STATUS AND TRENDS OF WETLAND AND AQUATIC HABITATS ON TEXAS BARRIER ISLANDS, MATAGORDA BAY TO SAN ANTONIO BAY

by

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TABLE OF CONTENTS

Figures

Tables

STATUS AND TRENDS OF WETLAND AND AQUATIC HABITATS ON TEXAS BARRIER ISLANDS, MATAGORDA BAY TO SAN ANTONIO BAY

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 in which a variety of flora and fauna depend. Scientific investigations of wetland distribution and abundance through time are prerequisites to effective habitat management, thereby insuring 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 the central Texas barrier island and delta system from San Antonio Bay to East Matagorda Bay.

The study area encompasses Matagorda Island, Matagorda Peninsula, and the Colorado River Delta, an area that is located within Matagorda and Calhoun Counties along the central Texas coast (Fig. I). Matagorda 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. In contrast is Matagorda Peninsula, a much more narrow barrier that is undergoing erosion along much of its length and is characterized by numerous hurricane washover channels. Back-island estuarine marshes are important components of the peninsula. Connecting Matagorda Peninsula to the mainland is the Colorado River Delta, an elongate delta that separates East Matagorda Bay from Matagorda Bay and that is the site of an extensive estuarine marsh complex. Although marshes on the east side of the delta are undergoing erosion, marshes on the west side are expanding, in part, along the dredged diversion channel that directs river flow to the west into Matagorda Bay.

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 November and December 2001. 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 to 1:24,000-scale base maps using a zoom transfer scope. The resulting maps were digitized and entered into a GIS, producing GIS maps for the two time periods. Both the 1950's and 1979 series USFWS maps, which are in digital format, were partially revised in this project to be more consistent with wetlands interpreted and delineated on the 2001 photographs.

Methods used to delineate 2001 habitats differed from the earlier methods. The 2001 photographs were scanned to create digital images with a pixel resolution of 1 meter, and registered to USGS Digital Orthophoto Quadrangles (DOQ's). Mapping of wetlands and aquatic habitats was accomplished through interpretation and delineation of habitats on screen in a

Figure I. Index map of wetland status and trends study area.

GIS at a scale of 1:8,000. 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 2001 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. Topographic surveys conducted at several field sites provided data on relative elevation that helped define habitat boundaries and potential frequency of flooding, or water regimes.

Current Status, 2001

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 fore beach and a higher, less frequently flooded backbeach.

In 2001, wetland and aquatic habitats (excluding open water) were dominated by estuarine marshes, with a total area of 11,257 ha (27,793 acres), followed by seagrass beds totaling 4,607 ha (11,374 acres), and tidal flats at 2,289 ha (5,652 acres) (Fig. II). Palustrine marshes (including ponds) had a total area of 857 ha (2,117 acres), and wetland scrub/shrub wetlands (primarily mangroves) 112 ha (276 acres). Along the Gulf shoreline, the area of mapped beaches totaled 1,124 ha (2,774 acres).

The study area was subdivided into geographic areas—east Matagorda Peninsula, Colorado River Delta, west Matagorda Peninsula, and Matagorda Island—to allow a more site-specific

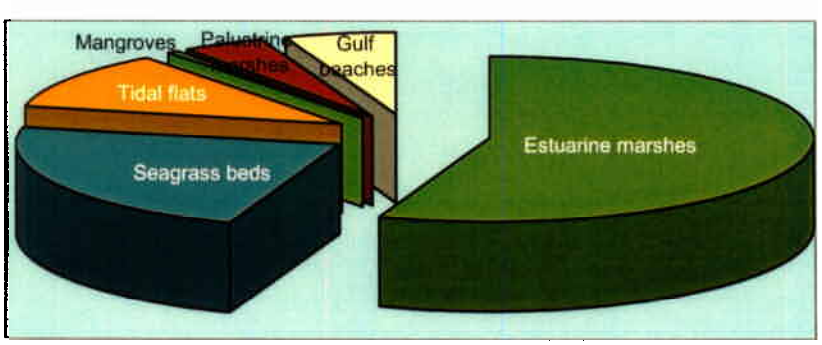

Figure II. Areal extent of selected habitats in the study area in 2001.

