STATUS AND TRENDS OF WETLAND AND AQUATIC HABITATS ON TEXAS BARRIERS: UPPER COAST STRANDPLAIN-CHENIER SYSTEM AND SOUTHERN COAST PADRE ISLAND NATIONAL SEASHORE

by

William A. White, Thomas A. Tremblay, Rachel L. Waldinger, and Thomas R. Calnan*

*Coastal Coordination Division, Texas General Land Office

Final Report
Prepared for the

Texas General Land Office
and
National Oceanic and Atmospheric Administration
under GLO Contract No. 06-044

A report of the Coastal Coordination Council pursuant to National Oceanic and Atmospheric Administration Award No. NA05NOS4191064

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EXECUTIVE SUMMARY

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Introduction

Wetland and aquatic habitats are essential components of barrier islands along the Texas coast. These valuable resources are highly productive both biologically and chemically and are part of an ecosystem on which a variety of flora and fauna depend. Scientific investigations of wetland distribution and abundance through time are prerequisites to effective habitat management, thereby ensuring their protection and preservation and directly promoting long-term biological productivity and public use.

This report is the last in a series of wetland status and trend investigations of barrier islands along the Texas Coast (White et al. 2002, 2004, 2005, and 2006). Presented in this report are results of two status-and-trend studies, (1) of the upper Texas coast along the strandplain-chenier system from Sabine Pass to East Galveston Bay, and (2) of the southern Texas coast along Padre Island National Seashore (PINS) that includes the central section of Padre Island (Fig. I).

The two study areas are very different. Geologically, the upper Texas coast is characterized by a modern stranplain-chenier system with well preserved chenier beach ridges with interlying marsh filled swales (Fisher et al. 1973). Relict beach ridges and intervening swales have an orientation roughly parallel to today's shoreline marked by the Gulf beach. The swales are the sites of extensive linear estuarine marshes. The strandplain-chenier system has gradually evolved through erosion, deposition, compaction, subsidence, and locally faulting. The strandplain extends along the Gulf shore toward the southeast to High Island. High Island is a salt dome near the Gulf shoreline with elevations exceeding 7.5 m (25 ft) (Fig. I).The study area extends landward to the Gulf Intracoastal Waterway.

Padre Island National Seashore, the South Texas study area (Fig. I.), is a barrier island that separates the Gulf of Mexico from Laguna Madre. The barrier is characterized by broad beaches, fore-island dunes, vegetation stabilized dunes, active dune fields, expansive wind-tidal flats, hurricane wash-over channels, and salt-, brackish, and fresh-water ponds and marshes. The study area extends southward to Mansfield Channel, and landward to the Gulf Intracoastal Waterway.

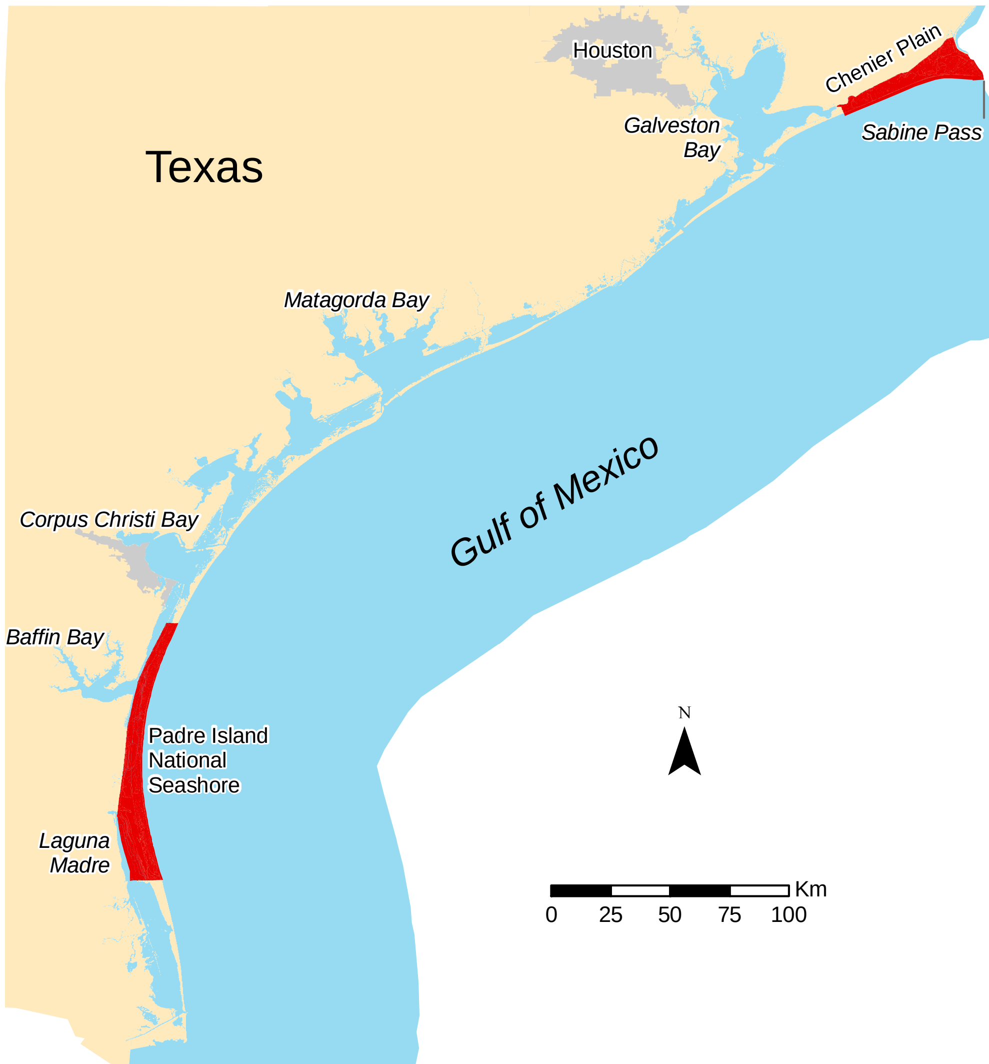


Figure I. Index map of study areas.

Methods

This study of status and trends is based on wetlands interpreted and mapped on recent and historical aerial photographs. Current distribution (status) of wetlands was determined using color-infrared (CIR) photographs taken in 2003 and 2004. Historical distribution is based on 1956 black-and-white and 1979/83 CIR photographs. Mapped wetlands for each period were digitized and entered into a GIS for analysis. Except for the 1956 map of the upper coast study area, which was mapped by BEG, the historical GIS maps were obtained from the U.S. Fish and Wildlife Service (USFWS), who mapped the wetlands using methods established as part of the National Wetlands Inventory program. Methods included interpreting and delineating habitats on aerial photographs, field checking delineations, and transferring delineations to 1:24,000-scale base maps using a zoom transfer scope. The resulting maps were digitized and entered into a GIS, producing GIS maps for the two time periods. Both 1956 and 1979/83 series USFWS maps, which are in digital format, were partially revised in this project to be more consistent with wetlands interpreted and delineated on the 2003 and 2004 photographs.

Methods used to delineate 2003/04 habitats differed from the earlier methods. The 2003/04 photographs were digital images with a pixel resolution of 1 meter, and registered to USGS Digital Orthophoto Quadrangles (DOQ's). Mapping of wetlands and aquatic habitats was accomplished through interpretation and delineation of habitats on screen in a GIS at a scale of 1:3,000 to 1:5,000. The resulting current-status GIS maps were used to make comparisons with the historical GIS maps to determine habitat trends and probable causes of trends.

Wetlands were mapped in accordance with the classification by Cowardin et al. (1979), in which wetlands are classified by system (marine, estuarine, riverine, palustrine, lacustrine), subsystem (reflective of hydrologic conditions), and class (descriptive of vegetation and substrate). Maps for 1979/83 and 2003/04 were additionally classified by subclass (subdivisions of vegetated classes only), water regime, and special modifiers. Field sites were examined to characterize wetland plant communities, define wetland map units, and ground-truth delineations.

In analyzing trends, wetland classes were emphasized over water regimes and special modifiers because habitats were mapped only down to class on 1956 photographs. We would also like to note that there is a margin of error in interpreting and delineating wetlands on aerial photographs, transferring delineations to base maps, and georeferencing the different vintages of maps to a common base for comparison. Accordingly, we have more confidence in the direction of trends than absolute magnitudes.

Strandplain-Chenier System, Upper Texas Coast

The strandplain-chenier study area along the upper Texas Coast contains the most extensive contiguous marshland along the Texas Gulf Coast. Most of the marshland falls within the McFaddin National Wildlife Refuge, Texas Point NWR, J.D. Murphree Wildlife Management Area, and Sea Rim State Park. Extensive brackish- and salt-water marshes and ponds characterize this area. Although there are local fresh ponds and marshes that have been isolated by levees and dikes, most of the fresh-water marshes that are part of the McFaddin National Wildlife Refuge occur inland of the Gulf Intracoastal Waterway (Personal Communication, 2006, Dean Bossert, Refuge Manager).

Current Status, 2004

Major estuarine habitats in the study area include salt and brackish marshes, and open water. Uplands are next in areal distribution (Fig. II). Palustine marshes are limited in extent. The primary habitat mapped in the marine system is the Gulf beach, which consists of a topographically lower forebeach and a higher, less frequently flooded backbeach.

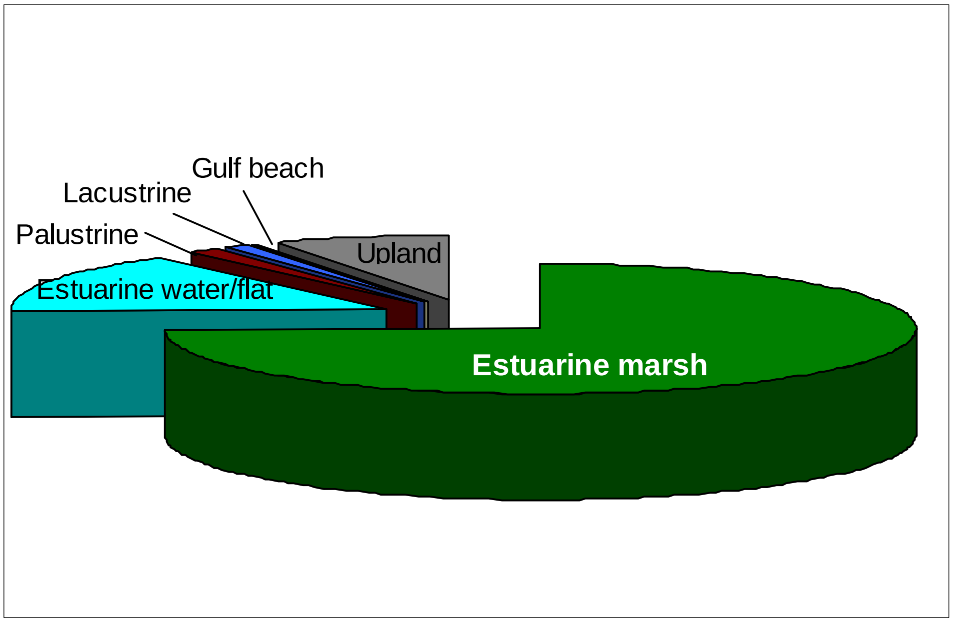


Figure II. Areal extent of selected habitats in upper coast study area in 2004. Palustrine in this figure includes palustrine marshes, water, and flats.

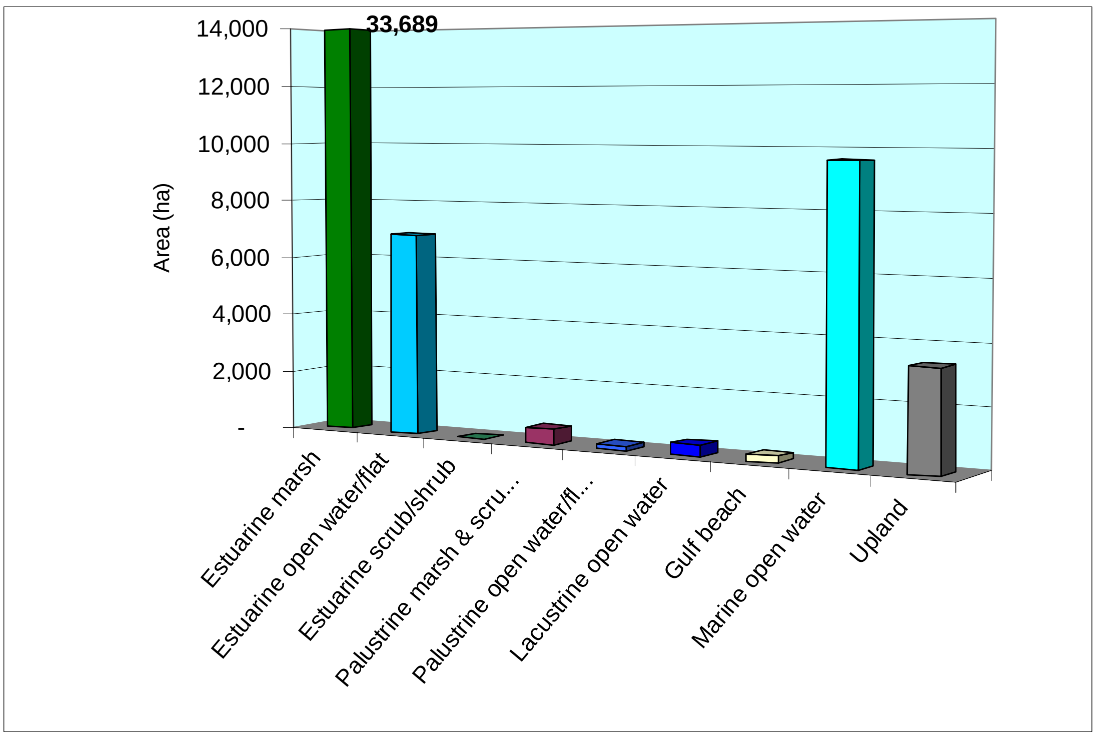


Figure III. Areal extent, in hectares, of habitats in strandplain-chenier system, 2004.

In 2004, wetland and aquatic habitats were dominated by estuarine marshes, with a total area of 33,689 ha (83,179 acres), followed by estuarine open water and flats totaling 6,866 ha (16,952 acres), and palustrine marshes at 511 ha (1,262 acres) (Fig. III).

Palustrine flats and water bodies had a total area of 150 ha (370 acres), and wetland scrub/shrub wetlands 8 ha (20 acres). Along the Gulf shoreline, the area of mapped beaches totaled 229 ha (566 acres). Lacustrine habitats, consisting in part of impounded water and Star Lake, had a total area of 390 ha (962 acres).

Wetland Trends and Probable Causes, 1956–2004

In analyzing trends, broad wetland classes were emphasized over water regimes and special modifiers because habitats were mapped only down to class on 1956 photographs. In addition, interpretation of the distribution of estuarine and palustrine systems varied from year to year. Estuarine marshes are by far the dominant class of emergent wetlands on the upper coast study area, thus for simplification and to reduce apparent changes due to interpretation, we combined the emergent wetland classes in the trend analysis.

From 1956 through 2004 within the upper coast study area, emergent wetlands (marshes) decreased from about 38,000 ha (93,819 acres) to 34,200 ha (84,454 acres), a loss of approximately 3,800 ha (9,382 acres) (Fig. IV, Table I). Most of the loss (68%) occurred during the earlier period (1956-1979/83). The rate of marsh loss from1956 to 1981 (1981 is used as the average of 1979 and 1983) was about 115 ha/yr (284 acres/yr), and from 1981 to 2004, about 40 ha/yr (99 acres/yr). In contrast to the loss of marsh was a gain in total estuarine and marine open water. The gain in open water was approximately 3,800 ha (9,382 acres), which is equivalent to the loss in marsh. The rates of gain in water were about 138 ha/yr (341 acres/yr) during the earlier period, and 16 ha/yr (40 acres/yr) during the later period. The area of Gulf beaches decreased slightly through time, from 318 ha (786 acres) in 1956 to 229 ha (566 acres) in 2004. Uplands increased in area from 3,260 ha (8,050 acres) in1956 to 3,346 ha (8,260 acres) in 2004, a gain of about 86 ha (210 acres).

An analysis of habitat changes along the upper Texas coast shows a systematic decline in marshes from 1956 to 2004 (Fig. IV). Countering this trend in decreasing emergent wetlands was an increase in open water, both estuarine and marine. The increase in estuarine open water since 1956 was in part because of dryer conditions in 1956. There was a severe drought in Texas that peaked in 1956 (Riggio et al. 1987). The drought apparently affected the extent of open water in the marshes on1956 maps. These differences in wet and dry conditions during the various years affected habitats, especially the extent of open water that was interpreted and mapped.

Part of the expansion of open water since 1956, however, was due to subsidence and relative sea-level rise. In several areas, subsidence occurred along active surface faults. For example, a major fault near Clam Lake contributed to an increase in water on the downside of the fault (Fig. V) (White et al., 1987). The fault could not be seen on

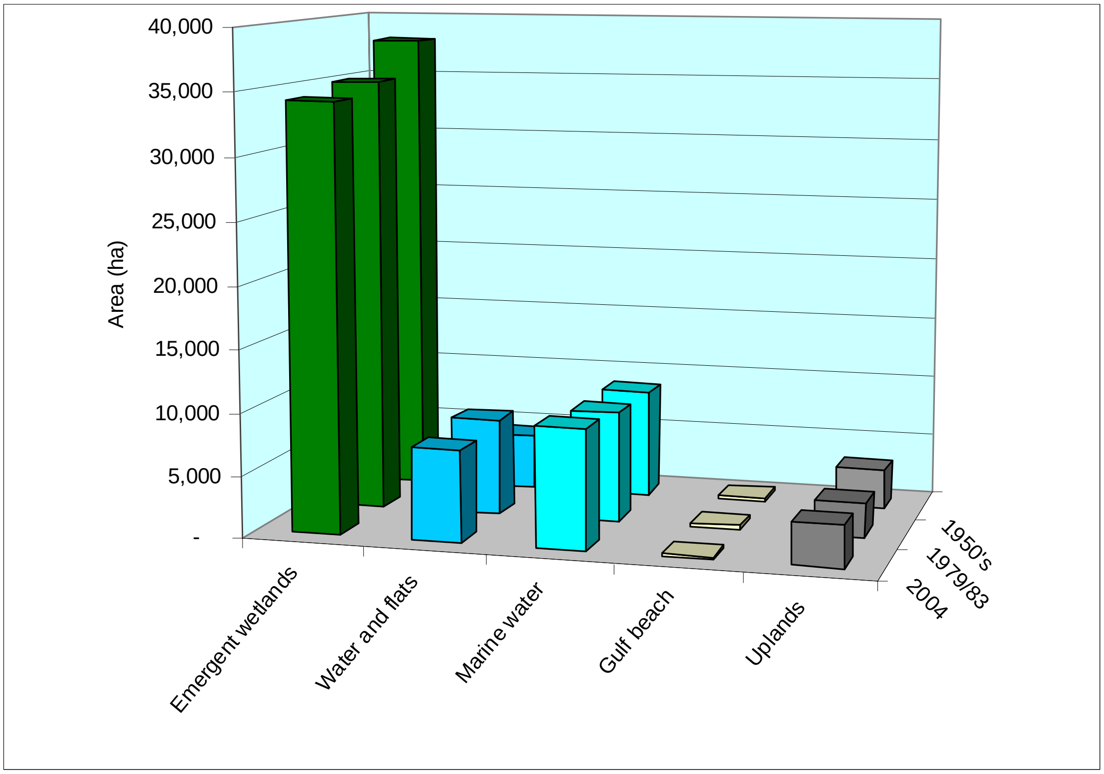


Figure IV. Areal distribution of major habitats in the study area in 1956, 1979/83, and 2004, strandplain-chenier system.

Table I. Total area of major habitats in1956, 1979/83, and 2004 in strand-plain chenier study area.

	1956		1979/83		2004	
	ha	acres	ha	acres	ha	acres
Emergent wetlands	37,999	93,819	35,117	86,704	34,206	84,454
Open water and flats	4,468	11,031	7,774	19,193	7,406	18,284
Marine water	8,771	21,656	8,918	22,019	9,645	23,812
Gulf beach	318	786	307	759	229	566
Uplands	3,260	8,050	2,731	6,742	3,346	8,260

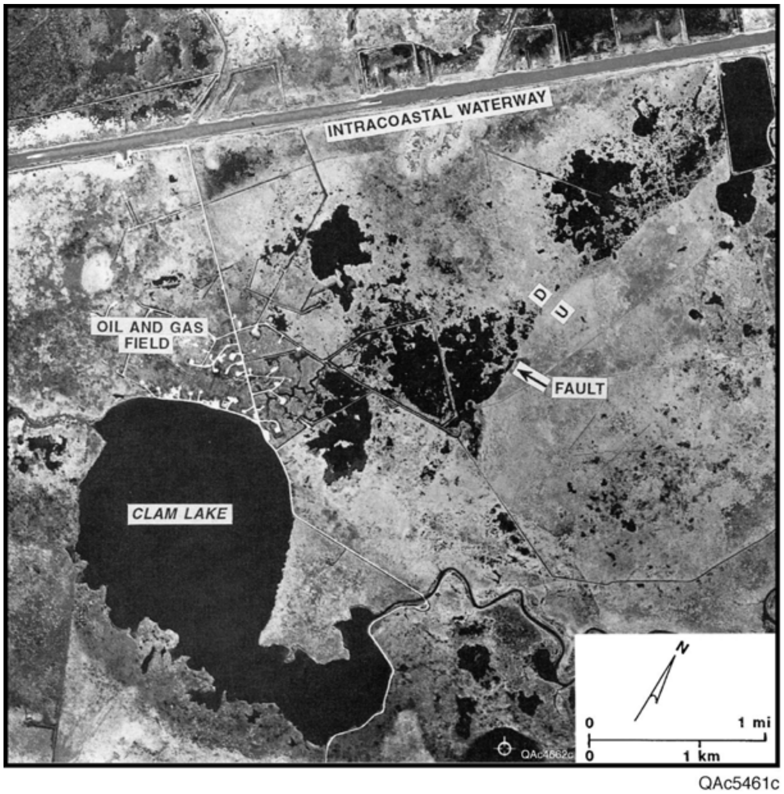


Figure V. Fault near Clam Lake downthrown toward the oil and gas field. Dark areas of open water increase on the downthrown side (D) of the fault relative to the upthrown side (U). This photograph was taken by NASA in 1989. The fault could not be seen on photographs taken in 1956. (From White and Tremblay, 1995).

photographs taken in 1956 and, thus, has apparently become active more recently. There is evidence that the fault has been activated by oil and gas production at the Clam Lake field (White and Tremblay, 1995; White and Morton, 1997; Morton et al., 2001). Several faults crossing marshes have been mapped along the upper coast (Fig. VI). Marsh losses have occurred on the downthrown sides of the faults where subsidence has promoted flooding and erosion of the marshes. The rate of subsidence and relative sea-level rise on the downside of the faults apparently exceeded the rate of marsh vertical accretion, and the marsh was replaced primarily by open water. Relative sea-level rise also appears to have contributed to expansion of water in marsh areas where there are no apparent faults.

Conversion of marsh to open water has also occurred where artificial levees, roads, and dikes have created “dams” along which water ponds and submerges marshes. A good example is southwest of High Island where roads and levees have been constructed for oil and gas field development adjacent to the salt dome. In summary, faults and artificial levees form topographic ridges against which water is ponded and which account, in part, for the expansion of open water into marsh areas.

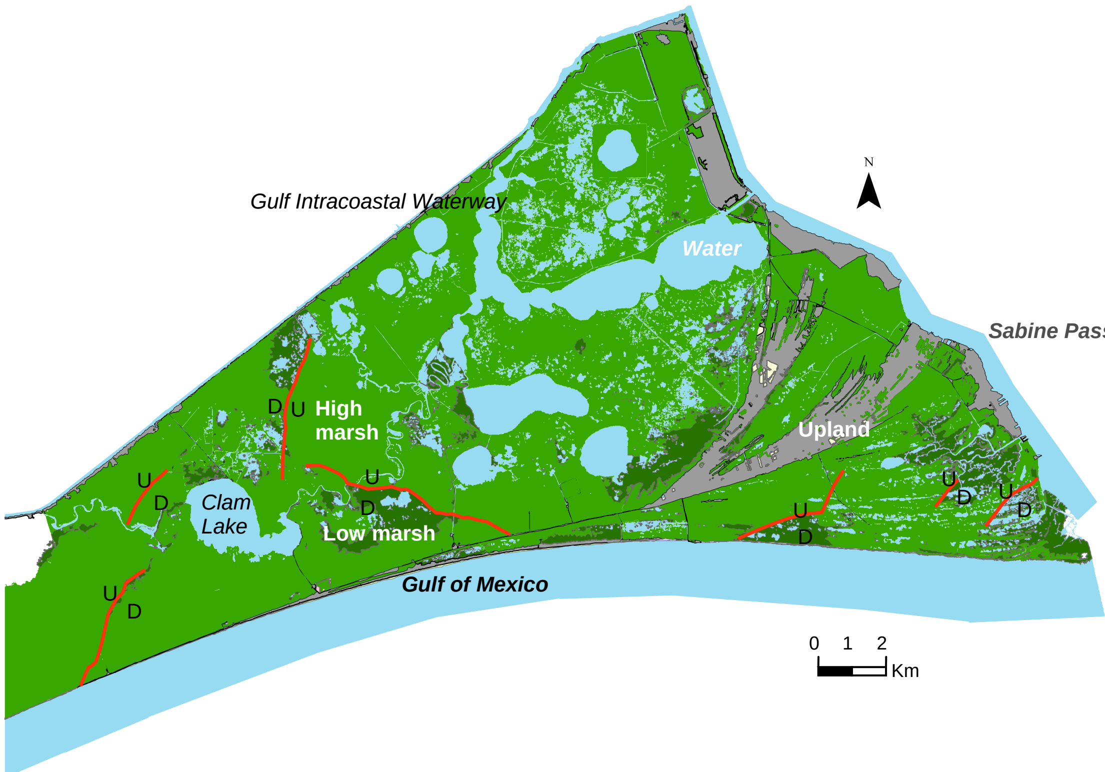
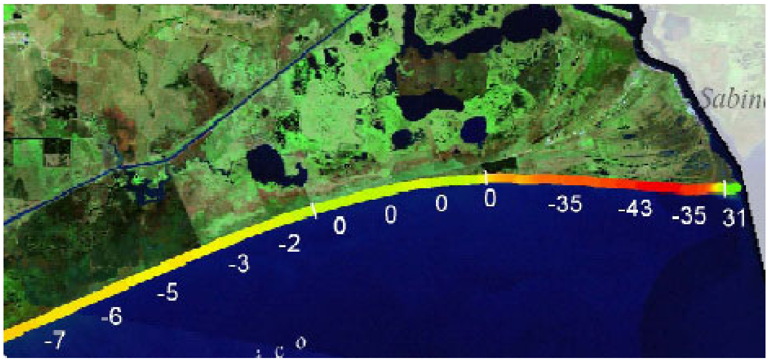


Figure VI. Faults intersecting wetlands from Clam Lake to Sabine Pass. Water and low marshes increase on the downthrown (D) side of the faults relative to the upthrown side, indicating higher rates of subsidence on the downthrown side.

