STATUS AND TRENDS OF WETLAND AND AQUATIC HABITATS ON TEXAS BARRIER ISLANDS COASTAL BEND

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. 05-041

A report of the Coastal Coordination Council pursuant to National Oceanic and Atmospheric Administration Award No. NA04NOS4190058

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FIGURES

TABLES

STATUS AND TRENDS OF WETLAND AND AQUATIC HABITATS ON TEXAS BARRIER ISLANDS, COASTAL BEND

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 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 presents results of an investigation to determine current status and historical trends of wetlands and associated aquatic habitats along south-central Texas barrier islands from Mesquite Bay to north Laguna Madre. The study area encompasses San José Island, Harbor Island, Mustang Island, and north Padre Island, an area that is located within Aransas, Nueces, and Kleberg Counties (Fig. I). San José Island is a broad accretionary barrier island with well-developed fore-island dunes, extensive back-island estuarine marshes, and numerous relict beach ridges and intervening swales that are the sites of palustrine marshes in the central part of the island; it has broad flood-tidal delta/washover fan complexes on its northeastern end. In contrast are Mustang Island and north Padre Island where eolian processes have erased most traces of accretionary features on the islands. Back-island estuarine marshes are important components of the islands, particularly at the bayward end of hurricane washover channels. Between and landward of San José and Mustang Islands is Harbor Island, a flood-tidal delta complex at the bayward mouth of the tidal inlet, Aransas Pass. Harbor Island is the site of extensive black mangroves and seagrasses.

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 2002–2004. Historical distribution is based on 1950’s black-and-white and 1979 CIR photographs. Mapped wetlands for each period were digitized and entered into a GIS for analysis. 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 to1:24,000-scale base maps using a zoom transfer scope. Resulting maps were digitized and entered into a GIS, producing GIS maps for the two time periods. Both the 1950's and 1979 series USFWS maps, which are in digital format, were partly revised in this project to be more consistent with wetlands interpreted and delineated on the 2002–04 photographs.

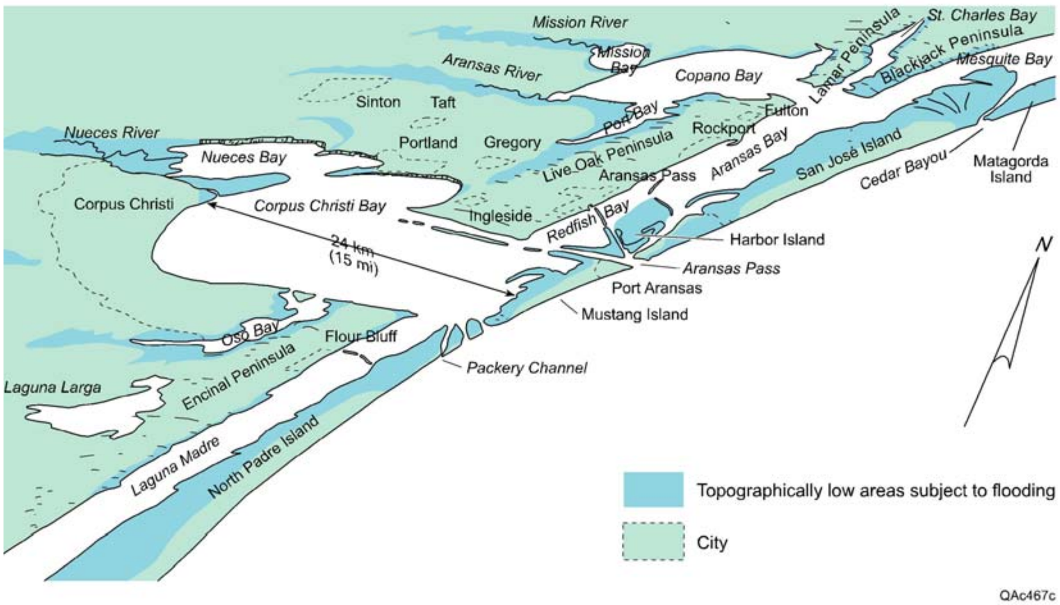


Figure I. Index map showing Texas Coastal Bend barrier islands that were investigated during this study. Modified from Brown et al. (1976).

Methods used to delineate 2002–04 habitats differed from the earlier methods. The 2002–04 photographs are digital images with a pixel resolution of 1 m 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 1:4,000. The resulting current-status GIS maps were used to make direct 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 and 2002–04 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. Lidar (light detection and ranging) surveys conducted of Mustang Island and parts of San José Island and two surveys across Mustang Island, which included lidar that coincided with electromagnetic induction (EM) surveys (Paine et al., 2004), provided data on relative elevation and salinities that helped define habitat boundaries and potential frequency of flooding, or water regimes.

Current Status, 2002–04

Major estuarine and palustrine habitats in the study area include salt, brackish, and fresh marshes; tidal flats; seagrass beds; and mangroves. Areas of estuarine open water are also important components of the salt and brackish-marsh complex. 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 2002–04 in the study area, wetland and aquatic habitats (excluding open water) were dominated by seagrass beds with a total area of 8,357 ha (20,650 acres), followed by tidal flats totaling 6,121 ha (15,125 acres) and estuarine marsh at 4,009 ha (9,906acres) (Fig. II). Scrub/shrub wetlands (primarily mangroves) had a total area of 837 ha (2,068 acres), and palustrine marshes (including ponds and flats) had an area of 767 ha (1,895 acres). Along the Gulf shoreline, the area of mapped beaches totaled 535 ha (1,322 acres).

The study area was subdivided into geographic areas—San José Island, Harbor Island, Mustang Island, and north Padre Island—to allow a more site-specific analysis of status and trends (Fig. III).

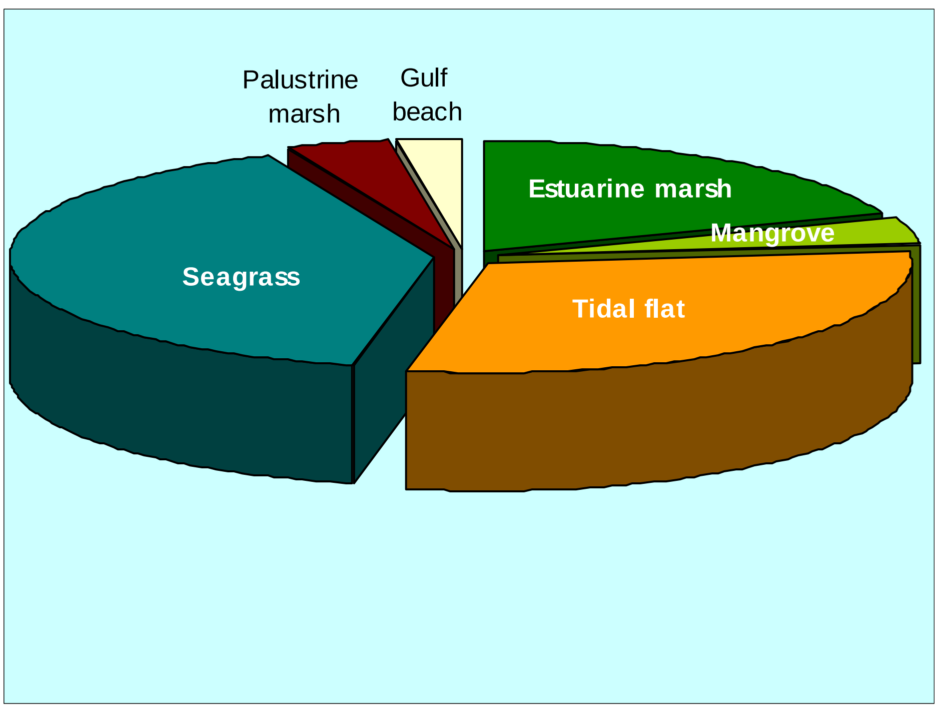


Figure II. Areal extent of selected habitats in the study area in 2002–04.

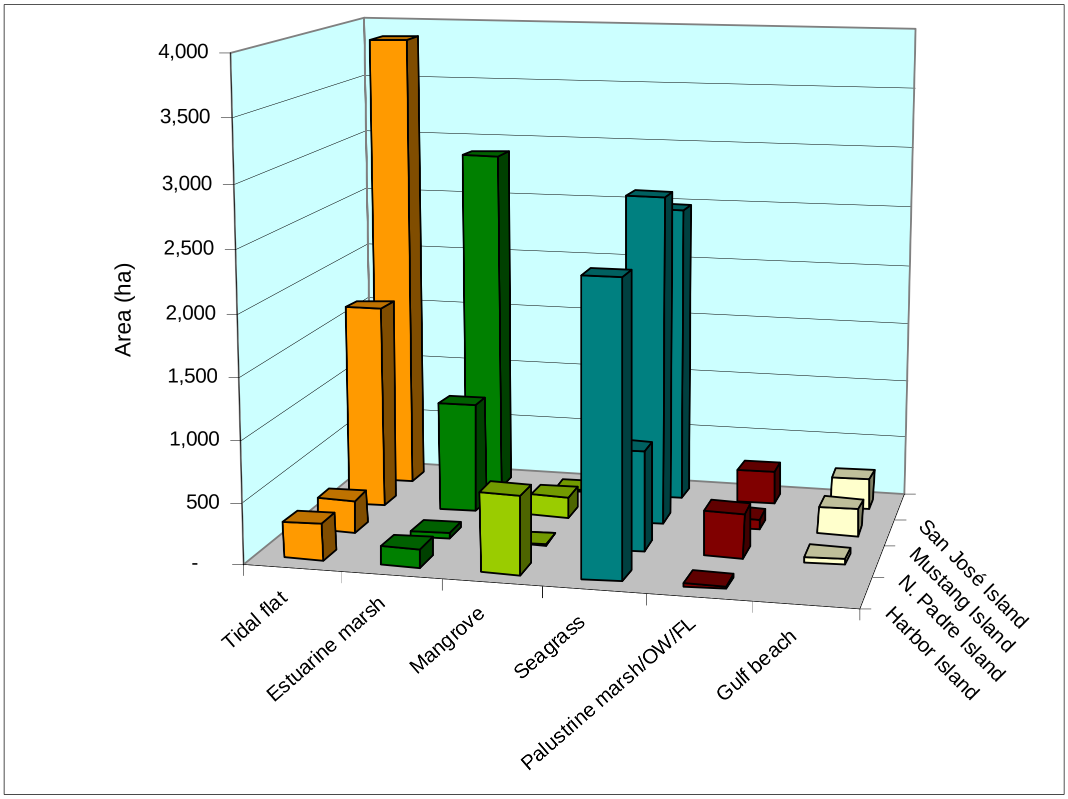


Figure III. Distribution of selected habitats by geographic area in 2002–04. The most extensive distribution of estuarine marshes and tidal flats is on San José Island. Mangroves are most extensive on Harbor Island.

The most extensive estuarine emergent wetlands (salt and brackish marshes) occurred on San José Island, where the total area of estuarine marshes in 2002–04 was 2,897 ha (7,158 acres) (Fig. III). Mustang Island was a distant second with 913 ha (2,256 acres). Harbor Island and north Padre Island, combined, had less than 200 ha (494 acres) of estuarine marsh (Fig. III). Tidal flats are most extensive on San José and Mustang Islands, where total areas were 3,866 ha (9,553 acres) and 1,695 ha (4,188 acres), respectively. On north Padre Island estuarine marshes and tidal flats are limited, with total areas of 47 ha (116 acres) and 264 ha (652 acres), respectively. These limited habitats on north Padre Island, compared with San José and Mustang Islands, are due partly to the absence of washover channels, fewer connections to the estuarine system, extensive upland vegetation-stabilized dune fields, and narrow fringing Laguna Madre. Eolian deflation flats in mid- and back-island areas on north Padre Island, however, are the sites of palustrine marshes and associated water and flats. Accordingly, north Padre has the largest distribution of palustrine habitat at 356 ha (880 acres). San José Island is next with 294 ha (727 acres), followed by Mustang and Harbor Islands (Fig. III). Seagrass beds were most abundant in the Mustang Island area with 2,726 ha (6,736 acres) (Fig. III). On San José and Harbor Island, seagrasses covered areas of 2,490 ha (6,152 acres) and 2,361 ha (5,834 acres), respectively. The north Padre Island study area, where 822 ha (2,031 acres) of seagrass was mapped, does not extend landward of the Gulf Intracoastal Waterway and, thus, excluded some seagrass beds that are very abundant in Laguna Madre. Mangrove habitats were most extensive on Harbor Island, where

634 ha (1,567 acres) was mapped, followed in abundance by Mustang Island at 179 ha (442 acres). San José and north Padre Islands had a combined total of 24 ha (59 acres) of scrub/shrub vegetation (mostly mangroves). The Gulf beach (marine unconsolidated shore) was most abundant on San José Island with 260 ha (642 acres), followed by Mustang Island with 227 ha (561 acres), and north Padre Island with 49 ha (121 acres).

Wetland Trends and Probable Causes, 1950's through 2002–04

In analyzing trends, wetland classes were emphasized over water regimes and special modifiers because habitats were mapped only down to class on 1950's photographs. It should be noted 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 direction of trends than absolute magnitudes. Probable causes of historical changes are discussed by geographic area toward the end of this summary. From the 1950's through 2002–04 within the study area, some wetland classes underwent substantial net losses and gains, whereas others remained more stable (Fig. IV; Table I). In general, estuarine marshes increased in total area during each period (1950's–1979 and 1979–2002–04), with a total net gain of 2,246 ha (5,550 acres) from the 1950's through 2002–04. Approximately 60% of this gain occurred from the 1950's through 1979, indicating that the rate of gain decreased from 1979 through 2002–04. The average rate of marsh gain during the earlier period was about 58 ha/yr (142 acres/yr) and for the more recent period, about 38 ha/yr (95 acres/yr). Combining mangroves with marshes to create a marsh-mangrove habitat, the average rates of gain through time are 86 ha/yr (214 acres/yr) and 46 ha/yr (113 acres/yr) for the early and later periods, respectively.

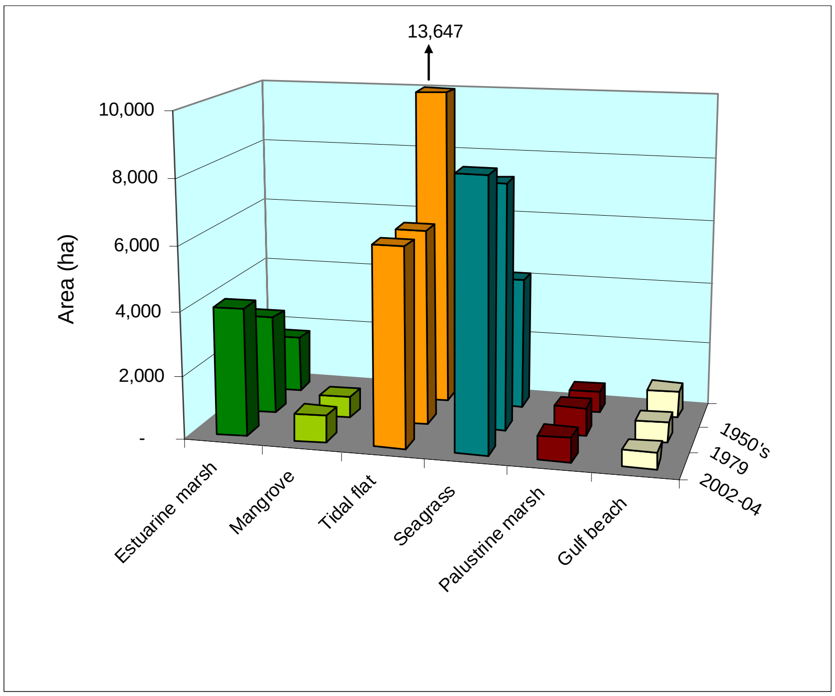


Figure IV. Areal distribution of major habitats in the study area in the 1950's, 1979, and 2002–04.

Table I. Total area of major habitats in the1950's, 1979 and 2002–04 in study area.

Habitat	*1950's*		*1979*		*2002-04*	
	ha	acres	ha	acres	ha	acres
Estuarine marsh	1,763	4,356	3,087	7,627	4,009	9,906
Mangrove	Not mapped	-	665	1,642	837	2,068
Tidal flat	13,647	33,722	6,114	15,109	6,121	15,125
Seagrass	4,167	10,297	7,704	19,036	8,398	20,752
Palustrine marsh	665	1,643	890	2,199	767	1,895
Gulf beach	861	2,128	630	1,557	535	1,322

The most extensive losses in habitats occurred in tidal flats, which underwent a major net decline from the 1950's through 1979 (Fig. IV). Total area of tidal flats decreased by 7,533 ha (18,613 acres) during this period (1950's–1979). During the later period (1979–2002–04), the total area of tidal flats remained rather stable with a net gain of 7 ha (16 acres). Seagrass beds increased in total area by 3,537 ha (8,739 acres) from the 1950's through 1979 and also increased from 1979 through 2002–04, but at a much smaller amount (694 ha; 1,715 acres). Palustrine habitats had their largest distribution in 1979, at 890 ha (2,199 acres), and lowest in the 1950's at 665 ha (1,643 acres) (Table I). The total area of mapped mangroves was slightly larger in 2002–04 than in 1979, indicating a net gain of 173 ha (426 acres) (this habitat was not mapped on the 1950's black-and-white photographs). Finally, there was a net decline in the mapped area of Gulf beaches, decreasing in total area by 231 ha (571acres) from the 1950's through 1979, and by 95 ha (235 acres) from 1979 through 2002–04, a net change of almost -40% since the 1950's.

An analysis of habitat changes within the different geographic areas reveals some interesting trends and helps elucidate some probable causes. At the northeastern part of the study area at **San José Island**, the most significant wetland trend was the systematic gain of estuarine marsh. The early time interval (1950's–1979) experienced a 93% increase as the area of marshes expanded from 1,102 ha (2,723 acres) in the mid-1950's to 2,122 ha (5,244 acres) by 1979. In 2002–04 the quantity of estuarine marsh rose to 2,897 ha (7,159 acres), an additional 37% gain. The trend was primarily characterized by expansion of marsh into low flats and to a lesser degree into former uplands. This phenomenon is seen widely on the Texas coast and is attributed to relative sea-level rise. Another example of the effect of relative sea-level rise is the systematic expansion of seagrass into submerging tidal flats. In both the mid-1950's (791 ha; 1,955 acres) through 1979 (1,402 ha; 3,464 acres) and the 1979 through 2002–04 (2,490 ha, 6,153 acres) time periods, seagrass increased by 77%. Seagrass expansion during the mid-1950's through 1979 was primarily into inland flats, whereas seagrass expansion during the later period was into open water on the island periphery. The area of tidal flats decreased by 39% during the early period, when 6,301 ha (15,570 acres) in the mid-1950's was reduced to 3,858 ha (9,533 acres) by 1979. Inundation of tidal flats by open water and eventual occupation by seagrasses are consistent with the effects of relative sea-level rise that has been documented in other parts of the Texas coast. The area of tidal flats in 2002–04 did not change significantly from that in 1979, remaining at 3,866 ha (9,553 acres). Losses in tidal flats in the later period were offset by large gains in former open water and marsh areas. The relative overall amounts of palustrine marsh are small on San José Island when compared with other habitats. However, the initial mid-1950's total of 196 ha (484 acres) increased significantly to 356 ha (880 acres) by 1979 (+82%). An increase in palustrine marsh is consistent with observed changes on other parts of the barrier system, where moisture levels have increased during the past decades. The large gain was reversed when palustrine marsh decreased by14% by 2002–04 (306 ha, 756 acres). Palustrine marsh appears to have been reduced through agricultural practices on the island and drier conditions compared with conditions of 1979. Another relatively small habitat, the Gulf beach, experienced a systematic loss in total area through time. A 41% loss between the mid-1950's, when the total area was 499 ha (1,233 acres), and 1979, when the total was 294 ha (727 acres), was followed by an additional loss of 14% by 2002–04, when the total was 260 ha (643 acres). Initial losses can be attributed to overmapping in the mid-1950's and a component of shoreline erosion that continued throughout the study time period.

The most significant change or trend on ***Mustang Island*** was an extensive loss of tidal flats after the1950's. From a total area of 3,974 ha (9,820 acres) mapped on 1950's photographs, only 1,526 ha (3,771 acres) remained in 1979, a loss of 2,448 ha (5,917 acres) or about 60% of the 1950's resource. This loss was followed by a small net gain of 169 ha (417 acres) from 1979 through 2002–04. In contrast to the decline in wind-tidal flats, estuarine marshes and seagrass beds increased from the 1950's through 2002–04. Much of the area mapped as tidal flats in the 1950's was converted to seagrass beds (~50%), open water (~20%), and marshes (~6%) as topographically low flats became submerged and slightly higher flats became more frequently flooded, contributing to a spread of marshes and mangroves. This conversion of tidal flats to more permanently flooded habitats, such as seagrass beds, since the 1950's can be explained, in large part, by a relative rise in sea level (sea-level rise + subsidence). For example, tide-gauge data at nearby Rockport indicates that from the mid-1960's through the mid-1970's average rise in relative sea level was almost 1.7 cm/yr. From the 1950's through 1979, seagrasses increased by 2,159 ha (5,218 acres). An apparent net loss of 777 ha (1,920 acres) of seagrass beds between 1979 and 2002–04, was due, in large part, to erroneous mapping of tidal flats as seagrass beds in several areas on the 1979 photographs. Although there were losses and gains in estuarine marsh throughout the island, the overall change was a systematic net gain of 325 ha (786 acres) from the 1950's through 1979, and 259 ha (641 acres) from 1979 through 2002–04, for a total gain of 584 ha (1,444 acres) since the 1950's. Combining mangroves and estuarine marshes into a single habitat for comparison with historical marshes reveals an increase of 763 ha (1,122 acres) since the 1950's, accounting for ~30% of the loss in 1950's tidal flats because the flats were converted to marshes and mangroves. Palustrine habitats (marsh/flat/water) on Mustang Island were most extensive in 1979, when 375 ha (927 acres) was mapped, and least extensive in 2002–04 at 93 ha (230 acres). In the 1950's the total area was 191 ha (472 acres). Wetter conditions on the island, when the 1979 aerial photographs were taken, apparently contributed to the 1979 total. Since 1979, island development has contributed to palustrine habitat loss in some areas. The area of mapped Gulf beach underwent a systematic net decline of -33 ha (-80 acres) from the 1950's through 1979 to -41 ha

(-101 acres) from 1979 through 2002–04, for a total loss of 74 ha (181 acres). This change was partly due to shoreline erosion, but also partly due to a narrowing of the beach in 1979 and 2002–04, as vegetation expanded.