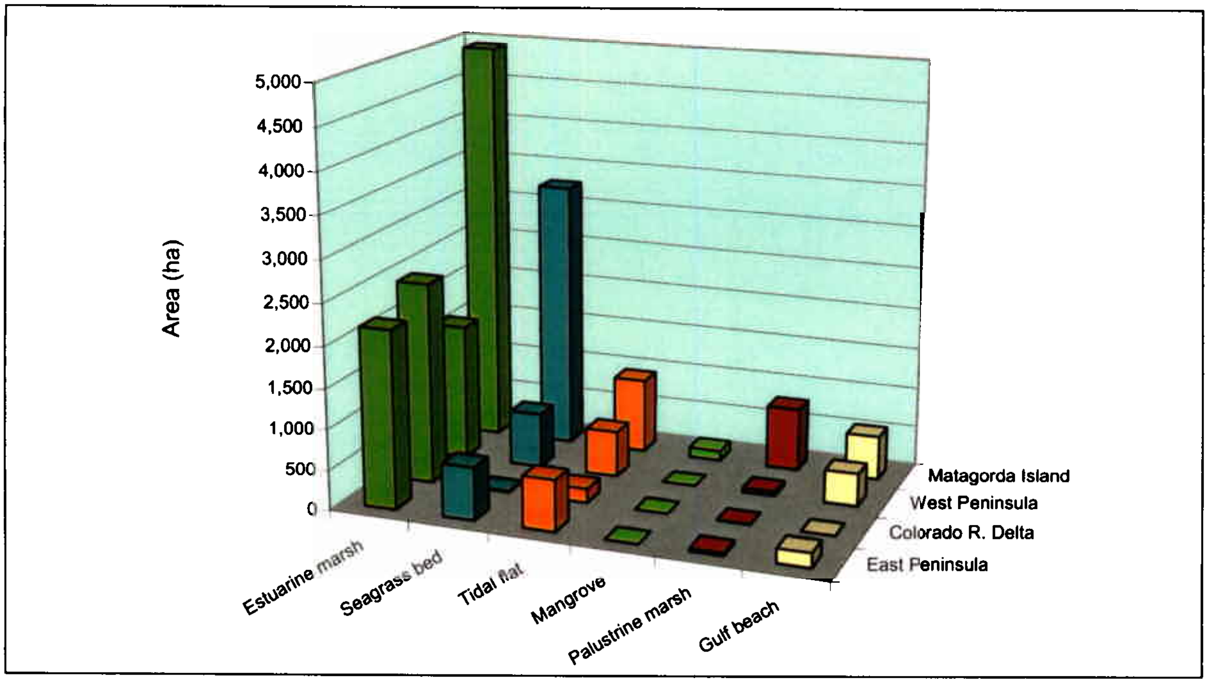

Figure III. Distribution of selected habitats by geographic area in 2001. The most extensive distribution of all habitats is on Matagorda Island.

analysis of status and trends (Fig. III). Included in the Matagorda Island subarea is the complex of smaller islands northwest of Pass Cavallo between Espiritu Santo and Matagorda Bays (Fig. I).

The most extensive estuarine emergent wetlands (salt and brackish marshes) occur on (1) Matagorda Island (4,936 ha; 12,187 acres), (2) the Colorado River Delta (2,346 ha; 6,082 acres), and (3) east Matagorda Peninsula (2,185 ha; 5,395 acres) (Fig. III). West Matagorda Peninsula, between Pass Cavallo and the Colorado River Delta, is relatively narrow, and marshes are less extensive (1,673 ha; 4,129 acres) than in the other areas. Nevertheless, these marshes are important habitats that fringe Matagorda Bay (Fig. 1), the largest bay system in the area. Seagrass beds are by far most abundant in the Matagorda Island area (Fig. III), where they exceed 3,260 ha (8,071 acres). Total areas of seagrasses are similar on east and west Matagorda Peninsulas, with areas of 655 ha (1,618 acres) and 671 ha (1,657 acres), respectively. Mangrove habitats were extensive enough to map as a separate class only in the Matagorda Island area. Thus, 100 percent of the estuarine scrub/shrub habitat (mangroves) (112 ha; 276 acres) occurs in the Matagorda Island area, which includes many smaller islands northwest of Pass Cavallo. Ninety percent of the palustrine marsh habitat, or 773 ha (1,909 acres), also occurs on Matagorda Island. Furthermore, the largest area of Gulf beach (540 ha; 1,334 acres) is along Matagorda Island, with the smallest area occurring on east Matagorda Peninsula (174 ha; 330 acres) (Fig. III).

Wetland Trends and Probable Causes, 1950's–2001

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 2001 within the study area, some wetland classes underwent substantial net losses and gains, while others remained more stable (Fig. IV; Table I). In general, estuarine marshes increased in total area during each period (1950's–1979 and 1979–2001), with a total net gain of 506 ha (1,248 acres) from the 1950's through 2001. Approximately 65 percent of this gain occurred from the 1950's through 1979, indicating that the rate of gain decreased from 1979 through 2001. The average rate of marsh gain during the earlier period was about 14 ha/yr (34 acres/yr) and for the more recent period, about 9 ha/yr (21 acres/yr). The most extensive losses in habitats occurred in tidal flats, which underwent a systematic net decline from the 1950's through 2001 (Fig. IV). Total area of tidal flats decreased by 1,188 ha (2,933 acres) during the earlier period (1950's–1979) and 654 ha (1,614 acres) during the later period (1979–2001). Seagrass beds decreased in total area by about 830 ha (2,048 acres) from the 1950's through 1979 but increased in area by a larger amount 915 ha (2,259 acres) from 1979 through 2001, for a net increase of 85 ha (211 acres) since the 1950's. Palustrine marshes had their largest distribution in 1979, at 1,991 ha (4,915 acres), and lowest in 2001, at 857 ha (2,117 acres) (Table I). The total area of mapped mangroves was slightly larger in 1979 than in 2001, indicating a net loss of 31 ha (77 acres) (this habitat was not mapped on the 1950's b&w photographs). Finally, there was a net decline in the mapped area of Gulf beaches, decreasing in total area by 730 ha (1,803 acres) from the 1950's thorough 1979 and 308 ha (760 acres) from 1979 through 2001, a net change of almost 50 percent since the 1950's.

An analysis of habitat changes within the different geographic areas reveals some interesting trends and helps elucidate some of the probable causes. At the north part of the study area at ***east Matagorda Peninsula***, there was a systematic decline in estuarine marshes from the 1950's through 1979 through 2001, ending in a net loss of about 700 ha (1,728 acres), or about 25 percent of the 1950's area. Losses were primarily the result of (1) active surface faults that intersect wetlands on the peninsula and (2) erosion. Several active faults were mapped, but one that crosses the peninsula near the Colorado River Delta had the largest impact on estuarine marsh. From the 1950's through 2001 more than 200 ha (~ 500 acres) was lost on the downthrown side of the fault primarily because of submergence and "drowning" of marsh vegetation. The rate of subsidence and relative sea level on the Gulfward side of the fault apparently exceeded the rate of marsh vertical accretion, and the marsh was replaced primarily by open water. Similar losses along active surface faults were reported by White et al. (1993) and White and Tremblay (1995) along the upper Texas coast. At the north end of east Matagorda Peninsula, severe erosion (as high as 8 m/yr or 27 ft/yr) of the Gulf shoreline near Mitchell's Cut