Additional losses in salt marsh occurred along the Gulf shoreline near Sabine Pass. This is an area of erosion with rates as high as 43 m/yr (142 ft/yr) (Fig. VII). The rate of marsh loss near Sabine Pass was approximately 17 ha/yr (42 acres/yr) from 1956 to 2004. Marsh along this shore was replaced by open marine water as the shoreline retreated landward. Losses of marsh also occurred along the ship channel at Sabine Pass as material derived from maintenance dredging was deposited along the channel creating uplands. Uplands can be seen along the channel in Figure VI.

(a)



(b)

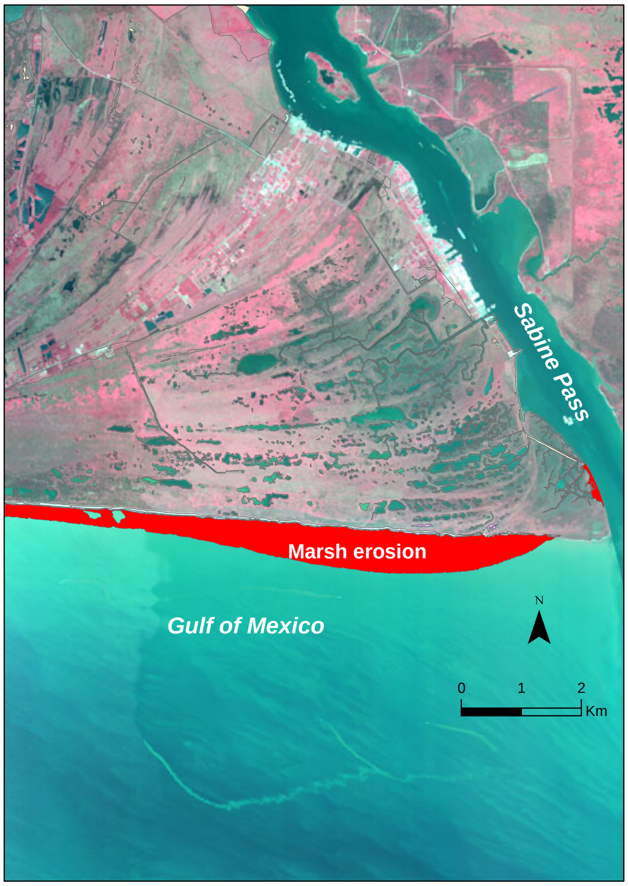


Figure VII. Marsh erosion near Sabine Pass. (a) Erosion rates (ft/yr) from Gibeaut et al., 2000. (b) Approximate area of marsh loss by erosion from 1956 to 2004.

Padre Island National Seashore

Current Status, 2003/04

In 2003/04, wetland, aquatic, and upland habitats covered 95,173 ha (235,077 acres) within the Padre Island study area. This area includes the Laguna Madre and Land Cut area between the Seashore boundary and the Gulf Intracoastal Waterway (GIWW). Approximately 20,681 ha (51,082 acres) within the study area was classified as uplands. Of the four wetland systems mapped, the estuarine system is the largest. The largest area of habitats are the wind-tidal and algal-flat classes (Fig.VIII and IX), together covering 35,356 ha (87,329 acres). Emergent vegetated wetlands (E2EM, E2SS, PEM) cover 3,930 ha (9,707 acres), about 63% of which is palustrine marsh. Another important habitat class is seagrass (E1AB3), which in the study area has an area of almost 14,572 ha (35,993 acres). The extent of all mapped wetlands, deepwater habitats, and uplands for each year is presented in the Appendix.

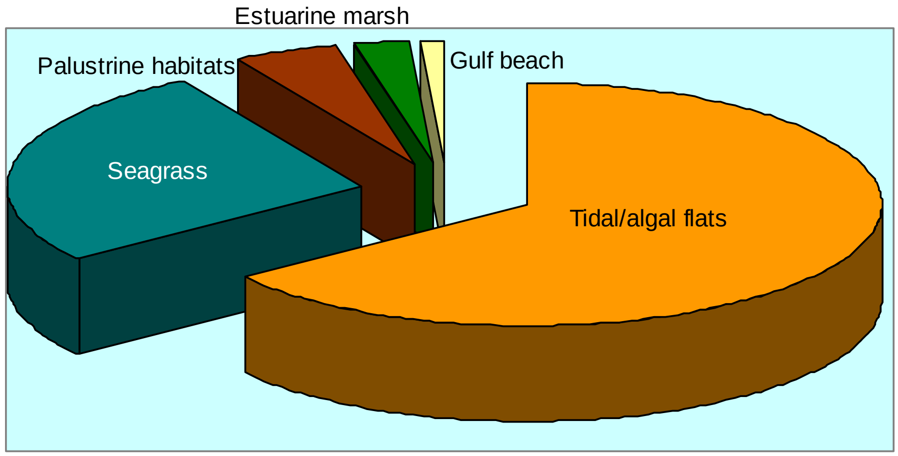


Figure VIII. Areal extent of selected habitats in PINS study area in 2003/04.

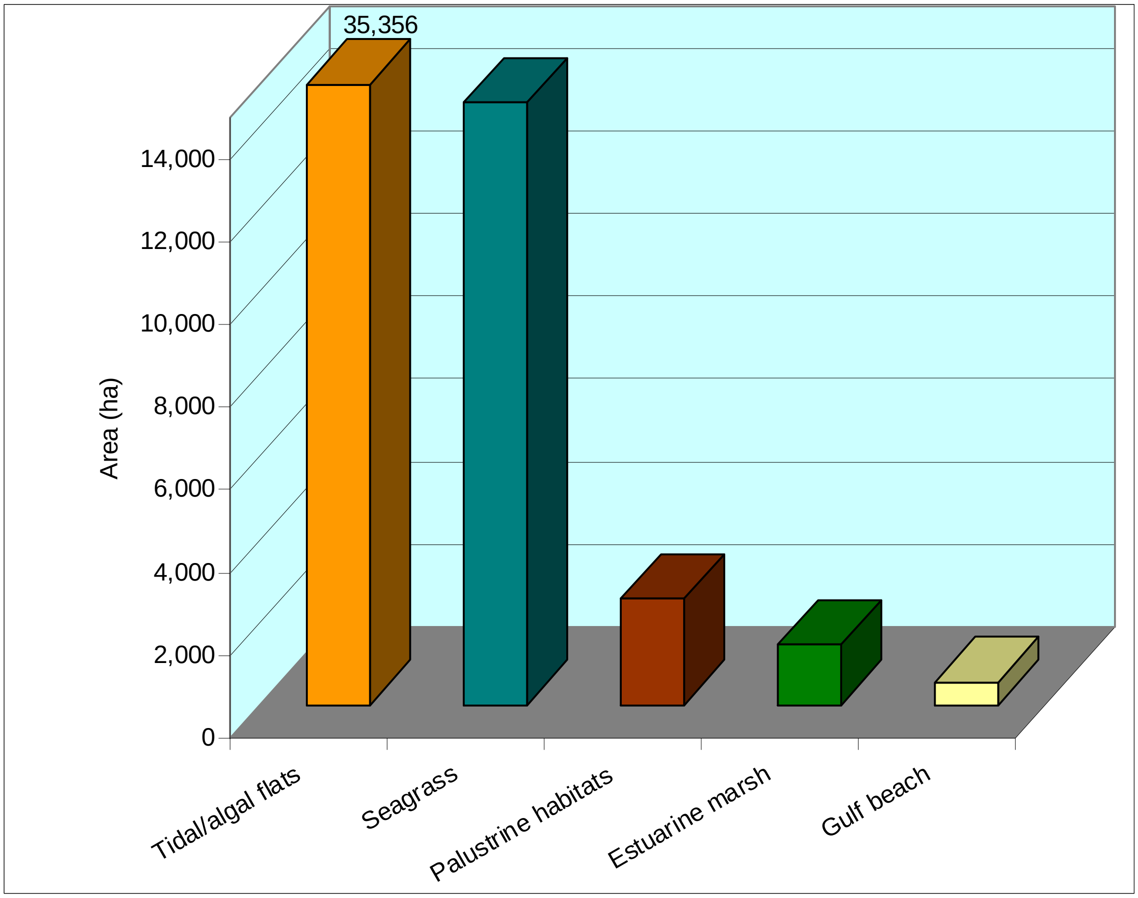


Figure IX. Areal extent of selected habitats in PINS study area in 2003/04.

Wetland Trends and Probable Causes, 1950's–2003/04

Analysis of trends in wetlands and aquatic habitats from the 1950's through 2003/04 shows that wind-tidal/algal flats increased slightly from the 1950's to 1979, and increased significantly from 1979 to 2003/04 (Table II; Fig. X). Wind-tidal flats are, by far, the most extensive habitat. The lesser distribution in the 1950's is primarily due to flooding of the Laguna Madre as a result of the construction of Mansfield Channel. Adjusting for the mid-1950's flooding produces a trend towards loss (-5 %) of tidal flat through 2003/04. Most flat loss was in the southern part of the island where sand dunes migrated onto flats. Seagrasses appear to have spread significantly from the 1950's to 2003/04. However, some of the change may have been an apparent and not real increase, as a result of under-mapping in the mid-1950's. Palustrine habitat area declined somewhat by 1979 but gained substantially (25 %) over the length of the study time period. A combination of factors, including relative sea-level rise and park management practices provided favorable conditions for palustrine habitat expansion. Estuarine marsh area also fluctuated over time, but lost (-) 26 % of the original mid-1950's resource. PINS has historically experienced both shoreline accretion and erosion. As a result of shoreline erosion, gulf beach has experienced a systematic decline in area over time.

Table II. Total area of selected habitats, 1950's to 2003/04, in the Padre Island National Seashore study area. Palustrine flat (US) and water (UB) are combined with palustrine marsh in the table.

Habitat	***1950's***		***1979***		***2003/04***	
	(ha)	(acres)	(ha)	(acres)	(ha)	(acres)
Tidal/algal flat	30,593	75,564	30,927	76,391	35,356	87,329
Seagrass	2,167	5,352	16,422	40,562	14,572	35,993
Palustrine habitats	2,062	5,093	1,885	4,655	2,575	6,361
Estuarine marsh	1,976	4,881	1,364	3,369	1,461	3,609
Gulf beach	1,085	2,680	849	2,097	558	1,378

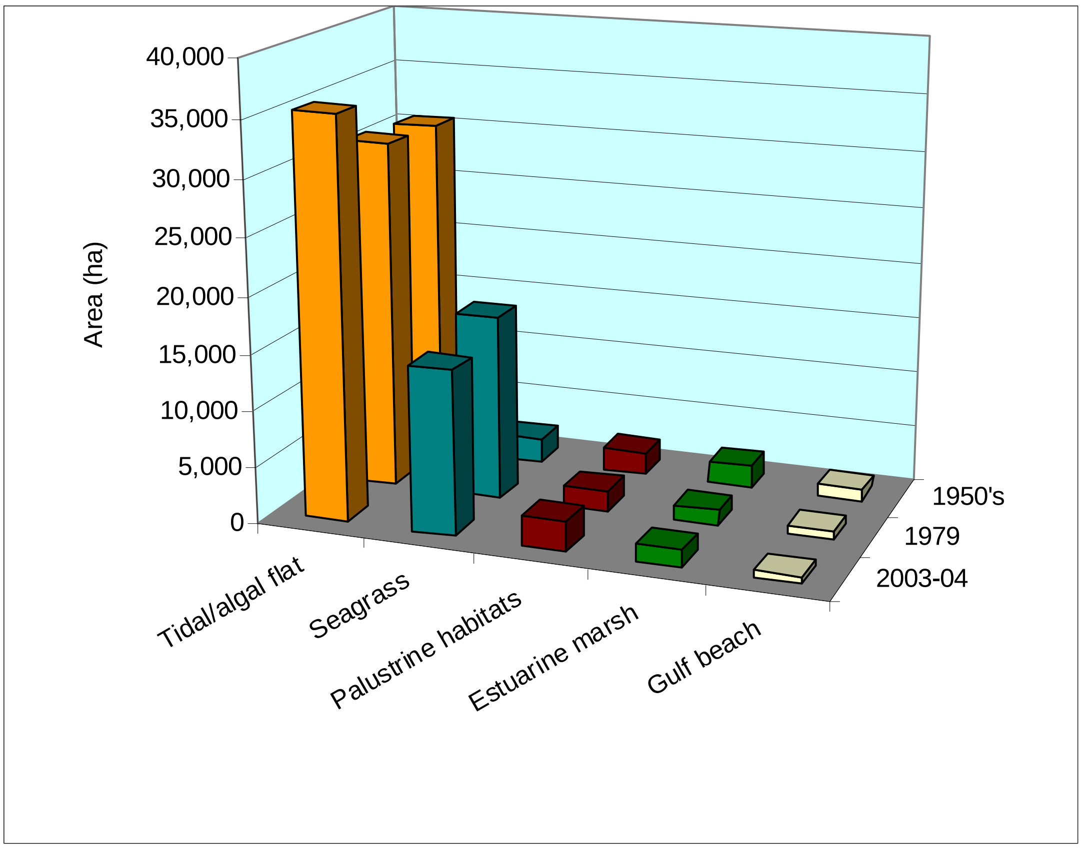


Figure X. Areal extent of selected habitats from the 1950's to 2003/04 in the Padre Island National Seashore study area.

STATUS AND TRENDS OF WETLAND AND AQUATIC HABITATS ON TEXAS BARRIERS: UPPER COAST STRANDPLAIN-CHENIER SYSTEM AND SOUTHERN COAST PADRE ISLAND NATIONAL SEASHORE

INTRODUCTION

Coastal wetlands on barrier islands and strandplain-chenier systems are essential natural resources that are highly productive biologically and chemically and are part of an ecosystem in which a variety of flora and fauna depend (Fig. 1). Scientific investigations to determine status and trends of wetlands assist in their protection and preservation, directly benefiting long-term productivity and public use. This report is the last in a series of wetland status and trend investigations of barrier islands along the Texas Coast (White et al. 2002, 2004, 2005, and 2006). Presented in this report are results of two status-and-trend studies, (1) of the upper Texas coast along the strandplain-chenier system from East Galveston Bay to Sabine Pass, and (2) of the southern Texas coast along Padre Island National Seashore that includes the central section of Padre Island.

Figure 1. Salt-water marsh (*Spartina alterniflora*) on the edge of the strandplain-chenier system along Sabine Pass.

Previous studies by the Bureau of Economic Geology (BEG) of wetland status and trends along the Texas coast, for example in the Galveston Bay system (White et al. 1993 and 2004) indicate substantial losses in wetlands have occurred due to subsidence and associated relative sea-level rise. Some of the losses on Galveston Bay barriers have occurred along surface faults that have become active as a result of underground fluid production. In contrast to the Galveston Bay system, studies of wetlands on barrier islands in the Corpus Christi Bay area by the BEG, Texas Parks and Wildlife Department, and Texas A&M University at Corpus Christi (White et al. 1998) show that marshes have expanded as a result of relative sea-level rise. Between these two bay systems is the Matagorda Bay/San Antonio Bay complex, where extensive wetlands on barrier islands and peninsulas have also undergone changes, including the Colorado River delta and associated diversion channel, which were investigated by White et al. (2002). Results of these kinds of studies improve our understanding of marsh changes on Texas barriers and pinpoint wetlands threatened from erosion, faulting, subsidence, and other processes. These data provide site-specific information for implementing marsh protection and restoration programs.

This study is based on wetlands interpreted and mapped using aerial photographs taken in 2003 and 2004, and on historical wetlands mapped on photographs taken in 1956 and 1979/83. The 1956 and 1979/1983 series USFWS maps, which are in digital format, were partially revised in this project to be more consistent with wetlands interpreted and delineated on the 2003 and 2004 photographs. The revisions are discussed in more detail in the methods section. The USFWS NWI maps based on 1992 photographs were used as collateral data in the delineation of wetlands.

Study Areas

The study areas include (1) the strandplain-chenier system (Fisher et al. 1973) along the upper coast from East Galveston Bay to Sabine Pass, and (2) PINS along the southern Texas coast from north Padre Island to Mansfield Channel (Fig. 2). The study areas are located in Jefferson County on the upper coast, and Kleberg and Kenedy Counties along the lower coast.

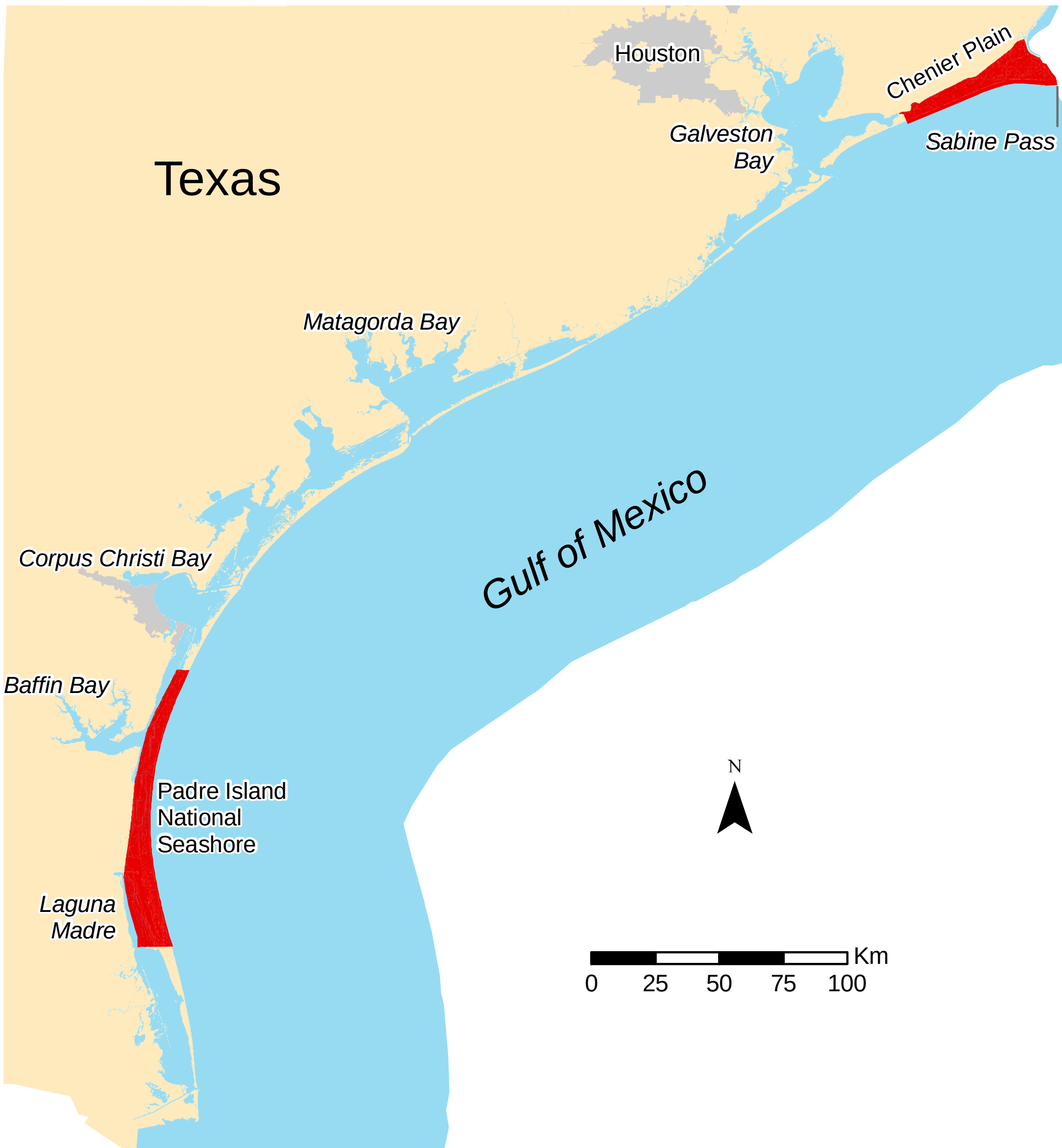


Figure 2. Index map showing study areas.

Geomorphic features on which various types of barrier island and strandplain-chenier wetlands have developed are the result of numerous interacting processes. Physical processes that influence wetlands include astronomical and wind tides, waves and longshore currents, storms and hurricanes, river flow, deposition and erosion, subsidence, faulting, sea-level rise, precipitation, water table fluctuations, and evapotranspiration. 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 inter-tidal wetlands that grade upward from the astronomical-tidal zone through the wind-tidal zone to the storm-tidal zone.

METHODS

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 1956, 1979/83, and 2003/04. Maps of the 1950's and 1979 for Padre Island National Seashore 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 1956 and 1979 series were digitized and initially analyzed in 1983 (USFWS, 1983). In the strandplain-chenier system, maps for 1956 were prepared by BEG, and maps for 1983 were prepared by USFWS as part of the NWI program. Current USFWS NWI maps and digital data for the Texas coast were prepared using 1992 aerial photographs. These maps were used as collateral data. The current status of wetlands in this study is based on photographs taken in 2003 and 2004.

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

[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.

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 this project was to determine status and trends of wetlands using aerial photographs, classification and definition of wetlands are integrally connected to the photographs and the interpretation of wetland signatures. Wetlands were not defined nor mapped in accordance with the USACE wetlands delineation manual for jurisdictional wetlands (U.S. Army Corps of Engineers, 1987).

Interpretation of Wetlands

Historical Wetland Distribution

Historical distribution of wetlands is based on 1956 and 1979/83 USFWS wetland maps. The exception is on the upper coast where 1956 USFWS maps were not available. In this area BEG mapped wetlands using 1956 photomosaics. Methods used by the USFWS include interpretation and delineation of wetlands and aquatic habitats on aerial photographs through stereoscopic interpretation. Field reconnaissance is an integral part of interpretation. Photographic signatures are compared to the appearance of wetlands in the field by observing vegetation, soil, hydrology, and topography. This information is weighted for seasonality and conditions existing at the time of photography and ground-truthing. Still, field-surveyed sites represent only a small percentage of the thousands of areas (polygons) delineated. Most areas are delineated on the basis of photointerpretation alone, and mis-classifications may occur. The 1956 photographs are black-and-white stereo-pair, scale 1:24,000, most of which along the Texas coast were taken in the mid-1950's, (Larry Handley, USGS, Personal Communication, 1997). The 1979 aerial photographs are NASA color-infrared stereo-pair, scale 1:65,000, that were taken in November.

The USFWS NWI maps were prepared by transferring wetlands mapped on aerial photographs to USGS 7.5-minute quadrangle base maps, scale 1:24,000, using zoom-transfer scopes. Wetlands on the completed maps were then digitized and the data entered into a GIS. As in the photointerpretation process, there is a margin of error involved in the transfer and digitization process.

Photographs used are generally of high quality. Abnormally high precipitation in 1979, however, raised water levels on tidal flats, and in many island fresh to brackish wetlands, produced more standing water than in the 1956 and 2004 photographs. Although 1956 photographs are black and white, they are large scale (1:24,000), which aids in the photointerpretation and delineation process. The1956 photographs may reflect the severe drought that peaked in 1956 in Texas (Riggio et al. 1987). The drought apparently reduced the number of open water areas that were mapped on the upper coast. These differences in wet and dry conditions during the various years affected habitats, and their interpreted, or mapped, water regimes.

The following explanation is printed on all USFWS wetland maps that were used in this project to determine trends of wetlands:

> 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. . .

Revision of Historical Wetland Maps

As part of this study, researchers at BEG revised USFWS historical wetland maps (1956 and 1979) so there would be closer agreement between the historical map units and the current (2003/04) wetland map units. Revisions of the USFWS data are restricted primarily to the estuarine marshes, tidal flats, and areas of open water. The principal reason for the revisions was that in many areas on the historical maps, estuarine intertidal emergent wetlands (E2EM) were combined with intertidal flats (E2FL) or open water (E1OW) as a single map unit (E2EM/E2FL and E2EM/E1OW). In our revisions, many of these areas were subdivided into E2EM and E2FL or E1OW where possible at the mapping scale. To accomplish the revisions on the USFWS maps, photographs taken in the 1950's and 1979 were scanned and georeferenced with respect to the 1950's and 1979 maps. Wetlands on the digital photos were then analyzed on the computer screen and changes were mapped directly on the digital wetland maps. The revised data were entered into the GIS.

Current Wetland Distribution

The current distribution of wetlands is based on digital, Color Infrared (CIR), 1-meter resolution aerial photographs, taken in 2003/04. The digital images were registered to USGS orthophoto quarter quadrangles (DOQQ's). Interpretation and mapping of wetlands and aquatic habitats were completed by BEG researchers through interactive digitization of habitats on screen in a GIS (ArcMap) at a scale of 1:3000 and 1:5000. Because of the method used, the current wetland maps show more detail than the historical maps.

Field Investigations

Field investigations (Figs. 3 – 9) 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. In a few areas, interpretations of wetlands were supported by Light Detection and Ranging (LIDAR) data acquired by BEG in the spring of 2002 (Fig. 7). The LIDAR images provide detailed elevation data that help differentiate between high and low marshes and flats, and areas that are transitional between uplands and wetlands.

