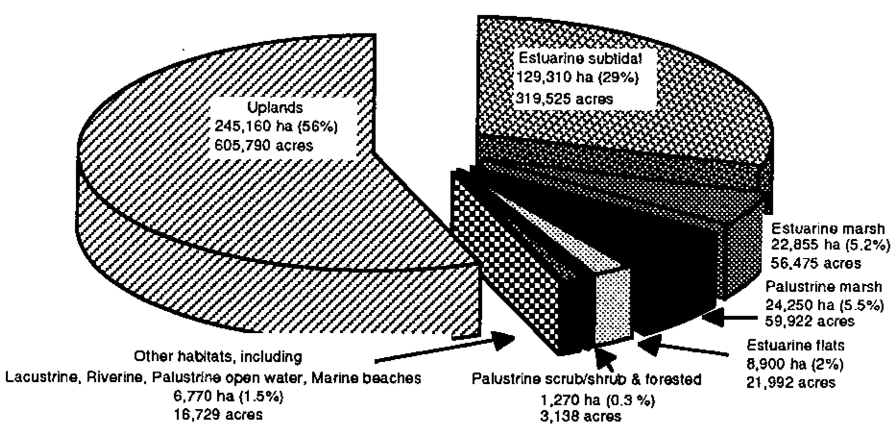

Figure II. Areal distribution, or status, of CCBNEP habitats in 1992. From NWI maps and unadjusted digital files.

Wetland Trends and Probable Causes

In analyzing trends, emphasis was placed on wetland classes and not on water regimes and special modifiers. This approach was taken because habitats were mapped only down to class on 1950's photographs. It should be noted that there are a number of possible photointerpretation shortcomings—not the least of which is involvement of different photointerpreters at different times. Because of photointerpretation and registration problems for the various vintages of maps, adjustments in wetland areas were made to more accurately reflect trends. There is more confidence in direction of trends than magnitudes.

From the 1950's and 1970's to the 1990's, some wetland classes underwent large-scale changes. In general, there were losses in tidal flats and gains in both estuarine (salt and brackish) and palustrine (fresh) marshes (Figs. III and IV). Forested and scrub-shrub wetland classes constitute a small part of the wetland system in the CCBNEP area. Relatively small changes (gains) occurred in both of these classes between the 1950's and 1992. Riparian woodlands in the Nueces, Aransas-Chiltipin, and Mission River valleys increased in area from 1979 to 1992.

Extensive changes in tidal flats occurred between the 1950's and 1979 when almost 10,000 ha (27,410 acres) was converted to other habitat classes. Approximately 55 percent of change in tidal flats was due to permanent inundation of flats and their replacement by either open water or seagrass beds. About 20% of the loss was due to conversion to marshes, and 20% to uplands. The most extensive losses in tidal flats occurred on the barrier islands, especially Mustang and San José Islands, and the flood-tidal delta, Harbor Island, where losses exceeded 2,000 ha (5,480 acres) from the 1950's to 1992 at each site. The other location where losses in tidal flats exceeded 2,000 ha (5,480 acres) was in the Corpus Christi/Nueces Bay – Laguna Madre system. The conversion of tidal flats to sub-tidal habitats (open water and seagrass beds) coincides with an accelerated rise in sea level from the mid-1960's to mid-1970's (Fig. V). In association with this sea-level rise and spread of seagrasses in newly submerged areas was a spread of emergent vegetation along the upper reaches of tidal flats. As topographically lower flats became permanently submerged and colonized by seagrass, higher, tidal flats became more frequently flooded, favoring growth of *Spartina alterniflora* (smooth cordgrass). This spread of *S. alterniflora* is apparent in sequential aerial photographs taken in 1952, 1979, 1992, and 1994. Loss of intertidal flat habitats in some areas was the result of dredge and fill activities related to navigation channel developments.

Analysis of adjusted digital data defining habitat class abundance and distribution from the 1950's to 1992 shows relatively large net gains in both estuarine (>4,600 ha) (11,365 acres) and palustrine marshes (>4,700 ha) (11,615 acres). Gains occurred during both periods, with the largest gain in estuarine marshes occurring during the 1950's to 1979, and the largest gain in palustine wetlands during 1979 to 1992 (Fig. IV). Whereas some gains in palustrine marsh were the result of photo-interpretative changes in class such as estuarine marsh to palustrine marsh, much of the gain was due to expansion of palustrine marsh in former upland areas on barrier islands and on the Pleistocene barrier strandplain ridge, Blackjack Peninsula. Although this increase in marsh may in many areas reflect differences in interpretation of historical and recent aerial photographs, there is evidence that island soils have become wetter since the 1950's and 1960's. Wetter conditions are in part a response to increasing amounts of precipitation since the mid-1950's drought, and rising sea level. We suspect that as sea level rises, the fresh-water lens, recharged by precipitation, also rises, creating wetter surface conditions and leading to more abundant and widespread hydrophytic vegetation. This scenario is supported by observations of environments on the Padre Island National Seashore where active back island dunes became stabilized by vegetation, and deflation areas and vegetated barrier flats became wetter and marshes more extensive. Furthermore, recent baseline studies of plant species on Mustang Island State Park indicate the presence of hydrophytic species not reported in previous plant surveys of Mustang and North Padre Islands.

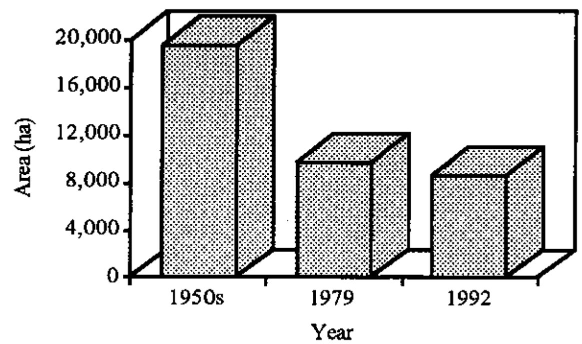

Figure III. Total area of estuarine intertidal flats in the CCBNEP study area for the 1950's, 1979, and 1992.

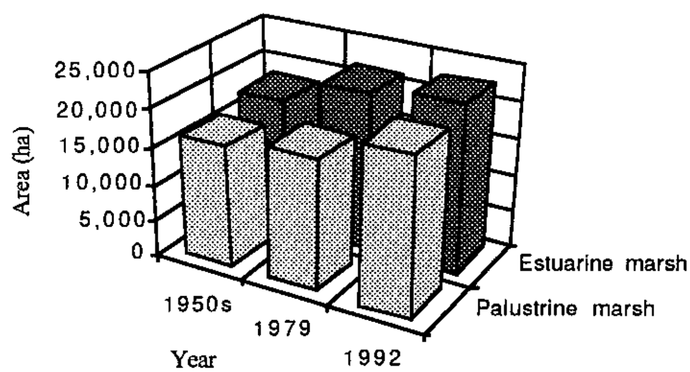

Figure IV. Total area of estuarine and palustine marshes in the CCBNEP study area for the 1950's, 1979, and 1992.

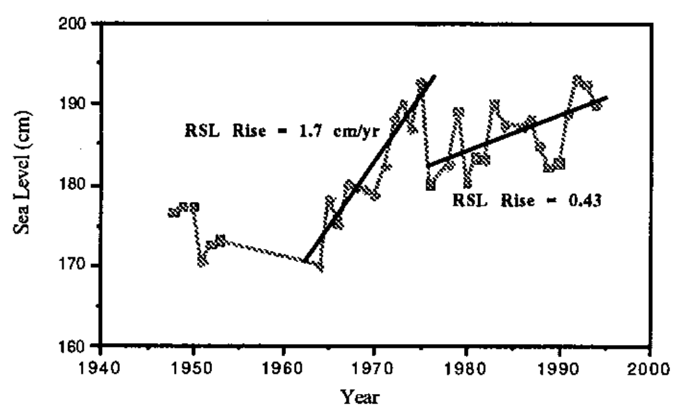

Figure V. Relative rise in sea level as recorded at the Rockport tide gauge. Data from NOAA.

Losses in marshes in the CCBNEP area, although limited in extent and offset by large gains, nevertheless have occurred. Types of marsh loss include conversion of marsh to agricultural and urban land and loss of marsh as a result of dredging, excavating, filling, draining, and leveeing. Among the significant losses are pothole wetlands on the coastal plain and Live Oak Peninsula/Ridge. Recent regional (White et al. 1993) and coast-wide studies (Moulton et al. 1997) have shown net loss of both vegetated wetlands and intertidal flats for areas of the Texas coast outside the CCBNEP area.

Shorelines

Maps prepared and digitized of hardened versus nonhardened shorelines indicate about 330 km (205 mi), or 16 percent, of shorelines are hardened or protected, and 1,684 km (1,047 mi) (84 percent) are natural or unprotected. Hardened shorelines include those that are protected by seawalls and other solid structures made of concrete, wood, or metal, and by riprap. Piers were also mapped, and the total linear kilometers of hardened shorelines includes piers. Unprotected shorelines include all nonhardened shorelines including those along dredged material. The most common shorelines are marshes, accounting for almost 900 km (559 mi) or 45 percent of the total shoreline length in the study area.

Rookery Islands

Rookery islands in the CCBNEP area are critical to the long-term survival of colonial waterbirds (gulls, terns, herons, egrets, pelicans, spoonbills, and ibises). Changes in island size, configuration, and available habitat types variously affected the success of certain species. Decreases in nesting pairs of bare-ground, nesting species (e.g., terns and skimmers) may be due primarily from loss of unvegetated beaches and flats to vegetated grasses, forbs, and shrubs. Some rookery islands were abandoned from extensive erosion.

American White Pelicans nested on three different islands in upper Laguna Madre since 1973. This population is the only coastal nesting population in the United States. Several explanations were postulated to understand this species' migration among these islands: elevated ectoparasite levels in established rookeries, storms, predators, disturbance, and brood reduction. Brown Pelicans made a dramatic recovery in the CCBNEP area since the mid-1970s, with consistently increasing nesting populations on Pelican Island Spoil rookery in Corpus Christi Bay. However, pelicans also nested briefly in other rookeries during the survey. No definitive data exists explaining if these pairs were expanding their nesting range from Pelican Island, or if they were migrating into the area from the north (upper Texas coast) or south (Mexican coast). Several potential factors were identified that may determine where pelican rookeries may be established: proximity to passes for increased water clarity and prey availability, vegetated areas that would support a nest on or near the ground, and limited human disturbance.

Factors that may negatively effect nesting trends of colonial waterbirds include: habitat loss and/or habitat degradation, predation, and human disturbance. Monitoring of colonial waterbird nesting success should be continued, as the Colonial Waterbird Census is the only long-term dataset available to assess status and trends. Continued partnerships among agencies, research and academic institutions, nonprofit conservation groups, and interest groups should be encouraged and supported financially. No quantitative data are presently available to evaluate successional changes in vegetation or spatial changes of island configuration and areal extent. Detailed studies of key rookeries (e.g., Pelican Island Spoil, Shamrock Island, 2nd Chain of Islands, Deadman Island, etc.) should be conducted, particularly those essential to species of concern.

CURRENT STATUS AND HISTORICAL TRENDS OF SELECTED ESTUARINE AND COASTAL HABITATS IN THE CORPUS CHRISTI BAY NATIONAL ESTUARY PROGRAM STUDY AREA

I. INTRODUCTION

Wetland and associated aquatic habitats are essential biological components of the Corpus Christi-Aransas Bay estuarine system. Understanding the spatial and temporal distribution of these habitats is critical for effective protection and management. This report presents results of an investigation to determine status and trends of wetlands, wind-tidal flats, riparian woodlands, shorelines, and dredged-material rookery islands in the Corpus Christi Bay-Aransas Bay system. The investigation, sponsored by the CCBNEP and funded by the EPA and TNRCC, was a cooperative effort between the Bureau of Economic Geology, TPWD, and Texas A&M University–Corpus Christi.

A. Objectives

The primary objective of this investigation was to determine the current status and historical trends of wetlands and wind-tidal flats in the Corpus Christi–Aransas Bay system (Fig. 1) based on maps prepared by the USFWS as part of the NWI. Associated objectives included (1) determining probable causes for documented wetland trends, (2) delineating trends in riparian woodlands, (3) characterizing wetland plant communities through field surveys, (4) mapping hardened and unprotected shorelines, and (5) analyzing changes in vegetation cover on rookery islands composed of dredged material.

B. Report Organization

The report is organized by chapters to allow more specific discussions of methods and results of the various topics presented. In Chapter I is the introduction, which treats the objectives, organization, wetland classification and definitions, setting of the study area, and general methods on status and trends. Presented in Chapter II is the classification of wetland and deepwater habitats (Cowardin et al. 1979) with examples of general vegetation types in the CCBNEP study area. A more detailed characterization of wetland plant communities by geographical areas is presented in Chapter III. Chapter IV is a discussion of the current status (1992) of the major estuarine and palustrine wetland classes and their areal distribution within the study area. Because of the complexity of analyzing historical wetland trends and the desire to define trends geographically, Chapter V emphasizes trends of marshes and tidal flats with respect to major geographic areas such as modern barrier islands, the Pleistocene barrier strandplain, fluvial-deltaic systems, and the coastal plain. Wetland distribution in 1992 is presented as part of the trend analysis, thereby documenting the current status of wetlands by major geographical area. Shorelines along the estuarine and marine systems are characterized by type in Chapter VI. Chapter VII presents a summary of the status and trends of rookery islands, a topic that is discussed more fully in a separate report (Smith and Cox, 1998). The conclusions are presented in Chapter VIII.

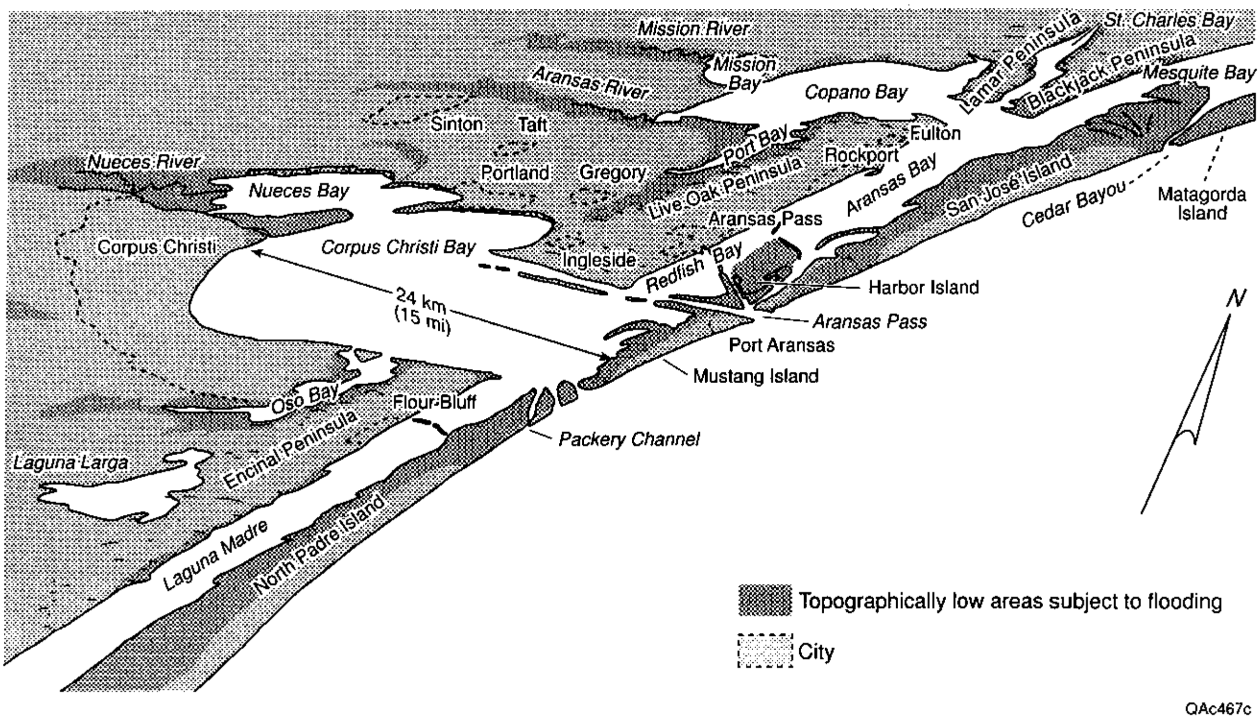

Figure 1. Index map of a selected portion of the CCBNEP study area.

C. Wetland Classification and Definition

For purposes of this investigation, wetlands were classified in accordance with *The Classification of Wetlands and Deepwater Habitats of the United States* by Cowardin et al. (1979). This is the classification used by the USFWS in delineating wetlands as part of the NWI.

Definitions of wetlands and deepwater habitats according to Cowardin et al. (1979) are:

> Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For purposes of this classification wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes[1]; (2) the substrate is predominantly undrained hydric soil[2]; and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year.
>
> Deepwater habitats are permanently flooded lands lying below the deepwater boundary of wetlands. Deepwater habitats include environments where surface water is permanent and often deep, so that water, rather than air, is the principal medium within which the dominant organisms live, whether or not they are attached to the substrate. As in wetlands, the dominant plants are hydrophytes; however, the substrates are considered nonsoil because the water is too deep to support emergent vegetation (U.S. Soil Conservation Service, Soil Survey Staff, 1975).

Because the fundamental objective of the CCBNEP project was to determine status and trends of wetlands in the Corpus Christi-Aransas Bay system using aerial photographs, classification and definition of wetlands were integrally connected to the photographs and the interpretation of wetland signatures. Wetlands were not defined nor mapped in accordance with the *Federal Manual for Identifying and Delineating Jurisdictional Wetlands* (Federal Interagency Committee for Wetland Delineation, 1989).

D. Study Area

The area for this study is defined by 30 USGS 7.5-minute quadrangles (quads) (Fig. 2) located in the northern half of CCBNEP project area shown on the cover of this report. For the South Bird Island quadrangle (Fig. 2), however, neither digital data nor maps were available for 1992 NRI delineations at the time of the study. Although the 1950's and 1979 wetlands data were analyzed for this quad, serious cartographic problems in the 1950's data prevented a meaningful quantitative comparison with 1979 data. Accordingly, the focus of the digital analysis was on the remaining 29 quads.

The study area covers the estuarine systems of Corpus Christi Bay and Aransas Bay, and secondary bay systems including Copano, Nueces, Mission, St. Charles, Redfish, and Mesquite Bays, and north Laguna Madre. Barrier islands include south Matagorda, San José, Mustang, and North Padre. Counties include Refugio, Aransas, San Patricio, and Nueces, and parts of Calhoun and Kleberg.

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[1]The USFWS has prepared a list of hydrophytes and other plants occurring in wetlands of the United States.

[2]The NRCS has prepared a list of hydric soils for use in this classification system.

Figure 2. Study area defined by 30 USGS 7.5-minute quads

E. General Setting of the Corpus Christi–Aransas Bay System

The geologic framework of the Corpus Christi-Aransas Bay area consists of Modern-Holocene and Pleistocene systems including the modern wetland system (Fig. 3). Geomorphic features on which various types of coastal wetlands have developed are the result of numerous interacting processes. Physical processes that influence wetlands include rainfall, runoff, water table fluctuations, streamflow, evapotranspiration, waves and longshore currents, astronomical and wind tides, storms and hurricanes, deposition and erosion, subsidence, faulting, and sea-level rise. These processes have contributed to development of a gradational array of permanently inundated to infrequently inundated environments ranging in elevation from estuarine subtidal areas to topographically higher wetlands that grade upward from the astronomical-tidal zone through the wind-tidal zone to the storm-tidal zone.

Bay-Estuary-Lagoon Setting

Exchange of marine waters with bay-estuary-lagoon waters in the Corpus Christi Bay-Aransas Bay system occurs primarily through a major tidal inlet, Aransas Pass, at the north end of Mustang Island (Fig. 1). Additional exchange occurs at Cedar Bayou, a narrow channel that connects the Gulf with Mesquite Bay. Predominant sources of freshwater inflow are the Nueces, Aransas, and Mission Rivers (Fig. 3), and the Guadalupe River, which although northeast of the study area is an important source of freshwater for Aransas Bay (Longley, 1994). Salinities in the estuarine system are generally highest in Laguna Madre, followed in order of decreasing average salinity, by Corpus Christi, Redfish, Aransas, Nueces, and Copano Bays (Holland et al. 1975, Brown et al. 1976, Hildebrand and King, 1978). Average salinities in Laguna Madre are generally above 30 parts per thousand (ppt), in marked contrast to Copano Bay where average salinities range from about 10 to 15 ppt, increasing toward the mouth of the bay. These numerous interacting processes in Corpus Christi Bay and adjacent bay systems have a major bearing on location and composition of wetland plant communities.

Relative Sea-level Rise

Relative sea-level rise is another important process affecting wetland and aquatic habitats. Relative sea-level rise as used here is the relative vertical rise in water level with respect to a datum at the land surface, whether it is caused by a rise in mean-water level or subsidence of the land surface. Along the Texas coast both processes, eustatic sea-level rise and subsidence, are part of the relative sea-level rise equation. Subsidence, especially associated with withdrawal of ground water and oil and gas, is the overriding component.

Over the past century, sea level has risen on a worldwide (eustatic) basis at about 0.12 cm/yr, with a rate in the Gulf of Mexico and Caribbean region of 0.24 cm/yr (Gornitz et al. 1982, Gornitz and Lebedeff, 1987). Adding compactional subsidence to these rates yields a relative sea-level rise that locally exceeds 1.2 cm/yr (Swanson and Thurlow, 1973, Penland et al. 1988). Short-term rates of sea level rise recorded at Port Aransas (1959-1969) exceeded 1.2 cm/yr (Swanson and Thurlow, 1973). These short-term rates can be affected by secular variations in sea level caused by climatic factors, such as droughts and periods of higher than normal precipitation and riverine discharge. Short-term sea-level variations produce temporary adjustments in the longer term trends related to eustatic sea level rise and subsidence.

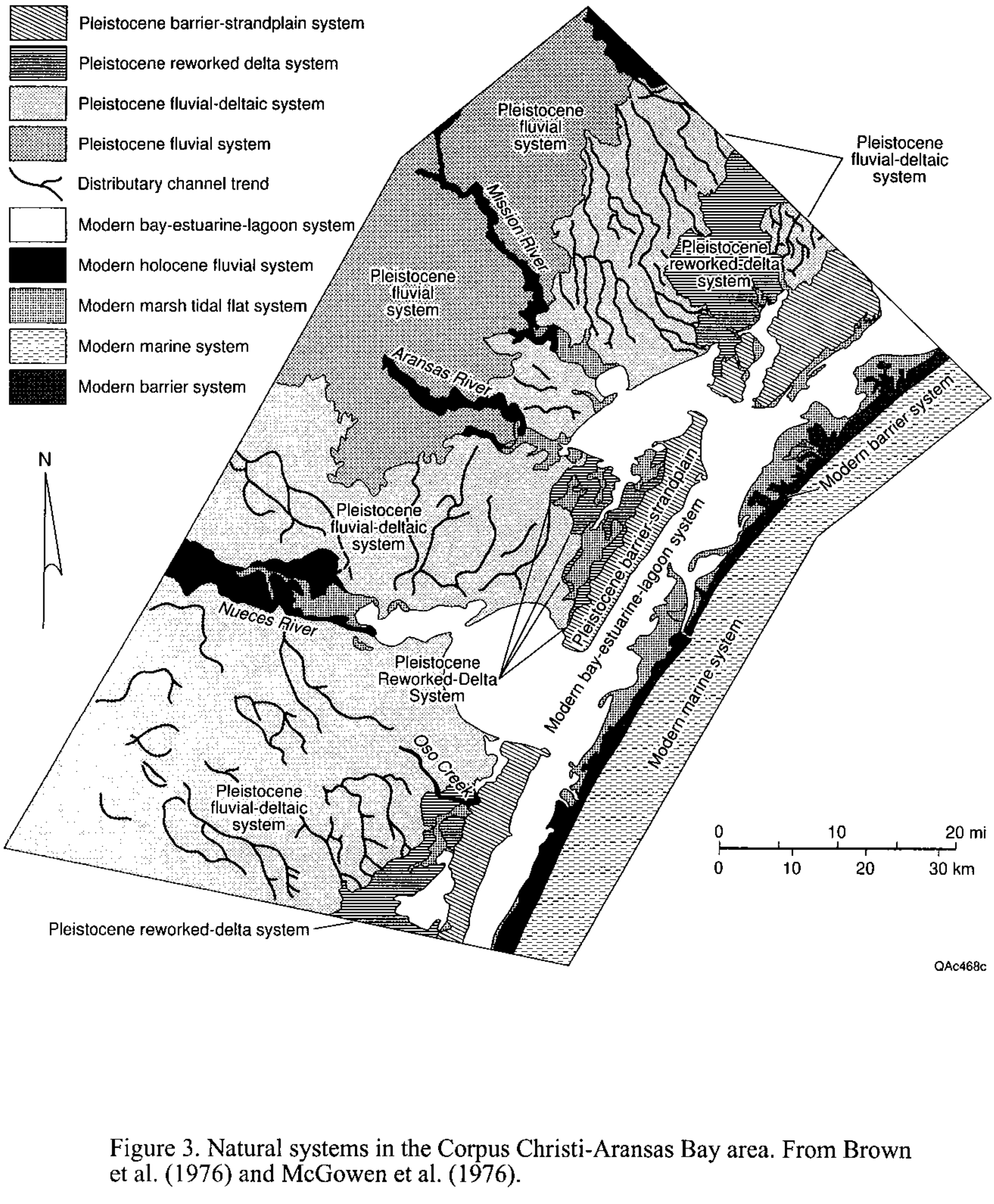


Figure 3. Natural systems in the Corpus Christi-Aransas Bay area. From Brown et al. (1976) and McGowen et al. (1976).

The tide gauge at Rockport provides the longest continuous record of sea-level variations in the CCBNEP study area. The average rate of sea-level rise from the 1950's to 1993 (with missing data in the late 1950's and early 1960's) is about 0.40 cm/yr. Rates of sea-level rise recorded by the tide gauge reached a high of 1.7 cm/yr from the mid 1960's to mid 1970's; this is time coincident with a maximum change in some habitats such as wind-tidal flats. These relationships are presented in detail in the discussion of wetland trends.

F. General Methods Used in Mapping and Analyzing Status and Trends

Status and trends of wetlands in the study area were determined by analyzing the distribution of wetlands mapped on aerial photographs taken in the 1950's, 1979, and 1992. Maps of the 1950's and 1979 were prepared as part of the USFWS-sponsored Texas Barrier Island Ecological Characterization study (Shew et al. 1981) by Texas A&M University and the National Coastal Ecosystems Team of the USFWS. Final maps of the 1979 series were prepared under the NWI program. Maps of the 1950's and 1979 series were digitized and initially analyzed in 1983 (USFWS, 1983). The 1992 maps of the CCBNEP area are part of a series of updated NWI maps of the Texas coastal zone.

Interpretation of Wetlands

Wetlands for all maps (1950's, 1979, and 1992) were delineated on aerial photographs through stereoscopic interpretation using procedures developed for the USFWS-NWI program. Field reconnaissance was an integral part of interpretation. Photographic signatures were compared to the appearance of wetlands in the field by observing vegetation, soil, hydrology, and topography. This information was weighted for seasonality and conditions existing at the time of photography and ground-truthing. Extensive field surveys of wetlands were conducted as part of this study in support of 1990's delineations (see discussions on field investigations and wetland plant communities). Still, field-surveyed sites represent only a small percentage of the thousands of areas (polygons) delineated. Most areas were delineated on the basis of photointerpretation alone, and mis-classifications may have occurred.

The following explanation is printed on all wetland maps that were used in this project to determine trends and status of wetlands in the CCBNEP area:

> This document (map) was prepared primarily by stereoscopic analysis of high-altitude aerial photographs. Wetlands were identified on the photographs based on vegetation, visible hydrology, and geography in accordance with "Classification of Wetlands and Deepwater Habitats of the United States" (FWS/OBS–79/31 December 1979). The aerial photographs typically reflect conditions during the specific year and season when they were taken. In addition, there is a margin of error inherent in the use of the aerial photographs. Thus, a detailed on-the-ground and historical analysis of a single site may result in a revision of the wetland boundaries established through photographic interpretation. In addition, some small wetlands and those obscured by dense forest cover may not be included on this document.
>
> Federal, State, and local regulatory agencies with jurisdiction over wetlands may define and describe wetlands in a different manner than that used in this inventory. There is no attempt in either the design or products of this inventory to define the limits of proprietary jurisdiction of any Federal, State or local government or to establish the geographical scope of the regulatory programs of government agencies. . .

Photographs

The 1950's photographs are black-and-white stereo-pair, scale 1:24,000, taken in the mid 1950's, mostly in 1956 but also in 1954 and 1958 (Larry Handley, NBS, Personal Communication, 1997). The 1979 and 1992 aerial photograhs are NASA color-infrared stereo-pair, scale 1:65,000, that were taken in November and December, respectively.

Photographs used are generally of high quality. Abnormally high precipitation in 1979, however, raised water levels in many interior fresh-water wetlands producing more standing water than in the 1950's and 1992. Although the 1950's photographs are black and white, they are large scale (1:24,000), which aids in the photointerpretation and delineation process. The severe drought that characterized the mid-1950's in Texas (Riggio et al. 1987) may have influenced wetland signatures on photographs taken in 1956, at the height of the drought. These differences affected certain habitats and their interpreted, or mapped, water regimes.

Maps

As part of the USFWS NWI program, draft maps were prepared from interpreted aerial photographs, distributed for review, and checked in the field. Draft and final maps were prepared by transferring lines delineated on aerial photographs to USGS 7.5-minute quadrangle base maps, scale 1:24,000, using Zoom-Transfer Scopes. As in the photointerpretation process (discussed more thoroughly in a following section of photointerpretation errors), there is a margin of error involved in the transfer process. Transfers to maps were completed by a different contractor for the 1950's photographs than for the 1979 and 1992 photographs. Accordingly, higher degrees of standardization and consistency were achieved in the 1979 and 1992 map series.

On 1979 and 1992 maps, wetlands were classified by system, subsystem, class, subclass (for vegetated classes), water-regime, and special modifier in accordance with Cowardin et al. (1979) (Figs. 4–6). For the 1950's maps, wetlands were classified by system, subsystem, and class. On 1979 maps, upland areas were also mapped and classified by upland habitats using a modified Anderson *et al.* (1976) land-use classification system (Fig. 6). Flats and beach/bar classes designated separately on 1950's and 1979 maps were combined into a single class, unconsolidated shore, on 1992 maps (Fig. 6).

Thirty 7.5-minute quadrangles make up the study area for this investigation (Fig. 2). As part of the USFWS NWI program, delineations for the 1992 maps were digitized and entered into the GIS ARC/INFO for analysis on a quadrangle by quadrangle basis. GIS data files previously digitized and maintained by the USFWS for the 1950's and 1979 photographs were obtained and translated to digital line graph (DLG) format in a form readable by ARC/INFO. Twelve historical NWI maps (four 1979 maps and eight 1956 maps) were not in digital form and had to be digitized (Table 1).

The digitizing process is a means of data capture of the lines, points, and polygons displayed on hard-copy maps. General procedures used by the UFWS are as follows. Data are captured with a digitizing tablet using a software package called the Analytical Mapping System (AMS). The AMS is a menu-driven geographically referenced digitizing system that contains predefined, sequential data-entry procedures, including: map preparation and georeferencing; digitizing and editing; polygon verification/formation; and data base construction and transfer. The base map to be digitized is registered to a geographic referencing system with AMS by establishing longitude and latitude registration marks (maximum 16, minimum 8) of the map as points within the

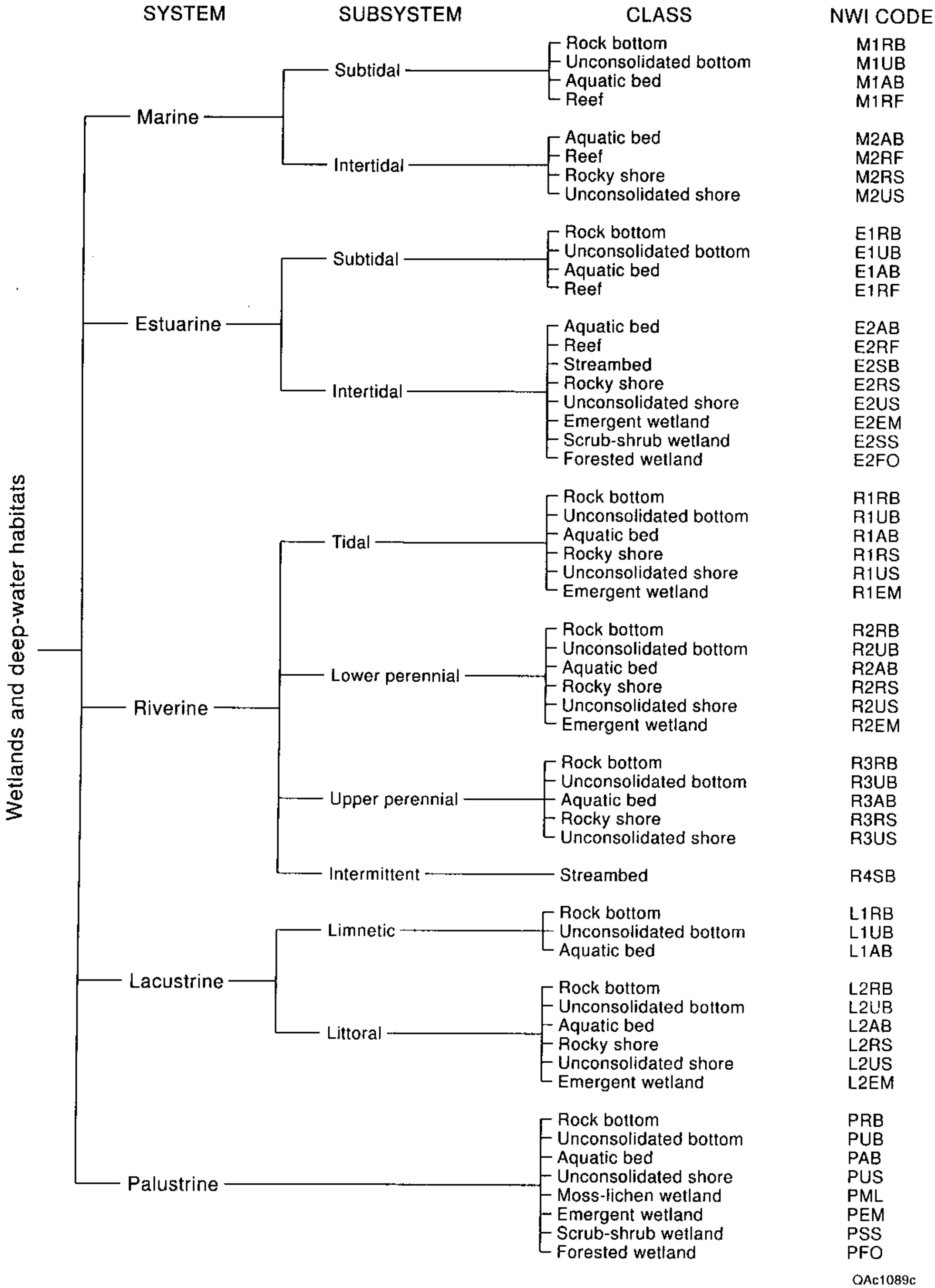


Figure 4. Classification hierarchy of wetlands and deepwater habitats showing systems, subsystems, and classes. From Cowardin et al. (1979).

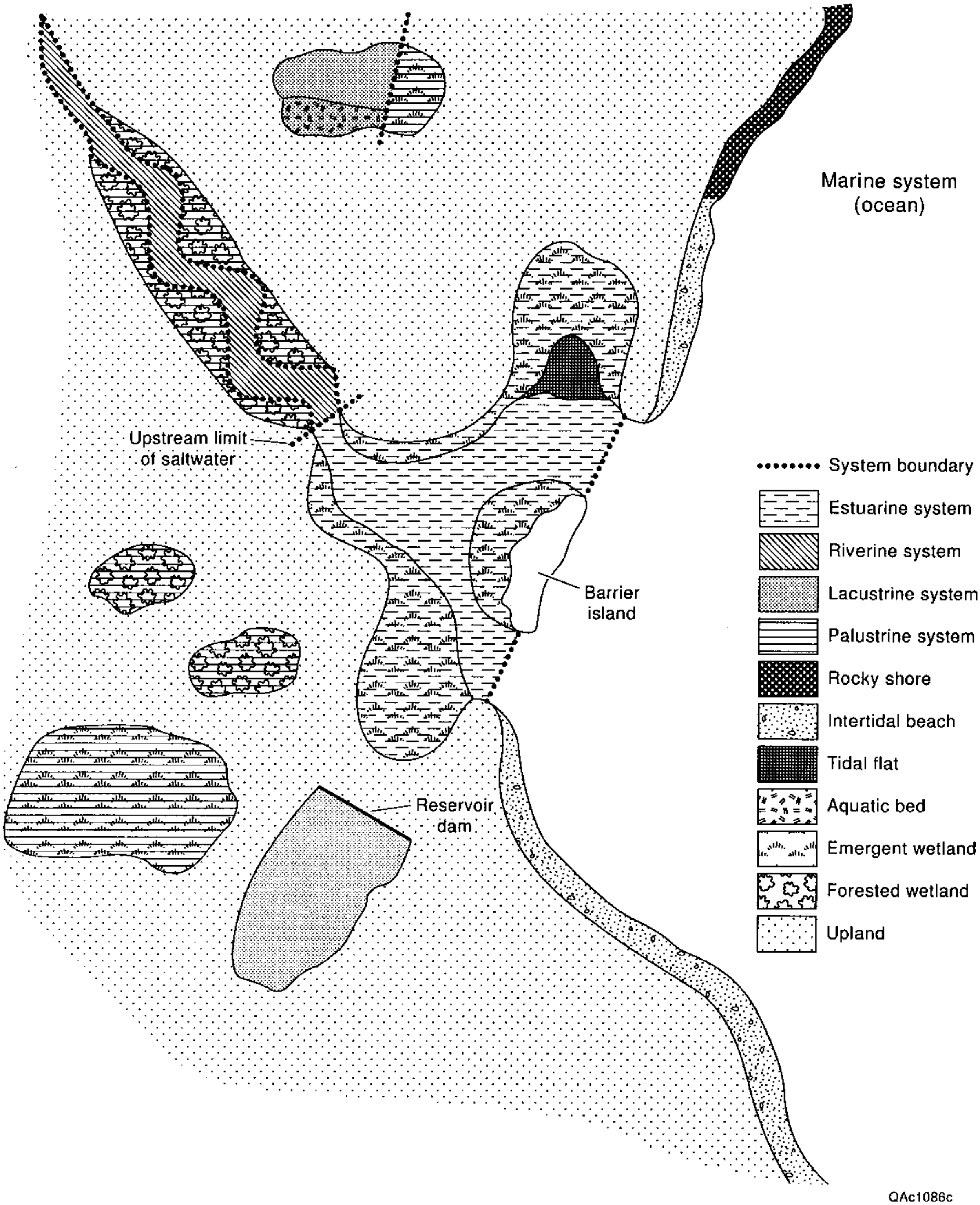
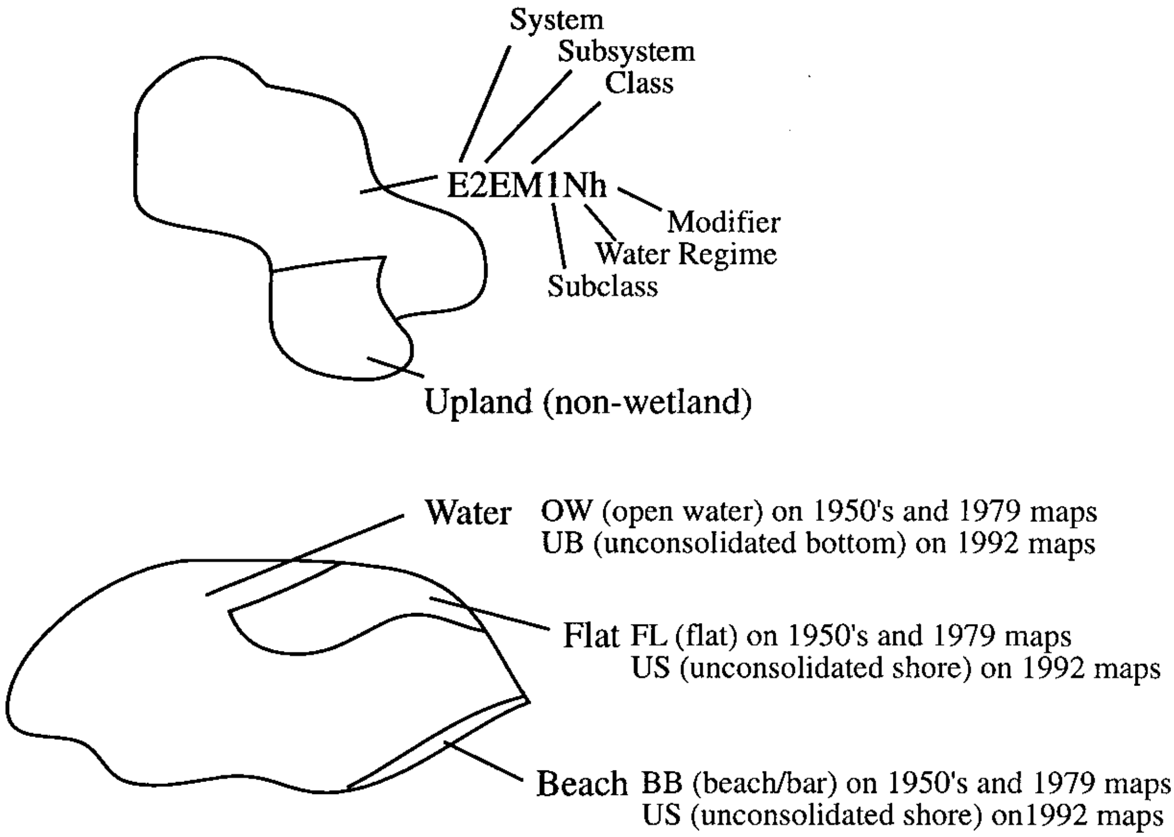


Figure 5. Schematic diagram showing major wetland and deepwater habitat systems. From Tiner (1984).



Upland Legend for 1979 maps only

Upland Classes	Modifying Terms
U-Urban or Developed	o-oil and gas
A-Agricultural	r-rice field
F- Forest	6-deciduous
SS-Scrub/shrub	7-evergreen
R-Range	8-mixed
B-Barren	s-spoil

Figure 6. Example of symbology used to define wetland and upland habitats on NWI maps.

Table 1. Status of wetland digital data available from USFWS for quadrangles in the CCBNEP study area. D=digital data available; x=no existing digital data -- wetlands digitized from USFWS maps as part of this project; NA=neither digital data nor map available.

Quad Name	1950's	1979	1992
Allyns Bight	D	D	D
Annaville	x	D	D
Aransas Pass	D	D	D
Bayside	x	D	D
Chapman Ranch	x	D	D
Corpus Christi	D	D	D
Crane Islands NW	D	D	D
Crane Islands SW	D	D	D
Edroy	x	x	D
Estes	D	D	D
Gregory	D	D	D
Lamar	D	D	D
Mesquite Bay	D	D	D
Mission Bay	x	D	D
Odem	x	x	D
Oso Creek NE	D	D	D
Oso Creek NW	D	D	D
Pita Island	D	D	D
Port Aransas	D	D	D
Port Ingleside	D	D	D
Portland	D	D	D
Rincon Bend	x	x	D
Robstown	x	x	D
Rockport	D	D	D
South Bird Island	D	D	NA
St Charles Bay	D	D	D
St Charles Bay SE	D	D	D
St Charles Bay SW	D	D	D
Taft	D	D	D
Tivoli SW	D	D	D

digitizing tablet grid and the latitude/longitude registration points of the map. These values are either accepted or declined by the digitizer in compliance with national map-accuracy standards. The data are digitized and stored in an arc-mode format. AMS provides internal verification of polygon closure, island formation, and edge matching. Quality control is performed within AMS to identify errors in attribute assignment, open polygons, crossing line segments, unattached edge modes, or misassigned islands. Additional quality control is done by the digitizer who produces a plot of the digitized data and compares it to the original map. This provides a check for errant lines, missed polygons, missing lines, or lines that diverge from the original in location, direction, or directness. Following editing and verification, digital map data are transferred to a permanent AMS data base and can be exported to the MOSS or to ARC/INFO for analysis.

Results include GIS data sets consisting of electronic-information overlays corresponding to mapped habitat features for the 1950's, 1979, and 1992. Data can be manipulated as information overlays, whereby scaling and selection features allow portions of the estuary to be electronically selected for specific analysis.

Among the objectives of GIS are to: (1) allow direct historical comparisons of habitat types to gauge historical trends and status of estuarine habitat, (2) allow novel comparisons of feature overlays to suggest probable causes of wetland changes, (3) make information on wetlands directly available to managers in a convenient and readily assimilated form, and (4) allow overlays to be combined from both this and future studies on other topics in a single system that integrates disparate environmental features for purposes of creating a CCMP. The GIS will become a flexible and valuable management tool for use by resource managers.

Field Investigations

Field investigations were conducted for two purposes: (1) to characterize wetland plant communities through representative field surveys and (2) to compare various wetland plant communities in the field with corresponding "signatures" on aerial photographs used to define wetland classes, including water regimes, for mapping purposes. Characterization of prevalent plant associations provided vital plant community information for defining mapped wetland classes in terms of typical vegetation associations.

II. CLASSIFICATION OF WETLAND AND DEEPWATER HABITATS IN THE CCBNEP AREA

Cowardin et al. (1979) defined five major systems in their classification of wetlands and deepwater habitats: Marine, Estuarine, Riverine, Lacustrine, and Palustrine (Fig. 4). All include wetlands and deepwater habitats except for the palustrine system, which includes only wetland habitats. Systems are divided into subsystems, which reflect hydrologic conditions, such as intertidal and subtidal for marine and estuarine systems. Subsystems are further divided into class, which describes the appearance of the wetland in terms of vegetation or substrate. Classes are divided into subclasses. Only vegetated classes were divided into subclasses for this project, and only for 1979 and 1992. In addition, water-regime modifiers (Table 2) and special modifiers were used for these years.

The USFWS-NWI program established criteria for mapping wetlands using the Cowardin et al. (1979) classification. Alphanumeric abbreviations are used to denote systems, subsystems, classes, subclasses, water regimes, and special modifiers (Table 3, Fig. 6). Symbols for certain habitats changed after 1979; these changes are shown in Figure 6 and are noted in the section on trends in wetland and aquatic habitats. Examples of alphanumeric abbreviations used in the section on status of wetlands apply only to 1992 maps. Much of the following discussion of wetland systems as defined by Cowardin et al. (1979) is modified from White et al. (1993). Nomenclature and symbols (Appendix) in this discussion are based primarily on the 1992 NWI maps.

A. Marine System

Marine areas include unconsolidated bottom (open water), unconsolidated shore (beaches), and rocky shore (jetties). Mean range of Gulf tides is about 0.6 m. Nonvegetated open water overlying the Texas Continental Shelf is classified as marine subtidal unconsolidated bottom (M1UBL) (Table 3). Unconsolidated shore is mostly irregularly flooded shore or beach (M2USP) with a narrow zone of regularly flooded shore (M2USN). Composition of these areas is primarily sand and shell. Granite jetties along the coast in the marine system are classified as rocky shore intertidal, irregularly flooded, artificial substrate (M2RS2Pr).

B. Estuarine System

The estuarine system consists of many types of wetland habitats. Estuarine subtidal unconsolidated bottom (E1UBL), or open water, occurs in the numerous bays and in adjacent salt and brackish marshes. Unconsolidated shore (E2US) includes intertidal sand and mud flats and estuarine beaches and bars. Water regimes for this habitat range primarily from regularly flooded (E2USN) to irregularly flooded (E2USP).

Aquatic beds observed in this system are predominantly submerged rooted vascular plants (E1AB3L) that include, in the CCBNEP area (Fig. 1), *Halodule wrightii* (shoalgrass), *Thalassia testudinum* (turtlegrass), *Ruppia maritima* (widgeongrass), *Syringodium filiforme* (manateegrass), and *Halophila engelmannii* (clover grass) (Pulich et al. 1997).

Emergent areas closest to estuarine waters consist of regularly flooded (E2EM1N), salt-tolerant grasses (low salt and brackish marshes). These communities are mainly composed of *Spartina alterniflora* (smooth cordgrass), *Batis maritima* (saltwort), *Distichlis spicata* (seashore saltgrass), *Salicornia* spp. (glasswort), *Monanthochloe littoralis* (shoregrass), *Suaeda linearis* (annual seepweed), and *Sesuvium portulacastrum* (sea-purslane) in more saline areas. In brackish areas,

Table 2. Water regime descriptions for wetlands used in the Cowardin et al. (1979) classification system.

Nontidal

(A)	Temporarily flooded—Surface water present for brief periods during growing season, but water table usually lies well below soil surface. Plants that grow both in uplands and wetlands are characteristic of this water regime.
(C)	Seasonally flooded—Surface water is present for extended periods, especially early in the growing season, but is absent by the end of the growing season in most years. The water table is extremely variable after flooding ceases, extending from saturated to well below the ground surface.
(F)	Semipermanently flooded—Surface water persists throughout the growing season in most years. When surface water is absent, the water table is usually at or very near the land's surface.
(H)	Permanently flooded—Water covers land surface throughout the year in all years.
(K)	Artificially flooded

Tidal

(K)	Artificially Flooded
(L)	Subtidal—Substrate is permanently flooded with tidal water.
(M)	Irregularly exposed—Land surface is exposed by tides less often than daily.
(N)	Regularly flooded—Tidal water alternately floods and exposes the land surface at least once daily.
(P)	Irregularly flooded—Tidal water floods the land surface less often than daily.
(S)*	Temporarily flooded—Tidal
(R)*	Seasonally flooded—Tidal
(T)*	Semipermanently flooded—Tidal
(V)*	Permanently flooded—Tidal

*These water regimes are only used in tidally influenced, fresh-water systems.

Table 3. Wetland codes and descriptions from Cowardin et al. (1979). Codes listed below were used on 1992 NWI maps, which varied in some cases from 1950's and 1979 maps (see Fig. 6).

NWI code (water regime)	NWI description	Common description	Characteristic vegetation
M1UB (L)	Marine, subtidal unconsolidated bottom	Gulf of Mexico	Unconsolidated bottom
M2US (P,N,M)	Marine, intertidal unconsolidated shore	Marine beaches, barrier islands	Unconsolidated shore
M2RS (P)	Marine, intertidal rocky shore	Marine breakwaters, beach stabilizers	Jetties
E1UBL (L)	Estuarine, subtidal unconsolidated bottom	Estuarine bays	Unconsolidated bottom
E1AB (L)	Estuarine, subtidal aquatic bed	Estuarine seagrass or algae bed	*Halodule wrightii* *Thalassia testudinum* *Ruppia maritima*
E2US (P,N,M)	Estuarine, intertidal unconsolidated shore	Estuarine bay, tidal flats, beaches	Unconsolidated shore
E2EM (P,N)	Estuarine, intertidal emergent	Estuarine bay marshes, salt and brackish water	*Spartina alterniflora* *Spartina patens* *Distichlis spicata*
E2SS (P)	Estuarine, intertidal scrub-shrub	Estuarine shrubs	*Iva frutescens* *Baccharis halimifolia*
R1UB (V)	Riverine, tidal, unconsolidated bottom	Rivers	Unconsolidated bottom
R1SB (T)	Riverine, tidal, streambed	Rivers	Streambed
R2UB (H)	Riverine, lower perennial, unconsolidated bottom	Rivers	Unconsolidated bottom
R4SB (A,C)	Riverine, intermittent streambed	Streams, creeks	Streambed
L1UB (H,V)	Lacustrine, limnetic, unconsolidated bottom	Lakes	Unconsolidated bottom
L2UB (H,V)	Lacustrine, littoral, unconsolidated bottom	Lakes	Unconsolidated bottom
L2AB (H,V)	Lacustrine, littoral, aquatic bed	Lake aquatic vegetation	*Nelumbo lutea* *Ruppia maritima*
PUB (F,H,K)	Palustrine, unconsolidated bottom	Pond	Unconsloidated bottom
PAB (F,H)	Palustrine, aquatic bed	Pond, aquatic beds	*Nelumbo lutea*
PEM (A,C,F,S,R,T)	Palustrine emergent	Fresh-water marshes, meadows, depressions, or drainage areas	*Scirpus californicus* *Typha spp.*
PSS (A,C,F,S,R,T)	Palustrine scrub-shrub	Willow thicket, river banks	*Salix nigra* *Parkinsonia aculeata* *Sesbania drummondii*
PFO (A,C,F,S,R,T)	Palustrine forested	Swamps, woodlands in floodplains depressions, meadow rims	*Salix nigra* *Fraxinus spp.* *Ulmus crassifolia* *Celtis spp.*

species composition changes to a salt to brackish-water assemblage including *Scirpus maritimus* (saltmarsh bulrush). At slightly higher elevations irregularly flooded estuarine emergent wetlands (E2EM1P) (high salt and brackish marshes) include *Borrichia frutescens* (sea oxeye), *Distichlis spicata, Spartina spartinae* (gulf cordgrass), *Spartina patens* (saltmeadow cordgrass), *Fimbrystylis castanea* (marsh fimbry), *Scirpus maritimus*, *Aster* spp.(aster), and many others.