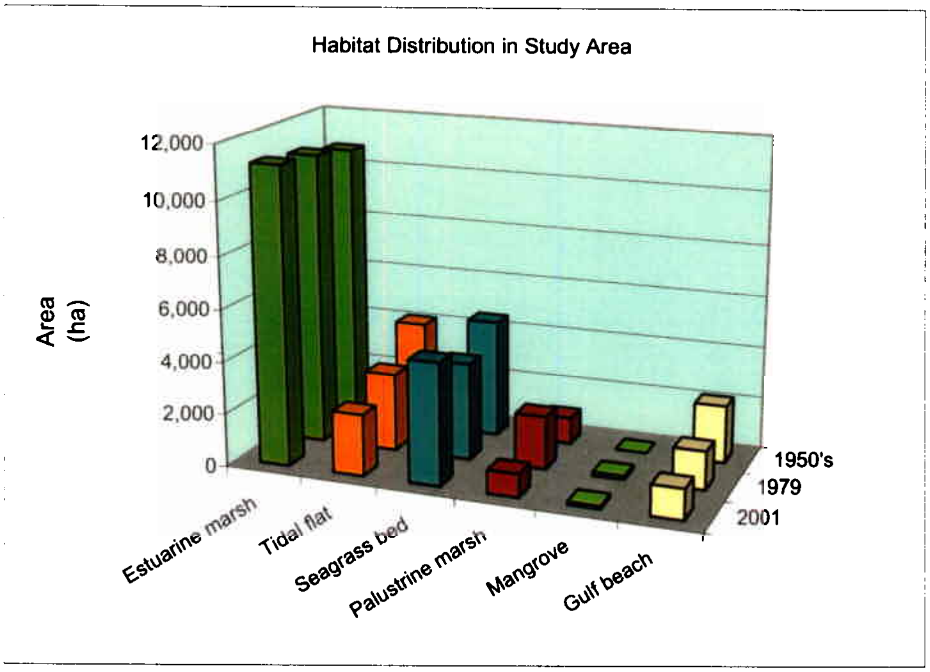

Figure IV. Areal distribution of major habitats in the study area in the 1950's, 1979, and 2001.

Table I. Total area of major habitats in the1950's, 1979 and 2001 in study area.

Habitat	1950's		1979		2001	
	(ha)	(acres)	(ha)	(acres)	(ha)	(acres)
Estuarine marsh	10,751	26,545	11,069	27,329	11,257	27,793
Tidal flat	4,131	10,199	2,943	7,266	2,289	5,652
Seagrass bed	4,521	11,163	3,692	9,115	4,607	11,374
Palustrine marsh	996	2,458	1,991	4,915	857	2,117
Mangrove	Not mapped	-	143	353	112	276
Gulf beach	2,162	5,337	1,431	3,534	1,124	2,774

caused the loss of about 50 ha (~123 acres) of estuarine marsh. Additional losses occurred from erosion of the bay shoreline and loss of interior marshes. In contrast to losses in estuarine marshes was a net gain in mapped seagrass beds. These aquatic habitats increased in total mapped area from 51 ha (126 acres) in 1979 to 655 ha (1,618 acres) in 2001. No seagrass beds were mapped in this area in the 1950's. The reason for this increase is not fully understood but may be related to natural cyclical variations in seagrass distribution. Some of the differences, however, can be attributed to photo interpretation. The distribution of seagrass beds and their visibility through the water column varies on a seasonal basis, so the month in which photographs are taken is important for mapping distribution. In addition, seagrasses can be obscured and not mapped because of high bay-water turbidities. Mapped palustrine marshes are limited in areal extent. This habitat was not mapped on east Matagorda Peninsula in the 1950's or 1979, but 33 ha (81 acres) was mapped in 2001. Some of this apparent increase is due to differences in photo interpretation and classification of habitats in the different years. The total area of Gulf beach mapped decreased systematically from the 1950's through 2001, for a net loss of 146 ha (360 acres). Much of this change was due to a narrowing through time of the area mapped as beach because of a spread of vegetation and vegetated dunes along the backbeach and shoreline erosion.

On the ***Colorado River Delta*** the historical trend of estuarine marsh, which is the principal habitat, was one of net gain. From the 1950's through 2001, there was a net increase of 352 ha (868 acres), more than 65 percent of which occurred from the1950's through 1979. This increase in marsh was primarily due to progradation and marsh development on a subdelta that formed at the mouth of an artificial cut in the southwest corner of the Colorado River Delta. The manmade channel feeding the subdelta was dammed in the early 1990's as part of the Colorado River Diversion Project, and progradation and marsh development in this area ceased. There were some gains in estuarine marshes near the mouth of the diversion channel, primarily on dredged material placed along the channel. Gains in marshes on the west side of the Colorado River Delta were partly offset by losses due to marsh erosion on the east side of the delta, which, geologically, is in a destructional phase.

On ***west Matagorda Peninsula*** there was a systematic gain in estuarine marshes but losses in seagrass beds and tidal flats. From a total area of 1,154 ha (2,850 acres) in the 1950's, estuarine marshes had a net gain of 518 ha (1,279 acres) by 2001. This is an increase of about 45 percent. Losses, however, occurred in tidal flats and seagrass beds, both of which decreased in total area by about 50 percent since the 1950's. Much of the gain in marshes and loss in seagrass beds occurred as a result of a single event, Hurricane Carla, a Category 5 hurricane, which made landfall between Port O'Connor and Port Lavaca in September 1961. The hurricane transported sediment bayward, depositing it in washover fans that eventually became the sites of new marshes. The sediment that was washed across the peninsula into the bay buried seagrass beds, causing net losses in this habitat primarily at the northeast end of the peninsula near the Colorado River Delta. Although seagrasses increased in area between 1979 and 2001, there has been a net loss since the 1950's. A systematic loss in tidal flats on west Matagorda Peninsula can be attributed in part to relative sea-level rise, which correlates with a loss in tidal flats in most areas. As sea level rises, the flats are replaced by other habitats, such as open water, seagrass beds, and marshes. Encroachment of estuarine marshes may reflect a trend toward more frequent flooding of the flats, promoting a spread of emergent vegetation, especially *Spartina alterniflora*.
A similar trend was reported by White et al.(1998) on Mustang Island and San José Island.
A systematic decline in area of Gulf beach along west Matagorda Peninsula is similar to that of east Matagorda Peninsula and is apparently due in part to erosion (although some areas accreted) but also to a narrowing of the area mapped as beach as a result of the encroachment of vegetation on small dunes, storm berms, and washovers along the backbeach.