On ***north Padre Island,*** the most significant habitat trend is a systematic loss of tidal flat. A large loss between the mid-1950's, when the total was 957 ha (2,365 acres), and 1979, when the total was 284 ha (702 acres), represents a 70% loss of the resource. This large loss is due partly to overmapping of seagrass in tidal flat areas in 1979. Tidal flats continued to decline in area, reaching a low of 264 ha (652 acres) by 2002–04, an additional 7% loss. The expansion of seagrass from the mid-1950's total of 642 ha (1,586 acres) to 1,143 ha (2,824 acres) in 1979 represents a 78% increase. Much of this increase is due to overmapping. Totals were reduced 28% by 2002—04, when the area was 822 ha (2,031 acres). Discounting the inflated 1979 area, it is likely that seagrasses expanded through the mid-1950's through 2002–04 period at a moderate rate. Palustrine marsh experienced a fluctuation in area through time. In the mid-1950's, palustrine marsh occupied 275 ha (680 acres), then lost 6% by 1979, when the total was reduced to 258 ha (638 acres). Reversing the trend in the later period, marshes rebounded to a total of 351 ha (867 acres), or a 36% increase. Palustrine marshes cover a relatively small area of north Padre Island, and their area fluctuates depending on the amount of moisture at the time of photo capture. An increase in the amount of moisture on north Padre Island is apparent in increasing palustrine marsh areas. The Gulf beach on north Padre Island experienced a fluctuation in area through time. An initial gain (+11%) of beach from the mid-1950's total of 61 ha (151 acres) to the 1979 total of 68 ha (168 acres) was reversed in the later period, when the Gulf beach lost 29% by 2002–04, with a total of 49 ha (121 acres). The Gulf beach was overmapped in 1979, possibly because of lower tides, and therefore created an artificial gain from the mid-1950's through 1979. The overall Gulf beach area has declined through time in this historically eroding section of the coastline.

On ***Harbor Island,*** the most significant change was an extensive decline in tidal flats since the 1950's. Of ~2,415 ha (5,965 acres) of tidal flats mapped in the 1950's, only 446 ha (1,102 acres) remained in 1979, and 298 ha (736 acres) in 2002–04. This change, from the 1950's through 2004, amounted to a loss of almost 90% of the tidal flats on Harbor Island since the 1950's. Countering the decline in tidal flats were major increases in seagrasses and open water. Beginning with an area of 1,390 ha (3,435 acres) in the 1950's, seagrass beds had a net gain of 971 ha (2,399 acres) by 2002–04. This gain was an increase of about 70% since the 1950's, with almost 60% of the change occurring during the earlier period, 1950's through 1979. Open-water areas increased from 1,203 ha (2,973 acres) in the 1950's to 1,717 ha (4,243 acres) by 1979 and maintained an area of 1,671 (4,129 acres) in 2002–04. The areas of mapped mangroves were similar in 1979 and 2002–04, at 665 ha (1,643 acres) and 634 ha (1,567 acres), respectively. Mangroves were not mapped on the 1950's black-and-white photos. The area of estuarine marshes in the 1950's covered 283 ha (699 acres), increasing slightly to 297 ha (734 acres) by 1979, and decreasing to 152 ha (376 acres) by 2002–04. Combining marshes and mangroves into a marsh-mangrove habitat for comparison with that of the 1950's, reveals that this habitat increased from 283 ha (699 acres) in the 1950's to 962 ha (2,377 acres) in 1979, but decreased to 786 ha (1,942 acres) by 2002–04. There is evidence, however, that mangroves were overmapped in 1979, suggesting that the marsh-mangrove habitat was similar in area in 1979 and 2002–04. From the 1950's through 2002–04, the marsh-mangrove habitat almost tripled in area. Harbor Island is a good example of where habitat changes have occurred as a result of a relative rise in sea level. As the broad tidal flats on Harbor Island in the 1950's became more frequently to permanently inundated, seagrasses and water expanded across the submerging flats. Marshes and mangroves spread into slightly higher flats. In general, by 1979, much of the 1950's tidal-flat habitat on Harbor Island had been converted to seagrasses, which accounted for ~50% of the change, marshes and mangroves ~33%, and open water ~12%.

STATUS AND TRENDS OF WETLAND AND AQUATIC HABITATS ON TEXAS BARRIER ISLANDS, COASTAL BEND

INTRODUCTION

Coastal wetlands on barrier islands 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 biological productivity and public use. This report presents results of an investigation to determine the current status and historical trends of wetlands and associated aquatic habitats along the south-central Texas barrier island system from Mesquite Bay to upper Laguna Madre. Previous studies of Galveston Bay barrier islands by the Bureau of Economic Geology (BEG) (White et al., 2004) indicate substantial losses in wetlands 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 those of the Galveston Bay system, studies of wetlands on barrier islands along the central Texas coast (White et al. 2002) show that marshes have expanded as a result of relative sea-level rise. Down the coast to the southeast of these two bay systems is the Aransas-Corpus Christi-north Laguna Madre bay system, where barrier islands support extensive wetlands. To determine wetland changes through time, we analyzed wetland status and trends and probable causes of trends on these Coastal Bend barriers. Results of the study help in 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 management programs for protecting and possibly restoring these valuable natural resources.

(a)

(b)

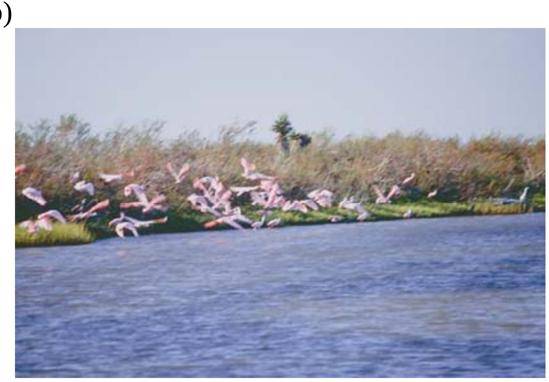


Figure 1. (a) Black mangroves on Harbor Island, as viewed from the light house, and (b) Roseate spoonbills on Shamrock Island (photo by Jay Raney).

Study Area

The study area includes the barrier-island system between Mesquite Bay and north Laguna Madre. Included are San José Island, Harbor Island, Mustang Island, and north Padre Island (Figs. 2 and 3). The estuarine system along these islands from north to south consists of Mesquite Bay, Aransas Bay, Redfish Bay, Corpus Christi Bay, and north Laguna Madre. The study area is located in Aransas, Nueces, and Kleberg Counties.

General Setting of Barrier Islands

Typical environments across the barrier islands are the Gulf beach, fore-island dunes, vegetated barrier flats, with local ridge and swale topography, and fresh to brackish marshes, salt marshes, wind-tidal flats, and seagrass beds in the adjacent bays and lagoons (Fig. 4). Geologically, San José Island, for example, is a modern accretionary barrier island with well-preserved ridge-and-swale topography locally (Fig. 5). The relict beach ridges and intervening swales have an orientation roughly parallel to the present island shoreline marked by the Gulf beach. The swales are the sites of linear palustrine wetlands. The northern half of San José Island is characterized by broad hurricane washover-fan/tidal delta complexes (Andrews, 1970; McGowen et al. 1976), on which extensive salt- and brackish-water marshes and tidal flats have developed. Mustang Island and north Padre Island are narrower than San José Island. Any traces of accretionary ridge and swale topography on these islands have been erased by eolian processes, which become more dominant to the southwest as climatic conditions become drier. Storm washover channels occur at the southern end of Mustang Island (Fig. 6). Much of the island has been inundated by major hurricanes such as Hurricane Carla in 1961, which opened washover channels, eroded the beach and dunes, and washed sediments composed of sand and shell bayward. Harbor Island is not classified as a barrier island, but is a broad fan-shaped flood-tidal delta (Hoover, 1968) that has developed between San José and Mustang Island at the bayward mouth of the tidal inlet, Aransas Pass. The island is divided into two sections by Aransas Channel, and is bordered to the north by Lydia Ann Channel, Redfish Bay, and Aransas Bay. Dredged material from the ship channel lines the island along Aransas Channel. Vegetation near and on the dredged mounds generally is characterized by marsh vegetation grading upward toward the mounds into higher marsh and then into a variety of upland shrubs and small trees, such as salt cedar.

Geomorphic features on which various types of barrier-island and flood-tidal-deltaic 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 intertidal wetlands that grade upward from the astronomical-tidal zone through the wind-tidal zone to the storm-tidal zone.

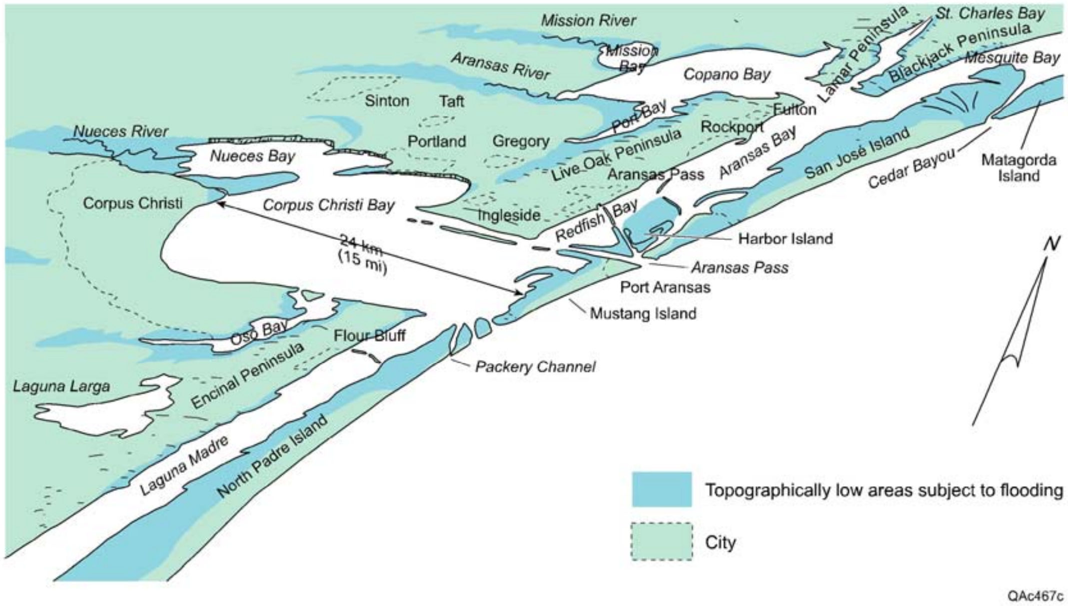


Figure 2. Index map showing Texas Coastal Bend barrier islands that were investigated during this study. Modified from Brown et al. (1976).

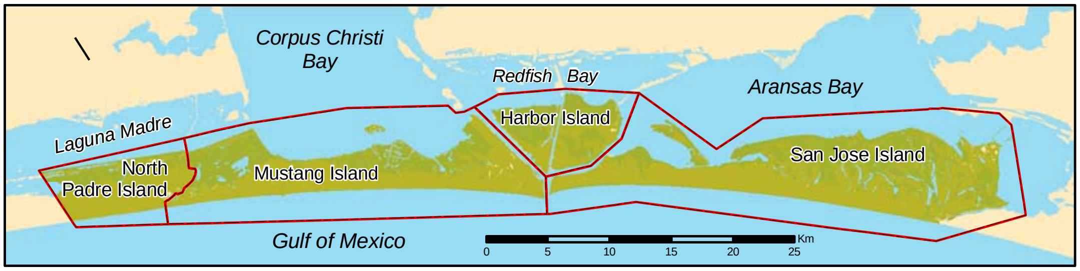


Figure 3. Map showing boundaries of the different geographic areas (islands) investigated.

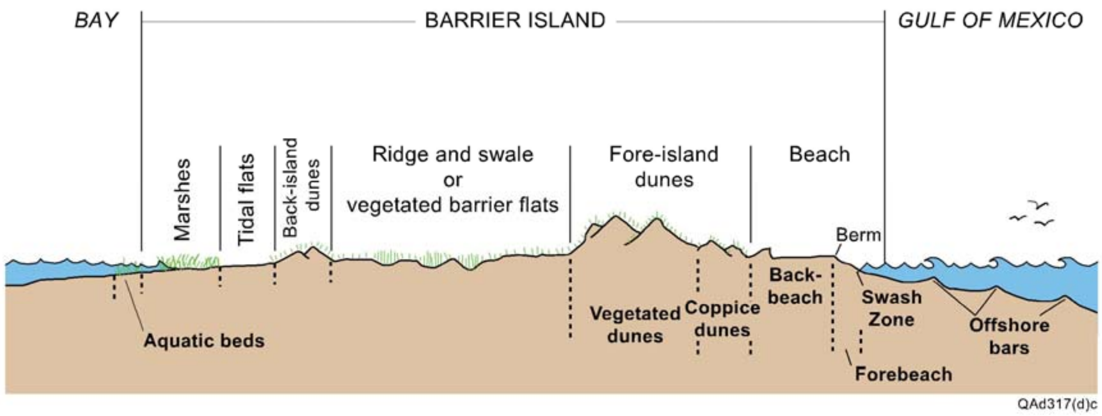


Figure 4. Schematic profile of a barrier island, such as San José Island, illustrating major environments from Gulf to bay. Not drawn to scale. Modified from Raney and White, 2002.

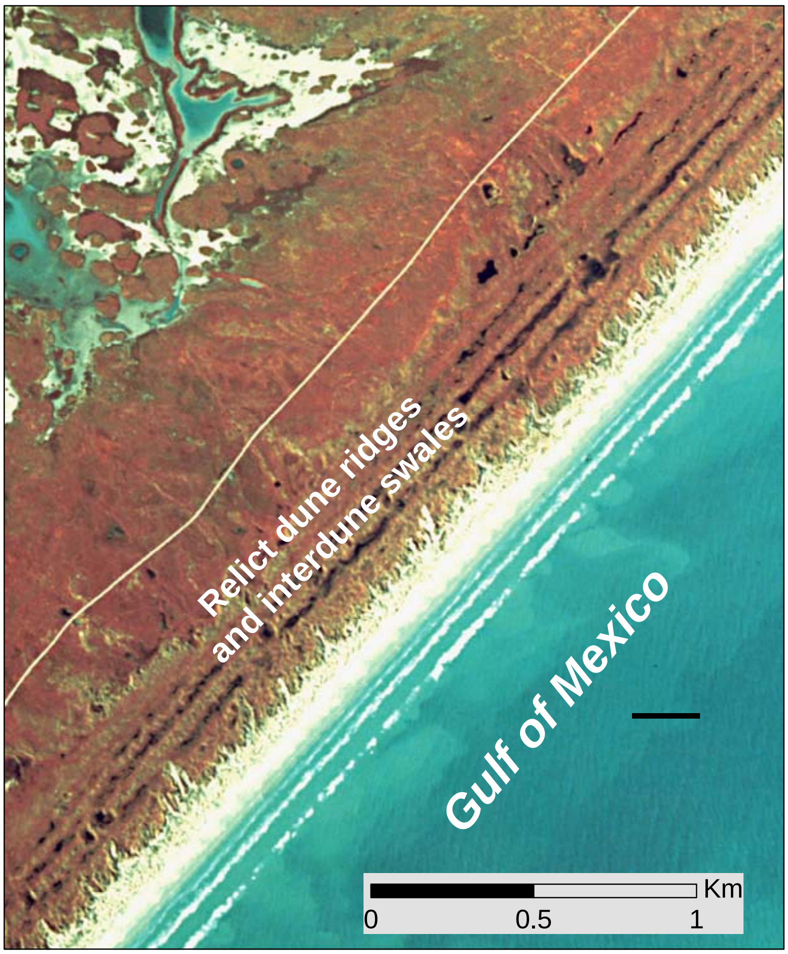


Figure 5. Example of ridge and swale topography on San José Island. Dark areas are wet zones supporting emergent vegetation in swales between relict beach ridges. Color infrared 1979 aerial photo taken by NASA.

(a)

(b)

Figure 6. Vertical aerial photograph (2002) of Corpus Christi Pass, a hurricane washover channel located at the southern end of Mustang Island (a), and Corpus Christi Pass a few days after Hurricane Allen made landfall in August of 1980 (b). Longshore currents and sand migration along the Gulf shoreline (foreground) close the pass between hurricanes, and the barren sand and washover fan deposits become vegetated with salt tolerant plants.

Bay-Estuary-Lagoon Setting

Exchange of marine waters with waters of the estuarine system occurs primarily through the tidal inlet, Aransas Pass, which separates San José Island from Mustang Island. Aransas Pass has been dredged and jettied to create the Corpus Christi Ship Channel (Fig. 2). Intermittent exchange of marine and estuarine water occurs at Cedar Bayou (when open) located at the north end of San José Island. It is a narrow channel that connects the Gulf with Mesquite Bay. Exchange of marine and estuarine waters can also occur through storm washover channels located at the south end of Mustang Island. Storm surge associated with hurricanes and tropical storms scour and wash sediments bayward opening the channels for a period of time (Fig. 6). This process has formed washover fans at the bayward end of the channels that are the sites of wind-tidal flats and marshes. Also, located at the south end of Mustang Island is Packery Channel (Fig. 2), which during this project was being dredged and jettied to form a "permanent" inlet to provide boating access to the Gulf of Mexico.

The main sources of fresh water inflow into the estuarine system in the study area are rivers that discharge at the heads of the bays approximately 40 km inland from the barrier islands. The principal rivers are the Nueces, Aransas, and Mission Rivers, which discharge into Nueces Bay, Copano Bay, and Mission Bay, respectively (Fig. 2). The Guadalupe River, which discharges into San Antonio Bay to the northeast, is an important source of freshwater for Aransas Bay (Longley, 1994). Salinities in the bay-estuary-lagoon system vary. Average salinities in Laguna Madre are generally above 30 parts per thousand (ppt), which is in marked contrast to Copano Bay where average salinities range from about 10-15 ppt, increasing toward the mouth of the bay. Average salinities are generally highest in Laguna Madre, followed in decreasing order by Corpus Christi, Redfish, Aransas, Nueces and Copano Bays (Holland et al. 1975, Brown et al. 1976, Hildebrand and King, 1978). Salinities decrease toward the heads of the bays where they are moderated by fresh-water inflows. Astronomical tides along the Gulf shore have a mean diurnal range of 0.5 m and maximum diurnal range of 0.76 m (Hayes, 1965; Collier and Hedgpeth, 1950). Along the bay shore mean tides are approximately 0.15 m (Watson and Behrens, 1976) although wind-generated tides in the bays can be substantially higher.

Relative Sea-Level Rise

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

Over the past century, sea level has risen on a worldwide (eustatic) basis at about 0.12 cm/yr, with a rate in the Gulf of Mexico and Caribbean region of 0.24 cm/yr (Gornitz et al. 1982; Gornitz and Lebedeff, 1987). Adding compactional subsidence to these rates yields a relative sea-level rise that locally exceeds 1.2 cm/yr (Swanson and Thurlow, 1973; Penland et al. 1988). Short-term rates of sea-level rise at Aransas Pass exceeded 1.28 cm/yr from 1959 through 1969 (Swanson and Thurlow, 1973). These short-term rates can be affected by secular variations in sea level caused by climatic factors, such as droughts and periods of higher than normal precipitation and riverine discharge. Short-term sea-level variations produce temporary adjustments in the longer term trends related to eustatic sea-level rise and subsidence.

The tide gauge at Rockport, located along the landward shore of Aransas Bay, provides the longest continuous record of sea-level variations near the study area. The average rate of sea-level rise from the 1950's through 1993 (with data missing in the late 1950's and early 1960's) is about 0.40 cm/yr. Rates of sea-level rise recorded by the tide gauge reached a high of 1.7 cm/yr from the mid-1960's to mid-1970's (Fig. 7); this time coincides with a maximum change in some habitats, such as wind-tidal flats (White et al. 1998). The impact that relative sea-level rise has on barrier island habitats is presented in the discussion of wetland trends.

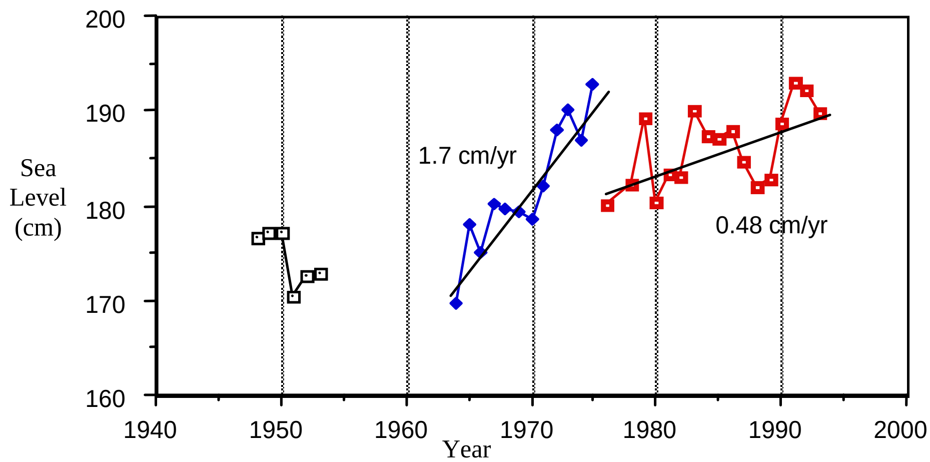


Figure 7. Sea-level rise at the Rockport tide gauge located near the landward margin of Aransas Bay. Tide data from NOAA.

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 the 1950's, 1979, and 2002-04. Maps of the 1950's and 1979 were prepared as part of the USFWS-sponsored Texas Barrier Island Ecological Characterization study (Shew et al. 1981) by Texas A&M University and the National Coastal Ecosystems Team of the USFWS. Final maps of the 1979 series were prepared under the NWI program. Maps of the 1950's and 1979 series were digitized and initially analyzed in 1983 (USFWS, 1983). Current USFWS

NWI maps and digital data for the Texas coast were prepared using 1992 aerial photographs. The current status of wetlands in this study is based on photographs taken in 2002, 2003, and 2004. The 1992 NWI maps were used as collateral information for interpreting and mapping current wetland distribution.

Wetland Classification and Definition

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

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

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

Because the fundamental objective of 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 neither defined nor mapped in accordance with the *U.S. Army Corps of Engineers Wetland Delineation Manual, 1987*, which applies to jurisdictional wetlands.

Interpretation of Wetlands

Historical Wetland Distribution

Historical distribution of wetlands is based on the 1950's and 1979 USFWS wetland maps. 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 with 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 misclassifications may occur. The 1950's

[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.

photographs are black-and-white stereo-pair, scale 1:24,000, most of the ones along the Texas coast having been 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.