Estuarine scrub-shrub wetlands (E2SS) are much less extensive than estuarine emergent wetlands. Representative plant species, in regularly flooded zones (E2SS1N) include *Avicennia germinans* (black mangrove) and in irregularly flooded zones (E2SS1P) between emergent wetland communities and upland habitats, include, *Iva frutescens* (big-leaf sumpweed), *Baccharis halimifolia* (sea-myrtle, or eastern false-willow), *Sesbania drummondii* (drummond's rattle-bush), and *Tamarix* spp. (salt cedar).

Mapping criteria allow classes to be mixed in complex areas where individual classes could not be separated. Most commonly used combinations include the estuarine emergent class and estuarine intertidal flat (E2EM/FL) and wetlands and uplands (PEM/U and POW/U). The class E2EM/FL was only used on 1956 and 1979 maps. In such combinations, each class must compose at least 30 percent of the mapped area (polygon); the dominant classes were listed first on 1992 maps, for example PEM/U or U/PEM, but on the 1950's and 1979 maps the wetland class was always listed first (PEM/U) whether or not it was most abundant. The wetland and upland combinations (PEM/U, POW/U) were used almost exclusively on the Pleistocene barrier-strandplain where complex topography produced complex configurations of wetlands and uplands that could not be adequately separated at the mapping scale.

The estuarine system extends upstream or landward to the point where ocean-derived salts are less than 0.5 ppt (during average annual low flow) (Cowardin et al. 1979). Mapping these boundaries is subjective in the absence of detailed long-term salinity data characterizing water and marsh features. Vegetation types, proximity and connection to estuarine water bodies, salinities of water bodies, and location of artificial levees and dikes are frequently used as evidence to determine the boundary between estuarine and adjacent palustrine (freshwater) systems.

C. Lacustrine System

Water bodies greater than 8 ha are included in this system with both limnetic and littoral subsystems represented. Several lakes and reservoirs exist within the CCBNEP study area.

Nonvegetated water bodies are labeled limnetic or littoral unconsolidated bottom (L1UB or L2UB) depending on water depth. Bodies of water with vegetation are classified with the subclass of rooted (L1AB3 and L2AB3) or floating (L1AB4 and L2AB4) aquatic bed. The impounded modifier (h) is used on bodies of water impounded by levees or artificial means. The artificially flooded modifier (K) is used in situations where water is controlled by pumps and siphons.

D. Riverine System

Three riverine subsystems occur in the project area: tidal (R1), lower perennial (R2), and intermittent (R4). The major rivers discharging directly into the bay sytems are the Nueces, Aransas, and Mission Rivers (Fig. 3). Ditches large enough to be delineated were identified with the excavated (x) modifier (for example, R2UBHx or R4SBAx).

E. Palustrine System

Palustrine areas include the following classes: unconsolidated bottom (open water), unconsolidated shore (including flats), aquatic bed, emergent (fresh or inland marsh), scrub-shrub, and forested. Naturally occurring ponds are identified as unconsolidated bottom permanently or semipermanently flooded (PUBH or PUBF). Excavated or impounded ponds and borrow pits are labeled with their respective modifiers (PUBHx or PUBHh), and artificially flooded areas by PUBK.

Palustrine emergent wetlands are generally equivalent to fresh, or inland marshes. Semipermanently flooded emergent wetlands (PEM1F) are low fresh marshes; seasonally flooded (PEM1C) and temporarily flooded (PEM1A) palustrine emergent wetlands are high fresh marshes. Emergent areas bordering estuarine vegetation and estuarine-influenced rivers are typically affected by tides. For these tidally influenced fresh-water systems, special water-regime modifiers are applied for seasonally (PEM1R) and temporarily (PEM1S) flooded areas. Artificially flooded areas are designated PEM1K.

Vegetation communities typically characterizing areas mapped as low emergent wetlands (PEM1F) include *Scirpus californicus* (California bulrush), *Typha domingensis* (southern cattail), *Scirpus pungens* (three-square bulrush), *Eleocharis* spp. (spikerush), and others. Areas mapped as topographically higher and less frequently flooded emergent wetlands (PEM1A) include *S. spartinae, Borrichia frutescens, S. patens*, *Cyperus* spp. (flatsedge), *Hydrocotyle bonariensis* (coastal plain penny-wort), *Aster spinosus* (spiny aster), *Paspalum* spp. (paspalum), *Panicum* spp. (panic), and *Andropogon glomeratus* (bushy bluestem) to mention a few.

It should be noted that in many areas, field observations revealed the existence of small depressions or mounds with plant communities and moisture regimes that varied from that which could be resolved on photographs. Thus, some plant species that may typify a low regularly flooded marsh, for example, may be included in a high marsh map unit. Differentiation of high and low marsh communities was better achieved through field transects, some of which included elevation measurements.

Palustrine scrub-shrub wetlands that were mapped are typically seasonally flooded (PSS1C) and dominated by *Salix nigra* (black willow), *Parkinsonia aculeata* (retama), *Acacia smallii* (huisache), and *Sesbania drummondii.* Temporarily and semipermanently flooded scrub-shrub habitat also occur with similar species. Water regimes include both tidally and nontidally influenced areas. *Tamarix* spp. is labeled PSS2A or PSS2C depending on the water conditions present (Table 2).

Palustrine forested areas, consisting of temporarily (PFO1A) and seasonally (PFO1C) flooded forested areas, incorporate a large mixture of tree species including *Parkinsonia aculeata, Acacia smallii, Salix nigra*, *Fraxinus spp.* (ash), *Ulmus crassifolia* (cedar elm), *Celtis spp.* (hackberry), *Carya illinoensis* (pecan hickory), and others.

III. CHARACTERIZATION OF WETLAND PLANT COMMUNITIES IN THE CCBNEP AREA

A. Introduction

The area encompasses an extensive, biologically productive estuarine and lagoonal system composed of numerous diverse and essential habitats and vast array of associated organisms. Understanding status and trends of these habitats is critical for comprehensive management plans. Characterization of wetland communities within the CCBNEP study area is necessary in evaluating changes in emergent wetland types. Therefore, the objectives of this portion of the project were to characterize the vegetation of typical wetland communities within the CCBNEP area.

B. Background

Extensive coastal marshes, predominantly brackish and saline, occur in the northern part of the CCBNEP study area where freshwater inflow and precipitation are higher than in the southern portion. Coastal marshes are replaced by extensive wind-tidal flats from Mustang Island southward, due to lower precipitation and high evaporation rates. Freshwater marshes located within the interior of Mustang and Padre Islands and along watercourses on the mainland are less extensive within the CCBNEP study area. Most freshwater marshes and riparian woodlands are located within the Nueces, Aransas, and Mission River floodplains. Decreases in freshwater wetland coverage have been attributed to diminished discharge resulting from upstream dams, clearing for urban and agricultural development, and hydrologic changes from brine discharge within creek systems (Brown et al. 1976).

C. Methods

Wetland Vegetation Characterization

Prevalent plant species characterizing NWI emergent, shrub-scrub, and forested wetland habitats were determined from limited field surveys and transects, and existing data from vegetation analysis of Chiltipin Creek (Tunnell et al. 1997), Aransas National Wildlife Refuge (Darnell et al. 1997), Copano Bay marsh (Wood et al. 1995), Mustang Island (Jenkins and Smith, 1997 and this study), Fennessey Flats (this study), Welder Wildlife Foundation oxbow lakes (Drawe et al. 1978, Haigh, 1984), and general literature. Site selection and number of transects for some field surveys were coordinated as part of the verification of photointerpretation work, and for use in characterization of wetland vegetation communities in the CCBNEP study area. Particular emphasis was placed on barrier island wetlands to evaluate changes in palustrine marshes over time; in general, a minimum of three transects was completed for each wetland community. Transects were aligned perpendicular to the elevation gradient that encompassed maximum number of vegetation associations.

A minimum of three transects within each wetland community were assessed for changes in vegetation association in relation to changes in elevation using a hand level and staff for transects of less than 100 m in length. A metric tape was used by field workers to locate appropriate points as delineated by wetland vegetation type along the transect. A Sokkia Set 3B electronic total station was used for transects > 100 m long at Mustang Island and Fennessey

Flats. The total station was positioned at the highest elevation point within the transect or most appropriate site to ensure safety of equipment and operator. All vegetation along a vertical plane was recorded at each point and data from the total station recorded to evaluate changes in horizontal distance and change in elevation from the instrument to each point sampled (1 cm accuracy). Time of day was recorded for reading at the water line for later comparison to water-level data from appropriate tide gauges (Conrad Blucher Institute data). Existing artificial structures (i.e., roads, paths, channels, buildings, etc.) were also recorded. The total station was moved along the transect as necessary when visibility to the prism pole as blocked. A location was recorded for all transects at each endpoint and incorporated into a GIS.

Data were recorded on Excel spreadsheets for comparison between wetland sites and wetland communities, and for future status and trends evaluation in the CCBNEP study area. Graphical representations of wetland vegetation/elevation relationships were constructed for visual assessment and interpretation. Descriptions of previous vegetation characterization in the CCBNEP study area were used to provide a comprehensive synthesis of available information. Wetland community assemblages were determined by grouping species with similar ecological requirements (i.e., Correll and Johnston, 1970, Jones, 1982, Tiner, 1993) as well as wetland indicator status (Reed, 1988).

D. Results

Wetland Vegetation Dynamics Overview

Coastal Marshes

Coastal marshes comprise an extensive part of shorelines along the East Coast of the United States, northern Gulf of Mexico, and, to a lesser extent, West Coast and western Gulf of Mexico. They are primarily associated with areas of low relief on the continental slope and coastal plains. Coastal marshes exhibit unique structural and functional characteristics primarily controlled by environmental factors. Individual species' responses to stresses of inundation and salinity generally determine location across an elevational and salinity gradient.

Marshes that are situated along gently-sloping coastlines typically exhibit species zonation parallel to the shoreline. Coastal marsh zones have been delineated according to their elevation and tidal inundation. The lower or intertidal marsh is generally flooded daily, the upper or high marsh is infrequently flooded (Mitsch and Gosselink, 1993). Chabreck (1972) divided Gulf coastal plain communities into four zones: saline, brackish, intermediate, and fresh. The saline zone is typified by daily tidal inundation and salinities of 20-35 ppt. The brackish zone has a salinity range of 5-19 ppt and is affected by seasonality of tides, especially in spring and fall, and by storm surges due to tropical storms. The intermediate zone is tidally affected only by extreme storm surge events, which may not change salinity (0.5-5 ppt) but may increase water depth by impeded normal runoff. Salinity ranges greater than 40 ppt are designated as hyperhaline (Cowardin et al. 1979).

Tidal cycles are a primary component of hydrologic dynamics in coastal marsh systems. Varying degrees of inundation in relation to marsh elevation differentially affect vegetation dynamics. Effects of tides can be stressful to plants (e.g., submergence, anaerobic-soil conditions, deposition of salts in the soil), but also have beneficial effects by periodic flushing of salts out of the marsh and nutrients into the marsh (Mitsch and Gosselink, 1986). Seasonal cycles are superimposed on diurnal tide patterns, and have an additional impact (Bleakney, 1972, Armstrong et al. 1985, Wood, 1986). Additional aperiodic events, such as hurricanes and tropical storms, influence vegetation dynamics in coastal marshes by either increasing freshwater or saline inflow into the marshes (Miller and Egler, 1950, Shiflet, 1963, Chabreck and Palmisano, 1973, Hopkinson et al. 1978).

Tidal amplitude is much less in Gulf marshes than East coast marshes, usually less than 0.5 m (Turner, 1991, Ward et al. 1980). Prevailing south to southeasterly winds occur throughout much of the year producing wind tides that usually override astronomical cycles. These wind tides push water to the north-northwest from the Gulf through passes into shallow estuaries and marshes. Strong northerly winds during winter can reverse wind tides resulting in rapid removal of large amounts of water from the shallow coastal marshes and bays.

Although tidal regimes are similar to those in Louisiana, salinity levels are higher in South and Central Texas coastal marshes due to decreased annual rainfall and increased temperatures and evaporation rates (Texas Dept. Water Resources, 1984). Therefore, Texas coastal marshes may experience more severe environmental conditions than other regional coastal marshes and these conditions may affect marsh vegetation dynamics. However, limited information is available for determining effects of variable environmental conditions (e.g., water depth, salinity) on species distribution and composition in Texas coastal marshes.

Typical species zonation in Gulf coastal marshes include *Spartina alterniflora* in the lower saline zone, *S. patens* in the middle brackish zone, and, *Paspalum vaginatum* (seashore paspalum) in the higher intermediate zone. *Distichlis spicata* generally occurs between brackish and saline zones, but *D. spicata* is present in varying amounts throughout the marsh community. Other species occur in Gulf coastal marshes and are variously affected by environmental influences in response to their physiological requirements (Chabreck, 1972; Gosselink, 1984).

Barrier Islands

Barrier islands are located along most portions of the Texas coast originating as offshore shoals about 4500 years before present (YBP) (LeBlanc and Hodgson, 1959, Otvos, 1970a, 1970b, Brown et al. 1976, 1977) (Fig. 3). When sea level reached its present level (about 2800 to 2500 YBP), these offshore shoals formed a chain of barrier islands fronting the mainland estuaries that now occupy drowned Pleistocene river valleys (Morton and McGowen, 1980). Development of islands continued through a process of spit accretion resulting from both longshore littoral sediment transport and eolian (or wind) deposition (Weise and White, 1980; Britton and Morton, 1989). Passes that allow flow of Gulf waters into estuarine systems and outflow of waters from associated rivers into the Gulf also delineate individual islands within the CCBNEP Study Area (Matagorda, San Jose, Mustang, and Padre Islands).

Barrier islands typically develop vegetation zones corresponding to an associated topographical zone. Gulf beach habitat is located along the easternmost barrier island beach environment in Texas consisting of a marine, intertidal unconsolidated shoreline (foreshore and backshore zones). This high-energy zone generally does not support long-term vegetation (Kaplan, 1988). Coppice or embryo dunes are small, vegetated mounds of sand located at the landward edge of the backshore and beginning of the foredune ridge complex. Vegetation zonation is prominent on the primary dunes, with distinctive windward and leeward plant communities. Along Mustang and Padre Islands, dune topography is dynamic and may change appearance through eolian forces.

The vegetated flats lying between foredune fields and back-island dunes have greatest vegetation coverage and diversity of all barrier island communities (Britton and Morton, 1989). White et al. (1983) described wetland locations and vegetation characteristics associated with Mustang

Island. Proximal (low) and distal (high) salt-water marshes occur to a limited extent along bay margins. The most extensive salt-water marshes occur along margins of Mustang Island southwest of the Water Exchange Pass and northeast of Wilson's Cut. Both brackish and freshwater wetlands associated with the freshwater ground lens may form in association with ephemeral ponds in depressional areas in central parts of the island. Marshes supported by fresher water occur near the island center of the occupying deflation troughs and depressions and, in some localities, relict washover channels separated from Gulf and bay waters.

Tidal flats are present along the bay margin of Mustang and Padre islands where they replace salt marshes located at similar elevations on northern barrier islands. This north-south geographic shift in habitats has been explained as a result of lower rainfall/higher evaporation rates and an increase of wind-driven erosion in the southern area which has resulted in a decrease in barrier island vegetation (Brown et al. 1976). The irregular tidal regime and extremely high temperatures of sheetwater on flats often raises soil salinities above salt marsh vegetation tolerance limits. Therefore, biologic activity is often restricted to mats of blue-green algae formed on and within the tidal flat surface (Pulich et al. 1982).

Extensive vegetation studies of North Padre Island have been conducted over the past three decades. The SCS (NRCS) conducted an ecological survey of vegetation of Padre Island National Seashore (Rechenthin and Passey, 1967). Five vegetative types were recognized: coastal dunes, low coastal sands, salt marsh, salty sands and shoregrass flats. Britton and Morton (1989) described the following habitats for Mustang Island: backshore pioneer habitats, backshore near dunes or dune ridges, windward slopes of dunes or dune ridges, leeward slopes of dunes or dune ridges, and vegetation-stabilized sands and flats.

Vegetation classification systems have been used to designate vegetation to ecoregions, and Texas barrier islands are defined as the dunes/barrier zone of the Gulf Coast Prairies and Marshes ecoregion (LBJ School of Public Affairs, 1978). Seral stages of plant communities on Mustang Island were further defined as both tall grassland, forb-dominated vegetation and marshes at the series-level classification. A summarization of representative plant communities of Mustang Island State Park along an east-west transect included: Cenicilla (Beach Purslane)-Beach Morning Glory Series, Midgrass grassland of Seacoast Bluestem-Gulfdune Paspalum Series, and Glasswort-Saltwort Series (TPWD, 1990).

1975 Classification of Emergent Wetlands in the CCBNEP Area

Diener (1975) characterized coastal prairie and marshes along the Texas coast and mapped emergent vegetation in each of the estuarine areas (Table 4). Coastal marsh included the beach vegetation consisting of plants variously influenced by degrees of tidal inundation. Plant dominance changes from north to south, where *S. alterniflora* and *Batis maritima* are replaced by more salt-tolerant species.

1976 Classification of Emergent Wetlands in the CCBNEP Area

Marshes were described for the CCBNEP area using definitions for amount of salinity in the wetland and position along an elevational gradient (Table 5) (Brown et al. 1976). These definitions took into account variability of climatic regimes in the area and corresponding position of wetlands in the Coastal Bend. Each wetland unit was mapped in association with soil and biotic descriptions.

Table 4. Some wetland plant species associated with each bay system in the CCBNEP area for coastal marshes (including beach vegetation) (modified from Diener, 1975).

Bay	Scientific Name	
Copano-Aransas Bays		
	Batis maritima	*Spartina alterniflora*
	Monanthochloe littoralis	*Spartina patens*
	Salicornia bigelovii	*Sporobolus virginicus*
Corpus Christi Bay		
	B. maritima	*S. alterniflora*
	M. littoralis	*S. virginicus*
	S. bigelovii	*Suaeda linearis*
	Scirpus maritimus	*Uniola paniculata*
	Schizachyrium scoparium	
Laguna Madre		
	M. littoralis	*S. scoparium*
	Paspalum monostachyum	*S. linearis*
	S. bigelovii	*U. paniculata*

Table 5. Definitions of emergent wetland units used to characterize wetlands (Brown et al. 1976).

Unit/Subunit	Definition
Salt-water Marshes	"kept perennially wet by salt water [which] varies from less [35 ppt] to greater than normal marine salinity (35 ppt)… on flood-tidal deltas, along bay margins, and along the back sides of barrier islands and peninsulas"
Low	"characterized by pure stands of smooth cordgrass (*Spartina alterniflora*) that grow at the margin of salt-water bodies in water a few inches deep"
High	"inundated almost daily by either astronomical or wind tides and is characterized by numerous salt-tolerant, largely succulent plants that show an orderly succession in types from the water margin toward the higher and more saline substrates"
Fresh- to Brackish-water Marshes	"present at slightly higher elevations than salt marsh… salinity varies… with climatological conditions.. during prolonged dry periods, both surface and soil water have salinity in excess of 35 ppt … whereas during periods of excessive rainfall may be virtually fresh… present on Nueces delta and along some active and inactive tidal creeks and tributaries associated with Port Bay"
Fresh-water Marshes	"pure stands of fresh-water vegetation in the Corpus Christi area are best developed on the Nueces and Mission deltas and along the Nueces, Chiltipin-Aransas, and Mission Rivers… during wet climatic cycles, an ephemeral, poorly developed fresh-water marsh occupies low areas adjacent to Port Bay and McCampbell Slough"

1983 Classification of Emergent Wetlands in the CCBNEP Area

Emergent wetland units utilized in characterization and mapping of wetlands for Aransas, Mission, Copano, Port, Redfish, Corpus Christi, Nueces, Oso bays, and upper Laguna Madre were generally similar to those used in the Environmental Geologic Atlas series (Brown et al. 1976). Modifications included subdividing salt-water marshes into Proximal, Distal, and Mangrove; and, brackish-water and fresh-water marshes into Low and High. In addition, the undifferentiated marsh unit was included in this wetland characterization. Specific definitions of each unit and subunit are summarized in Table 6).

Table 6. Definitions of emergent wetland units and subunits used to characterize wetlands (White et al. 1983).

Unit/ Subunit	**Definition**
Salt-water Marshes	areas frequently flooded by tidal exchange via tidal channels and open waters of the bay-estuary-lagoon
Proximal	"more frequently flooded because of lower elevations and proximity to open water"
Distal	"less frequently flooded because of higher elevations and distal locations with respect to bay-estuary water"
Mangrove	"tend to grow along levees and higher zones of marshy islands but also occurs in lower areas"
Brackish-water Marshes	"transitional between the salt-water and fresh-water-influenced environments"
Fresh-water Marshes	receive freshwater flow from rivers, precipitation, runoff, and/or ground water; generally beyond the limits of salt-water flooding except during hurricanes
Low	"areas characterized by relatively frequent inundation as denoted by vegetation types and soil moisture or standing surface water"
High	"areas that appear to be less frequently flooded, having a drier wetland-plant assemblage and lower soil and surface moisture"
Undifferentiated Marshes	"sand or mud flats that have become colonized with marsh vegetation covering about 30 to 60 percent of their area"
Transitional	"those areas that, in terms of flooding and plant communities, are intermediate between wetland and upland areas...occasionally inundated but with less frequency and duration than are marshes"

This approach allowed for more detailed mapping of the wetlands within the study area than had previously been achieved. Each Unit/subunit was characterized by representative plant assemblages from emergent wetlands mapped during this study (Table 7). Several species are listed under different types of marshes, which is indicative of the variable tolerance levels of these species to flooding and salinity ranges. However, broad assemblages of plant species could be differentiated in relation to location and probability of flooding frequency.

Table 7. Emergent wetland units/subunits characterized by vegetation assemblages in the Corpus Christi area (modified from White et al. 1983).

Unit	Scientific Name	
Salt-water Marsh		
Proximal	*Spartina alterniflora*	*Borrichia frutescens*
	Batis maritima	*Suaeda* spp.
	Salicornia virginica	*Monanthochloe littoralis*
	S. bigelovii	*Avicennia germinans*
	Distichlis spicata	*Iva frutescens*
Distal	*Borrichia frutescens*	*Suaeda* spp.
	Monanthochloe littoralis	*Iva frutescens*
	D. spicata	*A. germinans*
Mangrove	*A. germinans*	
locally abundant other species	*Spartina spartinae*	*Spartina patens*
	Lycium carolinianum	*Sesuvium portulacastrum*
	Limonium nashii	*Heliotropium curassavicum*
	Sporobolus spp.	
Brackish-water Marsh		
Low marsh	*S. maritimus*	*Typha* spp.
	Scirpus americanus	*M. littoralis*
	Juncus spp.	*Salicornia* spp.
	Eleocharis spp.	*D. spicata*
High marsh	*S. spartina*	*Iva* spp.
	S. patens	*Iva frutescens*
	B. frutescens	*Sporobolus* spp.
	Phragmites australis	*D. spicata*
	Baccharis halimifolia	*L. nashii*
other species	*Cyperus* spp.	*Fimbristylis castanea*
	Sesuvium portulacastrum	*Hydrocotyle* spp.
	L. carolinianum	
Fresh-water Marsh		
Low marsh	*Typha. latifolia*	*Cyperus* spp.
	T. domingensis	*Bacopa monnieri*
	S. americanus	*Juncus* spp.
	Scirpus californicus	*Ludwigia* spp.
	P. australis	*Sagittaria* spp.
	Eleocharis spp.	*Paspalum lividum*
High marsh	*S. spartinae*	*Rhynchospora macrostachya*
	Paspalum spp.	*Fimbrystylis* spp.
	Polygonum spp.	*Aster spinosus*
	Panicum spp.	*S. patens*
	B. frutescens	
other species	*Leersia hexandra*	*Pontedaria* spp.
	Echinodorus spp.	*Sesbania drummondii*
	Eichhornia crassipes	*B. halimifolia*
	Rhynchospora spp.	*Cephalanthus occidentalis*
	Lemna spp.	*Salix nigra*
	Hydrocotyle spp.	*Parkinsonia aculeata*

Table 7 (continued).

Undifferentiated Marshes		
	Salicornia spp.	*L. nashii*
	B. maritima	*L. carolinanum*
	M. littoralis	*S. spartinae*
	Borrichia frutescens	*Spartina patens*
	Distichlis spicata	
Transitional Areas		
	Spartina spartinae	*Helianthus spp.*
	Cynodon dactylon	*Sorghum halepense*
	Borrichia frutescens	*Cassia fasciculata*
	Aster spinosus	*Cyperus spp.*
	Paspalum monostachyum	*Eleocharis spp.*
	Paspalum lividum	*Scirpus spp.*
	Panicum spp.	*Leersia hexandra*
	Rhynchospora spp.	*Croton spp.*
	Dichromena colorata	*Spartina patens*
	Andropogon virginicus	*Arundo donax*
	Iva annua	*Bluetaparon (=Philoxerus) vermicularis*
	Aristida spp.	*Baccharis halimifolia*
	Setaria spp.	*Sesbanis drummondii*
Fluvial and Flood-prone Woodlands		
	Parkinsonia aculeata	*Cephalanthus occidentalis*
	Acacia smallii (A. farnesiana)	*Carya illinoensis*
	Salix nigra	*Ilex vomitoria*
	Fraxinus spp.	*Quercus spp.*
	Ulmus crassifolia	*Sesbania spp.*
	Celtis spp.	*Tamarix spp.*
	Populus deltoides	

National Wetlands Inventory Classifications Descriptions

Most comparative studies of wetlands utilize the classification within *The Classification of Wetlands and Deepwater Habitats of the United States* (Cowardin et al. 1979) including those status and trends investigations of coastal and inland areas. This portion of the report follows both the Cowardin System definitions (Table 2), classification codes (Table 8), and subdivisions of salinity listed in White et al. (1983).

Table 8. Wetland codes and descriptions for wetlands with emergent vegetation (Cowardin et al. 1979).

NWI Code (Water Regime)	NWI Description	Common Description	Characteristic Vegetation
E2EM (P,N,)	Estuarine, intertidal emergent	Estuarine bay marshes, salt and brackish water	*Spartina alterniflora* *Spartina patens* *Distichlis spicata*
E2SS (N,P)	Estuarine, intertidal scrub/shrub	Estuarine shrubs	*Avicennia germinans* *Iva frutescens* *Baccharis halimifolia*
PEM (A,C,F,H)	Palustrine, emergent	Fresh-water marshes, meadows, depressions, or drainage areas	*Scirpus californicus* *Typha* spp.
PSS (A,C,F)	Palustrine, scrub/shrub	Willow thicket, river banks	*Salix nigra* *Sesbania drummondii*
PFO (A,C,F)	Palustrine, forested	Swamps, woodlands in floodplains, depressions, meadow rims	*Taxodium distichum* *Quercus* spp. *Fraxinus* spp.

Predominant Emergent Vegetation Communities in the Estuarine System

Chiltipin Creek High Marsh (E2EM1P)

Chiltipin Creek is located in the Aransas River watershed in San Patricio County. Extensive high marsh communities are associated with the floodplain of the creek prior to its confluence with the Aransas River. The wetland is a typical example of South Texas middle and high marsh plant communities, with unvegetated salt pans and several ephemeral brackish-water ponds located in the vegetated marsh matrix.

In this Estuarine, Intertidal, Emergent, Irregularly Flooded marsh: thirteen coastal marsh species have been documented: *D. spicata, M. littoralis, Salicornia virginica* (perennial glasswort), *S. bigelovii* (Annual glasswort), *Borrichia frutescens, Suaeda linearis, Limonium nashi* (sea lavender), *Scirpus maritimus, Batis maritima, Lycium carolinianum* (wolfberry), *Spartina spartinae,* and *Sporobolus virginicus* (coastal dropseed). Five dominance plant species (*D. spicata, B. frutescens, M littoralis, S. virginica,* and *B. maritima*) accounted for 98% of plants most frequently encountered (Tunnell et al. 1997).

Distichlis spicata, a native, disturbance-dependent perennial species, has the ability to tolerate and recover from various forms of disturbance (i.e., high salinities, temporary high water levels, uprooting from grazing) (Pethick, 1974, Bertness, 1991). Colonization typically occurs through vegetative expansion of adventitious runners from adjacent colonies, although establishment through seed germination may occur under the right conditions (Bertness et al. 1992).

Borrichia frutescens, a perennial shrub, or subshrub that can achieve heights of about 75 cm, is common on brackish, saline soils, mainly along bay beaches and in salt marshes (Jones, 1982). There is virtually no ecological information available about this species, although this clonally-propagating species appears to be affected by disturbance and high water levels (Tunnell et al. 1997).

Salicornia virginica, a low-growing, succulent perennial that can form dense mats or clumps, is common in salt marshes, tidal flats, and along bay and island beaches (Jones, 1982). *S. virginica* does not appear to be as affected by disturbance, although this species can expand quickly under good conditions but does appear to be negatively impacted by extended periods of high water (Tunnell et al. 1997).

Monanthochloe littoralis a native, warm-season perennial locally abundant on saline sites, is found both on sandy and muddy soils (Gould and Box, 1965). Relatively little is known about ecological requirements of this species, although it does not appear to tolerate extensive inundation or disturbance.

Batis maritima a semi-deciduous, succulent-leaved perennial exhibits considerable seasonal changes (Jones, 1982). Common along bay shores and in salt marshes or tidalflats, it expands into bare areas of the marsh by means of spreading or creeping stems.

This marsh is characteristic of high marsh vegetation assemblages where tidal water only reaches the marsh during spring tides or storm surges. Most species are perennials and tolerant of saline soil conditions. In most cases, they are able to maintain low standing crop biomass during inclement periods, and expand during optimum conditions. Zonation is not as obvious at a given time and the vegetation assemblage appears to be more of a mosaic of robust, perennial climax species, with the exception of *D. spicata*. This species rapidly colonizes areas of disturbance, therefore, its dominance is related to degree of disturbance (Tunnell et al. 1997).

Aransas National Wildlife Refuge Estuarine High Marsh (E2EMIP)

This refuge encompasses a diversity of wetland types utilized by a number of estuarine-dependent species, including the endangered Whooping Crane (*Grus americana*). In a larger evaluation of vegetation among natural sites and created sites, representative plant communities were determined for a high, brackish marsh on the mainland of the refuge (Darnell et al. 1997). The natural marsh was characterized by a series of semi-isolated tidal ponds typically dry during drought and low tide periods. Water retained in the ponds often evaporates over time resulting in increased salinities in the soils; therefore, little vegetation is present during most years in the pond. *Batis maritima, M. littoralis,* and *Salicornia* spp. were predominant in the marsh, comprising 77% of the plants recorded by the point-intercept method (Fig. 7). Several transects were located in each of three natural marshes, and high similarity values among the marshes reflected the low relief of the marsh surface. These species were locally abundant in patches reflecting microtopographic differences within the marsh (Fig. 8).

Black Point Estuarine Marsh at Copano Bay (E2EMIN, E2EMIP)

Extensive open water tidal ponds and associated vegetated estuarine marshes are located at the Aransas River Delta and its confluence with Copano Bay at Hwy 136 south of the town of Bayside. Eleven plant species were recorded in fall 1995, with five species representing 90% of the vegetated cover: *D. spicata, S. virginica, B. frutescens, B. maritima,* and *S. maritimus* (Wood et al. 1995). *Spartina alterniflora* was present near tidal openings and along the southern

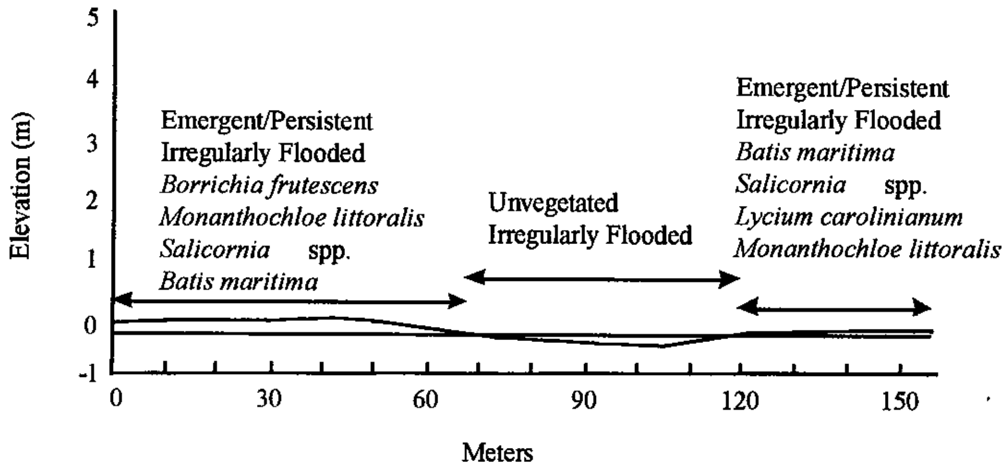


Figure 7. Profile of brackish, irregularly flooded marsh in Aransas National Wildlife Refuge showing relative elevations of plant communities through a marsh/ephemeral pond mosaic.

Figure 8. High brackish-marsh community on mainland of Aransas National Wildlife Refuge. Many salt-tolerant species share dominance including *Borrichia frutescens*, *Monanthochloe littoralis*, and *Lycium carolinianum*.

shorelines. Vegetation zonation was indicative of south Texas coastal salt marsh receiving adequate freshwater mixing with estuarine bay waters. *Spartina alterniflora* was present in intertidal, regularly flooded marsh zones (Fig. 9), while *D. spicata, S. maritimus,* and *S. virginica* were positioned in zones receiving irregular, estuarine flooding. Other species, such as *L. nashii, B. frutescens, Haplopappus phyllocephalus* (camphor daisy), and *Helianthus angustifolius* (Swamp Sunflower) were located at slightly higher elevations just below the road shoulder and higher shell berms on the Copano Bay shoreline.

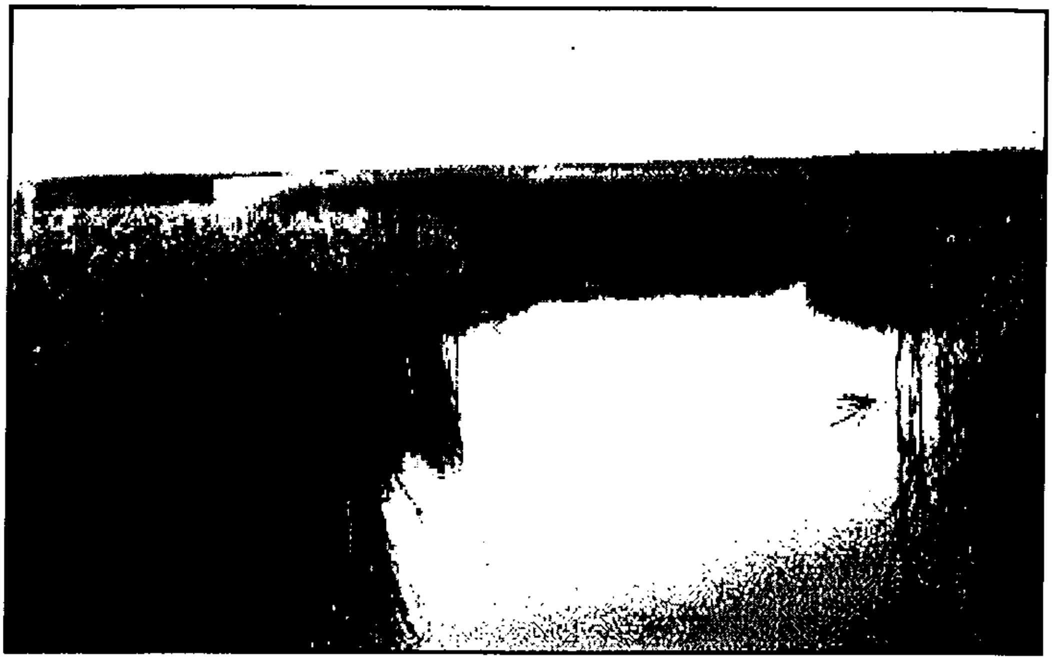


Figure 9. Low salt-marsh community of *Spartina alterniflora* and open water at Black Point wetland near Bayside along Copano Bay, Refugio County, Texas.

Mustang Island Back Bay Marsh (E2EM1P)

This Estuarine Intertidal Emergent Irregularly Flooded marsh is located along the bay shorelines of Mustang Island. Results of three transects (Figs. 10-12) completed for this area illustrated the variability of dominant vegetation within this wetland type (Table 9).

Predominant plant species in Transect 1 (closest to a washover pass) included *M. littoralis* and *B. maritima*. Both *S. bigelovii* and *S. virginica* occurred in locally abundant patches, although not present in large, contiguous areas (Fig. 13). Plant dominance on Transect 2, was located in a densely vegetated area and included high frequencies of occurrence of *M. littoralis* and low frequencies of *S. spartinae, L. carolinianum,* and *S. virginica*. By comparison, Transect 3, the northernmost transect, had low frequencies of *S. virginicus, M. littoralis,* and *B. maritima* and even lower occurrence of *B. frutescens, L. carolinianum, S. patens,* and *S. spartinae*.

Spartina spartinae, a perennial grass species that grows in dense clumps (Gould, 1978), can form extensive meadows along coastal salt flats, coastal brackish marshlands and other lowland areas. *Lycium carolinianum* a spiny, semi-evergreen shrub with upright to spreading stems that produce red fruits during winter. This species is common along coastal marshes or in salt flats (Jones, 1982).

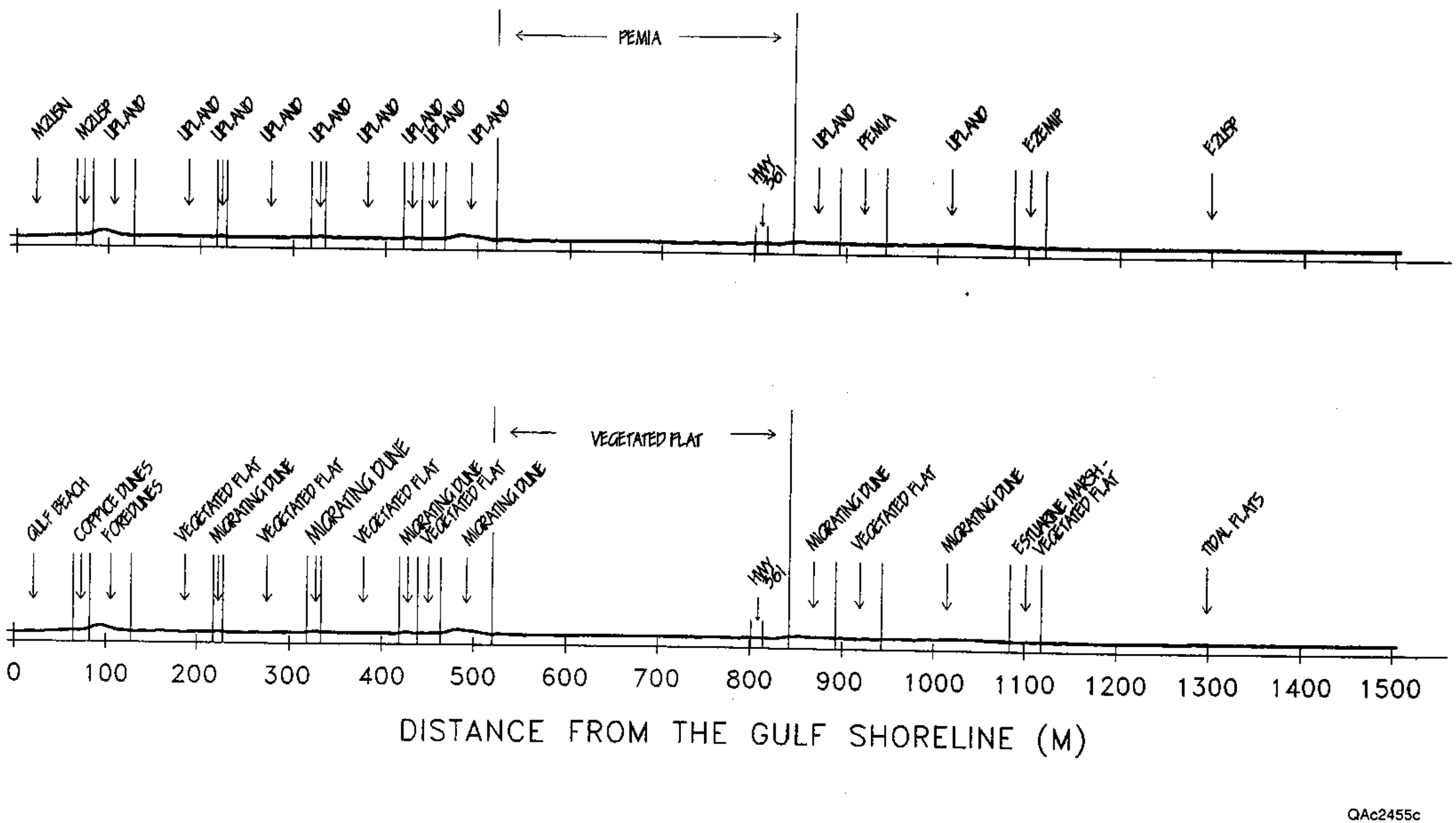


Figure 10. Elevation profile and wetland/upland communities along a cross-section of Mustang Island Transect 1, located north of Access Road 3.

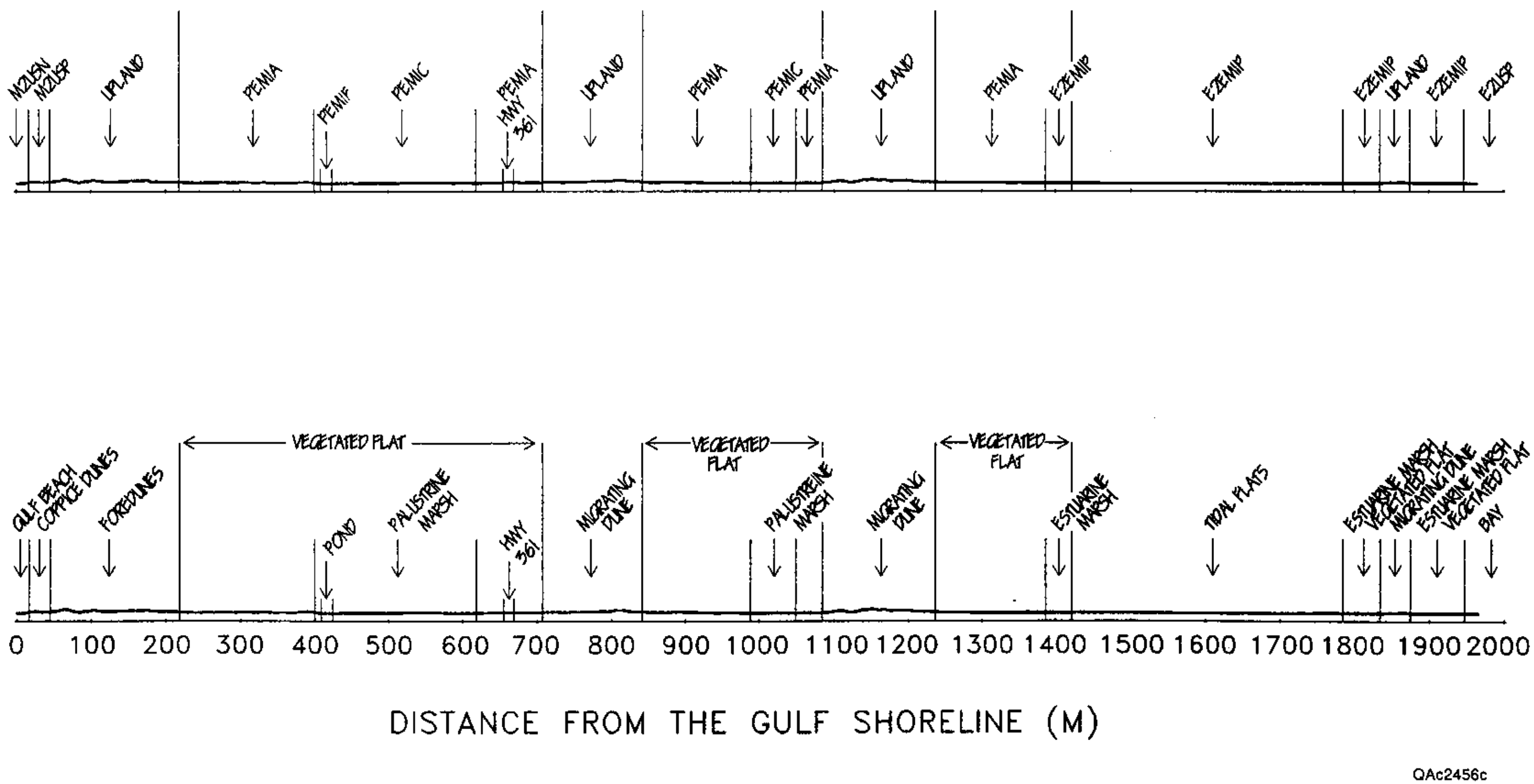


Figure 11. Elevation profile and wetland/upland communities along a cross-section of Mustang Island Transect 2, located one mile south of Mustang Island State Park headquarters.

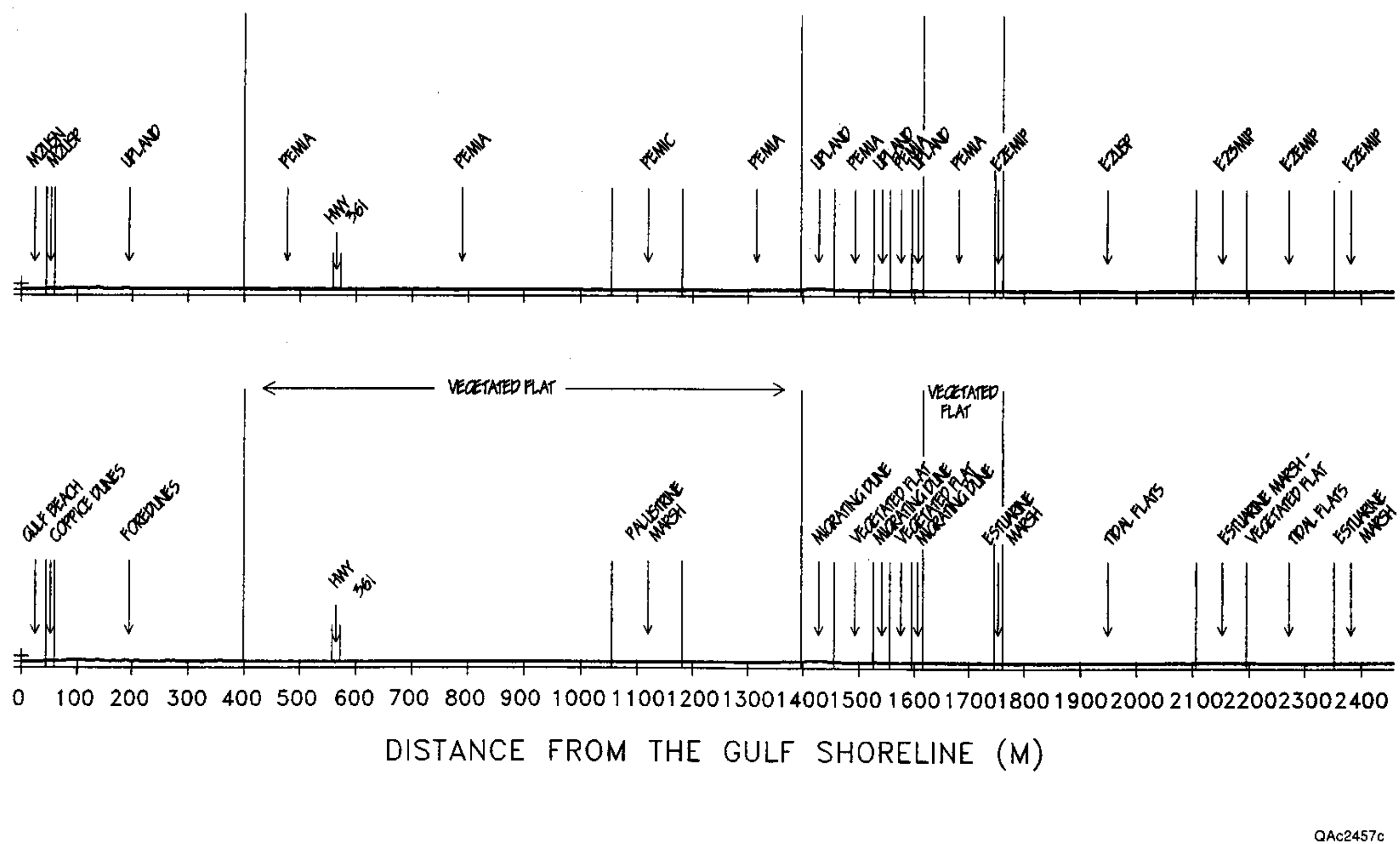


Figure 12. Elevation profile and wetland/upland communities along a cross-section of Mustang Island Transect 3, located north of Water Exchange Pass.

Table 9. Predominant plant species based on point-intercept sampling in Fall 1996 of the tidal flats zone on Mustang Island, Texas (modified from Jenkins et al. 1997).

Taxon	#Points	#Live Readings	#Dead Readings	% Frequency
Transect 1	78			
Batis maritima		15	0	19
Salicornia bigelovii		0	7	10
Monanthochloe littoralis		2	0	3
Transect 2	72			
M. littoralis		43	4	65
Spartina spartinae		2	0	3
Lycium carolinianum		4	1	7
Salicornia virginica		2	0	3
Transect 3	100			
Sporobolus virginicus		7	0	7
M. littoralis		8	2	10
B. maritima		17	0	17
Borrichia frutescens		3	0	3
L. carolinianum		2	0	2
Spartina patens		4	1	5
S. spartinae		3	1	4

Figure 13. High brackish marsh dominated by *Salicornia* spp. along the Corpus Christi Bay shoreline on Mustang Island.

A slightly different, more diverse plant assemblage occurred along the back shoreline of Mustang Island. This area was variably affected by extreme high storm tides that affected soil salinities and, thus, plant species dominance (Table 10). *Spartina patens* predominated in this high marsh, followed by *Fimbrystylis castanea, B. frutescens, Scirpus pungens, Paspalum monostachyum* (gulfdune paspalum), *Sporobolus virginicus,* and *Bluetaparon vermicularis* (silverhead).

Spartina patens is an erect or sometimes spreading perennial grass that can form monotypic stands, or it can be found in combination with other brackish marsh plants. This species is often documented in irregularly flooded brackish marshes, and tidal marshes, wet beaches, sand dunes and transitional borders of salt marshes. *Fimbrystylis castanea* was second in dominance on two of the transects and is a perennial sedge frequent in brackish or saline marshes, most often associated with barrier island flats (Jones, 1982). Generally, *F. castanea* and *S. pungens* are found in fresher soils than *B. frutescens*. *Paspalum monostachyum* is located within this area on slightly higher elevations, decreasing in frequency in lower swales. *Sporobolus virginicus* is a perennial grass species forming small clusters when well established. This species is most common on sandy soils in irregularly flooded estuarine marshes. *Bluetaparon vermicularis*, a perennial herb, expands by creeping stems and forms mats in moist, brackish or salty soils along beaches or in flats and marshes.

Table 10. Predominant plant species based on point-intercept sampling in Fall 1996 of the estuarine irregularly flooded, emergent marshes on Mustang Island, Texas (modified from Jenkins et al. 1997).