The most significant change or trend on ***Matagorda Island*** was a systematic loss in tidal flats between the1950's and 2001. From a total area of 2,214 ha (5,467 acres) in the 1950's, tidal flats decreased in area by 572 ha (1,413 acres) between the 1950's and 1979 and by an additional

716 ha (1,767 acres) between 1979 and 2001. This loss amounts to a net loss of 1,288 ha (3,179 acres), or almost 60 percent of this habitat since the 1950's. This loss of tidal flats can be explained, in part, by a relative rise in sea level. As mentioned previously, a similar trend was reported on Mustang and San José Islands to the southwest. Areas mapped as tidal flats in the 1950's were converted in large part to open water, seagrass beds, and marshes as topographically low flats became submerged and slightly higher flats became more frequently flooded, contributing to a spread of marsh vegetation. In contrast to the wind-tidal flats, total areas of estuarine marshes and seagrass beds remained relatively unchanged from the 1950's through 2001, with marshes increasing in area by 345 ha (852 acres) and seagrass beds by 212 ha (523 acres) since the 1950's. There were losses and gains throughout the island, resulting in a net gain in estuarine marsh overall. Significant losses were concentrated in some areas on the island, for example (1) at the north end at Pass Cavallo where severe erosion of the island cut into estuarine marshes mapped in the 1950's and (2) along the bay shore near the south end of the island where interior marshes were submerged and replaced by open water. Losses from erosion at Pass Cavallo were partly offset by accretion and marsh development along a spit that formed in the pass. In contrast to the net increase in estuarine marshes on the island, there was a decline in palustrine marshes. These marshes had their highest distribution in 1979 (1,942 ha; 4,795 acres) and their lowest in 2001 (773 ha; 1,909 acres). The apparent increase in palustrine marshes from the 1950's through 1979 and decrease from 1979 through 2001 are primarily due to wetter conditions in 1979. The topographically low swales between relict beach ridges on Matagorda Island ponded water and supported extensive fresh- to brackish-water marsh vegetation. Much drier conditions in 2001 limited the extent of these marshes, so fewer were mapped. In future wetter times, the swales will be flooded, and marshes will become reestablished. The estuarine scrub/shrub habitat (primarily mangroves) had total areas of 143 ha (353 acres) in 1979 and 112 ha (276 acres) in 2001. The distribution of mangroves could not be adequately delineated on the black-and-white 1950's photographs, and only 2 ha (6 acres) was mapped. The total area of Gulf beach mapped declined systematically from 1,157 ha (2,856 acres) in the 1950's to 673 ha (1,661 acres) in 1979, to 540 ha (1,334 acres) in 2001. This decline represents a 53-percent reduction in the area of beach mapped in the 1950's as compared with that mapped in 2001.

The systematic decrease in the total area mapped as Gulf beach can be attributed, as in other areas, to a narrowing of the beach primarily due to expansion of vegetation on the backbeach, on coppice dunes, and on barren storm washover sand flats, as well as to local erosion of the beach, including the Pass Cavallo area. In some areas the change was due to differences in photo interpretation and habitat classification.

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 central Texas barrier island system from San Antonio Bay to East Matagorda Bay, including the Colorado River Delta. Previous studies of Galveston Bay by the Bureau of Economic Geology (BEG) (White et al., 1993) 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 in the Corpus Christi Bay area (White et al. 1998) show that marshes have expanded as a result of relative sea-level rise. Between these two bay systems is the Matagorda Bay/San Antonio Bay complex, where extensive wetlands on barrier islands and peninsulas have not been recently studied to determine status and trends. This study focuses on this barrier system, including the Colorado River delta, and analyzes wetland status and trends and probable causes of trends. 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.

Figure 1. Salt marsh on the bayward side of Matagorda Peninsula.

Study Area

The study area includes the barrier/peninsula and delta system between Cedar Bayou and Brown Cedar Cut (Fig. 2). Included are Matagorda Island, Matagorda Peninsula, and the Colorado River Delta and associated diversion channel. The estuarine system along Matagorda Island consists of Espiritu Santo, San Antonio, and Mesquite Bays, as well as along Matagorda Peninsula, Matagorda Bay and East Matagorda Bay. The study area is located in Calhoun and Matagorda Counties.

General Setting of Barriers and Delta

Geologically Matagorda Island is a modern accretionary barrier island (Wilkinson, 1973) with well-preserved ridge-and-swale topography (Fig. 3a). 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 extensive linear palustrine wetlands. Matagorda Peninsula (Fig. 3b) is much more narrow and topographically lower than Matagorda Island. The peninsula, erosional along much of its length, is characterized by numerous storm washover channels that are filled with estuarine water and fringed by marshes. Much of the peninsula 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 forming coalescing storm deposits in mid-island. These storm deposits were mapped as shell ramps by McGowen and Brewton (1975) and are part of the upland system mapped in this project. Extensive salt and brackish marshes occur on the bayward side of Matagorda Island and Peninsula.