Figure 3. Texas General Land Office, Oil Spill Division boat used to check field sites along the Gulf Intracoastal Waterway on the upper Texas Coast.

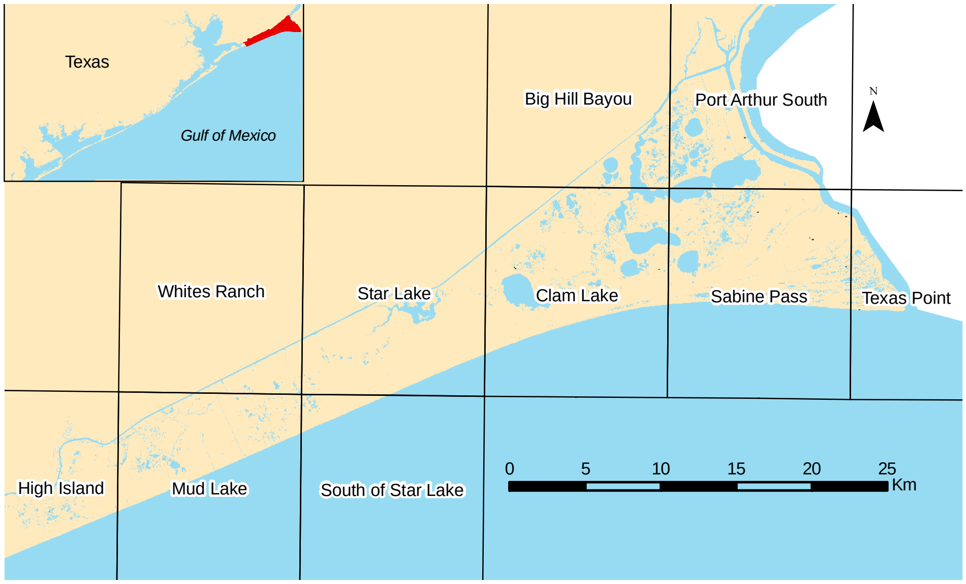


Figure 4. Index map of USGS 7.5 minute quadrangles that encompass the upper coast study area.

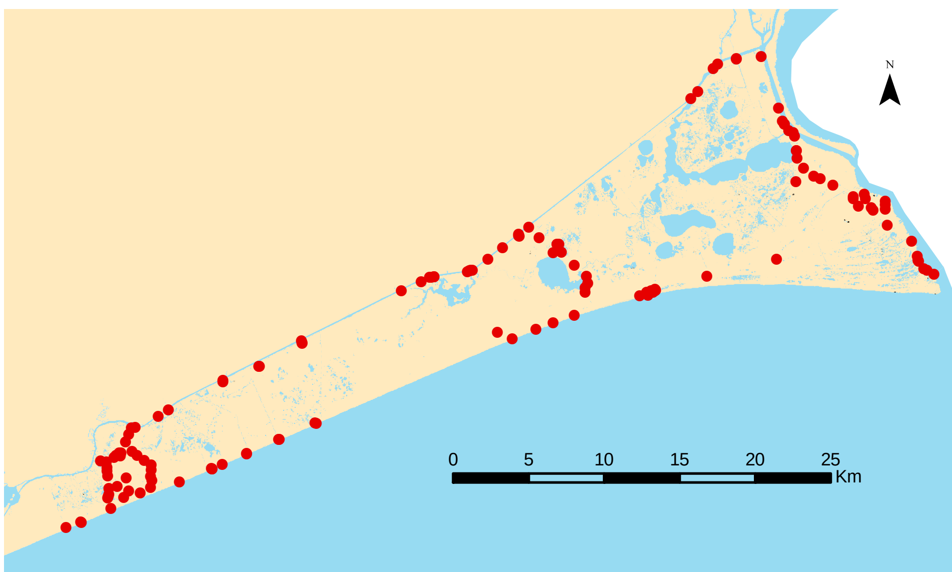


Figure 5. Index map of field-survey sites along the upper coast used for ground-truthing aerial photo delineations, and recording vegetation composition and water regimes.

Figure 6. Index map of USGS 7.5’quadrangles covering PINS study area (a), and field site locations (b).

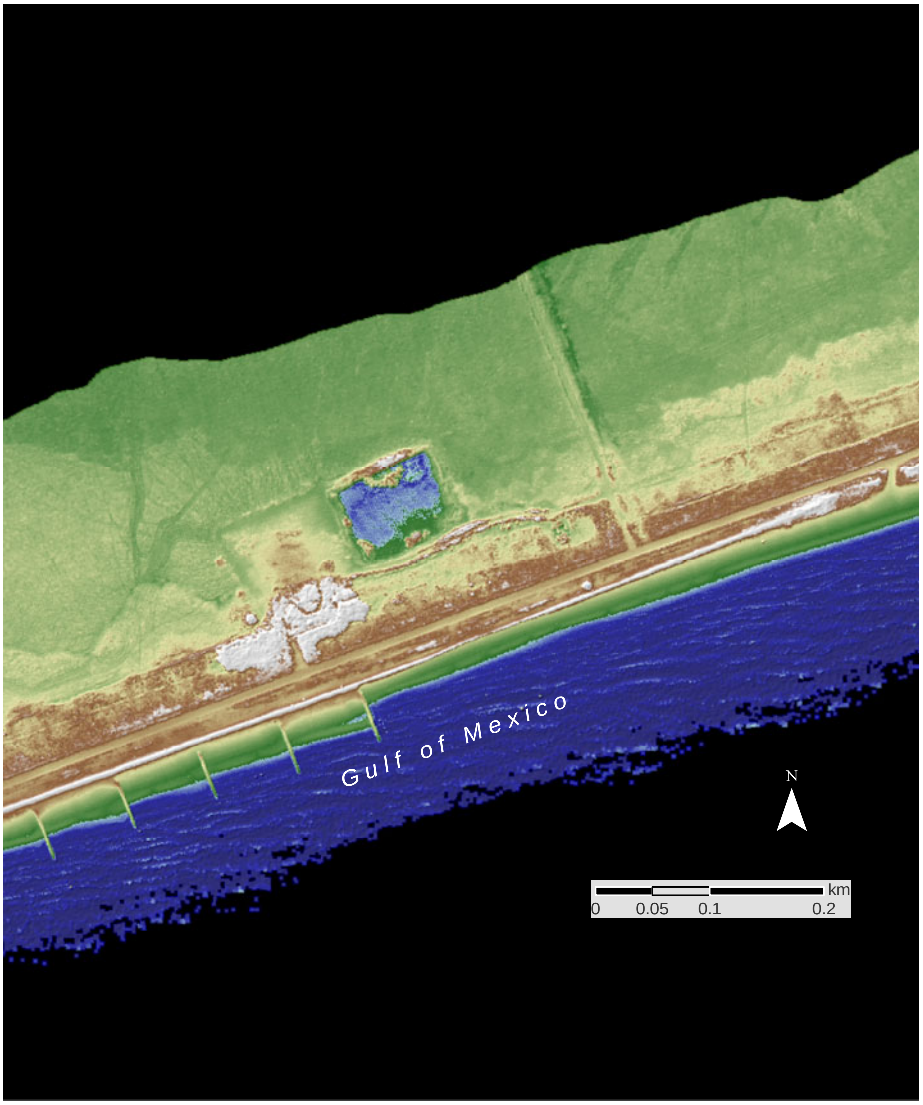


Figure 7. Example of Lidar image of short segment of the strandplain-chenier system. Images like this were used locally to help identify upland-wetland and high-low marsh boundaries. The linear features extending into the Gulf are geotubes placed there to slow shoreline erosion (see next figure for close-up).

Figure 8. Geotubes placed along the Gulf shoreline on the McFaddin NWR to help trap sediments and slow shoreline erosion show up well on Lidar images. See previous Lidar figure for plan view of tubes. Above photograph was taken from the northeast end of the tube field.

Figure 9. During field surveys, water salinities were measured at some locations to help define palustrine, lacustrine, and estuarine areas.

Variations in Classification

Classification of wetlands varied somewhat for the different years. On 1979/83 and 2003/04 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. 9-11). For the1956 maps, wetlands were classified by system, subsystem, and class. On 1979/83 maps, upland areas were also mapped and classified by upland habitats using a modified Anderson et al. (1976) land-use classification system (Fig. 12). Flats and beach/bar classes designated separately on 1956 and 1979/83 maps were combined into a single class, unconsolidated shore, on 2003/04 maps, in accordance with updated NWI procedures, as exemplified on 1992 NWI wetland maps (Fig. 12). USFWS data for the study area was selected from 7.5-minute quadrangles (Figs. 4 and 6) from files previously digitized and maintained by the USFWS for the1956 and 1979/83 wetland maps.

Results include GIS data sets consisting of electronic-information overlays corresponding to mapped habitat features for 1956, 1979/83, and 2003/04. 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 wetland types to gauge historical trends and status of habitats, (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 wetland studies and other topical studies in a single system that integrates disparate environmental features for planning and management purposes. The GIS is a flexible and valuable management tool for use by resource managers. Still, users must be aware of potential errors, for example from registration differences, which can arise from direct analysis of GIS overlays.

Map Registration Differences

There are map registration differences in the historical and recent digital data. This causes errors when the data sets are overlain and analyzed in a GIS. The 2003/04 aerial photographs are georeferenced to USGS DOQQ's. There is good agreement in registration with these base photographs. However, the historical data sets are not as well registered, and there is an offset in wetland boundaries between the historical and the 2003/04 data. When the two data sets are superimposed in a GIS, the offset creates apparent wetland changes that are in reality cartographic errors due to a lack of precision in registration.

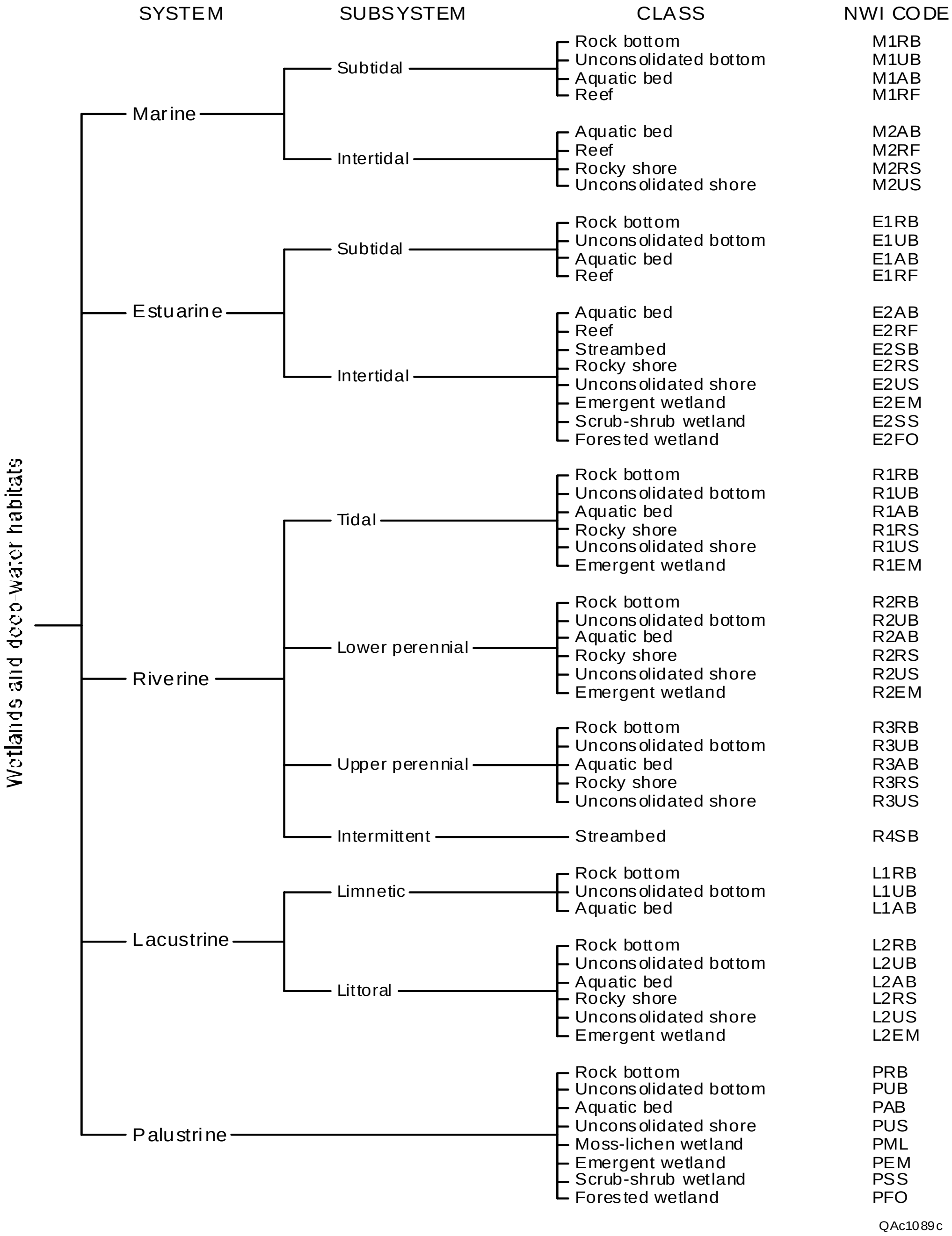


Figure 10. Classification hierarchy of wetlands and deepwater habitats showing systems, subsystems, and classes. From Cowardin et al. (1979).

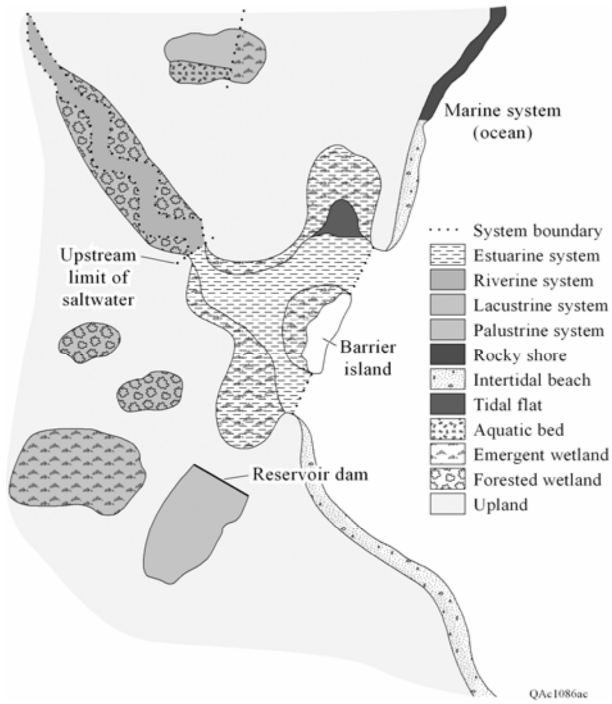


Figure 11. Schematic diagram showing major wetland and deepwater habitat systems. From Tiner (1984).

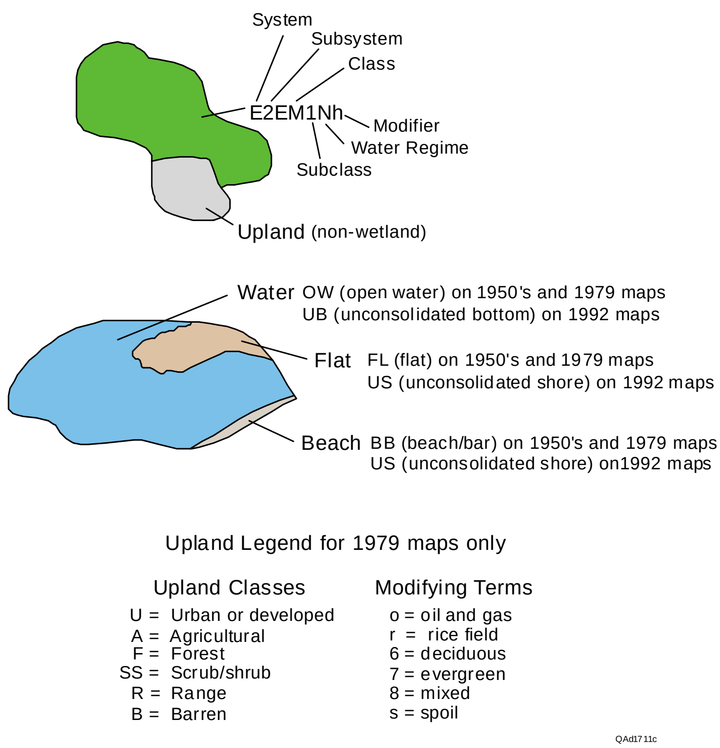


Figure 12. Example of symbology used to define wetland and upland habitats on NWI maps.

Re-registration of the USFWS digital data sets was done by georeferencing them to the USGS DOQQ's, which improved the agreement of the historical maps with the 2003/04 maps. Still, there is not "perfect" agreement in registration between the different maps. Thus, caution must be used in interpreting changes from direct projection of the different data sets as layers in a GIS. We tabulated wetland totals separately for each year to determine wetland changes within the given study area. Projection of the data sets with respect to each other was done primarily to identify significant wetland changes that could be verified by analyzing and comparing aerial photographs.

Methods used to Analyze Historical Trends in Wetland Habitats

Trends in wetland habitats were determined by analyzing habitat distribution as mapped on 2003/04, 1979/83, and 1950's 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 and precipitation.

ArcGIS was used to analyze trends. This software allowed for direct comparison not only between years, but also by geographic areas such as the barrier island, peninsula, and delta. Analyses included tabulation of losses and gains in wetland classes for each area for selected periods (Fig. 13). 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 ArcGIS.

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 is that different photointerpreters were involved for different time periods, and interpretation of wetland areas can vary somewhat among interpreters. As a result, some changes in the distribution of wetlands from one period to the next may not be real but, rather, relicts of the interpretation process. Inconsistencies in interpretation seem to have occurred most frequently in high marsh to transitional areas where uplands and wetlands intergrade.

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

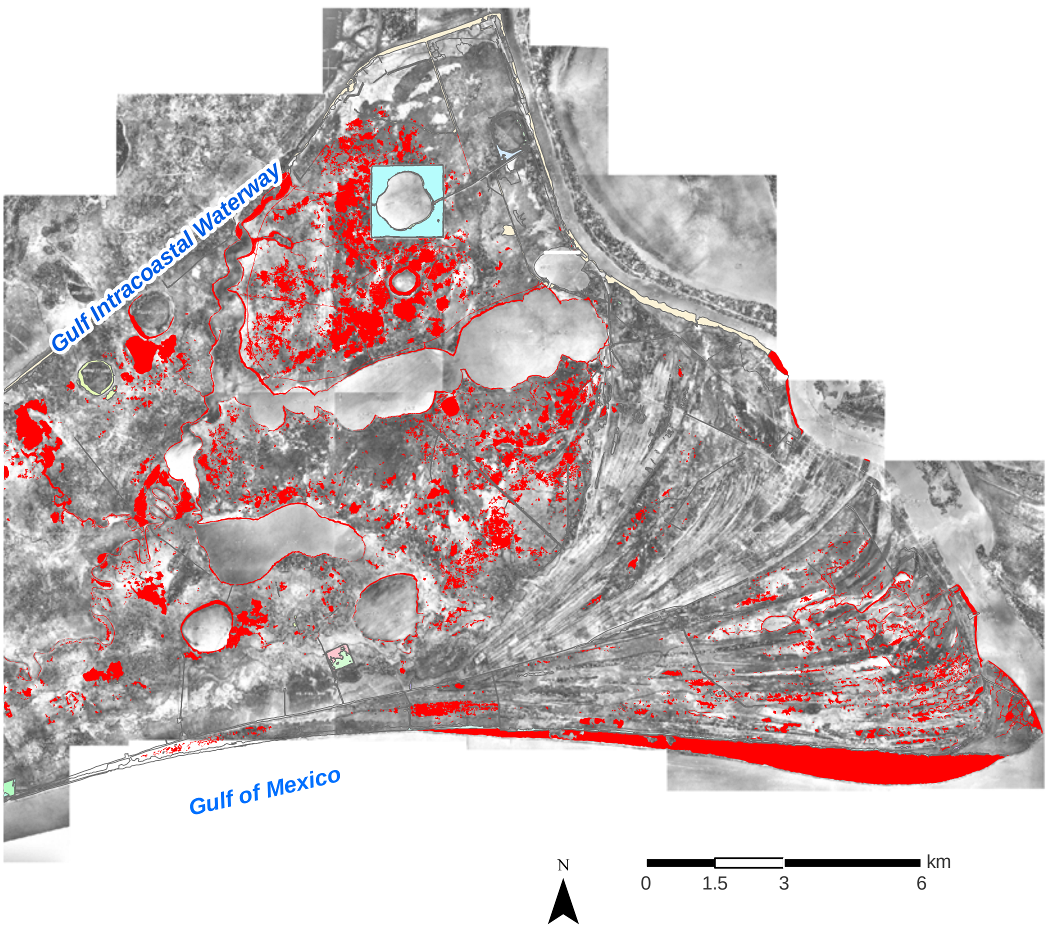


Figure 13. Example of GIS overlay analysis to determine losses in estuarine marsh (in red) between 1956 and 2004. Black and white image is made up of 1956 photo mosaic from Tobin Surveys, Inc.

In general, wetland changes that seem to have been influenced the most by photointerpretation problems are interior (palustrine), temporarily flooded wetlands bordering on being transitional areas. Some apparent losses in palustrine wetlands were documented on barrier islands, but appear to be due to drier conditions when the 2004 photographs were taken.

In the analysis of trends, wetland areas for different time periods are compared without an attempt to factor out all misinterpretations or photo-to-map transfer errors except for major, obvious problems. However, maps and aerial photographs representing each period were visually compared as part of the trend-analysis process and as part of the effort to identify potential problems in interpretation. Still, users of the data should keep in mind that there is a margin of error inherent in photo interpretation and map preparation.

Wetland Codes

As mentioned in the introduction, some wetland codes used on 2003/04 maps are different from those used on the 1950's and 1979 maps (Fig. 12). In the following discussion of trends, E2US rather than E2FL (used on the 1950's and 1979 maps) is generally used to denote tidal flats, and UB (rather than OW) is used to represent open water.

CLASSIFICATION OF WETLAND AND DEEPWATER HABITATS IN THE STUDY AREAS

Cowardin et al. (1979) defined five major systems of wetlands and deepwater habitats: Marine, Estuarine, Riverine, Lacustrine, and Palustrine (Fig. 10). 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 1979/93 and 2003/04. In addition, water-regime modifiers (Table 1) and special modifiers were used for these years.

The USFWS-NWI program established criteria for mapping wetlands on aerial photographs using the Cowardin et al. (1979) classification. Alphanumeric abbreviations are used to denote systems, subsystems, classes, subclasses, water regimes, and special modifiers (Table 2, Fig. 12). Symbols for certain habitats changed after 1979; these changes are shown in Figure 12 and are noted in the section on trends in wetland and aquatic habitats.

Table 1. Water-regime descriptions defined by Cowardin et al. (1979).

Nontidal	*Water-Regime Symbols and Description*
(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 2. Wetland codes and descriptions from Cowardin et al. (1979). Codes listed below were used in mapping wetlands on the 2002/04 delineations, which varied in some cases from 1956 and 1979 maps (see Fig. 12).

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* *Halophila engelmannii* *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	Unconsolidated 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	*Schoenoplectus 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.*

Examples of alphanumeric abbreviations used in the section on status of wetlands apply only to 2003/04 maps. Much of the following discussion of wetland systems, as defined by Cowardin et al. (1979), is modified from White et al. (1993, 1998, and 2002). Nomenclature and symbols (Appendix) in this discussion are based primarily on 1992 NWI maps.

Marine System

Marine areas include unconsolidated bottom (open water), unconsolidated shore (beaches) and rocky shore (jetties). Mean range of Gulf tides is about 0.5 m. Nonvegetated, open water overlying the Texas Continental Shelf is classified as marine subtidal unconsolidated bottom (M1UBL) (Table 2). Unconsolidated shore is mostly irregularly flooded shore or beach (M2USP) with a narrow zone of regularly flooded shore (M2USN) (Fig. 14). Composition of these areas is primarily sand and shell. Granite placed along shore and in jetties along the coast in the marine system are classified as marine intertidal, rocky shore, irregularly flooded, rubble, artificial (M2RS2Pr) (Fig. 15).

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 (wind-tidal flats) and estuarine beaches and bars. Water regimes for this habitat range primarily from regularly flooded (E2USN) to irregularly flooded (E2USP) (Fig. 16).

Aquatic beds observed in this system are at some locations, PINS, made up of submerged rooted vascular plants (E1AB3L) (Fig. 17) that include *Halodule wrightii* (shoalgrass), *Ruppia maritima* (widgeongrass), *Halophila engelmannii* (clover grass), and *Thalassia testudinum* (turtlegrass) (Weise and White, 1980). In many estuarine water areas in the strandplain-chenier system, floating leaf aquatics were mapped as E1AB4 (Fig. 18). Vegetation in these areas included *Lemna* sp., *Nymphaea mexicana*, and locally, *Eichhornia crassipes* and *Salvinia* sp.

Emergent areas closest to estuarine waters consist of regularly flooded salt-tolerant grasses (low salt and brackish marshes) (E2EM1N) (Fig. 19). Along the upper coast, 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, species composition changes to a salt to brackish-water assemblage including *Schoenoplectus* (formerly *Scirpus*) spp. (bulrush), *Paspalum vaginatum* (seashore paspalum), *Juncus roemerianus* (black needle rush), *Spartina patens* (saltmeadow cordgrass), and *Phyla* sp. (frog fruit). At slightly higher elevations, irregularly flooded estuarine emergent wetlands (E2EM1P) (high salt and brackish marshes) (Fig. 20) include *Borrichia frutescens* (sea oxeye), *Spartina patens*, *Spartina spartinae* (gulf cordgrass), *Distichlis spicata*, *Fimbrystylis castanea* (marsh fimbry), *Aster* spp. (aster), and many others. Most of the species listed above occur in the PINS, except *S. alterniflora*, which is essentially absent in this more saline area of Laguna Madre.

Figure 14. Marine beach along the Gulf shoreline. The forebeach (lower beach along the Gulf margin) was mapped as M2USN (marine intertidal unconsolidated shore, regularly flooded), and the backbeach as M2USP (marine intertidal unconsolidated shore, irregularly flooded.