Taxon	#Points	#Live Readings	#Dead Readings	% Frequency
Transect 1	7			
Spartina patens		3	0	43
Borrichia frutescens		2	0	29
Scirpus pungens		0	0	0
Spartina spartinae		3	0	43
Transect 2	32			
S. patens		18	1	59
Fimbrystylis castanea		2	0	6
B. frutescens		4	0	13
Paspalum monostachyum		4	0	13
Sporobolus virginicus		6	0	19
S. pungens		3	0	9
Transect 3	21			
S. patens		12	2	67
F. castanea		1	2	14
Bluetaparon vermicularis		6	0	29
S. virginicus		5	0	24
B. frutescens		3	0	14

Predominant Emergent Vegetation in the Palustrine System

Mustang Island Fresh-Water Swales (PEM1A and PEMIC)

Vegetation communities located within vegetated flats on barrier islands respond to the amount of flooding they receive over several -year periods. Microtopography within this zone produces a series of undulating marshes locally affected by the moisture regime. Predominant species associated with areas temporarily flooded and seasonally flooded include *T. domingensis, S. pungens, Ipomoea sagittata* (saltmarsh morningglory), *Flaveria brownii* (longleaf flaveria), *Hydrocotyle bonariensis, B. frutescens,* and *Digitaria texana* (Texas crabgrass) (Table 11). Variability in frequency of occurrence was a result of the length of the transect that bisected palustrine marshes.

Table 11. Predominant plant species based on point-intercept sampling in Fall 1996 of palustrine, emergent, temporarily and seasonally flooded marshes on Mustang Island, Texas (modified from Jenkins et al. 1997).

Taxon	#Points	#Live Readings	#Dead Readings	% Frequency
Transect 2	56			
Typha domingensis		29	10	70
Scirpus pungens		15	1	29
Ipomoea sagittata		0	0	0
Flaveria brownii		9	0	16
Borrichia frutescens		7	0	13
Transect 3	25			
T. domingensis		10	3	52
S. pungens		7	0	28
Hydrocotyle bonariensis		0	0	0
Digitaria texana		13	0	52
F. brownii		6	0	12

Typha domingensis, a perennial species forms dense colonies in wet, fresh or brackish soils typical of ditches, swales, and marshes. This species has formed dense inpenetrable, monotypic stands within portions of the island interior (Fig. 14). *Scirpus pungens,* a perennial sedge forming colonies of triangular stems arising from hard and elongate rhizomes (Jones, 1982, Tiner, 1993). This species is frequent in low, fresh or brackish sands in depressions, swales and ditches.

Seasonally flooded and semipermanently flooded (PEMIF) marshes are also located within the island's interior. Those wetlands that hold water most years are typically unvegetated and surrounded by emergent vegetation at the shallow edges (Fig. 14). These wetlands have been continuously inundated (~1 m) since 1995.

Figure 14. Fresh-marsh and open-water community on Mustang Island exhibiting both seasonally flooded and semipermanently flooded wetlands.

Fennessey Flats (PEMIA, PEMIC, PEMIF)

This palustrine wetland is located within one of the meanders of the Mission River in Refugio County and has some areas which are temporarily flooded, seasonally flooded, and semipermanently flooded (Fig. 15). This area encompasses about 500 acres of various wetland types, and depressional topography results in plant zonation ranging from transitional areas of *Leucosyris spinosa* (Mexican devil-weed) (previously *Aster spinosus*) and *Buchloë dactyloides* (buffalograss) downsloping to *S. spartinae*, then into *B. frutescens* and *L. carolinianum*. Water levels during this survey were located slightly below the monotypic zone of *S. californicus*. This species continued into the semipermanently flooded marsh to a water depth of about 15 cm, although it is presumed the wetland is typically at lower levels. No emergent, floating vegetation, or submergent vegetation was located at the lower end of the transect (Fig. 16).

Rob and Bessie Welder Wildlife Foundation Oxbow Lakes (PEMIC, PEMIF)

Two oxbow lakes are situated adjacent to the Aransas River within Welder Wildlife Refuge San Patricio County. They are typically flooded during most years, but dry out during droughts (Drawe et al. 1978). The vegetation responds to the wet/dry cycles and is characterized by persistent emergent vegetation capable of withstanding variable water regimes. Big Lake is about 52 ha in size, 1260 m long and 874 m wide and is bisected by a broken dike at the widest point with a 325 m X 152 m sand island in the center. Pollita Lake is 345 m northwest of Big Lake and is about 32 ha, and measures 893 m long and 305 m wide. Maximum sustained depths are

Figure 15. Saturated and temporarily flooded fresh-marsh community at Fennessey Flats adjacent to the Mission River in Refugio County. Predominant vegetation in foreground is *Spartina spartinae* with *Scirpus californicus* in background before riparian woodlands.

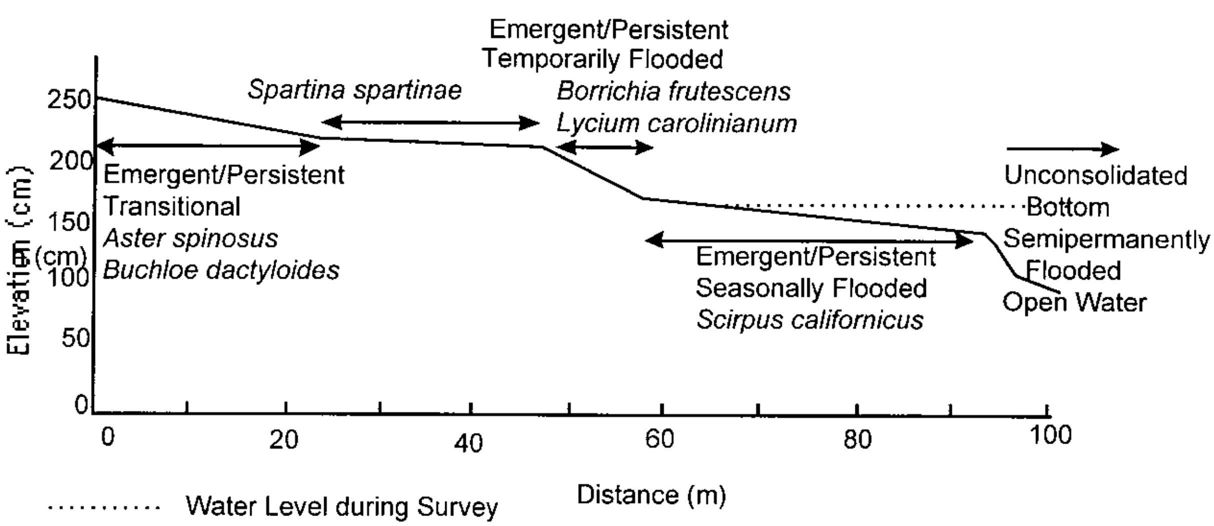


Figure 16. Profile of palustrine marsh in Fennessey Flats adjacent to Mission River, Refugio County showing elevations of plant communities in relation to degree of flooding.

typically 2 m, although these water levels are directly dependent upon direct precipitation and upland sheetflow runoff (Haigh, 1984). Water levels have been very high during this project and only visual observations could be undertaken. Many edge species characteristic of temporarily flooded marshes were barely emergent.

Predominant vegetation along lake margins is either dense stands of *T. domingensis* or *S. californicus* or open shoreline. Low swales associated with shallow shorelines included *S. drummondii*, *L. spinosa*, *Zizaniopsis miliacea* (Southern wildrice), *Echinodorus cordifolius* (burhead), and a few sedge species. Higher portions of the shoreline are dominated by *Paspalum* spp., *Panicum* spp., and *Leersia hexandra* (clubhead cutgrass). When water levels maintain deeper, open water areas, both lakes support dense stands of *Nelumbo lutea* (yellow lotus) and occasional patches of *Nymphea mexicana* (yellow water-lily) (Haigh, 1984). The islands in Big Lake have several tree species, *Acacia smallii* (Texas huisache), *Prosopis glandulosa* (mesquite), *Celtis pallida* (granjeno), *Celtis laevigata* (Texas sugarberry), and *Baccharis neglecta* (Roosevelt weed). Submergent and floating species documented during wet periods included *Ceratophyllum demersum* (coontail), *Zosterella dubia* (grassleaf mud-plantain) (previously *Heteranthera dubia*) and *Lemna minor* (duckweed) (Haigh, 1984). Other species documented during a wet year included *Ruppia maritima*, *Potamogeton pectinatus* (sago pondweed), and *Chara* spp. (muskgrass). During drought periods when even the deepest areas of the lakes are dry, vegetation is dominated by *Paspalum lividum* (longtom), *Neeragrostis reptans* (creeping lovegrass), and *Buchloe dactyloides* (Drawe et al. 1978).

IV. STATUS OF WETLANDS AND AQUATIC HABITATS (1992)

Based on unadjusted NWI data for 1992, wetland and aquatic habitats covered an area of about 193,357 ha (excluding the marine open-water class) within 29 7.5-minute quadrangles that define the study area (Figs. 2 and 17). This constitutes 44 percent of the map area. Of the five wetland systems mapped (Fig. 4; Table 12), the estuarine system encompasses about 161,069 ha and represents approximately 37 percent of the total map area (Fig. 18). The palustrine system is second at 6 percent (26,580 ha), followed by the lacustrine, marine (excluding marine open water), and riverine (Table 12). Upland areas (245,162 ha) represent the remaining 56 percent of the total mapped area.

Vegetated wetlands (E2EM, E2SS, PEM, PEM/U, PFO, and PSS areas; excluding AB areas) cover about 48,350 ha, or 25 percent of the wetland and aquatic habitat system (excluding the marine open water or M1UB class). The marsh system (E2EM, PEM and PEM/U) (Fig. 19) is approximately 46,980 ha in size, or about 97 percent of the total vegetated wetland area. Estuarine subtidal environments and intertidal flats constitute 71 percent (138,210 ha) of the total area of wetland and deep-water habitats (193,360 ha). The extent of all mapped wetlands, deep-water habitats, and uplands for each year are presented in the Appendix.

A. Estuarine System

Estuarine Intertidal Emergent Wetlands

The estuarine intertidal emergent wetland habitat (E2EM) (marsh) consists of about 22,760 ha of salt and brackish marshes (Figs. 17 and 18; Table 12), which make up almost 47 percent of vegetated wetland habitats (emergent, scrub-shrub, and forested wetlands), and 49 percent of marsh habitats (emergent wetlands) in the Corpus Christi-Aransas Bay system.

The most extensive estuarine emergent wetlands occur (1) on the bayward side of barrier islands including Harbor Island, (2) in fluvial-deltaic areas of the Nueces, Mission and Aransas Rivers, and (3) along bayward shores of Blackjack Peninsula (Fig. 17). Four 7.5 minute quadrangles (St. Charles Bay, St. Charles Bay SE, St. Charles Bay SW, and Mesquite Bay) located in the northeast corner of the map area (Fig. 2) have an area of E2EM (salt marsh) that makes up 40 percent of all E2EM in the CCBNEP study area. The two most extensive occurrences of salt marsh occur on the broad washover fan complex on San Josė Island and on the Nueces River fluvial-deltaic system (Figs. 1 and 17).

Estuarine Intertidal Unconsolidated Shores and Aquatic Beds

Estuarine intertidal unconsolidated shores and intertidal aquatic beds (E2US, E2AB) include wind-tidal flats (designated as E2FL on 1950's and 1979 maps), beaches, and algal flats. Approximately 8,900 ha of E2US and E2AB were mapped in the CCBNEP area (Table 12). Because of the low astronomical tidal range, many flats are flooded only by wind-driven tides and are, thus, designated as wind-tidal flats (Brown et al. 1976). These tidal habitats represent about 14 percent of the wetland system (excluding subtidal habitats, the E1 and M1 map units). The mapped extent of the tidal flats can be substantially affected by tidal levels at the time aerial photographs were taken. Accordingly, absolute areal extent of flats may vary considerably from that determined from aerial photographs.

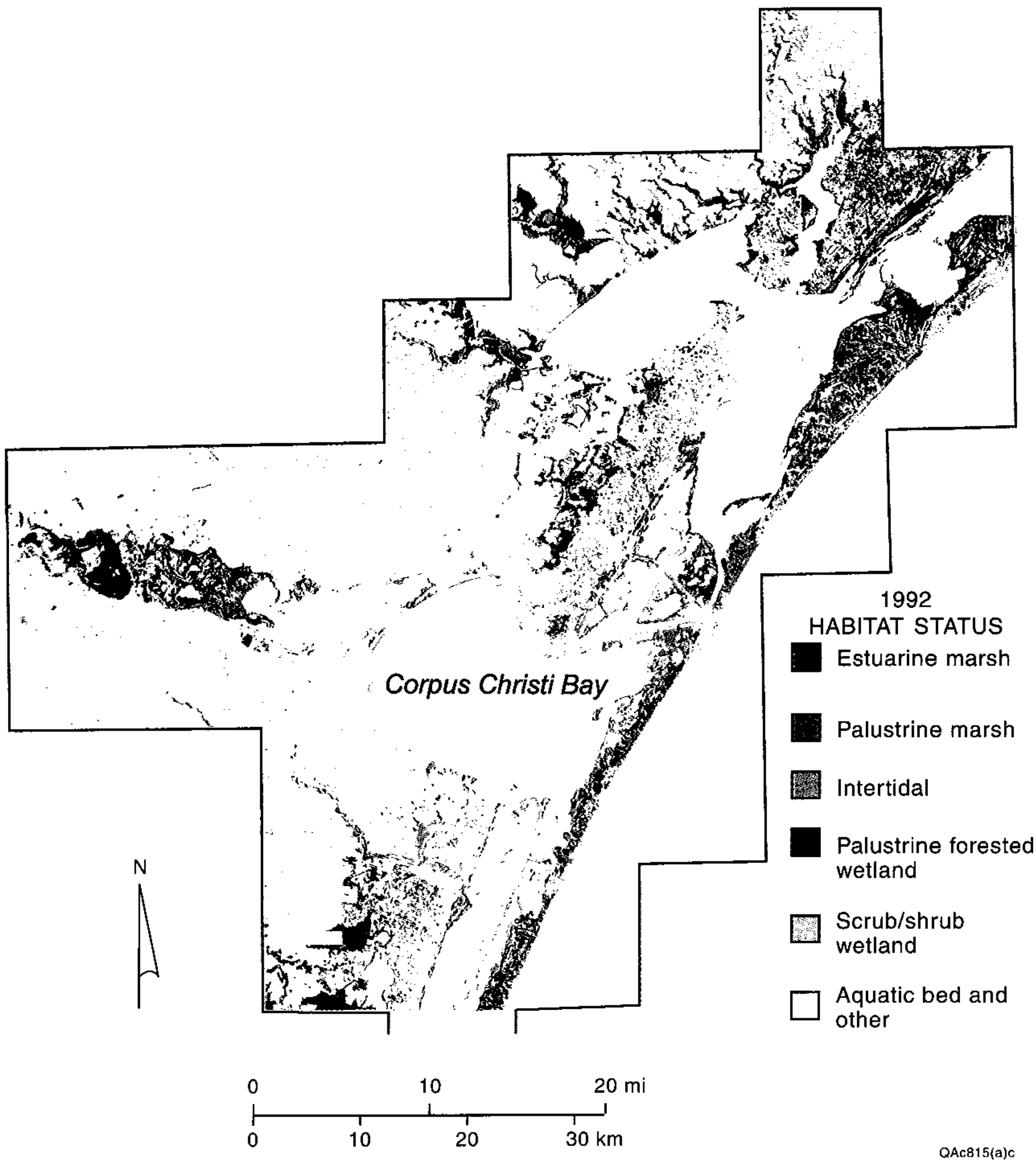


Figure 17. Distribution (1992) of wetland and aquatic habitats in the CCBNEP study area.

Table 12. Areal extent of mapped wetland and upland habitats in 1992. Based on compilation of habitat totals from NWI unadjusted digital data.

NWI CODE	National Wetlands Inventory Description	Hectares	Acres	Percent
E2EM	Estuarine Intertidal Emergent Vegetation	22,758	56,235	
E2SS	Estuarine Intertidal Scrub/Shrub Wetland	98	242	
E2FO	Estuarine Intertidal Forested Wetland	2	5	
E1AB	Estuarine Subtidal Aquatic Bed	18,727	46,274	
E1RF	Estuarine Subtidal Reef	31	77	
E2AB	Estuarine Intertidal Aquatic Bed	161	398	
E1UB	Estuarine Subtidal Unconsolidated Bottom	110,552	273,174	
E2US	Estuarine Intertidal Unconsolidated Shore	8,740	21,597	
	Total Estuarine System	161,069	398,001	37
PEM	Palustine Emergent Vegetation	23,292	57,555	
PEM/U	Palustrine Emergent Vegetation/Upland	537	1,327	
U/PEM	Upland/Palustrine Emergent Vegetation	392	969	
PSS	Palustrine Scrub/Shrub Wetland	527	1,302	
PFO	Palustrine Forested Wetland	743	1,836	
PAB	Palustrine Aquatic Bed	31	77	
PUB	Palustrine Unconsolidated Bottom	795	1,964	
PUS	Palustrine Unconsolidated Shore	263	650	
	Total Palustrine System	26,580	65,679	6
L1AB	Lacustrine Limnetic Aquatic Bed	22	54	
L2AB	Lacustrine Littoral Aquatic Bed	1,794	4,433	
L1UB	Lacustrine Limnetic Unconsolidated Bottom	1,557	3,847	
L2UB	Lacustrine Littoral Unconsolidated Bottom	8	20	
L2US	Lacustrine Limnetic Unconsolidated Shore	1,359	3,358	
	Total Lacustrine System	4,740	11,713	1
R1UB	Riverine Tidal Unconsolidated Bottom	4	10	
R2UB	Riverine Lower Perennial Unconsolidated Bottom	235	581	
R4SB	Riverine Intermittently Flooded Streambed	17	42	
	Total Riverine System	256	633	0.1
M2US	Marine Intertidal Unconsolidated Shore	716	1,769	0.2
U	Uplands	245,162	605,795	56
Total (Excluding Marine Unconsolidated Bottom-M1UB)		438,523	1,083,590	100

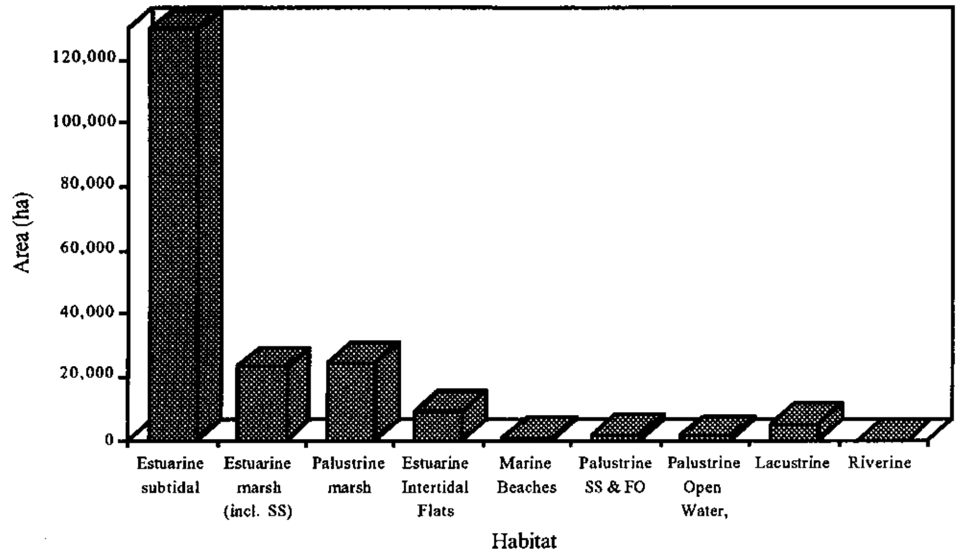


Figure 18. Graph showing areal extent of selected habitat classes and systems in the CCBNEP study area.

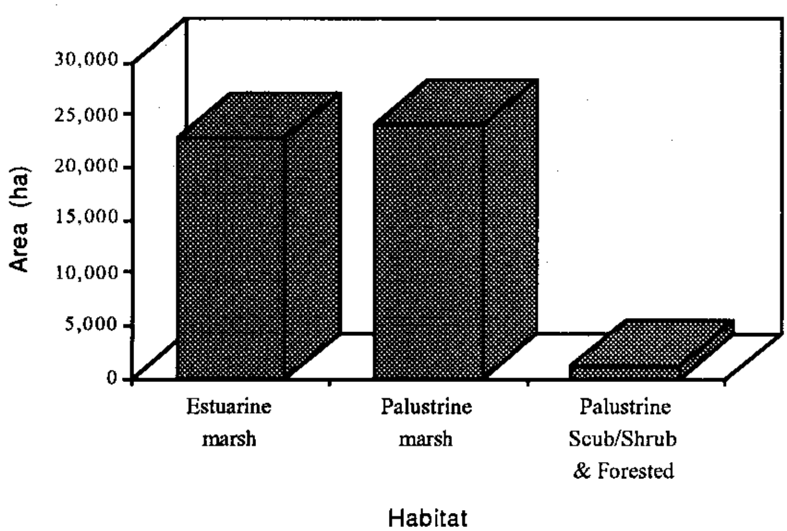


Figure 19. Graph showing areal extent of marshes and scrub/shrub–forested areas in the CCBNEP area.

Estuarine Intertidal Scrub/Shrub and Forested

The total area of mapped estuarine scrub-shrub wetlands (E2SS) in 1992 is approximately 100 ha. About 2 ha of estuarine forested habitat was mapped. Estuarine scrub-shrub habitat has broadest distribution on Harbor Island, where *Avicennia germinans* is abundant.

Estuarine Subtidal Aquatic Beds

Estuarine subtidal rooted vascular aquatic beds (E1AB3L) represent areas of submerged vascular vegetation, or seagrasses. Although this class was mapped as part of the NWI program using high-altitude aerial photographs, results are not presented here because of a more up-to-date and comprehensive analysis of seagrass beds by Pulich et al. (1997).

Estuarine Subtidal Unconsolidated Bottom

Estuarine subtidal unconsolidated bottom (open-water) habitat (E1UBL or E1OWL on 1950's and 1979 maps) is the heart of the estuarine system and consists principally of Corpus Christi, Nueces, Copano, and Aransas Bays, the northern tip of upper Laguna Madre, and associated smaller satellite bays and tidal lakes (Fig. 1). This habitat covers about 110,550 ha (Table 12). If other subtidal classes, such as subtidal aquatic beds and oyster reefs, are included with this class, the total area of subtidal estuarine habitats is 129,310 ha, about 67 percent of the wetland and deep-water habitat system (excluding M1UBL).

B. Palustrine System

Palustrine Emergent Wetlands

Palustrine emergent wetlands (PEM), or inland "freshwater marshes", cover approximately 24,220 ha (Figs. 18 and 19), and represent about 50 percent of the vegetated wetland system, and 51 percent of the marsh (emergent wetland) system. The broadest distribution of palustrine emergent wetlands is on the Pleistocene Barrier-Strandplain system (Blackjack Peninsula, Live Oak Peninsula/Ridge, and Encinal Peninsula), in inland areas of the Nueces River valley, and on Mustang and North Padre Islands (Figs. 1 and 17). In some areas, NWI maps include habitats designated as PEM/U (537 ha) and U/PEM (392 ha), which include palustrine emergent wetlands and uplands undifferentiated. This unit was mapped on the Pleistocene Barrier-Strandplain sands (Fig. 3) where complex, hummocky topography includes relict beach ridges and intervening swales, and eolian features characterized by blowouts, or deflation areas, and stabilized dunes. Within these areas is a complex network of wetlands juxtaposed with uplands that could not be adequately separated at the mapping scale of 1:24,000.

Palustrine Scrub-Shrub Wetlands

Palustrine scrub-shrub wetlands (PSS) total 527 ha (1 percent of vegetated wetlands). Most areas of scrub-shrub occur along rivers, bayous, and creeks, on the margins of reservoirs, and in relatively small depressions. The largest occurrence is in the Nueces River valley in the Edroy and Odem quadrangles.

Palustrine Forested Wetlands

The total area of forested wetland habitat (PFO) amounts to 743 ha, or about 1.5 percent of the vegetated wetland system . Forested wetlands are most extensive in the Nueces River valley in the Edroy quadrangle, where they make up more than 80 percent of the total PFO class in the CCBNEP study area.

V. HISTORICAL TRENDS IN WETLAND HABITATS

A. Methods Used to Analyze Trends

Trends in wetland habitats were determined by analyzing habitat distribution as mapped on 1950's (Fig. 20), 1979 (Fig. 21), and 1992 (Fig. 17) aerial photographs. In analyzing trends, emphasis was placed on wetland classes (for example, E2EM and PEM), with less emphasis on water regimes and special modifiers. This approach was taken because habitats were mapped only down to class level on 1950's photographs and because water regimes can be influenced by local and short-term events such as tidal cycles.

GIS

GIS-ARC/INFO and ARCVIEW were used to analyze trends. This software allowed for direct comparison between years, generally on a quadrangle by quadrangle basis, but also by major natural system or geographic areas such as the barrier islands, Pleistocene barrier-strandplain, and fluvial-deltaic systems of major rivers. Analyses included tabulation of losses and gains in wetland classes for each area for selected periods. In addition, full-color maps showing basic wetland classes as mapped on 1950's, 1979, and 1992 photographs were prepared to assist in analysis. Supplementary to these maps were full-scale (1:24,000) colored maps showing vegetated-wetland losses and gains for the 1950's-1979 and 1979-1992 periods for each of the quads (Fig. 2). These maps allowed relatively clear visual comparisons of changes to be made on a light table by overlaying them with the prints of the 1950's, 1979, and 1992 map series. The GIS allowed cross classification of habitats in a given area as a means of determining changes and probable cause of such changes. Maps used in this report showing wetland distribution and changes were prepared from digital data using ARC/INFO.

Possible Photointerpretation Errors

As mentioned previously, existing maps prepared from photointerpretation as part of the USFWS-NWI program and associated special projects were used to determine trends. Among the shortcomings of the photointerpretation process were that different photointerpreters were involved for different time periods, and for the 1950's and 1979 series, wetlands were interpreted on each set of photographs without reference to photographs taken during preceding or following years. This procedure, in part unavoidable, prevented photointerpreters from selecting the most consistent wetland boundaries, especially along wetland-upland breaks, for different periods. As a result, many changes in the distribution of wetlands from one period to the next are not real but are relicts of the interpretation process.

The most striking example occurred in the Nueces River valley, where certain areas of high palustrine marsh were mapped in the 1950's and 1992, but not in 1979. Adjustments had to be made to account for differences in photointerpretation. Inconsistencies in interpretation seem to have occurred most frequently in high marsh to transitional areas where uplands and wetlands intergrade.

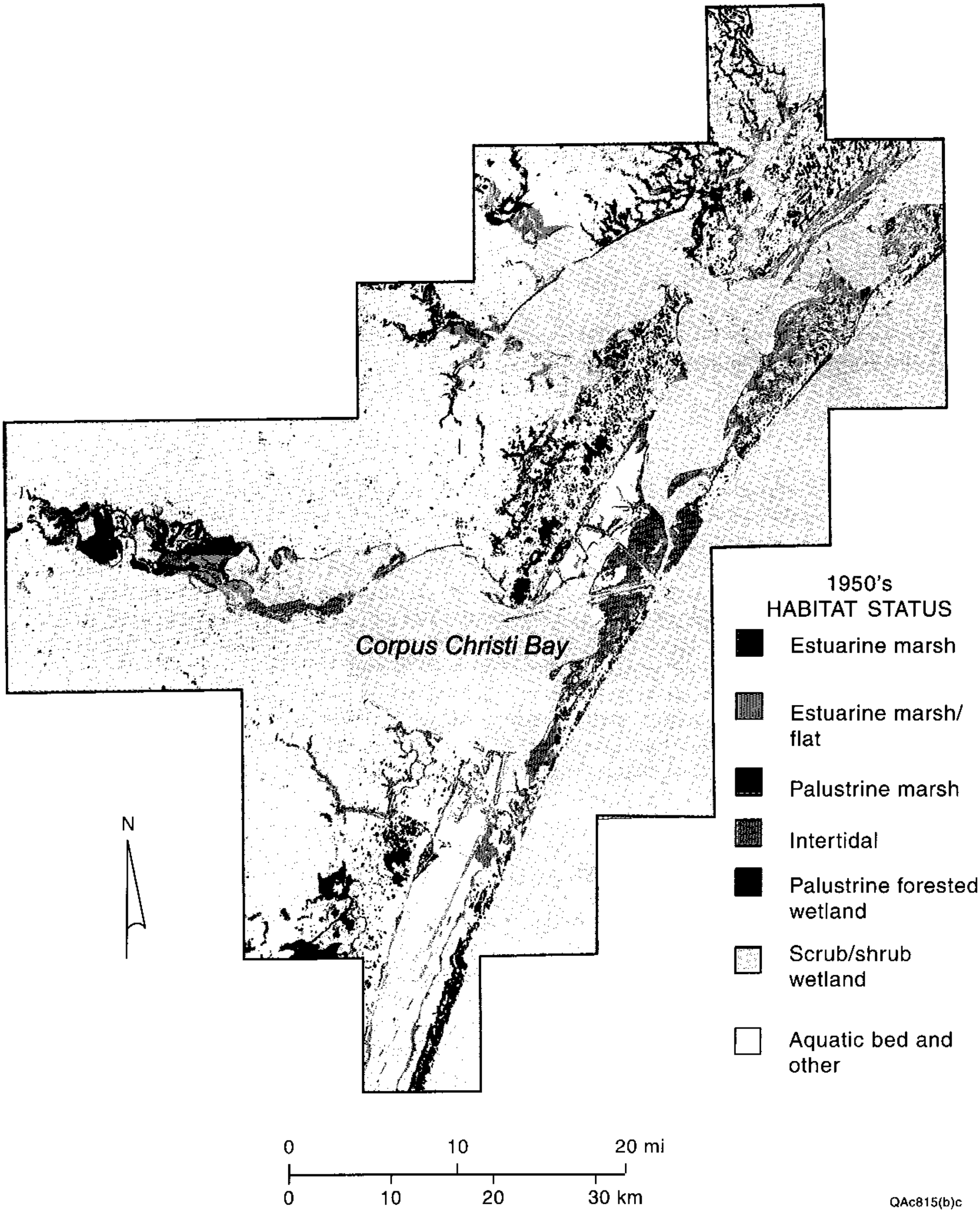


Figure 20. Distribution (1950's) of wetland and aquatic habitats in the CCBNEP study area.

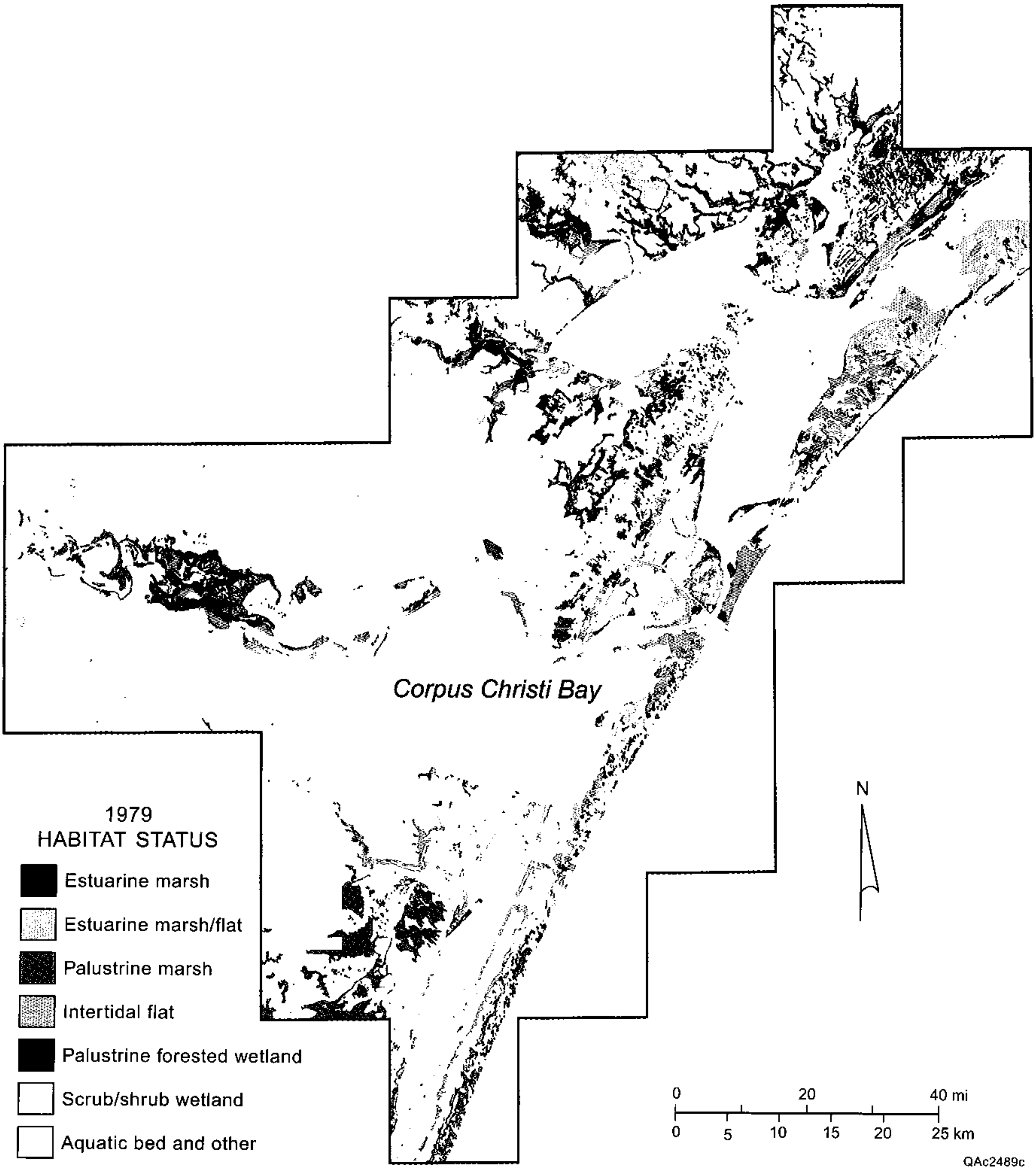


Figure 21. Distribution (1979) of wetland and aquatic habitats in the CCBNEP study area.

Some apparent wetland changes were due to different scales of aerial photographs. The 1950's aerial photographs were at a larger scale (1:24,000) than those taken in 1979 and 1992 (1:65,000), which affected the minimum mapping unit delineated on photographs. Accordingly, more small wetlands were mapped on earlier, larger-scale photographs, accounting for some wetlands losses between earlier and later periods.

In general, wetland changes that seem to have been influenced most by photointerpretation problems are interior (palustrine), temporarily flooded wetlands bordering on being transitional areas. Large apparent gains in palustrine wetlands were documented on barrier islands. We believe that the trend of net gain is real but that it is exaggerated by "undermapping" these areas in the 1950's and 1979 and "overmapping" them in 1992. As explained in a later section on wetland trends, adjustments were made on barrier island marshes to offset changes due to photointerpretation.

In the analysis of trends, wetland areas for different time periods are compared without attempting to factor out all misinterpretations and photo-to-map transfer errors except for major, obvious problems. However, maps and aerial photographs representing each period were visually compared for the 30 quads as part of the trend-analysis process and as part of the effort to identify potential problems in interpretation. Numerous comments in the text with respect to apparent changes are based on these comparisons, as well as on knowledge of the investigators of wetland distribution in the study area. Still, users of the data should keep in mind that there is a margin of error inherent in photointerpretation and map preparation.

In analyzing trends in the southern portion of the map area (including Nueces River, Coastal Prairie, Corpus Christi Bay, Laguna Larga, Encinal Peninsula, and North Padre Island, Fig. 22), a different method was used. Wetland changes in these areas were analyzed using GIS analyses to examine differences between 1950's, 1979, and 1992 map data. For each polygonal map, NWI category classes were re-coded to one of 16 look-up (LU) values and rasterized (converted to a 15 m grid layer) based on corresponding numeric values.

A "raster change" data layer was created and coded based on "change type." The "raster change" layer was subsequently overlaid on each of the three time period layers to create a thematic change map (or gain-loss map). Change maps were created for 1950's-1979, 1979-1992, and 1950's-1992. The advantage of this technique was that only raster cells which were classed as potential change were used to create change maps. Understanding the types of change and the spatial associations of change, greatly facilitated the process of determining actual changes.

Once change maps were developed for each time period, change areas identified by thematic raster polygons were analyzed based on change type, spatial attributes (size, shape and juxtaposition), checked visually against period photos, and, in some cases, on the ground. Raster polygons not representing actual change were deleted from the time-periods change map. Correction of change maps were done on a quad by quad basis and combined into a master 1950's, 1979 and 1992 change map.

Change matrixes for the lower study area were developed by combining master change maps, NWI map data, and system maps. Change matrixes are tables tabulating each category in an NWI map with an associated category in another NWI map (i.e., a table showing to-from values for each LU value in a 1979 to 1992 overlay). Change matrices are extremely useful in determining change dynamics of individual classes. Change matrices were used to further refine what was believed to be actual change. Three change matrices (1950's-1979, 1979-1992, and 1950's –1992) for each system were produced for the lower study area. Analyzing each change matrix resulted in calculation of the "final adjusted change estimate."

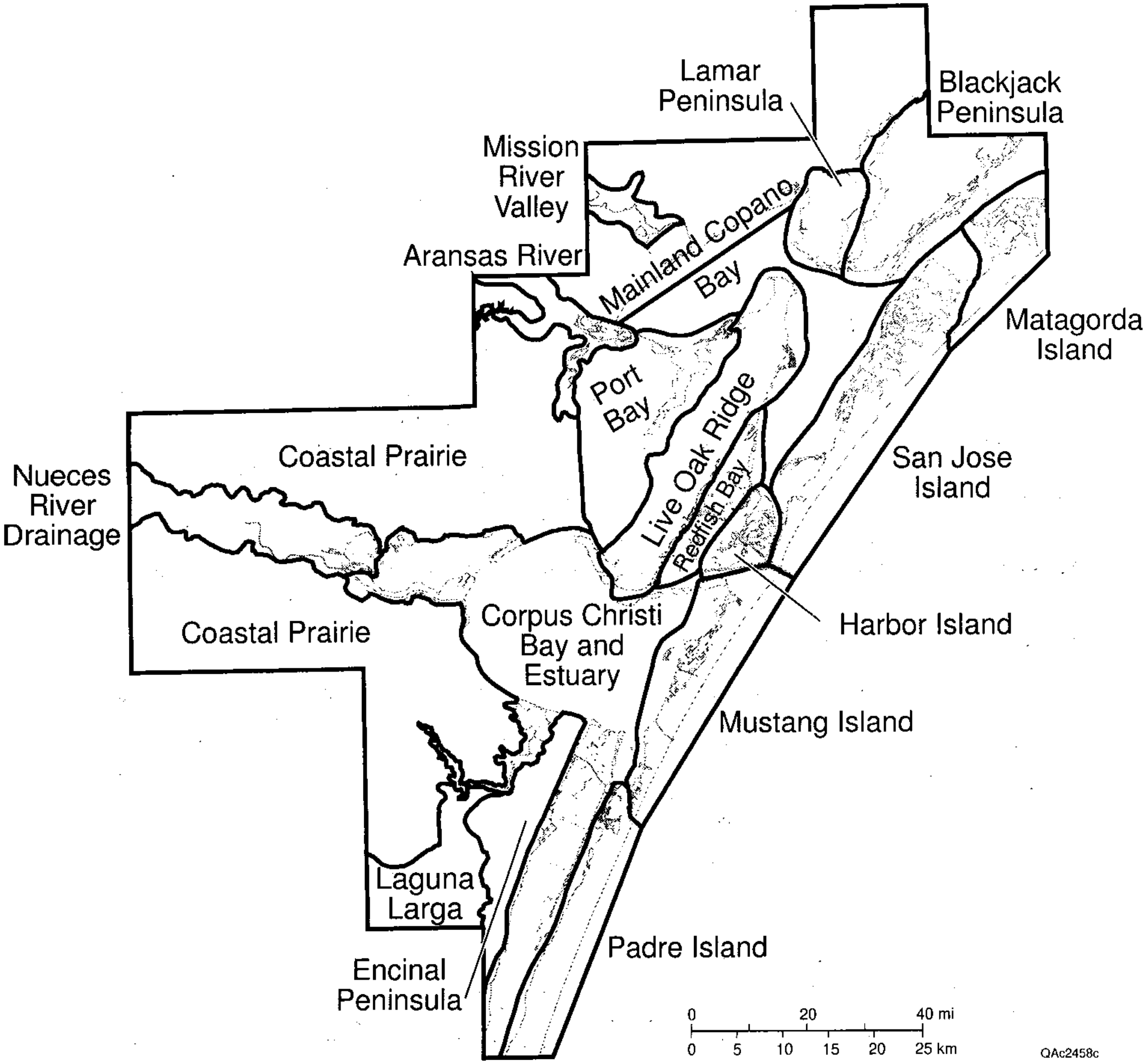


Figure 22. Major natural systems and geographic components analyzed to define wetland trends.

The final adjusted change estimates represented the best professional judgement of the investigators, and required considerable adjustment due to cartographic and photointerpretation errors, and inconsistent classification categories. In general, the 1992 NWI maps are the most accurate when allowance for overdelineation of the PEM1A (temporarily flooded fresh marsh) category is made. Use of change matrices allowed examination of change dynamics. In the southern part of the map area, final estimates of change were based on 1950's-1992 comparisons, with 1979 change derived from the other two periods.

Wetland Codes

As mentioned in the introduction (Fig. 6), some wetland codes used on 1992 maps are different from those used on the 1950's and 1979 maps. In the following discussion of trends, E2FL (instead of E2US used on 1992 maps) is generally used to denote tidal flats, and OW (rather than UB) is used to represent open water.

B. Analysis of Trends by Major Natural Systems

The CCBNEP study area was subdivided into major natural systems and geographic components for analysis of historical trends (Figs. 3 and 22). In general, systems are composed of genetically related environments, sedimentary substrates, and wetland types. This subdivision allowed a more site-specific analysis of trends and their probable causes. Natural systems include barrier islands, Pleistocene barrier-strandplain, major fluvial-deltaic areas, and selected bay and associated mainland areas (Figs. 3 and 22). Emphasis was placed on estuarine and palustrine marshes and tidal flats. In major fluvial-deltaic areas (Nueces River, Aransas-Chiltipin, and Mission), trends in riparian woodlands and forested and scrub-shrub wetlands were examined.

Modern/Holocene Barrier Island System

Modern/Holocene barrier islands include Mustang, San José, and Matagorda Islands, the flood-tidal delta Harbor Island, and North Padre Island (Figs. 3 and 22). Changes in marshes and tidal flats from the 1950's to 1992 varied on modern barrier islands and Harbor Island. The most extensive changes occurred in tidal flats, which decreased significantly in total area on all islands except Matagorda. Loss in tidal flats is a trend occurring throughout the CCBNEP area and can be related to an accelerated rise in relative sea level.

Although there have been real gains in PEM on barrier islands, we found that complex topography on the islands consisting of stabilized dunes and mounds and inter-dune depressions, created a mixture of wetlands and uplands that could not be easily separated on aerial photographs. Ninety percent of palustrine emergent wetlands mapped on 1992 photographs on Mustang Island were composed of PEM1A, which is a high, temporarily flooded interior or fresh marsh. After examining many areas of wetlands mapped on Mustang and North Padre Islands, we concluded that the class PEM1A was too liberally delineated including upland areas on 1992 maps. In addition, this wetland class was too conservatively mapped on the 1979 and 1950's maps by omitting some high marsh areas that should have been included. Based on many field observations on barrier islands, we estimated that this class on 1992 maps consisted, on average, of about 40 percent wetlands and 60 percent uplands. Accordingly, we applied a 60 percent correction to the PEM1A areas on barrier islands. Reducing the area of 1992 PEM1A habitats by 60 percent provided a more realistic assessment of the actual increase in palustrine emergent wetlands on barrier islands from 1979 to 1992.

Mustang Island

Marshes. *1950's-1979.* The total area of estuarine and palustrine emergent wetlands (marshes) expanded from the 1950's to 1979 on Mustang Island (Table 13). Estuarine marshes increased in area by 70 ha, and undifferentiated mixtures of estuarine emergent wetlands and flats (E2EM/FL) increased by 380 ha. Most gains occurred on the southern half of Mustang Island as broad tidal flats became more extensively vegetated. Among the notable increases in salt/brackish marsh on the northern end of the island was at the Port Aransas sewage treatment plant where emergent vegetation increased on flats (Fig. 23). The gain in E2EM/FL at the expense of E2FL in this and the surrounding area encompasses approximately 140 ha, but review of aerial photographs indicates less than half of the area had emergent vegetation. Accordingly, the actual increase in area of emergent vegetation on flats at the sewage treatment site is closer to 70 ha. Applying this adjustment reduces the total increase in E2EM/FL on Mustang Island to 310 ha (Table 13). This adjustment increased the E2FL class by 70 ha.

Net gain in fresh or nontidal marsh (PEM) was 85 ha, as gross losses of about 145 ha were offset by gains of 230 ha. Increases occurred mostly in central parts of the vegetated barrier flat primarily south of Wilson's Cut in the Crane Island NW quadrangle. Losses occurred near Port Aransas, some possibly in part due to development on the southern edge of the city; in the absence of 1979 photographs losses were partly verified using 1982 photographs.

1979 to 1992. Marshes continued to expand from 1979 to 1992 on Mustang Island (Table 14). Net gain in estuarine marshes (E2EM + E2EM/FL) was about 470 ha, some of which occurred in the outfall of the sewage treatment plant at Port Aransas. Confirmation of the spread of emergent vegetation on wind-tidal flats was provided by aerial photographic analysis (Fig. 23). The 1979 E2EM/FL class was adjusted as explained previously. Unadjusted gains in PEM show an increase of almost 1,500 ha from 1979 to 1992. Adjustments of the PEM1A class, as mentioned in the introduction to this section on barrier islands, still yields an increase in PEM of about 420 ha on Mustang Island (Table 14).

Table 13. Net change in marshes and intertidal flats from 1950's-1979, Mustang Island.

Habitat	1950's (ha)	1979 (ha)	1979 Adjusted	Adjusted Net Change
E2EM	181	251	251	70
E2EM/FL	169	549	479	310
PEM	183	268	268	85
Total EM	**533**	**1068**	**998**	**465**
E2FL	3708	1278	1348	-2360

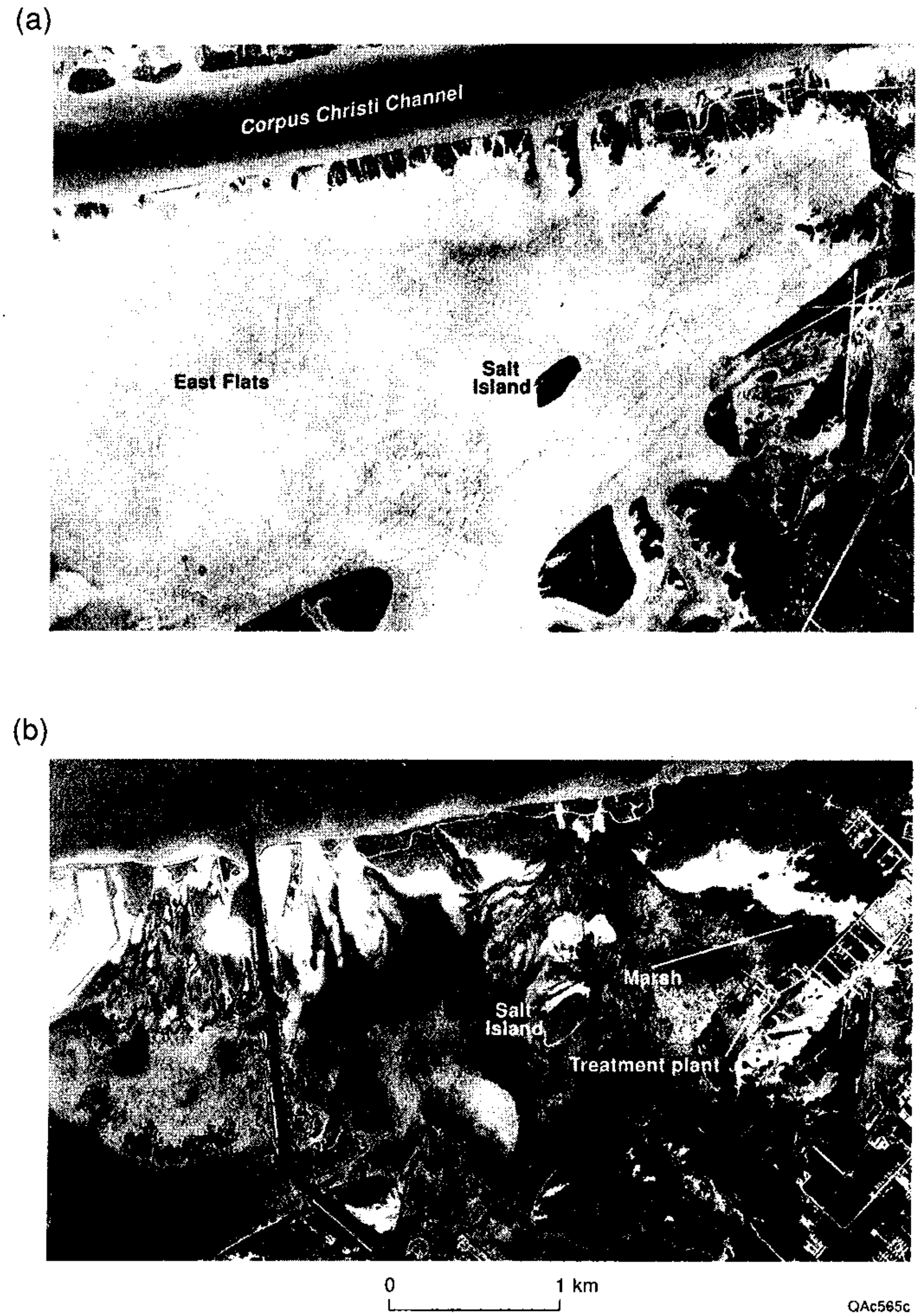


Figure 23. Development of a brackish marsh on a wind-tidal flat at the discharge site of a sewage treatment plant at Port Aransas. Aerial photographs were taken in (a)1958 and (b)1994.

Table 14. Net change in marshes and intertidal flats from 1979-1992, Mustang Island.

Habitat	1979 (ha)	1992 (ha)	1979 Adjusted	1992 Adjusted	Adjusted Net Change
E2EM	251	1203	251	1203	952
E2EM/FL	549	0	479	0	-479
PEM	268	1728	268	691	423
Total EM	**1068**	**2931**	**998**	**1894**	**896**
E2FL	1278	1343	1348	1343	-5

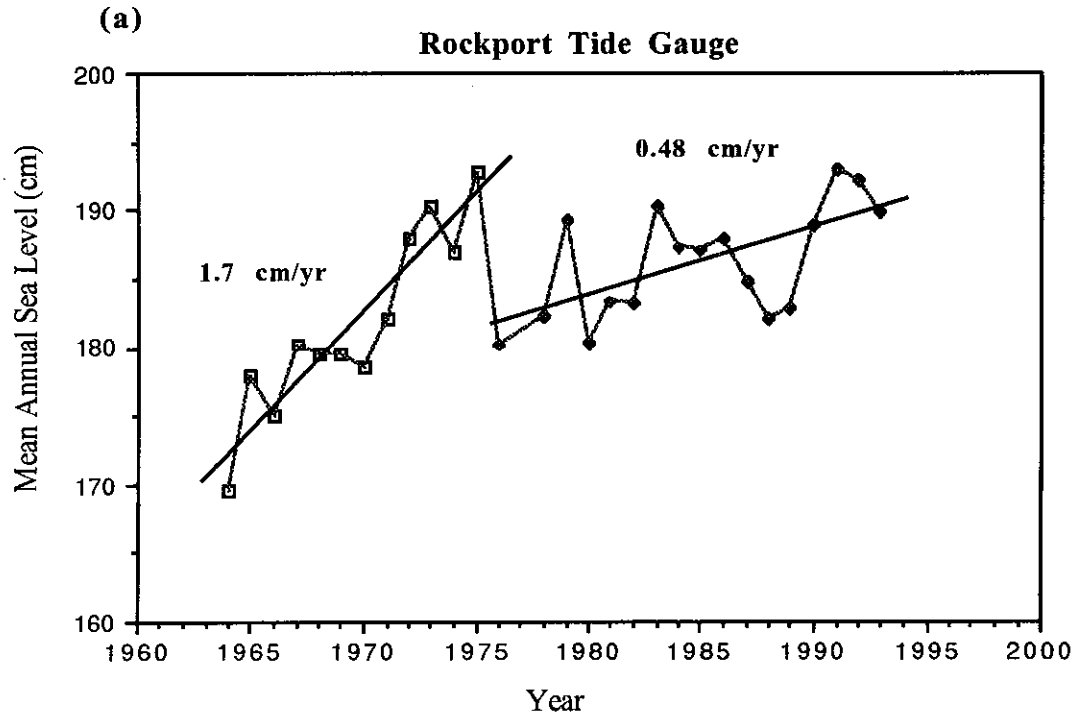
Estuarine intertidal flats (E2FL, E2US). *1950's-1979.* From the mid-1950's to 1979, tidal flats underwent the most extensive changes (net loss) of any habitat on Mustang Island. There was a net loss of almost 2,400 ha. More than 55 percent of gross losses were due to permanent inundation and conversion of the intertidal flats to subtidal aquatic beds and open water. Approximately 23 percent of the loss was to upland rangeland or grassland, and 21 percent was to emergent vegetation (E2EM) and emergent vegetation/intertidal flats (E2EM/FL).