The Colorado River Delta extends across the bay system, separating East Matagorda Bay to the northeast from Matagorda Bay to the southwest (Fig. 2). The delta has had a relatively brief history of development after removal of a log raft upstream that had trapped large amounts of sediments along its lower reaches. Removal of the raft in 1929 led to rapid progradation of the delta across the eastern arm of Matagorda Bay (approximately 6 km) between 1929 and 1935 (Wadsworth, 1966). In 1936, a channel was dredged across Matagorda Peninsula, allowing the river to discharge directly into the Gulf of Mexico. The Colorado River Diversion Project in the early 1990’s diverted the river back into Matagorda Bay. Habitats on the Colorado River Delta are primarily salt marshes.

Geomorphic features on which various types of barrier island and 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.

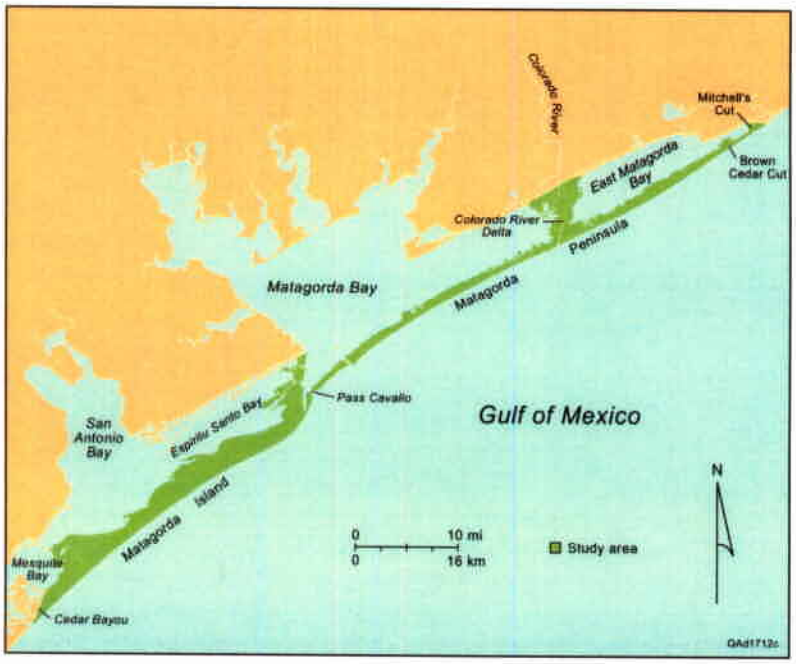

Figure 2. Index map of wetland status and trends in study area.

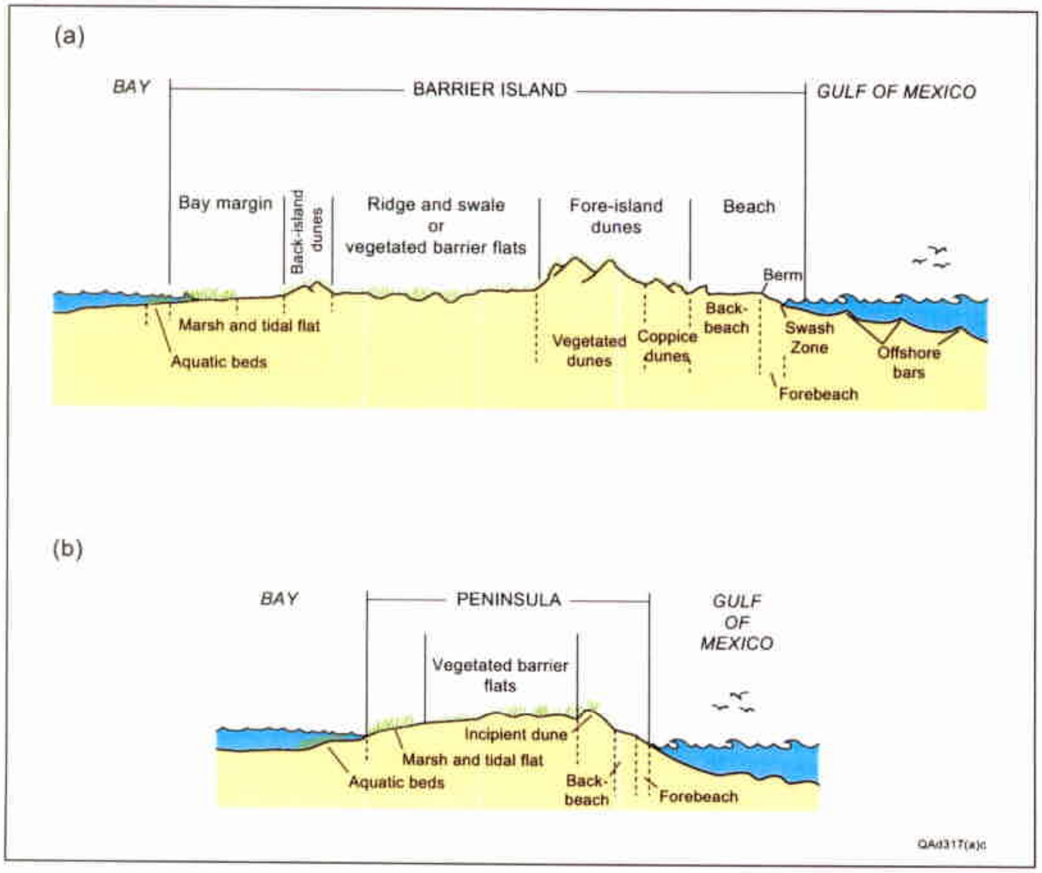

Figure 3. Schematic profiles across (a) Matagorda Island and (b) Matagorda Peninsula illustrating major environments. Not drawn to scale.