Figure 15. Rip rap along jetties at Mansfield Channel. These features were mapped as M2RS2Pr (Marine intertidal rocky shore, rubble, irregularly flooded, artificial).

Figure 16. Example of an irregularly flooded tidal flat and algal flat (in distance) on the lagoon side of Padre Island. These typically sandy flats were mapped as estuarine intertidal unconsolidated shore, irregularly flooded (E2USP) and estuarine intertidal aquatic bed, regularly flooded (E2AB1N).

Figure 17. Seagrass beds (dark area) in Laguna Madre. Areas like these were mapped as E1AB3L (estuarine subtidal aquatic bed, rooted vascular, subtidal water regime).

Figure 18. Floating leaf aquatics, mostly *Lemna* sp. in the McFaddin NWR on the upper Texas coast. These areas were mapped as E1AB4 (estuarine subtidal aquatic bed, floating vascular).

Figure 19. Estuarine intertidal low marsh (E2EM1N) near Sabine Pass, characterized by *Spartina alterniflora* along the water's edge. Small shrub is *Avicennia germinans* (black mangrove).

Figure 20. Estuarine intertidal high marsh on the Chenier Plain characterized by *Spartina spartinae* and *Spartina patens* in distance, and *Suaeda* sp. in foreground.

Estuarine scrub-shrub wetlands (E2SS) are much less extensive than estuarine emergent wetlands. Representative plant species in irregularly flooded zones (E2SS1P**)** between emergent wetland communities and upland habitats, include, *Tamarix* spp. (salt cedar) (Fig. 21), *Iva frutescens* (big-leaf sumpweed), *Baccharis halimifolia* (sea-myrtle, or eastern false-willow), and *Sesbania drummondii* (drummond's rattle-bush). In regularly flooded zones, *Avicennia germinans* (black mangrove) (Fig.19) occurs scattered with salt marsh vegetation, but its concentration is too sparse to map separately as a scrub-shrub wetland, so it is included in the marsh class.

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 estuarine open water (E2EM/OW). The classes E2EM/FL and E2EM/OW were only used on 1956 and 1979 maps. In such combinations, each class must compose at least 30% of the mapped area (polygon); on 1956 and 1979 maps the wetland class was always listed first (E2EM/OW) whether or not it was most abundant. For our purposes, we subdivided these classes into 50-50 components so that 50% was combined with the marsh (E2EM) and 50% with the water (E1OW).

The estuarine system extends 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 systems. In general, a pond or emergent wetland was placed in the palustrine system if there was an upland break that separated it from the estuarine system.

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 that are not inundated by estuarine tides. Semipermanently flooded emergent wetlands (PEM1F) are low fresh marshes; seasonally flooded (PEM1C) and temporarily flooded (PEM1A) palustrine emergent wetlands are high fresh marshes. Artificially flooded areas are designated PEM1K.

Vegetation communities typically characterizing areas mapped as low emergent wetlands (PEM1F) include *Paspalum vaginatum* (seashore paspalum), *Schoenoplectus* (formerly

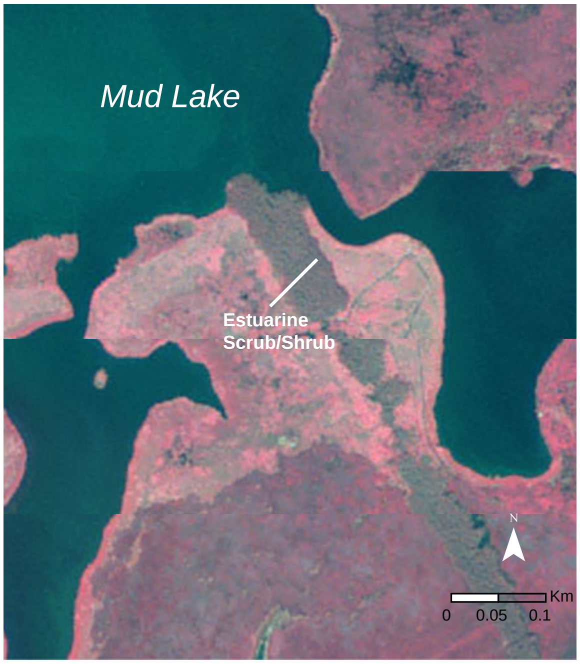


Figure 21. Estuarine scrub-shrub wetland (E2SS) composed of *Tamarix* sp. (salt cedar) on upper coast near Mud Lake.

Scirpus) *californicus*, *Typha domingensis* (southern cattail), *Schoenoplectus pungens* (formerly *Scirpus americanus*) (three-square bulrush), *Eleocharis* spp. (spikerush), *Bacopa monnieri* (coastal water-hyssop), *Juncus* sp., and others (Figs. 22 and 24). Areas mapped as topographically higher and less frequently flooded emergent wetlands (PEM1A) include *Spartina spartinae*, *Borrichia frutescens*, *S. patens*, *Cyperus* spp. (flatsedge), *Hydrocotyle bonariensis* (coastal plain penny-wort), *Phyla* sp. (frog fruit) *Aster spinosus* (spiny aster), *Paspalum* spp. (paspalum), *Panicum* spp. (panic), *Polygonum* sp. (smartweed) and scattered *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. Lidar data, which provided elevation measurements, helped to differentiate high and low marsh communities in some areas (Fig. 7).

Palustrine scrub-shrub wetlands that were mapped are typically seasonally (PSS1C) or temporarily flooded (PSS1A) and may include *Tamarix* spp., *Baccharis* sp., and *Iva frutescens*.

Figure 22. Palustrine marsh in depression on Padre Island. The dominant vegetation is *Tyhpa* sp. (cattail).

Figure 23. Alligator in brackish-marsh habitat at Sea Rim State Park.

Figure 24. Estuarine marsh in Sea Rim State Park. The dominant vegetation at this location includes *Typha* sp., *Schoenoplectus californicus, S. maritimus, Bacopa* sp., *Distichlis* sp., *Spartina alterniflora*, and *Phragmites* sp. Salinities measured at different places along the boardwalk ranged from 2 to 3 ppt.

Lacustrine System

Water bodies greater than 8 ha are included in this system with both limnetic and littoral subsystems represented. Few areas were classified as lacustrine in 1979/83 and in 2003/04. Nonvegetated water bodies are labeled limnetic or littoral unconsolidated bottom (L1UB or L2UB) (L1OW or L2OW in 1956 and 1979/83 data sets) 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 for 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, and in this study where water features are diked or leveed and water levels are affected by water associated with pumped, disposed sediments.

Riverine System

No areas were classified in the Riverine System in the study areas.

STRANDPLAIN-CHENIER SYSTEM, UPPER TEXAS COAST

Study Area

The strandplain-chenier system along the upper Texas Coast contains the most extensive contiguous marshland along the Texas Gulf Coast. Most of the marshland falls within the McFaddin National Wildlife Refuge, Texas Point NWR, J.D. Murphree Wildlife Management Area, and Sea Rim State Park (Fig. 25). Extensive brackish- and salt-water marshes and ponds characterize this area. Although there are local fresh ponds and marshes that have been isolated by levees and dikes, most of the fresh-water marshes that are part of the McFaddin National Wildlife Refuge occur inland of the Gulf Intracoastal Waterway (Personal Communication, 2006, Dean Bossert, Refuge Manager).

General Setting of the Strandplain-Chenier System

Geologically, the upper Texas coast is characterized by a modern stranplain-chenier system with well preserved chenier beach ridges with interlying marsh filled swales (Fig. 26) (Fisher et al. 1973). Relict beach ridges and intervening swales have an orientation roughly parallel to today’s shoreline marked by the Gulf beach (Fig. 27). The swales are the sites of extensive linear estuarine marshes. The strandplain-chenier system has gradually evolved through erosion, deposition, compaction, subsidence, and locally, faulting. The strandplain extends along the Gulf shore toward the southeast to High Island. High Island is a salt dome near the Gulf shoreline with elevations exceeding 7.5 m (25 ft). The study area extends landward to the Gulf Intracoastal Waterway.
The Gulf shoreline near Sabine Pass is characterized by erosion (Paine and Morton, 1989).

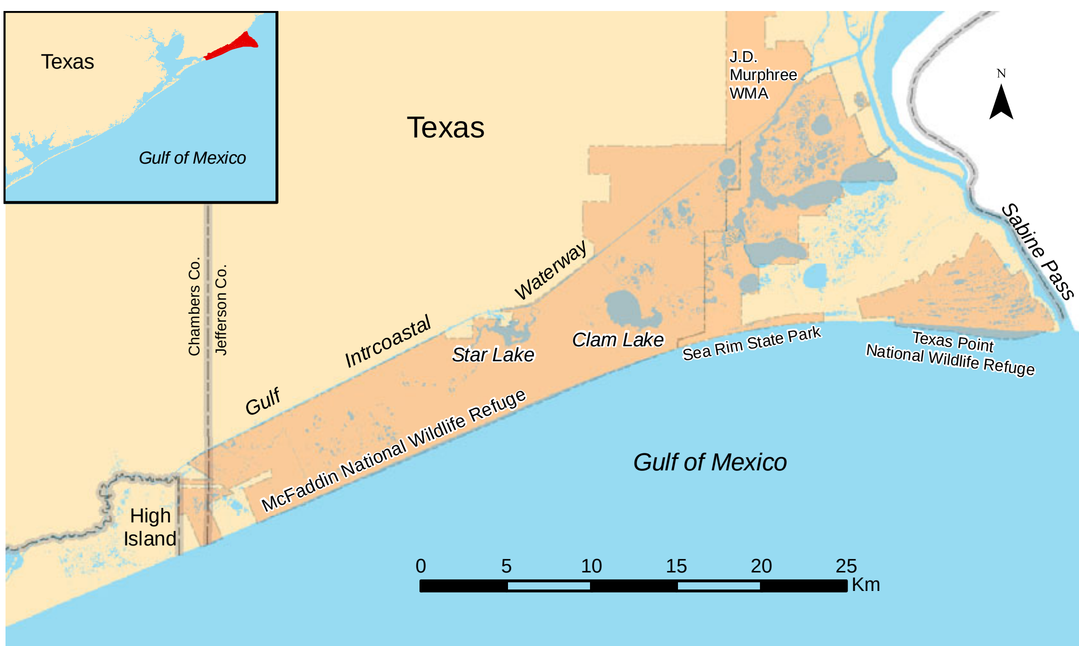


Figure 25. Location of Federal and State refuges, parks, and management areas.

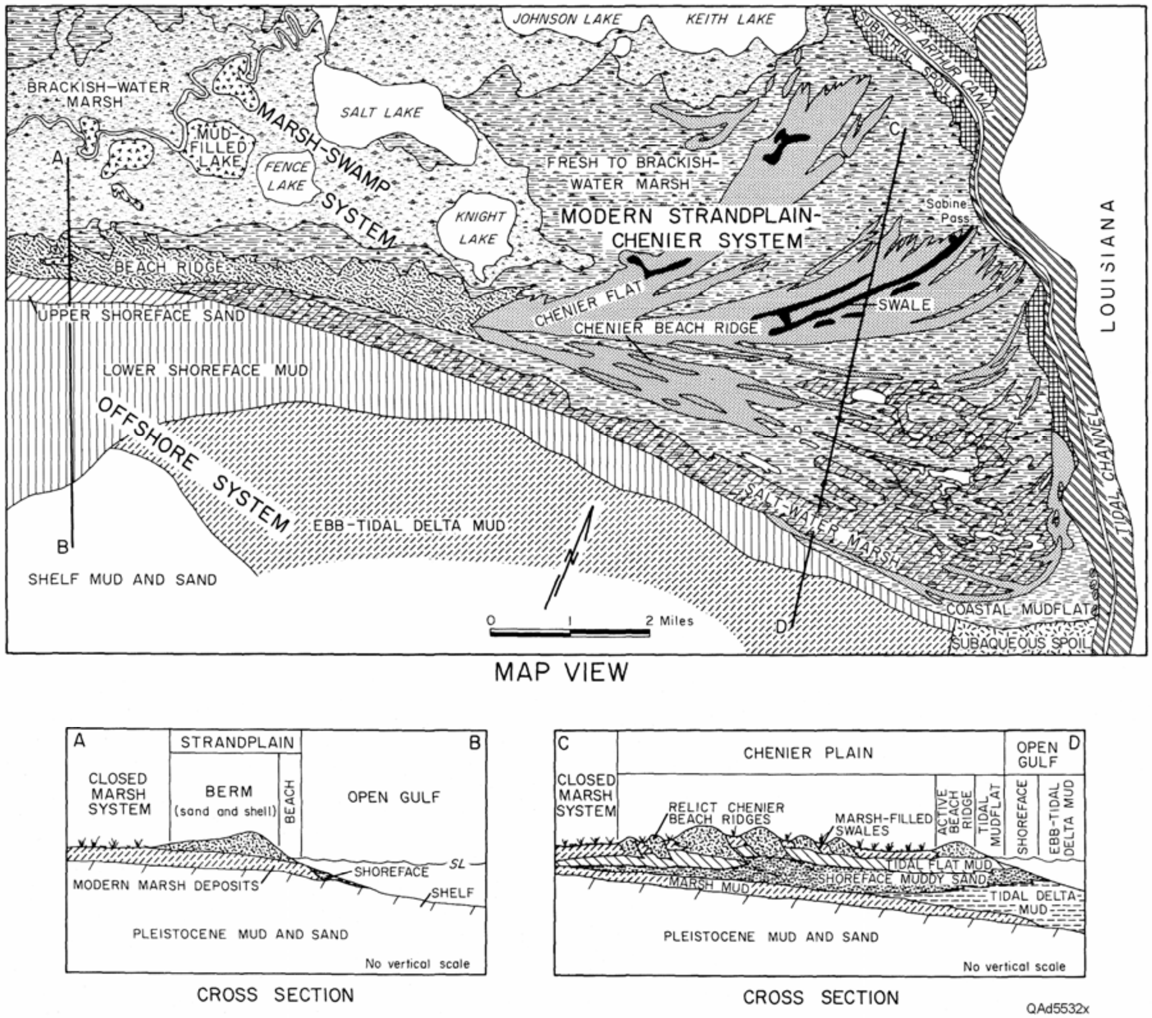


Figure 26. Modern strandplain-chenier and offshore systems along the Gulf of Mexico near Sabine Pass. Cross sections are generalized to contrast strandplains and chenier plains. From Fisher et al. (1973).

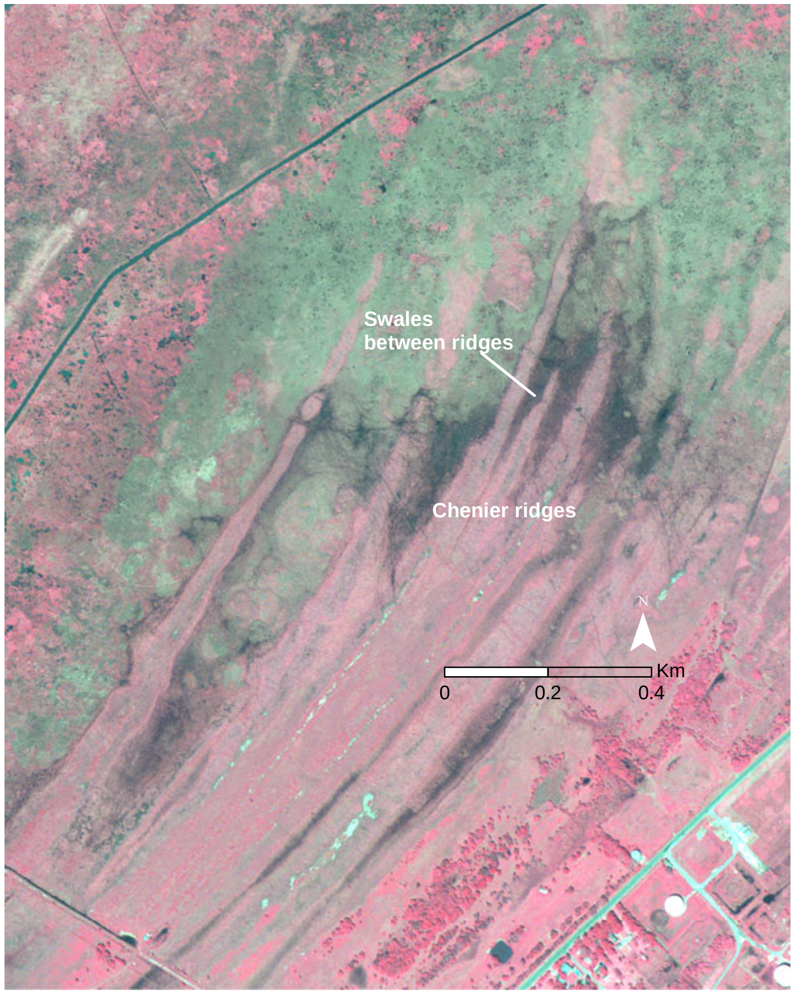


Figure 27. Aerial photograph taken in 2004 showing ridge and swale topography on the upper coast chenier plain. Dark areas are wet zones supporting emergent vegetation in swales between relict beach ridges.

Relative Sea-level Rise

Another important process affecting wetland and aquatic habitats is relative sea-level rise, which is the relative vertical rise in water level with respect to a datum at the land surface. This change in relative sea level can be 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). The tide gauge at Pier 21 at Galveston Island provides the longest continuous record of sea-level variations along the Texas coast. The average rate of sea-level rise from1909 to 2003 was 0.65 cm/yr (Fig. 28). Rates of sea-level rise recorded by the tide gauge reached a high of 1.9 cm/yr from 1963 to mid 1975. The mean sea-level trend at Sabine Pass is approximately 6.54 mm/yr (Fig. 29). 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. The period of rapid relative sea-level rise from the mid-1960's to mid-1970's is time coincident with a maximum change in some habitats such as wind-tidal flats (White et al. 1998).

Subsidence

Subsidence of varying amounts has occurred along the entire Texas coast, but the most significant subsidence is in the Houston-Galveston area where a large subsidence "bowl", with over 3 meters of subsidence near its center, has formed (Fig. 30) (Gabrysch, 1984; Gabrysch and Coplin, 1990). In this area, the amount of land undergoing at least 30 cm of subsidence, including the area around Texas City, has grown from about 360 km^2 in the 1940's to more than 10,000 km^2 in the 1980's. Average maximum rates of subsidence at the center of the "bowl" were as high as 12 cm/yr for the period 1964 to 1973 (Garbrysch and Bonnet, 1975). The subsidence bowl centered on Texas City encompasses much of Galveston Island.

There are many causes of subsidence, including regional downwarping or tilting of the earth's crust due to loading, which is significant over a geologic time frame along the Texas coast but not over an historic time frame (Winker, 1979). Within an historic time frame, the cause of subsidence in the Houston-Galveston area is primarily due to ground-water withdrawal and secondarily oil and gas production that began in the early part of this century. On the eastern side of the subsidence bowl in the Houston-Galveston region including Texas City, rates of subsidence have decreased dramatically in some areas due to curtailment of ground-water pumpage (Gabrysch and Coplin, 1990).

Faulting

Geologically, active surface faults along the Texas coast are fractures in the earth's crust along which movement has occurred within the past few thousand years. Generally, the earth's surface moves downward or subsides at a faster rate on one side (downthrown side) of the fault than on the other side. This produces a fault scarp or sharp change in elevation at the surface along the trace of the fault. Active faults are significant geologic hazards because their movement at the surface breaks and bows structures such as highways, railroads, foundations of residential and commercial developments, pipelines,

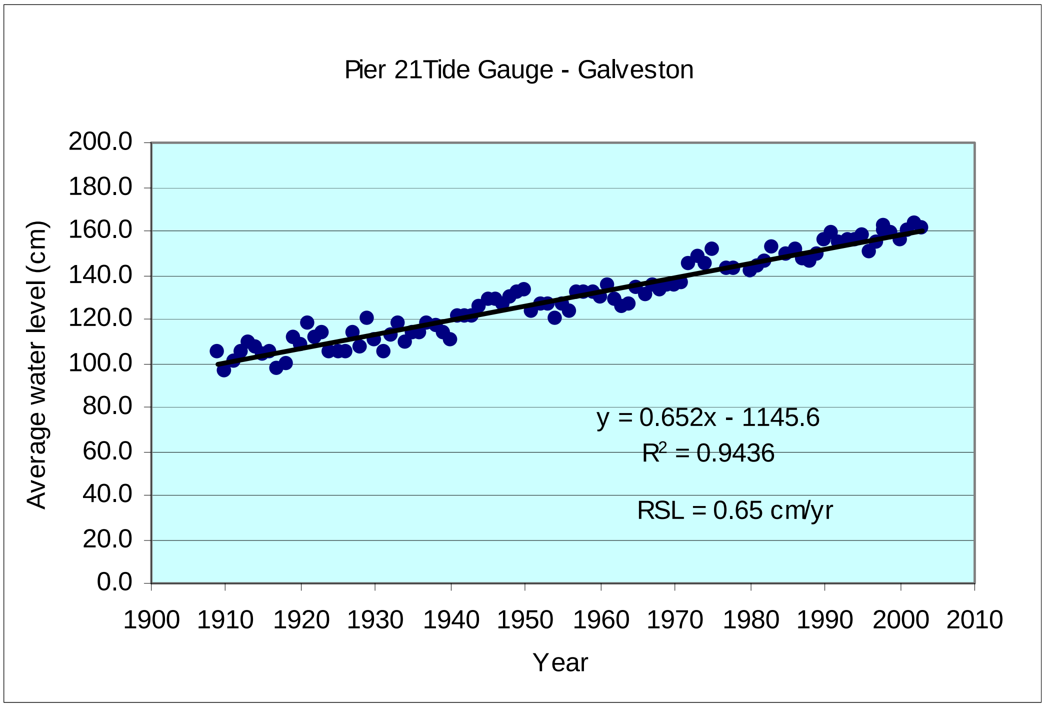


Figure 28. Tide gauge record at Pier 21, Galveston. The average rate of sea-level rise from 1909 to 2003 was 0.65 cm/yr. The highest short-term rate (1963-1975) was 1.92 cm/yr. Data from NOAA National Ocean Service.

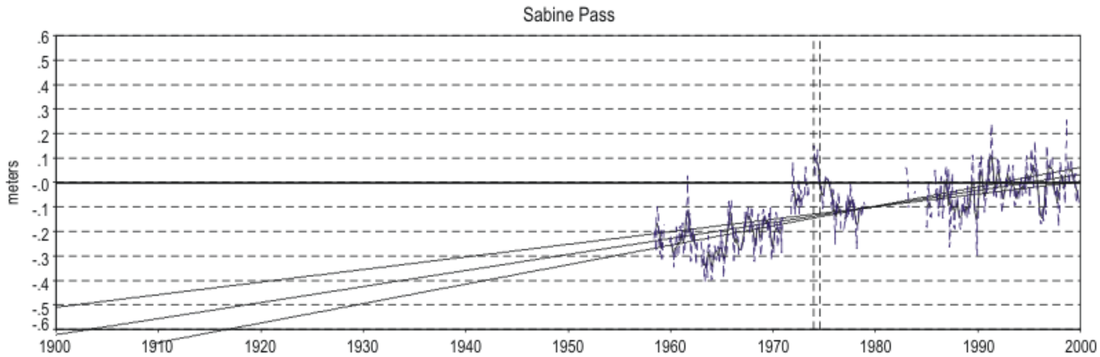


Figure 29. Mean sea level trend at Sabine Pass. The mean sea level trend is 6.54 mm/yr (2.15 feet/century) with a standard error of 0.72 mm/yr based on monthly mean sea level data from 1958 to 1999. Station 8770570. Data from NOAA.

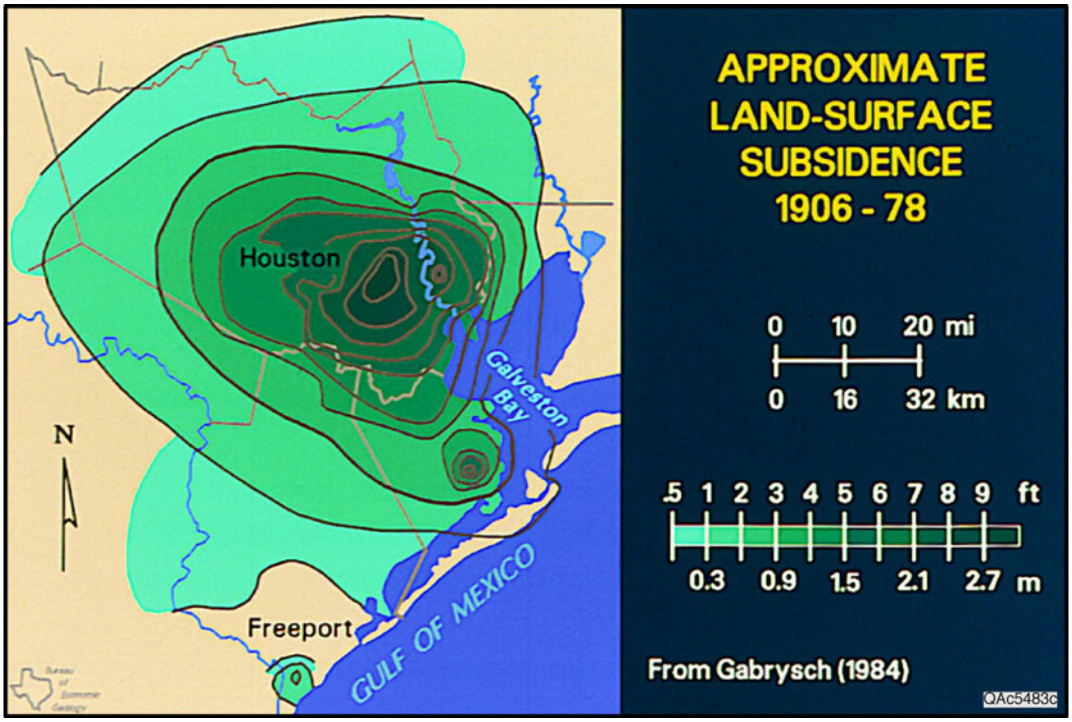


Figure 30. Houston-Galveston area subsidence from 1906 to 1978 caused primarily by ground-water withdrawal. Maximum subsidence in 1978 was near 9 ft at the center of the major subsidence bowl northwest of Galveston Bay. A secondary subsidence bowl is centered on Texas City across the bay from Galveston.

airfield runways, and other features. Millions of dollars of damage are caused annually by faults (Verbeek and Clanton, 1981). Natural resources such as wetlands are also affected by faulting. As the land surface moves downward along a fault that intersects a wetland, more frequent and eventually permanent inundation can lead to replacement of marsh vegetation by open water (Fig. 31) (White and Tremblay, 1995; White and Morton, 1997). Forty faults, together measuring about 150 km have been identified and mapped in marsh areas along the upper coast (Fig. 32) (White and Morton, 1997). The lengths of individual fault traces range from less than 1 km to more than 13 km. Surface faults correlate with, and appear to be natural extensions of subsurface faults in many areas (Weaver and Sheets, 1962; Van Siclen, 1967; Kreitler, 1977; Verbeek and Clanton, 1981; White and Morton, 1997). Although movement of the earth's surface along some faults is related to natural processes, there is evidence that most of the surface faulting in the Houston metropolitan area and the upper Texas coast has taken place during the last few decades, and is largely due to the withdrawal of water, oil, and gas, which has reinitiated and accelerated fault activity (Reid, 1973; Kreitler, 1977; Verbeek and Clanton, 1981; White and Morton, 1997). Most of the faults in the Houston-Galveston area occur within the subsidence bowl caused by ground-water withdrawal, but at some locations there is a close association between the faults and oil and gas production (Gustavson and Kreitler, 1976; Hillenbrand, 1985; White and Morton, 1997).