1979-1992. From 1979 to 1992, tidal flats were more stable in terms of net change. There were gains and losses resulting in a negligible net loss of less than 10 ha (Table 14). Of the gross losses more than 50 percent were converted to E2EM from an expansion of emergent vegetation, primarily *S.alterniflora*, over regularly flooded flats.

Probable Causes of Changes. *1950's-1979-1992.* From the 1950's to 1979, marshes increased in area on Mustang Island by approximately 465 ha. Most of the increase occurred in estuarine emergent wetlands. Salt marshes probably expanded on wind-tidal flats because flats became more frequently flooded from a relative rise in sea level (Fig. 24). Growth of emergent vegetation across flats was confirmed by comparing aerial photographs taken in the 1950's and 1979. Increases in estuarine (brackish) marsh near the sewage treatment plant was likely the result of treated water discharges and more frequent flooding of flats, creating favorable conditions for the growth and spread of emergent vegetation (Fig. 23). Increases in palustrine emergent wetlands on Mustang Island were less extensive and were due in part to wetter conditions in 1979 compared to the mid-1950's. Near Port Aransas, losses in PEM, part of which are interpretational, were less than 10 ha and appear to be due primarily to commercial property development.

Estuarine marshes on Mustang Island continued to expand from 1979 to 1992, although the rate of relative sea-level rise during this period was much slower (Fig. 24). Upper margins of tidal flats appear to have become more frequently flooded, thereby promoting the growth and spread of emergent vegetation (Fig. 25).

Palustrine emergent wetlands in mid-island areas expanded dramatically from 1979 to 1992. Whereas some of the gains in PEM were the result of photo-interpretative changes in classes such as E2EM to PEM, much of the gain was due to expansion of PEM into former upland areas. Although this increase in PEM may in many areas reflect differences in interpretation of historical and recent aerial photographs, there is evidence that island soils have become wetter since the 1950's and 1960's due to both higher levels of precipitation and rising sea level.



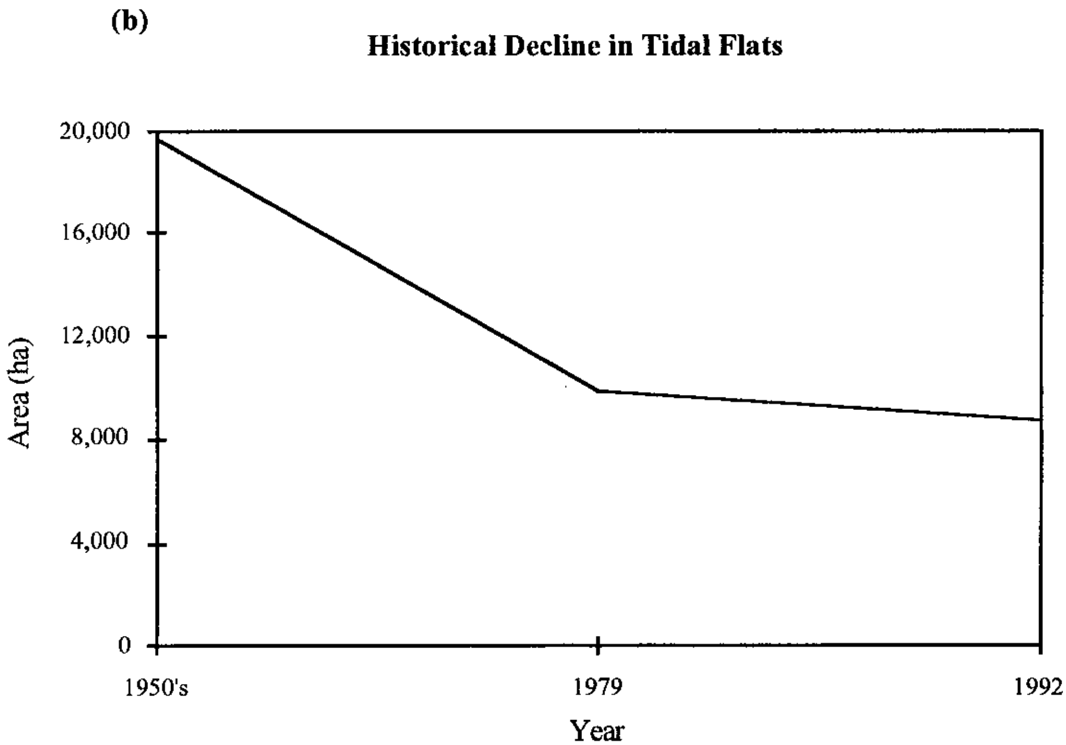


Figure 24. Relationship between (a) rate of relative sea level rise and (b) decline in area of estuarine intertidal flats in the study area.

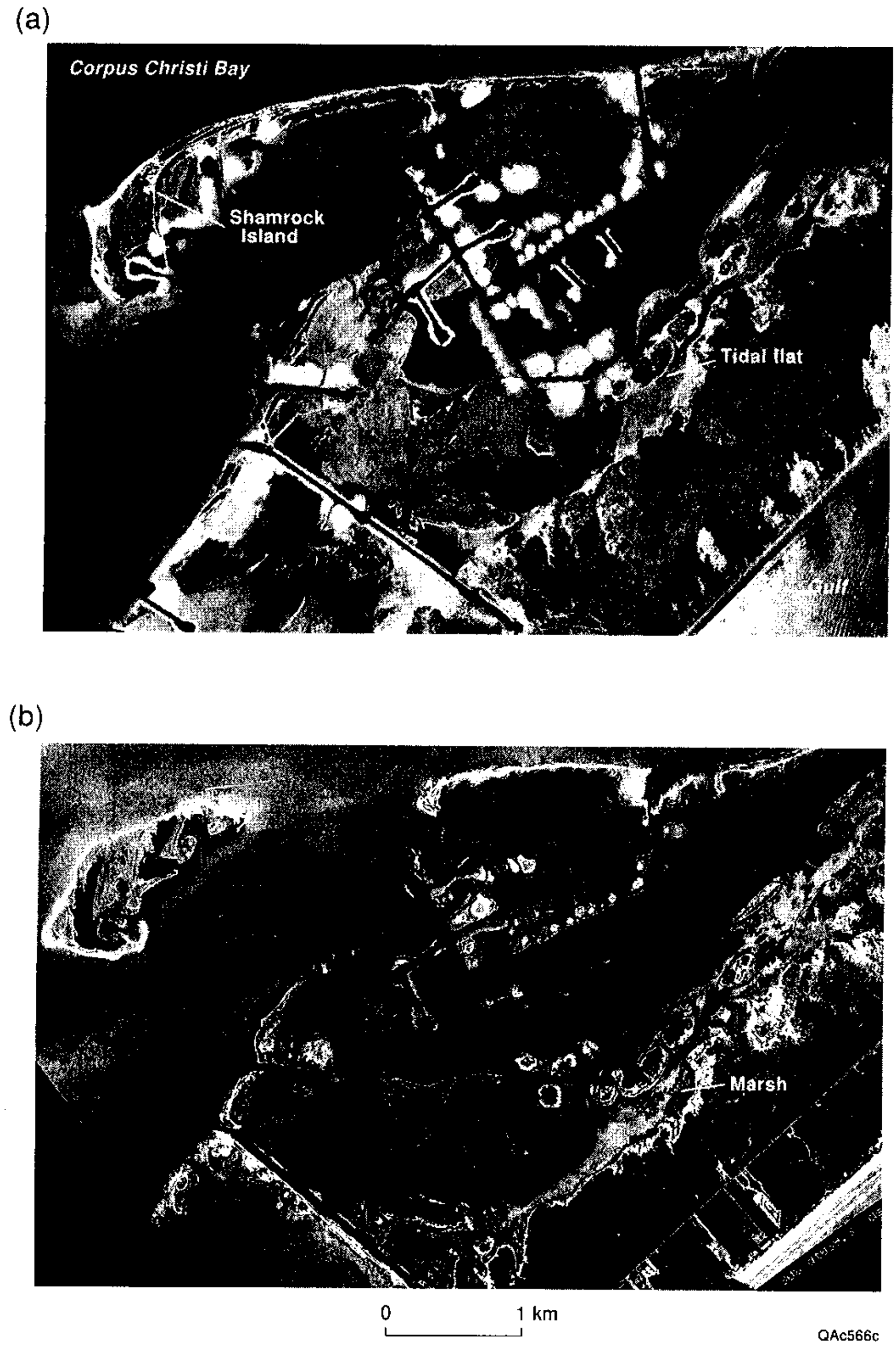


Figure 25. Changes on the bayward side of Mustang Island including Shamrock Island from (a) 1952 to (b) 1994. The breach in Shamrock Island spit apparently occurred during Hurricane Celia in 1970. A rise in relative sea level has contributed to a spread of marsh vegetation over flats and dredged material islands since the 1950's.

From the 1950's to 1979, the most extensive losses of tidal flats, more than 1,400 ha, were due to their conversion to subtidal areas. Flooding and permanent inundation of flats is in agreement with findings by White et al. (1983) and Pulich et al. (1997), and is attributed to an accelerated rise in relative sea level from the mid-1960's to the mid 1970's (Fig. 24). Coinciding with this rise in sea level was a spread of seagrass beds and shallow open water into these formerly intertidal areas. Conversion of tidal flats to uplands occurred in some areas and was most extensive at the southern end of the island where a mixture of broad barren flats and active dunes in the 1950's became vegetated by 1979 and were mapped as upland rangeland (UA). Additional changes from flats to uplands occurred along Fish Pass where dredged material was placed on flats along the channel forming upland mounds. Similar changes occurred along a channel dredged across East Flats southwest of Port Aransas.

From the 1950's to 1992, the loss in intertidal flats amounted to approximately 2,365 ha, or about 5 ha more than from the 1950's to 1979 (Table 13). The smaller net change in estuarine intertidal flats from 1979 to 1992, is attributed in part to a slower rise in sea level (Fig. 24), and to the fact that by 1979 a large percentage (65 percent) of the 1950's flats had already been replaced by other habitats (Tables 14 and 15).

Table 15. Net change in marshes and tidal flats from the 1950's-1992, Mustang Island.

Habitat	1950's (ha)	1992 (ha)	1992 Adjusted	Adjusted Net Change
E2EM	181	1203	1203	1022
E2EM/FL	169	0	0	-169
PEM	183	1728	691	508
Total EM	**533**	**2931**	**1894**	**1361**
E2FL	3708	1343	1343	-2365

Among the reasons for loss of some habitats was shoreline erosion. Williams (1997) concluded that the northwest shoreline of Shamrock Island (Fig. 25), a natural sand and shell spit formed and nourished by southwesterly moving currents and sediments on the western shore of Mustang Island, had retreated as much as 156 m between 1938 and 1995. He also concluded that material eroded from the northwest shoreline was deposited along the southwest shore of the spit, indicating a redistribution of sediment rather than a loss. Williams (1997) noted that transport of sediment feeding the spit from the northeast was interrupted by a channel dredged around 1951 across the neck of the spit connecting to Mustang Island. The spit was breached and separated from Mustang Island by Hurricane Celia in 1970 (White et al. 1978). Rates of shoreline erosion on Shamrock Island correlate well with rates of relative sea level rise; the most rapid rate of erosion and sea level rise occurred between the mid-1960's to 1975 (Fig. 26). About three ha of estuarine marsh was lost between 1979 and 1992 due to erosion of the northeastern part of the spit. Additional apparent losses in E2EM were due to conversion of E2EM to E2SS, a change partly due to photointerpretation.

San José Island

Marshes. *1950's-1979.* Overall, there was a net loss in marshes on San José Island between the 1950's and 1979 because of a large loss in E2EM/FL (Table 16). Analysis of 1950's aerial photographs, however, indicated that about 30 percent of the area of E2EM/FL had little

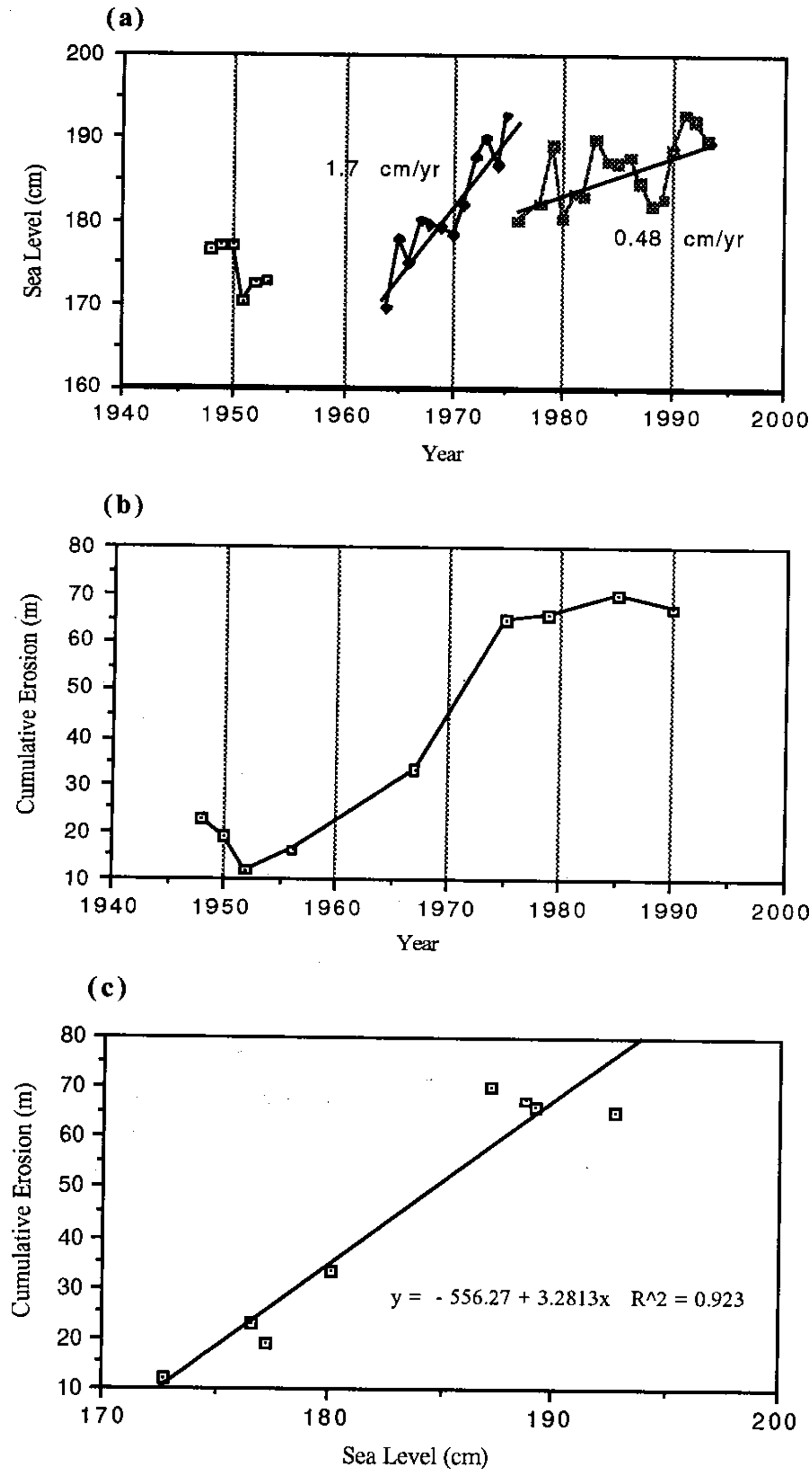


Figure 26. Relationship between sea level rise and erosion as shown by (a) sea level rise at the Rockport tide gauge, (b) shoreline erosion at one transect on Shamrock Island, and (c) high correlation (r^2=0.923). Tide data from NOAA; shoreline erosion data from Williams (1997).

emergent vegetation and could have more accurately been mapped as E2FL. Reduction of the E2EM/FL class by 30 percent reduces the net loss to 194 ha. Adding this loss to the 643 ha gain in E2EM (Table 16) yields a net gain in salt and brackish marshes of about 450 ha. We believe this is a more realistic approximation of the change that occurred on San José Island. Comparison of aerial photographs from the 1950's and 1979 shows an increase in emergent vegetation on intertidal flats. An increase of about 140 ha in fresh marsh (PEM) occurred in mid-island areas and in swales between vegetation stabilized dunes.

1979-1992. Marsh habitat on San José Island increased by more than 2,000 ha from 1979 to 1992, with estuarine marshes (E2EM + E2EM/FL) accounting for most of the gain (Table 17). More than 70 percent of the increase in E2EM wetlands occurred in areas formerly mapped as E2EM/FL and E2FL, indicating expansion of vegetation over intertidal flats. We believe the 2,000 ha gain is somewhat high because of inclusion of tidal flats in the E2EM class on the 1992 NWI maps. Nevertheless, the trend toward the spread of emergent vegetation over areas formerly mapped as flats is real and can be verified on sequential aerial photographs (Fig. 27). Palustrine emergent wetlands had an unadjusted gain of almost 500 ha, but a reduction of PEM1A areas by 60 percent (as discussed in the introduction to barrier islands) reduced the gain to 68 ha.

Table 16. Net change in marshes and intertidal flats from the 1950's-1979, San José Island.

Habitat	**1950's (ha)**	**1979 (ha)**	**1950's Adjusted**	**Adjusted Net Change**
E2EM	100	743	100	643
E2EM/FL	3460	2228	2422	-194
PEM	184	326	184	142
Total EM	**3744**	**3297**	**2706**	**591**
E2FL	3799	2977	4837	-1860

Table 17. Net change in marshes and intertidal flats from 1979-1992, San José Island.

Habitat	**1979 (ha)**	**1992 (ha)**	**1992 Adjusted**	**Adjusted Net Change**
E2EM	743	5097	5097	4354
E2EM/FL	2228	0	0	-2228
PEM	326	816	394	68
Total EM	**3297**	**5913**	**5491**	**2194**
E2FL, E2US	2977	2724	2724	-253

Estuarine Intertidal Flat. *1950's-1979*. Unadjusted net loss of E2FL on San José Island was more than 800 ha. It is estimated, however, that about 30 percent (1,038 ha) of E2EM/FL areas mapped on 1950's photographs should have been E2FL as noted above in the discussion of marshes. This adjustment increases the net loss in estuarine flat to 1,860 ha (Table 16).

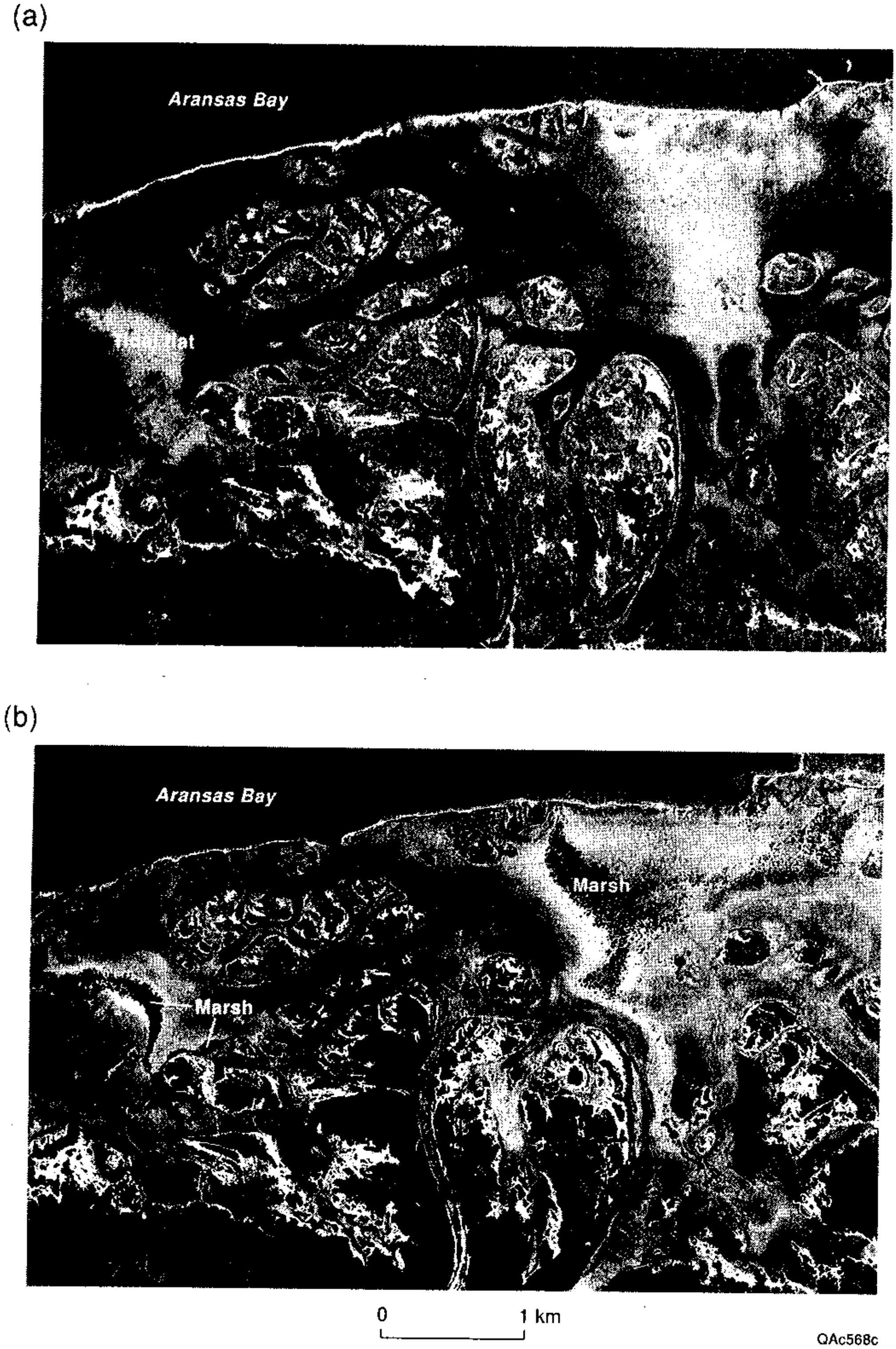


Figure 27. Example of the spread of marsh vegetation on tidal flats on San José Island from (a) 1979 to (b) 1994.

1979-1992. Losses of estuarine intertidal flats continued from 1979 to 1992, but at a slower rate than from the 1950's to 1979. There was a net loss of about 250 ha in E2FL, but additional losses occurred in areas mapped as E2EM/FL in 1979.

Probable Cause of Changes. *1950's-1979-1992.* Causes for changes are similar to those in Mustang Island. Some changes are interpretational, but gains in salt/brackish marsh are part of the trend toward more frequent flooding of wind-tidal flats and spread of emergent vegetation, especially *S. alterniflora* (Fig. 27). Gains in fresh marsh are partly interpretational and partly due to wetter conditions in 1979 and 1992 compared to the 1950's. As on Mustang Island, PEM1A areas appear to have been too liberally delineated on 1992 aerial photographs and were reduced by 60 percent. Still, there was a net gain in PEM.

Similar to Mustang Island, the major cause of loss in estuarine intertidal flats on San Josė Island (Table 18) was apparently a rise in relative sea level from the mid-1960's to 1979. Relative sea level rose about 25 cm during this period and flooded much of the intertidal flat habitat. From the 1950's to 1979, approximately 57 percent of the flats were converted to seagrass beds and open water and 25 percent to estuarine emergent marsh (E2EM, E2EM/FL). Most of the gross gain in intertidal flats from the 1950's to 1979 occurred in areas previously mapped as E2EM/FL, and is due more to interpretation than to loss of emergent vegetation. Continuing loss of tidal flats from 1979 to 1992 was in part due to the spread of emergent vegetation over flats (Fig. 27).

Table 18. Net change in marshes and intertidal flats from the 1950's-1992, San Josė Island.

Habitat	1950's (ha)	1992 (ha)	1950's Adjusted	1992 Adjusted	Adjusted Net Change
E2EM	100	5097	100	5097	4997
E2EM/FL	3460	0	2422	0	-2422
PEM	184	816	184	394	210
Total EM	**3744**	**5913**	**2706**	**5491**	**2785**
E2FL	3799	2724	4837	2724	-2113

Matagorda Island

Marshes. *1950's-1979.* In the marsh system, there was an apparent gain of about 60 ha in salt marsh (E2EM) (Table 19). However, the most extensive changes were in the E2EM/FL class, a net loss of 150 ha. Combining this class with E2EM yields a net loss in estuarine marsh of about 70 ha. Gross gains and losses were more substantial, with about 70 percent of gains occurring in estuarine subtidal and intertidal environments (changes in part due to photointerpretation). About 45 percent of the gross losses were to upland rangeland, 30 percent to subtidal classes (E1AB and E1OW), and 20 percent to emergent vegetation (E2EM). Comparison of photographs reveals some gain of emergent vegetation as it spread across tidal flats, but there was also some loss in emergent vegetation near the north margin of Mesquite Bay on the north side of Bray Cove. Palustrine emergent wetlands had a net loss of only 4 ha.

1979-1992. Net changes in marsh habitats were minor from 1979 to 1992. Losses in estuarine marshes (E2EM+E2EM/FL) were less than 50 ha (Table 20). A net gain of less than 20 ha occurred in palustrine marshes after adjustments to the PEM1A class as explained in the introduction to barrier islands. Overall, net change in emergent wetlands was a loss of 35 ha.

Table 19. Net change in marshes and intertidal flats from the 1950's-1979, Matagorda Island.

Habitat	1950's (ha)	1979 (ha)	Net change
E2EM	176	238	62
E2EM/FL	1858	1708	-150
PEM	103	99	-4
Total EM	**2137**	**2045**	**-92**
E2FL	86	109	23

Table 20. Net change in marshes and intertidal flats from 1979-1992, Matagorda Island.

Habitat	1979 (ha)	1992 (ha)	1992 Adjusted	Adjusted Net Change
E2EM	238	1898	1898	1660
E2EM/FL	1708	0	0	-1708
PEM	99	229	112	13
Total EM	**2045**	**2127**	**2010**	**-35**
E2FL	109	557	557	448

Estuarine Intertidal Flats. *1950's-1979.* Net loss in E2FL was only 23 ha from the 1950's to 1979. Losses were mostly due to conversion of flats to subtidal areas (E1AB and E1OW) and to estuarine marsh (E2EM and E2EM/FL).

1979-1992. An apparent net gain of more than 400 ha in estuarine flat occurred between 1979 and 1992. About 60 percent of the change occurred in subtidal habitats suggesting lower tides in 1992 compared to 1979. Most of the remaining 40 percent occurred in areas formerly mapped as E2EM/FL, indicating more detailed differentiation of the E2EM and E2FL (E2US) classes in 1992.

Probable Causes of Changes. *1950's-1979-1992.* From 1950's to 1979, there were losses in emergent vegetation on the north side of Bray Cove and Mesquite Bay. Losses apparently resulted from construction of a levee/road complex that cut off intertidal connections forming an impoundment that submerged marsh vegetation. Between 1979 and 1992 emergent vegetation increased in this area after the intertidal connection was restored. Although verified on aerial photographs, the quantitative extent of this change could not be determined because the area was mapped as E2EM/FL on both the 1950's and 1979 maps.

Marshes had minimal net losses during both periods but losses are questionable because of photointerpretation inconsistencies and map registration problems. Comparison of historical and recent photographs indicate a spread of intertidal vegetation in several areas. Overall, from the 1950's to 1992, there was a loss of approximately 125 ha of marsh and a gain of more than 470 ha of estuarine intertidal flat (Table 21).

Table 21. Net change in marshes and intertidal flats from the 1950's-1992, Matagorda Island.

Habitats	**1950's (ha)**	**1992 (ha)**	**1992 Adjusted**	**Adjusted Net Change**
E2EM	176	1898	1898	1722
E2EM/FL	1858	0	0	-1858
PEM	103	229	112	9
Total EM	**2137**	**2127**	**2010**	**-127**
E2FL	86	557	557	471

Harbor Island

Marshes. *1950's-1979.* The trend in marsh habitat on Harbor Island from the 1950's to 1979 was one of net gain (Table 22). For purposes of the Harbor Island anlaysis, estuarine intertidal scrub/shrub (E2SS, consisting mostly of black mangroves) was combined with estuarine emergent vegetation (marsh). This is because of inconsistencies in delineation of E2SS on the 1950's and 1979 maps; E2SS could not be adequately subdivided on the black and white 1950's aerial photographs from which the 1950's maps were prepared. E2SS was mapped, however, on the 1979 color-infrared aerial photographs and shown on the 1979 maps. Total gain in E2EM and E2SS was approximately 800 ha, most of which (678 ha) was E2SS. Although, there were gains and losses in the E2EM/FL class, overall there was a net loss of about 50 ha. Combining this loss with the 800 ha gain noted previously yields a net gain of 750 ha. Increases in estuarine emergent vegetation (and scrub/shrub) occurred primarily as marsh vegetation spread across estuarine intertidal flats. The palustrine emergent wetland class is negligible on Harbor Island.

Table 22. Net change in marshes and intertidal flats from the 1950's-1979, Harbor Island.

Habitat	**1950's (ha)**	**1979 (ha)**	**Net Change**
E2EM, E2SS	27	830	803
E2EM/FL	261	210	-51
PEM	2	0	-2
Total EM	**290**	**1040**	**750**
E2FL	2365	357	-2008

1979-1992. From 1979 to 1992 there was an apparent net decline in estuarine marshes (E2EM, E2EM/FL, and E2SS) on Harbor Island (Table 23). This is a reversal in the trend of net gain from the 1950's to 1979. However, analysis of aerial photographs indicates photointerpretion inconsistencies. There is evidence of a continuing spread of emergent vegetation over intertidal flats at a much slower rate than that occurring from the 1950's to 1979. Use of the E2EM/FL class in 1979 accounts for some of the apparent loss.

Table 23. Net change in marshes and intertidal flats from 1979-1992, Harbor Island.

Habitat	1979 (ha)	1992 (ha)	Net Change
E2EM	152	831	679
E2EM/FL	210	0	-210
E2SS	678	40	-638
PEM	0	29	29
Total EM&SS	**1040**	**900**	**-140**
E2FL	357	295	-62

Estuarine Intertidal Flats. *1950's-1979.* There was a net loss of approximately 2,000 ha of estuarine intertidal flats on Harbor Island from the 1950's to 1979. The most extensive losses occurred on the western half toward Redfish Bay.

1979-1992. The area of estuarine intertidal flat continued to decrease after 1979, but at a much slower rate than during the earlier period. From 1979 to 1992 the net decline in this habitat was about 60 ha.

Probable Causes of Changes. *1950's-1979-1992.* Harbor Island is one of the best examples of changes that occur from a rise in sea level (Figs. 24 and 28). Broad tidal flats became permanently flooded between the 1950's and 1979 promoting expansion of seagrass beds. Salt-marsh vegetation, including *Avicennia germinans* spread on topographically higher flats and mounds.

There is photographic evidence indicating a continuing spread of estuarine marsh from 1979 to 1992, although digital data indicate a loss. Photo analysis shows that some areas mapped as E2EM/FL in 1979 should have been mapped as E2FL, which would have produced a larger gain in E2EM from 1979 to 1992. The change in E2SS to E2EM habitats from 1979 to 1992 is both interpretational and real. Extreme low temperatures in 1983 killed many black mangroves. Still, much of the difference in area of E2SS in 1979 and 1992 is due to aerial photographic quality and interpretation differences. From the 1950's to 1992, relative rise in sea level contributed to a net gain of 610 ha of marsh and a loss of more than 2,000 ha of estuarine intertidal flat (Table 24).

Table 24. Net change in marshes and intertidal flats from the 1950's-1992, Harbor Island.

Habitat	1950's (ha)	1992 (ha)	Net Change
E2EM, E2SS	27	871	844
E2EM/FL	261	0	-261
PEM	2	29	27
Total EM	**290**	**900**	**610**
E2FL	2365	295	-2070

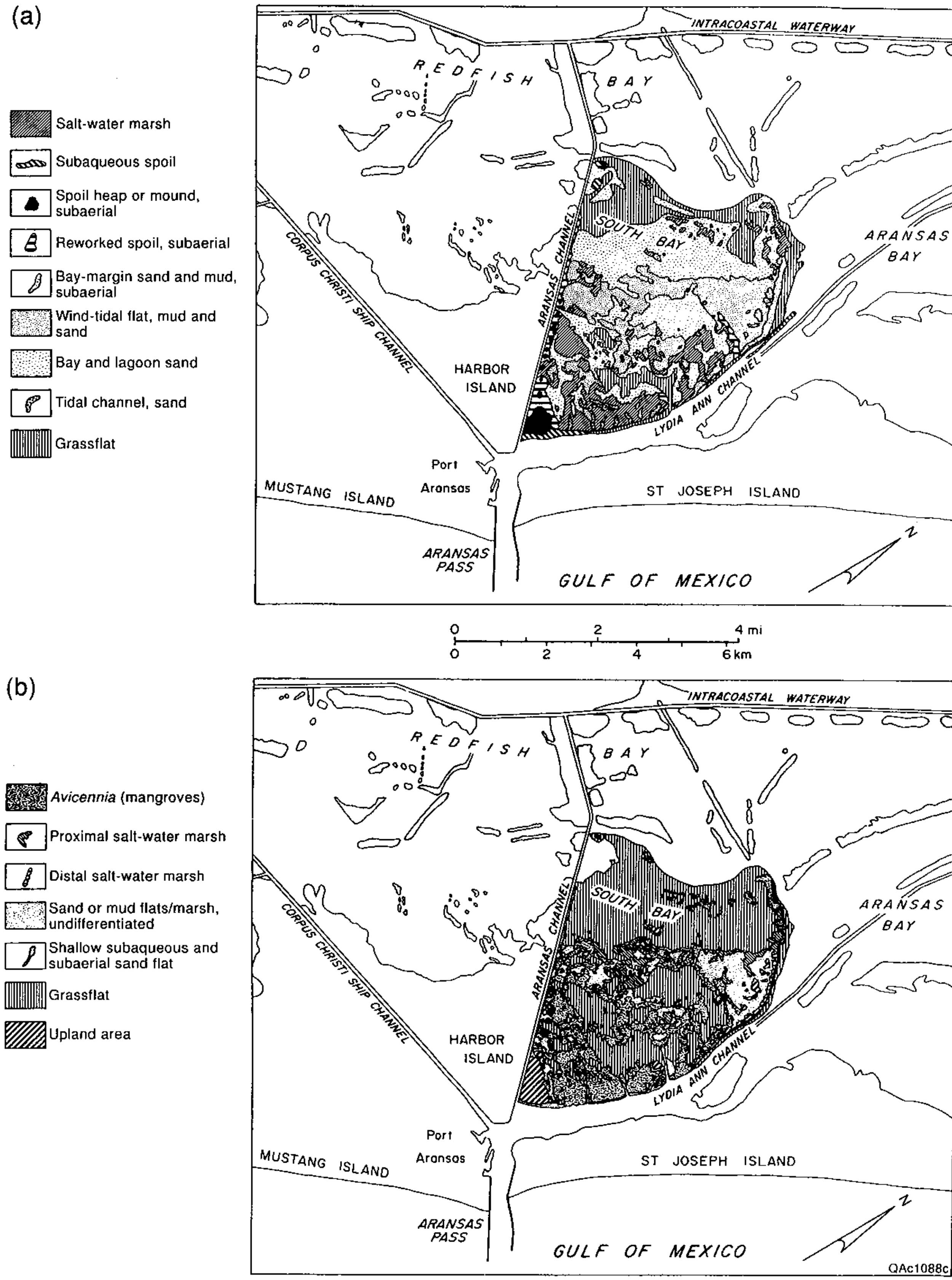


Figure 28. North Harbor Island environments (a) in 1958 (from Brown et al. 1976) and (b) in 1979 (from White et al. 1983).

North Padre Island

Marshes. *1950's-1992.* Tables 25-27 present habitat changes for this region. It appears that PEM marshes have increased in area on North Padre Island. The net gain was estimated at 663 ha. As on other barrier islands, we estimated, based on ground-truthing, that about 40 percent of the area classified as PEM1A on the 1992 photos was actually PEM wetlands. The rest would be more appropriately called wetland/upland transitional area. Areas totaling about 360 ha classified as seasonally flooded marsh (PEM1C), wetter than PEM1A, remained constant in area although not in spatial distribution. About 80 percent of the increase in PEM1A was classified as U in the 1950's. There was a net gain of about 87 ha of E2EM; 37 ha from E2FL and 51 ha from U. This expansion of E2EM occurred along the Laguna Madre shore of the island. This change analysis did not include the South Bird Island quadrangle for which no 1992 data were available. Also, the 1950's data exhibited serious cartographic errors that made a 1950's-1979 comparison untenable. The available photos of South Bird Island and Pita Island gave no indication that wetland trends on the two quads differed.

Table 25. Net change in marshes and intertidal flats from the 1950's-1979, North Padre Island.

Habitat	1950's (ha)	1979 (ha)	1950's Adjusted	1979 Adjusted	Adjusted Net Change
E2EM	18	7	82	77	-6
E2EM/FL	40	58	36	45	9
PEM	360	458	335	548	213
Total EM	**419**	**523**	**454**	**671**	**217**
E2FL	793	284	669	300	-369

Table 26. Net change in marshes and intertidal flats from 1979-1992, North Padre Island.

Habitat	1979 (ha)	1992 (ha)	1979 Adjusted	1992 Adjusted	Adjusted Net Change
E2EM	7	169	77	169	92
E2EM/FL	58	0	45	0	-45
PEM	458	1951	549	999	450
Total EM	**523**	**2120**	**671**	**1168**	**497**
E2FL	284	197	300	197	-103

Table 27. Net change in marshes and intertidal flats from the 1950's-1992, North Padre Island.

Habitat	1950's (ha)	1992 (ha)	1950's Adjusted	1992 Adjusted	Adjusted Net Change
E2EM	18	169	82	169	87
E2EM/FL	40	0	36	0	-36
PEM	360	1951	335	999	663
Total EM	**419**	**2120**	**454**	**1168**	**714**
E2FL	793	197	669	197	-472

Estuarine Intertidal Flats. *1950's-1992*. There was a loss of 521 ha of E2FL; 230 ha went to upland, 223 ha to E1OW, and 37 ha to E2EM. About 49 ha of E2FL were gained, 26 ha from E1OW and 22 ha from U, so the net change was a 472 ha loss of E2FL.

Probable Causes of Changes. *1950's-1992*. About 453 ha of E2FL loss was due to residential development (Padre Isles), i.e., dredge and fill conversion to E1OW (canals) and uplands (Fig. 29). Other losses of E2FL along the Laguna Madre shore may be the result of several active processes. A rise in relative sea level plus vegetative stabilization of dunes, resulting in less sand blowing into the bay, may have caused submergence of some E2FL. A study of historical changes in the upper Laguna Madre shoreline on the South Bird Island quad attributed shoreline progradation between 1941 and the late 1970's to the effects of below average rainfall and heavy grazing pressure upon island vegetation (Prouty and Prouty 1989). Since 1979 and stabilization of active dune fields, the shoreline has been eroding. Rising relative sea level may also have caused expansion of PEM on the island. As sea level rises, the island's freshwater lens also rises and the island may be getting wetter.

Pleistocene Barrier–Strandplain System

The Pleistocene barrier-strandplain system consists of a series of Pleistocene sand ridges characterized by a network of pothole wetlands and live oak mottes. A major component of this barrier-strandplain system is Live Oak Peninsula/Ridge, located at the heart of the CCBNEP study area (Figs. 3 and 22). To the northeast are Blackjack and Lamar Peninsulas, and to the southwest is Encinal Peninsula (Fig. 22). Because of the complex topography consisting of relict beach ridges, inter-ridge swales, deflation troughs, and stabilized dunes, this system is host to one of the most complex array of palustine marshes and ponds that exist in the CCBNEP area. This complex interrelationship between wetlands and uplands was simplified for mapping purposes by using combinations of classes that do not spatially differentiate wetlands from uplands (Fig. 30).

Live Oak Peninsula/Ridge

Marshes. *1950's-1979*. There were losses and gains in salt and brackish marshes (E2EM, E2EM/FL) on Live Oak Peninsula and Ridge from the 1950's to 1979, but overall, there was a net gain of almost 400 ha (Table 28, E2EM+E2EM/FL). Increases occurred primarily along the margins of Redfish Bay and to a lesser extent on the Port Bay side of the peninsula.

Table 28. Net change in marshes and intertidal flats from the 1950's-1979, Live Oak Ridge/Peninsula.

Habitat	1950's (ha)	1979 (ha)	1950's Adjusted	1979 Adjusted	Adjusted Net Change
E2EM	207	472	207	472	265
E2EM/FL	228	356	228	356	128
PEM	995	938	995	938	-57
PEM/U	1233	37	432	13	-419
POW/U	0	1606	0	562	562
POW, PFL	243	306	243	306	63
Total EM + POW	**2906**	**3715**	**2105**	**2647**	**542**
E2FL	1084	214	1084	214	-870

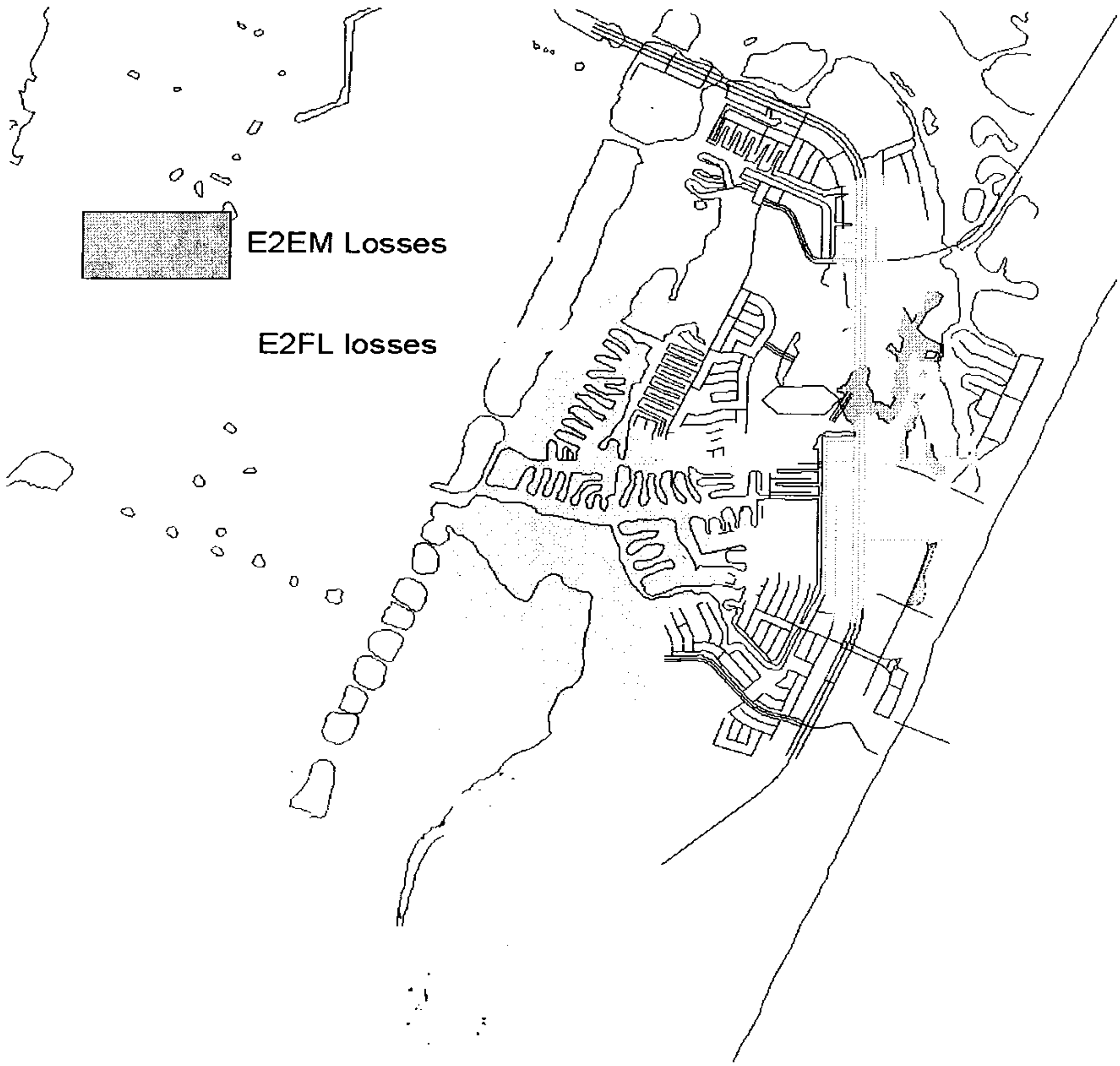


Figure 29. Padre Isles residential development and loss of E2FL and E2EM since the 1950's.

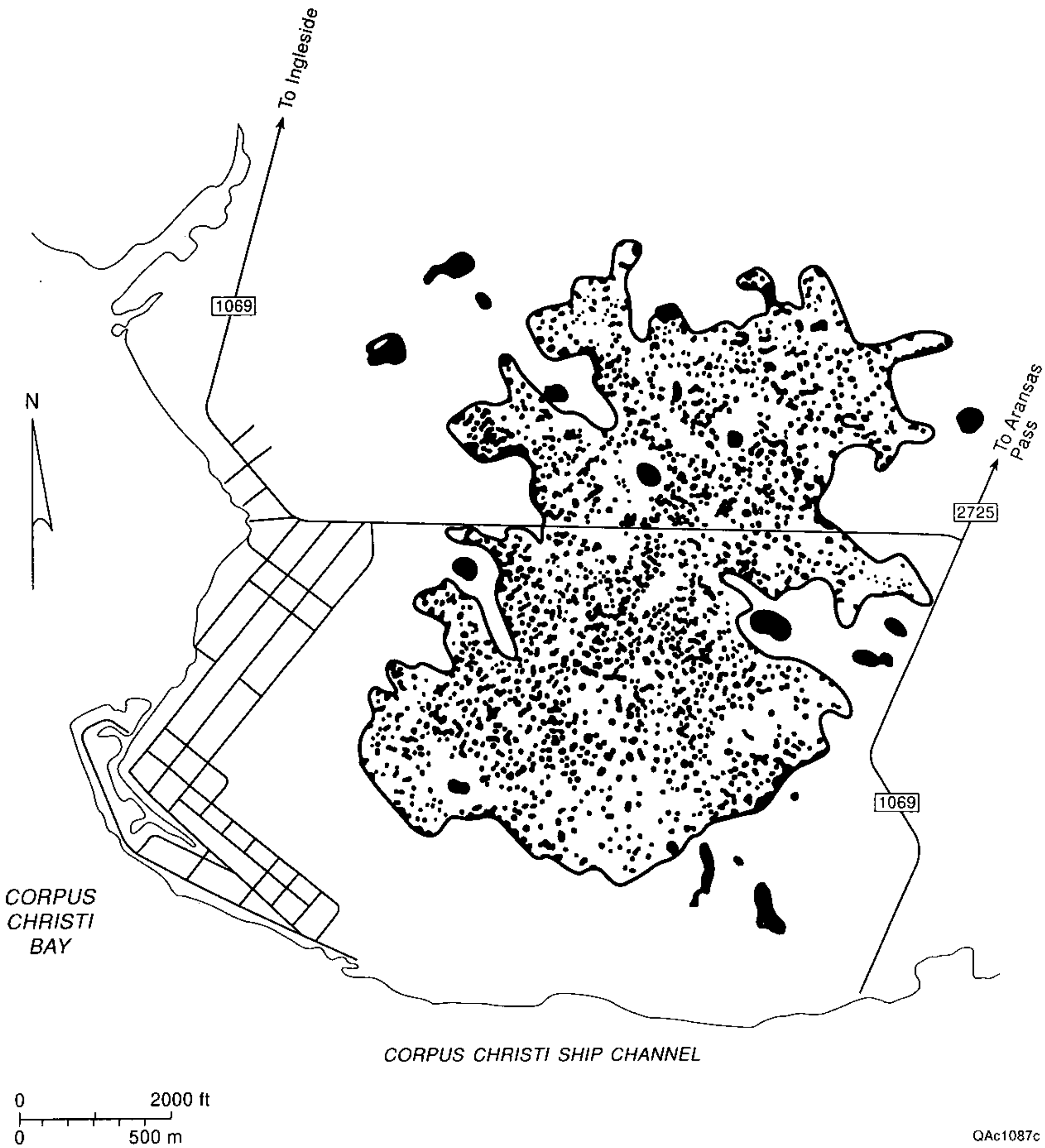


Figure 30. Example of the complexity of areas mapped as wetland/uplands undifferentiated (PEM/U and POW/U) on Live Oak Ridge. Within the irregularly shaped area defined by the dark line, the dark circles represent ponds and marshes that are surrounded by upland live oak mottes (white areas). On wetland maps these areas are defined only by the outer boundary. From White et al. (1983).

A straight comparison of 1950's and 1979 palustrine emergent wetland (PEM) digital data shows a loss of about 1,250 ha. However, a large part of the PEM resource (1,233 ha) in the 1950's was mapped as palustrine emergent wetlands and uplands undifferentiated (PEM/U), which is a complex mixture of numerous, small isolated wetland depressions surrounded by uplands (Fig. 30). Because of much wetter conditions in 1979, many depressions were filled with water and were mapped as palustrine open water and uplands undifferentiated (POW/U) (Table 28). Collins (1987), in a study of the pothole wetlands on the barrier-strandplain including Live Oak Peninsula, reported that average rainfall in 1956 was almost 44 cm less than in 1979. By 1992, most ponds had reverted back to marshes. Thus, depressions may be characterized by marsh or open water depending on local climatic conditions and water levels when aerial photographs were taken. Accordingly, the unadjusted loss of almost 1,200 ha of PEM/U from the 1950's to 1979 (Table 28), was not a permanent loss but rather a temporary conversion from marsh to open water. The 1979 increase in POW/U of 1,600 ha more than offset the loss. If we consider POW/U mapped in 1979 as equivalent to PEM/U mapped in the 1950's, and if we further assume that the wetland portion of these units is approximately 35 percent of the whole, then the net change in total PEM and PEM/U from the 1950's to 1979 is a gain of 86 ha (or about 150 ha including POW and PFL).

If only change in the PEM class on Live Oak Peninsula is considered, there is a resulting net loss of marsh of 57 ha. Of the gross loss of PEM, 52 ha was converted to open water by excavation for development. Because of drier conditions in 1956 compared to 1979, Collins (1987) concluded that NWI data underestimated the number and size of palustrine wetlands in the 1950's relative to 1979. Nevertheless, he noted the data showed a considerable decline in number and area of pothole wetlands on Live Oak Peninsula. A difference in this study and the one by Collins, is that we used digital data in a GIS to focus only on Live Oak Peninsula and exclude areas south of Port Bay in the Aransas Pass quadrangle that were included in Collin's analysis. We found that an area of more than 400 ha of high marsh south of Port Bay mapped in the 1950's and 1992 should have also been mapped in 1979 (see later section on Port Bay area). This omission in the 1979 NWI data exaggerated the loss in palustrine wetlands reported by Collins whose study was based on a comparison of the 1979 and 1956 data. Still, we agree that the 1950's data probably underestimated pothole wetlands on Live Oak Peninsula.

1979-1992. There was an apparent net loss in estuarine marsh (E2EM + E2EM/FL) of about 270 ha from 1979 to 1992 on Live Oak Peninsula (Table 29). There were losses and gains in the E2EM class, although most of the estuarine marsh loss occurred in the E2EM/FL class, which was not mapped in 1992. In one area west of Rockport near Port Bay, approximately 100 ha of land mapped as E2EM in 1979, was mapped as upland in 1992. This is a complex area consisting primarily of upland "pimple" mounds and inter-mound depressions supporting a vegetation community dominated by *Spartina spartinae* .