Bay-Estuary-Lagoon Setting

Exchange of marine waters with waters of the estuarine system occurs primarily through the tidal inlet, Pass Cavallo, which separates Matagorda Island from Matagorda Peninsula, and through a dredged ship channel crossing Matagorda Peninsula just to the northeast of the pass (Fig. 2). Intermittent exchange occurs at Cedar Bayou (when open), a narrow channel that, after storms, connects the Gulf with Mesquite Bay at the southwest end of the study area, and an artificial pass (Mitchell's Cut) at the northeast end of the study area, near Brown Cedar Cut. The main sources of fresh-water inflow into the estuarine system of the study area are the Colorado River, which discharges into Matagorda Bay, the Lavaca and Navidad Rivers, which discharge at the head of Lavaca Bay, and the San Antonio and Guadalupe Rivers, the latter discharging at the head of San Antonio Bay (Fig. 2). Average tidal range is approximately 0.5 m in the Gulf and 0.2 m in the bays (U.S. Department of Commerce, 1978), although wind-generated tides in the bays can be substantially higher. Salinities in the estuarine system are generally at a maximum (20 to 30 parts per thousand) near Pass Cavallo, reflecting the influence of marine water in tidally influenced areas (White et al. 1988, 1989). Salinities decrease toward the heads of the bays where they are moderated by fresh-water inflows.

Relative Sea-Level Rise

Relative sea-level rise is another important process affecting wetland and aquatic habitats. Relative sea-level rise, as used here, is the relative vertical rise in water level with respect to a datum at the land surface, whether it is caused by a rise in mean water level or subsidence of the land surface. Along the Texas coast, both processes, eustatic sea-level rise and subsidence, are part of the relative sea-level rise equation. Subsidence, especially associated with withdrawal of 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 Freeport northeast of the study area exceeded 1.1 cm/yr from 1959 through 1971, (Swanson and Thurlow, 1973), and 1.4 cm/yr from 1954 through 1986 (records were incomplete for the years 1954, 1966, and 1984) (Lyles et al. 1988). 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 provides the longest continuous record of sea-level variations near the southwest end of 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; this time coincides with a maximum change in some habitats, such as wind-tidal flats (White et al. 1998). These relationships on the barrier islands are presented in the discussion of wetland trends.

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 2001. 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 November and December 2001 by Andrew Lonnie Sikes, Inc., Surveying & Mapping (ALS), contracted by GLO. 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).

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

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

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 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). We think that the photographs covering our study area, however, were taken in 1953, on the basis of comparison of the 1950's wetland delineations with a photograph taken in 1953. 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 2001 photographs, which were taken during much drier conditions. Although the 1950's photographs are black-and-white, they are large scale (1:24,000), which aids in the photointerpretation and delineation process. The 1950's photographs were apparently taken before the severe drought that peaked in 1956 in Texas (Riggio et al. 1987), which accounts for extensive palustrine marshes on Matagorda Island 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 (2001) 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, many of these areas were subdivided into E2EM and E2FL where possible at the mapping scale. In addition, because of the larger scale of the 1950's aerial photographs (1:24,000) as compared with the 1979 photographs (~1:65,000), smaller wetlands, particularly water features, were mapped on the 1950's photographs. As part of the revisions, many of these smaller water bodies were mapped and added to the 1979 wetland maps.

To accomplish the revisions, USFWS maps for the1950's and 1979 were plotted on a quadrangle-by-quadrangle basis, and wetlands were analyzed and revised at a scale of 1:24,000 by optically rectifying the aerial photographs (1950's and 1979) to the wetland maps using a zoom-transfer scope. Wetlands on the aerial photographs were interpreted and changes mapped directly on the plotted wetland maps. Changes were digitized, and the revised data were entered into the GIS. Revised maps were then plotted in color on a quadrangle-by-quadrangle basis and the revision checked for accuracy and completeness. Problem areas were marked, and the digital data were revised accordingly.

Current Wetland Distribution

The current distribution of wetlands and aquatic habitats is based on color infrared (CIR) aerial photographs taken in November and December 2001 by ALS, Inc., under contract with the GLO. Photographs were scanned to create digital images with a pixel resolution of 1 meter and registered to USGS Digital Orthophoto Quads (DOQ's) by ALS, Inc. 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 (ArcInfo and ArcView) at a scale of 1:8,000. An attempt was made to show about the same amount of detail as that in the historical maps in order to make accurate comparisons of wetland changes through time. Still, 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. 4). Characterization of prevalent plant associations provided vital plant community information for defining mapped wetland classes in terms of typical vegetation associations. In addition, topographic profiles along selected transects on the island and peninsula provided additional information for interpreting wetland habitats (Fig. 5). Interpretations of wetlands at the southwest end of Matagorda Island were supported by Light Detection and Ranging (LIDAR) data acquired by BEG in the spring of 2002 (Fig. 6). The LIDAR images provide detailed elevation data that help differentiate between high and low marshes and flats and areas that are transitional between uplands and wetlands.

Variations in Classification

Classification of wetlands varied somewhat for the different years. On 1979 and 2001 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. 7–9). 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. 9). Flats and beach/bar classes designated separately on 1950's and 1979 maps were combined into a single class, unconsolidated shore, on 2001 maps, in accordance with updated NWI procedures as exemplified on 1992 NWI wetland maps (Fig. 8). USFWS data for the study area were selected from 18 7.5-minute quadrangles (Fig. 10) 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 2001. Data can be manipulated as information overlays, whereby scaling and selection features allow portions of the estuary 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