Many faults are not visible on historical photographs but are visible on more recent photographs, which indicates that they have become active recently. Other lines of evidence of fault activity are (1) reoccurring breaks and repairs in pavements, buildings,

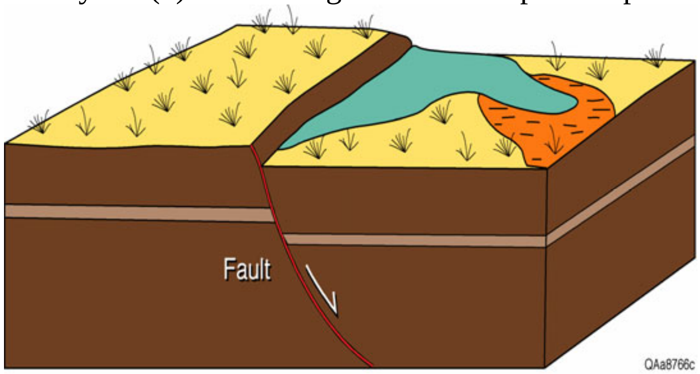


Figure 31. Diagram illustrating changes in wetlands along an active surface fault. There is generally an increase in low marshes and ponded water on the side of the fault that is moving downward. From White and Tremblay (1995).

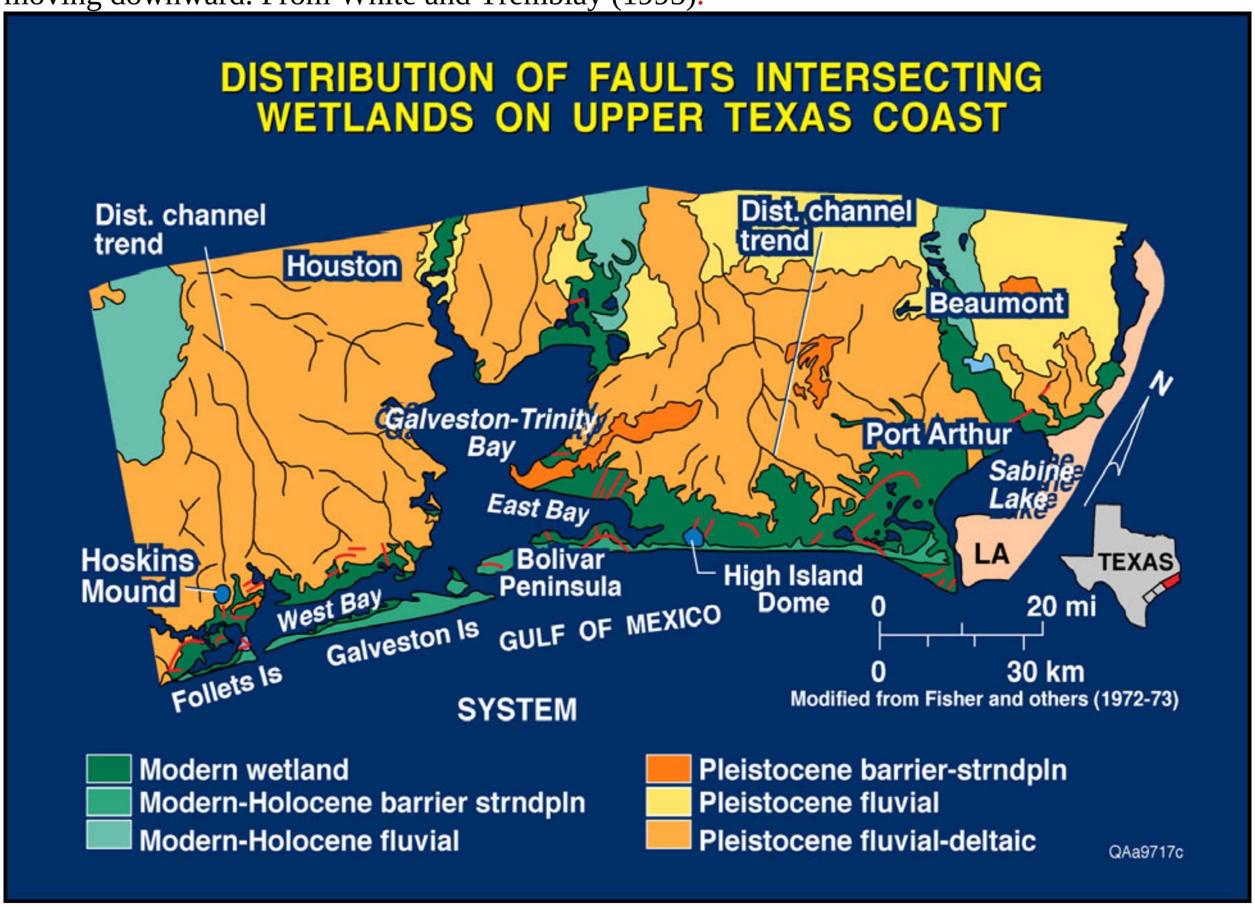


Figure 32. Surface faults, shown in red, that intersect marshes between Follet's Island and the Louisiana border. The faults were mapped from sequential aerial photographs. Only about 25% of the faults were visible on photographs taken in the 1930's, but the remaining 75% could be seen on later photographs indicating that they have become active since the 1930's. From White and Morton (1997).

and other structures, (2) abrupt changes in elevations as shown on topographic maps, and (3) sharp changes in the rates of subsidence along benchmark releveling profiles.

Differences in plant communities across faults in some areas appear to be related to a successional change in vegetation as subsidence and associated relative sea-level rise increase the depth, frequency, and duration of flooding on the downthrown sides of faults. Because *Spartina alterniflora* can withstand more frequent flooding than *Spartina patens* and *Distichlis spicata* (Adams, 1963; Chabreck, 1972; Gleason and Zieman, 1981; Mendelssohn and McKee, 1988a; Naidoo et al. 1992), a gradual replacement of these higher marsh species by *Spartina alterniflora* is expected. In a salt marsh in North Carolina, Adams (1963) attributed the replacement of portions of a maritime forest (*Juniperus virginiana*) by *Spartina alterniflora* to a relative rise in sea level. If fault-related subsidence and relative sea-level rise continue at rates that surpass rates of marsh sedimentation, eventually water depths and frequency of inundation will exceed even that which *Spartina alterniflora* can tolerate (Mendelssohn and McKee, 1988b) and all emergent vegetation will be replaced by open water.

Water and low marshes increase on the downthrown (D) side of the faults relative to the upthrown side (U), indicating higher rates of subsidence on the downthrown side. Relative sea-level rise on the downthrown sides is apparently exceeding rates of marsh vertical accretion.

Status of Wetlands and Aquatic Habitats, Strandplain-Chenier System, 2004

As mentioned previously, the strandplain-chenier system contains the most extensive contiguous marshland along the Texas Gulf Coast. Major estuarine habitats in the study area include salt and brackish marshes, and open water. Palustine marshes are limited (Fig. 33-34). Most of the fresh-water marshes apparently occur inland of the Gulf Intracoastal Waterway (Personal Communication, 2006, Dean Bossert, McFaddin NW Refuge Manager).

Uplands are next in areal extent (Fig. 33).The primary habitat mapped in the marine system is the Gulf beach, which consists of a topographically lower forebeach and a higher, less frequently flooded backbeach.

In 2004, wetland and aquatic habitats were dominated by estuarine marshes, with a total area of 33,689 ha, followed by estuarine open water and flats totaling 6,866 ha, and palustrine marshes at 511 ha (Fig. 33, Table 3). Palustrine flats and water bodies had a total area of 150 ha, and wetland scrub/shrub wetlands 8 ha. Along the Gulf shoreline, the area of mapped beaches totaled 229 ha. Lacustrine habitats, consisting in part of impounded water and Star Lake, had a total area of 390 ha.

Estuarine System

Marshes (Estuarine Intertidal Emergent Wetlands)

The estuarine intertidal emergent wetland habitat (E2EM) consists of 33,689 ha of salt and brackish marshes (Figs. 33 and 34). The irregularly flooded estuarine marsh, or high marsh, is most abundant at 30,972 ha (Tables 3 and 4). The regularly flooded estuarine marsh, or low marsh, covers 2,718 ha. The most extensive estuarine emergent wetlands (salt and brackish marshes) occur in the McFaddin National Wildlife Refuge (Fig. 25 and 34). The estuarine intertidal marsh habitat makes up about 75% of the study area, excluding the marine water (M1) map unit.

Tidal Flats (Estuarine Intertidal Unconsolidated Shores)

Estuarine intertidal unconsolidated shores (E2US) include wind-tidal flats, beaches, and algal flats. Approximately 17 ha of E2US was mapped in the study area (Table 3). Low, regularly flooded tidal flats are approximately equal in area to high flats. Because of the low astronomical tidal range, many flats are flooded only by wind-driven tides. These tidal habitats represent less than 1% of the intertidal wetland system (excluding subtidal habitats and the E1 and M1 map units). The mapped extent of the tidal flats can be affected by tidal levels at the time aerial photographs were taken. Accordingly, absolute areal extent of flats may vary from that determined using aerial photographs.

Aquatic Beds (Estuarine Subtidal Aquatic Beds)

Estuarine subtidal rooted vascular aquatic beds (E1AB3L) represent areas of submerged vascular vegetation, or seagrasses. Accurate delineation of seagrasses on aerial photographs is dependent on the season in which the photographs were taken and water turbidities, which can obscure seagrass areas. No seagrass areas were mapped in the strandplain-chenier system.

Open Water (Estuarine Subtidal Unconsolidated Bottom)

Estuarine subtidal unconsolidated bottom (E1UBL), or open water, includes water features across the strandplain system that are not completely isolated from wind tides and storm tides. A portion of the GIWW and Sabine Pass waters are included. The total area of estuarine open water is 6,848 ha, which is about 12% of all mapped habitats in the study area including uplands.

Table 3. Areal extent of mapped wetland and aquatic habitats in the strandplain-chenier.

NWI Code	*National Wetlands Inventory Description*	*Hectares*	*Acres*	*Percent*
E1AB3	Estuarine Subtidal Aquatic Bed, Rooted Vascular	0.0	0	0
E1AB4	Estuarine Subtidal Aquatic Bed, Floating Vascular	103.7	256	0.19
E1UB	Estuarine Subtidal Unconsolidated Bottom	6,744.6	16,652	12.30
E2EM1N	Estuarine Intertidal Emergent Wetland, Regularly Flooded	2,718	6,711	4.96
E2EM1P	Estuarine Intertidal Emergent Wetland, Irregularly Flooded	30,971.9	76,470	56.49
E2SS	Estuarine Intertidal Scrub/Shrub	5.2	13	0.01
E2USN	Estuarine Intertidal Flat, Regularly Flooded	8.6	21	0.02
E2USP	Estuarine Intertidal Flat, Irregularly Flooded	8.8	22	0.02
Subtotal		**40,650.8**	**100,145**	**74.14**
L1UBH	Lacustrine Littoral Aquatic Bed, Unknown Submergent	389.6	962	0.71
Subtotal		**389.6**	**962**	**0.71**
M1UB	Marine Subtidal Unconsolidated Bottom	9,644.5	23,812	17.59
M2USN	Marine Intertidal Unconsolidated Shore, Regularly Flooded	123.4	305	0.23
M2USP	Marine Intertidal Unconsolidated Shore, Irregularly Flooded	105.7	261	0.19
Subtotal		**9873.6**	**24,378**	**18.01**
PAB4F	Palustrine Aquatic Bed, Floating Vascular, Semi-Permanently flooded	7.8	19	0.01
PEM1A	Palustrine Emergent Wetland, Temporarily Flooded	128.3	317	0.23
PEM1C	Palustrine Emergent Wetland, Seasonally Flooded	190.5	470	0.35
PEM1F	Palustrine Emergent Wetland, Semi-Permanently Flooded	38.2	94	0.07
PEM1K	Palustrine Emergent Wetland, Artificially Flooded	151.1	373	0.28
PSS1A	Palustrine Scrub/Shrub Wetland	3.2	8	0.01
PUB	Palustrine Unconsolidated Bottom	7.1	18	0.01
PUBC	Palustrine Unconsolidated Bottom, Seasonally Flooded	4.6	11	0.01
PUBF	Palustrine Unconsolidated Bottom, Semi-Permanently Flooded	1.9	5	0.00
PUBH	Palustrine Unconsolidated Bottom, Permanently Flooded	72.3	179	0.13
PUBK	Palustrine Unconsolidated Bottom, Artificially Flooded	32.3	80	0.06
PUS	Palustrine Unconsolidated Shore	2.2	5	0.00
PUSC	Palustrine Unconsolidated Shore, Seasonally Flooded	0.7	2	0.00
PUSK	Palustrine Unconsolidated Shore, Artificially Flooded	21.0	52	0.04
Subtotal		**661.2**	**1,633**	**1.21**
U	Upland	3,345.6	8,260	6.10
Total		**54,830.8**	**135,377**	**100.00**

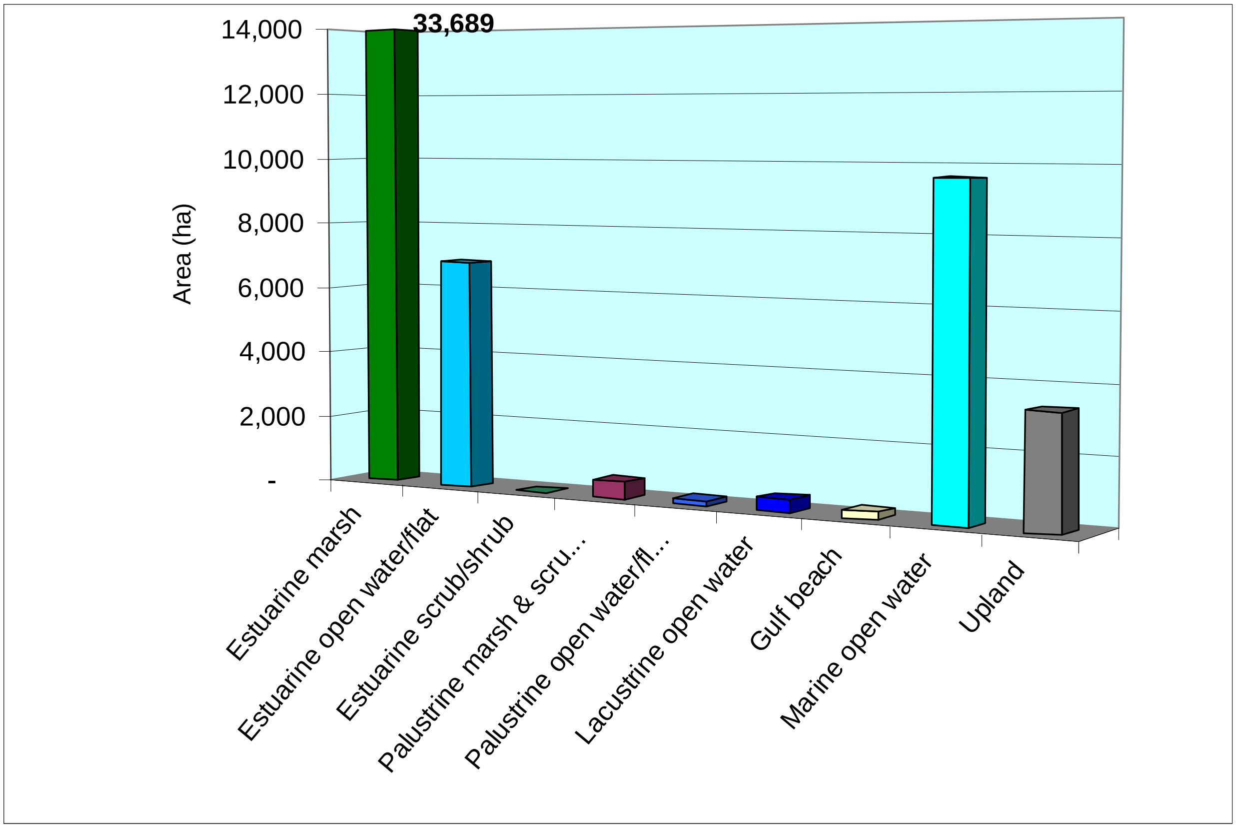


Figure 33. Areal distribution of selected habitats in the upper Texas coast study area in 2004.

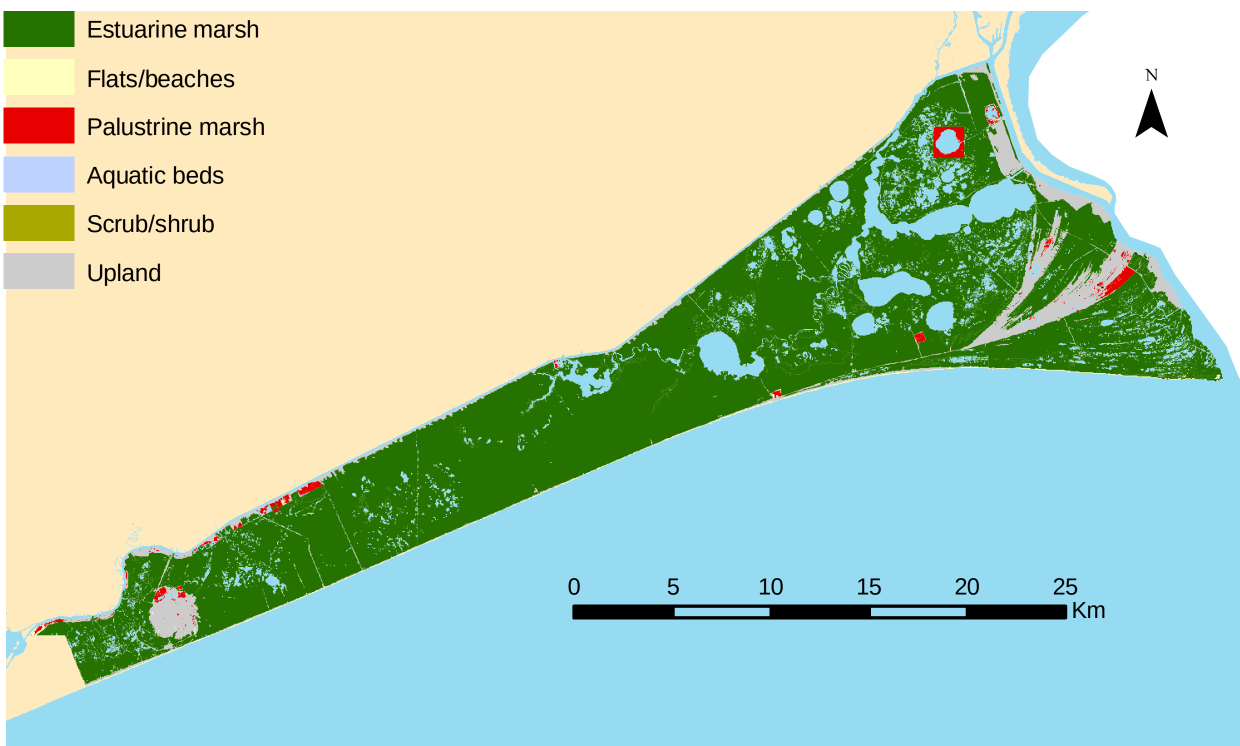


Figure 34. Distribution of major habitats in 2004 in the upper coast study area.

Table 4. Areal extent (ha) of selected habitats for the strandplain-chenier system, 2004.

Habitat	Area (ha)
Estuarine marsh	33,689
Estuarine open water/flat	6,866
Estuarine scrub/shrub	5
Palustrine marsh & scrub/shrub	511
Palustrine open water/flat/aquatic bed	150
Lacustrine open water	390
Gulf beach	229
Marine open water	9,645
Upland	3,346

Oyster Reefs (Estuarine Reefs)

Only those oyster reefs (E2RF2M) that were near the water's surface and were clearly visible were mapped. None were large enough or visible enough to map in the study areas.

Palustrine System

Marshes (Palustrine Emergent Wetlands)

Palustrine emergent wetlands (PEM), or isolated "freshwater marshes," cover 511 ha (including scrub/shrub wetlands) (Fig. 33; Table 4) and represent only 1.5% of emergent vegetated wetlands (EM + SS). Typically, palustrine marshes were classified into one of four water regimes: (1) temporarily flooded, (2) seasonally flooded, (3) semi-permanently flooded, and (4) artificially flooded.

Open Water and Flat (Palustrine Unconsolidated Bottom and Shore)

Palustrine unconsolidated bottom (PUB), or open water, and palustrine unconsolidated shore (PUS), or flat, habitats are generally small-fresh to brackish water ponds and flats. The total mapped area of these habitats was only 110 ha, almost 60% of which were flats in artificially flooded dredged material disposal areas (Table 3).

Marine System

Gulf Beach and Open Water (Marine Intertidal Unconsolidated Shore and Subtidal Unconsolidated Bottom)

The Gulf beach represents the marine intertidal unconsolidated shore (M2US). Two components were mapped; the topographically lower, regularly flooded fore beach and irregularly flooded backbeach (Fig. 14). The total area of this habitat in the study area is 229 ha. A buffer zone approximately 1.5 km wide of marine subtidal unconsolidated bottom (M1UB), or marine open water was included along the Gulf shoreline, primarily to standardize the size of the map area for each time period analyzed. The area of marine water included in this strip was about 9,645 ha.

Historical Trends in Wetland and Aquatic Habitats, Strandplain-Chenier System

In analyzing trends, broad wetland classes were emphasized over water regimes and special modifiers because habitats were mapped only down to class on 1956 photographs. In addition, interpretation of the distribution of estuarine and palustrine systems varied from year to year. Estuarine marshes are by far the dominant class of emergent wetlands on the upper coast study area, thus for simplification and to reduce apparent changes due to interpretation, we combined the emergent wetland classes in the trend analysis. In addition, because the areal extent of tidal flats and estuarine water vary with tidal conditions, we combined water and flats into a single unit for analysis of trends. This was partly because flats interpreted and mapped in 1979/83 were so much more extensive than in 1956 and 2004. Tide levels at the time the photos were taken may have contributed to this difference in mapped tidal flats. As noted previously, there is a cumulative error that arises from interpreting and delineating wetlands on aerial photographs, transferring delineations to base maps, and georeferencing the different vintages of maps to a common base for comparison. Accordingly, we have more confidence in direction of trends than in absolute magnitudes.

General Trends

Analysis of trends in wetlands and aquatic habitats in the strandplain-chenier system shows that there was a net decline in marshes from 1956 to 2003/04. The total area of estuarine marshes decreased from 37,827 ha in 1956 to 34,254 ha in 1979, and 33,689 ha in 2004 (Figs. 35-36).

From 1956 through 2004, within the strandplain-chenier study area, emergent wetlands (marshes) decreased from about 38,000 ha to 34,200 ha, a loss of approximately 3,800 ha (Fig. 37, Table 5). Most of the loss (68%) occurred during the earlier period (1956-1979/83). The rate of marsh loss from1956 to 1981 (the year 1981 is used as the average for 1979 and 1983) was about 115 ha/yr and from 1981 to 2004, about 40 ha/yr. In contrast to the loss of marsh was a gain in total estuarine and marine open water. The gain in open water was approximately 3,800 ha, which is equivalent to the loss in marsh. The rates of gain in water were about 138 ha/yr during the earlier period, and 16 ha/yr during the later period. The area of Gulf beaches decreased slightly through time, from 318 ha in 1956 to 229 ha in 2004. Uplands increased in area from 3,260 ha in1956 to 3,346 ha in 2004, a gain of about 86 ha.