Methods used by the USFWS NWI program involved transferring wetlands mapped on aerial photographs to USGS 7.5-minute-quadrangle base maps, scale 1:24,000, using a zoom-transfer scope. 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. Thus, more standing water and wetter conditions were apparent on the 1979 photographs than on the 2002-04 photographs. Although the 1950's photographs are black-and-white, they are large scale (1:24,000), which aids in the photointerpretation and delineation process. There was a severe drought in the 1950's that peaked in 1956 in Texas (Riggio et al. 1987), which may have affected the palustrine marshes on the 1950's maps. These differences in wet and dry conditions during the various years affected habitats, especially palustrine, 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 (1950's and 1979), so that there would be closer agreement between the historical map units and the current (2002-04) wetland map units. Revisions of the USFWS data were 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) as a single map unit (E2EM/E2FL). In our revisions, these areas were subdivided into E2EM and E2FL.

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 and aquatic habitats is based on color infrared (CIR) aerial photographs taken in 2002-2004. Interpretation and mapping of wetlands and aquatic habitats were completed by BEG researchers through on-screen delineation of habitats. Delineations were digitized directly into the GIS (ArcMap) at a scale of 1:4,000. Because of the method used, the current wetland maps show more detail than do the historical maps.

Field Investigations

Field investigations were conducted (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 to define wetland classes, including water regimes, for mapping purposes (Fig. 8). Characterization of prevalent plant associations provided vital plant community information for defining mapped wetland classes in terms of typical vegetation associations. In addition, profiles along two selected transects on Mustang Island provided additional information for interpreting wetland habitats (Figs. 9-11). Interpretations of wetlands along these transects were supported by Light Detection and Ranging (Lidar) and electromagnetic induction (EM) data acquired by BEG (Paine et al. 2004; 2005). The Lidar images (Fig. 9) provide detailed elevation data that help differentiate between high and low marshes and flats and areas that are transitional between uplands and wetlands, and the EM-derived conductivity data help quantify the known strong relationship between soil and water salinity and marsh type.

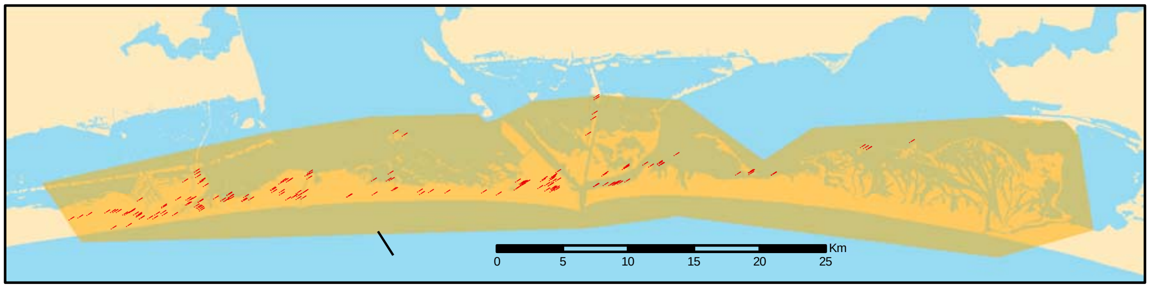


Figure 8. Map of field-survey sites used for ground-truthing aerial photo delineations and collecting field data.

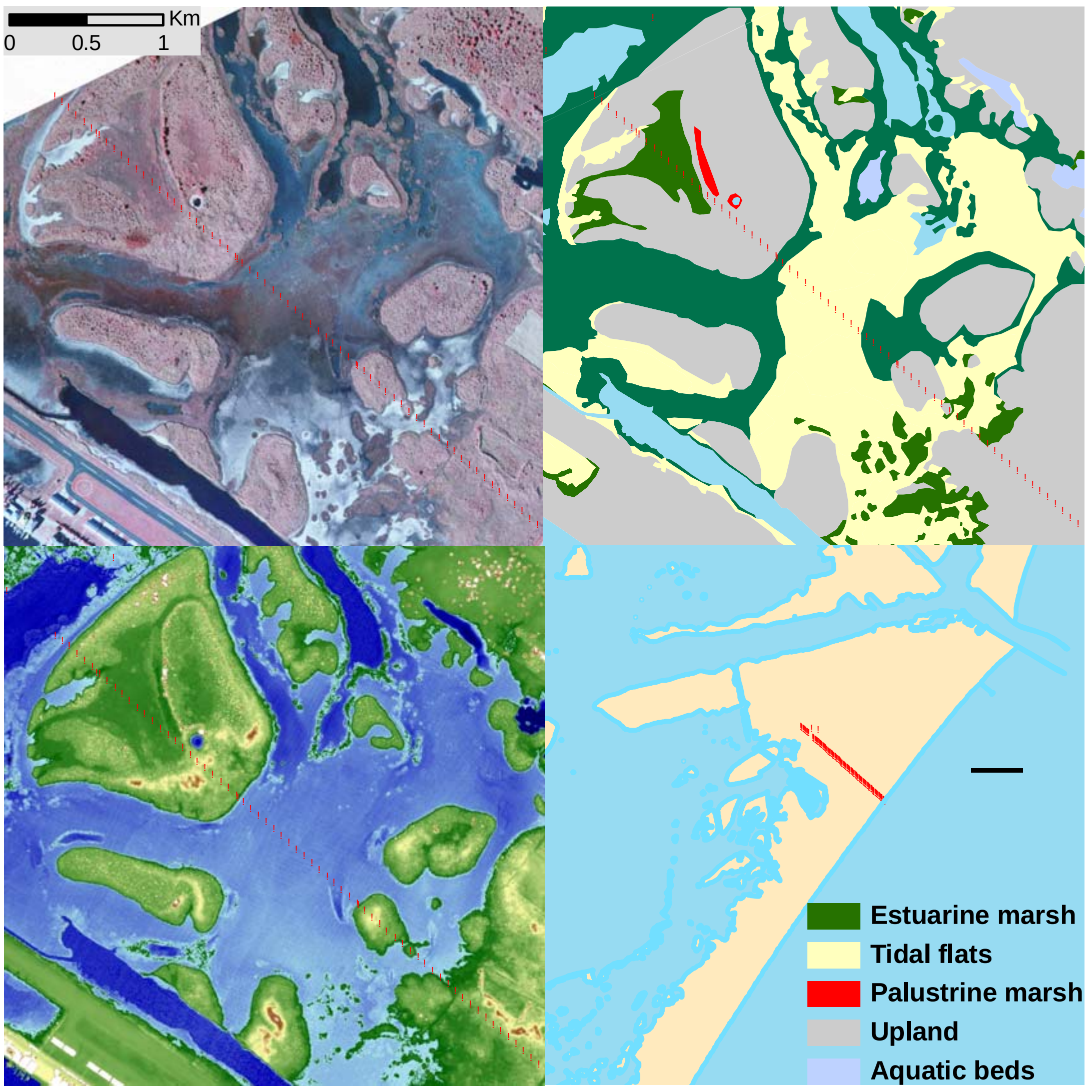
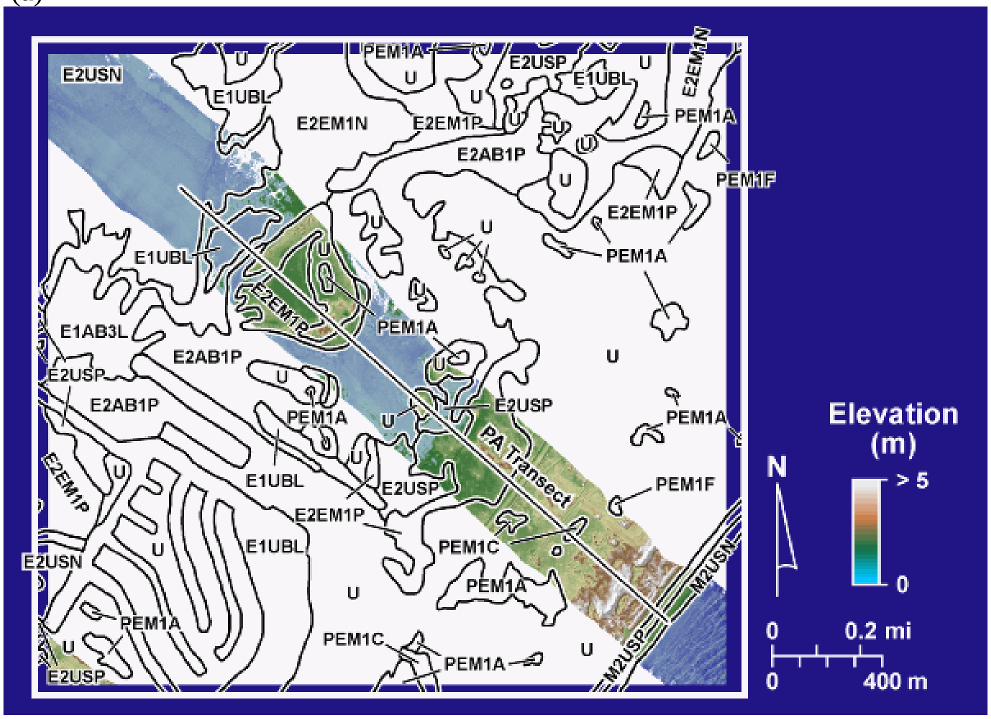


Figure 9. Comparison of color infrared aerial photograph (upper left) taken in 2004, map of wetland habitats (upper right) based on 2002 photo, Lidar image (lower left) acquired in 2005, and index map (lower right) showing map legend. Yellow to dark brown colors in Lidar image highlight higher elevations such as dunes. Red dotted line is a transect line across the island shown in Figure10. Lidar data from Gibeaut et al. (2006).

(a)



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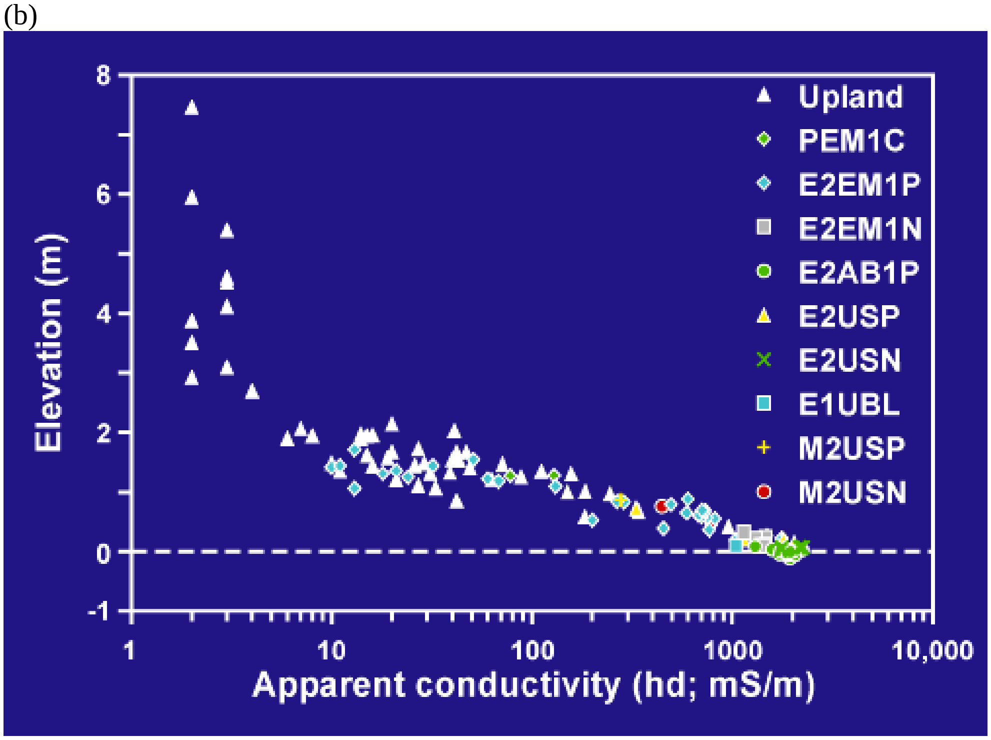
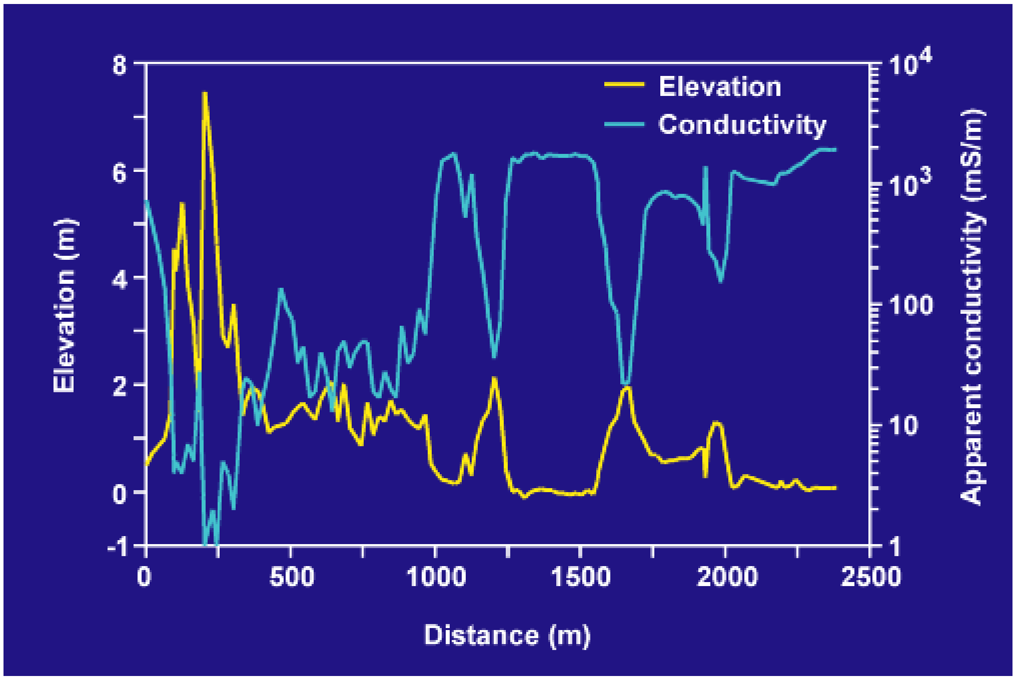


Figure 10. Digital elevation model (DEM) of a transect near Port Aransas showing habitats identified on USFWS NWI (1992) maps (a), and relationship between elevation, conductivity, and habitats along transects (b). The DEM was constructed from Lidar data acquired along the transect in 2003. From Paine et al. 2004a and b, 2005.



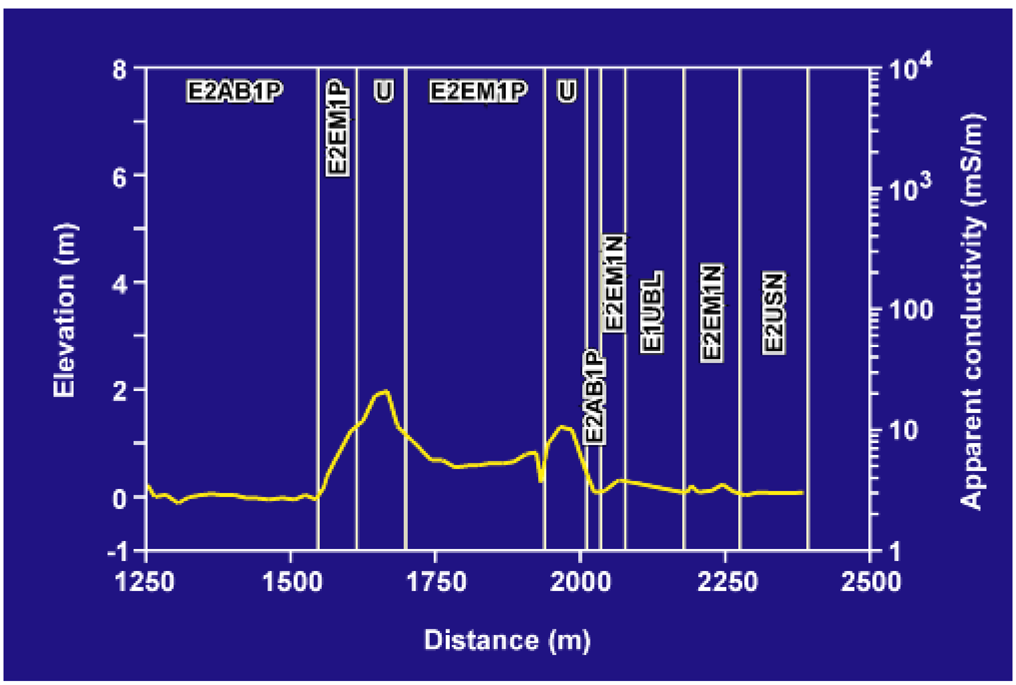


Figure 11. Relationship between soil conductivity, elevation, and habitat type along a transect on Mustang Island near Port Aransas. Habitats are from USFWS NWI maps based on 1992 aerial photos. From Paine et al. 2004.

Variations in Classification

Classification of wetlands varied somewhat for the different years. On 1979 and 2002-04 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. 12-14). For the 1950's maps, wetlands were classified by system, subsystem, and class. On 1979 maps, upland areas were also mapped and classified by upland habitats using a modified Anderson et al. (1976) land-use classification system (Fig. 14). Flats and beach/bar classes designated separately on 1950's and 1979 maps were combined into a single class, unconsolidated shore, on 2002-04 maps, in accordance with updated NWI procedures as exemplified on 1992 NWI wetland maps (Fig. 12). USFWS data for the study area were selected from nine 7.5-minute quadrangles (Fig. 15) from files previously digitized and maintained by the USFWS for the 1950's and 1979 wetland maps. Results include GIS data sets consisting of electronic-information overlays corresponding to mapped habitat features for the 1950's, 1979, and 2002-04. Data can be manipulated as information overlays, whereby scaling and selection features allow portions of the barrier island to be selected electronically for specific analysis. Among the objectives of the 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 between the historical and recent digital data. These cause errors when the data sets are overlain and analyzed in a GIS. The 2002-04 aerial photographs are georeferenced to USGS DOQ'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 2002-04 data. When the two data sets are superimposed in a GIS, the offset creates apparent wetland changes that are in reality cartographic errors resulting from a lack of accuracy in registration. Reregistration of the USFWS digital data sets is complicated and was beyond the scope of this project. Thus, caution must be used in interpreting changes from direct overlay 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. Overlay of the data sets was done primarily to identify significant wetland changes that could be verified by analyzing and comparing aerial photographs.

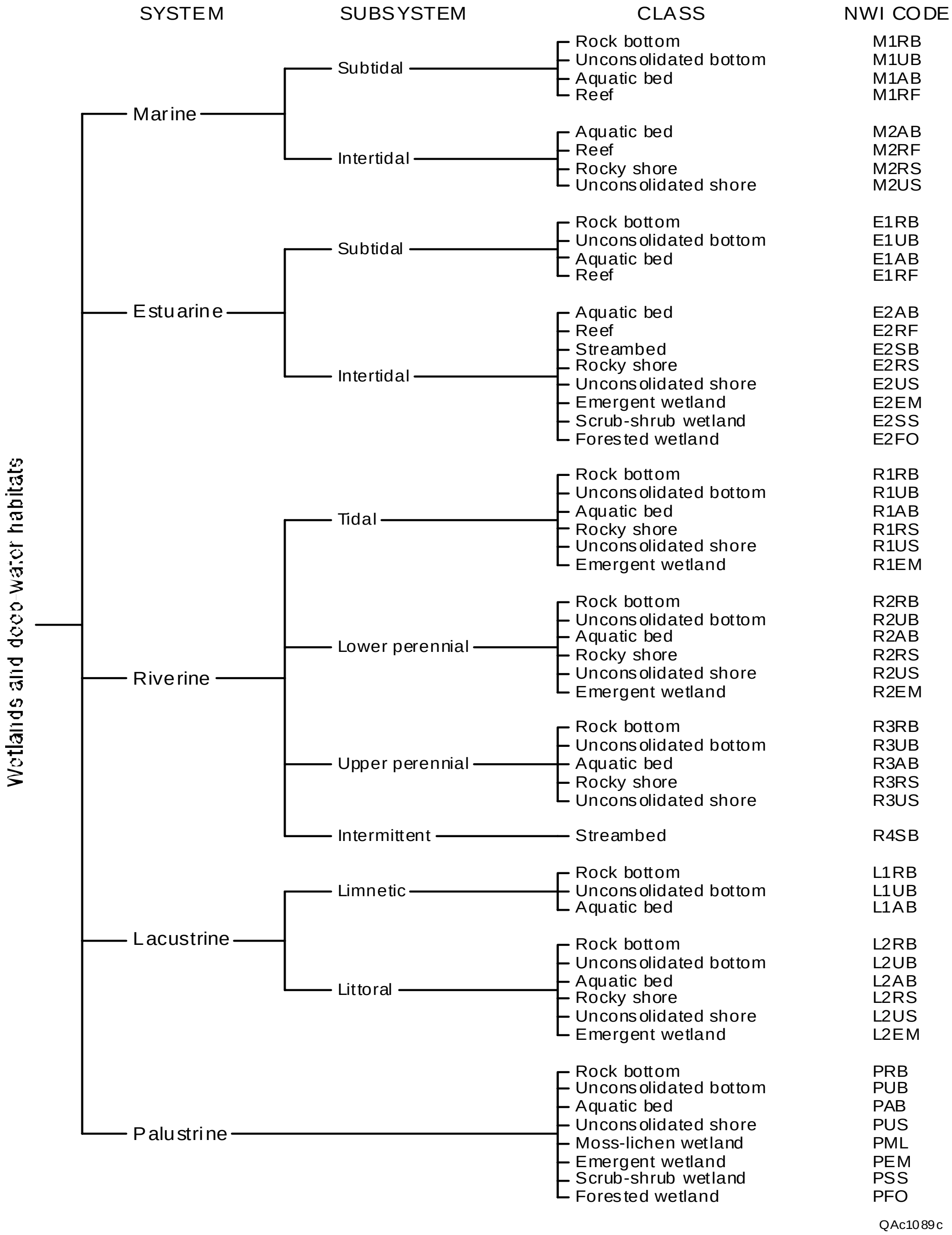


Figure 12. Classification hierarchy of wetlands and deepwater habitats showing systems, subsystems, and classes. From Cowardin et al. (1979).