Palustrine wetlands declined in area between 1979 and 1992 on Live Oak Peninsula. For reasons discussed previously, areas of palustrine open water (POW, POW/U and PUB) were combined with areas of emergent vegetation (PEM, PEM/U, and U/PEM) because of the unique topography of this Pleistocene sand ridge characterized by hundreds of potholes that have fluctuating seasonal and annual water regimes dependent on precipitation. In addition, the complexed areas (as explained previously) were assumed to contain approximately 35 percent wetlands. With these considerations, net adjusted loss in palustrine wetlands was about 155 ha from 1979 to 1992. Overall, net change in emergent wetlands was a decline of more than 400 ha (Table 29), which is a reversal in the net gain from 1950's to 1979 (Table 28).

Estuarine Intertidal Flats. *1950's-1979.* Tidal flats declined by 870 ha from the 1950's to 1979 (Table 28). Losses in flats occurred on the eastern margin of the Live Oak Ridge landward of the GIWW and Redfish Bay.

Table 29. Net change in marshes and intertidal flats from 1979-1992, Live Oak Ridge/Peninsula.

Habitat	1979 (ha)	1992 (ha)	1979 Adjusted	1992 Adjusted	Adjusted Net Change
E2EM	472	558	472	558	86
E2EM/FL	356	0	356	0	-356
PEM	938	1405	938	1405	467
PEM/U	37	379	13	133	120
POW/U	1606	0	562	0	-562
POW, PFL	306	126	306	126	-180
Total EM + POW	**3715**	**2468**	**2647**	**2222**	**-425**
E2FL	214	272	214	272	58

1979-1992. There was a small net gain of less than 60 ha in estuarine flats between 1979 and 1992 (Table 29). Changes occurred primarily on the margins of Aransas and Redfish Bays.

Probable Causes of Changes. *1950's-1979-1992*. The trend or change in estuarine marsh (E2EM, E2EM/FL) and palustrine marsh (PEM) on Live Oak Peninsula and Ridge from the 1950's to 1979 was one of net gain of more than 500 ha. Gains of estuarine marsh occurred along the margins of the ridge and peninsula landward of the GIWW where emergent vegetation encroached on to intertidal flats, and into areas previously mapped as uplands. There were increases in estuarine marsh on the western margins of the peninsula near Port Bay, partly due to interpretation, but also possibly due to higher water levels in 1979. Apparent losses in estuarine marsh from 1979 to 1992 were due to drier conditions in 1992 compared to 1979, and to delineation of irregularly flooded areas consisting mostly of *S. spartinae* as E2EM in 1979 and upland in 1992. In addition, some areas on the west side of Live Oak Peninsula that were classified as E2EM in 1979 were classified as PEM in 1992. A few areas of E2EM/FL on the eastern side of the peninsula were developed and converted to uplands, but some apparent losses in E2EM/FL from 1979 to 1992 were interpretational, including changes in class and a more detailed subdivision of E2EM and E2FL in 1992. From the 1950's to 1992, there was a net loss in estuarine intertidal flats and a small net gain in palustrine wetlands (Table 30).

Table 30. Net change in marshes and intertidal flats from the 1950's-1992, Live Oak Ridge/Peninsula.

Habitat	1950's (ha)	1992 (ha)	1950's Adjusted	1992 Adjusted	Adjusted Net Change
E2EM	207	558	207	558	351
E2EM/FL	228	0	228	0	-228
PEM	995	1405	995	1405	410
PEM/U	1233	379	432	133	-299
POW/U	0	0	0	0	0
POW, PFL	243	126	243	126	-117
Total EM + POW	**2906**	**2468**	**2105**	**2222**	**117**
E2FL	1084	272	1084	272	-812

Wetter conditions in 1979 and its effect on palustine emergent wetlands is discussed previously. Although the overall trend from the 1950's to 1979 was a net gain, it should be noted that local losses of estuarine and palustrine emergent marsh occurred from land development on Live Oak Peninsula. For example, losses of about 50 ha of E2EM and E2EM/FL occurred east of Rockport, from development of Key Allegro (Fig. 31). An example of losses in palustrine marsh occurred from development of a trailer park west of Rockport, which displaced approximately 7 ha of marsh. Marsh habitat was excavated to form ponds and filled to create uplands (Fig. 32). More extensive losses in palustine emergent wetlands occurred from 1979 to 1992 and can be attributed in part to filling, draining, excavating, and quarrying potholes for residential, commercial, and recreational development, and for sand (Figs. 31-33).

Of the gross losses in estuarine intertidal flats from 1950's to 1979, about 40 percent was lost to uplands (more than half of which was to upland development), about 39 percent to permanent submergence, and 28 percent to the spread of emergent vegetation and conversion to E2EM and E2EM/FL habitats. Small gains in estuarine flats from 1979 to 1992 were not significant, and are attributed in part to the subdivision of 1979 E2EM/FL areas into marshes and flats in 1992.

Blackjack Peninsula

Marshes. *1950's-1979.* On Blackjack Peninsula, losses and gains in estuarine marsh (E2EM and E2EM/FL) resulted in a net gain of about 50 ha between 1950's to 1979 (Table 31). Most of the estuarine marsh is characterized as E2EM/FL on 1950's maps and E2EM on 1979 maps. This change reflects, in part, a spread of emergent vegetation over intertidal flats, principally along the eastern margins of Blackjack Peninsula (Figs. 20 and 21). Palustrine emergent wetlands (PEM and PEM/U) also underwent a net gain from the 1950's to 1979. Assuming that 35 percent of the PEM/U class (mapped only in 1979 in this area) consisted of emergent vegetation, the total net gain in PEM was about 1,500 ha (Table 31). Much of this gain is (1) interpretational, including the use of the PEM/U class in 1979, and (2) the result of wetter conditions in 1979 compared to the mid 1950's, which also affected interpretation.

1979-1992. There was a small gain in estuarine marsh of about 5 ha and a larger gain in palustrine marsh of almost 1,000 ha on Blackjack Peninsula from 1979 to 1992. Most of the gross gain in E2EM occurred in areas mapped in 1979 as E2EM/FL and E2FL, indicating some expansion of emergent vegetation over flats. Analysis of aerial photographs supported this expansion especially on the southern tip and eastern side of the peninsula. There were extensive gross losses and gains in the palustine emergent wetlands. As noted in the previous paragraph, PEM/U and U/PEM areas were assumed to consist of 35 percent PEM and were adjusted accordingly (Table 32). Extensive net gains in the PEM class occurred thoughout the peninsula but were more extensive on the eastern side inland from estuarine marshes fringing the bay-estuarine-lagoon system. Extensive PEM1A areas were mapped on 1992 photographs in areas previously (1979) mapped as uplands.

Estuarine Intertidal Flats. *1950's-1992.* There was a net gain of 152 ha in estuarine intertidal flat on Blackjack Peninsula from the 1950's to 1979. Gains were primarily in areas previously mapped as E2EM/FL.

1979-1992. There was little change in estuarine flats from 1970 to 1992. Although there were gross losses and gains of more the 100 ha, the net change was a loss of about 40 ha.

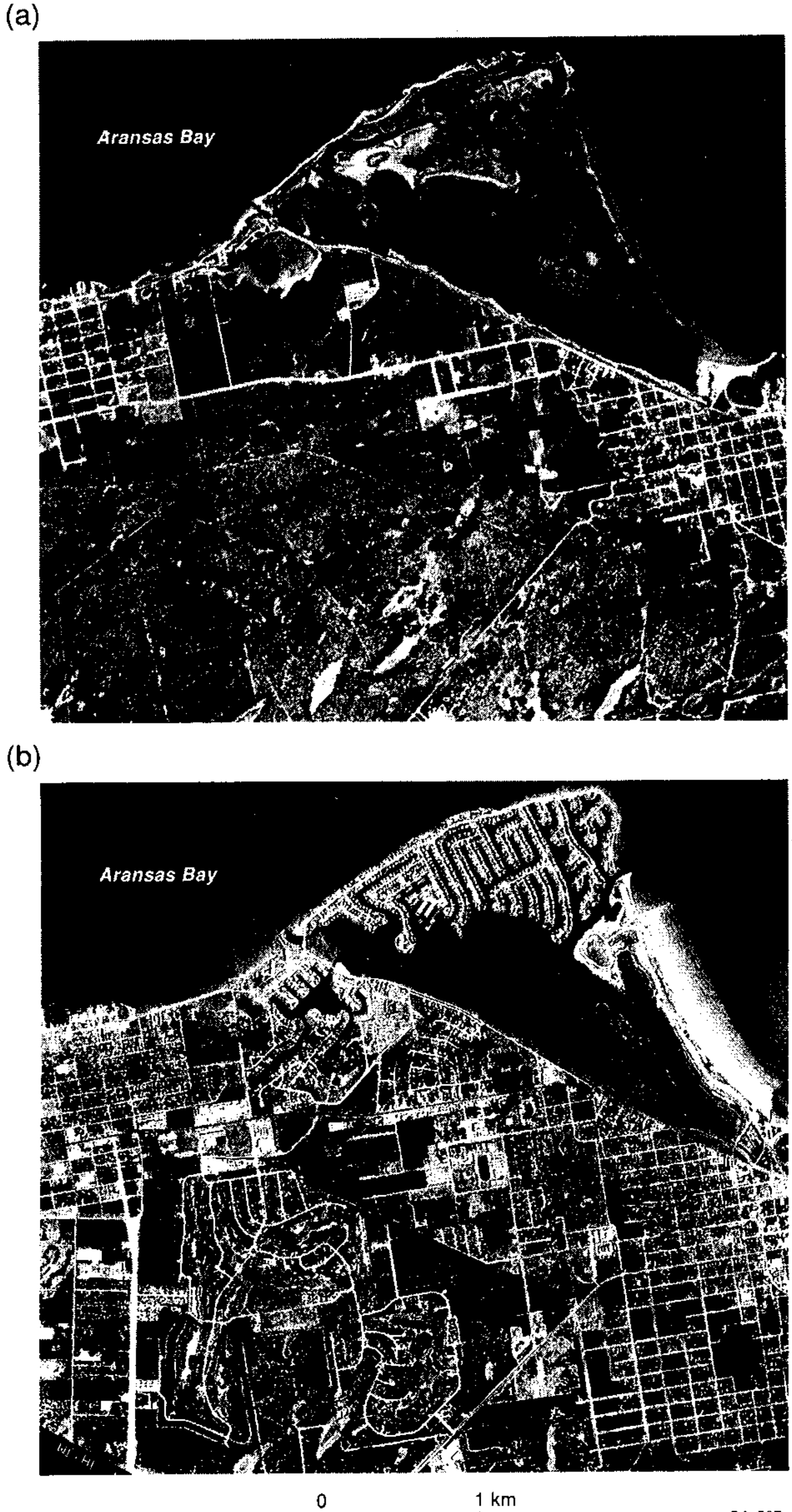


Figure 31. Examples of changes in intertidal flats, and estuarine and palustrine marshes on Live Oak Peninsula. Photographs were taken in (a) 1952 and (b) 1994.

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Figure 32. Example of loss of palustrine marsh from trailer park development west of Rockport.

(a)

(b)

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Figure 33. Quarrying of pot hole wetlands for sand resources on Live Oak Peninsula converts (a) palustrine marshes into (b) ponds or palustrine open water. Photographs taken in 1997.

Table 31. Net change in marshes and intertidal flats from the 1950's-1979, Blackjack Peninsula.

Habitat	1950's (ha)	1979 (ha)	1979 Adjusted	Adjusted Net Change
E2EM	76	1708	1708	1632
E2EM/FL	2344	764	764	-1580
PEM	727	1801	1801	1074
PEM/U	0	1205	422	422
Total EM	**3147**	**5478**	**4695**	**1548**
E2FL	152	306	304	152

Table 32. Net change in marshes and intertidal flats from 1979-1992, Blackjack Peninsula.

Habitat	1979 (ha)	1992 (ha)	1979 Adjusted	1992 Adjusted	Adjusted Net Change
E2EM	1708	2478	1708	2478	770
E2EM/FL	764	0	764	0	-764
PEM	1801	3061	1801	3061	1260
PEM/U, U/PEM	1205	489	422	171	-251
POW	25	2	25	2	-23
Total EM, OW	**5503**	**6030**	**4720**	**5712**	**992**
E2FL	306	263	306	263	-43

Probable Causes of Changes. *1950's-1979-1992.* Much of the change in marsh habitat on Blackjack Peninsula can be attributed to interpretation and classification differences of 1950's and 1979 aerial photographs. Overall, there was a marsh habitat gain of more than 1,500 ha, most of which was in the PEM and PEM/U classes. Considering the E2EM and E2EM/FL classes together, losses in E2EM/FL are virtually offset by gains in E2EM from 1950's to 1979, from 1979 to 1992, and from 1950's to 1992 (Tables 31-33). This is, in part, reflective of a real change toward a spread of emergent vegetation across intertidal flats. The cause, as on the barrier islands, is thought to be due to a rise in relative sea level (Fig. 24).

Table 33. Net change in marshes and intertidal flats from the 1950's-1992, Blackjack Peninsula.

Habitat	1950's (ha)	1992 (ha)	1992 Adjusted	Net Adjusted Change
E2EM	76	2478	2478	2402
E2EM/FL	2344	0	0	-2344
PEM	727	3061	3061	2334
PEM/U	0	489	171	171
Total EM	**3147**	**6028**	**5710**	**2563**
E2FL	152	263	263	111

Large gains in the palustrine classes (Tables 32 and 33) is largely interpretational due to the topographic complexity of this peninsula, and the use of the PEM/U class in 1979 and 1992 but not in the 1950's. The peninsula is part of the Pleistocene barrier-strandplain system composed almost entirely of fine grained, well-sorted sand. It has a complex geomorphology characterized by relict beach ridges and inter-ridge swales, as well as relict depressions and dunes caused by wind deflation and migrating sand. These features produce a complex topography of wet depressions in which marshes and ponds have formed, surrounded by upland, stabilized dunes and ridges covered with live oak trees. Most of this land is within the Aransas National Wildlife Refuge, and although there are some artificial ditches and levees that may have produced local changes, most changes are thought to be due to interpretation and to wetter conditions in 1979 compared to the mid 1950's. Wetter conditions and color infrared photographs in 1979 aided photointerpreters in delineating depressions that intermittently contain emergent vegetation. The gain in PEM between 1979 and 1992, although possibly in part real, is also due to photointerpretation and more liberal classification of topographically high marshes (PEM1A) in 1992.

Lamar Peninsula

Marshes. *1950's-1979.* On Lamar Peninsula, gains and losses in estuarine emergent wetlands resulted in a net gain of 756 ha. Much of the gain was offset by a loss in palustrine emergent wetlands of 506 ha (Table 34). Changes occurred primarily in the northern half of the peninsula in a topographically low area between the tip of Copano Bay and St. Charles Bay.

1979-1992. Between 1979 and 1992, estuarine marshes had an apparent loss of several hundred hectares, although this loss was partly offset by gains in palustrine marshes (Table 35). Much of the loss occurred in the northern part of the peninsula where gains were noted between 1950's and 1979.

Table 34. Net change in marshes and intertidal flats from the 1950's-1979, Lamar Peninsula.

Habitat	1950's (ha)	1979 (ha)	Net Change
E2EM	263	1214	951
E2EM/FL	346	151	-195
PEM	598	92	-506
Total EM	**1207**	**1457**	**250**
E2FL	285	150	-135

Table 35. Net change in marshes and intertidal flats from 1979-1992, Lamar Peninsula.

Habitat	1979 (ha)	1992 (ha)	Net Change
E2EM	1214	776	-438
E2EM/FL	151	0	-151
PEM	92	438	346
POW	40	10	-30
Total EM, OW	**1497**	**1224**	**-273**
E2FL, E2US	150	45	-105

Estuarine Intertidal Flat. *1950's-1979.* The general trend in tidal flats on Lamar Peninsula was one of net loss (-135 ha). Losses occurred primarily on the western side of the peninsula along the margins of Copano Bay.

1979-1992. The trend toward a loss in tidal flats established earlier, continued from 1979 to 1992 (Table 35). Net loss was slightly more than 100 ha.

Probable Causes of Changes. *1950's-1979-1992.* Most of the estuarine intertidal flat on Lamar Peninsula was converted to water (55 percent), marsh (28 percent) or uplands (15 percent) from 1950's to 1979. One area was the site of a housing development that altered the flats, converting some areas to uplands for houses and roads, and some to channels for boat access (Fig. 34). About 95 percent of the loss in estuarine intertidal flat from 1979 to 1992 was due to its replacement by estuarine marsh. Conversion of flats to open water, seagrass beds, and marshes is attributed primarily to a rise in relative sea level (Fig. 24), a common scenario throughout the study area.

Much of the estuarine and palustrine marsh change, resulting in a net gain of 250 ha from the 1950's to 1979, was due to photointerpretation. A large area on the northern half of the peninsula was mapped as PEM on the 1950's maps and E2EM on 1979 maps. This is an interpretative difference, because most of this area is characterized by *S. spartinae*. There is little evidence that vegetation composition and tidal communication in this area was different in the 1950's. Drainage ditches that cross the area were completed before the 1950's (Fig. 35a). Of the gross loss in PEM, about 60 percent was mapped as E2EM on 1979 maps, and about 35 percent was mapped as uplands. Some conversion to uplands was the result of residential/commercial development near State Highway 35. The net gain in marsh, however, is supported by actual expansion of emergent vegetation across estuarine flats on both the Copano Bay and St. Charles Bay sides of Lamar Peninsula.

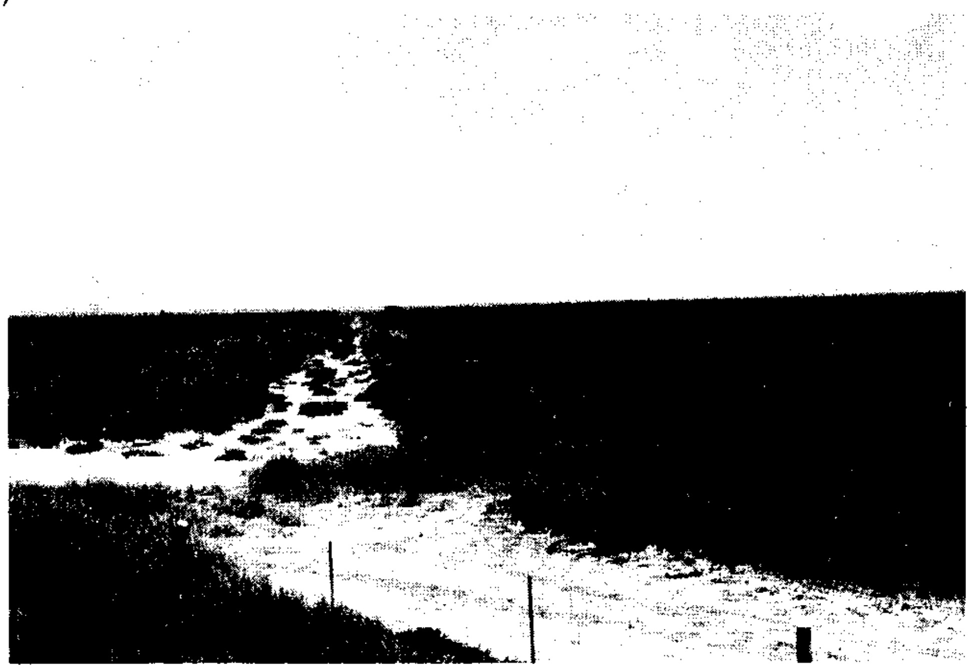
Losses in estuarine marsh between 1979 and 1992 are in large part interpretational. Much of the area dominated by *S. spartinae* that extends between St. Charles and Copano Bays at the north end of Larmar Peninsula (mentioned in the preceding paragraph) was delineated as uplands and locally palustrine emergent wetlands in 1992. Recent field surveys revealed that the area is still dominated by *S. spartinae*, although shrubs such as *Iva frutescens* are more abundant than in the past (Fig. 35a). This area is very distinct on 1992 photographs, but the more abundant shrubs may have influenced the interpreters to map the area as uplands in 1992. The net change from the 1950's to 1992 in total emergent wetlands was a gain of less than 10 ha (Table 36).

Table 36. Net change in marshes and intertidal flats from the 1950's-1992, Lamar Peninsula.

Habitat	1956 (ha)	1992 (ha)	Net Change
E2EM	263	776	513
E2EM/FL	346	0	-346
PEM	598	438	-160
Total EM	**1207**	**1214**	**7**
E2FL	285	45	-240

Figure 34. Changes in estuarine intertidal flats and marshes from community development on Lamar Peninsula along the margin of Copano Bay as shown on photographs taken in (a) 1952 and (b) 1979.

(a)



(b)

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Figure 35. Examples of drainage ditches that cross *Spartina spartinae* marshes located (a) between State Highway 136 and St. Charles Bay and (b) south of Port Bay. The marsh at (b) was mapped in the 1950's and 1992 but not in 1979.

Encinal Peninsula

Marshes. *1950's-1979.* From the 1950's to 1979, there was a net loss of 80 ha of PEM and a net gain of 426 ha of L1OW (Table 37). These changes were due to construction of the Central Power and Lighting Barney M. Davis cooling reservoir (472 ha).

Table 37. Net change in marshes, intertidal flats, and lacustrine habitats from the 1950's-1979, Encinal Peninsula.

Habitat	1950's (ha)	1979 (ha)	1950's Adjusted	1979 Adjusted	Adjusted Net Change
E2EM	5	1	5	0	-5
PEM	598	562	548	468	-80
Total EM	**603**	**563**	**553**	**468**	**-85**
E2FL	15	11	15	16	1
L1OW/L2	0	451	9	436	426

1979 -1992. Lacustrine open water (L1OW) increased in area due to construction of a hatchery on the King Ranch (52 ha) (Table 38). PEM was greatly overdelineated in 1979; the 1992 delineation of PEM was more conservative despite overdelineation of the PEM1A category. The adjusted value for PEM showed an increase because of reclassification of uplands as PEM1A.

1950's-1992. Table 39 shows an adjusted net increase of 487 ha of L1OW, which replaced 400 ha of uplands and 84 ha of PEM. There was an adjusted net increase of about 90 ha of PEM.

Table 38. Net change in marshes, intertidal flats, and lacustrine habitats from 1979-1992, Encinal Peninsula.

Habitat	1979 (ha)	1992 (ha)	1979 Adjusted	1992 Adjusted	Adjusted Net Change
E2EM	1	1	0	0	0
PEM	562	638	468	638	170
Total EM	**563**	**639**	**468**	**638**	**170**
E2FL	11	18	16	18	1
L1OW/L2	451	496	436	496	61

Table 39. Net change in marshes, intertidal flats, and lacustrine habitats from 1950's-1992, Encinal Peninsula.

Habitat	1950's (ha)	1992 (ha)	1950's Adjusted	1992 Adjusted	Adjusted Net Change
E2EM	5	1	5	0	-5
PEM	598	638	548	638	90
Total EM	**603**	**639**	**553**	**638**	**85**
E2FL	15	18	15	18	3
L1OW/L2	0	496	9	496	487

Probable Causes of Changes. *1950's-1992.* The loss of uplands and conversion of PEM to L1OW was real. On the other hand, the dynamics of PEM-U changes are less certain. In 1992, the fact that 129 ha of PEM were reclassified as uplands and 318 ha of uplands reclassified as PEM reflects the difficulty of distinguishing PEM1A from upland grasslands or upland/wetland transitional areas.

Fluvial-Deltaic System

As in other natural systems, there were losses and gains in marshes and tidal flats in the three fluvial-deltaic systems analyzed: Nueces, Aransas-Chiltipin, and Mission Rivers (Figs. 3 and 22). The fluvial-deltaic systems lie within valleys entrenched during the most recent Pleistocene sea-level low stand (Brown et al. 1976). Riparian woodlands, which were analyzed in the fluvial-deltaic systems, consist of forested and scrub-shrub wetlands as well as other forested areas that are within entrenched river valleys.

Nueces River

Estuarine Intertidal Marshes and Flats. *1950's-1992.* In the Nueces River valley (Tables 40-42), there was a small net loss of E2EM (34 ha) to E1OW (30 ha) and PEM (4 ha) (Table 42). E2EM/FL decreased by about 300 ha with conversions to E1OW (150 ha), uplands (130 ha), and PEM (17 ha). PEM gained 291 ha, mostly from uplands (249 ha). E2FL showed a net loss of 18 ha due to conversion to E1OW.

Riparian Woodlands. *1950's-1992.* PFO showed a net gain of 35 ha mostly from uplands (32 ha). PSS showed a 23 ha net gain from uplands. These changes were likely due to differences in photointerpretation and classification. Since the 1950's, there has been relatively little net change in the amount of forested riparian habitat.

Table 40. Net change in marshes, intertidal flats, and other habitats from the 1950's to 1979, Nueces River valley.

Habitat	1950's (ha)	1979 (ha)	1950's Adjusted	1979 Adjusted	Adjusted Net Change
E2EM	1280	3461	2581	2677	96
E2EM/FL	2967	4	299	103	-196
PEM	2584	1050	3798	3741	-56
Total EM	**6831**	**4516**	**6677**	**6522**	**-156**
E2FL.	439	895	647	677	30
PSS	274	27	153	74	-78
PFO	599	156	617	569	-47
Riparian Woodlands	873	183	770	643	-125
L1OW/L2	6	58	5	46	41

Table 41. Net change in marshes, intertidal flats, and other habitats from 1979 to 1992, Nueces River valley.

Habitat	1979 (ha)	1992 (ha)	1979 Adjusted	1992 Adjusted	Adusted Net Change
E2EM	3461	2547	2677	2547	-130
E2EM/FL	4	0	103	0	-103
PEM	1050	4089	3741	4089	347
Total EM	**4516**	**6635**	**6522**	**6635**	**114**
E2FL	895	629	677	629	-48
PSS	27	176	74	176	101
PFO	156	652	569	652	83
Riparian Woodlands	183	828	643	828	184
L1OW/L2	58	121	46	121	75

Table 42. Net change in marshes, intertidal flats, and other habitats from the 1950's to 1992, Nueces River valley.

Habitat	1950's (ha)	1992 (ha)	1950's Adjusted	1992 Adjusted	Adusted Net Change
E2EM	1280	2547	2581	2547	-34
E2EM/FL	2967	0	299	0	-299
PEM	2584	4089	3798	4089	291
Total EM	**6831**	**6635**	**6677**	**6635**	**-42**
E2FL	439	629	647	629	-18
PSS	274	176	153	176	23
PFO	599	652	617	652	35
Riparian Woodlands	873	828	770	828	58
L1OW/L2	6	121	5	121	116

Probable Causes of Change. *1950's-1992.* Gains in PEM and L1OW were the result of dredging along the Viola Channel, and creation of spoil impoundments. These gains were at the expense of the E2EM/FL and upland categories. A salt-marsh creation project converted about 80 ha of E2EM to E1OW and E2FL (Nicolau and Adams, 1993, Nicolau 1995).

Aransas River-Chiltipin Creek

Marshes. *1950's-1979.* Direct analysis of GIS digital data of habitat distribution from the 1950's to 1979 shows a net gain of 227 ha of estuarine marsh (E2EM and E2EM/FL) and a loss of 547 ha of palustrine marsh (Table 43). Part of the apparent palustrine loss was due to an interpretative classification change from PEM to E2EM. Marshes as a whole had a net loss of 324 ha. Approximately 60 ha of loss could be verified from photographs, but most of the remaining apparent loss in PEM (265 ha) appears to be from inconsistences in photointerpretation and registration problems. Analysis of aerial photographs indicates an actual spread of estuarine emergent vegetation into areas of estuarine intertidal flats.

1979-1992. During this period, there was an apparent increase in marsh habitat, primarily palustrine emergent wetlands in which a net gain of 349 ha was recorded (Table 44). Estuarine emergent wetlands (E2EM and E2EM/FL) increased by about 90 ha. Of the gross gains in E2EM, about 50 percent occurred in areas mapped as E2EM/FL in 1979, and 40 percent in areas mapped as uplands. Of the gross gains in PEM, about 35 percent occurred in upland areas, 30 percent in lacustrine areas, and 30 percent in E2EM areas. Except for the lacustrine area, other changes are due primarily to interpretation.

Table 43. Net change in marshes, intertidal flats, and other habitats from the 1950's-1979, Aransas River-Chiltipin Creek fluvial-deltaic system.

Habitat	1950's (ha)	1979 (ha)	Net change
E2EM	242	1016	774
E2EM/FL	665	118	-547
PEM	917	366	-551
Total EM	**1824**	**1500**	**-324**
E2FL	432	546	114
PSS	20	48	28
PFO	0	34	34

Table 44. Net change in marshes, intertidal flats, and other habitats from 1979-1992, Aransas River and Chiltipin Creek fluvial-deltaic system.

Habitat	1979 (ha)	1992 (ha)	Net Change
E2EM	1016	1225	209
E2EM/FL	118	0	-118
PEM	366	715	349
Total EM	**1500**	**1940**	**440**
E2FL, E2US	546	368	-178
PSS	48	29	-19
PFO	34	8	-26
Riparian Woodlands	758	769	11
Lacustrine	178	51	-127

Estuarine Intertidal Flats. *1950's-1979*. There was a net loss of about 115 ha of estuarine intertidal flats in the Aransas River and associated fluvial deltaic area from the 1950's to 1979. About 75 percent of the gross losses in flats was due to replacement by subtidal habitats including open water and seagrass beds.

1979-1992. Estuarine flats continued to decline from 1979 to 1992. Approximately 75 percent of the gross loss in tidal flats was due to replacement by E2EM.

Riparian Woodlands. *1979-1992.* Riparian woodlands in the Aransas and Chiltipin fluvial-deltaic system increased slightly (11 ha) from 1979 to 1992 (Table 44). Apparent loss of PSS and PFO is due primarily to photointerpretation. Analysis of aerial photographs indicate that woodland areas, overall, had more gains than losses.

Probable Causes of Changes. *1950's-1979-1992.* From 1950's to 1979, gains and losses in marshes in fluvial-deltaic areas of Aransas River, Chiltipin Creek, and the drainage south of Chiltipin resulted in an apparent net loss of more than 300 ha of marsh habitat as a result of losses in PEM that exceeded gains in E2EM (Table 43). Changes were primarily due to photointerpretation and map registration problems. Overall, it appears that estuarine emergent vegetation had a limited expansion into flats. This is reflected in Table 43, which shows gains in E2EM and losses in E2EM/FL.

Losses in tidal flats were largely due to (1) conversion to subtidal areas, which accounted for 75 percent of the gross loss, and (2) replacement by estuarine intertidal marsh accounting for about 15 percent. There was an actual loss of about 60 ha of PEM north of the Aransas River as a result of inundation and formation of a lake (lacustrine system). This water feature is connected to the Aransas River and water levels dropped in 1992 allowing vegetation to become re-established. Almost 120 ha of the apparent 350 ha gain in PEM from 1979 to 1992 occurred in this area mapped as lacustrine in 1979. The net gain in E2EM and loss of E2FL from 1979 to 1992 and the 1950's to 1992 (Table 45) is believed in part related to rise in relative sea level.

Table 45. Net change in marshes, tidal flats, and other habitats from the 1950's-1992, Aransas River and Chiltipin Creek fluvial-deltaic system.

Habitat	1950's (ha)	1992 (ha)	Net Change
E2EM	242	1225	983
E2EM/FL	665	0	-665
PEM	917	715	-202
Total EM	**1824**	**1940**	**116**
E2FL	432	368	-64
PSS	20	29	9
PFO	0	8	8

Mission River

Marshes. *1950's-1979.* Aerial photographic analysis indicates few changes in this fluvial deltaic system except locally where emergent vegetation spread over wind-tidal flats. This change is reflected in part by expansion of E2EM and reduction in E2EM/FL (Table 46). Estuarine intertidal marshes were mapped farther up the river valley in 1979 than in the 1950's, indicating a conversion of PEM to E2EM in some areas. Analysis of changes before adjustments were made, indicates that marshes (E2EM, E2EM/FL, and PEM) decreased in area in the Mission River fluvial deltaic system between the 1950's and 1979. After adjustments for photointerpretation inconsistences, a net gain in emergent wetlands was realized. The apparent increase in flats, as shown in Table 46, is due to photointerpretation and is the result of a more concerted effort by interpreters to subdivide emergent vegetation and flats on the 1979 CIR aerial photographs. From the 1950's to 1979, a more realistic appraisal of the changes in flats would be to assume no change, and that E2EM/FL in the 1950's included areas that should have been mapped only as E2FL. To make adjustments, 278 ha (the difference between the 1950's and 1979 E2FL) was subtracted from the E2EM/FL resource in the 1950's and this amount was added to E2FL. This adjustment produced a net gain of 166 ha in emergent vegetation (E2EM, E2EM/FL, and PEM) (Table 46).

Table 46. Net change in marshes, intertidal flats, and other habitats from the 1950's-1979, Mission River.

Habitat	1950's (ha)	1979 (ha)	1950's Adjusted	Adjusted net change
E2EM	79	728	79	649
E2EM/FL	774	255	496	-241
PEM	594	352	594	-242
Total EM	**1447**	**1335**	**1169**	**166**
E2FL	22	300	300	0
PSS	196	31	196	-165
PFO	13	50	13	37

1979-1992. There was an apparent net gain of more than 200 ha in estuarine marshes (E2EM + E2EM/FL) in the Mission River fluvial-deltaic area from 1979 to 1992. A small net loss in palustrine emergent wetlands produced a total gain in emergent marshes of less than 200 ha (Table 47).

Estuarine Intertidal Flats. *1950's-1979.* Unadjusted data indicate that estuarine intertidal flats increased from the 1950's to 1979, but this is a reflection primarily of differences in aerial photointerpretation and inclusion of too many E2FL areas in E2EM/FL class in the 1950's. To make adjustments, we increased the area of E2FL for the 1950's so there was effectively no change from the 1950's to 1979.

1979-1992. Estuarine intertidal flats had a small net gain of less than 70 ha from 1979 to 1992. This was an apparent change due mostly to photointerpretation.

Table 47. Net change in marshes, intertidal flats, and other habitats from 1979-1992, Mission River.

Habitat	1979 (ha)	1992 (ha)	Net change
E2EM	728	1224	496
E2EM/FL	255	0	-255
PEM	352	305	-47
Total EM	**1335**	**1529**	**194**
E2FL	300	367	67
PSS	31	0	-31
PFO	50	2	-48
Riparian Woodlands	214	226	12

Riparian Woodlands. *1979-1992.* Riparian woodlands in the entrenched Mission River fluvial-deltaic area increased in area by about 12 ha (Table 47). Apparent loss in PSS and PFO is due to photointerpretation and inclusion of woodlands in the palustrine system in 1979 and the 1950's, and in the upland system in 1992. Much loss in the 1950's PSS was due to mapping of a mixed class, PSS/EM, that was classified only as PEM in 1979 and 1992. The area in question could have been mapped as PEM in the 1950's as well. Woodlands changed very little overall, with gains exceeding losses.

Probable Causes of Changes. *1950-1979-1992.* Changes were not extensive in the Mission River delta and were more reflective of photointerpretation differences on the 1950's and 1979 and 1992 aerial photographs. However, the increase in E2EM and decrease in E2EM/FL (Table 48) indicates an actual expansion of emergent vegetation into areas of intertidal flats. This was verified on aerial photographs. Increase in emergent vegetation may be due in part to sea-level rise contributing to more frequent inundation of flats and subsequent expansion of emergent vegetation.

Table 48. Net change in marshes, intertidal flats, and other habitats from the 1950's-1992, Mission River.

Habitat	1950's (ha)	1992 (ha)	1956 Adjusted	Adjusted Net Change
E2EM	79	1224	79	1145
E2EM/FL	774	0	496	-496
PEM	594	305	594	-289
Total EM	**1447**	**1529**	**1169**	**360**
E2FL	22	367	300	67
PSS	196	0	196	-196
PFO	13	2	13	-11

Selected Bays and Associated Topographically Low Mainland Areas

This system encompasses selected bays and associated adjacent lowlands. Included are Corpus Christi Bay-Upper Laguna Madre-Oso Bay, Redfish Bay, Port Bay, and Laguna Larga (Fig. 22). In Port Bay and Laguna Larga, wetland trends in the higher areas are among the most complex to decifer because of variable moisture levels and gently sloping landscapes characterized by topographically high marsh and transitional areas. Vegetation, in many areas is predominately *S. spartinae*, and delineation on aerial photographs was inconsistent from year to year.

Corpus Christi Bay – Upper Laguna Madre – Oso Bay

Marshes. *1950's –1992.* Tables 49-51 present habitat changes. This analysis was complicated by differential use of the E2EM/FL mixed category. This category was not used in 1992. There was an adjusted net gain of 358 ha of E2EM, coming mostly from E2FL (262 ha) and uplands (81 ha). About 285 ha of E2EM/FL was lost to E1OW (98 ha), uplands (107 ha), and L1OW (65 ha), independent of reclassification of the E2EM/FL category. There was a 68 ha gain of PEM coming mostly from uplands (28 ha) and E2FL (27 ha).

Table 49. Net change in marshes, intertidal flats, and other habitats from the 1950's-1979, Corpus Christi Bay–Upper Laguna Madre.

Habitat	1950's (ha)	1979 (ha)	1950's adjusted	1979 Adjusted	Adusted net Change
E2EM	271	461	418	537	120
E2EM/FL	636	232	285	60	-225
PEM	35	54	40	32	-7
Total EM	**943**	**747**	**742**	**629**	**-113**
E2FL	3151	1396	3058	1549	-1509

Table 50. Net change in marshes, intertidal flats, and other habitats from 1979-1992, Corpus Christi Bay–Upper Laguna Madre.

Habitat	1979 (ha)	1992 (ha)	1979 Adjusted	1992 Adjusted	Adusted net Change
E2EM	461	776	537	776	239
E2EM/FL	232	0	60	0	-60
PEM	54	107	32	107	75
Total EM	**747**	**883**	**629**	**883**	**254**
E2FL	1396	957	1549	957	-592

Table 51. Net change in marshes, intertidal flats, and other habitats from the 1950's-1992, Corpus Christi Bay–Upper Laguna Madre.

Habitat	1950's (ha)	1992 (ha)	1950's Adjusted	1992 Adjusted	Adusted net Change
E2EM	271	776	418	776	358
E2EM/FL	636	0	285	0	-285
PEM	35	107	40	107	68
Total EM	**943**	**883**	**742**	**883**	**141**
E2FL	3151	957	3058	957	-2101

Estuarine Intertidal Flats. *1950's-1992.* Table 51 shows an adjusted net loss of 2,100 ha of E2FL to E1OW (926 ha), E2EM (262 ha), L1OW (214 ha), uplands (563 ha), and POW (110 ha).

Probable Causes of Changes. *1950's-1992.* Many spoil containment areas were developed prior to 1979, and this was the main reason for losses of E2FL and E2EM/FL and gains in uplands, L1OW, and PEM. At the White's Point Oil Field, 135 ha of E2FL were converted to E1OW (63 ha) and E2EM (72 ha). Dredge and fill along the ship channel created upland, L1OW, and POW areas mostly at the expense of E2FL habitat.

Oso Bay Subunit. *1950's-1992.* In Oso Bay, there was a loss of E2FL (272 ha) and a gain of E2EM (117 ha) (Table 52), much of which occurred at a sewage plant outfall near Suter Park (Fig. 36). The input of fresh water and nutrients accounted for this expansion of E2EM.

Table 52. Net change in marshes, intertidal flats, and other habitats from the 1950's-1992, Oso Bay. Numbers presented are included in preceding Tables 49, 50, and 51.

Habitat	1950's (ha)	1992 (ha)	1950's Adjusted	1992 Adjusted	Adjusted Net Change
E2EM	33	261	144	261	117
E2EMFL	73	0	18	0	-18
PEM	17	34	23	34	11
Total EM	**123**	**295**	**184**	**295**	**111**
E2FL	773	444	716	444	-272

Redfish Bay

Marshes. *1950's-1979.* The Redfish Bay area consists almost entirely of estuarine habitats (Table 53). From the 1950's to 1979, there was an expansion of estuarine intertidal marsh (E2EM) of about 225 ha and a small decrease in estuarine intertidal marsh and flat, undifferentiated (E2EM/FL) (Table 53). The total change in emergent vegetation was a net gain of almost 200 ha, and including E2SS exceeded 200 ha.

Table 53. Net change in marshes and intertidal flats from the 1950's-1979, Redfish Bay.

Habitat	1950's (ha)	1979 (ha)	Net Change
E2EM	54	278	224
E2EM/FL	176	148	-28
E2SS	0	15	15
PEM	0	2	2
Total EM, SS	**230**	**443**	**213**
E2FL	708	111	-597

1979-1992. The trend toward a net increase in emergent vegetation that was begun in the preceding period in Redfish Bay continued from 1979 to 1992, although at a slower rate. There was a net gain of 7 ha of marsh and scrub-shrub (Table 54). Gain in PEM was a photointerpretation class change in the interior and higher portions of an island formerly (1979) mapped as E2EM.

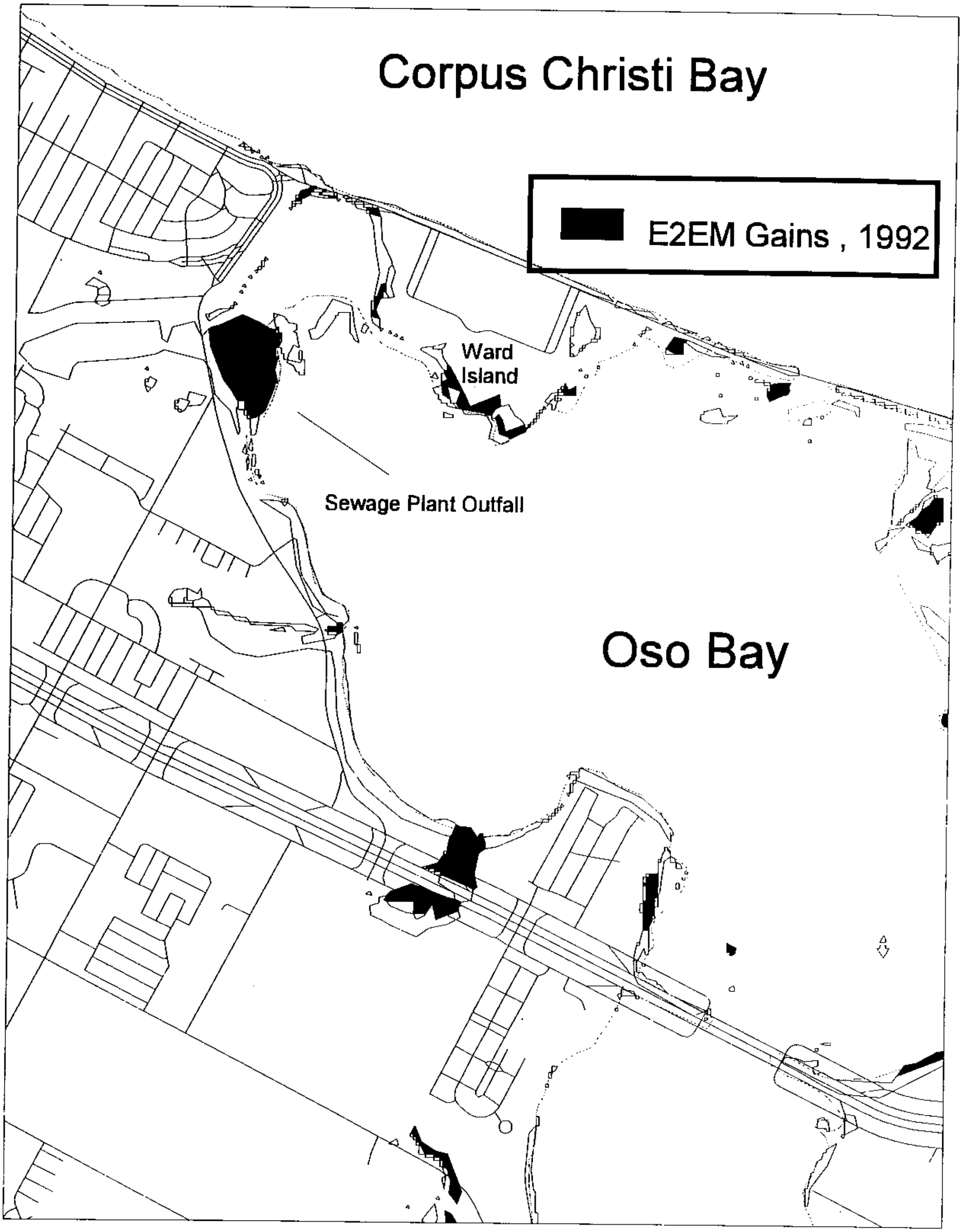


Figure 36. Increase of E2EM at sewage plant outfall on Oso Bay, 1950's-1992.

Table 54. Net change in marshes and intertidal flats from 1979-1992, Redfish Bay.

Habitat	1979 (ha)	1992 (ha)	Net Change
E2EM	278	414	136
E2EM/FL	148	0	-148
E2SS	15	6	-9
PEM	2	30	28
Total EM, SS	**443**	**450**	**7**
E2FL	111	87	-24

Estuarine Intertidal Flats*. 1950's-1979.* The most extensive change in Redfish Bay was a net loss of almost 600 ha of intertidal flats. An area of approximately 700 ha in the 1950's was reduced to about 110 ha by 1979.

1979-1992. There was a continuing decline in estuarine intertidal flats of almost 25 ha from 1979 to 1992.

Probable Causes of Changes. *1950's-1979-1992.* Loss in tidal flat from the 1950's to 1979 occurred as approximately 65 percent was converted to subtidal environments and 30 percent to estuarine marsh. Much of this change was apparently a result of accelerated relative sea-level rise from the mid 1960's to 1975 (Fig. 24), which inundated some flats and increased the frequency of flooding of others. Some loss was a result of dredging of the GIWW in the late 1950's and disposing of dredged material on the flats. By 1979, however, inundation of the margins of the dredged material led to expansion of emergent vegetation in these areas; this expansion continued from 1979 to 1992. Expansion of marshes over flats is in part reflected by a conversion of E2EM/FL and E2FL to E2EM from 1950's and 1979 to 1992 (Tables 54-55). More than 50 percent of the gross gain in E2EM occurred in areas formerly mapped as E2EM/FL and E2FL.

Table 55. Net change in marshes and intertidal flats from the 1950's-1992, Redfish Bay.

Habitat	1950's (ha)	1992 (ha)	Net Change
E2EM	54	414	360
E2EM/FL	176	0	-176
E2SS	0	6	6
PEM	0	30	30
Total EM, SS	**230**	**450**	**220**
E2FL	708	87	-621

Port Bay Area

***Marshes**. 1950's-1979.* Major adjustments in marsh distribution had to be made in the Port Bay area. The major problem was caused by inconsistent delineations of a large *S. spartinae* marsh southwest of Port Bay that was mapped as PEM in the 1950's and 1992, but mapped as uplands in 1979. Analysis of aerial photographs indicates that this marsh, despite being crossed by drainage channels (Fig. 35b), did not change significantly from the 1950's to 1992 and should have been mapped as marsh on 1979 aerial photographs. This marsh encompassed about 470 ha on the 1950's map and 650 ha on the 1992 map. Accordingly, 560 ha was added to the total PEM habitat for 1979. In addition, a review of photographs taken in 1952 and 1958 of areas around Port Bay indicates more PEM could have been delineated on the 1950's photographs. In fact, about 75 percent of an apparent 530 ha PEM gain from 1950's to 1979 west of Port Bay can be eliminated because of this. These two adjustments reduced the net gain of PEM between the 1950's and 1979 (Table 56). In addition, a smaller error was made on the 1950's maps, in which an E2EM area of 45 ha was mistakenly mapped as E1AB. In the adjusted net changes shown in Table 56, this area was added to the 1950's E2EM habitat total. Considering these adjustments, there was a net loss of about 110 ha in the estuarine marsh (E2EM and E2EM/FL), and a larger net gain of 125 ha in palustrine marsh (PEM). The overall change in the marsh resource was a gain of 15 ha from the 1950's to 1979 (Table 56). Net gains occurred in areas both east and west of Port Bay.

Table 56. Net change in marshes and intertidal flats from the 1950's-1979, Port Bay area.

Habitat	**1950's (ha)**	**1979 (ha)**	**1950 Adjusted**	**1979 Adjusted**	**Adjusted Net Change**
E2EM	609	1389	654	1389	735
E2EM/FL	1140	295	1140	295	-845
PEM	978	940	1375	1500	125
Total EM	**2727**	**2624**	**3169**	**3184**	**15**
E2FL	437	320	437	320	-117

1979-1992. An apparent net loss of more than 300 ha in estuarine marsh occurred between 1979 and 1992, but the loss was more than offset by a larger net gain, > 400 ha, in palustrine marsh after adjustments were made for 1979 photointerpretation inconsistencies. Considering all areas of emergent vegetation, there was net gain of almost 140 ha (Table 57). Gains in PEM were in part due to reclassification of 1979 E2EM areas to PEM in 1992.

Table 57. Net change in marshes and intertidal flats from 1979-1992, Port Bay area.

Habitat	**1979 (ha)**	**1992 (ha)**	**1979 Adjusted**	**Adjusted Net Change**
E2EM	1389	1341	1389	-48
E2EM/FL	295	0	295	-295
PEM	940	1980	1500	480
Total EM	**2624**	**3321**	**3184**	**137**
E2FL	320	205	320	-115

Estuarine Intertidal Flats. *1950's-1979*. Intertidal flats in the Port Bay area decreased by more than 100 ha from the 1950's to 1979. About 80 percent of the gross losses in E2FL occurred from conversions to subtidal habitats, primarily, and to E2EM habitats, secondarily.

1979-1992. Estuarine intertidal flats continued their decline from 1979 to 1992, decreasing in net area by 115 ha. Most of the gross loss occurred as estuarine flats were replaced by estuarine marsh.

Probable Causes of Changes. *1950's-1979-1992.* As discussed previously, many changes in the Port Bay area, including some changes from E2EM to PEM, were due to differences in photointerpretation of the 1950's, 1979, and 1992 aerial photographs.

Eighty percent of the gross loss in E2EM/FL was to E2EM from 1979 to 1992. Although some change was due to photointerpretation, much was real indicating a spread of emergent vegetation into areas formerly characterized by estuarine flats. These changes were verified on aerial photographs, and were more apparent in intertidal flats near the head of Port Bay. From the 1950's to 1992, there were net gains in marshes and net losses in intertidal flats (Table 58).

Table 58. Net change in marshes and intertidal flats from the 1950's-1992, Port Bay area.

Habitat	**1950's (ha)**	**1992 (ha)**	**1950's Adjusted**	**Adjusted Net Change**
E2EM	609	1341	654	687
E2EM/FL	1140	0	1140	-1140
PEM	978	1980	1375	605
Total EM	**2727**	**3321**	**3169**	**152**
E2FL	437	205	437	-232

Many gains and losses in palustrine marshes are also due to interpretaton. Much of the PEM habitat is PEM1A, a topographically high, infrequently flooded marsh bordering on a classification of upland prairie. Therefore, interpreters had difficulty in defining the upland-wetland break consistently. Although there was a net gain in marsh habitat, losses did occur. One example is in the Bayside quadrangle east of Port Bay where between the 1950's and 1979, about 60 ha of estuarine marsh was flooded by a dam constructed across an entrenched drainage into Swan Lake on the edge of Copano Bay (Fresh Water Lake on Bayside quadrangle) (Fig. 37). The area behind the dam was mapped as estuarine in 1979 and lacustrine in 1992. From 1979 to 1992, there was an increase in marsh vegetation along the margins of the lake, offsetting some of the 1950's to 1979 marsh loss due to impoundment. Another example of marsh loss resulted from construction of tailing ponds east of Port Bay (Fig. 37); about 20 ha of estuarine marsh was displaced. Of the gross losses in estuarine marsh from 1979 to 1992, 50 percent was mapped as uplands, and 30 percent was changed to palustrine marsh (PEM). Much of the change to uplands was due to photointerpretation. Many areas, for example, west of Port Bay mapped as high palustrine marsh in 1979 (Fig. 21) could have been mapped as marsh in the 1950's and 1992. Almost all of the larger areas of high marsh have drainage ditches crossing them to reduce flooding and ponding of water (Fig. 38). Most ditches were dug before the 1950's, however, so they would have affected moisture levels for each period (1950's, 1979, and 1992). Variations in the extent to which high marshes were delineated is in part a reflection of the moisture levels at the time photographs were taken.