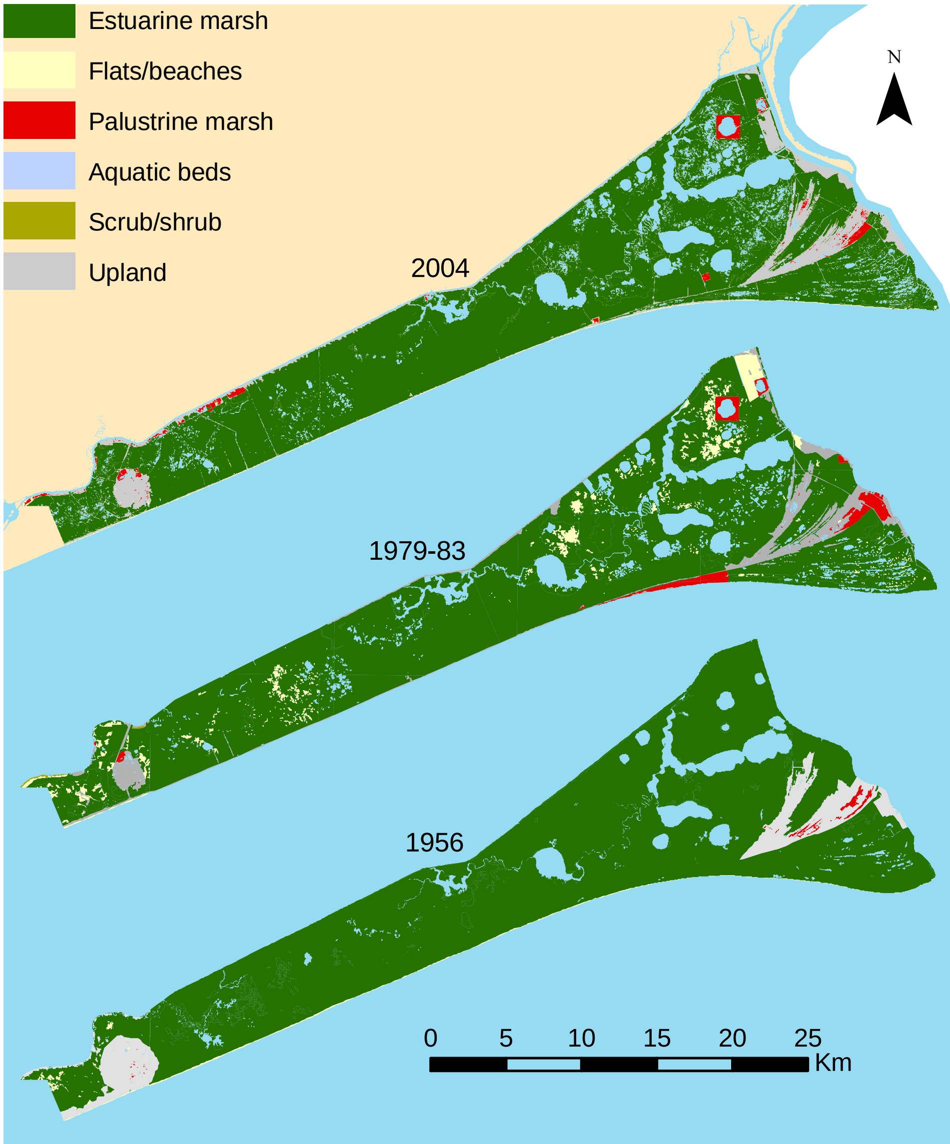


Figure 35. Map showing distribution of major wetland and aquatic habitats in 2004, 1979/83, and 1956 in the upper coast study area.

Table 5.Total area of major habitats in1956, 1979/83, and 2004 in upper coast study area.

	1956	*1979/83*	*2004*
Emergent wetlands	37,999	35,117	34,206
Open water and flats	4,468	7,774	7,406
Marine water	8,771	8,918	9,645
Gulf beach	318	307	229
Uplands	3,260	2,731	3,346

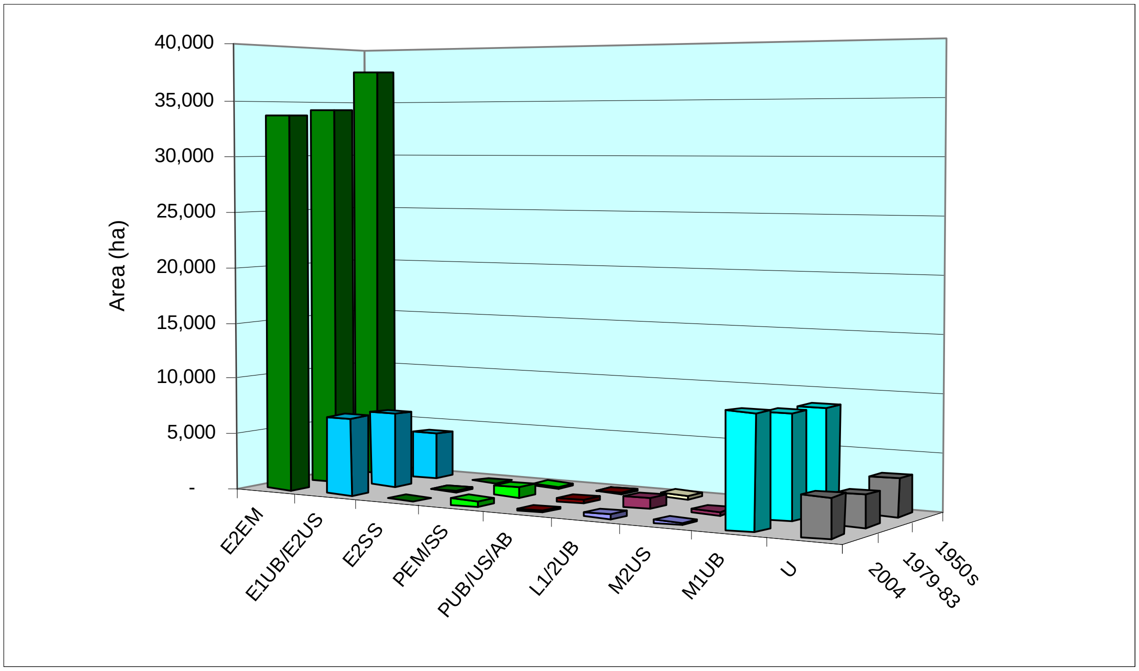


Figure 36. Areal distribution of habitats in the strandplain-chenier system study area in 1956, 1979/83, and 2004.

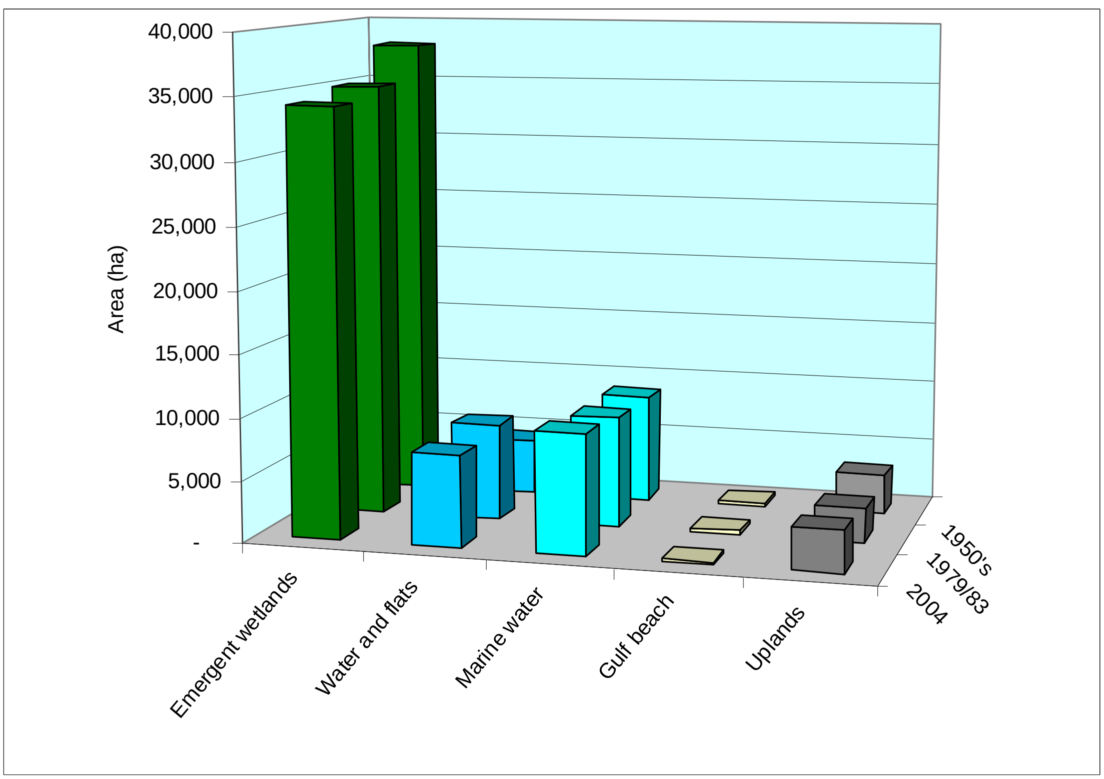


Figure 37. Areal distribution of major habitats in the study area in 1956, 1979/83, and 2004, strandplain-chenier system. Emergent wetlands include estuarine and palustrine marshes and scrub/shrub assemblages.

Probable Causes of Trends

An analysis of habitat changes along the upper Texas coast shows a systematic decline in marshes from 1956 to 2004 (Fig. 37). Overlay analysis of the 1956 and 2004 maps to identify the cause of the changes, shows that about 65% was due to conversion of marsh to open water, primarily estuarine open water (54%), and a smaller amount to marine open water (11%). The increase in estuarine open water since 1956 was in part because of dryer conditions in 1956. There was a severe drought in Texas that peaked in 1956 (Riggio et al. 1987). The drought apparently affected the extent of open water in the marshes on1956 maps. However, the Texas Parks and Wildlife Department (German et al. 2002), using aerial photographs taken in 1953 before the drought, also mapped few areas of open water in the marshes during this period.

Part of the expansion of open water since 1956 was due to subsidence and relative sea-level rise. In several areas, subsidence occurred along active surface faults. The faults contributed to an increase in water in the marshes on the downthrown sides of the faults (Fig. 38- 41). Evidence that the faults are active is illustrated by a fault near Clam Lake that could not be seen on photographs taken in 1956 but was easily traceable on more recent photographs (Figs. 38 and 39).

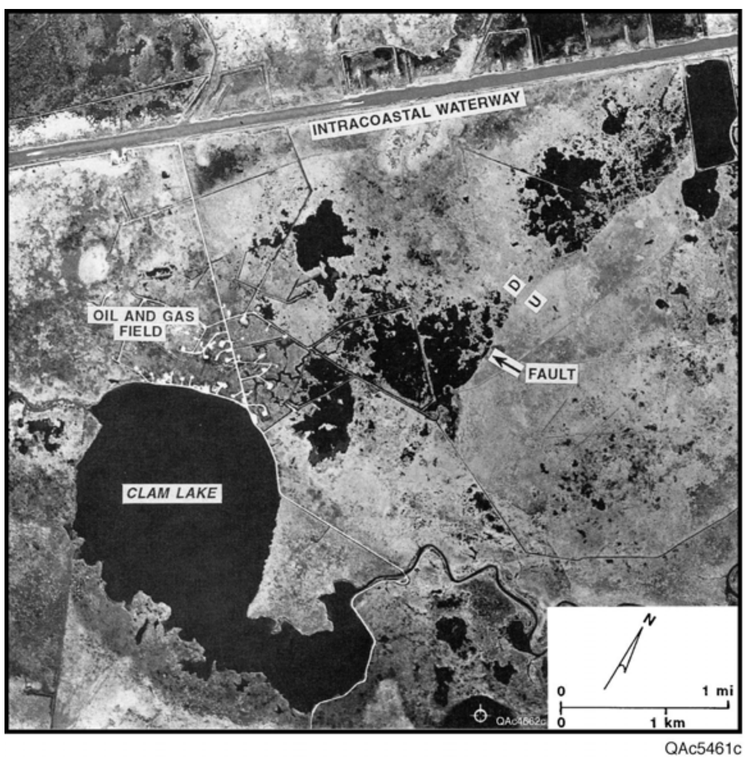


Figure 38. Fault near Clam Lake downthrown toward the oil and gas field. Dark areas of open water increase on the downthrown side (D) of the fault relative to the upthrown side (U). This photograph was taken by NASA in 1989. The fault could not be seen on photographs taken in 1956. (From White and Tremblay, 1995).

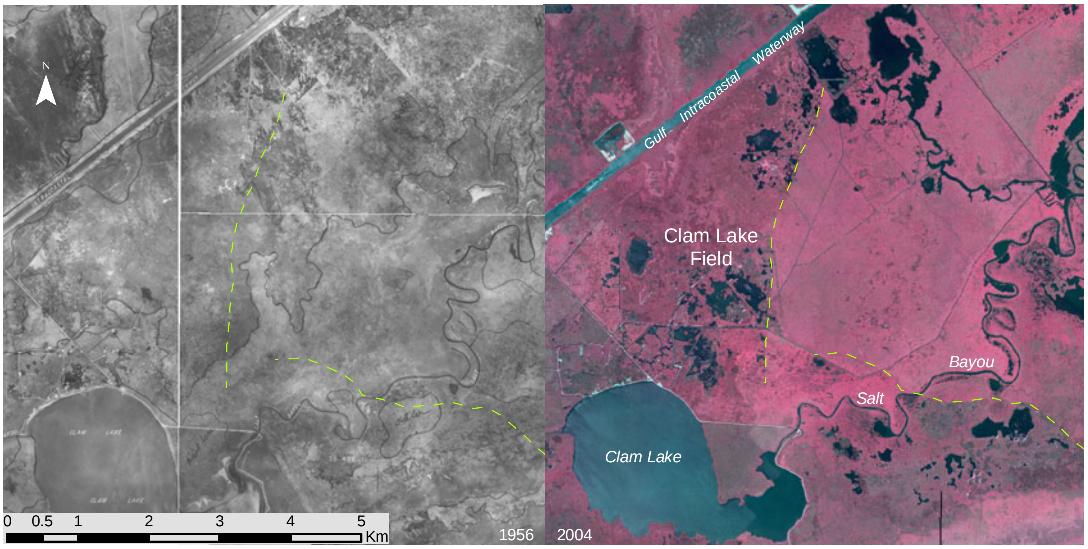


Figure 39. Faults that were not visible on 1956 photograph (on left) are very visible on photograph taken in 2004 (on right). Location of faults are shown by dashed green lines. The impact of the faults on the marsh is apparent on the more recent photographs.

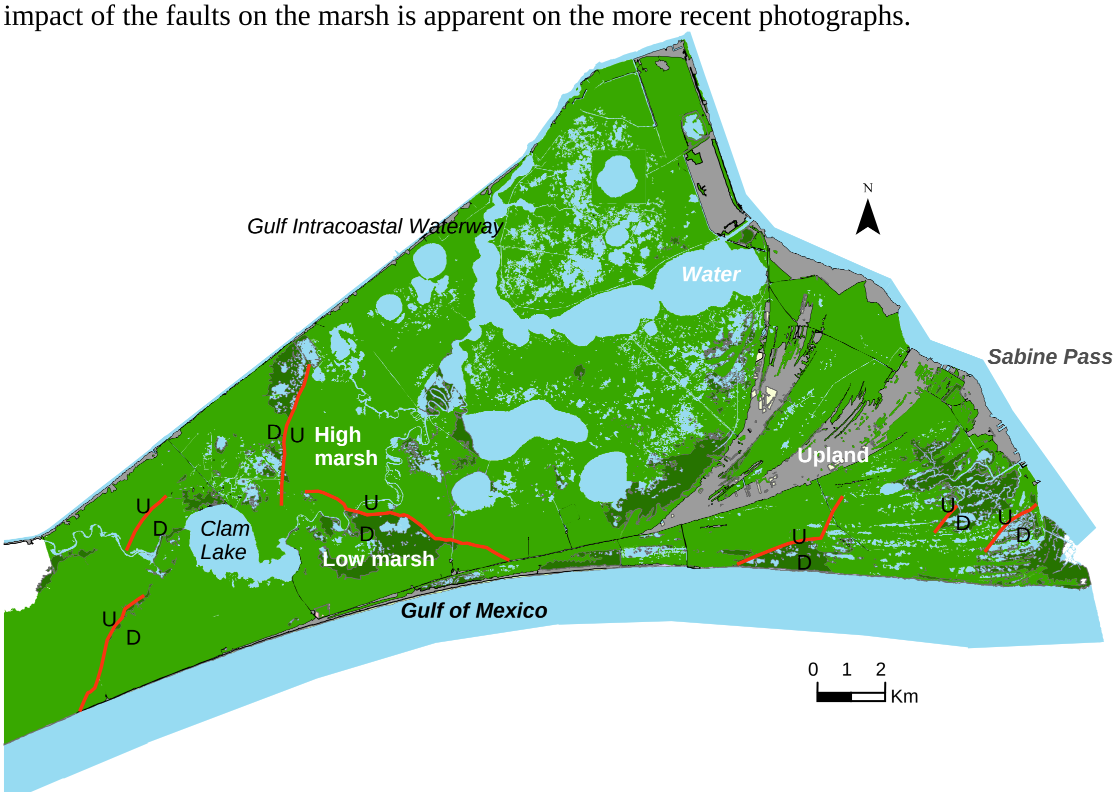


Figure 40. Wetland map of upper coast showing marshes affected by active faults (in red) from Sabine Pass to Clam Lake.

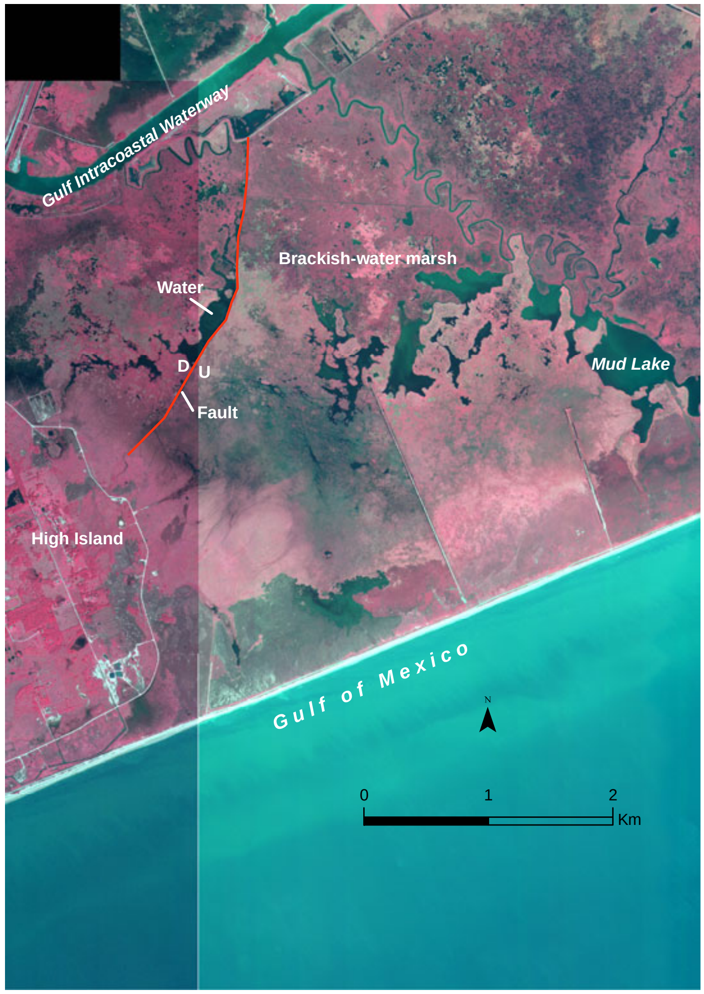


Figure 41. Radial fault intersecting High Island salt dome and brackish-water marshes in the upper coast study area. Note water feature that has developed on the downthrown (D) side of the fault on this 2004 aerial photograph. Although the fault is visible on photographs taken in 1956, water had not yet ponded on the downthrown side suggesting that the fault is active.

There is evidence that the fault has been activated by oil and gas production at the Clam Lake field (White and Morton, 1997; Morton et al. 2001 a,b). Several faults crossing marshes have been mapped along the upper coast (Figs. 32 and 40). Marsh losses have occurred on the downthrown sides of the faults where subsidence has promoted flooding and erosion of the marshes. The rate of subsidence and relative sea-level rise on the downside of the faults apparently has exceeded the rate of marsh vertical accretion, and the marsh has been replaced primarily by open water.

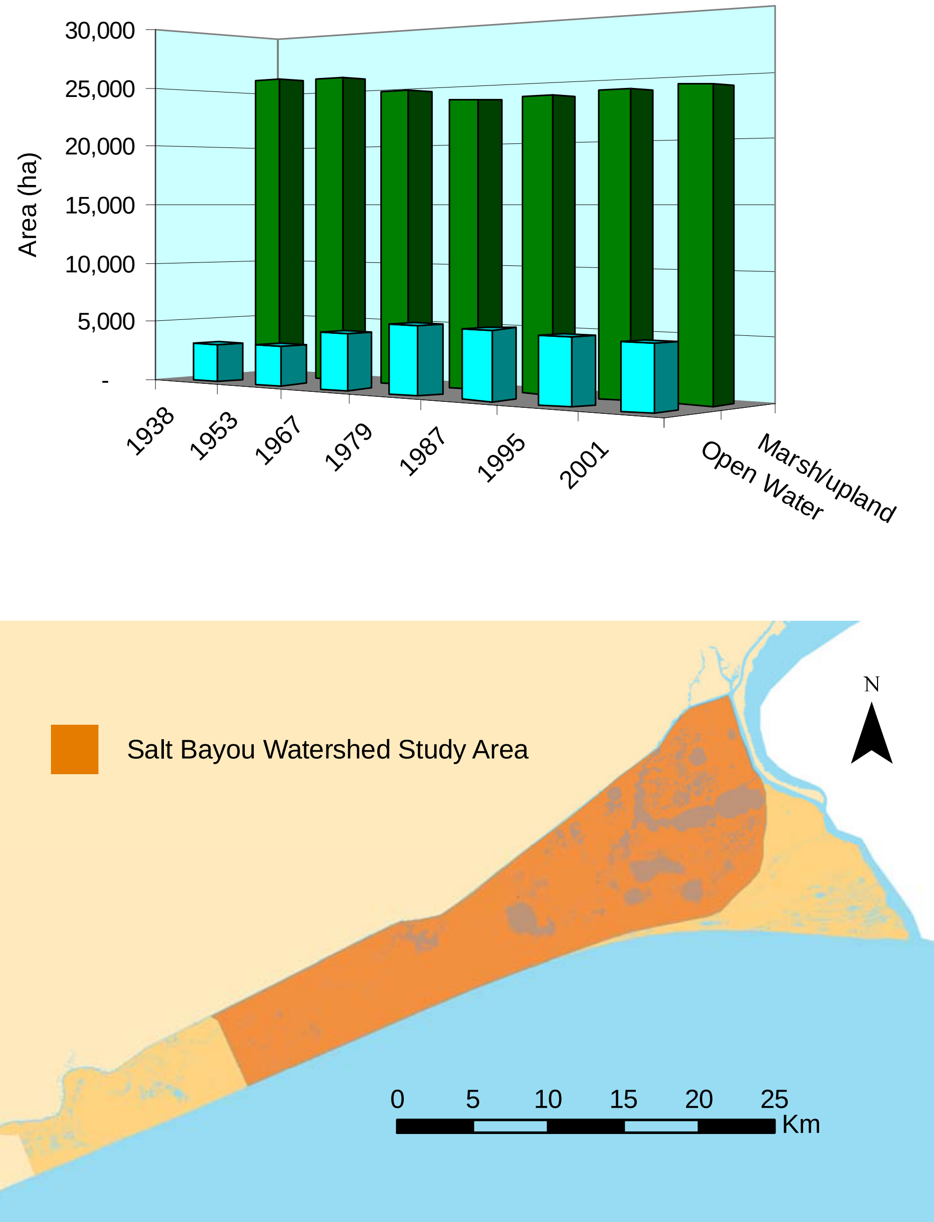


Figure 42. Relationship between open water and marsh/upland from 1938 to 2001 in the Salt Bayou watershed study area as determined by the Texas Parks and Wildlife Department (From German, et al. 2002).

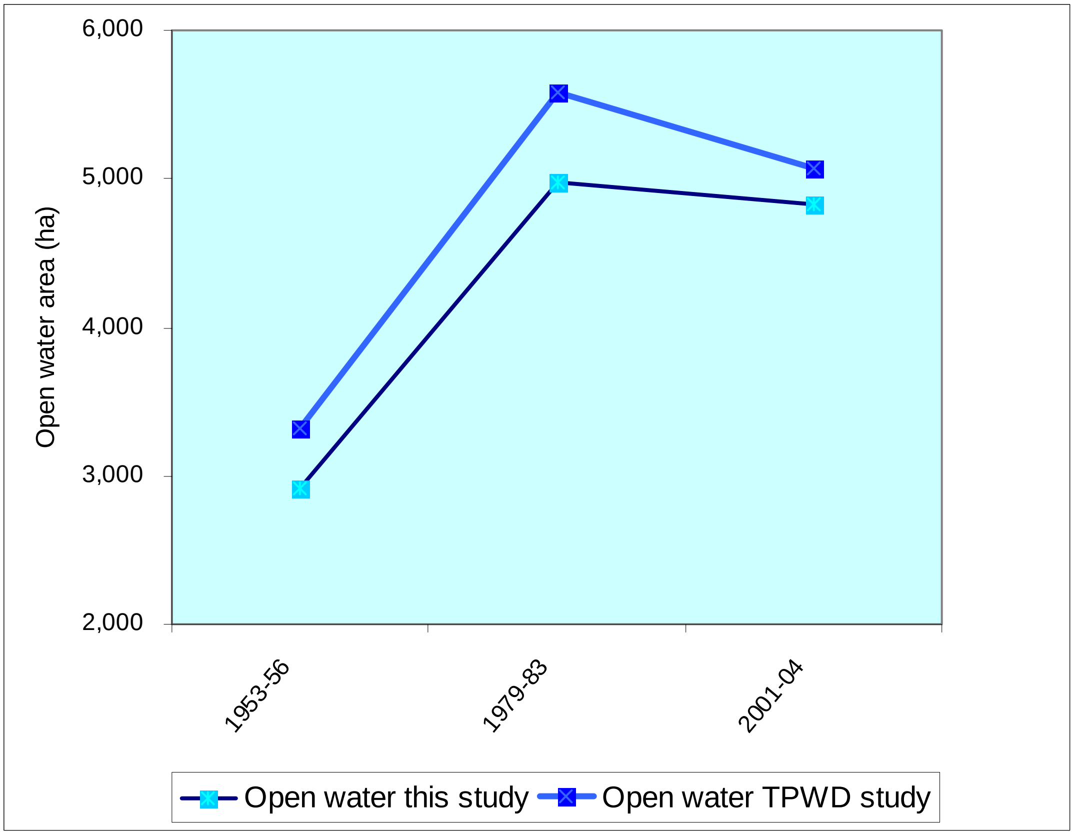


Figure 43. Comparison of trends in open water through time as mapped in this study and by German et al (2002) in the Salt Bayou watershed study area as defined in Figure 42.