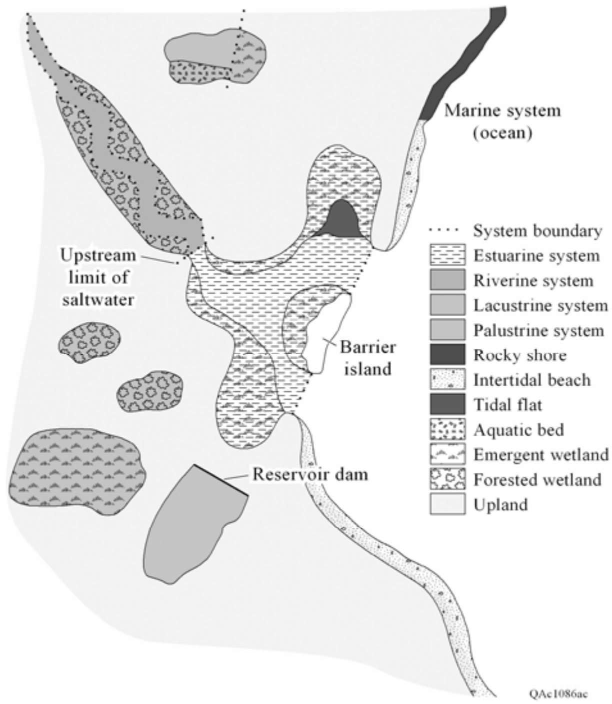


Figure 13. Schematic diagram showing major wetland and deepwater habitat systems. From Tiner (1984).

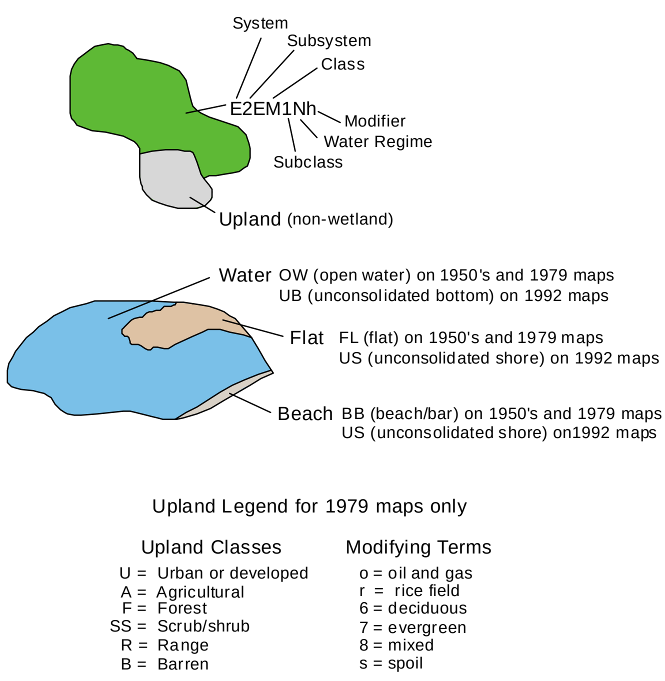


Figure 14. Example of symbology used to define wetland and upland habitats on NWI maps.

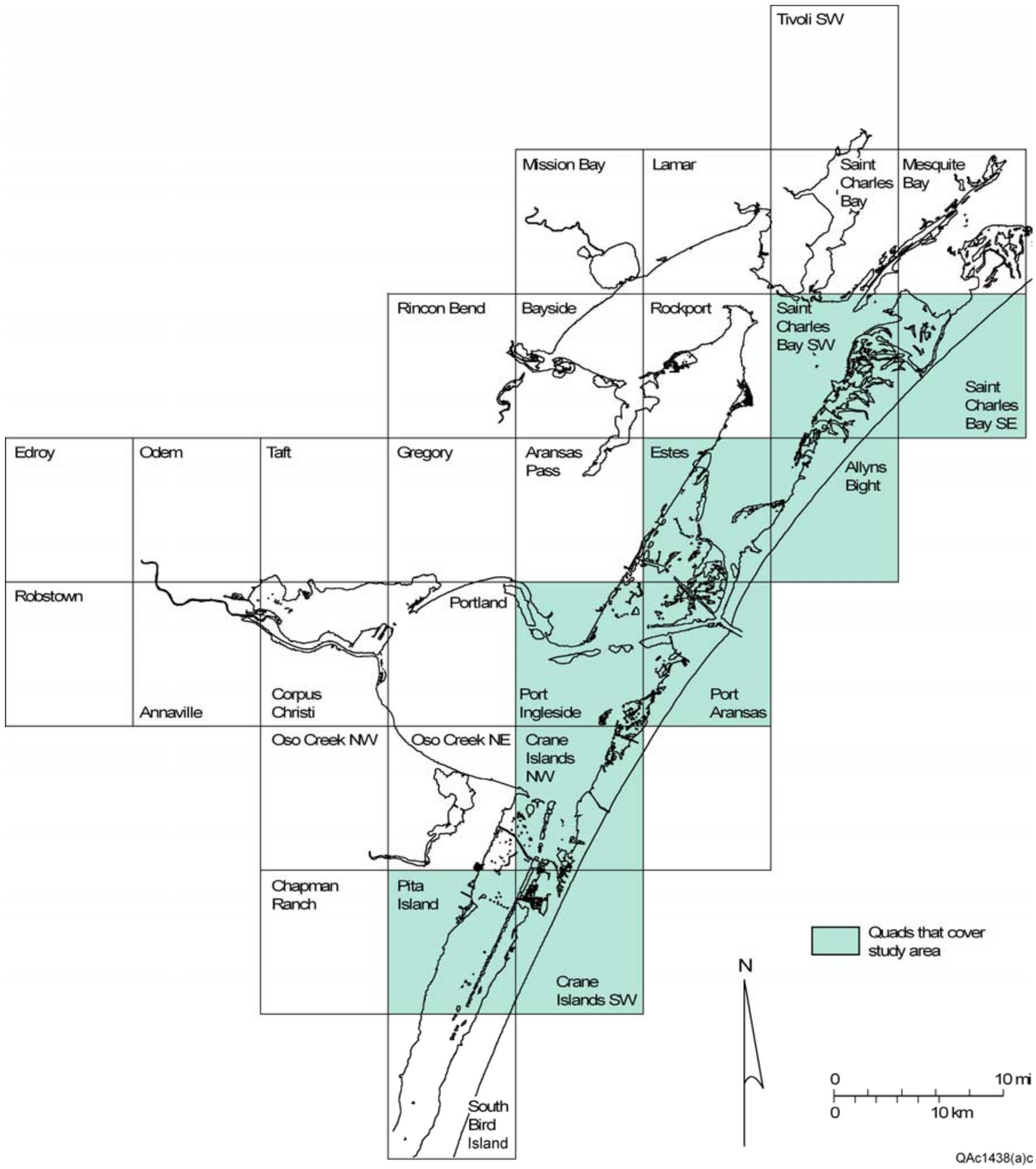


Figure 15. U.S. Geological Survey 7.5 minute quadrangles that encompass the barrier islands mapped in this investigation.

CLASSIFICATION OF WETLAND AND DEEPWATER HABITATS IN STUDY AREA

Cowardin et al. (1979) defined five major systems of wetlands and deepwater habitats: marine, estuarine, riverine, lacustrine, and palustrine (Fig. 12). Systems are divided into subsystems, which reflect hydrologic conditions, such as intertidal and subtidal for marine and estuarine systems. Subsystems are further divided into class, which describes the appearance of the wetland in terms of vegetation or substrate. Classes are divided into subclasses. Only vegetated classes were divided into subclasses for this project, and only for 1979 and 2002-04. In addition, water-regime modifiers (Table 1) and special modifiers were used only 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. 14). Symbols for certain habitats changed after 1979; these changes are shown in Figure 14 and are noted in the section on trends in wetland and aquatic habitats. Examples of alphanumeric abbreviations used in the section on status of wetlands apply only to 2002-04 maps. Much of the following discussion of wetland systems, as defined by Cowardin et al. (1979) is modified from White et al. (1993, 1998). Nomenclature and symbols (Appendix) in this discussion are based primarily on 1992 NWI maps.

Table 1. Water-regime descriptions for wetlands used in the Cowardin et al. (1979) classification system.

Water Regimes	
Nontidal	
(A)	Temporarily flooded—Surface water present for brief periods during growing season, but water table usually lies well below soil surface. Plants that grow both in uplands and wetlands are characteristic of this water regime.
(C)	Seasonally flooded—Surface water is present for extended periods, especially early in the growing season, but is absent by the end of the growing season in most years. The water table is extremely variable after flooding ceases, extending from saturated to well below the ground surface.
(F)	Semipermanently flooded—Surface water persists throughout the growing season in most years. When surface water is absent, the water table is usually at or very near the land's surface.
(H)	Permanently flooded—Water covers land surface throughout the year in all years.
(K)	Artificially flooded
Tidal	
(K)	Artificially flooded
(L)	Subtidal—Substrate is permanently flooded with tidal water.
(M)	Irregularly exposed—Land surface is exposed by tides less often than daily.
(N)	Regularly flooded—Tidal water alternately floods and exposes the land surface at least once daily.
(P)	Irregularly flooded—Tidal water floods the land surface less often than daily.
(S)*	Temporarily flooded—Tidal
(R)*	Seasonally flooded—Tidal
(T)*	Semipermanently flooded—Tidal
(V)*	Permanently flooded—Tidal

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

Table 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 1950's and 1979 maps (see Fig. 14).

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* *Ruppia maritima* *Thalassia testudinum*
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	*Avicennia germinans* *Iva frutescens*
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.*

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. 16). Composition of these areas is primarily sand and shell. Granite jetties along the coast in the marine system are classified as marine intertidal, rocky shore, irregularly flooded, rubble, and artificial (M2RS2Pr).

Figure 16. Marine beach along the Gulf shoreline on Mustang Island. 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).

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 tidal flats and estuarine beaches and bars. Water regimes for this habitat range primarily from irregularly flooded (E2USP) to regularly flooded (E2USN) to irregular exposed (E2USM) (Fig. 17). Aquatic beds (Fig. 18) observed in this system are predominantly submerged, rooted vascular plants (E1AB3L) that may include *Halodule wrightii* (shoalgrass), *Ruppia maritima* (widgeongrass), *Thalassia testudinum* (turtlegrass), *Syringodium filiforme* (manateegrass), and *Halophila engelmannii* (clovergrass) (Pulich et al. 1997).

(a)

(b)

Figure 17. Examples of high and low tidal flats (E2US) and algal flats (E2AB) on the bayward side of Mustang Island and north Padre Island (a), and shell berm on San José Island (b), which is also coded as E2US (estuarine intertidal unconsolidated shore).

Figure 18. Seagrass in water below the boat, *Thalassia testudinum* along the margin of San José Island in Aransas Bay, and upper photo of seagrass (*Halodule wrightii*) exposed by low tides in a shallow dredged channel near Packery Channel on north Padre Island.

Emergent areas closest to estuarine waters consist of regularly flooded, salt-tolerant grasses (low salt and brackish marshes) (E2EM1N) (Figs. 19-21). These communities are mainly composed of *Spartina alterniflora* (smooth cordgrass), *Batis maritima* (saltwort), *Distichlis spicata* (seashore saltgrass), *Sporobolus virginicus* (coastal dropseed), *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), *Spartina patens* (saltmeadow cordgrass) (Fig. 22), and *Phyla* sp. (frog fruit), among others. At slightly higher elevations, irregularly flooded estuarine emergent wetlands (E2EM1P) (high salt and brackish marshes) include *Borrichia frutescens* (sea oxeye), *Spartina patens*, *Spartina spartinae* (gulf cordgrass), *Distichlis spicata*, *Fimbrystylis castanea* (marsh fimbry), *Aster* spp. (aster), and many others.

Estuarine scrub/shrub wetlands (E2SS) are much less extensive than estuarine emergent wetlands. Representative plant species, in regularly flooded zones (E2SS1N), include *Avicennia germinans* (black mangrove) (Figs. 1 and 23), and in irregularly flooded zones (E2SS1P**)** between emergent wetland communities and upland habitats, include *Iva frutescens* (big-leaf sumpweed), *Baccharis halimifolia* (sea-myrtle, or eastern false-willow), *Sesbania drummondii* (drummond's rattle-bush), and *Tamarix* spp. (salt cedar).

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), and scrub/shrub. Naturally occurring ponds are identified as unconsolidated bottom, permanently or semipermanently flooded (PUBH or PUBF). Excavated or impounded ponds and borrow pits are labeled (on 1979 maps) with their respective

Figure 19. *Spartina alterniflora*, E2EM1N, on Mustang Island.

Figure 20. E2EM1N composed of *Spartina alterniflora* and scattered *Avicennia germinans* along the margin of San José Island.

Figure 21. Individual is standing on the contact between *Batis maritima* in distance mapped as E2EM1N, and dead, annual *Salicornia bigelovii* in foreground mapped as part of tidal flat E2US1N.

Figure 22. *Spartina patens* in foreground of photographs mapped as E2EM1P. Top photo taken on Mustang Island and bottom on San José Island.

(a)

(b)

Figure 23. Shrubs of *Avicennia germinans* on Mustang Island (a) and San José Island (b) mapped as E2SS.

modifiers (PUBHx or PUBHh). Palustrine emergent wetlands (Fig. 24) are generally equivalent to fresh to brackish, 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.

Vegetation communities typically characterizing areas mapped as low emergent wetlands (PEM1F) include *Paspalum vaginatum* (seashore paspalum), *Typha domingensis* (southern cattail), *Schoenoplectus pungens* (formerly *Scirpus americanus*) (three-square bulrush), *Eleocharis* spp. (spikerush), *Bacopa monnieri* (coastal water-hyssop), *Pluchea purpurascens* (saltmarsh camphor-weed), and others. Other species reported include *Schoenoplectus californicus* and *Juncus* sp. (White et al. 1983). Areas mapped as topographically higher and less frequently flooded emergent wetlands (PEM1A) include *S. spartinae*, *Borrichia frutescens, S. patens*, *Cyperus* spp. (flatsedge), *Hydrocotyle bonariensis* (coastal-plain penny-wort), *Phyla* sp. (frog fruit) *Aster spinosus* (spiny aster), *Paspalum* spp. (paspalum), *Panicum* spp. (panic), *Polygonum* sp. (smartweed), *Andropogon glomeratus* (bushy bluestem), and *Cynodon dactylon* (Bermuda grass), to mention a few.

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

Palustrine scrub/shrub and forested wetlands are very limited in extent. They are typically seasonally flooded and may fringe a pond. Species include *Salix* (Figs. 25 and 26).

Lacustrine System

Water bodies greater than 8 ha are included in this system, with both limnetic and littoral subsystems represented. Only one area was classified as lacustrine in 1979 wetlands and none in the 2002-04 wetlands. Nonvegetated water bodies are labeled limnetic or littoral unconsolidated bottom (L1UB or L2UB) (L1OW or L2OW in 1950's and 1979 data sets), depending on water depth. The impounded modifier (h) is used on bodies of water impounded by levees or artificial means, and the modifier "s" to indicate spoil or dredged material.

Figure 24. Examples of palustrine marshes on Mustang and north Padre Island. Vegetation includes *Typha* sp., *Eleocharis* sp., and other species listed in text.

Figure 25. Palustrine scrub/shrub wetland (PSS) on north Padre Island. Species include *Salix* sp.

Figure 26. Palustrine forested wetland (PFO) on Mustang Island. Trees include *Salix nigra*, *Sesbania macrocarpa*, and *Sapium sebiferum* (Chinese tallow), among others.

STATUS OF WETLANDS AND AQUATIC HABITATS IN 2002-04

Major estuarine habitats in the study area include salt and brackish marshes, tidal flats, seagrass beds, and mangroves. Areas of open water are also important components of the salt and brackish marsh complex. The palustrine system consists of marshes, flats, and open water that are not tidally influenced, and are typically characterized by fresh-water marsh assemblages. The marine system occurs along the shore of the Gulf of Mexico and is composed of the topographically lower forebeach and the higher, less frequently flooded backbeach.

In 2002-04, wetland and aquatic habitats covered about 50,580 ha within the study area (Fig.27, Table 3), which includes a buffer zone of open water that surrounds and "parallels" the shoreline in the bays and the Gulf (Fig. 3). Approximately 12,055 ha within the study area was classified as uplands. Of the three wetland systems mapped, the estuarine system is by far the largest (Fig. 28, Table 3). Emergent vegetated wetlands (E2EM, E2SS, PEM areas) cover 5,537 ha, 72% of which is estuarine marsh. The extent of all mapped wetlands, deepwater habitats, and uplands for each year is presented in the appendix. The study area was subdivided into geographic areas—San José Island, Mustang Island, north Padre Island, and Harbor Island —to allow a more site-specific analysis of status and trends (Figs. 3 and 27).

The most extensive estuarine emergent wetlands (salt and brackish marshes) occurred on San José Island, where the total area of estuarine marshes in 2002-04 was 2,897 ha (Fig. 29). Mustang Island was a distant second with 913 ha. Harbor Island and north Padre Island, combined, had less than 200 ha of estuarine marsh. Tidal flats are most extensive on San José and Mustang Island where the total areas were 3,866 ha and 1,695 ha, respectively. North Padre Island is relatively narrow, has no washover channels, has fewer connections to the estuarine system, and has extensive upland vegetation-stabilized dune fields, thus estuarine marshes and tidal flats, with total areas of 47 ha and 264 ha, respectively, are less extensive than in the other areas. Eolian deflation flats in mid-and back-island areas on north Padre Island, however, are the sites of palustrine marshes and associated water and flats. Accordingly, north Padre has the largest distribution of palustrine habitat at 356 ha. San José Island is next with 294 ha, followed by Mustang and Harbor Islands (Fig. 29). Seagrass beds were most abundant in the Mustang Island area with 2,726 ha (Fig. 29). On San José and Harbor Island, seagrasses covered areas of 2,490 ha and 2,361 ha, respectively. The north Padre Island study area, where 822 ha of seagrass was mapped, does not extend landward of the Gulf Intracoastal Waterway and, thus, excluded some seagrass beds that are very abundant in Laguna Madre. Mangrove habitats were most extensive on Harbor Island, where 634 ha were mapped, followed in abundance by Mustang Island at 179 ha. San José and north Padre Island had a combined total of 24 ha of mangrove/scrub/shrub vegetation. The Gulf beach, marine unconsolidated shore, was most abundant on San José Island at 260 ha, followed by Mustang Island at 227 ha, and north Padre Island at 49 ha.

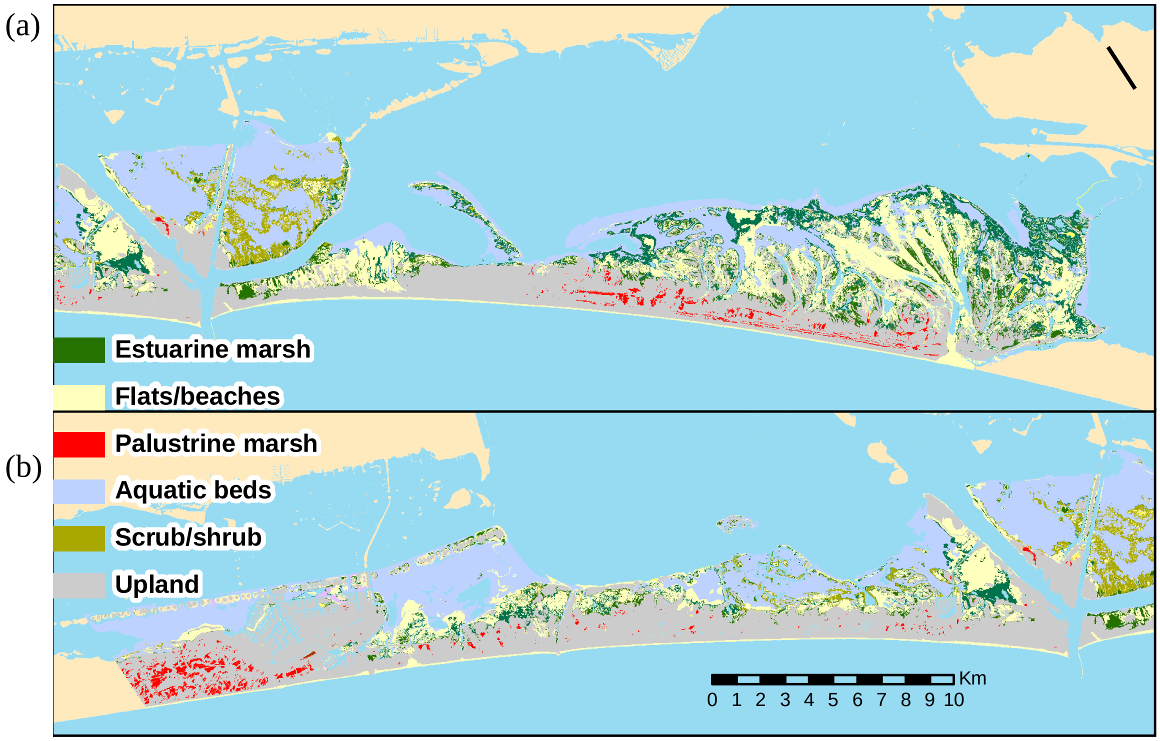


Figure 27. Maps of major habitats on Coastal Bend islands in 2002-04. San José Island and Harbor Island are shown in (a) and Mustang Island and north Padre Island in (b).

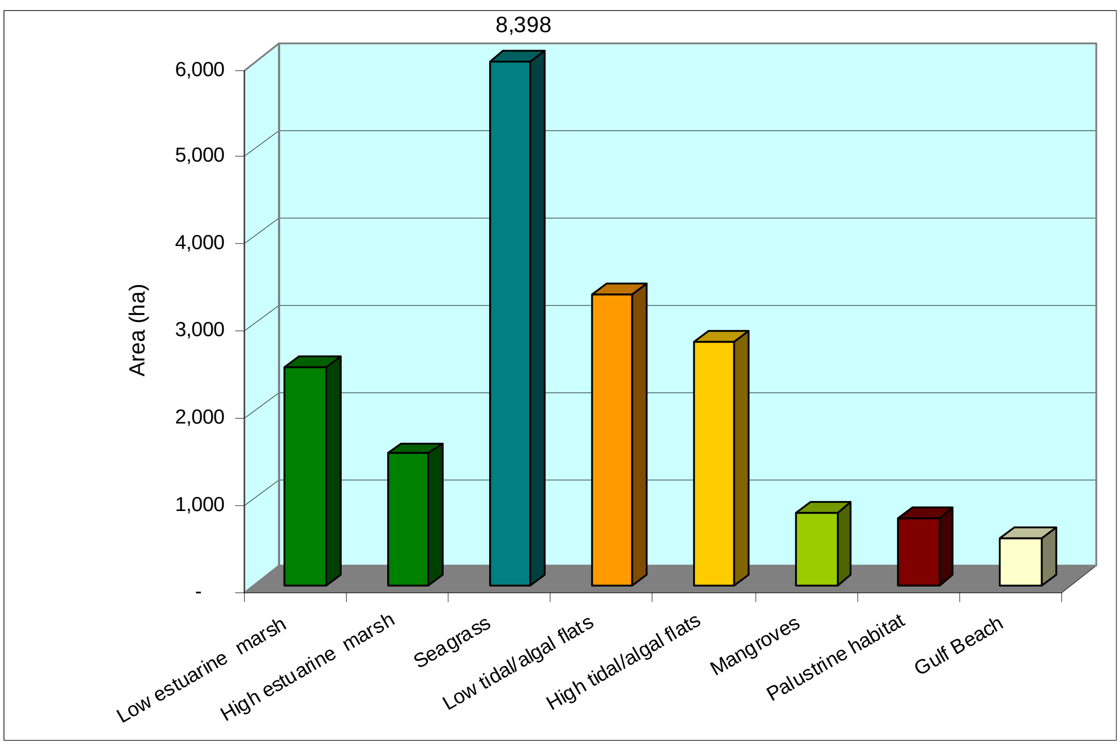


Figure 28. Areal extent of selected habitats in the study area in 2002-04.