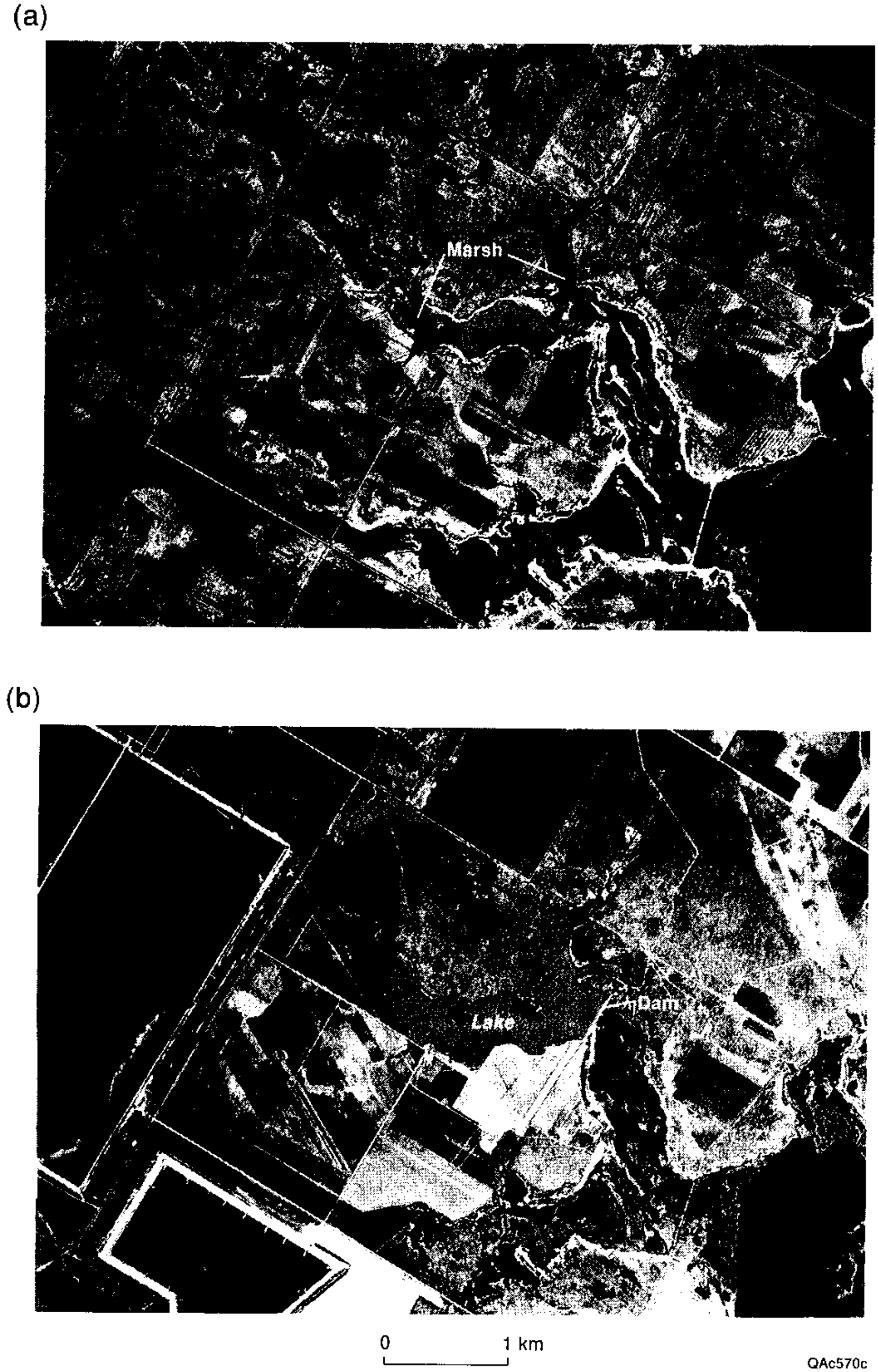


Figure 37. Example of marsh loss from a small impoundment west of Port Bay as illustrated by aerial photographs taken in (a) 1952 and (b) 1979.

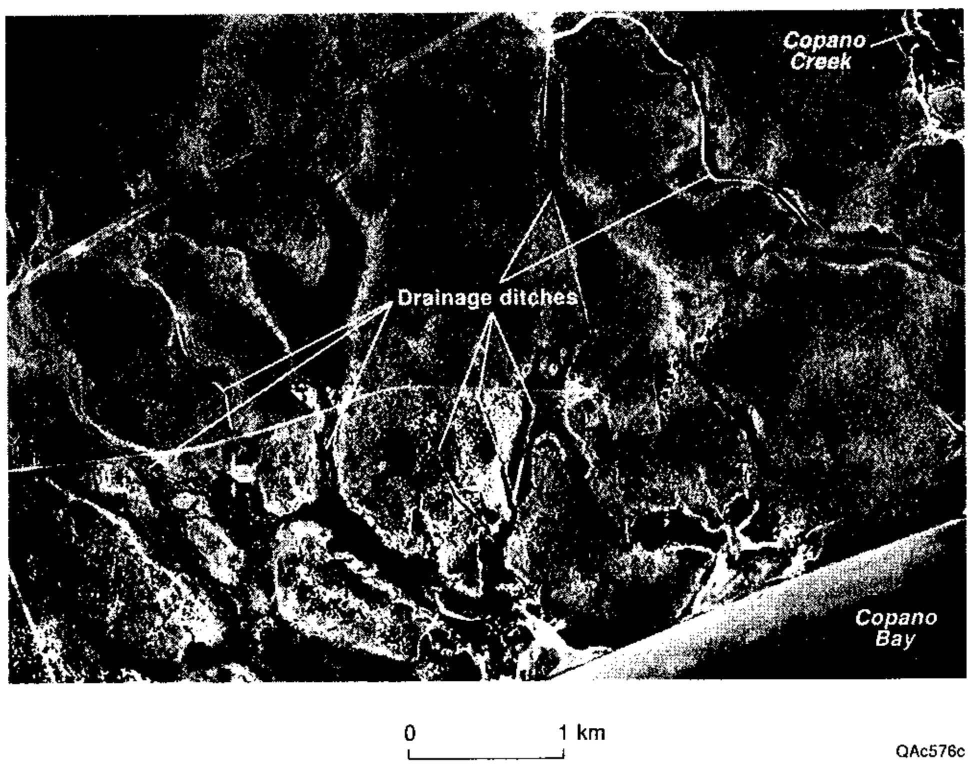


Figure 38. Example of drainage ditches in marshes north of Copano Bay and east of Copano Creek in the Lamar Quadrangle. Photograph was taken in October 1952.

Laguna Larga

Marshes. *1950's-1992.* Tables 59-61 show habitat changes for this region. From the 1950's to 1992, PEM gained 737 ha from uplands and lost 177 ha to uplands for a net increase of 560 ha. About 83 percent of the PEM gain was due to reclassification of uplands as PEM1A in 1992. Overall, PEM showed an adjusted net increase of about 122 ha (Table 61).

Lacustrine. *1950's-1992.* All L1OW changes were within the Laguna Larga depression. A gain of 606 ha and a loss of 90 ha gave a net gain of 516 ha of L1OW. About 89 percent of the gain (540 ha) came from the PEM category; mostly (98 percent) from PEM1C.

Table 59. Net change in marshes and lacustrine habitats from the 1950's-1992, Laguna Larga.

Habitat	1950's	1979	1950's Adjusted	1979 Adjusted	Adjusted Net Change
PEM	2560	3432	3421	3648	227
L1OW/L2	1289	1361	1225	1326	101
POW/PFL	28	24	21	21	0
PSS/EM/OW	83	0	48	22	-26
U	8230	7373	7476	7174	-302

Table 60. Net change in marshes and lacustrine habitats from 1950's-1992, Laguna Larga.

Habitat	1979 (ha)	1992 (ha)	1979 Adjusted	1992 Adjusted	Adjusted NetChange
PEM	3432	3543	3648	3543	-105
L1OW/L2	1361	1741	1326	1741	415
POW/PFL	24	17	21	17	-4
PSS/EM/OW	0	50	22	50	29
U	7373	6839	7174	6839	-335

Table 61. Net change in marshes and lacustrine habitats from 1950's-1992, Laguna Larga.

Habitat	1950's (ha)	1992 (ha)	1950's Adjusted	1992 Adjusted	Adjusted Net Change
PEM	2560	3543	3421	3543	122
L1OW/L2	1289	1741	1225	1741	517
POW/PFL	28	17	21	17	-4
PSS/EM/OW	83	50	48	50	2
U	8230	6839	7476	6839	-637

Probable Causes of Change. *1950's-1992.* Spatially, most upland change occurred along drainageways and appeared to be wetland/upland transitional areas. Overdelineation of PEM1A in 1992 has been mentioned. It seems likely that the L1OW changes were the result of photointerpretation and classification differenes caused by fluctuating lake water levels. Eutrophication due to nonpoint source pollution and efforts to drain the basin may have also affected the distribution of PEM in Laguna Larga.

Coastal Plain System

The coastal plain system encompasses mainland areas inland from Corpus Christi and Copano Bays (Fig. 22). Most of the area is characterized by cropland and rangeland. In addition to broad flat coastal prairies, however, it includes small entrenched intertidal to supratidal valleys, creeks, and bayous along the northern and western shore of Copano Bay.

Corpus Christi Bay Coastal Prairie

Marshes and Ponds. *1950's-1979.* Depressional wetlands and ponds are scattered across the coastal plain. Many of these small prairie potholes (PEM = 135 ha) and ponds (POW = 67 ha) (Table 62) were lost to agriculture prior to 1979. About 1,400 PEM and POW habitats averaging about 0.2 ha were lost; about 90 percent of those losses were to upland agriculture.

1950's-1992. Gains (126 ha) and losses (171 ha) of PEM resulted in a net loss of 45 ha. There was a net loss of 78 ha of PSS; 95 ha of loss and 17 ha of gain. About 75 percent of PSS loss was to agriculture.

Impoundments. *1950's-1979.* An adjusted net increase of 179 ha of L1OW due to enlargement of tailing ponds occurred at an aluminum plant near Portland (Table 62). About 218 ha of uplands were converted to L1OW.

Table 62. Net change in marshes, lacustrine, and other habitats from the 1950's-1979, Corpus Christi Bay Coastal Plain.

Habitat	1950's (ha)	1979 (ha)	1950's adjusted	1979 Adjusted	Adjusted Net Change
E2EM	4	9	1	5	4
E2EM/FL	30	0	14	0	-14
PEM	328	85	326	192	-135
Total EM	**363**	**95**	**341**	**197**	**-144**
L1OW/L2	73	246	77	257	179
POW/PFL	260	218	212	144	-67
PFO/EM/SS	37	7	31	27	-5
PSS/EM/OW	207	36	131	46	-85

1979 -1992. Total emergent marsh showed a net increase (Table 63) due to an increase of PEM within large impoundments previously classified as upland areas. Uplands had an adjusted net decrease of about 170 ha.

1950's-1992. There was a net adjusted increase of 175 ha of L1OW for the region (Table 64).

Table 63. Net change in lacustrine and other habitats from 1979-1992, Corpus Christi Bay Coastal Plain.

Habitat	1979 (ha)	1992 (ha)	1979 Adjusted	1992 Adjusted	Adjusted Net Change
E2EM	9	1	5	1	-4
E2EM/FL	0	0	0	0	0
PEM	85	281	192	281	89
Total EM	**95**	**281**	**197**	**281**	**85**
L1OW/L2	246	253	257	253	-4
POW/PFL	218	206	144	206	61
PFO/EM/SS	7	53	27	53	26
PSS/EM/OW	36	52	46	52	6

Table 64. Net change in lacustrine and other habitats from the 1950's-1992, Corpus Christi Bay Coastal Plain.

Habitat	1950's (ha)	1992 (ha)	1950's Adjusted	1992 Adjusted	Adjusted Net Change
E2EM	4	1	1	1	0
E2EM/FL	30	0	14	0	-14
PEM	328	281	326	281	-46
Total EM	**363**	**281**	**341**	**281**	**-60**
L1OW/L2	73	253	77	253	175
POW/PFL	260	206	212	206	-6
PFO/EM/SS	37	53	31	53	21
PSS/EM/OW	207	52	131	52	-78

Probable Causes of Changes. *1950's -1992.* Loss of palustrine wetlands (PEM, POW, PSS) was due to agricultural development. Most of the PEM and POW losses were comprised of small, scattered depressional wetlands. About 50 percent of PEM gains (68 ha) resulted from reclassification of uplands within drainageways and may not be real gains but differences in photointerpretation.

Coastal Plain Inland from Copano and St. Charles Bays

Marshes. *1950's-1979.* There was a substantial apparent net gain in both estuarine and palustrine marshes inland (northwest) of Copano Bay from the 1950's to 1979 (Table 65). The largest gains occurred northeast of Mission Bay in the Lamar and Tivoli SW quadrangles. This map area includes Copano Creek, Mullens Bayou, Salt Creek, and Willow Creek and wetlands at the mouth of Mission Bay (Mission Bay and Bayside quadrangles). Losses in the E2EM/FL class were offset by gains in E2EM, yielding a net increase in estuarine marsh of approximately 400 ha. There was a similar gain in PEM of almost 400 ha (Table 65). Much of the change in marshes, however, is interpretational and largerly dependent on moisture levels at the time aerial photographs were taken. Among the real changes, however, was a spread of estuarine emergent vegetation into estuarine flats. This change is reflected in part by the loss of E2EM/FL and gain in E2EM.

Table 65. Net change in marshes and intertidal flats from the 1950's-1979, Copano Bay Coastal Plain.

Habitat	1950's (ha)	1979 (ha)	1950's Adjusted	Adjusted Net Change
E2EM	903	2352	903	1449
E2EM/FL	1285	244	1285	-1041
PEM	1650	2044	1637	394
Total EM	**3838**	**4640**	**3838**	**802**
E2FL	908	522	738	-216

1979-1992. There was an apparent net loss of more than 400 ha of estuarine marsh from 1979-1992 (Table 66). Most of the loss occurred in the 1979 E2EM/FL class, which was mapped primarily as E2EM in 1992. These changes occurred at the mouths of Mission Bay and other entrenched drainages on the northern margin of Copano Bay and St. Charles Bay. Some losses in estuarine marsh occurred in Burgentine Lake at the head of St. Charles Bay. About half of this lake is in the Blackjack Peninsula area of analysis. Almost 50 ha of estuarine marsh along the margins of the lake in 1979 were submerged in 1992 and replaced by lacustrine open water (L1UB). Primarily due to interpretation, more than 150 ha of E2EM extending landward from Copano Bay on the northeast side of Mission Bay was mapped as uplands in 1992; this accounts for much of the loss in E2EM. There was a small net change in PEM (Table 66), that resulted from relatively large gross losses offset by gains.

Table 66. Net change in marshes and intertidal flats from 1979-1992, Copano Bay Mainland Coastal Plain.

Habitat	1979 (ha)	1992 (ha)	Net Change
E2EM	2352	2158	-194
E2EM/FL	244	0	-244
PEM	2044	2004	-40
Total EM	**4640**	**4162**	**-478**
E2FL	522	331	-191

Estuarine Intertidal Flat. *1950's-1979.* Estuarine intertidal flats decreased in area from 1950's to 1979. Photo analysis shows a spread of emergent vegetation in some estuarine flats, but about 170 ha of the gross loss in flats was to subtidal habitats such as open water. Much of this loss is not real but misinterpretation on 1950's photographs; a strip of subtidal bay margin sand was interpreted as intertidal estuarine flats along the northern shore of Copano Bay. This misclassification may have been due in part to low tides. Substracting the 170 ha from the 1950's estuarine flat yields an adjusted net loss of 216 ha (Table 65).

1979-1992. Estuarine intertidal flats continued to decline in area from 1979 to 1992 (Table 66). Losses occurred along Copano Creek and in intertidal areas of other entrenched drainages into Copano Bay. Most tidal flats were replaced by estuarine marsh.

Probable Causes of Changes. *1950's-1979-1992.* The apparent net gain of more than 800 ha of marsh habitat from 1950's to 1979 and the net loss of more than 475 ha from 1979 to 1992 yielded a net gain of about 325 ha from 1950's to 1992 (Table 67). Net loss in emergent vegetation from 1979 to 1992 is in large part a result of photointerpretation. The mainland area of Copano Bay, especially between Mission Bay and St. Charles Bay, has numerous relict, subtle entrenchments that slope toward Copano Bay. Most have drainage ditches dug before the 1950's (Fig. 38). High marshes and prairie grasslands have developed in these areas, and distinction and classification depend on existing moisture levels. Many changes in higher marshes are thus interpretational. Changes include a reclassification of some 1950's/1979 interior E2EM areas to PEM in 1992.

Table 67. Net change in marshes and intertidal flats from 1950's-1992, Copano Bay Mainland Coastal Plain.

Habitat	1950's (ha)	1992 (ha)	1950's Adjusted	Adjusted Net Change
E2EM	903	2158	903	1255
E2EM/FL	1285	0	1285	-1285
PEM	1650	2004	1637	367
Total EM	**3838**	**4162**	**3838**	**324**
E2FL	908	331	738	-407

Among real trends was conversion of estuarine intertidal flats to estuarine marsh. From 1979 to 1992, more than 85 percent of the gross loss in intertidal flat and 95 percent of the loss in E2EM/FL was due to conversion to estuarine marsh (E2EM). Growth of emergent vegetation over flats occurred along Copano Creek and other creeks and bayous as well as at the mouth of Mission Bay and tidal inlets to the southwest toward the Aransas River. Some losses in estuarine marsh and flat occurred in Burgentine Lake at the head of St. Charles Bay from impounded water in 1992 that submerged 1979 fringing marshes and estuarine flats. Water levels in Burgentine Lake are managed using a water control structure.

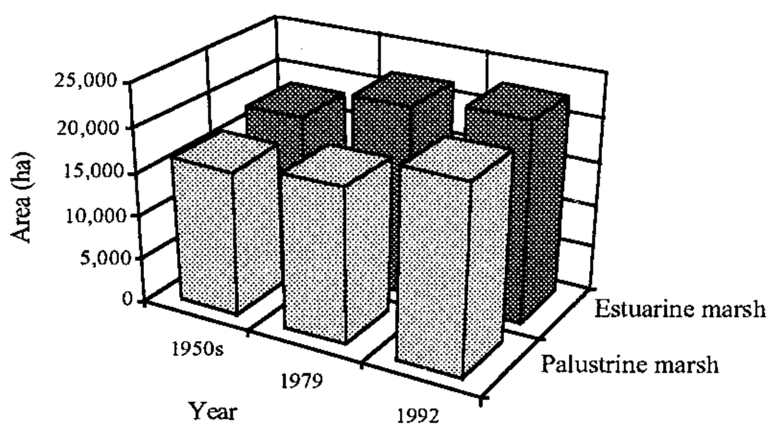
C. Summary of Trends

The general trend in wetland habitats in the CCBNEP study area from the 1950's to 1992 was one of marsh gains and tidal flat losses (Figs. 39-40). The largest increase in estuarine marshes occurred from the 1950's to 1979, the period that coincides with the largest decrease in intertidal flats (Fig. 40). From 1979 to 1992, estuarine marshes continued to increase and intertidal flats continued to decrease but at slower rates. Similar to estuarine marshes, palustrine marshes increased during both periods, with the largest increase occurring from 1979 to 1992 (Figs. 39–40). This trend of palustrine marsh increase does not hold for most of the Texas coast; Moulton et al. (1997) showed large decreases in palustrine marsh along the entire coast.

Because of inconsistencies in photointerpretation for different periods, emphasis is placed on the direction of trends rather than magnitude, even though adjustments were made to lessen photointerpretation effects. Nevertheless, subdivision of the study area into 18 areas (Fig. 22) for analysis revealed consistent trends: expansion of marshes and decline of intertidal flats. The most extensive losses in intertidal flats occurred on barrier islands. From the 1950's to 1992 there was a net loss in area of more than 6,000 ha, the largest loss (>2,300 ha) occurring on Mustang Island. Largest gains in estuarine marshes occurred on barrier islands, exceeding 3,900 ha from the 1950's to 1992; about 65 percent of the increase was on San José Island. Palustine marshes had greatest gains (>1,400 ha) on barrier islands, with Padre Island having the largest gain at more than 650 ha.

There is evidence that much of the decline in intertidal flats and expansion of estuarine marshes is related to relative sea-level rise. The large decline in tidal flats from the 1950's to 1979 coincides with an accelerated rise in relative sea level from the mid 1960's to mid 1970's. The average annual rate of rise during this period (1.7 cm/yr) was more than three times the rate from the mid 1970's to early 1990's (0.48 cm/yr). Tidal flats were permanently inundated in many areas, and replaced by seagrass beds or open water. On upper margins of the flats, salt marshes expanded. In the interior of barrier islands, palustrine marshes increased in total area. We believe that as relative sea level rises, the fresh-water lens, recharged by precipitation, also rises, creating wetter surface conditions and leading to more abundant and widespread hydrophytic vegetation. This scenario is supported by observations of environments on Padre Island National Seashore

(a)



(b)

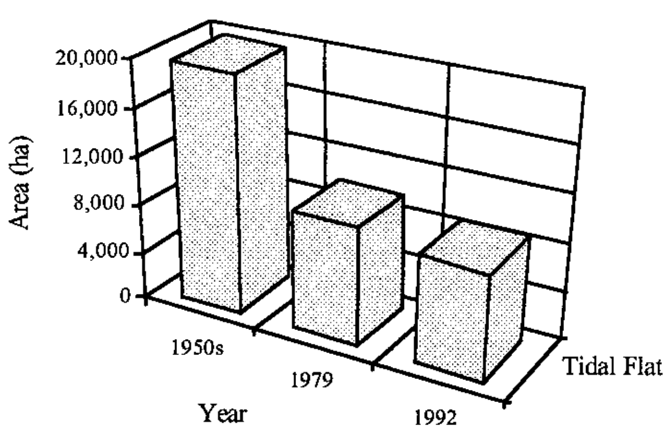


Figure 39. Area of (a) palustrine and estuarine marshes and (b) estuarine intertidal flats in the CCBNEP study area from the 1950's to 1992.

where active back island dunes have become stabilized by vegetation, and deflation areas and vegetated barrier flats have become wetter and marshes more extensive (Paul Eubanks, Padre Island National Seashore, personal communication, 1997). Furthermore, recent baseline studies of plant species on Mustang Island State Park indicate the presence of hydrophytic species not reported in previous plant surveys of Mustang and North Padre Island (Jenkins and Smith, 1997).

Although the general net trend was one of marsh gains, there were also marsh losses. Among the more prominent losses were pothole wetlands on the Pleistocene barrier strandplain (Live Oak Peninsula/Ridge) and the coastal plain. These depressional wetlands, though small (many <0.2 ha), are important natural resources (Collins, 1987) that generally have not been protected by regulation. On the coastal plain, many have been converted to uplands for agricultural purposes. On Live Oak Peninsula/Ridge, they have been quarried for sand resources, and filled and drained as the peninsula was developed.

Additional losses in marshes and tidal flats have occurred from dredging and filling activities for development of marinas, navigation channels, and residential and commercial development. Along high energy shores, marshes have been lost due to erosion (Paine and Morton, 1993; White and Calnan, 1990, Morton and Paine, 1990). Additional losses have been caused by human activities and natural processes (Table 68).

The areal distribution of riparian woodlands increased in all three fluvial-deltaic systems. The largest increase, from 1979 to 1992, was in the Nueces River valley and exceeded 180 ha. The Aransas-Chiltipin and Mission River valleys had small gains totaling slightly more than 20 ha.

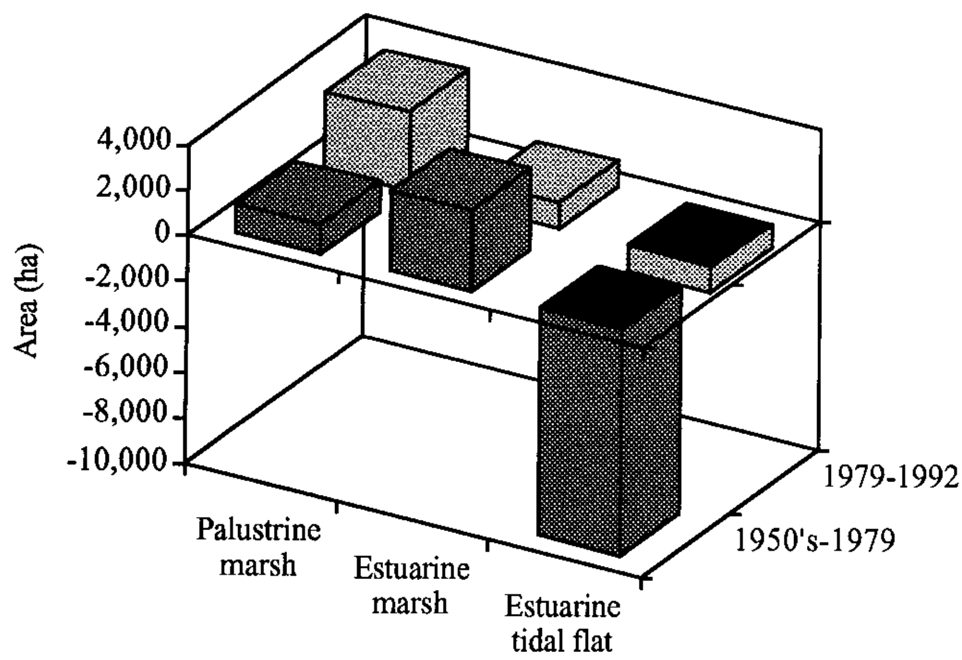


Figure 40. Changes in total area of marshes and intertidal flats in the CCBNEP study area for the periods 1950's-1979 and 1979-1992.

Table 68. Major causes of wetland loss and degradation. Modified from Tiner (1984) as compiled from Zinn and Copeland (1982) and Gosselink and Baumann (1980). Relative importance of causes in the CCBNEP area in parenthesis.

HUMAN THREATS

Direct:

1. Drainage for crop production and expansion of upland rangeland **(Moderate)**
2. Dredging and stream channelization for navigation channels, flood control, coastal housing developments, and reservoir maintenance **(Moderate)**
3. Filling for dredged spoil and other solid waste disposal, roads and highways, and commercial, residential and industrial development **(Moderate)**
4. Construction of dikes, dams, levees and seawalls for flood control, water supply, industrial purposes, irrigation and storm protection **(Minor to Moderate)**
5. Discharges of materials (e.g., pesticides, herbicides, other pollutants, nutrient loading from domestic sewage and agricultural runoff, and sediments from dredging and filling, agricultural and other land development) into waters and wetlands (Undetermined)
6. Mining of wetland soils for sand, gravel, peat, and other materials **(Moderate)**

Indirect:

1. Sediment diversion by dams, deep channels, and other structures (**Moderate**)
2. Hydrologic alterations by canals, spoil banks, roads and other structures (Undetermined)
3. Subsidence due to extraction of groundwater, oil, gas, sulphur, and other minerals **(Undetermined - possibly important locally)**
4. Salt-water intrusion resulting from indirect threats noted above (Undetermined)

NATURAL THREATS

1. Subsidence (including natural rise of sea level) **(Moderate, difficult to separate from humanly-induced subsidence**)
2. Erosion **(Moderate**)
3. Droughts (Undetermined)
4. Hurricanes and other storms (Undetermined)
5. Biotic effects (e.g., muskrat, nutria and goose "eat-outs") (Undetermined)

VI. SHORELINE TYPES IN THE CCBNEP STUDY AREA

A. Mapping Procedures

The objective of shoreline mapping was to differentiate shores artificially hardened by riprap, bulkheads, seawalls, and other human structures, from natural or nonhardened shorelines consisting of sand and shell beaches, marshes, tidal flats, etc. Shorelines were mapped and classified using numeric or alpha-numeric codes that define shoreline types. Shoreline codes were derived from those developed for characterizing sensitivity of shores to oil impacts (Tables 69 and 70).

Mapping procedures consisted of identifying shoreline boundaries, marking boundaries on topographic base maps, and labeling each shoreline segment with the appropriate code. Shorelines were delineated on USGS 7.5 minute quadrangles using plots of the most up-to-date shorelines, which in the CCBNEP area are from USFWS NWI 1992 digital files compiled by the GLO.

Shorelines were mapped primarily using recent, vertical aerial photographs, and low altitude aerial videotape surveys of coastal Texas produced by the Center for Coastal, Energy and Environmental Resources at LSU, and recorded during cooperative helicopter flights by staff of LSU and the Bureau of Economic Geology in May of 1997. Videotapes are high quality and are accompanied by audio commentaries of shoreline types made by experienced coastal geologists.

Shoreline types were classified and mapped while viewing videotapes on a 68.5 cm, high-resolution color monitor and using a video cassette recorder with slow and fast advance and reverse features. In areas not covered by videography, shorelines were mapped using low and high altitude vertical stereographic aerial photographs taken during the 1990's. Where necessary, shorelines were analyzed using stereoscopes with a magnification of at least 6X.

Along some shoreline segments, more than one shoreline type was present. For example, shells may have been concentrated in beaches that front a clay scarp. Such a shoreline was assigned two codes, given in the order in which they occur going from the most landward to the most seaward position. Accordingly, a shell beach seaward of a clay scarp was designated as 2/6 on maps. The first numeric code, 2, refers to the landward most feature, or clay scarp, and the succeeding code refers to the seaward most feature, the shell beach. Locally, as many as three shoreline types were recognized in an alpha-numeric sequence, such as 2/10A/3, which details a shoreline that progresses from a clay scarp to a salt/brackish marsh to a sand beach.

Shoreline types were digitized from the 7.5 minute quadrangles on which shorelines were mapped. These digital data were entered into the GIS ArcInfo from which hard copy maps were plotted for verification.

Where possible, questionable sites were field checked to ensure completeness and accuracy of shoreline designations. Digitized shorelines were compared with mapped shorelines for accuracy and completeness. Areas needing correction were marked on work maps, and corrections were made in digital files.

Table 69. Standardized Environmental Sensitivity Index (ESI) rankings for Texas. From Morton and White (1995) as modified from Hayes et al. (1980).

ESI No.	Shoreline Type
1	Exposed walls and other structures made of concrete, wood, or metal
2A	Scarps and steep slopes in clay
2B	Wave-cut clay platform
3A	Fine-grained sand beaches
3B	Scarps and steep slopes in sand
4	Coarse-grained sand beaches
5	Mixed sand and gravel (shell) beaches
6A	Gravel (Shell) beaches
6B	Exposed riprap structures
7	Exposed tidal flats
8A	Sheltered solid man-made structures, such as bulkheads and docks
8B	Sheltered riprap structures
8C	Sheltered scarps
9	Sheltered tidal flats
10A	Salt- and brackish-water marshes
10B	Fresh-water marshes (herbaceous vegetation)
10C	Fresh-water swamps (woody vegetation)
10D	Mangroves

Table 70. Codes used in shoreline type mapping for this project. Modified from Table 69.

Code	Shoreline Type
1	Solid man-made structures such as bulkheads and other structures made of concrete, wood, or metal, and riprap
2	Clay scarps
3	Sand beaches and shores
5	Sand and shell
6	Shell beaches and berms
7	Tidal flats
8C	Sheltered scarps and slopes
10A	Salt and brackish water marshes
10D	Mangroves

B. Shoreline Types

Shores along the Gulf coast including the CCBNEP area (Fig. 41) are dynamic features that influence flora and fauna as well as economic and recreational value. Many shorelines are erosional (Morton and Paine, 1984, Paine and Morton, 1993) and have been armored with rip rap, bulk heads, groins and other structures to slow or prevent shoreline retreat (Figs. 42 and 43). Non-armored shorelines include those along natural and dredged material shores, and may be characterized by salt marshes (Fig. 44), tidal flats, sand and shell beaches, or sand and clay scarps and slopes. In some areas, natural resources such as salt marshes have been lined with armor, including bulkheads, articulated concrete mats, and grout bags to prevent erosion. Most marsh shoreline along the GIWW in the Aransas National Wildlife Refuge has been protected in this manner. The most extensive hardened shoreline occurs along the south shore of Corpus Christi Bay (Figs. 41, 42 and 43). Some shorelines have been artificially nourished to create or restore eroded sand beaches for recreational purposes (Fig. 43a).

Shoreline types listed in Table 71 are those along the waters edge and do not include the upper shore that may be of a different type. For example, a sand beach shoreward of a marsh or tidal flat is listed as sand. Hardened shorelines include all shorelines that have bulkheads, rip rap, groins or other structures even though some may have a fringing marsh or sand and shell beach seaward of the structure. Beaches that have been artificially nourished are included in the sand or sand and shell types. The most extensive artificially nourished beach is about 2 km in length at North Beach in the Corpus Christi quadrangle.

Cumulatively, marshes are the most common shoreline type, making up 45 percent of the total length of shorelines (Table 71). Marsh shorelines in Table 71 include narrow fringing marshes as well as more extensive marshes that extend landward of the shore. Mangroves (included with the marsh shorelines) are abundant along some shores especially on Harbor Island, but cumulatively have a length of less than 0.2 km. Shell berms and beaches (6 percent) are common along shores with high wave energy and are often erosional. Many of the shorelines characterized by sheltered scarps and steep slopes (11 percent of total) occur along unarmored dredged and natural channels or in protected embayments. Hardened or armored shorelines represent more than 16 percent of the total length. Major concentrations of hardened shorelines include bulk-headed navigation channels in recreational-community developments such as on north Padre Island and along erosional shores such as the south and west sides of Corpus Christi Bay (Fig. 42).

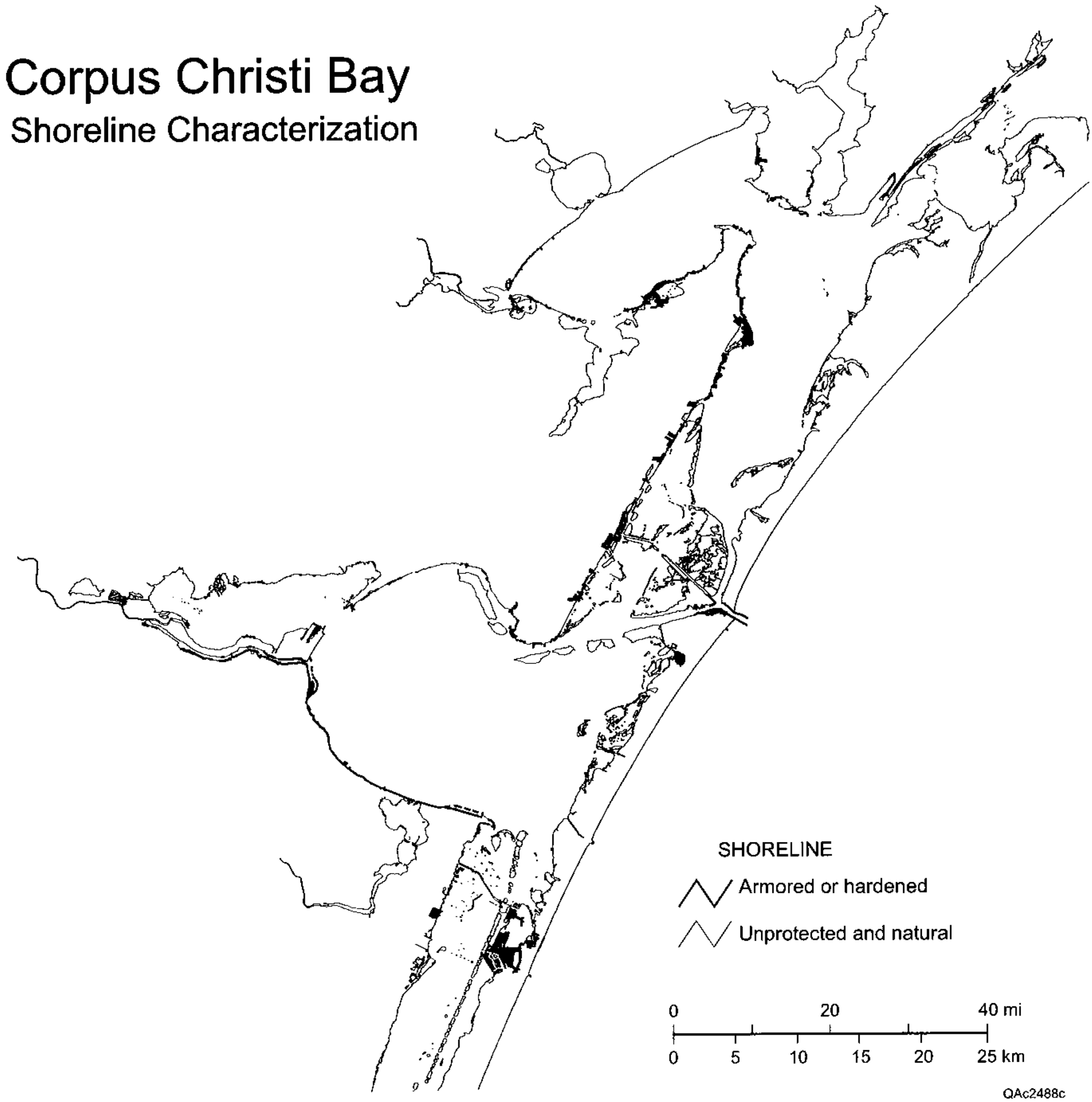


Figure 41. Location of hardened and nonhardened shorelines in the CCBNEP study area.

(a)

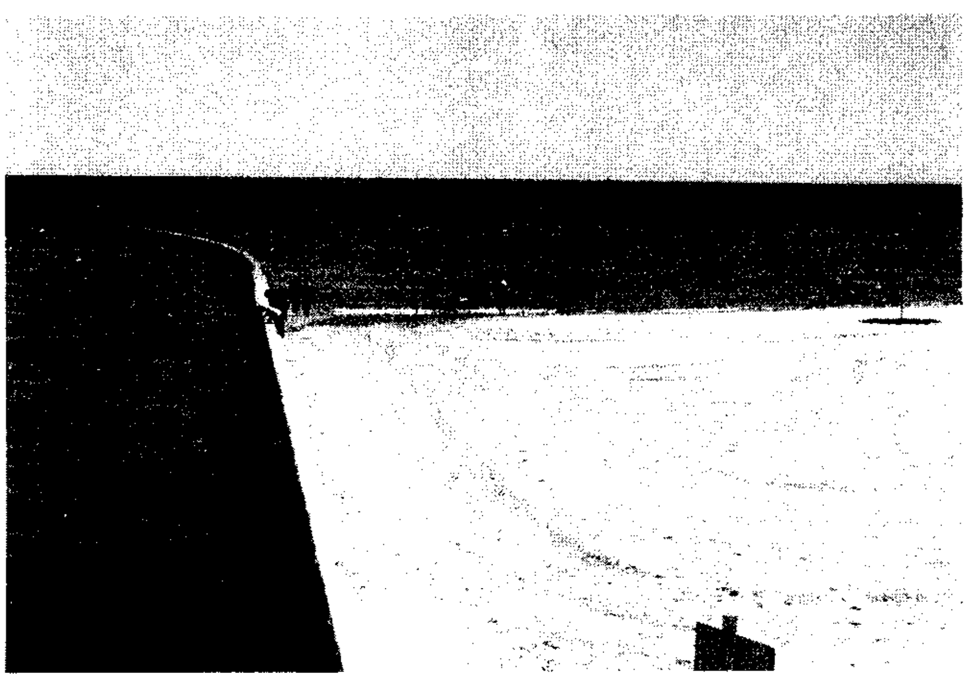
(b)

QAc571c

Figure 42. Example of (a) riprap shoreline on the south side of Corpus Christi Bay east of the mouth of Oso Bay and (b) concrete bulkhead "backed" by stone riprap and concrete apron at a park on the west side of Corpus Christi Bay.

(a)

(b)



QAc572c

Figure 43. Example of (a) shell beach, low bulkhead, and piers along the shore of Live Oak Peninsula on Aransas Bay and (b) artificially constructed beach and concrete groin on the west side of Corpus Christi Bay.

QAc575c

Figure 44. Shoreline fringed by marsh and scattered shrubs of black mangrove along the navigation channel to Aranasas Pass.

Table 71. Type and length of shorelines in the CCBNEP study area. Does not include Pita and South Bird Island quadrangles. Lengths of natural or non-hardened shores based on type of shoreline along waters edge.

Shoreline Type	Length (km)	Percent of Total Shoreline
Natural and Non-Hardened		
Marsh	899	45
Sand	161	8
Shell	122	6
Sand and Shell	65	3
Clay	87	4.3
Tidal flats	128	6.3
Sheltered scarps/slopes	222	11
Subtotal	1,684	83.6
Hardened or Armored	330	16.4
Total	2,014	100

VII. A SUMMARY OF THE STATUS AND TRENDS OF ROOKERY ISLANDS IN THE CCBNEP AREA

A. Introduction

The CCBNEP area encompasses an extensive, biologically productive, estuarine and lagoonal system composed of numerous diverse and essential habitats and vast array of associated organisms. One such habitat type is natural and dredged material islands that are crucial to colonial nesting waterbirds. Evaluating rookery islands through time is critical in developing a comprehensive management plan for the Texas Coastal Bend. Chaney et al. (1996) overviewed habitats utilized by avian species within the CCBNEP area surrounding the bay systems. They emphasized the importance of natural and dredged material islands as nesting habitat for many species of gulls, terns, herons, egrets, pelicans, spoonbills, ducks, and ibises. Their assessment grouped all data for each species from all colonies surveyed and evaluated trends for 22 species during 1973-1990.

In a recent report (Smith and Cox, 1998), data were summarized by colony through time to qualitatively assess changes in nesting habitat types on islands for both common and selected rare species. This approach allowed a more detailed overview of ecological dynamics of selected colonies located in the CCBNEP area in relation to natural and human-induced events serving as probable causes for observed nesting dynamics. Suggestions were also included evaluating current surveys, continued monitoring programs, data gaps, research needs, and conservation efforts useful in developing a rookery island management plan for the CCBNEP area. Examples of the approach taken are summarized in this chapter.

Background

Natural and dredge material islands located within the bay systems of the CCBNEP area support high numbers of colonial nesting waterbirds (Texas Colonial Waterbird Society 1982). Changes in island area and vegetative diversity through time may affect use as rookeries. Five natural bay islands, five natural rookeries, 13 natural islands with dredged material deposits, and 27 dredged material islands occur within the study area delineated previously in this report.

Colonial waterbirds are dependent upon estuarine habitats for both foraging and reproduction. These species typically feed on fish and crustaceans in shallow and open water areas. Natural and created bay islands away from disturbance for nesting are critical for continued survival. Therefore, colonial waterbirds are excellent indicators of ecosystem health (Soots and Landin, 1978). Islands in Texas are used in varying degrees depending upon one or more of the following factors: 1) accessibility of islands to predators; 2) human disturbance and activities; 3) size of islands; and, 4) presence of vegetation, topography, or elevation suitable to support one or more nesting species (Chaney et al. 1978). Islands may also be important to non-breeding birds (e.g., resident and migratory waterbirds, shorebirds, songbirds, and raptors) for resting, roosting, and feeding (Soots and Landin, 1978).

Objectives

Objectives of the rookery island study were to (1) evaluate vegetation succession and spatial configuration of selected rookery islands throughout a 20-year period, (2) overview potential relationships between vegetation structure and colonial waterbird nesting success, and (3) propose probable causes for changes in nesting dynamics as related to habitat availability and/or human activities.

B. Methods

Rookery Island Nesting Habitat Evaluation

Rookery and natural areas used as bird nesting sites were delineated for the CCBNEP study area from historical data (Chaney et al. 1978, Texas Colonial Waterbird Society 1982). Five natural bay islands, five natural rookeries, 13 natural islands with dredged material depositions, and 27 dredged material islands were variously used to accomplish tasks in Smith and Cox (1998). The following rookery islands were selected in that report to evaluate current vegetation patterns based on availability of historic vegetation analyses: Pelican Island Spoil, Shamrock Island, Marker 17 Island in Marker 2-17 Spoil Islands (New Markers 13-35), North Bird Island, South Bird Island, South of South Bird Island (Marker 55, 57, 57a islands), Marker 63-65 Spoil Island (New Marker 127-131), and Marker 81 (New Marker 163) rookeries. In this summary, Marker 17 Island in Marker 2-17 Spoil Islands (New Markers 13-35), South of South Bird Island (Marker 55, 57, 57a islands), and Marker 81 (New Marker 163) rookeries will be overviewed.

Number of transects were determined individually on each island in relation to vegetative complexity and to assist in verification of photointerpretation work. Field work was conducted during October - December 1996, as islands are inaccessible during the January-September nesting season. Transects were aligned perpendicular to the elevational gradient that encompassed the maximum number of vegetation associations and, when appropriate, along a similar direction as historic transects (Chaney et al. 1978). Vegetation type was recorded as: dominant grass, dominant herb (perennial), dominant forb, or dominant shrub. Unvegetated areas were recorded as unvegetated shell or unvegetated sand. Using a hand level and staff, elevations were recorded at each dominant floral change, unvegetated or pond area to evaluate changes in horizontal distance and the change in elevation between each habitat type in relation to relative sea level. Both field data in this study and historic data were grouped according to the following categories: bare, sparse herbaceous, herbaceous, herbaceous/shrub, shrub, shrub/tree, and tree.
Initially, habitat types were to be used to describe wetland and upland habitats from the National Wetland Inventory (NWI) data for 1992; however, important habitat characteristics were documented in the field surveys were not mapped on NWI draft maps due to scale limitations. In addition, upland designations on the islands were not differentiated into vegetation types critical to nesting use evaluation. Therefore, 1995 aerial photographs (CCBNEP files) were scanned using Adobe Photoshop and imported into Microsoft Powerpoint V.7. Habitat types were determined by unique color signatures and field transect data, and polygons were constructed for each type. Due to scaling problems, no attempt to quantitatively compare habitat changes was undertaken. These habitat maps were visually compared to historic data from the 1970s (Chaney et al. 1978) to determine major changes in habitat on each rookery island.

Colonial Waterbird Nesting Dynamics

Bird atlas and census information during 1973-1994 formed the basis of determining nesting use changes for the CCBNEP area (north of Baffin Bay) and selected rookery sites (Smith and Cox, 1998). Species pair data from Texas Colonial Waterbird censuses were summarized in relation to preferred nesting substrate (ground, shrub/tree) for the entire study area and for selected rookery islands with sufficient data throughout the survey. Graphics were organized similarly by rookery to facilitate visual comparisons and missing data were not graphed. Rookeries located in upper Laguna Madre are described within this summary to determine if population shifts were occurring among rookeries. Brown and American White Pelicans are included here to postulate nesting population movements within the CCBNEP area. Other species having significant population changes (Chaney et al. 1996) were examined in relation to habitat requirements to identify probable causes of change.

C. Results

Status and Trends of Rookery Islands Use in CCBNEP Area

Selected Island Vegetation Dynamics

All islands evaluated for vegetation dynamics in Smith and Cox (1998) are depicted in Fig. 45. Marker 17 (New Marker 35) dredged material island is the southernmost island of the Marker 2-17 Spoil Island (New Marker 13-35) Colony in upper Laguna Madre (TCWS, 1982) and most active rookery within the colony area (Coste and Skoruppa, 1989). The island was about 6.8 hectares in the 1970s, and encompassed several nesting habitats of trees, prickly pear, shrubs, subshrubs, grasses and forbs, annuals, and shell, sand and mud beaches (Chaney et al. 1978, TCWS, 1982). Historically, this island represents one of the oldest dredged material islands as defined by timing of the dredged material deposition and vegetation establishment. The island changed relatively little from 1975 to 1995 in physical configuration (Fig. 46). However, more herbaceous/shrub habitat covers the island, replacing herbaceous species documented in 1975. Small areas of *Paspalum monostachyum* (gulfdune paspalum) and *Sporobolus virginicus* (seashore dropseed) are still dominant along the north and east portions of the island. The bare area located in the southeast quadrant of the island ponded, holding tidal waters following high tide events. In addition, tree habitat covers the high ridge of the island, surrounded by an impenetrable ring of prickly pear cactus and tall (>1 m) *Baccharis neglecta* (Roosevelt weed). Available habitat types appear to have increased in complexity through the last 20 years, although less bare substrate may be available for ground-nesting species requiring sand or shell substrate. The TGLO owns this and other dredged material islands along the GIWW (TCWS, 1982).

LM 55, 57, and 57A dredged material islands are located in upper Laguna Madre immediately north of the junction of Bird Island Basin Channel and GIWW and are included in the South of South Bird Island Colony (see Fig. 45). Four islands are broadly connected by intertidal infrequently exposed flats and encompass a broad range of nesting habitats of trees, prickly pear, shrubs, subshrubs, grasses and forbs, annuals, and bare beaches of sand and clay. Chaney et. al (1978) described three islands. LM 57a was chosen as a representative island in this rookery and encompasses diverse habitat types (Fig. 47). The island eroded along the north, east, and south

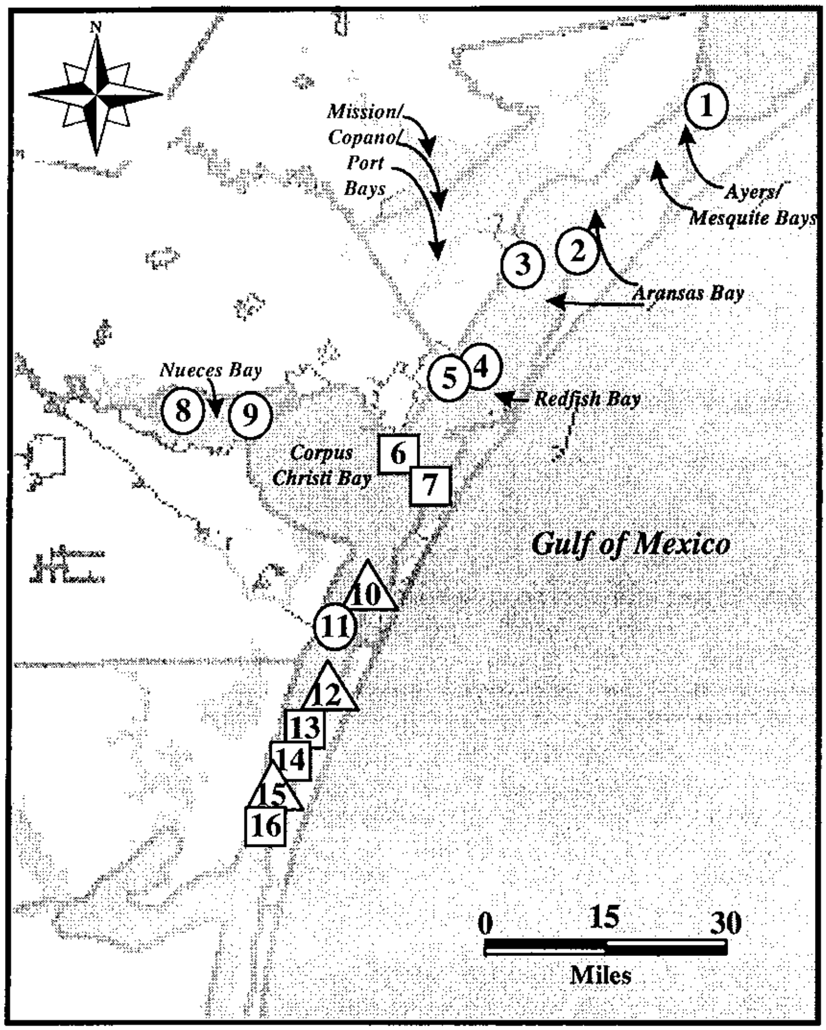


Figure 45. Locations of rookery islands evaluated in Smith and Cox (1998) for status and trend assessments. Circles denote rookeries where Colonial Waterbird (CWB) census were used, squares denote both CWB and habitat descriptions, and triangles denote habitat descriptions only.