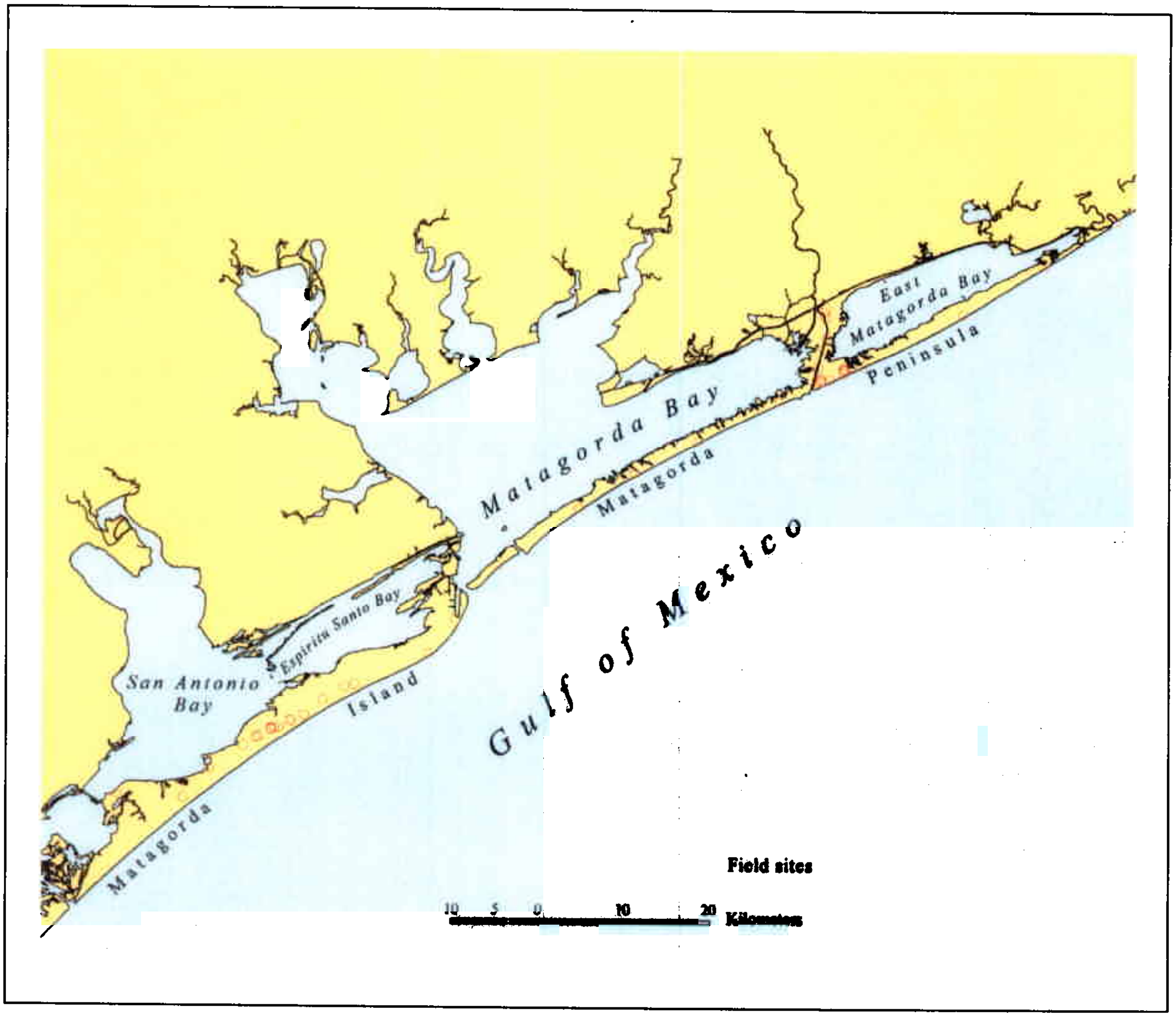

Figure 4. Index map of field-survey sites used for ground-truthing photo delineations and/or surveying elevations to construct topographic profiles.