Table 3. Areal extent of mapped wetland and aquatic habitats in 2002-04.

NWI Code	National Wetlands Inventory Description	Hectares	Acres	Percent
E1AB3	Estuarine Subtidal Aquatic Bed, Rooted Vascular	8,398	20,751	13.41
E1AB5	Estuarine Subtidal Aquatic Bed, Unknown Submergent	101	249	0.16
E1UB	Estuarine Subtidal Unconsolidated Bottom	16,947	41,876	27.05
E2AB1N	Estuarine Intertidal Aquatic Bed, Algal Regularly Flooded	1,818	4,492	2.90
E2AB1P	Estuarine Intertidal Aquatic Bed, Algal Irregularly Flooded	1,277	3,155	2.04
E2EM1N	Estuarine Intertidal Emergent Wetland, Regularly Flooded	2,502	6,183	3.99
E2EM1P	Estuarine Intertidal Emergent Wetland, Irregularly Flooded	1,507	3,724	2.41
E2RF2M	Estuarine Intertidal Reef, Irregularly Exposed	9	22	0.01
E2SS3	Estuarine Intertidal Scrub/Shrub Wetland	837	2,068	1.34
E2USM	Estuarine Intertidal Flat, Irregularly Exposed	516	1,275	0.82
E2USN	Estuarine Intertidal Flat, Regularly Flooded	997	2,464	1.59
E2USP	Estuarine Intertidal Flat, Irregularly Flooded	1,513	3,739	2.42
Subtotal		**36,422**	**90,000**	**58.14**
M1UB	Marine Subtidal Unconsolidated Bottom	12,860	31,777	20.53
M2USN	Marine Intertidal Unconsolidated Shore, Regularly Flooded	167	413	0.27
M2USP	Marine Intertidal Unconsolidated Shore, Irregularly Flooded	368	910	0.59
Subtotal		**13,395**	**33,099**	**21.38**
PEM1A	Palustrine Emergent Wetland, Temporarily Flooded	226	559	0.36
PEM1C	Palustrine Emergent Wetland, Seasonally Flooded	342	845	0.55
PEM1F	Palustrine Emergent Wetland, Semi-Permanently Flooded	123	304	0.20
PFO1A	Palustrine Forested, Temporarily Flooded	2	5	0.00
PSS1A	Palustrine Scrub-Shrub	1	2	0.00
PUB	Palustrine Unconsolidated Bottom	57	141	0.09
PUS	Palustrine Unconsolidated Shore	17	43	0.03
Subtotal		**769**	**1,899**	**1.23**
U	Upland	12,055	29,788	19.24
Total		**62,641**	**154,786**	**100.00**

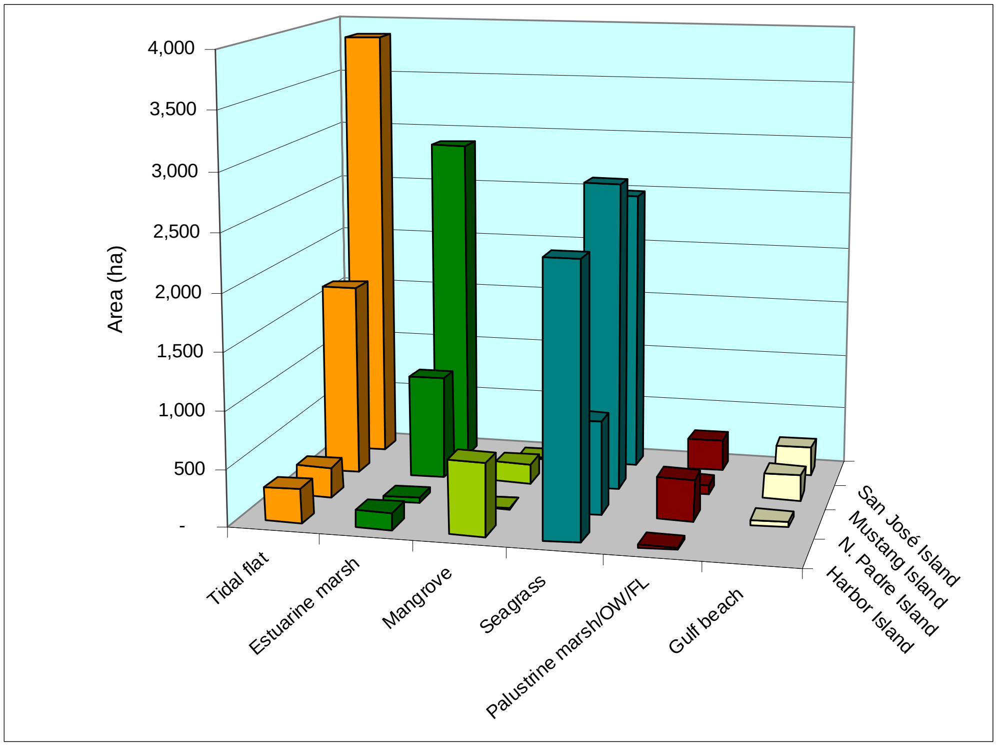


Figure 29. Distribution of selected habitats by geographic area in 2002-04. The most extensive distribution of estuarine marshes and tidal flats is on San José Island. Mangroves are most extensive on Harbor Island.

Table 4. Areal extent (in hectares) of selected habitats for each island in 2002-04.

Habitat	*San José*	*Mustang*	*North Padre*	*Harbor*
Tidal/algal flat	3,866	1,695	263	298
Estuarine marsh	2,897	913	47	152
Mangroves/scrub/shrub	15	179	9	634
Palustrine marsh/flat/water	294	93	356	24
Seagrass/aquatic bed unknown	2,553	2,741	822	2,383
Gulf beach	260	227	49	0
Estuarine open water	8,154	6,413	731	1,648
Marine open water	5,718	6,408	733	0
Oyster reef	9	0	0	0
Upland	4,929	4,379	2,310	436
Total	**28,694**	**23,049**	**5,320**	**5,575**

Estuarine System

Marshes (Estuarine Intertidal Emergent Wetlands)

The estuarine intertidal emergent wetland habitat (E2EM) in the study area consists of 4,009 ha of salt- and brackish-water marshes. The low marsh, or regularly flooded estuarine marsh, is most abundant at 2,502 ha (Fig. 28; Table 3). The higher, irregularly flooded estuarine marsh covers about 1,507 ha. The most extensive estuarine marshes (Fig. 29) occur on (1) San José Island where relatively broad areas of marsh have spread over relict tidal inlet/washover fan complexes at the northeast end of the island, and (2) on Mustang Island, for example, where extensive marshes have developed near Port Aransas in the outflow reaches of a sewage treatment plant. Estuarine marshes are less abundant on Harbor Island and north Padre Island, together accounting for less than 200 ha.

Tidal Flats (Estuarine Intertidal Unconsolidated Shores and Aquatic Beds)

Estuarine intertidal unconsolidated shores (E2US) include wind-tidal flats, beaches, and some algal flats (Fig. 17). Estuarine intertidal aquatic beds (E2AB) include well defined algal flats with distinct signatures on the aerial photographs. Approximately 6,120 ha of E2US/E2AB was mapped in the study area (Table 3). Tidal flats are most extensive on San José Island, followed by Mustang Island, Harbor Island, and north Padre Island (Fig. 29; Table 4). Low, regularly flooded tidal/algal flats are slightly more extensive than high flats (Fig. 28). Because of the low astronomical tidal range, many flats are flooded only by wind-driven tides and are, thus, designated as wind-tidal flats (McGowen et al. 1976). These tidal habitats represent about 56% 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 aerial photographs were taken. Accordingly, absolute areal extent of flats may vary from that determined using aerial photographs.

Mangroves (Estuarine Intertidal Scrub/Shrub)

Estuarine scrub/shrub wetlands (E2SS) (mostly black mangrove habitat, Fig. 23) have a total area of 837 ha, or about 8 percent of the estuarine intertidal vegetated classes. It should be noted that scattered mangrove shrubs are a common component of many estuarine marshes, particularly on Mustang Island (Fig. 20). Only in areas where the mangrove shrubs were dominant were they mapped separately as E2SS habitat. This habitat has its broadest distribution on Harbor Island and Mustang Island where *Avicennia germinans* is abundant (Figs. 1 and 23; Table 4). Sherrod and McMillan (1981) noted that mangroves in this Coastal Bend area are one of the three major concentrations along the Texas coast and are typically mixed with *Spartina*, *Batis*, and *Salicornia*.

Seagrass Beds (Estuarine Subtidal Aquatic Beds)

Estuarine subtidal rooted vascular aquatic beds (E1AB3L) represent areas of submerged vascular vegetation, or seagrasses (Fig. 18). 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 quite visible in most areas on the 2002-04 imagery but are obscured by turbidities in some areas and could not be mapped in total. Before this study was completed, color infrared digital orthophotographs (1-meter resolution) acquired in 2004 as part of the National Agriculture Imagery Program (NAIP), U. S. Department of Agriculture (USDA) became available. These photos were used to help define seagrass areas and refine the original delineations based on previously acquired 2002-04 photo series. Densities of the mapped seagrass ranged from very dense to patchy. Seagrass beds throughout the study area covered 8,398 ha in 2002-04 and are the most extensive habitat (excluding open water). The largest distribution of seagrasses is along the margins of and in the numerous shallow areas on the bayward side of Mustang Island, San José Island, and Harbor Island (Figs. 18 and 29); the areal extent of seagrasses are similar on these three islands accounting for 32%, 30%, and 28% of this habitat, respectively. The remaining 10% is in Laguna Madre along north Padre Island. For additional data on Coastal Bend seagrass see Pulich et al. 1997.

Open Water (Estuarine Subtidal Unconsolidated Bottom)

In addition to the shallow lagoons and ponds within the marsh complexes, estuarine subtidal unconsolidated bottom (E1UBL), or open water, includes sections of bay water paralleling the bayward shores of the islands. This area was included primarily for cartographic purposes to help standardize the study area for each time period, but also to include Shamrock Island bayward of Mustang Island and Mud Island bayward of San José Island. The total area of estuarine open water including subtidal algae and subtidal unknown bottom mapped in the study area is 17,048 ha (Table 3).

Oyster Reefs (Estuarine Reefs)

Oyster reefs (E2RF2M) mapped on the 2002-04 photographs amounted to just 9 ha. Only those reefs that were very near the water's surface and were clearly visible were mapped, thus, many were not mapped.

Palustrine System

Marshes (Palustrine Emergent Wetlands)

Palustrine emergent wetlands (PEM) (Fig. 24), or inland "freshwater marshes", cover 691 ha (Fig. 28) and represent only 12 percent of emergent vegetated wetlands in the study area. The broadest distributions of palustrine emergent wetlands are on north Padre Island and San José Island (Figs. 27 and 29). On north Padre Island, eolian deflation troughs and depressions provide topographic lows in which water ponds and supports hydrophytic vegetation, whereas on San José Island swales between relict dune ridges are more typical sites for palustrine marshes (Figs. 4 and 5). Palustrine marshes were classified into one of three water regimes: (1) temporarily flooded, (2) seasonally flooded, or (3) semi-permanently flooded. Most extensive marshes were those that are seasonally flooded. Palustrine marshes on north Padre Island account for almost 50% of this habitat, San José Island, about 40%, and Mustang and Harbor Islands together, a little more than 10%.

Shrubs and Trees (Palustrine Scrub-Shrub and Forested Wetlands)

Less than a hectare, each, of palustrine scrub-shrub and forested wetlands were mapped in the study area (Figs. 25 and 26). These habitats were mapped only on north Padre Island and Mustang Island.

Open Water and Flat (Palustrine Unconsolidated Bottom and Unconsolidated Shore)

Palustrine unconsolidated bottom (PUB), or open water, generally consists of small, fresh- to brackish-water ponds, and palustrine unconsolidated shore consists of small unvegetated flats. The total mapped area of these habitats together is 74 ha, approximately 57 ha of water and 17 ha of flats. The largest area of palustrine water habitat is on Mustang Island, where 23 ha was mapped, most of which was associated with development ponds.

Marine System

Gulf Beach (Marine Intertidal Unconsolidated Shore)

The Gulf beach represents the marine intertidal unconsolidated shore (M2US). Two components were mapped; the topographically lower regularly flooded forebeach and irregularly flooded backbeach (Figs. 4 and 16). The total area of this habitat in the study area is 535 ha. Almost 50% of this habitat occurs on San José Island, the longest island mapped, followed by Mustang Island at 42% (Fig. 29 and Table 4). A buffer zone 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.

HISTORICAL TRENDS IN WETLAND HABITATS

Methods Used to Analyze Trends

Trends in wetland habitats were determined by analyzing habitat distribution as mapped on 2002-04, 1979, and 1950's aerial photographs (Fig. 30). 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.

Geographic Information System

The GIS-ArcInfo and ArcMap were used to analyze trends. This software allowed for direct comparison not only between years, but also by each island. Analyses included tabulation of losses and gains in wetland classes for each area for selected periods. 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 ArcInfo.

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 photo-interpreters 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 (1:24,000) larger 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.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. Large apparent losses in palustrine wetlands were documented on barrier islands, but much of this change we think is due to drier conditions when the 2002-04 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

Some wetland codes used on 2002-04 maps are different from those used on the 1950’s and 1979 maps (Fig. 14). 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.

Wetland Trends and Probable Causes, 1950’s through 2002–04

In analyzing trends, wetland classes were emphasized over water regimes and special modifiers because habitats were mapped only down to class on 1950’s photographs. It should be noted 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 direction of trends than absolute magnitudes. Probable causes of historical changes are discussed by geographic area toward the end of this summary. From the 1950’s through 2002–04 within the study area, some wetland classes underwent substantial net losses and gains, whereas others remained more stable (Table 5; Figs. 30 and 31).

Table 5. Total area (ha) of major habitats in the 1950’s, 1979 and 2002–04 in study area.

Habitat	***1950’s***	***1979***	***2002-04***
Estuarine marsh	1,763	3,087	4,009
Mangrove/scrub/shrub	Not mapped	665	837
Tidal flat	13,647	6,114	6,121
Seagrass	4,167	7,704	8,357
Palustrine marsh	665	890	767
Gulf beach	861	630	535

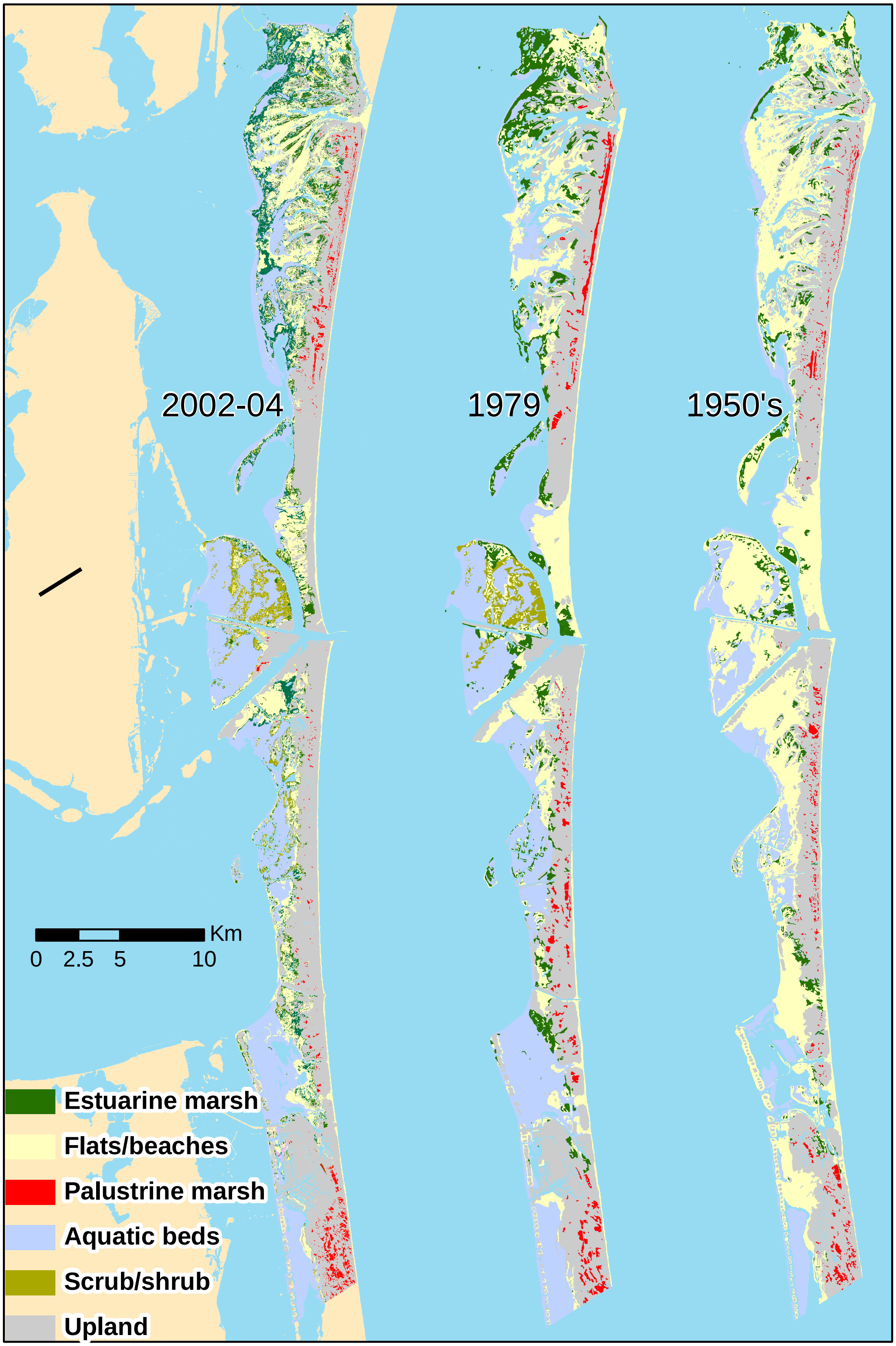


Figure 30. Map showing distribution of major wetland and aquatic habitats in 2002–04, 1979, and 1950’s in study area.

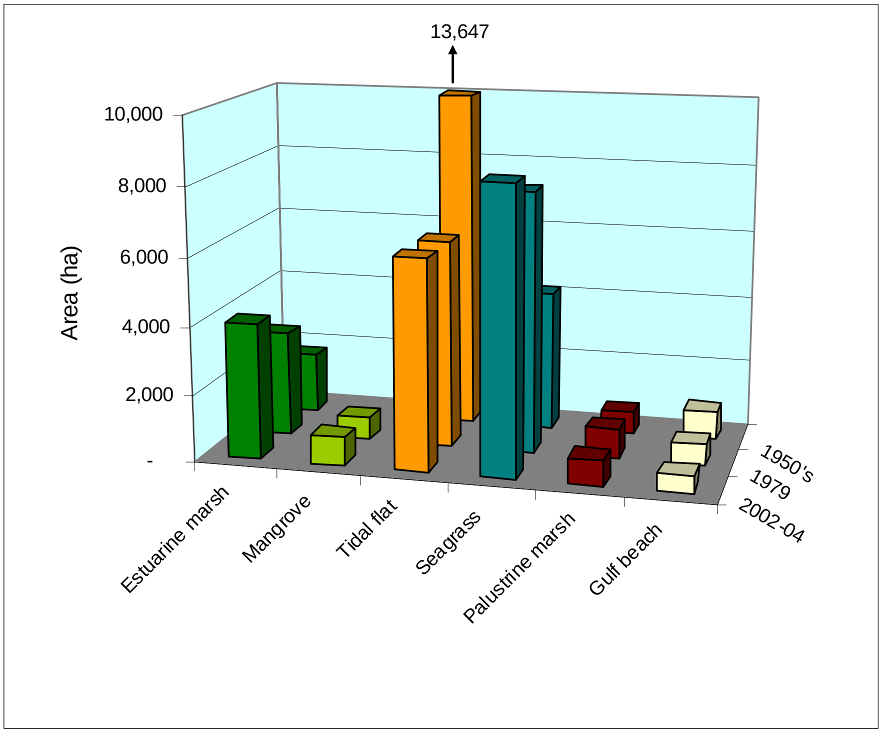


Figure 31. Areal distribution of major habitats in the study area in the 1950’s, 1979, and 2002–04.

In general, estuarine marshes increased in total area during each period (1950’s–1979 and 1979–2002–04), with a total net gain of 2,246 ha from the 1950’s through 2002–04. Approximately 60% of this gain occurred from the 1950’s through 1979, indicating that the rate of gain decreased from 1979 through 2002–04. Average rate of marsh gain during the earlier period was about 58 ha/yr, and for the more recent period, about 38 ha/yr. Combining estuarine scrub/shrub with marsh (mangrove/marsh habitat), the rate of gain through time was 86 ha/yr and 46 ha/yr for the earlier and later periods, respectively.

The most extensive losses in habitats occurred in tidal flats, which underwent a major net decline from the 1950’s through 1979 (Fig. 31). The total area of tidal flats decreased by 7,533 ha during this period (1950’s–1979). During the later period (1979–2002–04), the total area of tidal flats remained rather stable, with a small net gain of 7 ha. Seagrass beds increased in total area by 3,537 ha from the 1950’s through 1979 and also increased from 1979 through 2002–04, but at a much smaller amount (653 ha). Palustrine habitats had their largest distribution in 1979, at 890 ha, and lowest in the 1950’s, at 665 ha (Table 5). The total area of mapped mangroves was slightly larger in 2002–04 than in 1979, indicating a net gain of 173 ha (this habitat was not mapped on the 1950’s black-and-white photographs). Finally, there was a net decline in the mapped area of Gulf beaches, decreasing in total area by 231 ha from the 1950’s through 1979, and by 95 ha from 1979 through 2002–04, a net change of almost -40% since the 1950’s.