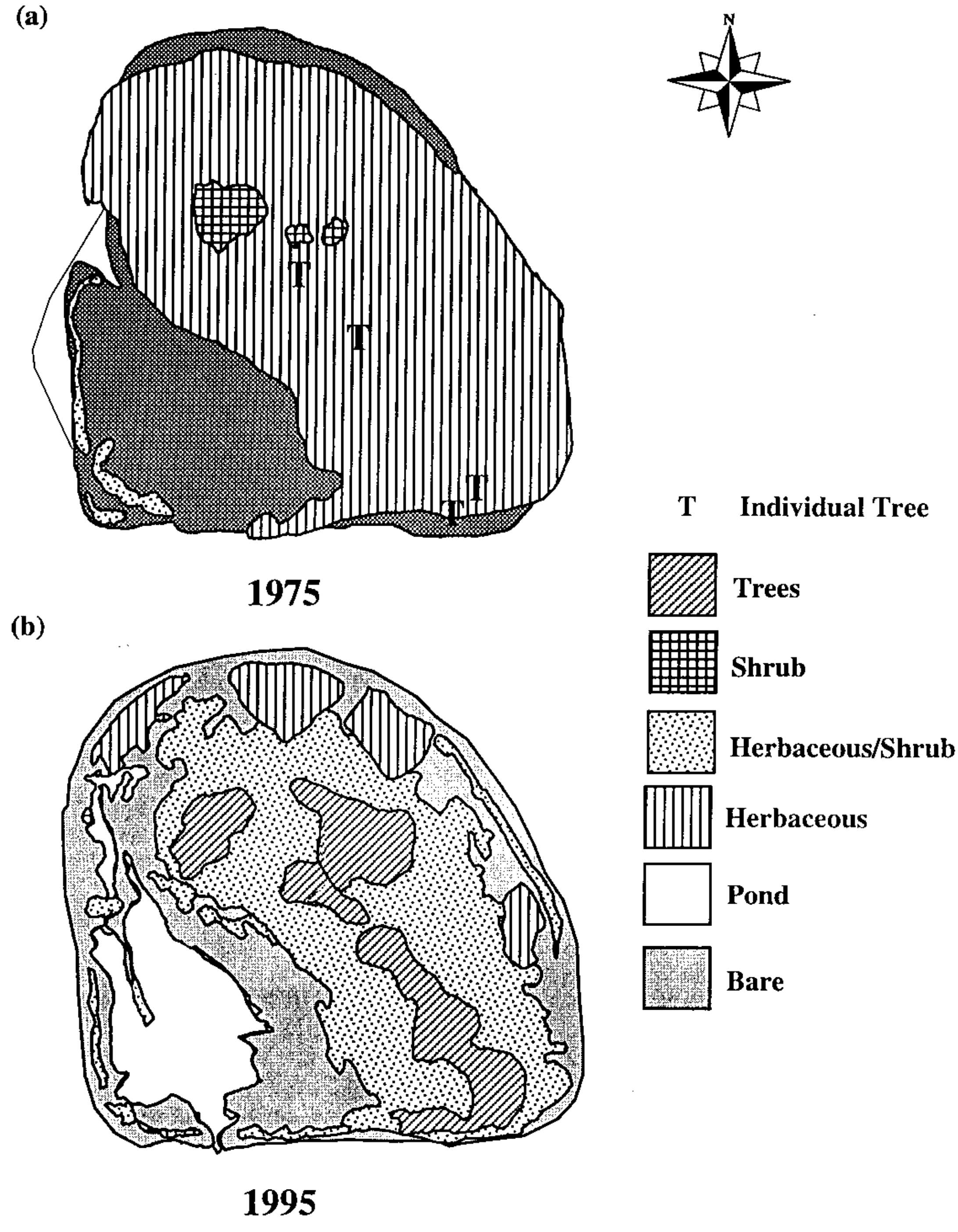


Figure 46. Nesting habitat for Marker 17 (New Marker 35) in Marker 2-17 (New Marker 13-35) from (a) 1975 (modified from Chaney et al. 1978) and (b) 1995.

shorelines since 1978, resulting in loss of some herbaceous, salt-tolerant species on the east, and several grass/shrub (herbaceous/shrub) associations along the southern shoreline. Increase in shrub and shrub/tree habitats occurred in the middle of the island, as well as development of shrub habitat in the southeastern quadrant. The islands are within the boundary of PINS (Chaney et al. 1978, TCWS, 1982).

Marker 81 (New Marker 163) Spoil Island is located in upper Laguna Madre adjacent to the GIWW within the boundary of PINS (see Fig. 45). The dredged material island encompassed about 1.7 hectares in the 1970's (TCWS, 1982) but had decreased to about 1.11 hectares in 1986 (Coste and Skoruppa 1989); nesting habitats include shrubs, subshrubs, and bare sand (TCWS, 1982). The entire island continued to decrease in areal extent from erosion (Fig. 48). Bare habitat suitable for ground-nesters in the 1970s became intertidal flats along the southern portions, and the northern perimeter exhibits an abrupt terrace from herb/shrub habitat to a narrow bare beach, intertidal habitat. A narrow herbaceous area is located downslope from the higher, herbaceous/shrub habitat primarily composed of *Paspalum vaginatum* (seashore paspalum). The herb/shrub habitat included *Aster tenuifolius* (saline aster), *Ambrosia psilostachya,* overlying *Cynodon dactylon* (bermudagrass).

Selected Rookery Island Nesting Population Trends

Twenty colonies were variously surveyed between 1973-1990 in upper Laguna Madre (TCWS, 1998). Many colonies encompass several dredged material islands in proximity to each other and adjacent to other colony designations. Two islands have sufficient data during the survey to assess within-colony population trends; however, since numerous colonies are located in a limited spatial area, no evaluation can be attempted for among-colony dynamics.

The South of South Bird Island rookery appeared to exhibit two cycles of nesting populations (Fig. 49a). Most years ranged about 4000 nesting pairs of colonial waterbirds, although the 1978 survey documented >15,000 pairs, a peak year for Laughing Gulls (Fig. 49e), Sandwich Terns (Fig. 49a), and Cattle Egrets (Fig. 49f). The rookery is important to many shrub/tree nesting species, such as White-faced Ibises, Tricolored Herons, and Reddish Egrets (Fig. 49b). Rookery use increased through time for Great Egrets, whereas peak usage for Great Blue Herons occurred in the 1980's (Fig. 49c). Roseate Spoonbills also increased in the rookery beginning in the 1980's (Fig. 49e). Snowy Egrets exhibited variable pair values throughout the survey, and during the 1980's exceeded 100 pairs (Fig. 49d). Numbers of Black-crowned Night-Herons and White Ibises were sporadic with low pair values throughout the survey (Fig. 49d,e). Cattle Egrets were documented most years with about 500 pairs each year, with peaks in 1976, 1978, 1979, and 1984. Sandwich Tern numbers typically were less than Royal Tern numbers when both were present, however, an extremely high pair value for Sandwich Terns was recorded in 1978 (Fig. 50a). Black Skimmers were not numerous in the 1970's and early 1980's, and were not recorded in the rookery after 1982 . Although 1978 was a peak year for Gull-billed Terns, this species and Caspian Terns were virtually nonexistent in the following years (Fig. 50c). Least Terns were only documented in 1979 and 1984, and two pairs of Forster's Tern were recorded in 1975 (Fig. 50d). Laughing Gulls were variable in pair values throughout the survey, but appeared to maintain a nesting population of 2000-3500 pairs (Fig. 50e). This rookery was utilized by American White Pelicans as they moved off South Bird Island in the mid-1970's and peak use occurred in the early 1980s (Fig. 50f). The nesting population moved to Marker 81 (New Marker 163) rookery, where they remained throughout the 1990's.

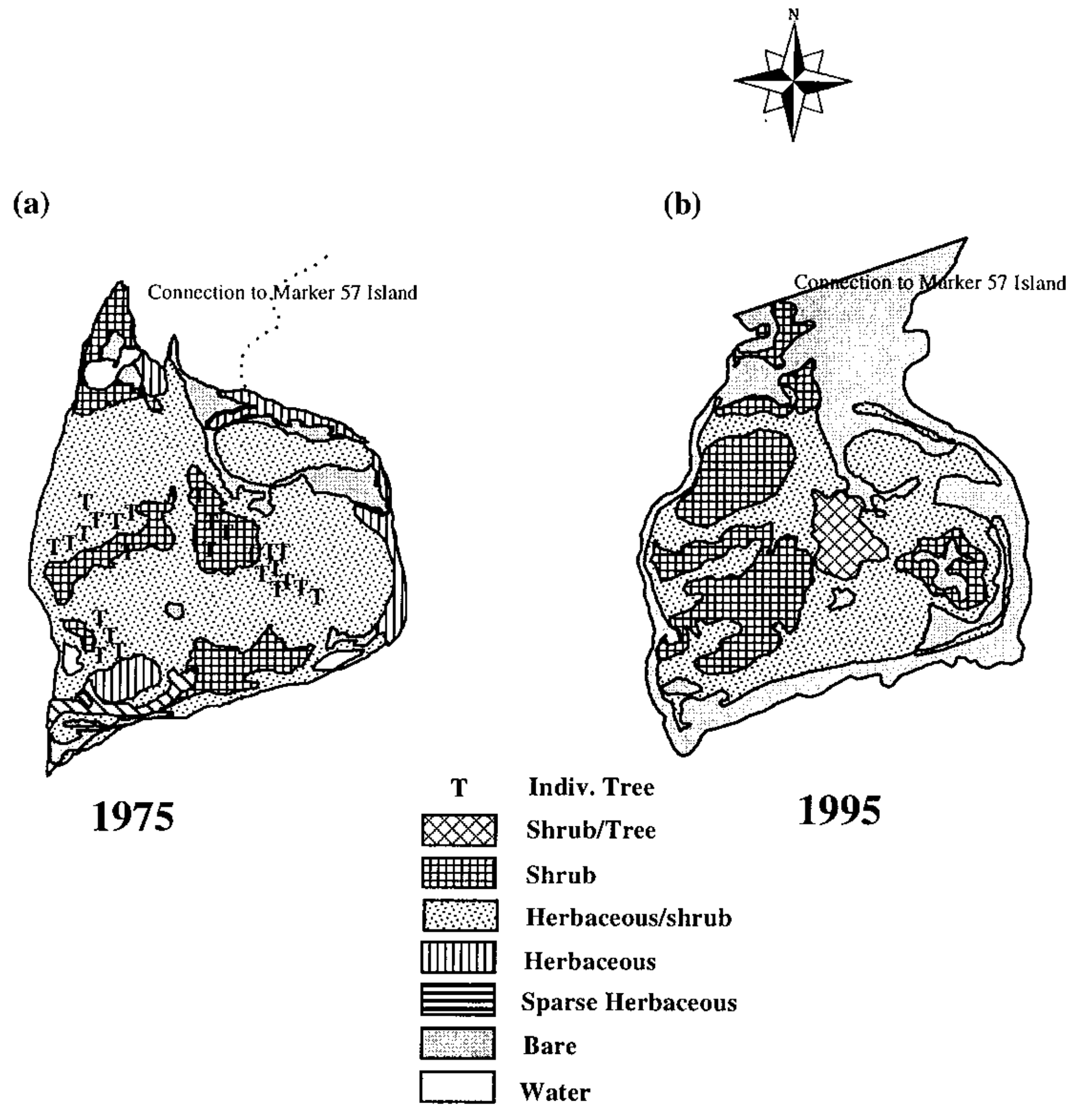


Figure 47. Nesting habitat for Marker 57A island (part of South of South Bird Island rookery) from (a) 1975 (modified from Chaney et al. 1978) and (b) 1995.

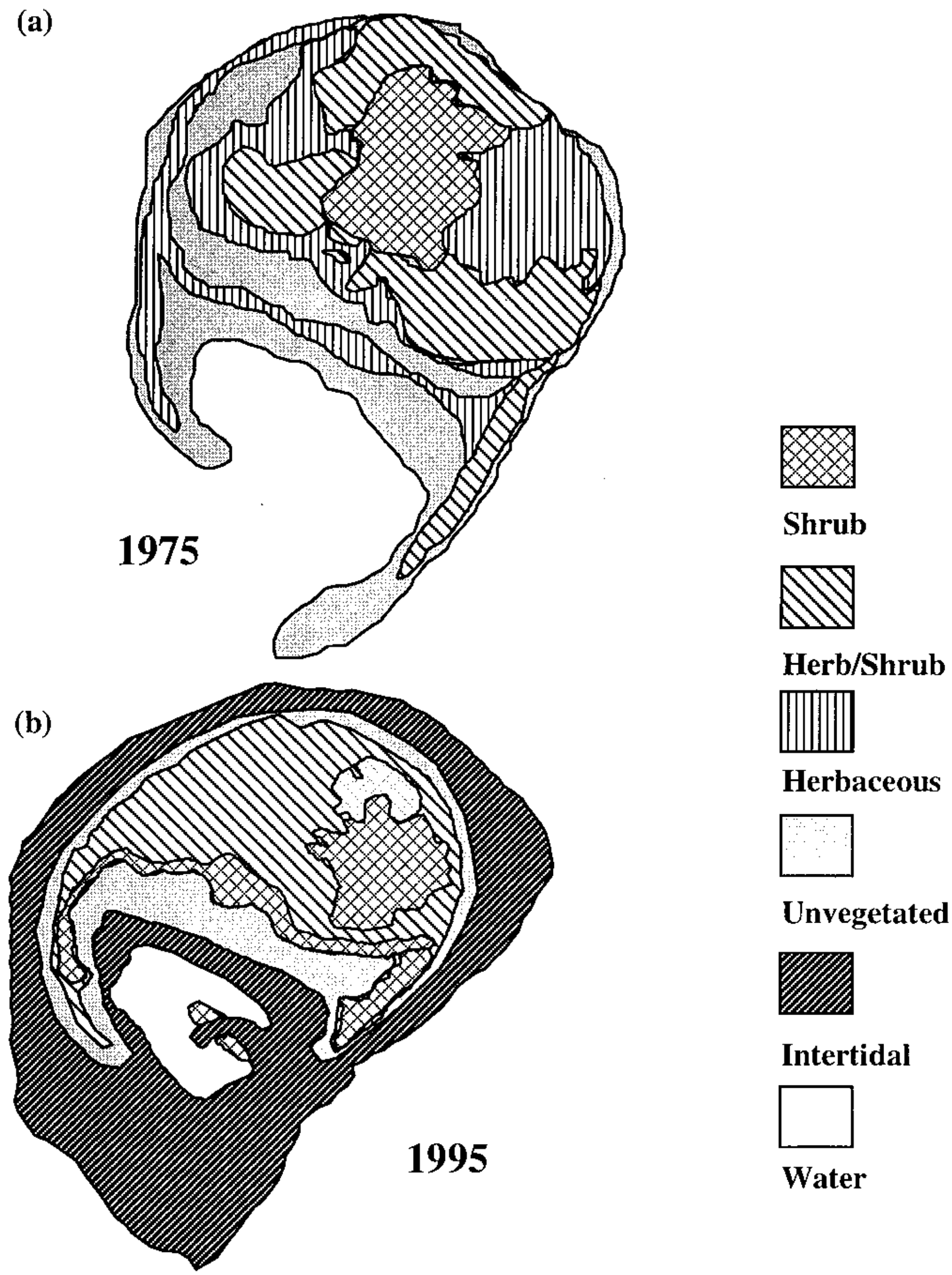
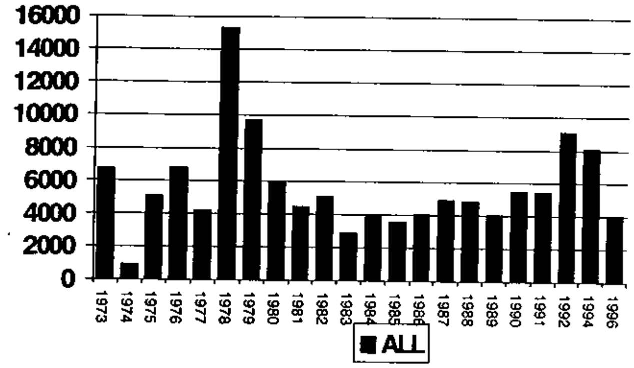
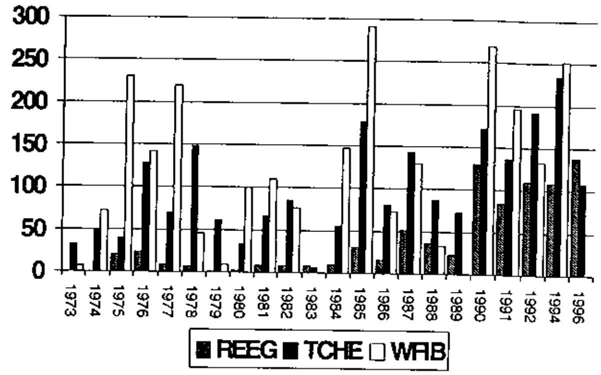


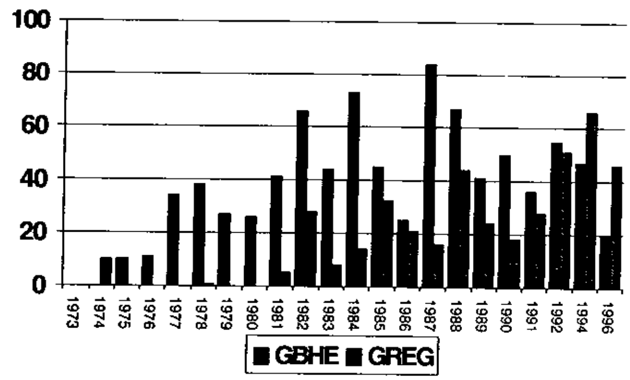
Figure 48. Nesting habitat for Marker 81 (New Marker 163) rookery from (a) 1975 (modified from Chaney et al. 1978) and (b) 1995.



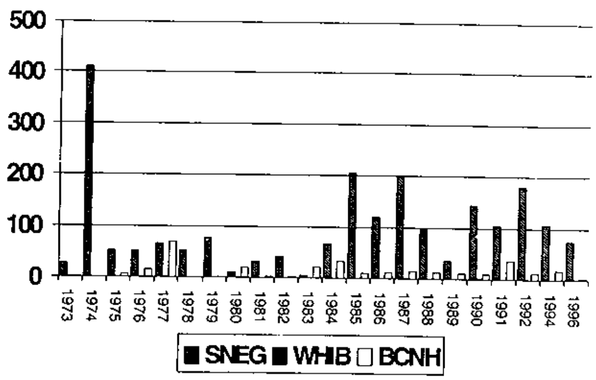
(a) all pairs



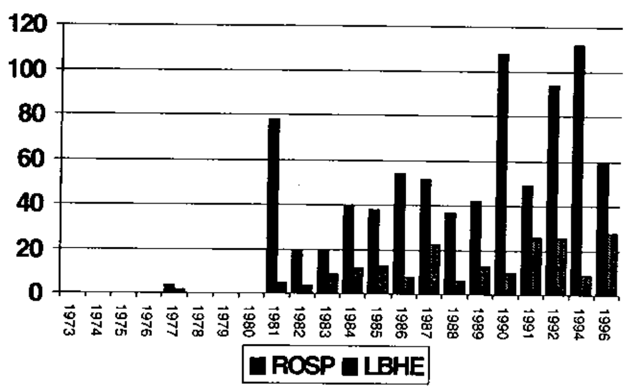
(b) Reddish Egret, Tricolored Heron, White-faced Ibis



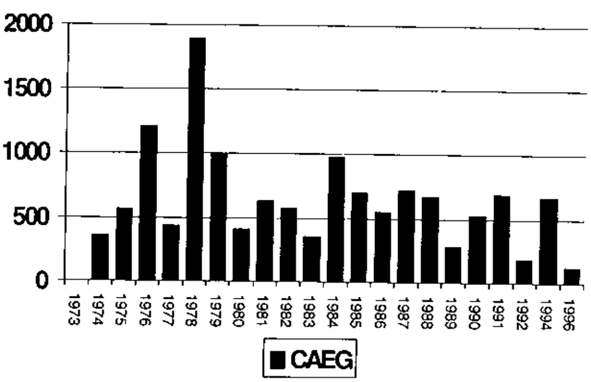
(c) Great Blue Heron, Great Egret



(d) Snowy Egret, White Ibis, Black-crowned Night-Heron



(e) Roseate Spoonbill, Little Blue Heron



(f) Cattle Egret

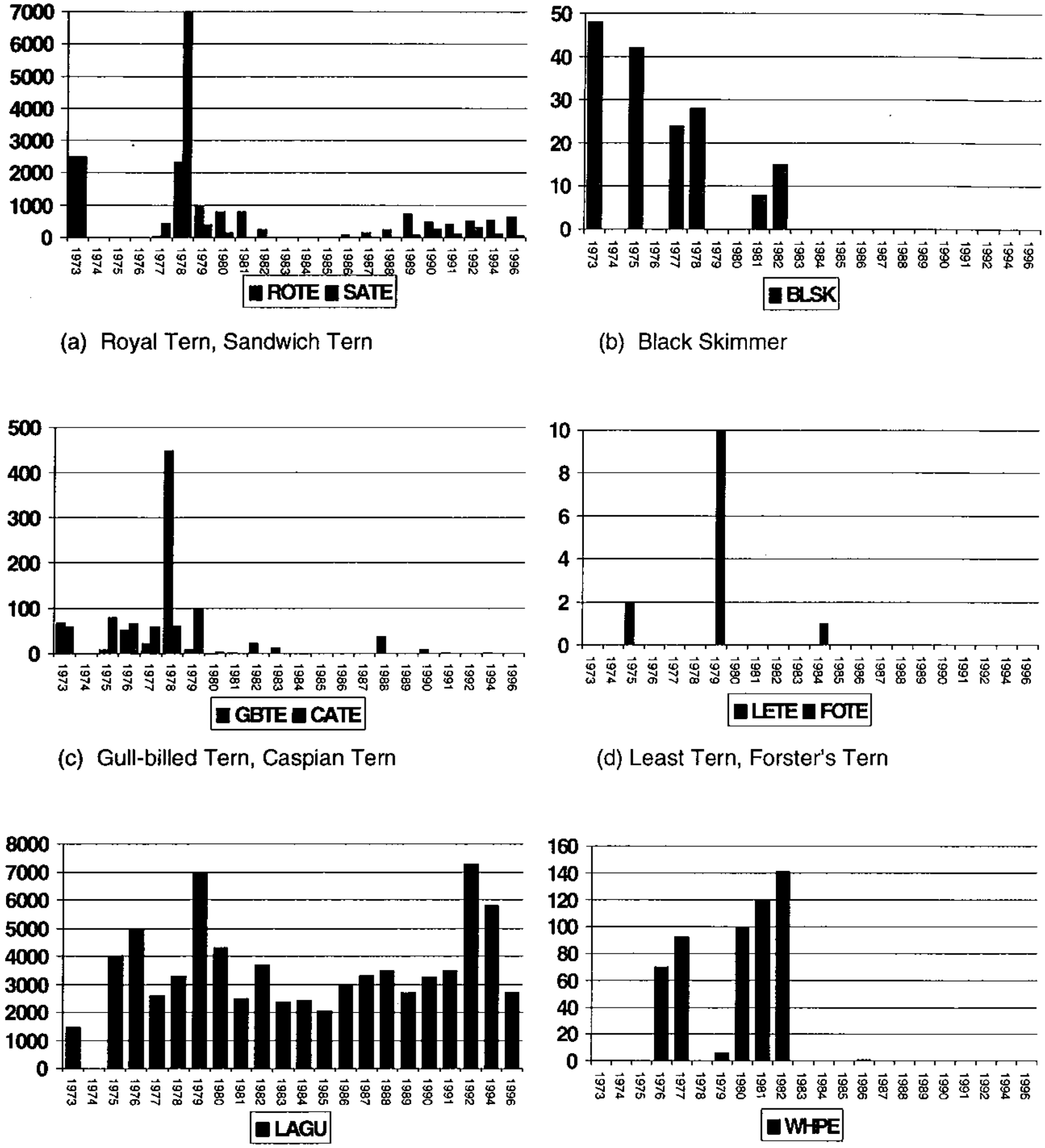
Figure 49. Year pair totals of (a) all colonial waterbird species that have utilized South of South Bird Island rookery, and (b-f) species that prefer shrub/tree habitat from 1973-1996.

Marker 81 (New Marker 163) rookery generally supported between 500 and 1000 pairs of nesting colonial waterbirds during 1973-1994, with values decreasing in 1992 and 1994 (Fig. 51a). The rookery originally supported abundant nesting populations of Reddish Egrets, Tricolored Herons, and White-faced Ibises in 1970's, but all populations decreased through time (Fig. 51b). Snowy Egrets generally maintained a nesting population at about 40 pairs each year, although some years the rookery supported higher pairs (1974, 1976, 1979, 1985) and other years much lower (1978, 1983, 1989, 1994) (Fig. 51d). Great Egrets were not predominant shrub/tree nesters; White Ibises, Black-crowned Night-Herons, and Little Blue Herons nested intermittently (Fig. 51c,d,e). Roseate Spoonbill numbers peaked in 1978 at 120 pairs, decreased for several years, then were not present after 1986 (Fig. 51e). Cattle Egret numbers increased during 1976-1980, then decreased to low pair values (Fig. 51f). Several ground-nesting species were predominant in the first year of the survey including Black Skimmers, Gull-billed Terns, and Forster's Terns; these species were not abundant in following years (Figs. 52b,c). Laughing Gull pair values decreased throughout the survey (Fig. 52e), whereas royal and Sandwich Terns were first recorded in 1986 (Fig. 52a). The American White Pelican colony began shifting to Marker 81 (New Marker 163) rookery in 1982, supporting the main nesting population along the Texas Coast (Fig. 52f).

Selected Species of Concern Overview

Brown Pelicans made a dramatic recovery in the CCBNEP area since the early 1970s, pirmarily establishing a rookery on Pelican Island Spoil in northern Corpus Christi Bay (Fig. 53). However, pelicans also nested in other rookeries during the survey. Brown Pelicans were recorded in the Second Chain of Islands rookery in Ayres Bay at the northern edge of the CCBNEP area. Few pairs (<10) were documented in the 1970's, but between 12-22 pairs nested in the rookery in the early 1980s. Then, no nesting birds were observed until 1989, when ten pairs were documented. Long Reef/Deadman Island Rookery recorded ten pairs in 1977 and 17 pairs in 1979. No definitive data exists explaining if these pairs were expanding their nesting range from Pelican Island, or if they were migrating into the area from the north (upper Texas coast and Louisiana) or the south (Laguna Madre Tamaulipas and other populations along the Mexican coast) (Elliott, 1995). However, populations did not persist in either rookery. Several potential factors were identified that may determine where rookeries may be established: proximity to passes for increased water clarity and prey availability, vegetated areas that would support a nest on or near the ground, and limited human disturbance (Elliott, 1995). Importance of Pelican Island Spoil rookery to this Brown Pelican nesting population necessitates close supervision and protection for continued recovery.

American White Pelicans sustained a nesting population in upper Laguna Madre for many years, although they moved from island to island in the past 20+ years (Fig. 54). The nesting population was documented on South Bird Island rookery during 1973-1975. In 1976 and 1977, some pairs had established nests at nearby South of South Bird Island Rookery. No birds nested in the latter rookery in 1978 and few were recorded in 1979. On South Bird Island, total pair numbers were lower during these years, and 100 pairs nested in South of South Bird Island in 1980. In 1981, the only nesting population occurred in this rookery. The birds appeared to begin migrating southward to Marker 81 (New Marker 163) Island rookery in 1982, then the entire nesting population began nesting in this rookery during 1983-present; one nesting pair was documented in South of South Bird Island rookery in 1986. Several explanations were postulated to understand this species' migration among these islands: elevated ectoparasite levels in established rookeries, storms, predator disturbance, and brood reduction (Chapman, 1988). Since the islands are located within the PINS, the rookeries experience limited human disturbance. Alternately, the island's location in proximity of the bay shoreline of Padre Island and the shallow lagoon between the rookeries and island could be a corridor for predators (e.g., coyotes,



(a) Royal Tern, Sandwich Tern

(b) Black Skimmer

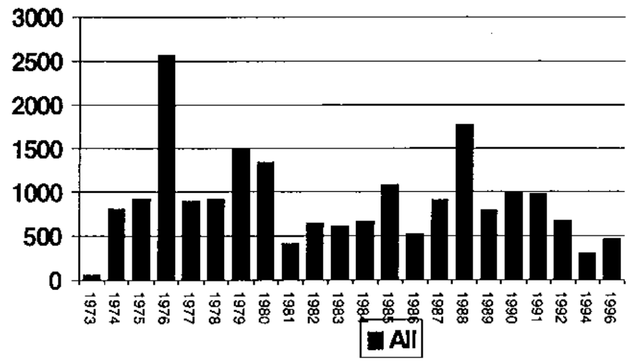
(c) Gull-billed Tern, Caspian Tern

(d) Least Tern, Forster's Tern

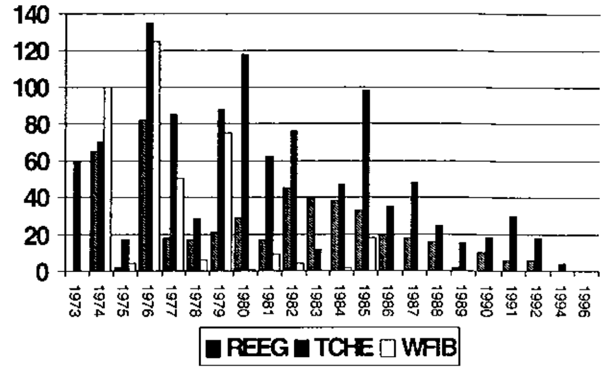
(e) Laughing Gull

(f) American White Pelican

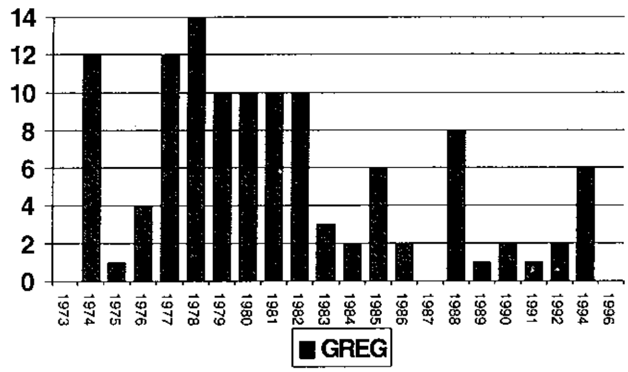
Fig. 50. Year pair totals of (a-f) ground-nesting colonial waterbird species that have utilized South of South Bird Island rookery from 1973-1996.



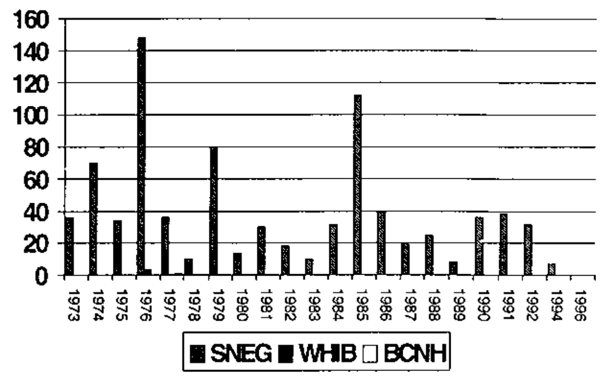
(a) all pairs



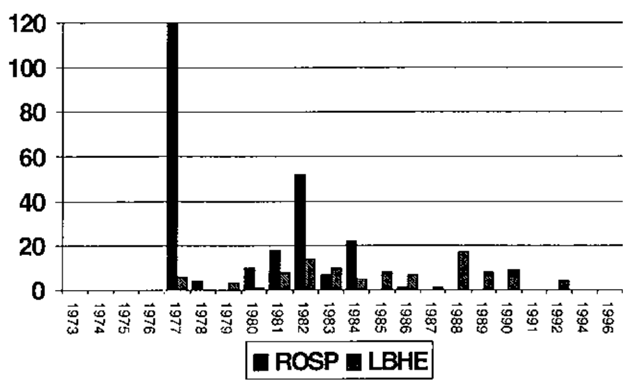
(b) Reddish Egret, Tricolored Heron, White-faced Ibis



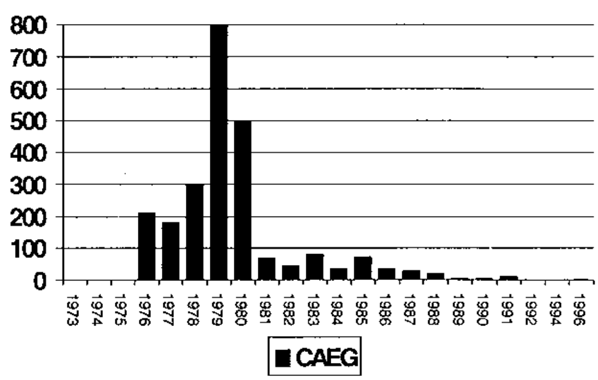
(c) Great Egret (no Great Blue Heron)



(d) Snowy Egret, White Ibis, Black-crowned Night-Heron

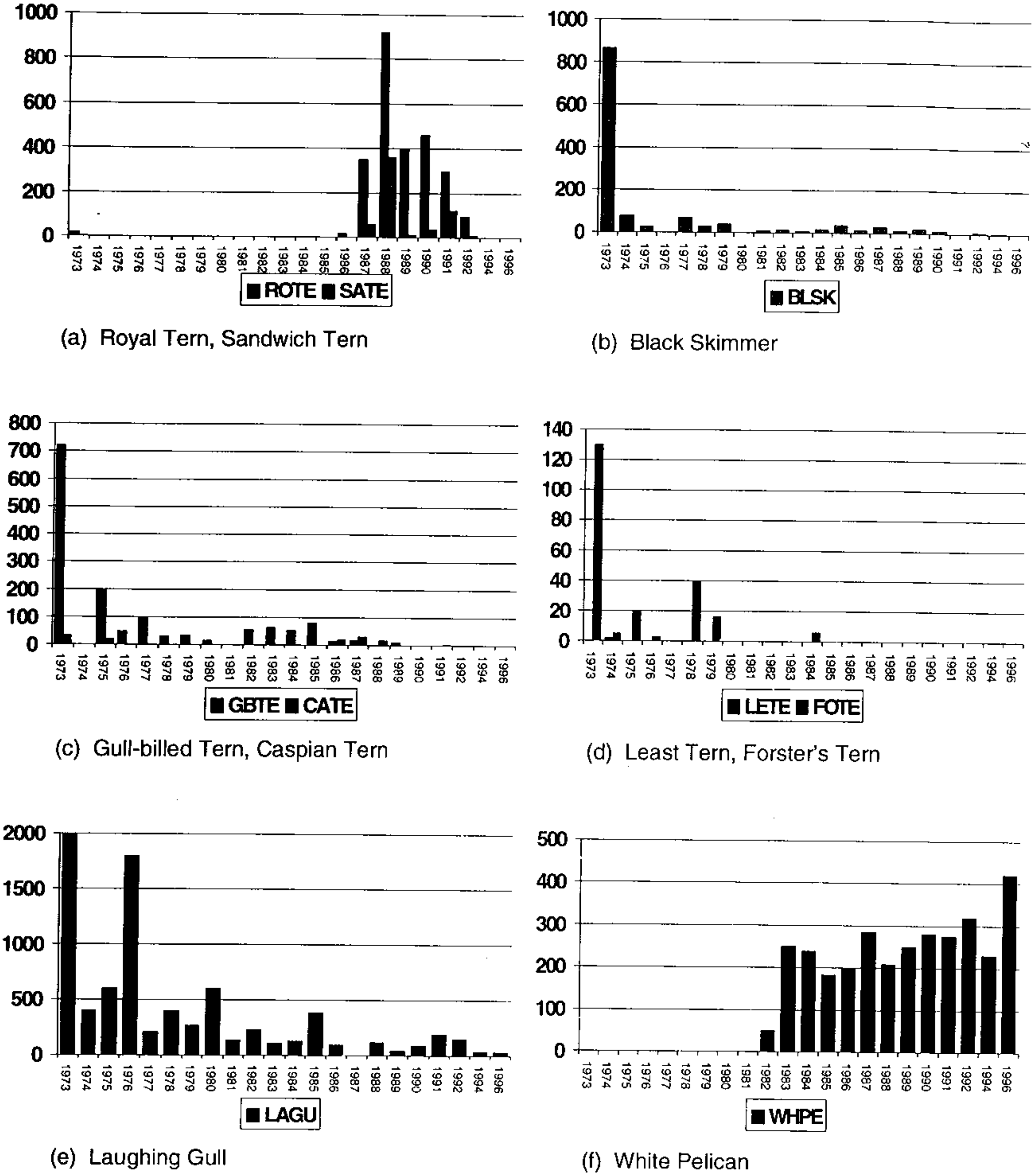


(e) Roseate Spoonbill, Little Blue Heron



(f) Cattle Egret

Figure 51. Year pair totals of (a) all colonial waterbird species that have utilized Marker 81 Dredged Material Island Rookery, and (b-f) species that prefer shrub/tree habitat from 1973-1996.



(a) Royal Tern, Sandwich Tern

(b) Black Skimmer

(c) Gull-billed Tern, Caspian Tern

(d) Least Tern, Forster's Tern

(e) Laughing Gull

(f) White Pelican

Figure 52. Year pair totals of (a-f) ground-nesting colonial waterbird species that have utilized Marker 81 Dredged Material Island Rookery from 1973-1996.

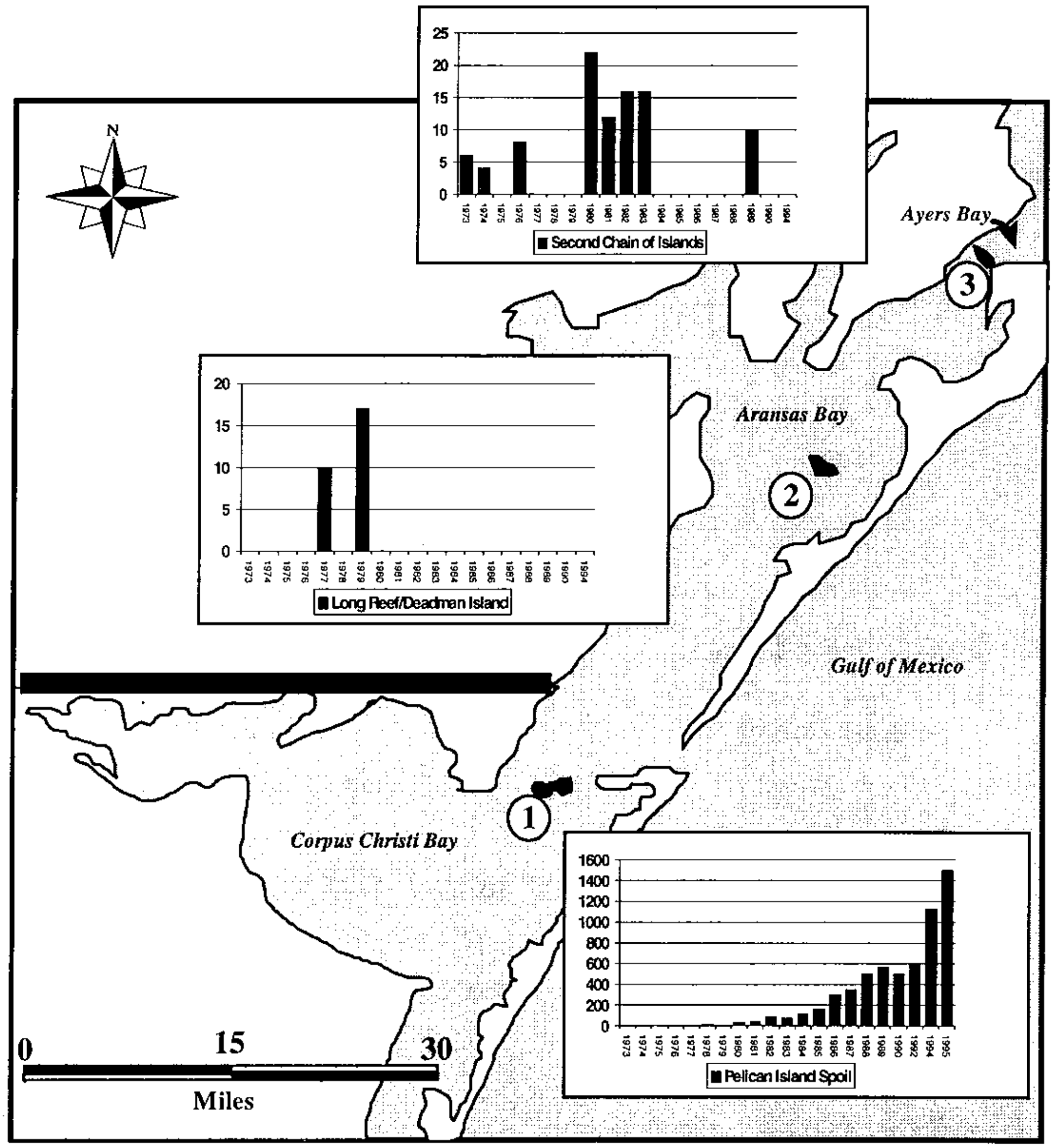


Figure 53. Summary of nesting population dynamics for the Brown Pelican in CCBNEP area documented from (1) Pelican Island Spoil, (2) Long Reef/Deadman Island, and (3) Second Chain of Islands rookeries.

raccoons, feral hogs) in years of extremely low spring tides. Although no documentation exists of storm tides decimating the nests and young, it is possible the birds moved following repeated nest failures. Additionally, it was noted that although nesting pairs are an indirect indicator of nest success, years were documented (1930, 1978, 1981) where pairs produced eggs or young later abandoned prior to fledging.

Probable Causes of Changes in Rookery Island Dynamics and Recommendations

Habitat Loss and/or Habitat Degradation

Natural and dredged material island loss has not been quantified in the CCBNEP area, although some islands became inactive as rookeries through time. Because a rookery often encompasses several islands, nesting populations may shift among islands within a colony, making distinct evaluations of an island's importance difficult. Erosion was cited as a primary factor as well as changes in vegetation types (i.e., from bare to vegetated) (Chaney et al. 1996). Factors driving erosion in south Texas include predominant southeast winds in summer and high-velocity winds from northers during winter. Wave action from watercraft may accelerate rate of erosion.

Several rookeries were identified as exhibiting erosion problems (Table 72). Islands composed of finer clays and silt often exhibit steep shelf shorelines, eliminating potential habitat for ground nesters around the island perimeter. Dredged material islands, such as Marker 81 Spoil Island (New Marker 163) rookery, exhibited low, sloping elevation gradients to the south and abrupt shoreline terrace along the northern shorelines. Even natural islands, such as North Bird Island, eroded to where most habitat is comprised of vegetated areas, with little to no beach habitat for ground-nesters requiring bare substrates above the high tide level.

Reworking of shoreline sediments is difficult to evaluate without aerial photographs of sufficient resolution throughout successive years. Shamrock Island changed considerably through time, losing unvegetated shell berms on the north end, yet increasing the areal extent of this habitat on the southern end. Other natural islands eroded such that frequent tidal inundation occurs during the nesting season, resulting in nest failure for that year. Some rookeries were renourished through beneficial uses of dredged material to reestablish unvegetated nesting habitats. Through a cooperative effort of the National Audubon Society and US Army Corps of Engineers, renourishment programs were implemented in Long Reef/Deadman Island and Pelican Island Spoil rookeries. Renourishment activities should be designed to increase habitat area for nesting colonial waterbird, yet maintain structural diversity of other important habitats within the rookery. Renourishment should not "link" independent islands together, as a corridor for predators may be established [e.g., Marker 103-117 (New Marker 207-221) Spoil Island rookery in Baffin Bay area] (Coste and Skoruppa, 1989). Sediment size is an important consideration when evaluating renourishment options, as finer sediments settle in existing channels and are difficult to place in a selected areas. Some rookeries adjacent to maintained channels will not result in substrate enhancement because of this type of dredged material available (e.g., False Live Oak Point) (Coste and Skoruppa, 1989). Source of dredged material is critical to evaluate potential of pollutants in the sediments (heavy metals, petroleum hydrocarbons, polychlorinated biphenyls, and organochlorines) (L. Gamble, pers. comm., in Coste and Skoruppa, 1989). Final elevations of the renourished site are very important as well, as sediments at low elevations will wash away during high tides and sediments at high elevations are subject to wind erosion (Chaney et al. 1978). Often islands are not adjacent to dredged material sources, either because of natural locations or they were created with material from a channel no longer maintained. The

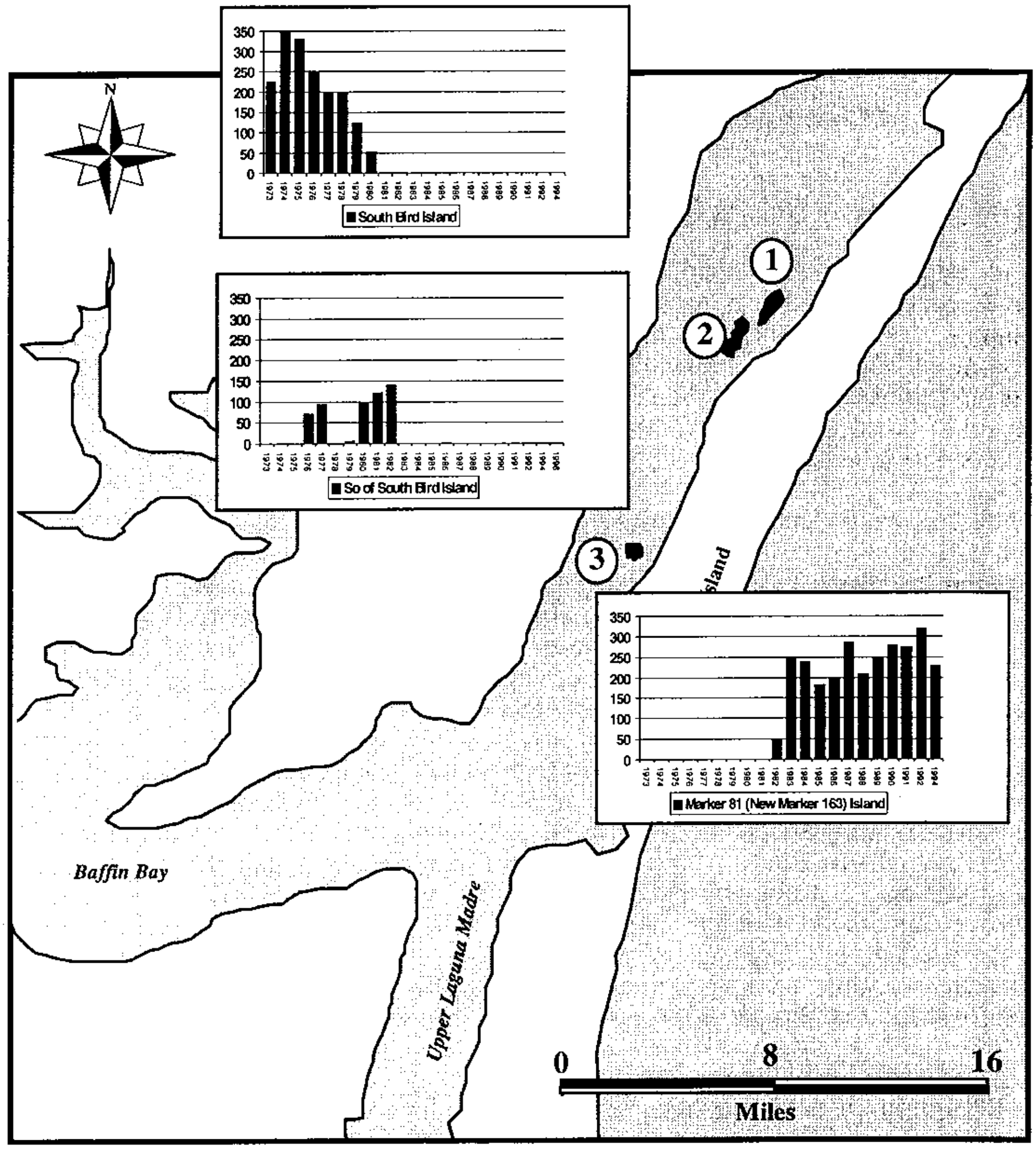


Figure 54. Summary of nesting population dynamics for the American White Pelican in CCBNEP area documented from (1) South Bird Island, (2) South of South Bird Island, and (3) Marker 81 (New Marker 163) spoil island rookeries.

Table 72. Potential causes of nesting colonial waterbird population shifts, declines or abandonment in rookeries within the CCBNEP area (north of Baffin Bay) (adapted from Coste and Skoruppa, 1989).

Rookery	Erosion	Vegetation succession	Predation	Human disturbance
Ayres/Mesquite Bays				
False Live Oak Point	X			
Aransas Refuge Spoil		X	Raccoons	Limited
Second Chain of Islands	X			Moderate
Cape Carlos Dugout			Raccoons	
Cedar Bayou			Coyotes, Raccoons	Minimal
Aransas Bay				
Panther Reef			Raccoons	Limited
Ballou Island			Raccoons	Moderate
Long Reef/Deadman Island	X		Fire Ants	Limited
San Jose Reef/Platforms			Raccoons	Limited
Balckjack Point Reef		X	Raccoons	
Redfish Bay				
Danger Island			Coyotes, Raccoons	Minimal
Aransas Channel Spoil			Coyotes, Raccoons	Limited
Ransom Island/Spoil		X	Coyotes, Raccoons	Moderate
Causeway Islands/Platforms	X			Moderate
Big Bayou Spoil			Coyotes, Raccoons	Heavy
Hog Island Complex			Coyotes, Raccoons	Heavy
Harbor Island			Raccoons	Moderate
Stedman Island			Raccoons	Heavy
Emilie Island			Raccoons	Moderate
Hwy 361 Spoil			Raccoons	
East Shore Spoil			Coyotes, Raccoons	
Nueces Bay				
West Nueces Bay	X		Fire Ants	Moderate
East Nueces Bay	X		Fire Ants	Heavy
Sunset Lake			Domestic dogs	Heavy
Corpus Christi Bay				
LaQuinta Spoil Islands			Raccoons	
Sun Oil Channel Spoil			Raccoons	Heavy
Castor's Cut			Coyotes	
Upper Laguna Madre				
GIWW Marker 51 Spoil			Raccoons	Moderate
NAS Islands			Coyotes, Raccoons	Limited
Marker 13-35 Spoil			Coyotes	Moderate
Marker 65-74				Moderate-Heavy
Marker 72-75			Coyotes, Raccoons	Heavy
North of Bird Island (Marker 87-91)			Coyotes, Raccoons	
North Bird Island	X		Coyotes, Raccoons	
West Side Spoil Islands			Coyotes, Feral Cats	
South Bird Island			Coyotes	
South of South Bird Island			Coyotes, Badger	Limited
Marker 72 Spoil Island				Moderate-Heavy
Marker 81 (New Marker 163)	X			Minimal

Causeway Islands/Platforms rookery in Redfish Bay is adjacent to a channel no longer in use, so renourishment is unlikely (Coste and Skoruppa, 1989). In many cases, the rookery may be surrounded by other sensitive estuarine habitats; for example, Second Chain of Islands in Ayres Bay is adjacent to prime oyster reef and seagrass meadow habitat. Renourishment activities around this rookery would probably result in degradation of other essential habitats, a strategy strongly discouraged (Coste and Skoruppa, 1989).

Other rookeries experiencing continued erosion may benefit from placement of sandbags, riprap, or offshore reefs. One of the islands in the East Nueces Bay rookery had protective measures employed along portions of the shoreline to reduce erosion (Coste and Skoruppa, 1989). Riprap placed on the northern shoreline of Pelican Island Spoil rookery resulted in erosion rate reduction and perches for Brown Pelican (E. Payne, pers. comm. in Coste and Skoruppa, 1989). The Causeway Islands/Platforms and Marker 81 (New Marker 163) rookeries in Redfish Bay and upper Laguna Madre, respectively, were suggested as potential sites for shoreline protection on the north side and protecting existing vegetated habitats and south-facing unvegetated shorelines from further erosion (Coste and Skoruppa 1989). Shamrock Island in Corpus Christi Bay is under consideration for extensive shoreline protection measures to minimize further erosion to the islands north and interior habitats (J. Bergan, pers. comm.).

Vegetation succession on dredged material islands along the south Texas coast proceed at a slower rate in south Texas than was documented in the upper coast of Texas and other East Coast areas due to lower rainfall and higher evaporation rates (Chaney et al. 1978). Existing island vegetation communities appeared to be maintaining similar patterns on islands evaluated in this study, although the density of prickly pear and mesquite increased at the apex of many islands since 1978. Several rookeries were listed as becoming inactive due to loss of ground-nesting habitat for skimmers, gulls, and terns (see Table 5). Some species may tolerate changes in vegetation in their nest site if they selected the site under optimum conditions. Eventually, if succession continues, the species will abandon the site in search of an alternate area (Parnell et al. 1988). Therefore, sites in various stages of succession will support a diversity of colonial waterbirds in an area. Some vegetation communities may be maintained naturally at a particular stage as a result of limited nutrients, water, or space; other methods were employed to mechanically set back successional stages (e.g., burning, mowing, use of herbicides, placement of dredged material) (Parnell et al. 1988). All methods may change the vegetation composition structure for a period of time; however, some methods may actually enhance vegetation growth (Soots and Landin, 1978). Placement of new material should be designed to minimally change the site elevation (Chaney et al. 1978).