Relative sea-level has also apparently contributed to expansion of open water in areas where there are no visible faults (Figs. 42-45). This has occurred in the area of Keith Lake (Fig. 44), for example, where marshes in the mid-1950's were eventually replaced by open water. Although the 1956 drought may have lowered water levels in the marshes, therefore, reducing the extent of open water areas, German et al. 2002, using photographs taken in 1953 before the drought also mapped few open water areas during that year (Fig. 42). Water areas increased in later years as documented in this and German et al. studies (Fig. 43). There was a slight decline in the expansion of open water after 1979/83.

Conversion of marsh to open water southwest of High Island was in large part due to roads and levees constructed across the marshes to gain access to oil and gas well sites and to prevent flooding in some areas (Fig. 45). Ponded water can submerge and kill marsh grass. Additional losses in salt marsh occurred as a result of erosion along the Gulf shoreline (Figs. 46 and 47). Near Sabine Pass, erosion has been especially severe, with rates as high as17 ha/yr. From 1956 to 2004, marsh along this shore was replaced by open marine water as the shoreline retreated landward.

Part of the marsh loss since 1956, approximately 24% of the loss, was due to conversion of marshes to uplands. For example, marsh loss occurred along the ship channel at Sabine Pass as material derived from maintenance dredging was deposited along the channel creating uplands. Uplands can be seen along the channel in Figure 35. Around High Island salt dome, however, some areas mapped as uplands in 1956 were converted to marshes by 1979/83 and 2004 (Fig 35).

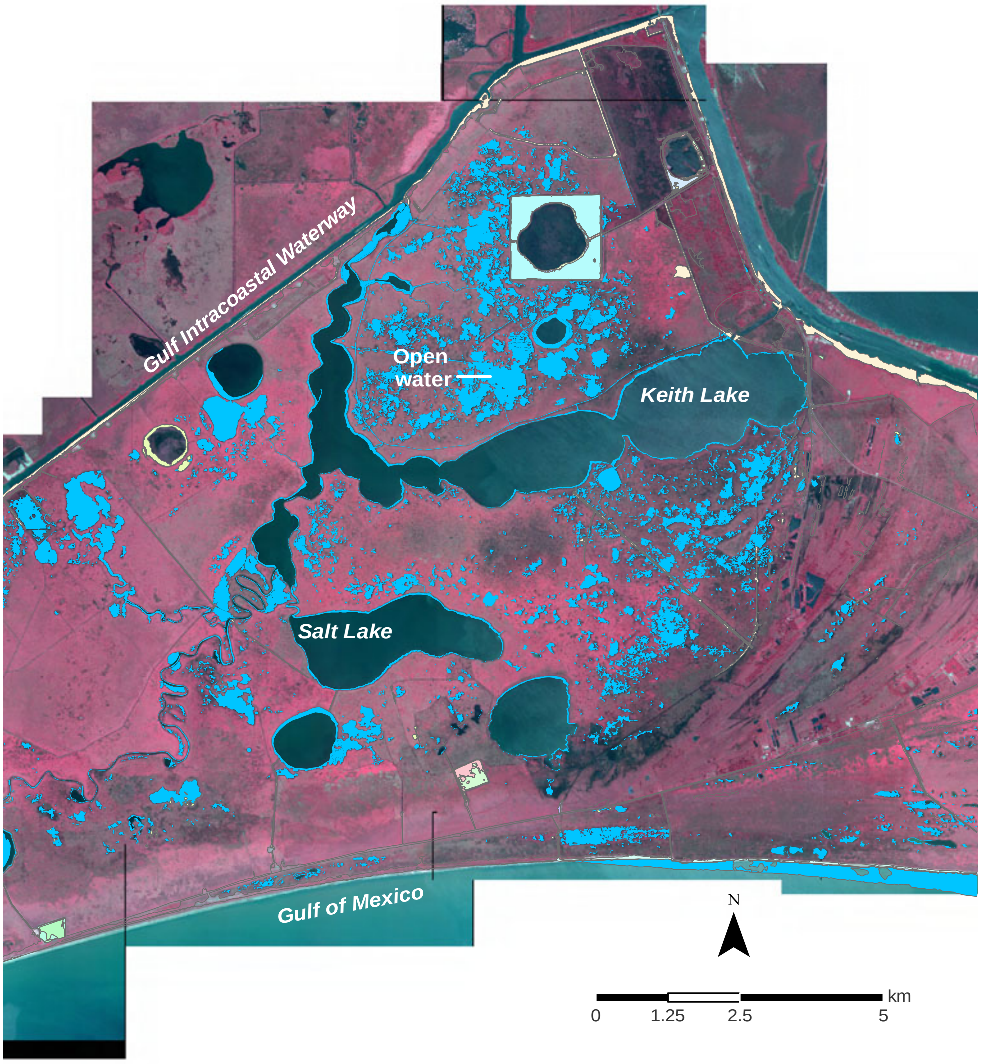
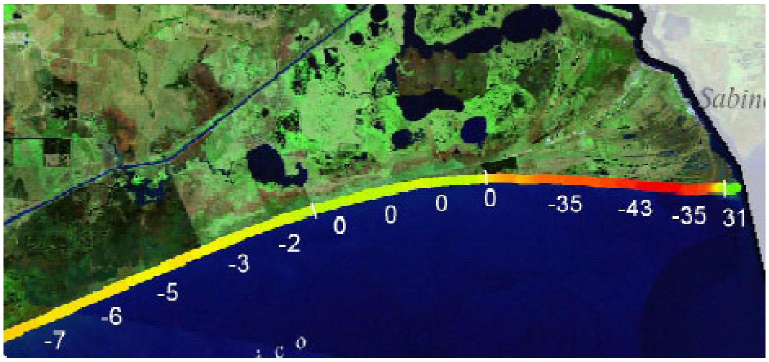


Figure 44. Expansion of open water into marsh areas from 1956 to 2004 in the strandplain-chenier system, upper Texas coast. Open water, blue areas, displaced marshes during this period. The expansion of water since the mid-1950's is in agreement with findings by the Texas Parks and Wildlife Department (German et al. 2002).

Figure 45. Example of water ponded by roads and levees southwest of High Island. Aerial photograph was taken in 2004.

(a)



(b)

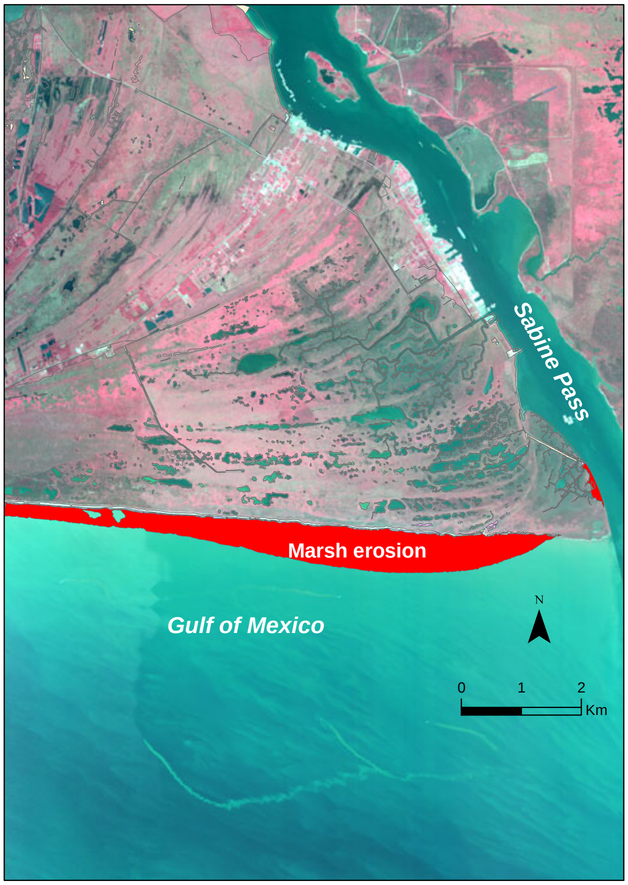


Figure 46. Marsh erosion near Sabine Pass. (a) Erosion rates (ft/yr) from Gibeaut et al., 2000. (b) Approximate area of marsh loss by erosion from 1956 to 2004.

Figure 47. Evidence of Gulf shoreline erosion along the strandplain-chenier system. Photo, taken in October 2006, shows remnants of Highway 87 approximately 6.5 km northeast of High Island.

PADRE ISLAND NATIONAL SEASHORE (PINS)

Study Area

Padre Island National Seashore, the South Texas study area (Fig. 2), is a barrier island that separates the Gulf of Mexico from Laguna Madre. The barrier is characterized by broad beaches, fore-island dunes, vegetation stabilized dunes, active dune fields, expansive wind-tidal flats, hurricane wash-over channels, and salt-, brackish, and fresh-water ponds and marshes. The study area extends southward to Mansfield Channel, and landward to the Gulf Intracoastal Waterway.

General Setting of Padre Island National Seashore

Unlike estuaries of the central and upper Texas coast, where rivers discharge into bays forming typical estuaries diluted by fresh water inflows, Laguna Madre has no major rivers discharging into it. That fact, coupled with the fact that this area receives the least amount of precipitation of all areas along the Texas coast (average annual precipitation in Willacy County is about 70 cm and in Cameron County 68 cm) (Texas Almanac, 2000-2001) contribute to high salinities in Laguna Madre. Salinities at the southern end of Laguna Madre typically range from 23-36 parts per thousand (ppt) and are influenced by exchange of Gulf water through Brazos Santiago Pass (White et al., 1986). In the southern part of the PINS study area near Mansfield Channel, salinities typically range from 20 to 40 ppt and average about 38 ppt.

In addition to high salinity regimes, climate strongly dictates the relative importance of many significant geological processes. Among them, are the direction and intensity of persistent winds that control the movement of wave trains approaching shore and the resulting direction of long shore currents and sediment transport. Geologically, Padre Island developed initially as a spit extending from the eroding, relict Rio Grande Holocene-Modern deltaic system that has been retreating for hundreds of years (Brown et al., 1980).

Padre Island National Seashore is situated in a zone of longshore convergence and has historically experienced both erosion and accretion. In general, the Gulf shoreline in the northern half of the Seashore has been accreting through time. Rates of net accretion ranged from 0.8-5.2 m/yr (2.6-16.9 ft/yr). In contrast to shorelines along the northern half of PINS, shorelines retreated through time in the southern half of the Seashore. Shorelines eroded at average rates of between 1.2-2.4 m/yr (4-8 ft/yr) (Paine and Morton, 1989).

Prominent features on PINS are shown in the profile in Figure 48. Not shown, however, are the numerous hurricane washover channels through which hurricane surge waters flow, scouring channels and depositing sediments in washover fans on the lagoonward tidal flats. The dry climate and storm washovers lead to vegetation fragmentation and blowouts that are the sources of active dunes that migrate landward. Left behind, the migrating dunes are deflation flats and troughs that are topographic lows in which higher moisture levels support marsh vegetation such as *Schoenoplectus pungens*. In contrast to deflation that can create depressions for marsh development, migrating active dunes can fill the depressions and cover the vegetation. Low amounts of rainfall in this area produce

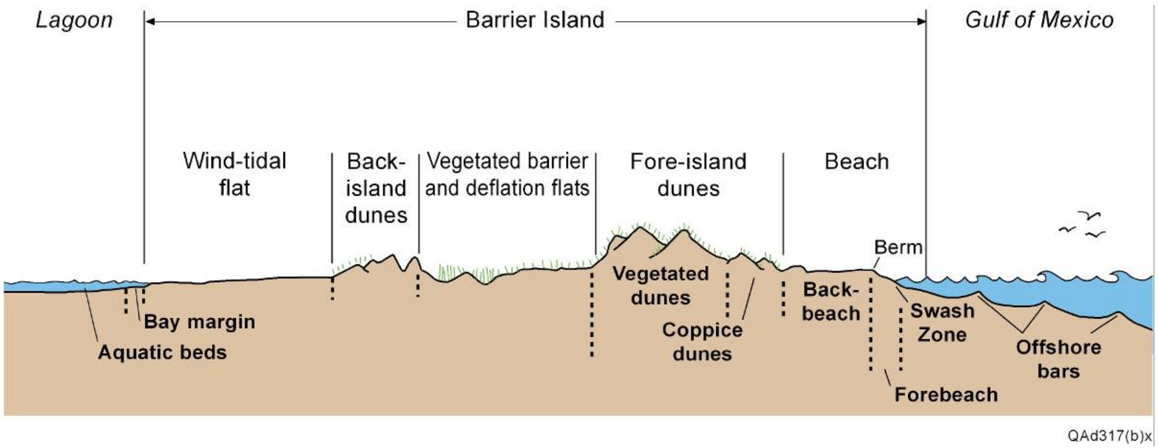


Figure 48. Generalized barrier island profile illustrating prominent features.

higher lagoon salinities that inhibit the growth of some marshes, like broad stands of *Spartina alterniflora* that are typical in the central and upper Texas coast. In this semi-arid climate, the most extensive habitats are broad wind-tidal flats (Fig. 16). Astronomical tides on the Gulf shore are about 0.4 m and in lower Laguna Madre about 0.3 m (Diener, 1975). The range in tides caused by persistent winds, however, can be much higher than the astronomical tides, flooding much broader flats. The numerous storm washover channels that become active during hurricanes and tropical storms, are closed between storms by sediments transported along shore. The scoured channels pond water and support marshes along their margins.

Relative Sea-Level Rise

Relative sea-level rise (RSLR) is another important process affecting wetland and aquatic habitats. Along the Texas coast, both processes, eustatic sea-level rise and subsidence, are part of the RSLR equation. Subsidence, especially associated with withdrawal of groundwater and oil and gas, is the overriding component (White and Morton, 1997). 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). Relative sea-level rise in South Texas (Port Isabel) averaged 3.38 mm/yr from 1944 to 1999 (NOAA, NOS). High rates of RSLR can cause changes in habitats, such as estuarine marshes and wind-tidal flats (White et al. 1998). The Port Isabel tide gauge shows that RSLR rates are lower along the South Texas Gulf Coast than the middle or upper coast. Still, this lower RSLR rate can have an impact through time, as discussed in the sections on probable cause of habitat trends.

Status of wetlands and Aquatic Habitats, Padre Island National Seashore, 2003/04.

In 2003/04, wetland, aquatic, and upland habitats covered 95,175 ha within the PINS study area. This area includes the Laguna Madre and Land Cut area between the Seashore boundary and the Gulf Intracoastal Waterway (GIWW). Approximately 20,681 ha within the study area was classified as uplands. Of the four wetland systems mapped, the estuarine system is the largest. The largest habitats are the wind-tidal and algal-flat classes, together covering 35,356 ha (Figs. 49 and 50; Table 6). Emergent vegetated wetlands (E2EM, E2SS, PEM) cover 3,930 ha, about 63% of which is palustrine marsh. Another important habitat is seagrass (E1AB3), which in the study area has an area of almost 14,572 ha. The extent of all mapped wetlands, deepwater habitats, and uplands for each year is presented in the appendix. Field site locations visited during this study are shown in Figure 51.

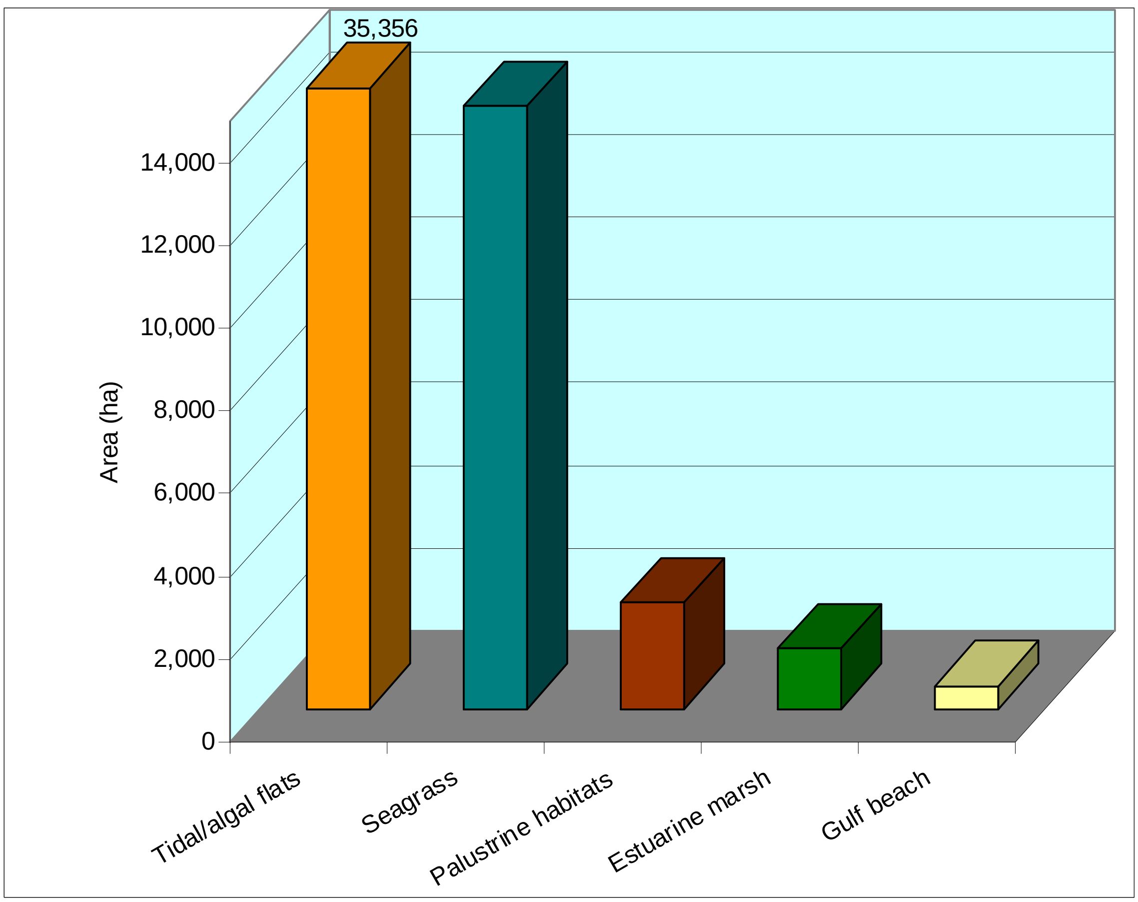


Figure 49. Areal extent of selected habitats in PINS study area in 2003/04.

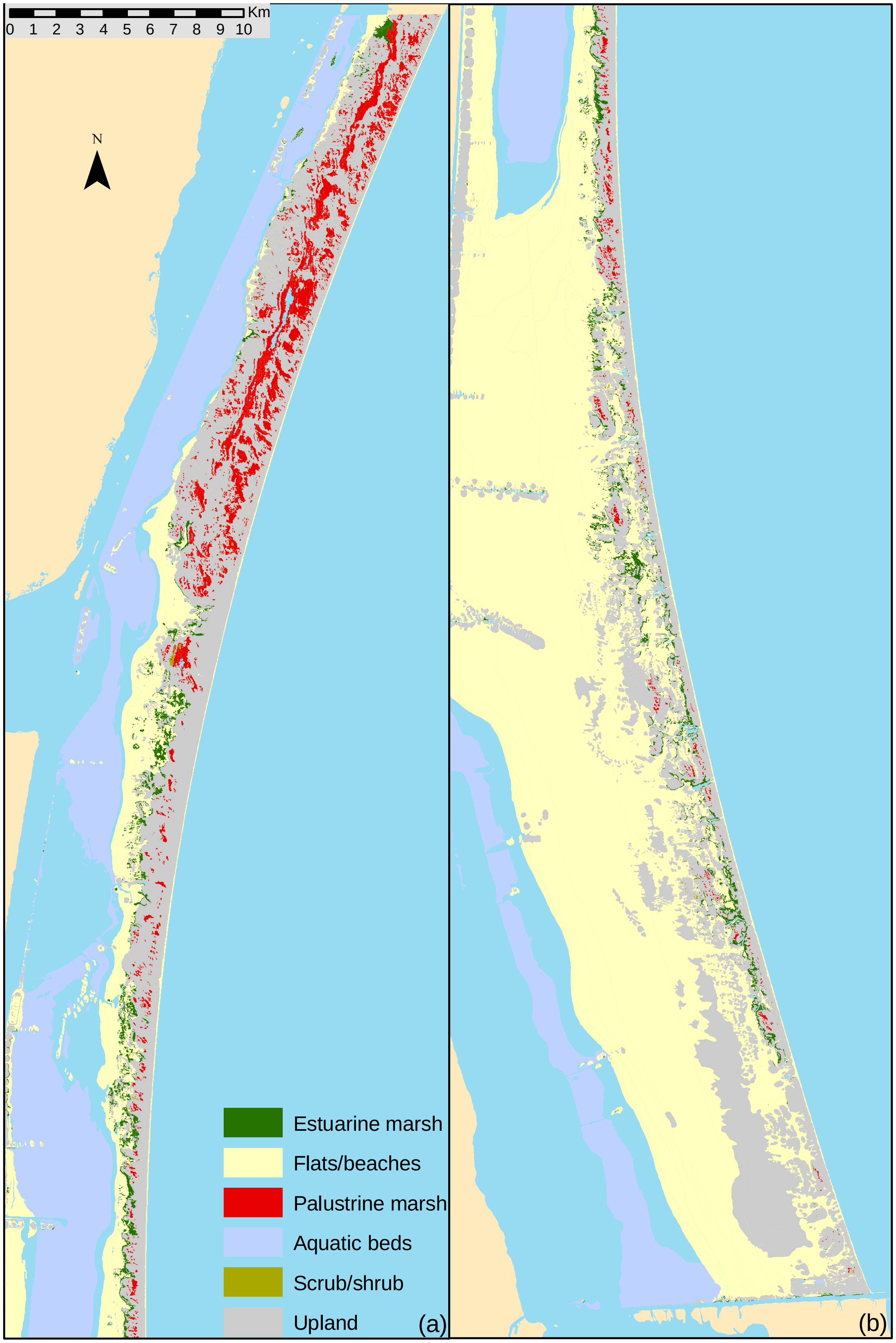


Figure 50. Map of habitats in 2003/04 for the Padre Island National Seashore study area. North part of PINS shown in (a) and south part of PINS shown in (b).

Table 6. Areal extent of mapped wetland and aquatic habitats in 2003/04, and percentage that each habitat represents in the study area.

NWI Code	National Wetlands Inventory Description	Hectares	Acres	%
E1AB3	Estuarine Subtidal Aquatic Bed, Seagrasses	14,573	35,995	15.31
E1AB5	Estuarine Subtidal Aquatic Bed, Algae or Unknown	10	25	0.01
E1UB	Estuarine Subtidal Unconsolidated Bottom	13,743	33,945	14.44
E2AB1N	Estuarine Intertidal Aquatic bed, Reg. Flooded	1,692	4,179	1.78
E2AB1P	Estuarine Intertidal Aquatic bed, Irr. Flooded	10,698	26,425	11.24
E2EM1N	Estuarine Intertidal Emergent , Reg. Flooded	358	884	0.38
E2EM1P	Estuarine Intertidal Emergent, Irr. Flooded	1,103	2,724	1.16
E2SS	Estuarine Intertidal Scrub Shrub	0.03	0	0.00
E2USM	Estuarine Intertidal Flat, Irregularly Exposed	378	934	0.40
E2USN	Estuarine Intertidal Flat, Regularly Flooded	3,372	8,330	3.54
E2USP	Estuarine Intertidal Flat, Irregularly Flooded	19,215	47,462	20.19
Subtotal		65,143	160,903	68.45
L1UB	Lacustrine Unconsolidated Bottom	44	109	0.05
M1UB	Marine Subtidal Unconsolidated Bottom	6,169	15,238	6.48
M2RS2P	Marine Intertidal Rocky Shore	2	5	0.00
M2USP	Marine Intertidal Unconsolidated Shore	558	1,379	0.59
Subtotal		6,730	16,623	7.07
PAB1	Palustrine Aquatic Bed, Algae	22	55	0.02
PEM1A	Palustrine Emergent Wetland , Temp. Flooded	747	1,845	0.78
PEM1C	Palustrine Emergent Wetland , Seas. Flooded	1,051	2,596	1.10
PEM1F	Palustrine Emergent , Semi-Perm. Flooded	656	1,620	0.69
PEM1K	Palustrine Emergent Wetland , Artificially Flooded	16	40	0.02
PSS	Palustrine Scrub Shrub	1	2	0.00
PUB	Palustrine Unconsolidated Bottom	29	71	0.03
PUBK	Palustrine Unconsolidated Bottom, Art. Flooded	12	30	0.01
PUS	Palustrine Unconsolidated Shore	33	81	0.03
PUSKhs	Palustrine Unconsolidated Shore, Art. Flooded	10	24	0.01
Subtotal		2,577	6,364	2.71
U	Upland	20,681	51,082	21.73
Total		95,175	235,081	100.00

Figure 51. Index map of USGS 7.5'quadrangles covering PINS study area (a), and field site locations (b).

Estuarine System

Marshes (Estuarine Intertidal Emergent Wetlands)

The estuarine intertidal emergent wetland habitat (E2EM) consists of 1,461 ha of salt and brackish marshes. Unlike the central and upper coastal barriers, where the regularly flooded marshes are more abundant (White et al. 2002; 2004), irregularly flooded marshes are more abundant on these south Texas coastal barriers (Table 6). The irregularly flooded marshes cover 1,103 ha and the regularly flooded marshes only 358 ha. The most extensive estuarine emergent wetlands are in the central and south areas of the island. Locally, salt marsh assemblages fringe Laguna Madre.

Tidal and Algal Flats (Estuarine Intertidal Unconsolidated Shores and Aquatic Beds)

Estuarine intertidal unconsolidated shores (E2US) include tidal flats and lagoon beaches (Fig. 16). Estuarine intertidal aquatic beds (E2AB) are tidal flats in which blue-green algae have formed algal mats on the surface (Fig.16). Approximately 22,966 ha of E2US and 12,390 ha of E2AB were mapped in the study area (Figure 49; Table 6). Low, regularly flooded tidal flats are less extensive than high, irregularly flooded flats (Table 6). 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. 1980). A much larger area of high, irregularly flooded aquatic beds (flats with algal mats) were mapped than low, regularly flooded aquatic beds (Table 6). Together, tidal and algal flats, represent approximately 96% of the intertidal wetland system (excluding subtidal habitats and the E1 and M1 map units). The mapped extent of the tidal flats can be substantially affected by tidal levels at the time the aerial photographs were taken. Accordingly, absolute areal extent of flats may vary from that determined using aerial photographs.