Analysis of Wetland Trends by Geographic Area

As in previous sections, the study area was subdivided into major natural areas and geographic components for analysis of historical trends (Fig. 27). The barrier islands are presented from northeast to southwest in the following order (1) San José Island, (2) Mustang Island, and (3) north Padre Island. The flood tidal delta, Harbor Island, is presented last. The subdivision allowed a more site-specific analysis of trends and their probable causes. Estuarine marshes, tidal flats, seagrass beds, mangroves, and palustrine marshes are emphasized.

San José Island

General Trends. The most significant wetland trend on San José Island was the systematic gain of estuarine marsh. The early time interval experienced a 93% increase, when 1,102 ha in the mid-1950's increased to 2,122 ha by 1979 (Fig. 32). By 2002–04 the estuarine marsh area increased by 37% to 2,897 ha. Seagrasses expanded throughout the study period at a consistent rate. In both the mid-1950's (791 ha) through 1979 (1,402 ha) and 1979 through 2002–04 (2,490 ha) periods, seagrasses increased by 77%. Tidal flats, the remaining dominant habitat type on San José Island, lost 39% in the early period, when 6,301 ha in the mid-1950's was reduced to 3,858 ha by 1979. The 2002–04 tidal-flat total did not change significantly, remaining at 3,866 ha. Relative overall amounts of palustrine marsh are small on San José Island when compared with that of other habitats. However, the initial mid-1950's total of 196 ha increased significantly to 356 ha by 1979 (+82%). The large gain was reversed when palustrine marsh lost 14% by 2002–04 (306 ha). The Gulf beach, another relatively small habitat, experienced a systematic loss through time. A 41% loss occurred from the mid-1950's through 1979, when the total beach areas were 499 ha and 294 ha, respectively. This loss was followed by an additional loss of 14% by 2002–04, when the total area was 260 ha.

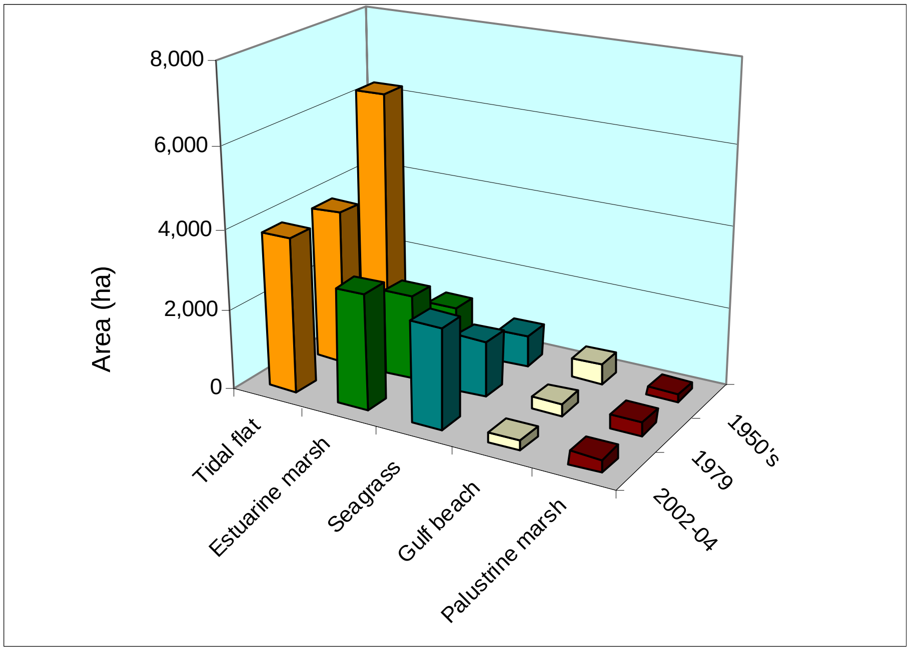


Figure 32. Areal extent of major habitats on San José Island in the 1950's, 1979, and 2002–04.

Probable Causes of Trends. In the 1950's through 1979 period, ~60% of the gain of estuarine marsh on San José Island was into areas of estuarine tidal flat. Due north of North Pass (Fig. 33) on the bay side of the island is an area where marsh spread into flats. Another example is on the gulfward side of Mud Island. The washover fan/flood-tidal delta complex (Fig. 33) also experienced large amounts of marsh spreading into tidal flats. Change occurred primarily on the older and topographically lower distal parts of the fan complex. Marsh spread into the distal part of the active fan near Spalding Cove, the distal inactive fan, and throughout the flood-tidal delta. Some marsh gain occurred in areas previously mapped as uplands, where high marsh migrated into the lower parts of eolian mounds on the inactive fan, and to some degree on the active fan. Eolian mounds are elongate sand mounds that occupy the interdistributary areas of the washover fan (Andrews, 1970). Marsh migration into low tidal-flat areas and eolian mound uplands are thought to be the result of relative sea-level rise.

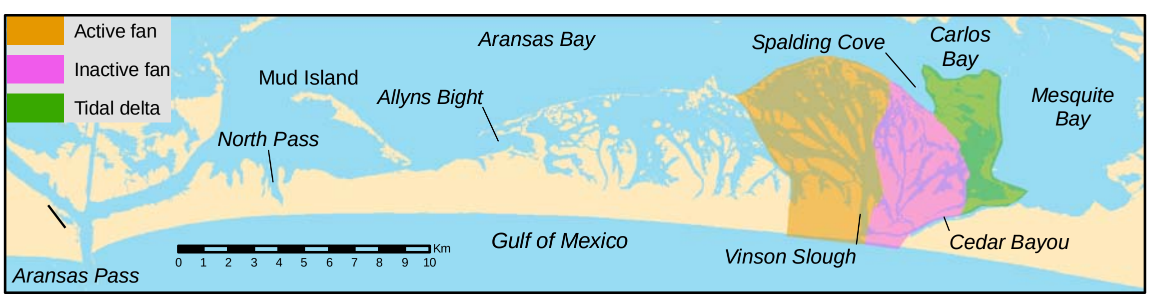


Figure 33. Index map showing features on San José Island. Washover fan/flood-tidal delta features after Andrews (1970).

During the early period, large areas of estuarine flats were lost to open water and submerged aquatic beds (~54%). Significant losses of tidal flats occurred on (1) Mud Island, (2) the back side of the main island including North Pass, (3) the proximal and central active washover fan including Vinson Slough, and (4) in the mid-inactive fan. Another important trend was the loss of flats to marsh (~29%). As noted earlier, the washover fan/flood-tidal delta complex was the site of large losses of flat as estuarine marsh spread into the flats. Marsh expanded into channels on the distal active washover fan, into the distal inactive fan, and into the flood-tidal delta near Carlos Bay. In addition, marsh spread into flats on the main part of the island, along the gulfward edge of Allyns Bight and due north of Allyns Bight in the bay, on Mud Island, and in the bay north of North Pass.

Changes in seagrass area on San José Island between the 1950's and 1979 occurred primarily on the bay side of the main part of the island, where ~59% of seagrass expansion was into tidal flats and ~33% of seagrass expansion was into open water. A large area of seagrass was mapped in 1979 in the bayside, sheltered area of the broad section of the island, in prior tidal flats along the gulfward side of Mud Island, and in the distal part of the washover fan at North Pass. Seagrass gain was more limited on the washover fan/flood-tidal delta complex. Some seagrasses were mapped in the open water in Spalding Cove, the nearby edge of the active washover fan, and in open water of Mesquite Bay near Cedar Bayou. The topographically lower main island is more subject to the effects of relative sea-level rise and experienced a larger amount of seagrass expansion than did the topographically higher washover fan. Encroachment of seagrasses into former tidal-flat areas along San José Island requires more frequent flooding. These conditions suggest that once relatively dry exposed areas have been inundated through relative sea-level rise.

Palustrine marsh is a relatively small habitat when compared with the overall wetland system on San José Island. However, palustrine marsh experienced one of the larger net gains in the early time interval (~82%). A large increase in palustrine marsh is consistent with observed changes on other parts of the barrier system on the south Texas coast. Higher amounts of moisture collecting in the troughs of the ridge-and-swale topography provided suitable habitat for palustrine marsh expansion in 1979.

Another relatively small wetland habitat is the Gulf beach. Net losses in beach area over time may be due to overmapping in the mid-1950's. A broader beach in the mid-1950's, however, may have resulted from drier conditions that inhibited the growth of vegetation on the back beach. The beach at Vinson Slough extends well inland, resulting in an artificially high beach area.

In the period between 1979 and 2002–04, extensive estuarine areas of marsh spread into areas previously occupied by tidal flat. Roughly 46% of the gain in estuarine marsh between 1979 and 2002–04 occurred in tidal flats. Marsh spread into many low flats on the bay side of the main island, especially the northeast shore of Allyns Bight and on a broad tidal flat farther to the north (figs. 30 and 34). The large washover area south of

North Pass also experienced the spread of marsh into tidal flats, as did the washover fan/flood-tidal delta complex on the tidal delta in the vicinity of Cedar Bayou. Approximately 32% of estuarine marsh gain was in areas previously mapped as uplands. Most of the gain from uplands was on the main body of the island and the washover fan/flood-tidal delta complex, particularly the inactive fan. On the main island, marsh spread islandward to occupy narrow strips of former upland. The inactive fan is older and topographically lower relative to the active fan that occasionally receives hurricane washover deposits. The relatively low topography of the inactive fan makes it more susceptible to the effects of relative sea-level rise. On the washover fan, estuarine marsh migrated into low swales and low ridge flanks of eolian mounds. Eolian mound ridges and interlying swales were described by Andrews (1970) as containing *Spartina spartinae* and, to a lesser extent, *Monanthochloe-Salicornia-Chaenopodium* communities. Signatures on 2002–04 photographs indicate wetter conditions on many eolian mounds.

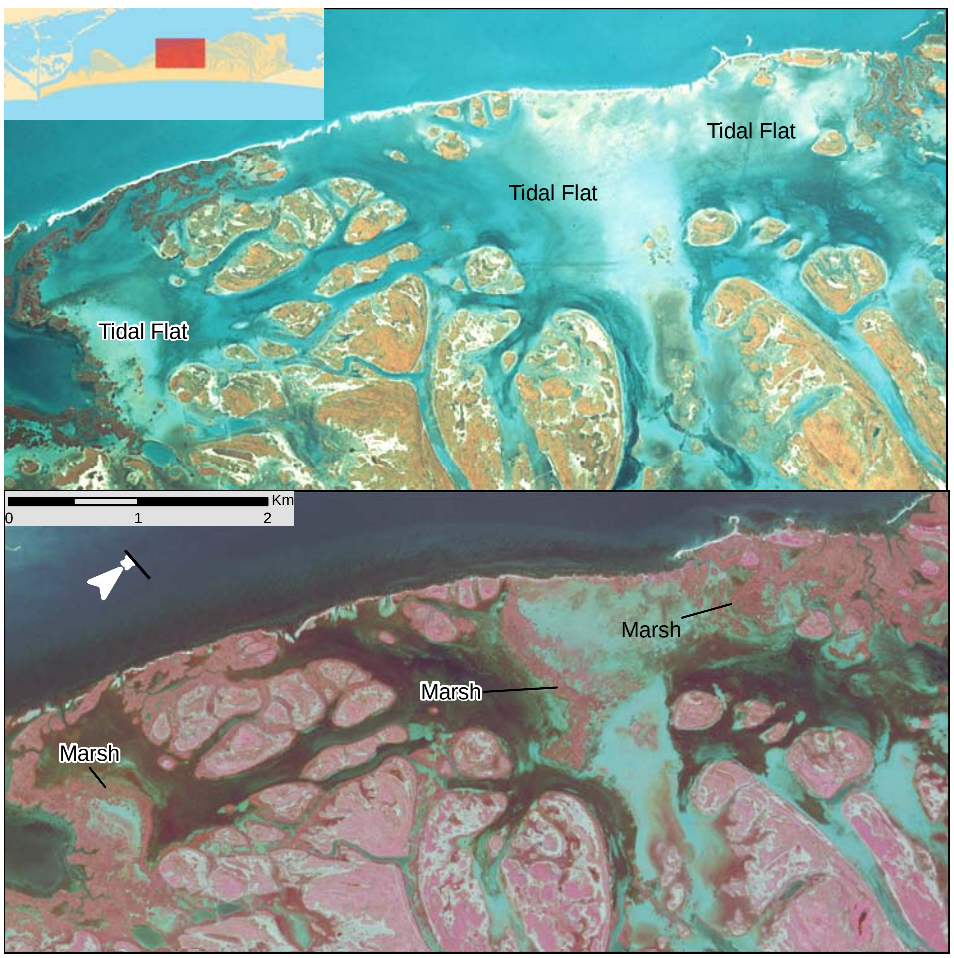


Figure 34. Spread of estuarine marsh into tidal flats on San José Island from 1979 (top) through 2004 (bottom).

Tidal-flat area during this later period remained at 1979 levels despite large losses to estuarine marsh. Many low areas mapped as open water in 1979 were mapped in 2002-04 as tidal flat. Low tidal flats occupied by annual *Salicornia* and algal mats were often interpreted as marsh in 1979. These areas were mapped as tidal flat in the recent mapping. Photo signatures in these areas are difficult to discern and are often confused. The increase in mapped flats in 2002–04 offset the loss to marsh.

Seagrass expansion continued into the later period, with 78% of the increase occurring in formerly open-water areas. Most seagrass expansion into open water occurred near Allyns Bight. Whereas seagrass expansion in the earlier period was limited to the interior flats and open water of the island, a large amount of expansion between 1979 and 2002–04 occurred in open water on the bay side of the island. Seagrass expansion on the bay side of the island extended from Allyns Bight north to the midpoint of the active washover fan. Much of the length of Mud Island also became inhabited by seagrass. Seagrass expanded bayward near the washover fan at North Pass and continued spreading into Spalding Cove and Mesquite Bay near Cedar Bayou. In a few instances, primarily in the more interior area of the main island, seagrasses were missed in 1979 and mapped as open water. Comparison with 1979 and recent photos confirms the existence of seagrass in this area.

Palustrine marsh has been affected on much of the island by land management practices. Burning and cutting of grasses on the vegetated barrier flat is a common practice. Vehicle traffic associated with grass cutting has left distinct patterns on the landscape that most likely altered surface hydrology. Alteration of the landscape appears to have reduced the amount, or at a minimum, checked the spread, of palustrine marsh on San José Island.

The Gulf beach continued a systematic loss during the later period. San José Island has historically suffered shoreline erosion and may have lost beach through erosion.

Mustang Island

General Trends. The most significant change or trend on Mustang Island was an extensive loss of tidal flats after the 1950’s (Fig.35). From a total area of 3,974 ha mapped on 1950’s photographs, only 1,526 remained in 1979, a loss of 2,448 ha, or about 60% of the 1950’s resource. This loss of tidal flats was followed by a small net gain of 169 ha from 1979 through 2002–04. In contrast to the overall decline in wind-tidal flats, the total areas of seagrass beds and estuarine marshes increased from the 1950’s through 2002–04. From the 1950’s through 1979, seagrasses increased by 2,159 ha, primarily from their spread into areas previously mapped as tidal flats. There was an apparent net loss of 777 ha of seagrasses between 1979 and 2002–04; this apparent loss is discussed in the following section on probable causes of trends. Although losses and gains were in estuarine marsh throughout the island, the overall change was a systematic net gain of 325 ha from the 1950’s through 1979, and 259 ha from 1979 through 2002–04, for a total gain of 584 ha since the 1950’s. Black mangroves were mapped on Mustang Island neither in the 50’s nor in 1979, but were included in the estuarine marshes in those years.

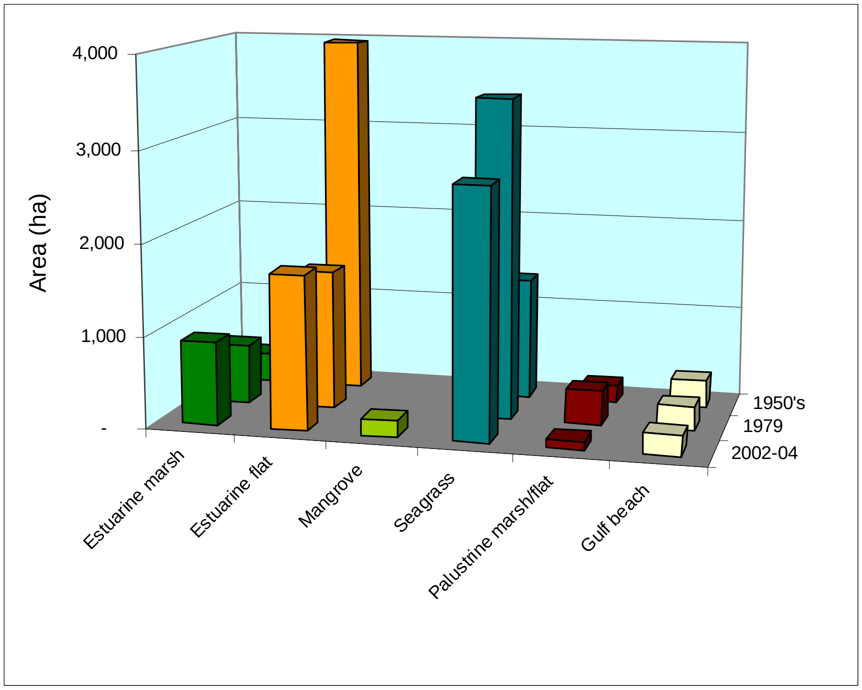


Figure 35. Areal extent of major habitats on Mustang Island in the 1950's, 1979, and 2002–04.

In 2002–04, however, mangroves had spread and could be mapped separately from the marshes. The extent of mangroves in 2002–04 was almost 180 ha. Combining mangroves and estuarine marshes mapped in 2002–04 into a single habitat for comparison with historical marshes reveals an increase of 763 ha of this habitat since the 1950's, accounting for about 30% of the loss in 1950's tidal flats because the flats were converted to marsh/mangroves (Figs. 36 and 37). Among the mapped changes in estuarine marshes was that which occurred on Shamrock Island (Figs. 38-41). Approximately 30 ha of estuarine high marsh was mapped in 1979, but only 5 ha in the 1950's and about 7 ha of mostly high marsh in 2002–04. Some upland areas were mapped as marsh on the 1979 photos (a comparison of photos is shown in Figure 40). For instance, the area of uplands mapped on Shamrock Island was 31.4 ha in the 1950's and 21 ha in 2002–04, but only 5.3 ha in 1979.

Palustrine habitats (marsh/flat/water) on Mustang Island were most extensive in 1979, with 375 ha, and least extensive in 2002–04, with 93 ha. In the 1950's the total area was 191 ha. Accordingly, from the 1950's through 1979, there was a net gain of 184 ha (445 acres). This gain was followed by a loss of ~282 ha from 1979 through 2002–04. The area of mapped Gulf beach underwent a systematic net decline from the 1950's through 2002–04, decreasing in area by 33 ha during the earlier period (1950's–1979), and 41 ha during the later period (1979–2002–04).

Probable Causes of Trends. The loss of tidal flats since the 1950's can be explained, in large part, by a relative rise in sea level, which correlates very well with erosion of Shamrock Island (Figs. 38–41). Geotubes have been installed along the north margin of Shamrock Island to help control erosion (Fig. 41). Much of the area mapped as tidal flats on Mustang Island in the 1950's was converted to seagrass beds (~50%), open water (~20%), and marshes (~6%) as topographically low flats became submerged and slightly higher flats became more frequently flooded, contributing to a spread of marsh vegetation (Fig. 30). Another reason for losses in 1950's tidal flats was that almost 25% was mapped as uplands in 1979. Most of this change was on south Mustang Island, where barren features such as tidal flats, active dunes, and blowouts (White et al., 1978) were difficult to distinguish on the black-and-white 1950's photographs, and were mapped, as a whole, as tidal flat (Fig. 42). By 1979 the dunes and upland flats had become vegetated and were mapped as upland rangeland, which accounts for the ~25% conversion of tidal flats to uplands. Only about 1% of the tidal flats were converted to upland urban land. Another indicator of a relative rise in sea level was an increase in low estuarine marsh (E2EM1N) relative to high marsh (E2EM1P) from 1979 through 2002–04. For example, the area of low marsh to high marsh in 1979 was 153 to 501 ha for a ratio of 0.3, and in 2002–04 it was 545 to 368 ha for a ratio of 1.5 (see Appendix). The increase in low marsh from 1979 through 2002–04 was 2.6 fold, whereas there was a decrease in high marsh of about 27% during this period.

Much of the decline in seagrasses (-777 ha) from 1979 through 2002–04 that followed the large expansion in seagrasses from the 1950's through 1979 was not real but was due to inclusion of tidal flats as seagrass habitat in many areas on the 1979 NWI map. Remapping these areas on the 1979 database was not within the scope of this project.

The more extensive distribution of palustrine habitat in 1979 was in large part associated with wetter conditions on the island when the 1979 aerial photographs were taken.