Predation

Many rookeries became inactive or exhibit decreased numbers in the CCBNEP area due to increased predation pressure by raccoons, coyotes, fire ants, feral hogs, and other species of colonial waterbirds. Rookeries having mainland connections or shallow waters between the mainland and the rookery increase probability of mammalian predation. Several rookeries were listed as inactive due to predation in the CCBNEP area (see Table 72). Implementation of predator removal/control is dependent upon probability of reestablishment and effects of other impacts on the rookery recovery (human disturbance, appropriate habitat). Active removal of predators on Harbor Island by Animal Damage Control was undertaken in the past, however, continued removal is necessary through annual or semi-annual trapping. The islands within the Naval Air Station rookery in upper Laguna Madre are isolated from both the mainland and each other. This rookery is stable, therefore, an active predator removal program on a semi-annual or annual basis would be beneficial. Other rookeries with stable populations were recommended as well: Marker 35 dredged material island (part of Marker 2-17 Spoil Islands (New Marker 13-35), Marker 72 Spoil Island) New Marker 152), North of Bird Island Marker 43 (New Marker 87-91), South Bird Island, and South of South Bird Island (Coste and Skoruppa, 1989). Fire ant control was suggested for Long Reef/Deadman Island, West Nueces and East Nueces Bay rookeries (Coste and Skoruppa, 1989). A project was initiated in Second Chain of Islands rookery following 100% mortality of colonial waterbird chicks on some islands in 1991 (A. Strand and S. Robertson, pers. comm. in Roper, 1992). An insecticide (Logic) was applied in 1991 and 1992, however, the birds did not recolonize the site. Therefore, quantitative assessments of the treatment were not obtainable. Treatments using the same insecticide was employed during the fall in a rookery at Rollover Pass in east Galveston Bay, where suppression of fire ant populations was achieved. This method of treatment may be cost prohibitive and insecticide effects on other organisms is not well understood (Roper 1992).

The introduction of domestic and/or feral animals within or adjacent to a rookery may have devastating effects on colonial waterbird nesting success. Rookeries in proximity to urban areas may be preyed on by domestic dogs (Sunset Lake rookery) feral cats (West Side Spoil Islands rookery) (Coste and Skoruppa, 1989), or feral hogs (South of South Bird Island rookery) (Smith and Cox pers. observ.). Other studies identified similar introduced predators, including domestic cats and rats (Anderson et al. 1989). The introduction of rabbits on some dredged material islands in upper Laguna Madre may support predators year-round, increasing their potential of being present when the colonial waterbirds begin the nesting phase.

Predation by other species within the colony also occurs; Black-crowned Night-Herons were associated as predators by Common Terns at night in a rookery in New Jersey. Nocturnal predation by the night herons also caused an increase in predation by gulls and ants when the parents deserted the nest (Shealer and Kress, 1991). Nocturnal predation by owls on adult gulls was documented in several studies, and indicate avian predators may maximize prey availability in colonial waterbird colonies. The adults may be the prime prey target, but the young are also negatively impacted by environmental stresses or surplus taking by the owls. Newly hatched chicks are particularly susceptible to low temperatures or rain when left unprotected (Southern et al. 1982).

Effects of continued predation may be directed toward a particular suite of colonial waterbird species. During a three-year study of dredged material island rookery in South Carolina, White Ibises were continually predated upon by fish crows and large mammals to local extinction. Other wading bird species' survival rates were lower one year, but returned to previous values the following year. Factors attributing to the ultimate decline of White Ibises included the significant interspecific differences of nest height and nest stability (Post 1990).

Human Disturbance

Nesting success of colonial waterbirds is differentially affected by human disturbance. Each species appears to exhibit a different tolerance level to the presence of humans, that may also change during the breeding cycle. Whereas wading birds often leave the nest and retreat to nearby shallow water habitats, gulls and terns often fly overhead until the disturbance is abated (Vos et al. 1985, Erwin, 1989). The additional impact of prolonged disturbance occurs when the young are unprotected from environmental conditions (e.g., intense heat during day, cold temperatures at night), when young chicks retreat to the water and are blown offshore, or from predation on the eggs and young from other colonial waterbirds (primarily Laughing Gulls) (Chaney et al. 1978). Additional mortality may occur as the result of hatching failure, lower feeding rates, injury, lower growth rates (as a result of less food or regurgitation of food), premature fledging, and colony abandonment (Burger, 1981, Rodgers and Burger, 1981).

Disturbance by humans may occur by physically walking on the islands, wading around the islands, or passing by in a boat; and, unintentional and intentional disturbance have the same negative effect. Additional impacts occur when colonial waterbirds establish nests on dredged material islands where cabins are still permitted or where houseboats are anchored nearby (Coste and Skoruppa, 1989). Whereas humans are not allowed in rookery areas in CCBNEP area during January-September, enforcement is difficult. Public education may be the most important deterrent to continued human disturbance. Monitoring and research activities during the breeding cycle should also be designed carefully. The presence of a human in the rookery may modify the behavior of the colony, thus biasing the observation, or may cause the colony to abandon the site. The timing and frequency of the visits should be carefully assessed (Tremblay and Ellison, 1979, Rodgers and Burger, 1981).

Black Skimmers appear to be extremely sensitive to disturbance, although the degree of impact changes throughout the reproductive cycle. They seem most sensitive to disturbance early in the prelaying phase, where they would abandon the disturbed site and select an alternate, less-disturbed site nearby. Because of these early movements to alternate sites, these sites may result in higher nesting densities. Intraspecific aggression may increase in the colony, and lowering nesting success. The early incubation phase was also a sensitive period in response to disturbance, and the skimmers would abandon their nests if disturbed. As incubation progressed, the skimmers were less likely to abandon or leave the nest for long periods. Hatching success was lower when disturbance occurred more frequently. Survivability during the chick phase was dependent upon amount of stresses experienced by the young. Gulls may predate on unprotected chicks, but other skimmer parents may also kill a chick wandering too close to their nest site (Burger, 1983).

Disturbance may be reduced by establishing "barriers" between the colony and human activities. Heronries isolated from adjacent human use areas by fencing or water-filled moats had a higher fledgling rate, than those surrounded by adjacent buffers of land or water. These two methods were most likely successful due to the degree of structure permanence; foot traffic through the rookery was effectively eliminated (Carlson and McLean 1996). Fencing was assessed for terns and skimmers, when low direct mortality by Black Skimmer chicks was observed, whereas Roseate Terns were injured more often (Safina and Burger, 1983). In a study assessing disturbance effects of several species after nest territories had been established, most birds did not flush when disturbance was >150 m away. Because birds are more easily disturbed when establishing nests, 200 m was suggested for Black Skimmers and Common Terns and 100 m for least and Royal Terns. Signs should be erected at least three weeks before nest establishment and should be spaced at 50 m intervals around the colony perimeter (Erwin, 1989).

Oil well activities during the breeding season may have negatively affected colony establishment and/or fledgling success in a Galveston Bay rookery. Breeding bird use in the rookery may have been affected early in the season when the pairs were establishing nesting territories. Many pairs did not use the previous year's site, but were still located within the rookery. Some species, such as Roseate Spoonbill, did not establish nests at all that year, whereas White-faced Ibis established their nests after drilling activities had ceased (Mueller and Glass, 1988).

D. Management Recommendations

All avian nesting information used for this report focused on the Colonial Waterbird Census data. This database was maintained by the volunteer efforts of several individuals, and most data in the CCBNEP area was collected by a handful of individuals during the 20+ year period. This invaluable information is the only long-term database available to assess status and trends of colonial waterbirds and the habitats they require for nesting success. All efforts should be made to continue the collection of this information combining financial, logistical, and volunteer support levels. Continued partnerships among agencies, research and academic institutions, nonprofit conservation groups, and interest groups should be encouraged.

At present, quantitative data are not available to evaluate successional changes in vegetation or spatial changes of island configuration. Detailed studies of key rookeries should be conducted, particularly those essential to species of concern. This information would be useful to identify those islands that would benefit from dredged material deposits. In addition, personal observations and recommendations of colonial waterbird census participants are not documented. A workshop should be organized with the goal to synthesize all available information and comments. Through such an approach, recommendations could be made concerning how to protect sensitive rookery habitat, which areas are in need of restoration or enhancement, and methodologies necessary for future quantitative status and trends assessments.

VIII. CONCLUSIONS

A. Wetland Status (1992)

- Wetlands and aquatic habitats in the CCBNEP study area are dominated by an estuarine system that encompasses about 161,000 ha and represents 83 percent of the wetland and deep-water habitats. The palustrine system is second at 14 percent (26,578 ha), followed by lacustrine (2.5 percent), marine (0.37 percent, excluding open water), and riverine (0.13 percent).
- Vegetated wetlands (marshes, scrub-shrub, and forested wetlands) have a total area of about 48,375 ha; 97 percent are marshes (estuarine and palustrine emergent wetlands).
- Salt and brackish marshes (estuarine intertidal emergent wetlands) constitute about 48 percent (22,855 ha) of the marsh system; fresh or inland marshes (palustrine emergent wetlands) make up the remaining 52 percent (24,250 ha). These numbers are unadjusted.
- Forested (740 ha) and scrub-shrub (530 ha) wetlands have a total area of about 1,270 acres, representing about 3 percent of all vegetated wetland habitats.
- Riparian woodlands in the three major fluvial-deltaic systems (Nueces, Aransas–Chiltipin, and Mission Rivers) have an area of about 1,820 ha.
- Approximately 8,900 ha of sand and mud flats and bay beaches (estuarine intertidal unconsolidated shores and estuarine intertidal aquatic bed) were mapped on the 1992 photographs.

B. Wetland Trends

- The trend in vegetated wetlands is one of net gain as revealed by total marsh areas of 34,550 ha in the 1950's, 39,460 ha in 1979, and 43,970 ha in 1992. Numbers were adjusted to offset some photointerpretation inconsistencies. The rate of gain, increased over time from about 200 ha per year between the 1950's and 1979, to more than 300 ha per year between 1979 and 1992. The total gain in marshes was about 14 percent from the 1950's to 1979, and 11 percent from 1979 to 1992.
- Marshes (emergent wetlands) experienced losses in some areas. Among notable losses were pothole wetlands, on the coastal prairie and on the Pleistocene barrier-strandplain ridge, Live Oak Peninsula/Ridge.
- Estuarine intertidal flats underwent major losses. From the 1950's to 1979 more than 50 percent of this habitat was converted to other habitat types, primarily subtidal classes such as seagrass beds and open water.
- Riparian woodlands expanded in total area from 1979 to 1992 by about 200 ha.

C. Causes of Trends

Marshes (Emergent Wetlands)

- Much of the gain in estuarine marshes occurred on intertidal flats as vegetation spread in areas that became more frequently flooded. Largest gains in estuarine marshes occurred from the 1950's to 1979, coinciding with an accelerated rise in relative sea level of 1.7 cm/yr from the mid 1960's to 1975. This annual rate of rise is substantially higher than the subsequent rate of 0.5 cm/yr from 1976 to 1993.

- Marsh expansion on intertidal flats was aided by sewage treatment discharges in some areas such as near Port Aransas and along the margins of Oso Bay.

- Palustrine marshes had largest gains on barrier islands and the Pleistocene barrier-strandplain, Blackjack Peninsula. Although some gain is due to photointerpretation and more inclusive delineations in 1992, there is evidence that island environments have become wetter, possibly from a combination of higher amounts of precipitation and rising sea level since the 1950's.

- Marsh losses in some areas were associated with human activities. From the 1950's to 1992, many pothole wetlands were converted to agricultural land on the coastal prairie. Pothole wetlands on Live Oak Peninsula/Ridge were also affected by human activities including quarrying to develop sand resources.

- Marshes in some areas were lost by draining, impounding, filling, and dredging.

- Marshes were eroded along high energy shorelines.

Estuarine Intertidal Flats

- Major conversions of wind-tidal flats to subtidal habitats correlate spatially and temporally with a relative sea-level rise. Most loss in flats occurred during the 1950's-1979, coinciding with an accelerated rise in relative sea level from the 1960's to 1975.

- Modest losses in tidal flats occurred as a result of dredging and filling activities.

Riparian Woodlands

- There were modest gains in riparian woodlands in the major fluvial-deltaic systems of the Nueces, Aransas-Chiltipin, and Mission Rivers. Clearing of woodlands occurred primarily before the 1950's, which preceded the period of analysis for this study. Since the 1950's, woodlands in the various valleys have generally been maintained.

D. Shoreline Types

- Total cumulative length of mapped shorelines in the study area is 2,014 km.
- About 330 km, or 16.4 percent, of shorelines are hardened.
- Marshes (about 900 km in cumulative length) are the most common shoreline type, composing 45 percent of the total shoreline length.

E. Rookery Islands

- Rookery islands in the CCBNEP area are critical to the long-term survival of colonial waterbirds (gulls, terns, herons, egrets, pelicans, spoonbills, and ibises).
- Changes in island size, configuration, and available habitat types variously affected the success of certain species. Decreases in nesting pairs of bare-ground, nesting species (e.g., terns and skimmers) may be due primarily to loss of unvegetated beaches and flats to vegetated grasses, forbs, and shrubs. Some rookery islands were abandoned from extensive erosion.
- American White Pelicans nested on three different islands in upper Laguna Madre since 1973. This population is the only coastal nesting population in the United States.
- Brown Pelicans made a dramatic recovery in the CCBNEP area since the mid-1970s, with consistently increasing nesting populations on Pelican Island Spoil rookery in Corpus Christi Bay.
- Factors that may negatively effect nesting trends of colonial waterbirds include: habitat loss and/or habitat degradation, predation, and human disturbance.
- Monitoring of colonial waterbird nesting success should be continued, as the Colonial Waterbird Census is the only long-term dataset available to assess status and trends. Continued partnerships among agencies, research and academic institutions, nonprofit conservation groups, and interest groups should be encouraged and supported financially.
- No quantitative data are presently available to evaluate successional changes in vegetation or spatial changes of island configuration and areal extent. Detailed studies of key rookeries should be conducted, particularly those essential to species of concern.

IX. REFERENCES

(Includes relevant references not cited in report)

Anderson, J. R., Hardy, E. E., Roach, J. T., and Witmer, R. E., 1976, A land use and land cover classification system for use with remote sensor data: U.S. Geological Survey Professional Paper 964, 27 p.

Armstrong, W., Wright, E. J., Lythe, S., and Gaynard, T. J., 1985, Plant zonation and the effects of the spring-neap cycle on soil aeration in a Humber salt marsh: Journal of Ecology 73:323-339.

Baccus, J. T., and Horton, J. K., 1979, An ecological and sedimentary study of Padre Island National Seashore: Southwest Texas State University, Department of Biology, for Office of Natural Resources, Southwest Region, National Park Service, Santa Fe, New Mexico, 272 p.

Benton, A. R., Jr., Hatch, S. L., Kirk, W. L., Newnam, R. M., Snell, W. W., and Williams, J. G., 1977, Monitoring of Texas coastal wetlands: College Station, Texas A&M University, Remote Sensing Center, Technical Report RSC-88, 124 p.

Bertness, M. D, 1991, Interspecific interactions among high marsh perennials in a New England salt marsh: Ecology 72:125-137.

Bertness, M. D., Gough, L., and Shumway, S. W., 1992, Salt tolerances and the distribution of fugitive salt marsh plants: Ecology 73:1842-1851.

Bleakney, J. S, 1972, Ecological implications of annual variation in tidal extremes: Ecology 53:933-938.

Britton, J. D., and Morton, B., 1989, Shore ecology of the Gulf of Mexico: University of Texas Press, Austin, Texas, USA.

Brown, L. F. Jr., Morton, R. A., McGowen, J. H., Kreitler, C. W., and Fisher, W. L., 1974, Natural hazards of the Texas Coastal Zone: The University of Texas at Austin, Bureau of Economic Geology, 13 p., 7 maps.

Brown, L. F., Jr., Brewton, J. L., McGowen, J. H., Evans, T. J., Fisher, W. L., and Groat, C. G., 1976, Environmental geologic atlas of the Texas Coastal Zone—Corpus Christi area: The University of Texas at Austin, Bureau of Economic Geology, 123 p., 9 maps.

Brown, L. R., Jr., McGowen, J. H., Evans, T. J., Groat, C. G., and Fisher, W. L., 1977, Environmental geologic atlas of the Texas Coastal Zone—Kingsville area: The University of Texas at Austin, Bureau of Economic Geology, 131 p., 9 maps.

Burger, J., 1981, Effects of human disturbance on colonial species, particularly gull: Colonial Waterbirds 4:28-36.

Carlson, B. A., and McLean, E. B., 1996, Buffer zones and disturbance types as predictors of fledging success in Great Blue Herons, *Ardea herodias*: Colonial Waterbirds 19:124-127.

Chabreck, R. H., 1972, Vegetation, water and soil characteristics of the Louisiana coastal region: Louisiana Agricultural Experiment Station Bulletin 664, Baton Rouge, Louisiana, USA.

Chabreck, R. H., and Palmisano, A. W., 1973, The effects of Hurricane Camille on the marshes of the Mississippi River delta: Ecology 54:1118-1125.

Chaney, A. H., Blacklock, G. W., and Bartels, S. G., 1996, Current status and historical trends of avian resources in the Corpus Christi Bay National Estuary Program study area, Vol. 2 in J. W. Tunnell, Q. R. Dokken, E. H. Smith, and K. Withers, Current status and historical trends of the estuarine living resources within the Corpus Christi Bay National Estuary Program study area: CCBNEP-06B, Texas Natural Resource Conservation Commission, Austin, Texas.

Chaney, A. H., Chapman, B. R., Karges, J. P., Nelson, D. A., Schmidt, R. R., and Thebeau, L. C, 1978, Use of dredged material islands by colonial seabirds and wading birds in Texas, Technical Report D-78-8: U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Cobb, R. A., 1987, Mitigation evaluation study for the South Texas Coast, 1975 - 1986: Corpus Christi State University, Center for Coastal Studies, Report prepared for U. S. Fish and Wildlife Service Ecological Services, Corpus Christi, Texas, under Cooperative Agreement No. 14-16-0002-86-919, 88 p.

Collins, K. D., 1987, The distribution, status and ecological value of inland pothole wetlands associated with the live oak brush community in South Texas: U. S. Fish and Wildlife Service, Ecological Services, Corpus Christi, Texas, 21 p.

Correll, D. S., and Johnston, M. C., 1970, Manual of the vascular plants of Texas: Texas Research Foundation, Renner, Texas, USA.

Coste, R. L., and Skoruppa, M. K., 1989, Colonial waterbird rookery island management plan for the South Texas Coast: Center for Coastal Studies, Corpus Christi State University, Corpus Christi, Texas.

Cowardin, L. M., Carter, V., Golet, F. C. and LaRoe, E. T., 1979, Classification of wetlands and deepwater habitats of the United States: United States Department of Interior, Fish and Wildlife Service, Washington, D.C., USA, 103 p.

Darnell, T. M., Smith, E. H., Tunnell, J. W., Withers, K., and Jones, E. R., 1997, The influence of landscape features on bird use of marsh habitat created for Whooping Cranes (*Grus americanus*) through beneficial use of dredged material: Final Report: Center for Coastal Studies, TAMU-CC-9704-CCS. Texas A&M University-Corpus Christi, Corpus Christi, Texas, USA.

Davis, R. A., and Fox, W. T., 1972, Coastal dynamics along Mustang Island, Texas: Western Michigan University Technical Report No. 9, ONR Contract No. 388-092, 68 p.

Deegan, L. A., Day, J. W., Jr., Gosselink, J. G., Yanez-Arancibia, A., Chavez, G. S., and Sanchez-Gil, P., 1986, Relationships among physical characteristics, vegetation distribution and fisheries yield in Gulf of Mexico estuaries, in Wolfe, D. A., ed., Estuarine variability: Academic Press, Inc., Orlando, p. 83-100.

Diener, R. A., 1975, Cooperative Gulf of Mexico estuarine inventory and study-Texas: area description: National Oceanic and Atmospheric Administration, Technical Report, National Marine Fisheries Service Circular 393, 129 p.

Drawe, D. L., Chamrad, A. D., and Box, T. W., 1978, Plant communities of the Welder Wildlife Refuge: Welder Wildlife Foundation, Sinton, Texas, Contribution No. 5, Series B, revised, 2 maps, 40 p.

Duxbury, A. C., 1971, The earth and its oceans: Reading, Massachusetts, Addison-Wesley Publishing Company, 381 p.

Elliott, L. F., 1995, Reddish Egret/Brown Pelican colony monitoring: Final report to Texas Parks and Wildlife Department, Project No. 9.4.

Erwin, R. M., 1989, Responses to human intruders by birds nesting in colonies: Experimental results and management guidelines: Colonial Waterbirds 12:104-108.

Espey, Huston and Associates, Inc., 1977, Marsh plant production and potential detritus in Lavaca, San Antonio, and Nueces Bays: report prepared for Texas Department of Water Resources, Document No. 7688, variable pages, 3 maps.

Federal Intergency Committee for Wetland Delineation, 1989, Federal manual for identifying and delineating jurisdictional wetlands: U.S. Army Corps of Engineers, U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service and U.S.D.A. Soil Conservation Service, Washington, D.C.. Cooperative technical publication, 76 p. plus appendices.

Franki, G. E., Garcia, R. N., Hajek, B. F, Arriaga, D., and Roberts, J. C., 1965, Soil Survey Nueces County, Texas: U. S. Department of Agriculture, Soil Conservation Service, 65 p. 79 maps.

Funicelli, N. A., and Benson, N. G., 1983, Choke Canyon Reservoir: Estuarine impacts and management, in, Magoon, O. T., and Converse, Hugh, Coastal Zone '83, Volume III: American Society of Civil Engineers, New York, p. 2866-2876.

Gabrysch, R. K., 1969, Land-surface subsidence in the Houston–Galveston region, Texas: United Nations Educational, Scientific and Cultural Organization (UNESCO), Studies and Reports in Hydrology, Land Subsidence Symposium, v. 1, p. 43–54.

Gabrysch, R. K., 1984, Ground-water withdrawals and land-surface subsidence in the Houston–Galveston region, Texas, 1906–1980: Texas Department of Water Resources Report 287, 64 p.

Gabrysch, R. K., and Bonnet, C. W., 1975, Land-surface subsidence in the Houston–Galveston region, Texas: Texas Water Development Board, Report 188, 19 p.

Gabrysch, R. K., and Coplin, L. S., 1990, Land-surface subsidence resulting from ground-water withdrawals in the Houston–Galveston region, Texas, through 1987: U.S. Geological Survey Report of Investigations No. 90-01, 53 p.

Gornitz, V., and Lebedeff, S., 1987, Global sea-level changes during the past century: Society of Economic Paleontologists and Mineralogists, Special Publication No. 41, p. 3–16.

Gornitz, V., Lebedeff, S., and Hansen, J., 1982, Global sea level trend in the past century: Science, v. 215, p. 1611–1614.

Gosselink, J. G, 1984, The ecology of delta marshes of coastal Louisiana: a community profile: U.S. Fish and Wildlife Service. FWS/OBS-84/09.

Gosselink, J. G., and Bauman, R. H., 1980, Wetland inventories: Wetland loss along the United States Coast: Journal of Geomorphology Supp. v. 34, p. 173-187.

Gould, F. W., 1978, Common Texas grasses: an illustrated guide: Texas A&M University Press, College Station, Texas, USA.

Gould, F. W., and Box, T. W, .1965, Grasses of the Texas Coastal Bend (Calhoun, Refugio, Aransas, San Patricio and northern Kleberg counties): Texas A&M Press, College Station, Texas, USA.

Guckian, W. J., and Garcia, R. N., 1979, Soil survey of San Patricio and Aransas Counties, Texas: U. S. Department of Agriculture, Soil Conservation Service, 122 p., 96 maps.

Gustavson, T. C., and Kreitler, C. W., 1976, Geothermal resources of the Texas Gulf coast—environmental concerns arising from the production and disposal of geothermal waters: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 76-7, 35 p.

Haigh, S. L., 1984, Habitat selection and production of nesting birds on two lakes in South Texas: Master's thesis. Texas A&I University, Kingsville, Texas, USA.

Hayes, M. O., 1974, Hurricanes as geological agents: case studies of Hurricanes Carla, 1961, and Cindy, 1963: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 61, 56 p.

Hayes, M. O., Gundlach, E. R., and Getter, C. D., 1980, Sensitivity ranking of energy port shorelines, in Proc. Specialty Conference, American Society of Civil Engineers, New York, N.Y., p. 697-709.

Hildebrand, H., and King, D., 1978, A biological study of the Cayo del Oso and the Pita Island area of the Laguna Madre, final report, 1972-1978, volume I: Corpus Christi, Texas, Central Power and Light Company, 253 p.

Hillenbrand, C. J., 1985, Subsidence and fault activation related to fluid extraction Saxet Field, Nueces County, Texas: University of Houston, Master's thesis, 144 p.

Holland, J. S., Maciolek, N. J., Kalke, R. D., and Oppenheimer, C. H., 1975, A benthos and plankton study of the Corpus Christi, Copano, and Aransas Bay systems: report on data collected during the period July 1974–May 1975 and summary of the three-year project: The University of Texas at Port Aransas Marine Science Institute, Final report to the Texas Water Development Board, 171 p.

Holmes, C. W., and Martin, E. A., 1976, Rates of sedimentation, *in* Holmes, C. W., and others, Environmental studies, South Texas Outer Continental Shelf, 1976, Geology report for the Bureau of Land Management prepared by the U.S. Geological Survey, 626 p.

Hopkinson, C. S., Gosselink, J. G., and Parrondo, R. T., 1978, Aboveground production of seven marsh plant species in coastal Louisiana: Ecology 59:760-769.

Hunter, R. E., Watson, R. L., Hill, G. W., and Dickinson, K. A., 1972, Modern depositional environments and processes, northern and central Padre Island, Texas, in Padre Island National Seashore field guide: Gulf Coast Association of Geological Societies, convention field trip, p. 1-17.

Jenkins, K.V., and Smith, E.H., 1997, Baseline evaluation of the natural resources of Mustang Island State Park, Nueces County, Texas: Center for Coastal Studies Technical Report (draft).

Johnston, J. B., and Ader, R. A., 1983, The use of a GIS for Gulf of Mexico wetland change: in Magoon, O. T., and Converse, H., eds., Coastal Zone '83, Volume I: American Society of Civil Engineers, New York, p. 362-371.

Jones, F. B, 1982, Flora of the Texas Coastal Bend: Welder Wildlife Foundation, Sinton, Texas, USA, 262 p.

Kaplan, E. H, 1988, Southeastern and Carribean seashores: Cape Hatteras to the Gulf coast, Florida, and the Caribbean: The Easton Press, Norwalk, Connecticut, USA.

Kier, R. S., and White, W. A., 1978, Land and water resources of the Corpus Christi Area, Texas: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 95, 22 p., 1 map.

Kreitler, C. W., 1977, Faulting and land subsidence from ground-water and hydrocarbon production, Houston–Galveston, Texas: The University of Texas at Austin, Bureau of Economic Geology Research Note 8, 22 p.

Kreitler, C. W., White, W. A., and Akhter, M. S., 1988, Land subsidence associated with hydrocarbon production, Texas Gulf Coast (abs.): American Association of Petroleum Geologists Bulletin, v. 72, no. 2, p. 208.

LBJ School of Public Affairs, 1978, Preserving Texas' natural heritage. Research project report No. 31: The University of Texas at Austin, Austin, Texas, USA.

LeBlanc, R. J., and Hodgson, W. D., 1959, Origin and development of the Texas shoreline: Gulf Coast Association of Geological Societies Transactions 9:197-220.

Liebbrand, N. F., 1987, Estimated sediment deposition in Lake Corpus Christi, Texas, 1972–1985: U.S. Geological Survey Open-File Report 87-239, 26 p.

Longley, W. L., ed., 1994, Freshwater inflow to Texas bays and estuaries: ecological relationships and methods for determining needs: Texas Water Development Board and Texas Parks and Wildlife Department, Austin, Texas, 386 p.

McGowen, J. H., 1971, Gum Hollow fan delta, Nueces Bay, Texas: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 69, 91 p.

McGowen, J. H., Proctor, C. V., Jr., Brown, L. R., Jr., Evans, T. J., Fisher, W. L, and Groat, C. G., 1976, Environmental geologic atlas of the Texas Coastal Zone—Port Lavaca area: The University of Texas at Austin, Bureau of Economic Geology, 107 p.

Miller, W. R., and Egler, F. E., 1950, Vegetation of the Wequetequock-awcatuck tidal marshes, Connecticut: Ecological Monographs 20:147-170.

Mitsch, W. J., and Gosselink, J. G., 1993, Wetlands, 2nd edition: Van Nostrand Reinhold, New York, USA.

Morton, R. A., 1977, Historical shoreline changes and their causes, Texas Gulf Coast: Gulf Coast Association of Geological Societies Transactions, v. 27, p. 352-364.

Morton, R. A., and McGowen, J. H., 1980, Modern depositional environments of the Texas coast: The University of Texas at Austin, Bureau of Economic Geology Guidebook 20, 167 p.

Morton, R. A., and Paine, J. G., 1984, Historical shoreline changes in Corpus Christi, Oso, and Nueces Bays, Texas Gulf Coast: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 84-6, 66 p.

Morton, R. A., and Paine, J. G., 1990, Coastal land loss in Texas–an overview: Gulf Coast Association of Geological Societies Transactions, v. 40, p. 625-643.

Morton, R. A., and White, W. A., 1995, Shoreline Types of the Upper Texas Coast: Sabine-Galveston-Freeport-Sargent Areas, Final report prepared for the Texas Natural Resources Invertory Program, Texas General Land Office, Texas Natural Resources Conservation Commission, Texas Parks and Wildlife Department, and Minerals Management Service: The University of Texas at Austin, Bureau of Economic Geology, 42 p.

Morton, R. A., and Pieper, M. J., 1976, Shoreline changes on Matagorda Island and San Jose Island (Pass Cavallo to Aransas Pass), An analysis of historical changes of the Texs Gulf shoreline: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 76-4, 42 p.

Moulton, D. W., Dahl, T. E., and Dall, D. M., 1997, Texas coastal wetlands; status and trends, mid-1950s to early 1990s: U. S. Department of the Interior, Fish and Wildlife Service, Albuquerque, New Mexico, 32 p.

Mueller, A. J., and Glass, P. O., 1988, Disturbance tolerance in a Texas waterbird colony: Colonial Waterbirds 11:119-122.

Nicolau, B. A., 1995, Estuarine faunal use in a mitigation project, Nueces River delta, Texas: year five: Texas A&M University–Corpus Christi, Center for Coastal Studies, 107 p.

Nicolau, B. A., and Adams, J. S., 1993, Estuarine faunal use in a mitigation project, Nueces River delta, Texas: years two and three: Texas A&M University–Corpus Christi, Center for Coastal Studies, 114 p.

Nittrouer, C. A., Sternberg, R. W., Carpenter, R., and Bennett, J. T., 1979, The use of Pb-210 geochronology as a sedimentological tool: application to the Washington continental shelf: Marine Geology, v. 31, p. 297–316.

Oldfield, F., and Appleby, P. G., 1984, Empirical testing of ^{210}Pb-dating models for lake sediments, *in* Haworth, E. Y., and Lund, J. W. G., eds., Lake sediments and environmental history: Minneapolis, Minnesota, University of Minnesota Press, p. 93–124.

Otvos, E. G., 1970b, Development and migration of barrier islands, northern Gulf of Mexico: Geological Society of America Bulletin 81:3783-3788.

Otvos, E. G., 1970a, Development and migration of barrier islands, northern Gulf of Mexico: Geological Society of America Bulletin 81:241-246.

Paine, J. G., and Morton, R. A., 1989, Shoreline and vegetation-line movement, Texas Gulf Coast, 1974-1982: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 89-1, 50 p.

Paine, J. G., and Morton, R. A., 1993, Historical shoreline changes in Copano, Aransas, and Redfish Bays, Texas Gulf Coast: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 93-1, 66 p.

Paine, J. G., 1993, Subsidence in the Texas coast: inferences from historical and late Pleistocene sea levels: Tectonophysics, v. 222, p. 445–458.

Parnell, J. F., Ainley, D. G., Blokpoel, H., Cain, B., Custer, T. W., Dusi, J. L., Kress,S., Kushlan, J. A., Southern, W. E., Stenzel, L. E., and Thompson, B. C., 1988, Colonial waterbird management in North America: Colonial Waterbirds 11:129-169.

Penland, Shea, Ramsey, K. E., McBride, R. A., Mestayer, J. T., and Westphal, K. A., 1988, Relative sea level rise and delta-plain development in the Terrebone Parish region: Baton Rouge, Louisiana Geological Survey, Coastal Geology Technical Report No. 4, 121 p.

Pethick, J. S, 1974, The distribution of salt pans on tidal salt marshes: Journal of Biogeography 1:57-62.

Post, W., 1990, Nest survival in a large ibis-heron colony during a three-year decline to extinction: Colonial Waterbirds 13:50-61.

Pratt, W. E., and Johnson, D. W., 1926, Local subsidence of the Goose Creek oil field: Journal of Geology, v. 34, p. 577–590.

Price, W. A., and Gunter, Gordon, 1943, Certain recent geological and biological changes in South Texas, with consideration of probable causes: The Texas Academy of Science Proceedings and Transactions, v. 26, p. 138-156.

Prouty, J. S. and Prouty, D B., 1989, Historical back barrier shoreline changes, Padre Island National Seashore, Texas: Transactions--Gulf Coast Association of Geological Societies, v. 39, p. 481-490.

Pulich, W., Jr., Blair, C, and White, W. A., 1997, Current status and historical trends of seagrasses in the Corpus Christi Bay National Estuary Region: Corpus Christi Bay National Estuary Program, CCBNEP report.

Pulich, W., Jr., Rabalais, S., and Wellso, S., 1982, Food chain components on Laguna Madre tidal flats, Contribution No. 572: The University of Texas, Marine Science Institute, Port Aransas, Texas, USA.

Ratzlaff, K W., 1980, Land-surface subsidence in the Texas coastal region: U. S. Geological Survey Open-File Report 80-969, 18 p.

Rechenthin, C. A., and Passey, H., 1967, The vegetation of Padre Island National Seashore: Soil Conservation Service, Temple, Texas, USA.

Reed, P. B, 1988, National list of plant species that occur in wetlands: 1988 Texas: USFWS, NERC-88/18.43, St. Petersburg, Florida, USA.

Riggio, R. R., Bomar, G. W., and Larkin, T. J., 1987, Texas drought: its recent history (1931-1985): Texas Water Commission, LP 87-04, 74 pp.

Rodgers, J. A., and Burger, J., 1981, Concluding remark: Symposium on human disturbance and colonial waterbirds: Colonial Waterbirds 4:69-70.

Roper, J. C., 1992, Effects of fire ant predation on colonial waterbirds on the Texas coast: A literature review, CCSU-9202-CCS: Center for Coastal Studies, Corpus Christi State University, Corpus Christi, Texas.

Ruth, B. F., 1990, Establishment of estuarine faunal use in a salt marsh creation project, Nueces River delta, Texas: Texas A&M University-Corpus Christi, Center for Coastal Studies, 51 p.

Scott, A. J., Hoover, R. A., and McGowen, J. H., 1969, Effects of Hurricane Beulah, 1967, on Texas coastal lagoons and barriers, in Castanares, A. A., and Phleger, F. B., eds., Lagunas costeras, un simposio: Mexico, D. F., UNAM-UNESCO, Memoir Simposio International Lagunas Costeras, Nov. 28-30, 1967, p. 221-236.

Shealer, D. A., and Kress, S. W., 1991, Nocturnal abandonment response to black-crowned night-heron disturbance in a Common Tern colony: Colonial Waterbirds 14:51-56.

Shew, D. M., Baumann, R. H., Fritts, T. H., and Dunn, L. S., 1981, Texas barrier island region ecological characterization: environmental synthesis papers: Washington, D. C., U. S. Department of the Interior, Fish and Wildlife Service, Office of Biological Services, FWS/OBS-81/82, 413 p.

Shiflet, T. N, 1963, Major ecological factors controlling plant communities in Louisiana marshes: Journal of Range Management 16:231-235.

Smith, E. H., and Cox, S., 1998, Status and trends of rookery islands in the Corpus Christi Bay National Estuary Program Area.

Southern, L. K., Patton, S. R., and Southern, W. E., 1982, Nocturnal predation on *Larus* gulls: Colonial Waterbirds 5:169-172.

Starkey, H. C., Blackmon, P. D., and Hauff, P. L., 1984, The routine mineralogical analysis of clay-bearing samples: U.S. Geological Survey Bulletin 1563, 32 p.

Swanson, R. L., and Thurlow, C. I., 1973, Recent subsidence rates along the Texas and Louisiana coasts as determined from tide measurements: Journal of Geophysical Research, v. 78, no. 5, p. 2665–2671.

Texas Colonial Waterbird Society, 1982, An atlas and census of Texas waterbird colonies 1973-1980: Kingsville, Texas, Caesar Kleberg Wildlife Research Institute.

Texas Department of Water Resources, 1981, Nueces and Mission-Aransas estuaries: a study of the influence of freshwater inflows: Texas Department of Water Resources, LP-108, 308p.

Texas Department of Water Resources, 1983, Laguna Madre estuary: a study of the influence of freshwater inflows: Texas Department of Water Resources, LP-182, 250p.

Texas Department of Water Resources, 1984, Mathematical simulation capabilities in water resources systems analysis: estuarine hydrodynamics, salinity, and water quality simulation: LP-16.

Tiner, R. W., 1993, Field guide to coastal wetland plants of the southeastern United States: The University of Massachusetts Press, Amherst, Massachusetts, USA.

Tiner, R. W., Jr., 1984, Wetlands of the United States: Current status and recent trends: U.S. Department of the Interior, U.S. Fish and Wildlife Service, 59 p.

TPWD, 1990, Mustang Island State Park: summary of representative plant communities: Unpublished report, Texas Parks and Wildlife Department, Austin, Texas, USA.

Tremblay, J., and Ellison, L. N., 1979, Effects of human disturbance on breeding of Black-crowned Night-Herons: Auk 96:364-369.

Tunnell, J. W., Jr., Withers, K., and Hardegree, B., 1997, Environmental impact and recovery of the Exxon Pipeline oil spill and burn site, Upper Copano Bay Texas: Final report: Center for Coastal Studies, TAMU-CC-9703-CCS, Corpus Christi, Texas, USA.

Turner, R. E., 1991, Tide gauge records, water level rise, and subsidence in the Northern Gulf of Mexico: Estuaries 14:139-147.

Verbeek, E. R., and Clanton, U. S., 1981, Historically active faults in the Houston metropolitan area, Texas, *in* Etter, E. M., ed., Houston area environmental geology: surface faulting, ground subsidence, hazard liability: Houston Geological Society, p. 28–68.

Vos, D. K., Ryder, R. A., and Graul, W. D., 1985, Response of breeding Great Blue Herons to human disturbance in northcentral Colorado: Colonial Waterbirds 8:13-22.

Ward, G. H., Jr., Armstrong, N. E., and the Matagorda Bay Project Teams, 1980, Matagorda Bay, Texas: its hydrography, ecology, and fishery resources: U.S. Fish and Wildlife Service, Washington, D.C. FWS/OBS-81/52.

Watson, R. L., and Behrens, E. W., 1976, Hydraulics and dynamics of New Corpus Christi Pass, Texas: a case history, 1973-75: U. S. Army Coastal Engineering Research Center, GITI Report 9, 175 p.

Weise, B. R., and White, W. A., 1980, Padre Island National Seashore, a guide to the geology, natural environments, and history of a Texas Barrier Island: The University of Texas at Austin, Bureau of Economic Geology Guidebook 17, 94 p., 1 map.

White, W. A., and Calnan, T. C., 1990, Sedimentation and historical changes in fluvial-deltaic wetlands along the Texas Gulf Coast with emphasis on the Colorado and Trinity River deltas: The University of Texas at Austin, Bureau of Economic Geology, report prepared for the Texas Parks and Wildlife Department and Texas Water Development Board under interagency contract (88-89) 1423, 124 p., 6 appendices.

White, W. A., and Calnan, T. C., 1991, Submergence of vegetated wetlands in fluvial-deltaic areas, Texas Gulf Coast, *in* Coastal depositional systems in the Gulf of Mexico: Quaternary framework and environmental issues: 12th Annual Research Conference, Society of Economic Paleontologists and Mineralogists, Gulf Coast Section, Houston, Texas, p. 278–279.

White, W. A., and Morton, R. A., 1993, Determining recent sedimentation rates of the Nueces River System, Texas: The University of Texas at Austin, Bureau of Economic Geology, report prepared for the Texas Water Development Board under interagency contract no. 95-483-075, 123 p.

White, W. A., Calnan, T. C., Morton, R. A., Kimble, R. S., Littleton, T. G., McGowen, J. H., Nance, H. S., and Schmedes, K. S., 1983, Submerged lands of Texas, Corpus Christi area: sediments, geochemistry, benthic macroinvertebrates, and associated wetlands: The University of Texas at Austin, Bureau of Economic Geology Special Publication, 154 p.

White, W. A., Morton, R. A., Kerr, R. S., Kuenzi, W. D., and Brogden, W. B., 1978, Land and water resources, historical changes, and dune criticality: Mustang and North Padre Islands, Texas: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 92, 46 p., 1 map.

White, W. A., Tremblay, T. A., Wermund E. G., Jr., and Handley, L. R., 1993, Trends and status of wetland and aquatic habitats in the Galveston Bay system, Texas: The Galveston Bay National Estuary Program, Publication GBNEP-31, 225 p.

Williams, H. F. L., 1997, Shoreline erosion at Shamrock Island Preserve, Nueces County, Texas: University of North Texas, Denton, Department of Geography, 30 p., 1 Appendix.

Winslow, A. G., and Doyel, W. W., 1954, Land-surface subsidence and its relation to the withdrawal of ground water in the Houston–Galveston region, Texas: Economic Geology, v. 49, no. 4, p. 413–422.

Withers, K., and Tunnell, J. W., Jr., In Press, Wind-tidal flat ecology in the Corpus Christi Bay National Estuary Program study area: Effects of natural and anthropogenic disturbance on biological productivity and function: Corpus Christi Bay National Estuary Program, CCBNEP Report.

Wood, F. J., 1986, Tidal dynamics: Coastal flooding, and cycles of gravitational force: D. Reidel Publishing Co., Dordrect, The Netherlands.

Wood, T., T. Engelhard, and Kelly, K., 1995, Baseline survey of Black Point wetland, Refugio County, Texas: Unpublished report, Texas A&M University-Corpus Christi, Corpus Christi, Texas, USA.

Wright, S. S., 1980, Seismic stratigraphy and depositonal history of Holocene sediments on the central Texas Gulf coast: The University of Texas at Austin, Master's thesis, 123 p.

Zinn, J. A., and Copeland, C., 1982, Wetland management: Environment and Natural Resources Policy Division, Congressional Research Service, Library of Congress Serial No. 97-11, 149 p.

Appendix. Total habitat areas determined from seamless data sets of 29 quad area.

1950's and 1979 data include South Bird Island quadrangle but not Tivoli SW

1992 data include Tivoli SW quadrangle but not South Bird Island

1992 Habitats	Hectares	1979 Habitats	Hectares	1950's Habitats	Hectares
E1AB1L	224	E1AB2L	68	E1AB.	15,005
E1AB3L	18,404	E1AB2L.	21,796	E1ABOW.	616
E1AB3Lx	41	E1AB2L/E1OWL.	1,049		
E1AB5L	58	E1AB6L	68	E1OW.	113,625
		E1AB6L.	894	E1OW/RF.	78
E1RF2M	31	E1AB6L/E1OWL.	8		
E1UBL	108,177	E1AB7L.	3	E1RF.	277
E1UBLx	2,375			E2BB.	59
		E1OWL	1,208	E2EM.	6,213
E2AB1N	32	E1OWL.	110,888	E2EM/FL.	2,338
E2AB1P	107	E1OWLH.	88	E2EMFL.	11,759
E2AB3L	1	E1OWLX.	364		
E2AB3N	20			E2FL.	19,416
		E1RF2M.	19	E2RF.	94
E2EM1N	12,009	E2AB2L.	58	E2RS.	1
E2EM1Ns	54	E2AB2M.	20	E2SB.	3
E2EM1Nx	3	E2AB6M.	4	E2SS.	17
E2EM1P	10,576			E2SSEM.	5
E2EM1Ps	114	E2BBP.	2		
E2EM1Px	2	E2EM1P	38	L1OW.	159
		E2EM1P.	8,115	L2AB.	7
E2FO2P	2	E2EM1PH.	14	L2FL.	61
E2SS1P	10	E2EM1N	114	L2OW.	1,361
E2SS3N	42	E2EM1N.	5,578	M1OW.	77,138
E2SS3P	46	E2FM1P.	3	M2BB.	780
				M2BB2.	339
E2USM	53	E2EM1P/E2FLP.	1,410		
E2USN	5,917	E2EM1M/E2FLM.	4	PAB.	0
E2USNs	185	E2EM1N.E2FLN.	2	PABOW.	2
E2USNx	62	E2EM1N/E23FLN.	1		
E2USP	2,422	E2EM1N/E2FLM.	1	PEM	4
E2USPs	92	E2EM1N/E2FLN	57	PEM.	13,539
E2USPx	10	E2EM1N/E2FLN.	5,884	PEM/FL.	36
				PEM/OW.	0
L1AB3Hh	22	E2FL.	1	PEMFL.	85
L1UBH	12	E2FL6N.	156	PEMOW.	197
L1UBHh	199	E2FL6Y.	12	PEMOW..	2
L1UBHx	89	E2FLM	53	PEMU.	1,840
L1UBKh	78	E2FLM.	533		
L1UBKhs	384	E2FLMH.	12	PFL.	275
L1UBKx	795	E2FLN	129	PFO.	559
		E2FLN.	5,796	PFOEM.	112
L2AB3H	1,785	E2FLP	91	PFOSS.	8
L2AB4Hx	9	E2FLP.	3,157		
		E2FLPH.	32	POW.	721
L2UBFx	8	E2FLUH.	26	POWFL.	1

1992 Habitats	Hectares	1979 Habitats	Hectares	1950's Habitats	Hectares
L2USCh	11			POWU.	15
L2USCx	19				
L2USKh	514	E2RF2M.	20	PSS.	499
L2USKhs	787	E2SS3N.	569	PSS/EM.	305
L2USKx	28	E2SS3N/E2FLN.	125	PSSEM.	147
				PSSFL.	3
M1UBL	55,787	L1AB2H/L1OWH.	21	PSSOW.	5
M1UBL.	17,031	L1AB6G/L1OWG.	13		
				R1FL.	8
M2USN	376	L1OWG.	16	R1OW.	170
M2USN.	4	L1OWH	13	R1SB.	14
M2USP	331	L1OWH.	132	R2OW.	221
M2USP.	4	L1OWHH.	30	R2SB.	19
		L1OWHHX.	1,338	R4OW.	1
PAB3F	0	L1OWHx.	59	R4SB.	9
PAB3Fx	0	L1OWV.	83	U.	243,412
PAB3Kh	4				
PAB4F	4	L2AB6F.	35		511,558
PAB4Fx	12	L2AB6F/L2OW6F.	2		
PAB4Hx	10	L2AB6F/L2OWF.	20		
		L2AB6FHX/L2OWFHX	7		
PEM1A	18,361	L2AB6H/L2OWH.	147		
PEM1A.	16	L2AB7G/L2OWG.	33		
PEM1A/U	494	L2AB7H.	34		
PEM1Ad	133	L2AB7T.	13		
PEM1Ah	96				
PEM1As	3	L2FLC.	10		
PEM1Ax	8	L2FLH.	54		
PEM1B	1	L2FLR.	45		
PEM1C	3,207	L2FLU.	27		
PEM1C.	1				
PEM1C/U	43	L2OWF.	1,426		
PEM1Cd	11	L2OWGh.	11		
PEM1Ch	116				
PEM1Chs	4	M1OWL	30,189		
PEM1Cx	68	M1OWL.	48,017		
PEM1F	745				
PEM1Fh	61	M2BBP	119		
PEM1Fhs	3	M2BBP.	734		
PEM1Fx	92				
PEM1Kh	78				
PEM1Khs	120	PAB5HH.	16		
PEM1Kx	68	PAB6FHX.	1		
PEM1R	79	PAB7F.	11		
PEM1S	22	PAB7F/POWF.	1		
		PAB7FD.	1		
PFO1A	687	PAB7T.	9		
PFO1Ah	5				
PFO1Ax	17	PEM1A	2		
PFO1C	18	PEM1A.	511		
PFO1Ch	3	PEM1AD.	3		

1992 Habitats	Hectares	1979 Habitats	Hectares	1950's Habitats	Hectares
PFO1Cx	12	PEM1AHX.	217		
PFO1S	0	PEM1C	39		
PFO2A	0	PEM1C.	4,359		
		PEM1C/UA.	111		
PSS1A	433	PEM1CD.	13		
PSS1Ah	0	PEM1CH.	3		
PSS1C	80	PEM1CHX.	1		
PSS1Ch	2	PEM1CU.	985		
PSS1Cx	4	PEM1CX.	1		
PSS1Fx	1	PEM1Cd.	30		
PSS2A	1	PEM1Ch.	5		
PSS3A	5	PEM1F	38		
		PEM1F.	1,314		
PUBF	78	PEM1F/POWF.	760		
PUBFh	33	PEM1F/U.	8		
PUBFx	276	PEM1F/UA.	1,462		
PUBFx.	0	PEM1FD.	3		
PUBH	34	PEM1FH.	2		
PUBHh	41	PEM1FHX.	1		
PUBHx	202	PEM1FU.	24		
PUBHx.	1	PEM1FUF6.	16		
PUBKh	17	PEM1FX.	3		
PUBKhs	27	PEM1Fx.	9		
PUBKx	86	PEM1H/POWH.	2		
		PEM1O.	1		
PUSA	12	PEM1P/POWP.	3		
PUSAh	3	PEM1R.	1,005		
PUSAx	17	PEM1S.	22		
PUSC	36	PEM1T.	115		
PUSCh	10	PEM1Y	59		
PUSChs	0	PEM1Y.	4,278		
PUSCx	54	PEM1Y/POWY.	1		
PUSKhs	110	PEM1YHX.	0		
PUSKx	21	PEMR/PFLR.	9		
R1UBV	4	PFL2C.	0		
R2UBH	229	PFLC.	2		
R2UBHx	6	PFLCH	0		
		PFLJ.	10		
R4SBAx	0	PFLR.	39		
R4SBCx	16	PFLY.	22		
		PFLYX.	7		
U	245,141				
U.	21	PFO1R.	4		
		PFO6.	1		
U/PEM1A	232	PFO65.	1		
U/PEM1C	161	PFO6A.	66		
		PFO6C.	13		
	511,337	PFO6F.	1		
		PFO6R.	18		
		PFO6S.	47		
		PFO6Y.	170		

1992 Habitats	Hectares	1979 Habitats	Hectares	1950's Habitats	Hectares
		PFOGY.	3		
		POW.	0		
		POWF	6		
		POWF.	612		
		POWF/AU.	68		
		POWF/UA.	285		
		POWF/UF6.	45		
		POWFH.	10		
		POWFHX.	30		
		POWFU.	33		
		POWFUA.	1,097		
		POWFUF6.	84		
		POWFX	0		
		POWFX.	243		
		POWFh.	10		
		POWFhx	1		
		POWFhx.	13		
		POWFx.	104		
		POWG.	15		
		POWGH.	6		
		POWGHX.	8		
		POWGX.	9		
		POWGhx.	3		
		POWGx.	2		
		POWH	4		
		POWH.	87		
		POWHH	2		
		POWHH.	32		
		POWHHX.	4		
		POWHX.	103		
		POWHx.	7		
		POWT.	21		
		PSS6A.	636		
		PSS6C.	286		
		PSS6CD.	10		
		PSS6R.	97		
		PSS6S.	6		
		PSS6Y/PEM1Y.	8		
		R1FLR.	17		
		R1OWV.	142		
		R2OWH.	193		
		U.	2		
		UA	1,672		
		UA.	193,734		
		UAR.	96		
		UB.	58		
		UBD	5		
		UBD.	784		
		UBS.	589		
		UF6.	10,536		

1992 Habitats	Hectares	1979 Habitats	Hectares	1950's Habitats	Hectares
		UF7.	1		
		UR.	123		
		UU	17		
		UU.	28,584		
		UUO.	1,982		
		UUO/A.	563		
		UUO/F6.	140		
		UUOA.	51		
		UUo.	14		
		UUo/A.	1,262		
			511,501		