Aquatic Beds (Estuarine Subtidal Aquatic Beds)

Estuarine subtidal, rooted, vascular aquatic beds (E1AB3L) represent areas of submerged, rooted, vascular vegetation, or seagrasses (Fig. 17). Accurate delineation of seagrasses on aerial photographs is dependent on the season in which the photographs were taken and water turbidities, which can obscure seagrass areas. Seagrasses are visible in most of the 2004 photographs but are obscured by turbidities in some areas. Densities of the mapped seagrass ranged from very dense to patchy. Within the study area, about 14,572 ha of seagrass beds was mapped. Seagrasses extend along most of PINS, outside the Land Cut.

Palustrine System

Marshes (Palustrine Emergent Wetlands)

Palustrine emergent wetlands (PEM), or inland, non-tidal "freshwater" marshes, cover 2,576 ha (Fig 49; Table 6), and represent 63% of emergent vegetated wetlands. The broadest distribution is in the north (Figs. 50 and Table 6). Much of the PEM in the north area occurs in a depression formed along the axis of the island (Fig. 22). Although brackish vegetation occurs in this area, it was mapped as palustrine because it is not connected to estuarine tidal flats. Palustrine marshes on PINS often occur in isolated depressions deflated by the wind or scoured by past storm washover events. These marshes typically were classified into one of three water regimes: (1) temporarily flooded, (2) seasonally flooded, or (3) semi-permanently flooded. Nearly 70% of palustrine marshes were mapped as either seasonally or semipermanently flooded, the wetter water regimes. This is due in part to exceptionally high amounts of precipitation in 2003.

Open water (Palustrine Unconsolidated Bottom)

Palustrine unconsolidated bottom (PUB), or open water, habitats are generally small fresh- to brackish-water ponds. The total mapped area of this habitat was only 41 ha, mostly in the north.

Marine System

Gulf Beach (Marine Intertidal Unconsolidated Shore) and Other Marine Classes

The Gulf beach represents marine intertidal unconsolidated shore (M2US). Only the topographically higher, irregularly flooded backbeach was mapped (Figs. 49 and 52). The total area of this habitat in the study area is 558 ha. A buffer zone of approximately 0.5 km wide of marine subtidal unconsolidated bottom (M1UB), or marine open water, was included along the Gulf shoreline, primarily to standardize the size of the map area for each time period analyzed. Also, mapped in the marine system are the jetties at Mansfield Channel. These features were mapped as marine intertidal rocky shore, rubble, irregularly flooded (M2RS2P), and have an area of about 2 ha.


Figure 52. Irregularly flooded backbeach (M2US).

Historical Trends in Wetlands and Aquatic Habitats, Padre Island National Seashore

General Trends

Padre Island National Seashore has experienced several changes in habitats through time. Initial analysis of trends in wetlands and aquatic habitats from the 1950's through 2003/04 shows that wind-tidal/algal flats increased from the 1950's (30,593 ha) to 1979 (30,927 ha) and again in 2003/04 (35,356 ha) (Figs. 53 and 54; Table 7). Further examination reveals that regional and local hydrologic conditions contributed to the apparent, but not real, increase of flats through time. Modifications to the data, based on supporting evidence, produce a trend towards loss (-5 %) of tidal flat through time. Seagrasses spread through time in PINS, having their largest distribution in 1979 (16,422 ha). The mid-1950's total of 2,167 ha increased to 14,572 ha by 2003/04. The Laguna Madre is a shallow water body with water depths ranging from 1 to 8 feet, averaging 3 feet. With these shallow depths, turbidity in the Laguna may have obscured seagrasses leading to a low amount of seagrass habitat reported in the mid-1950's. Palustrine habitats had their largest distribution of 2,576 ha in 2003/04, a gain of 25 % from the mid-1950's total of 2,062 ha. The smallest amount of palustrine marsh was mapped in 1979 (1,885 ha). The larger 2003/04 number is due in part to the high amount of

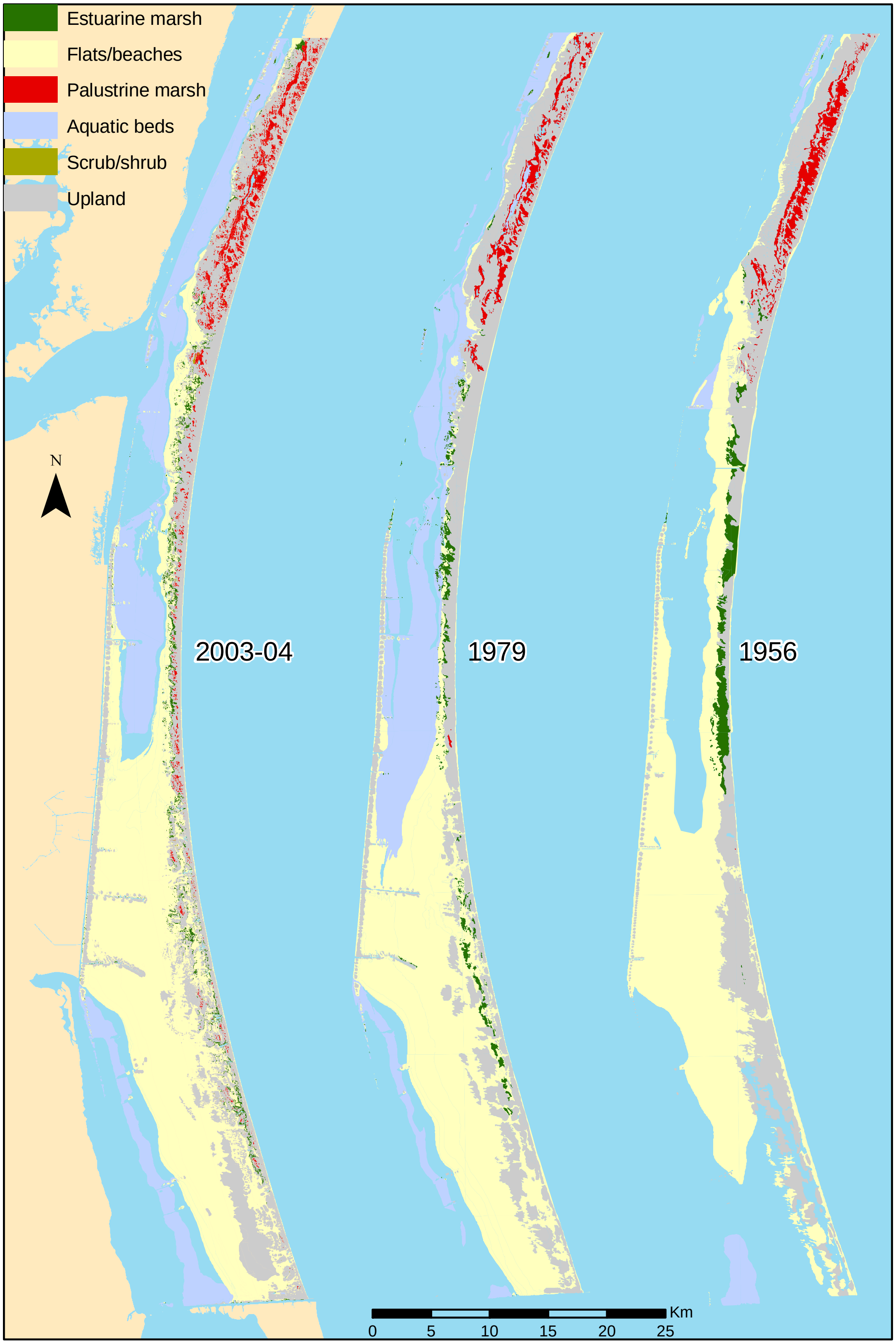


Figure 53. Maps showing distribution of major wetland and aquatic habitats in 2003/04, 1979, and the 1950's in the PINS study area.

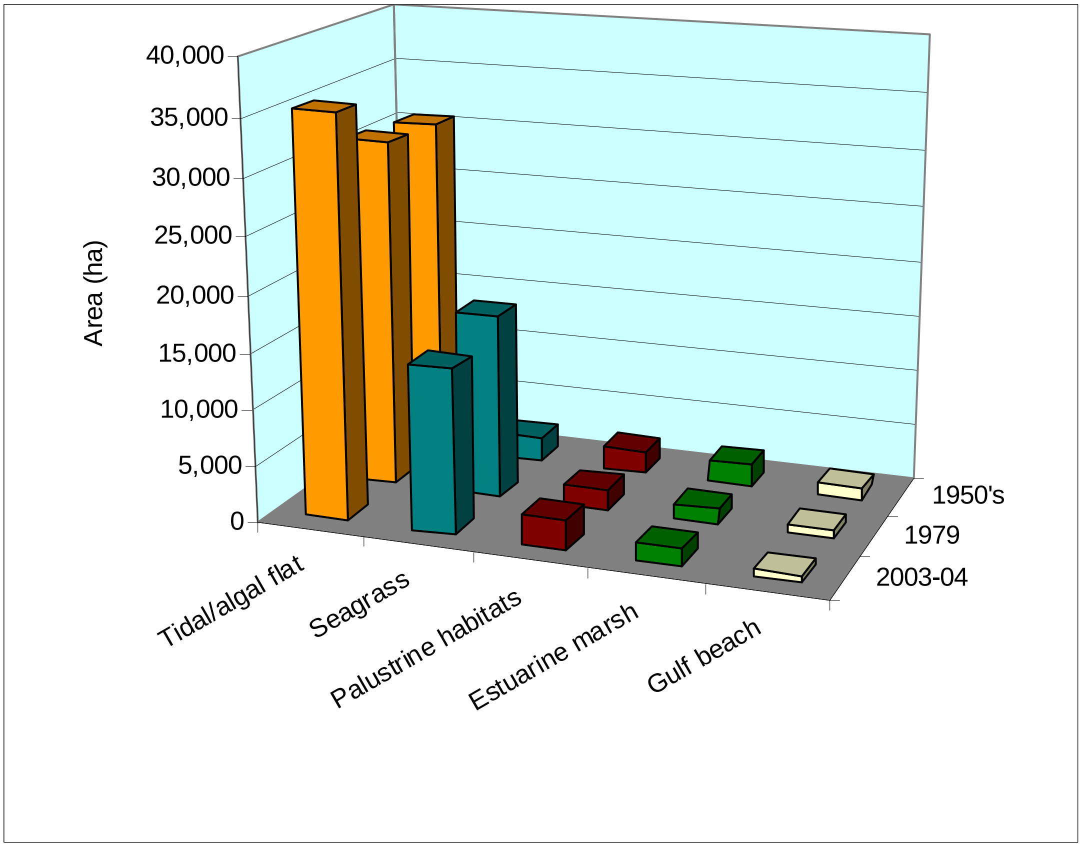


Figure 54. Areal extent of selected habitats from the 1950's to 2003/04 in the Padre Island National Seashore study area. Wind-tidal flats are, by far, the most extensive habitat.

Table 7. Areal distribution (ha) of selected habitats, 1950's to 2003/04, in the Padre Island National Seashore study area.

Habitat	*1950's*	*1979*	*2003/04*
Tidal/algal flat	30,593	30,927	35,356
Seagrass	2,167	16,422	14,572
Palustrine habitats	2,062	1,885	2,575
Estuarine marsh	1,976	1,364	1,461
Gulf beach	1,085	849	558

precipitation in 2003. Mapping from 2003 photography represents the extreme range of palustrine emergent wetlands habitat distribution on PINS. The total area of estuarine marshes declined 26 % between the mid-1950's (1,976 ha) and 2003/04 (1,461 ha). Like the palustrine habitats, the smallest amount of estuarine marsh was mapped in 1979 (1,364 ha). The area of gulf beach experienced a steady decline through time. Gulf beaches covered 1,085 ha in the mid-1950's, 849 ha in 1979, and only 558 ha by 2003/04, a 49 % loss of the resource through the study time period.

Probable Causes of Trends. A direct comparison of tidal/algal flat areas (Table 7) suggests a reversal of the trend found on other southern coastal barriers, where tidal flats have declined through time (White et al. 2002, 2005, 2006). This apparent increase in flats is primarily due to local inundation of flats in the mid-1950's as a result of the opening of Mansfield Channel. An area of ~ 6,647 ha directly north of the channel was mapped as open water in the mid-1950's. The Environmental Geologic Atlas of Texas (Brown et al., 1980) mapped environmental geology based on 1960 photography. The environmental geology map portrays this area as tidal flat. Inundation as a result of channel construction has been documented south of Mansfield Channel (White, et al., 2005). Adding 6,647 ha to the 1956 flat total results in a net loss of -5 % (-1,884 ha) of flats between 1956 and 2003/04. About 72 % of the net flat decline was due to lagoonward migration of back-island dunes. Dune migration into prior flat environments occurred primarily in the area between the Land Cut and Mansfield Channel (Fig. 55). This portion of the barrier island has historically been subject to the highest amount of shoreline erosion and presently contains the largest amount of active dunes in PINS. The large increase in flats between 1979 and 2003/04 was due primarily (62 %) to replacement of seagrasses bordering The Hole. Additional flats formed in depressions created when fore-island dunes south of the Land Cut migrated toward the Laguna Madre, adding to the gross flat gain. The gross gains in flats were offset by gross losses, resulting in a net loss of flats through time.

Seagrass expanded throughout the study area between the mid-1950's and 1979. Expansion occurred primarily (61 %) in areas previously mapped as open water. Prior areas of tidal flats located in the Laguna Madre between The Hole and Baffin Bay comprise the remainder of the expanded seagrass area (~38 %). As mentioned earlier, seagrasses are obscured by high turbiditiy and were apparently under-mapped in the mid-1950's. The EGAT, Kingsville area (Brown et al., 1977), used early 1950's photography to map environmental geology. On the environmental geology map, large expanses of seagrasses are mapped in the Laguna Madre adjacent to PINS. The transitional area between The Hole and the Land Cut was mapped as flat habitat in the mid-1950's (E2US) and 2003/04 (E2AB) but was mapped as seagrass in 1979. This area accounts for most of the decline in seagrass between 1979 and 2003/04.

The long term trend in palustrine habitats is towards an increase of the resource, with the majority of change occurring between Dagger Hill and the northern park boundary. Palustrine marsh was lost in the early time period when fore-island sand dunes migrated across the island in the direction of the Laguna Madre. As of 1975, sand dunes weren't stabilized (Weise and White, 1980) and migrated at much higher rates than today. Some palustrine marsh was lost due to inundation by open water in a depression that runs along the central axis of the island. The year 2003 experienced high amounts of rainfall and wet

Figure 55. Tidal flat and upland habitats mapped in 2003/04 that were mapped as open water in the mid-1950's. Long term shoreline erosion rate in linear feet per year, adapted from Gibeaut et al. (2001).

ground conditions during photography capture, resulting in a more liberal interpretation of palustrine habitats in some areas. In addition to relatively high amounts of rainfall, other factors influenced the spread of palustrine habitat through time. As relative sea-level rises the groundwater lense expands and obtains a higher elevation, coming into contact more frequently with the ground surface. Wet ground surface provides favorable conditions for wetland expansion. In addition, park management practice changed after 1970 when the park opened. Curtailment of cattle grazing in the early 1970's and prescribed burns created a more suitable environment for upland habitats. Sand dunes became vegetated and no longer migrated into wetland areas (Fig. 56).

Figure 56. Stabilized sand dune.

Estuarine marsh area also fluctuated over time. A large area of estuarine marsh mapped in the central part of the island between Yarborough Pass and Green Hill (Fig. 57) in the mid-1950's had become upland by 1979. This section of PINS is near a convergence zone of longshore currents where sand is deposited and accumulates in dunes (Weise and White, 1980). Dune migration from the gulf towards the Laguna Madre eliminated much of the original estuarine marsh (-73 %). By 2003/04 estuarine marsh area had increased slightly from the 1979 total. The slight increase in estuarine marsh between 1979 and 2003/04 is the result of the same factors that have led to an increase in the overall area of palustrine marsh. RSLR and park management practices combined with high precipitation in 2003 led to a spread of estuarine marsh in the later study period. Unlike palustrine habitats, estuarine marsh saw an overall decline in the long term (mid-1950's to 2003/04).

PINS has experienced both shoreline accretion and erosion through time. The statistical mean for the entire PINS shoreline is - 2.3 linear feet per year (Gibeaut et al., 2001), with the highest rates of shoreline erosion occurring due north of Mansfield Channel (Fig. 55). As a result of shoreline erosion, gulf beach has experienced a systematic decline in area over time.

Figure 57. Index map of PINS study area.

SUMMARY AND CONCLUSIONS

Strandplain-Chenier System

The most significant trend or change along the strandplain-chenier system and surrounding area was the loss of marsh from 1956 to 1979/83 and 2004. Although there were losses and gains in marshes at different locations through time, the total area of marsh habitat, which was about 38,000 ha in 1956, had a net loss of 3,793 ha from 1956 to 2004. This decrease in marsh represents a loss of about 10% of this habitat in the strandplain-chenier system since 1956. The 10% decline occurred primarily as marshes in many areas were converted to open water. Part of the conversion occurred along active faults that intersect the marshes. Through time, higher rates of subsidence on the downthrown sides of the faults submerged marsh vegetation replacing it with open water. In addition, relative sea-level rise, a major component of which is subsidence, apparently has outpaced marsh vertical accretion in some areas, thereby contributing to the conversion of marsh to open water. In addition, landward retreat of the Gulf shoreline contributed to marsh loss as shorelines eroded by as much as 17 ha/yr in some areas, such as near Sabine Pass. Conversion of marsh to open water also occurred where artificial levees, roads, and dikes created “dams” along which water ponded and submerged marsh vegetation.

Although the conversion of marsh vegetation was widespread through time in the strandplain-chenier system, rates of conversion declined during the later study period, 1979/83 to 2004, compared to the earlier period, 1956 to 1979/83. During the earlier period, the rate of loss was 115 ha/yr and during the later period 40 ha/yr. It should be noted that part of the decline in marshes since 1956 was due to a climatic factor, a major drought that occurred in 1956. Lower levels of water during the drought apparently reduced the number of open water areas during that year and more extensive marshes were mapped. During later years, water areas expanded as water levels in the marsh became higher than during the 1956 drought. Finally, some loss of marsh occurred from conversion of marsh to uplands, as dredged material was deposited along the Sabine Pass shipping channel.

Padre Island National Seashore

In 2003/04, wetland, aquatic, and upland habitats covered 95,175 ha within the PINS study area. Approximately 20,681 ha within the study area was classified as uplands. Of the four wetland systems mapped, the estuarine system is the largest (88 %). The largest area of habitats are the wind-tidal and algal-flat classes, together covering 35,356 ha. Emergent vegetated wetlands (E2EM, E2SS, PEM) cover 3,930 ha, about 63 % of which is palustrine marsh. Another important habitat is seagrass (E1AB3), which in the study area has an area of almost 14,572 ha.

Padre Island National Seashore has experienced several changes in habitats through time. Initial analysis of trends in wetlands and aquatic habitats from the 1950’s through 2003/04 shows that wind-tidal/algal flats increased from the 1950’s (30,593 ha) to 2003/04 (35,356 ha). Further examination reveals a trend towards loss (-5 %) of tidal flat through time. Approximately 72 % of tidal flat decline was due to lagoonward migration of back-island dunes. Seagrasses spread through time in PINS. The mid-1950's total of 2,167 ha increased to 14,572 ha by 2003/04. Seagrass expansion occurred primarily (61 %) in areas previously mapped as open water. The remaining 38 % of seagrass expansion occurred in areas previously mapped as tidal flats. Turbidity in the Laguna may have obscured seagrasses leading to a low number of seagrass habitat reported in the mid-1950's. Palustrine habitats had their largest distribution of 2,576 ha in 2003/04. A 25 % increase from the mid-1950's total of 2,062 ha. The larger 2003/04 number is due to multiple factors. Increasing rates of relative sea-level rise, changing land management practices, and high amounts of precipitation in 2003 combined to increase palustrine habitat area through time. The total area of estuarine marshes declined 26 % between the mid-1950's (1,976 ha) and 2003/04 (1,461 ha). Dune migration from the gulf towards the Laguna eliminated estuarine marsh. The area of gulf beach experienced a steady decline through time. Gulf beaches covered 1,085 ha in the mid-1950's, 849 ha in 1979, and only 558 ha by 2003/04. As a result of shoreline erosion, gulf beach has experienced a systematic decline in area over time (-49 %).

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APPENDIX 1

Total habitat areas for 2003/04, 1979/83, and 1950's determined from GIS datasets of the study area.

Strandplain-Chenier System

2004		1979/83		1956	
Habitats	**Hectares**	**Habitats**	**Hectares**	**Habitats**	**Hectares**
E1AB3	0.0	E1OWL.	4,287.8	E10W.	0.2
E1AB4	103.7	E1OWL/E1ABL.	91.3	E1OW.	4,039.1
E1UB	5,812.7	E1OWLH.	0.8	E2EM.	37,827.3
E1UBs	4.5	E1OWLX.	781.2	E2FL.	90.6
E1UBx	927.4	E2AB1N.	2.9	E2OW.	0.2
E2EM1N	2,709.4	E2EM1N.	5,569.3	E2SS.	284.9
E2EM1Ns	6.2	E2EM1NX.	0.5	L1OW.	321.0
E2EM1Nx	1.9	E2EM1NX/E2FLNX.	5.9	M1OW.	8,771.3
E2EM1P	30,971.9	E2EM1P.	28,408.6	M2BB.	33.3
E2SS	5.2	E2EM1PH.	11.9	PEM.	171.3
E2USN	7.2	E2EM1PH/E2OWPH.	22.6	PFL.	2.0
E2USNx	1.3	E2EM1PUUO.	234.6	POW.	14.7
E2USP	8.8	E2EM1PX.	0.7	PSS.	0.6
L1UBH	389.6	E2FL6P.	26.0	U.	3,260.4
L1UBHx	-	E2FLM.	4.0		
M1UB	9,644.5	E2FLN.	206.5		
M2USN	123.4	E2FLP.	86.4		
M2USP	105.7	E2SS1P.	6.6		
PAB4F	7.8	E2SS3P.	28.8		
PEM1A	100.2	E2USN.	938.8		
PEM1Ah	19.7	E2USN/E2ABN.	151.4		
PEM1AX	8.4	E2USN/E2EMN.	1.6		
PEM1C	181.1	E2USP.	56.8		
PEM1Cd	9.0	L1OWHH.	468.7		
PEM1Ch	0.4	L1OWHX.	12.3		
PEM1F	12.7	L2OWH.	77.6		
PEM1Fh	22.6	L2OWHH/L2ABHH.	14.5		
PEM1Fx	2.8	L2USCH.	337.5		
PEM1Khs	151.1	M1OWL.	8,918.1		
PSS1A	3.2	M2BBP.	40.6		
PUB	7.1	M2USN.	266.7		
PUBCh	0.2	PAB4HX.	0.4		
PUBCx	4.4	PABF/PEM1F.	0.9		
PUBFh	1.9	PEM1AH.	19.1		
PUBHx	72.3	PEM1C.	487.9		
PUBKh	4.3	PEM1CH.	150.0		
PUBKhs	28.0	PEM1F.	127.6		
PUS	2.2	PEM1FH.	27.2		
PUSCx	0.7	PEM1FHX.	2.8		

PUSKhs	21.0	PEM1FX.	2.1
U	3,345.6	PEM1Y.	0.5
		PEMFX/POWFX.	0.1
		PFO1C/PEM1C.	0.6
		POWF.	1.6
		POWFHX.	22.6
		POWFX.	3.0
		POWH.	146.1
		POWHHX.	2.3
		POWHX.	48.7
		PSS6CH.	9.1
		PSS6F/PEM1F.	0.4
		PUSCX.	2.3
		UA.	337.0
		UBS.	480.3
		UF6.	9.7
		UR.	1,143.1
		UU.	667.6
		UUO.	73.3
		UUOA.	19.7

APPENDIX 2

Padre Island National Seashore

2003/04		1979		1956	
Habitats	Hectares	Habitats	Hectares	Habitats	Hectares
E1AB3	14,570	E1AB2L	16,422	E1AB.	2,167
E1AB3x	3				
E1AB5	10	E1OWL	19,507	E1OW.	37,367
E1UB	12,685	E2EM1N	89	E2EM.	1,976
E1UBs	9	E2EM1NS	11		
E1UBx	1,049	E2EM1P	1,247	E2FL.	30,593
		E2EM1PS	17		
E2AB1N	1,670			E2RF.	26
E2AB1Ns	22	E2FL6N	2,634		
E2AB1P	9,666	E2FLM	94	M1OW.	6,162
E2AB1Ps	1,032	E2FLN	12,254		
		E2FLNS	49	M2BB.	1,085
E2EM1N	358	E2FLP	15,890		
E2EM1Ns	0.3	E2FLPS	7	PEM.	1,922
E2EM1P	1,068				
E2EM1Ps	35	L2AB6H	147	PFL.	11
E2SS	0.03	M1OWL	5,389	POW.	129

E2USM	378	M2BBP	839	U.	16,778
E2USN	3,117				
E2USNs	256	M2FLN	10		
E2USP	17,586				
E2USPs	1,629	M2RS2PR	2		
L1UBH	44	PEM1A	2		
		PEM1C	99		
M1UB	6,169	PEM1F	1,243		
		PEM1Y	351		
M2USP	558				
		POWF	182		
PAB1Khs	22	POWFH	1		
		POWFX	0.4		
PEM1A	747	POWGH	1		
PEM1C	1,051	POWH	4		
PEM1F	655				
PEM1Fx	0.06	UA	13,903		
PEM1K	0.4	UB	0.4		
PEM1Khs	15	UBD	4,568		
		UBS	150		
PSS1A	1	UU	62		
		UUO	5		
PUB	29				
PUBHx	0.05				
PUBKhs	12				
PUS	33				
PUSKhs	10				
U	20,683				