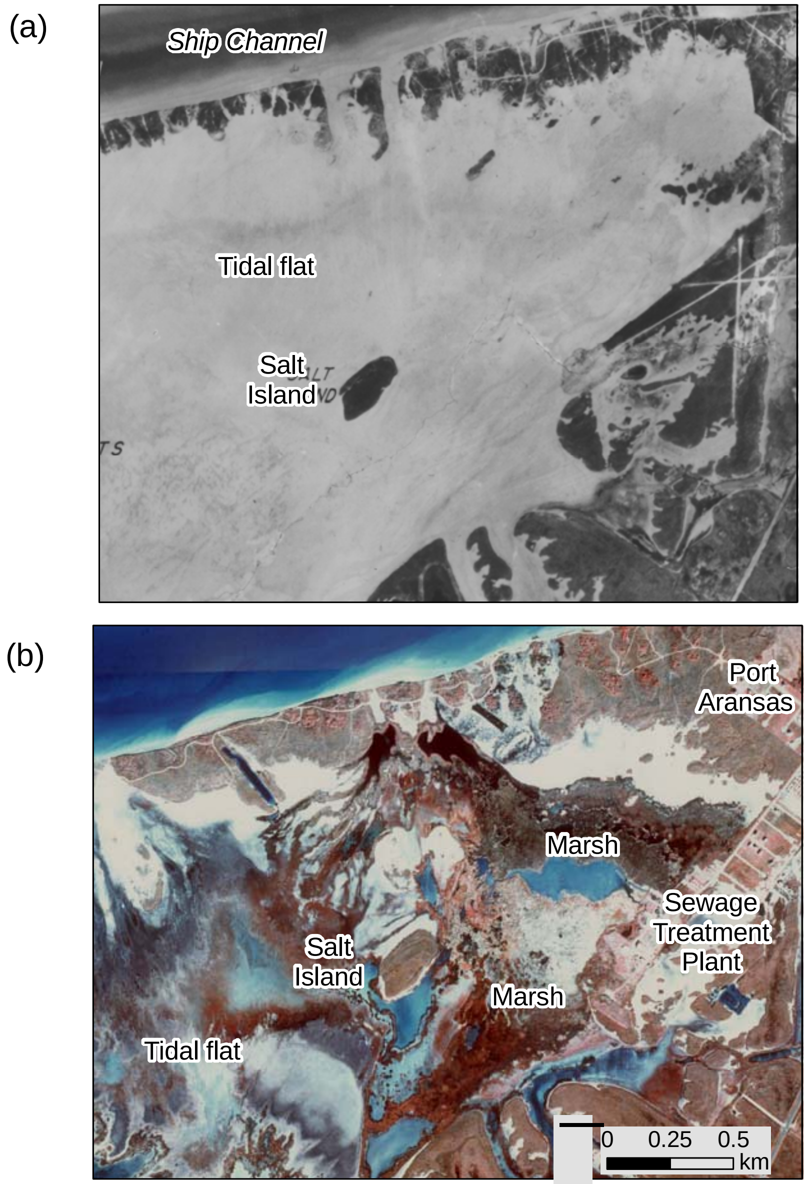


Figure 36. Broad tidal flat shown on 1958 photo (a), on which an extensive brackish- to salt-water marsh has developed at the outfall of the Port Aransas Sewage Treatment Plant, as shown on 2002 aerial photo (b). See Salt Island as reference point in two images.

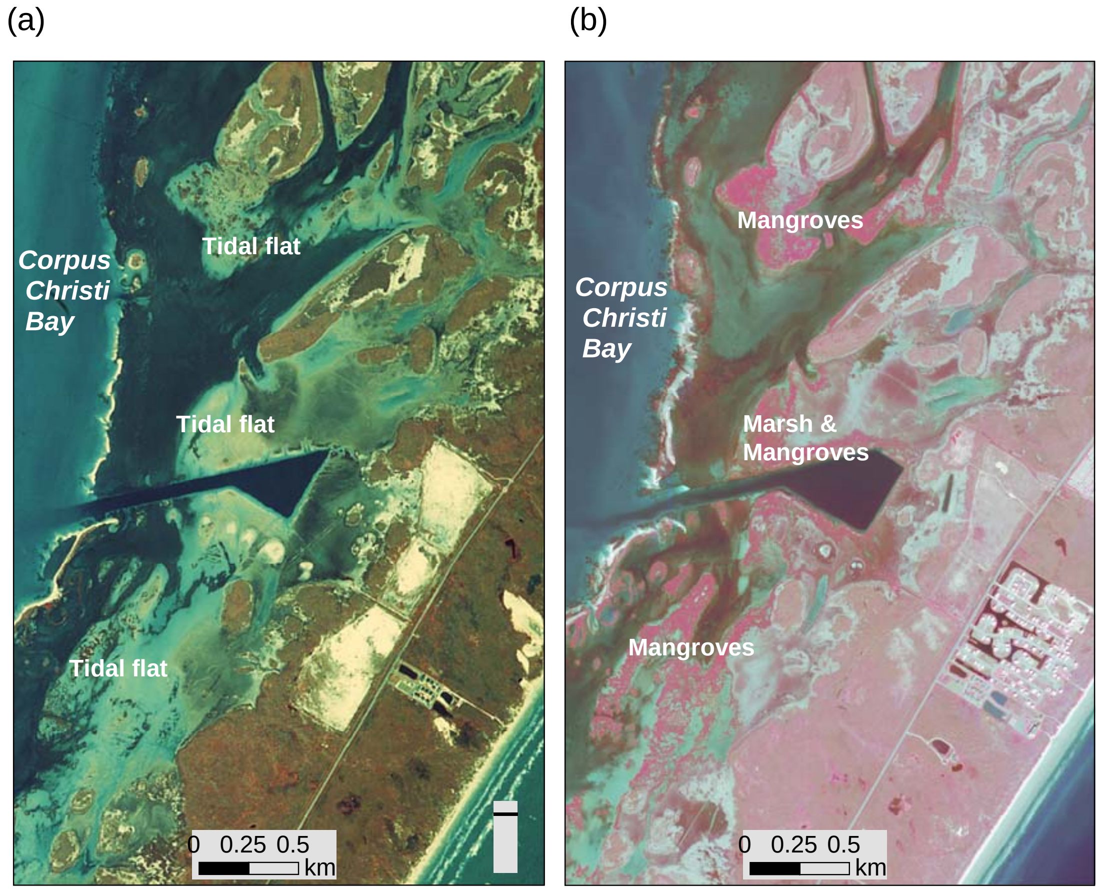


Figure 37. Expansion of estuarine marsh and mangroves on Mustang Island from 1979 through 2004. Many areas that were tidal flats in 1979 (a) were covered with marshes and mangroves in 2004 (b).

In future, wetter times, depressions will be flooded, and marshes will become reestablished. Some of the decline in palustrine habitat was due to expanded development on Mustang Island since 1979.

The decline in Gulf beach areas since the 1950's was partly due to shoreline erosion, but tide levels at the time the photographs were taken can also have a significant effect on the area of beach mapped. Drought-related lower tides in 1956 could possibly have contributed to the more extensive beach area mapped on the 1950's photographs. In addition, part of the decrease in area can be attributed to a narrowing of the beach in 1979 and 2002–04 as a result of expanding vegetation on the backbeach, on coppice dunes, and on barren storm washover sand flats. In some areas, the change was due to differences in photo interpretation and habitat classification.

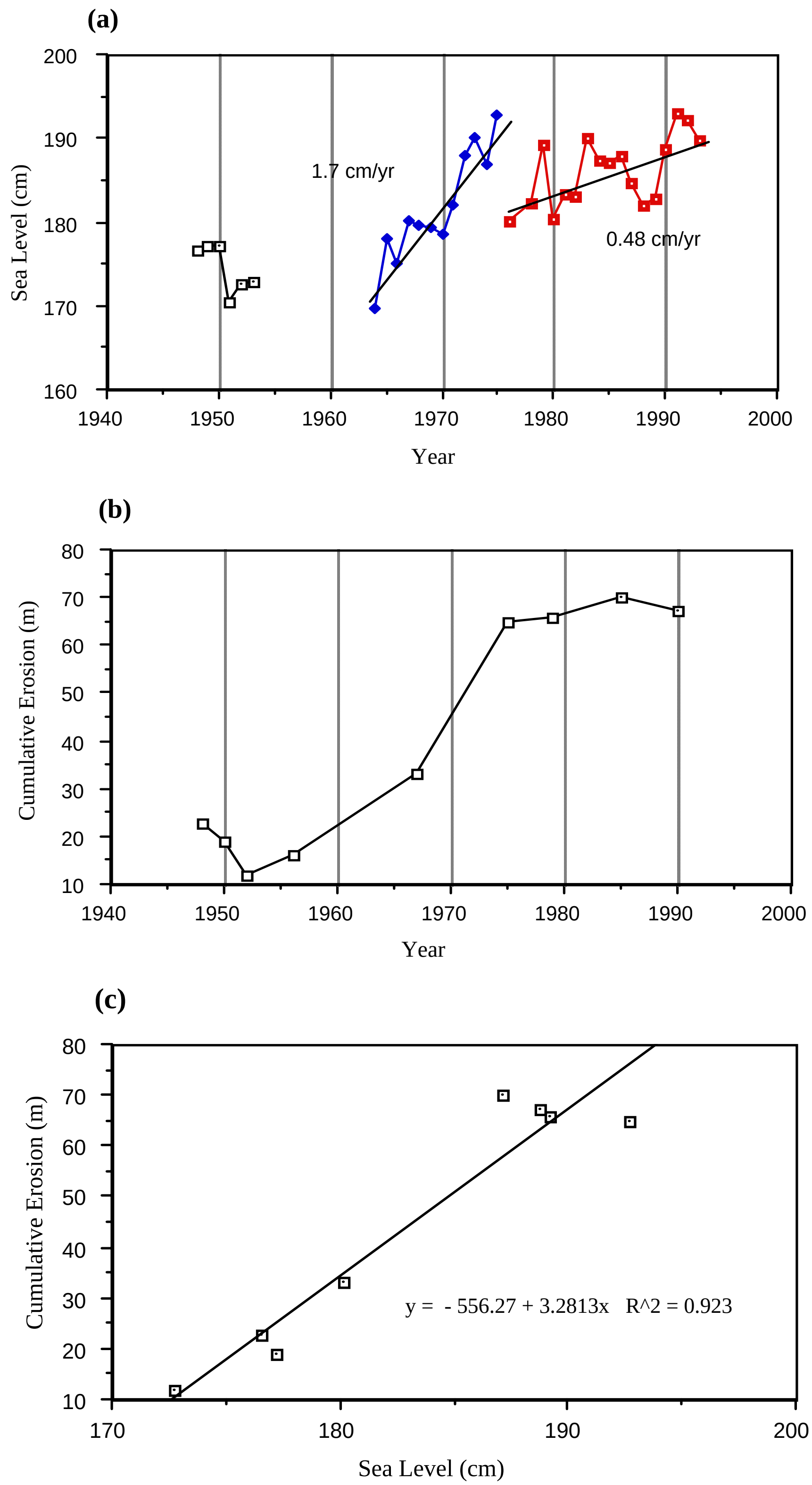


Figure 38. Relationship between sea-level rise and erosion as shown by (a) sea-level rise at the Rockport tide gauge, (b) shoreline erosion at one transect on Shamrock Island, and (c) high correlation (r^2=0.923). Tide data from NOAA; shoreline erosion data from Williams (1997).

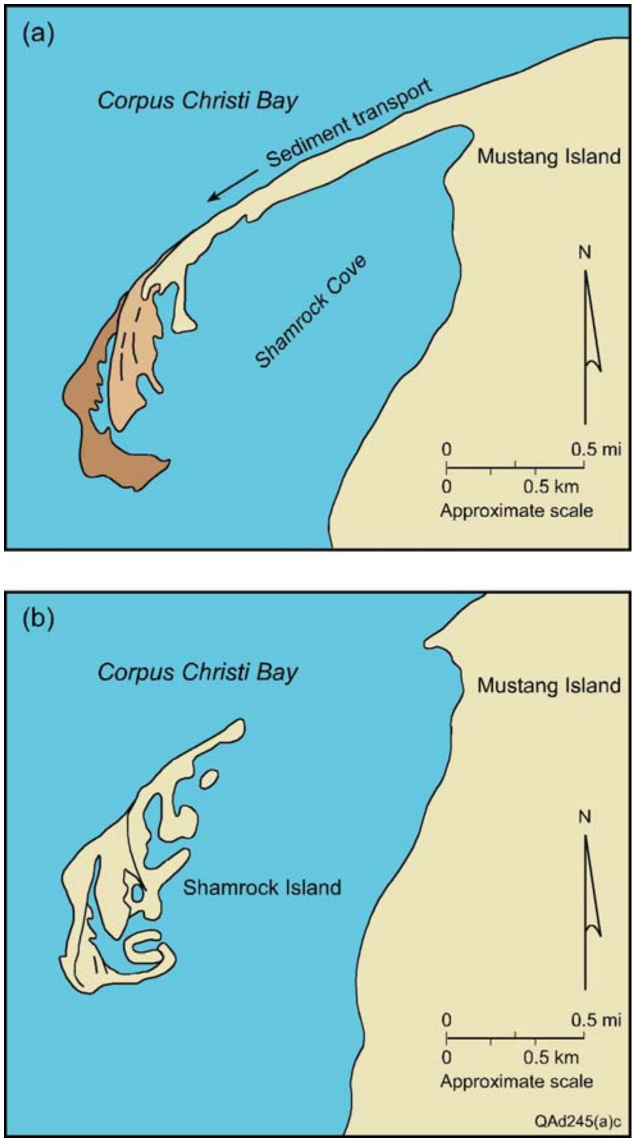


Figure 39. Illustration depicting how Shamrock Island grew as a compound recurved spit on the bayward side of Mustang Island, as shown in (a) on the basis of a 1958 aerial photo, and eventually was cut off from Mustang Island by Hurricane Celia in 1970; today it is an island (b). Also see Figures 40 and 41.

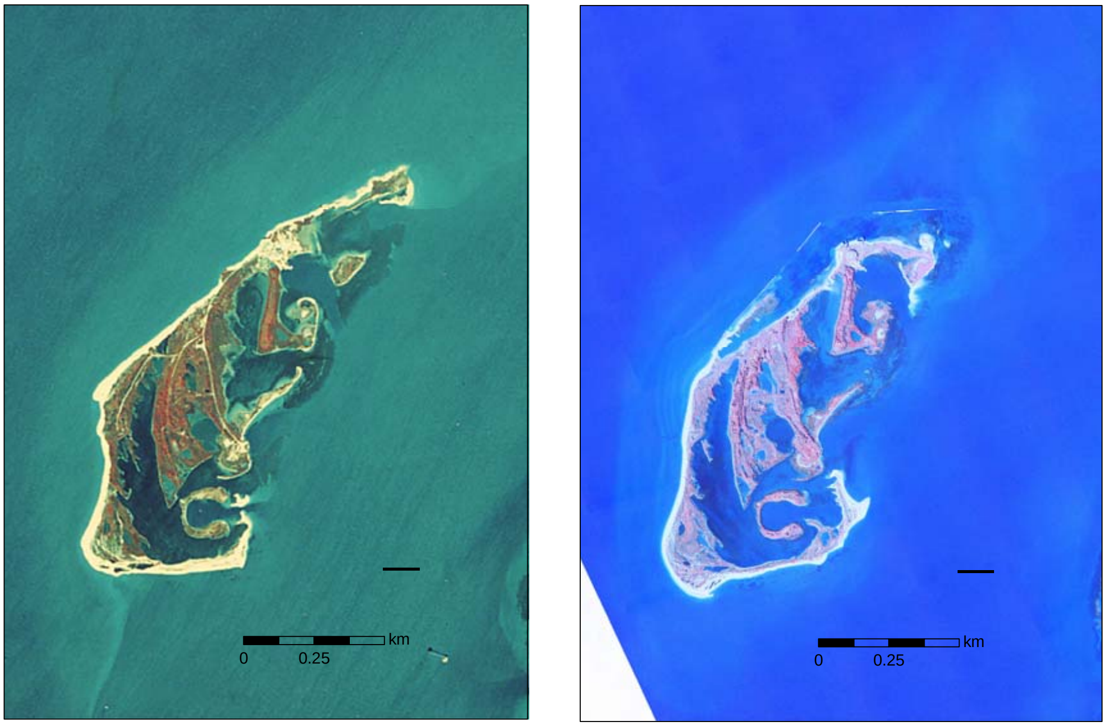


Figure 40. Shamrock Island in 1979 on left and 2004 on right. Faint linear features offshore on the northern part of the island are geotubes (Fig. 41) installed by GLO to slow shoreline erosion.

Figure 41. Shamrock Island in 2004. View is north. Geotubes are visible on northwestern margin of Island.

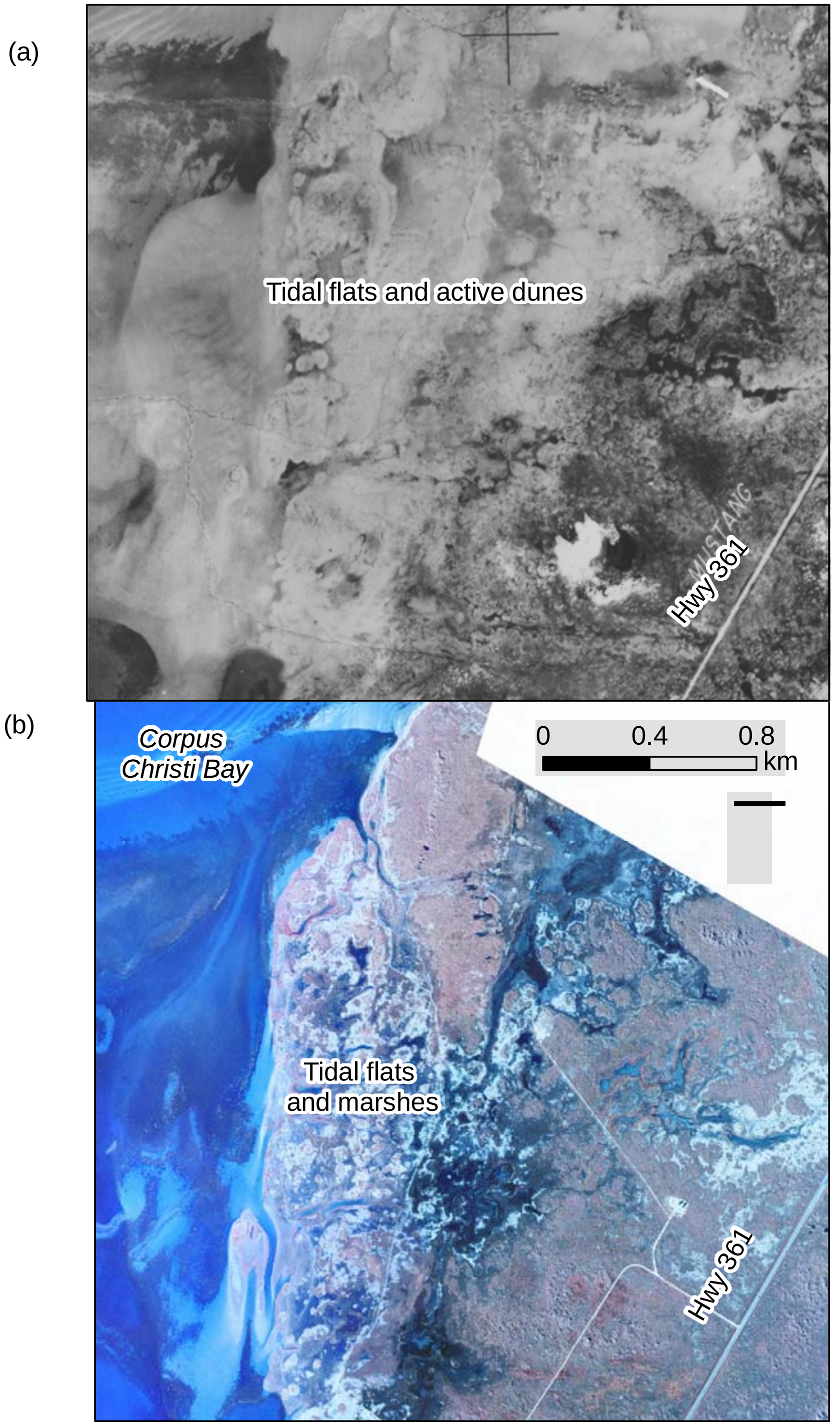


Figure 42. Comparison of aerial photographs of south Mustang Island taken in 1958 (a) and 2004 (b). Most of the barren area (white) in a was mapped as tidal flat in 1958, and tidal flat, marshes, and uplands in 2004 after vegetation stabilized the active dunes. See text for further explanation.

North Padre Island

General Trends. The most significant trend on north Padre Island was the loss of tidal flats. A large decline in total area between the mid-1950's when the total was 957 ha and 1979 when the total was 284 ha represents a 70% loss of the resource (Fig. 43). Tidal flats continued to decline from 1979 through 2002–04 to a total of 264 ha, a 7% decrease. Seagrasses increased in area from the mid-1950's total of 642 ha to 1,143 ha in 1979, representing a 78% increase. Seagrasses declined in area by 28% from 1979 through 2002–04 to a total of 822 ha. Discounting inflated 1979 numbers (discussed in the following section), seagrasses expanded through the mid-1950's through 2002–04 period at a moderate rate. Palustrine marsh experienced a fluctuation in area through time. In the mid-1950's, palustrine marsh occupied 275 ha, and then lost 6% by 1979, when the total was reduced to 258 ha. By reversing the trend in the later period, marshes rebounded to a total of 351 ha, an increase of 36%. The Gulf beach on north Padre Island experienced a fluctuation in area through time. An initial gain (+11%) of beach between the mid-1950's total of 61 ha and the 1979 total of 68 ha was reversed in the later period when the area of Gulf beach decreased by 29% to a total of 49 ha in 2002–04.

Probable Causes of Trends. Wetland habitat loss during the mid-1950's through 1979 period occurred in the north part of the island, where residential development encroached into tidal flats (Figs. 43 and 44). Roughly half the loss of flats to submerged habitats was in the algal mat area south of Padre Isles residential development that was mapped as seagrass in 1979. Owing to undermapping of tidal flats in 1979, the rate of tidal flat-loss from the mid-1950's is overestimated. The actual mid-1950's through 1979 loss rate would be more moderate.

A significant amount of the gain in seagrass is due to a combination of overmapping in 1979 and undermapping in the mid-1950's. A small amount of seagrass expanded into the channelized area near the GIWW in the Padre Isles development. Within this period, there was an increase in seagrass, but at a much reduced rate.

The net loss of palustrine marsh during the 1950's through 1979 period was relatively small but was opposite the general trend of increasing wetness and expansion of marsh experienced during the later period. Palustrine marsh loss was primarily (~90%) due to replacement by uplands. Some marsh toward the south was loss to active dune migration behind the fore-island dune ridge. North of the county park, dunes migrated inland from the fore-island dune ridge and replaced palustrine marsh. Construction of the golf course near Packery Channel eliminated ~14 ha of palustrine marsh.

The Gulf beach was somewhat overmapped in 1979, in that the gulfward boundary was extended too far into the surf. Dune migration near the county park widened the beach, increasing the 1979 Gulf beach area.

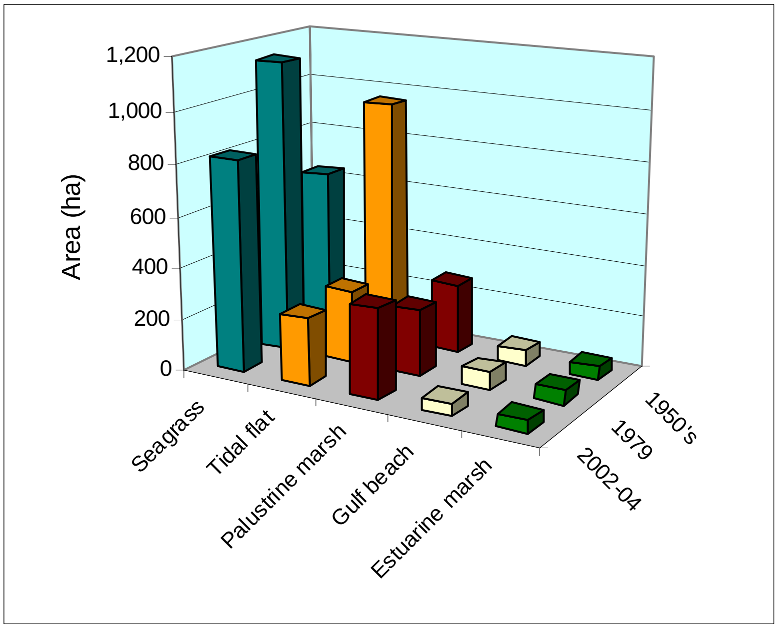


Figure 43. Areal extent of major habitats on north Padre Island in the 1950's, 1979, and 2002–04.

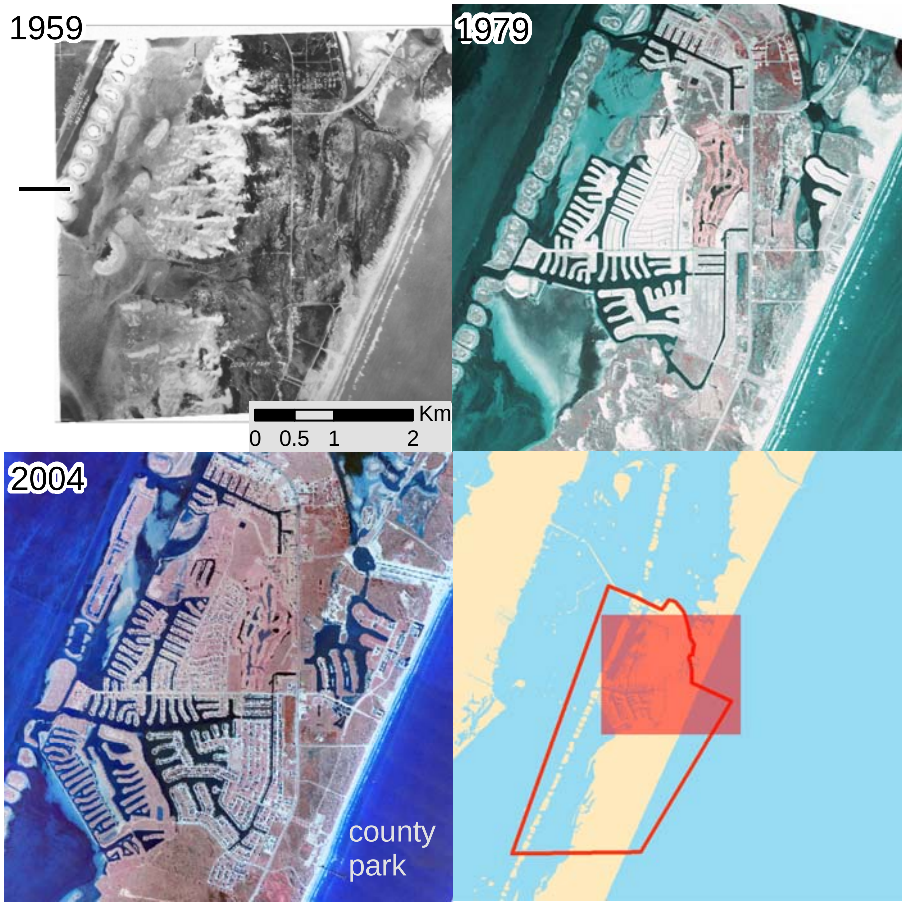


Figure 44. Expansion of Padre Isles residential development into former tidal-flat area 1959–2004.

The systematic loss of tidal flats continued on north Padre Island during the 1979 through 2002–04 period. A significant amount of flat loss occurred where Padre Isles residential development expanded south to the 2002–04 position (Fig. 44). This area was mapped as seagrass in the 1979 NWI dataset, but upon examination of 1979 photographs, it was determined that this area should have been mapped as flat. When remapped as tidal flat, the addition of this area to the tidal-flat habitat total would increase the 1979 through 2002–04 loss rate.

Most of the seagrass loss to development occurred in areas of low tidal flat that had been mismapped in 1979 as seagrass. A small amount of seagrass expanded into channels at the Padre Isles residential development gulfward of the GIWW. After adjustment for overmapping in 1979, the seagrass trend on north Padre Island would be one of net gain at a rate similar to that experienced during the mid-1950's through 1979 period.

Recent mapping indicates that over the past several decades, Padre Island has become more vegetated. This increase in vegetation is apparent in the increase of palustrine marsh on north Padre Island. More than 90% of the gain in marsh on north Padre Island was in areas previously mapped as uplands. Dunes that had migrated into marshes during the early period, causing marsh loss, had become stabilized during the later period. More inclusive mapping as a result of improved mapping technology also boosted the 2002–04 numbers. The ability to identify more palustrine marsh contributed somewhat to a higher rate of palustrine marsh gain during this period.

Gulf beach loss occurred where the gulfward extent of the 2002–04 beach line was placed farther inland than the 1979 line and where the beach narrowed to a more normal width at the county park. Some Gulf beach loss could be attributed to shoreline erosion. Historically the island is in a transitional area between an erosional environment to the north and a stable or slightly accreting system to the south

Harbor Island

General Trends. On Harbor Island, the most significant change was an extensive decline in tidal flats since the 1950's. Of the ~2,415 ha of tidal flats mapped in the1950's, only 446 ha remained in 1979, and 298 ha in 2004. This change, from the 1950's through 2004, amounted to a loss of almost 90% of the tidal flats on Harbor Island since the 1950's. Contributing to the decline in tidal flats were major increases in seagrasses and open water (also documented by White et al., 1983, and Pulich et al., 1997). Beginning with an area of 1,390 ha in the 1950's, seagrass beds had a net gain of 971 ha by 2002–04. This was an increase of about 70% since the 1950's, with almost 60% of the change occurring during the earlier period, 1950's through 1979. Open water areas increased from 1,203 ha in the 1950's to 1,717 ha by 1979 and maintained an area of 1,671 ha in 2002–04. The areas of mapped mangroves (Fig. 45) were similar in 1979 and 2002–04, at 665 ha and 634 ha, respectively. Mangroves were not mapped in the 1950's because of the difficulty in distinguishing them from marshes on black-and-white photos. The area of estuarine marshes in the 1950's covered 283 ha, increasing slightly to 297 ha by 1979 and decreasing to 152 ha by 2004. Combining marshes and mangroves into a marsh-mangrove habitat, however, allows a more refined look at the trends from the 1950's.

There was an increase in this habitat from 283 ha in the 1950's to 962 ha in 1979, and a decrease to 786 ha by 2002–04. From the 1950's through 2002–04, the marsh-mangrove habitat almost tripled in area (Fig. 46).

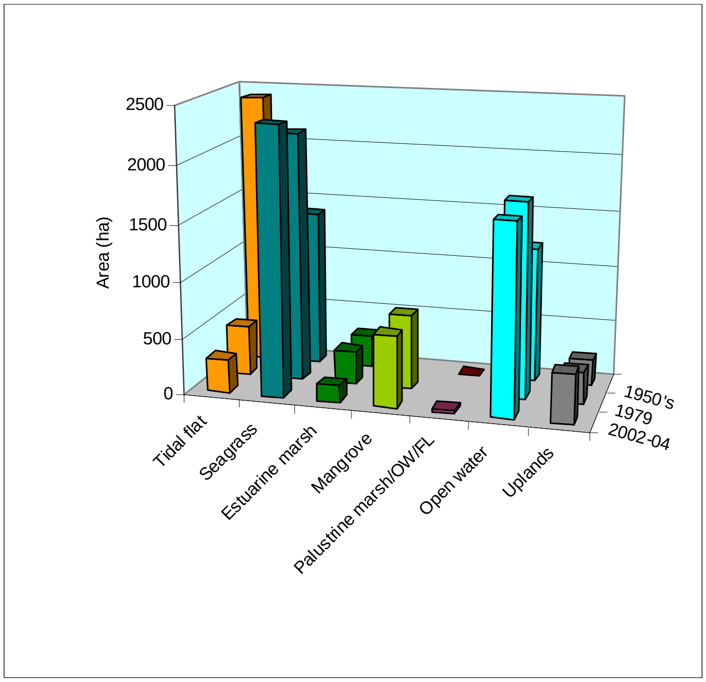


Figure 45. Areal extent of major habitats on Harbor Island in the 1950's, 1979, and 2002–04.

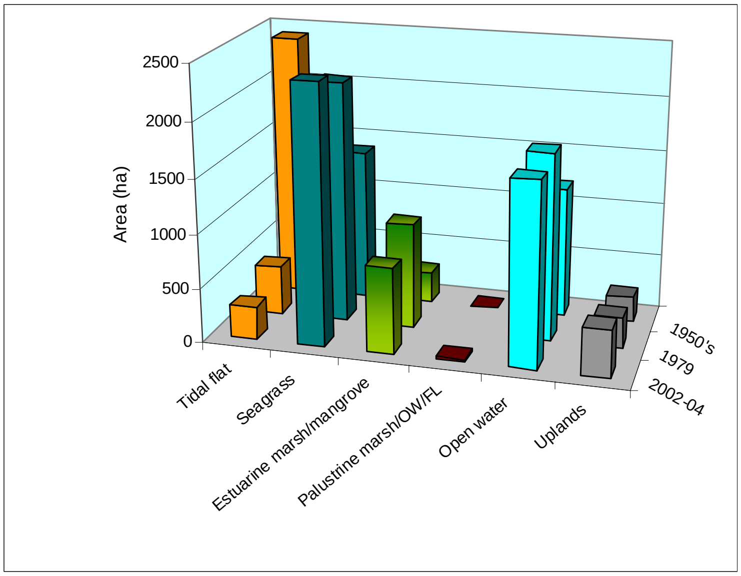


Figure 46. Areal extent of major habitats, including the mangrove-marsh habitat, on Harbor Island in the 1950's, 1979, and 2002–04. The estuarine marsh and mangrove habitats were combined into a single unit for illustrative purposes.

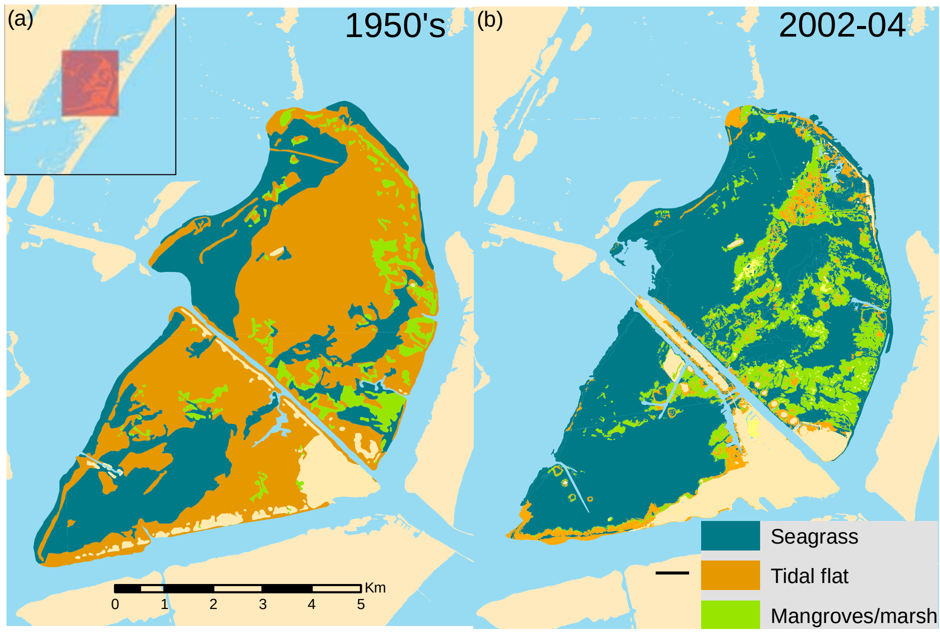


Figure 47. Habitat changes on Harbor Island from (a) 1950’s through (b) 2002–04. Note the spread of seagrasses in 2002–04 over 1950’s tidal flats. The mangrove-marsh habitat also expanded on Harbor Island since the 1950’s.

Probable Cause of Trends. Harbor Island is a good example of where habitat changes have occurred as a result of a relative rise in sea level. As the broad 1950’s tidal flats on Harbor Island became more frequently to permanently inundated, seagrasses and water expanded across the submerging flats (Figs. 30 and 47). Marshes and mangroves spread into slightly higher flats. In general, by 1979, much of the 1950’s tidal-flat habitat on Harbor Island had been converted to seagrasses, which accounted for ~50% of the change, marshes and mangroves ~33%, and open water ~12%. An analysis of changes in tidal flats from the 1950’s through 2002–04, indicates a similar percentage, with the spread of seagrasses accounting for ~50% of the change, marsh-mangrove habitat ~25%, and open water ~12%. It should be noted that the extensive mangroves in 1979 were temporarily set back by hard freezes along the coast in the 1980’s. Extremely low temperatures in 1983, for example, killed many black mangroves. They have recovered, however, and are again very extensive on Harbor Island (Figs. 1 and 47). Their expansion is probably due to a lack of freezes between 1993 and 2004.

SUMMARY AND CONCLUSIONS

Wetlands and aquatic habitats on barrier islands along the Texas Gulf Coastal Bend are dominated by seagrasses, which, in 2002–04, encompassed an area of almost 8,400 ha, accounting for about 40% of the mapped wetland and aquatic habitats. The second-most-extensive habitats were tidal/algal flats, with an area of 6,121 ha, comprising ~30%. Estuarine emergent wetlands (salt and brackish marshes) covered an area of 4,009 ha, or about 20% of the wetland and aquatic habitats. Among other mapped classes (excluding open water and uplands), mangroves are most abundant at 837 ha (4%), followed by palustrine habitats (767 ha; 4%), and Gulf beaches (535 ha; 3%).

Examination of wetland distribution in four geographic subareas within the study area (San José Island, Mustang Island, north Padre Island, and Harbor Island) shows that San José Island has the largest distribution of estuarine marshes and tidal/algal flats, with 72% and 63%, respectively. San José Island also has the most Gulf beach area, at 49%. The largest distribution of seagrass, or aquatic bed, occurs on Mustang Island, where 32% was mapped. North Padre Island has the largest area of palustrine habitat, at 46%, and Harbor Island the most mangrove area, at 76%.

In analyzing trends, wetland classes were emphasized over water regimes and special modifiers because habitats were mapped only down to class on 1950’s photographs. It should be noted 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 direction of trends than absolute magnitudes.

From the 1950’s through 2002–04 within the study area, some wetland classes underwent substantial net losses and gains, whereas others remained more stable. Historically, losses and gains in habitats have occurred throughout the study area, but the overall trend in vegetated estuarine emergent wetlands (marshes and mangroves) is one of net gain, as revealed by increases in the estuarine marsh-mangrove habitat of 1,988 ha from the 1950’s through 1979 and 1,095 ha from 1979 through 2002–04. The average rate of marsh-mangrove habitat gain, however, decreased from about ~85 ha/yr during the earlier period to ~45 ha/yr during the later one. Mangroves increased in total area from 665 ha in1979 to 837 ha in 2002–04, a gain of 173 ha. Trends in mangrove distribution from the 1950’s could not be determined because they were not mapped separately from marshes. The total area of tidal/algal flats decreased by 7,533 ha from the 1950’s through 1979 and remained relatively stable from 1979 through 2002–04, during which time there was an increase of only 7 ha. The average rate of tidal-flat loss decreased dramatically through time, from about 328 ha/yr during the earlier period to 0 ha/yr during the later period. Seagrass beds increased in total area from the 1950’s through 1979 by 3,537 ha, and continued to increase, although by a smaller amount, 653 ha, from 1979 through 2002–04, reflecting a net gain of 4,190 ha since the 1950’s. Palustrine marshes and associated habitats (water and flats) increased in total area by 225 ha between the 1950’s and 1979 but decreased by 123 ha between 1979 and 2002–04. There was a decline in the area of mapped Gulf beaches, which decreased in total area by 231 ha and 95 ha, from the 1950’s through 1979, and 1979 through 2002–04 periods, respectively.

Analysis of habitat distribution by geographic subarea reveals local differences in historical trends. The most significant wetland trend on San José Island was the systematic gain of estuarine marsh. The trend is characterized primarily by expansion of marsh into low flats and to a lesser degree into uplands. This phenomenon has been encountered in several locations on the Texas coast and is attributed to relative sea-level rise. Another example of the effect of relative sea-level rise is the systematic expansion of seagrass into tidal flats. Mid-1950’s through 1979 seagrass expansion was primarily into inland flats, whereas the later-period seagrass expansion was into open water on the island periphery. Tidal-flat areas declined in the early period but did not change significantly in the later period. Net losses in the later period were offset by large net gains from open water and marsh. Relative overall amounts of palustrine marsh are small on San José Island when compared with that of other habitats. However, the initial amount increased significantly by 1979. An increase in palustrine marsh is consistent with observed changes on other parts of the barrier system, where moisture levels have increased during the past decades. The large gain was reversed when palustrine marsh had declined by 2002–04. Palustrine marsh appears to have been reduced through agricultural practices on the island and drier conditions in 2002–04 than in 1979. Another relatively small habitat, the Gulf beach, experienced a systematic loss through time. Initial losses can be attributed to overmapping in the mid-1950’s and a component of shoreline erosion that continued throughout the study period.

Among the most significant changes on Mustang Island was a loss of ~60% of tidal flats since the 1950’s. This loss appears to be explained largely by a rise in relative sea level, causing the flats to be replaced by other habitats, such as open water, seagrass beds, and marshes. Thus, in contrast to the loss of tidal flats, there were substantial gains in seagrass beds and estuarine marshes after the 1950’s. Although marshes expanded during both the earlier period (1950’s–1979) and the later period (1979–2002–04), after the large gain in seagrasses during the earlier period, there was an apparent net loss during the later period, although this loss is explained partly by overmapping of seagrass beds on the 1979 aerial photographs (e.g., including some tidal-flat areas with seagrasses). It is more likely that the seagrass beds were relatively stable in area during the later period. Palustrine marshes were very limited on Mustang Island, having their largest distribution in 1979, when wetter-than-normal conditions contributed to their expansion. A systematic net decline in mapped Gulf beaches that occurred during both periods appears to be due primarily to a narrowing of the beach through time as a result of a spread of vegetation along the backbeach and erosion along the forebeach.

The trend of systematic loss of tidal flats on north Padre Island is artificially high during the earlier period because of overmapping of seagrasses in 1979. Large areas of tidal flats were lost during the study period but at a moderate rate. Part of the interpretation error is reflected in the unusually high seagrass gain during the mid-1950’s through 1979 period. Discounting the inflated 1979 area, it is likely that seagrasses expanded through the overall study period at a moderate rate. Palustrine marsh area increased through time, reflecting the general increase in moisture on north Padre Island. This trend has been documented in other areas on Padre Island. Taking into consideration differences in the interpreted position of the Gulf beach shoreline, the overall Gulf beach area has eroded through time.

The most significant change on Harbor Island was an extensive decline of ~90% of tidal-flat habitat since the 1950's. Countering the loss of tidal flats were major increases in seagrasses and moderate increases in open water and marsh-mangrove habitat. The largest spread of seagrasses occurred from the 1950's through 1979, a period that coincides with a rapid relative sea-level rise, averaging ~1.7 cm/yr from the mid-1960's through the mid-1970's, as recorded by the Rockport tide gauge located along the landward shore of Aransas Bay across from the barrier islands. As the broad tidal flats on Harbor Island in the 1950's became more frequently to permanently inundated, seagrasses and water expanded across the submerging flats. Marshes and mangroves spread into slightly higher flats. In general, by 1979, much of the 1950's tidal-flat habitat on Harbor Island had been converted to seagrasses, which accounted for ~50% of the change, marshes and mangroves ~33%, and open water ~12%.

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APPENDIX: Total habitat areas for 2002-04, 1979, and 1950's from GIS data of study area.

2002-04		*1979*		*1950's*	
Habitats	**Hectares**	**Habitats**	**Hectares**	**Habitats**	**Hectares**
E1AB1	18	E1AB2L.	7,704	E1AB.	4,167
E1AB3	8,357	E1AB6L.	547		
E1AB3x	41			E1OW.	17,590
E1AB5	83	E1OWL.	18,215		
		E1OWLX.	184	E1RF.	33
E1UB	16,450				
E1UBx	497	E2EM1N.	1,891	E2EM.	1,763
		E2EM1P.	1,195		
E2AB1N	1,817			E2FL.	13,647
E2AB1Ns	0	E2FL.	1		
E2AB1P	1,277	E2FL6N.	138	E2RF.	0
		E2FL6Y.	12		
E2EM1N	2,496	E2FLM.	279	M1OW.	12,711
E2EM1Ns	6	E2FLN.	4,318		
E2EM1P	1,467	E2FLP.	1,366	M2BB.	522
E2EM1Ps	39			M2BB2.	339
		E2SS3N.	665		
E2RF2M	9			PEM.	573
		L1OWH.	12		
E2SS	9			PFL.	4
E2SS3	828	M1OWL.	12,832		
				POW.	86
E2USM	516	M2BBP.	630		
E2USN	920			PSS.	1
E2USNs	65	PEM1A.	29		
E2USNx	12	PEM1C.	443	U.	11,208
E2USP	1,393	PEM1F.	123		
E2USPs	120	PEM1Y.	229		
M1UB	12,860	PFL2C.	0		
		PFLCH.	0		
M2USN	167				
M2USP	368	POWF.	36		
		POWFH.	1		
PEM1A	220	POWFX.	8		
PEM1Ah	6	POWH.	12		
PEM1C	334	POWHH.	8		
PEM1Ch	8	POWHX.	0		
PEM1F	122				
PEM1Fh	0	U.	1		
PEM1Fx	0	UA.	10,162		
		UB.	10		
PFO1A	1	UBD.	163		
		UBS.	101		
PSS1A	1	UF6.	8		
		UR.	123		
PUB	20	UU.	1,083		
PUBCh	0	UUO.	111		
PUBFh	1				
PUBHx	34				
PUBKh	3				
PUS	14				
PUSCx	0				
PUSh	4				
U	12,055				