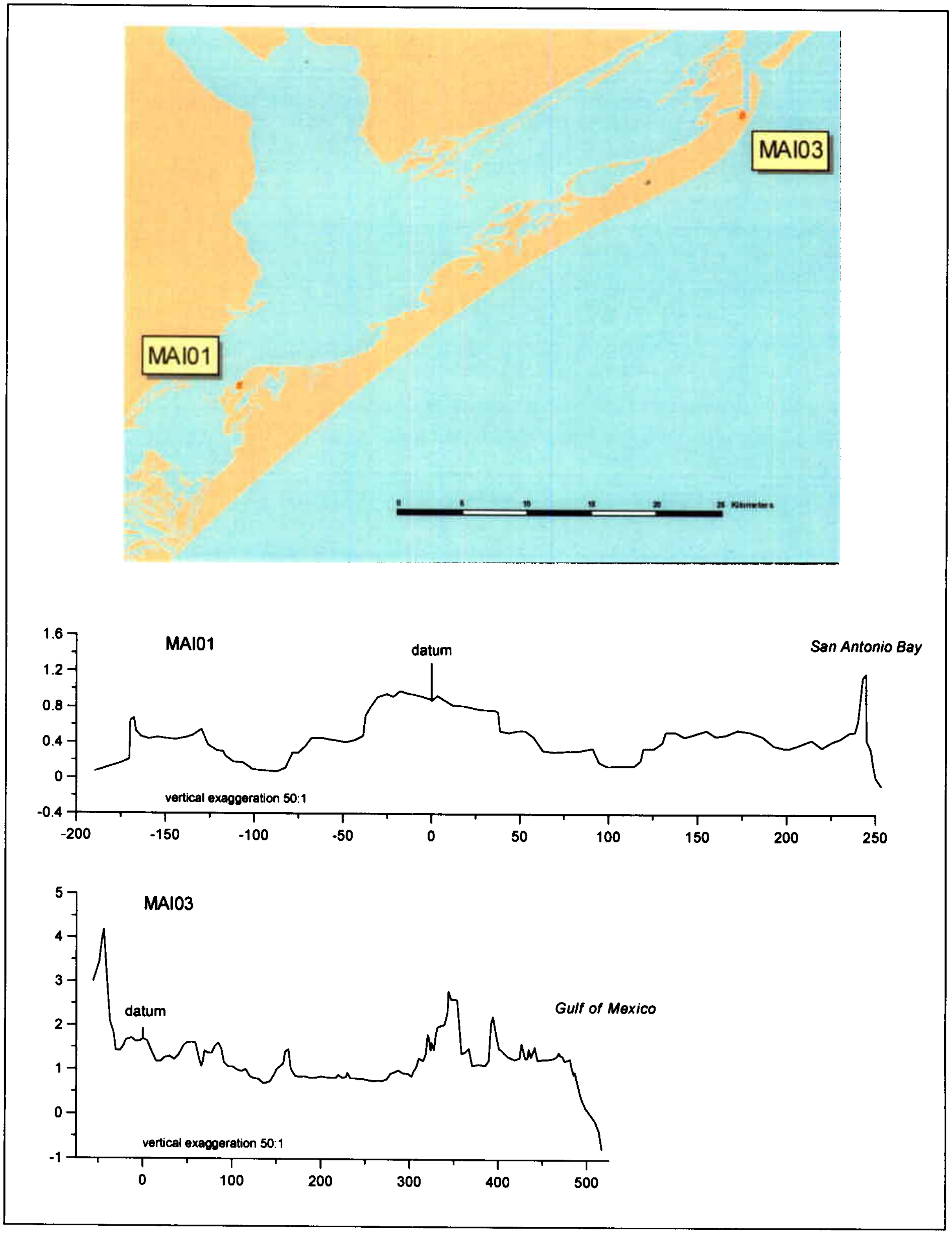

Figure 5. Example of topographic profiles surveyed across parts of Matagorda Island using a Total Station. Surveys completed in conjunction with the Texas Shoreline Change Project. Scale in meters.

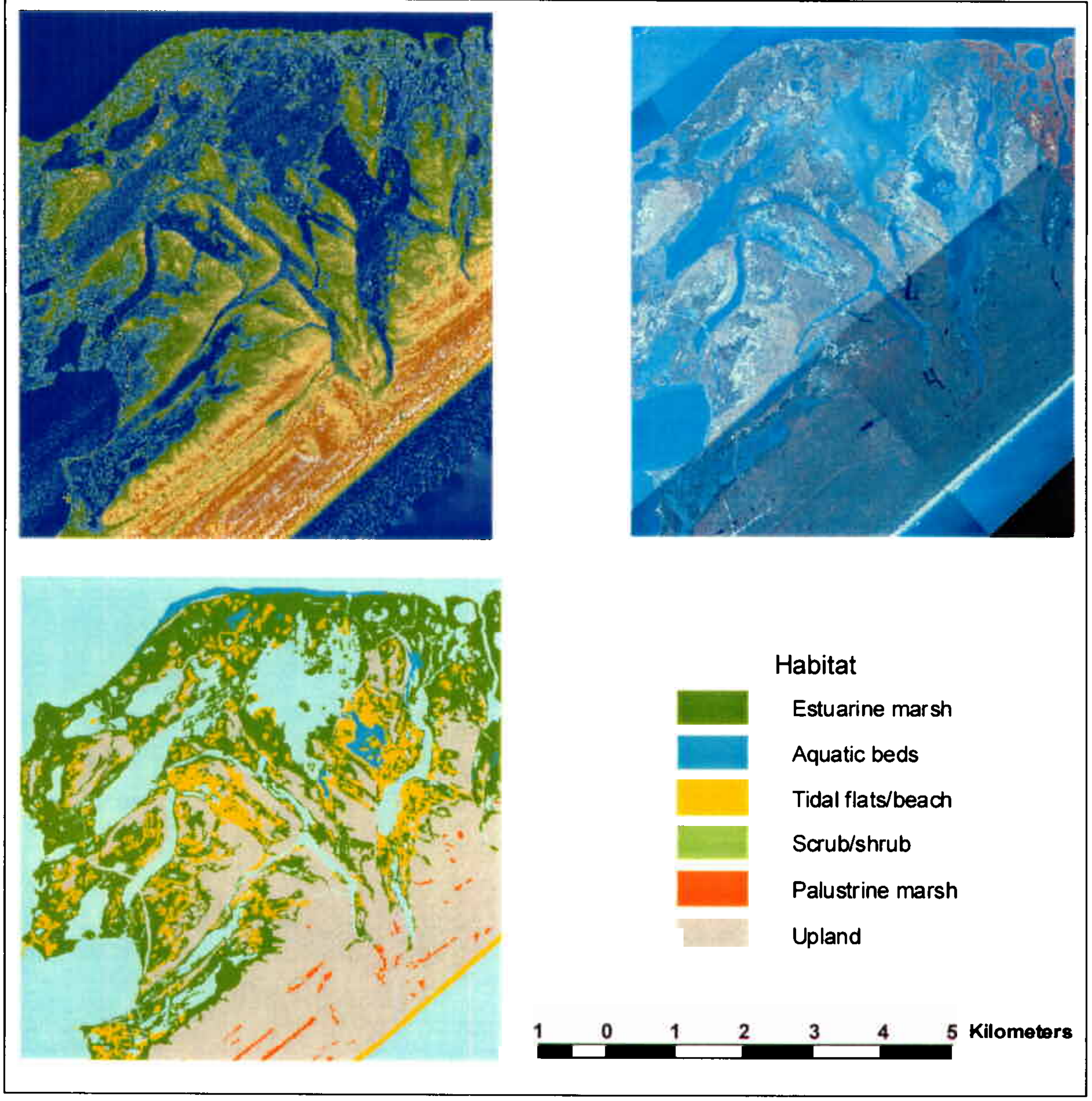

Figure 6. Comparison of LIDAR image, 2001 aerial photograph, and wetlands map of relict flood-tidal delta/washover fan complex at the south end of Matagorda Island. LIDAR data, collected by BEG researchers as part of another project, were used as collateral information for mapping wetlands.

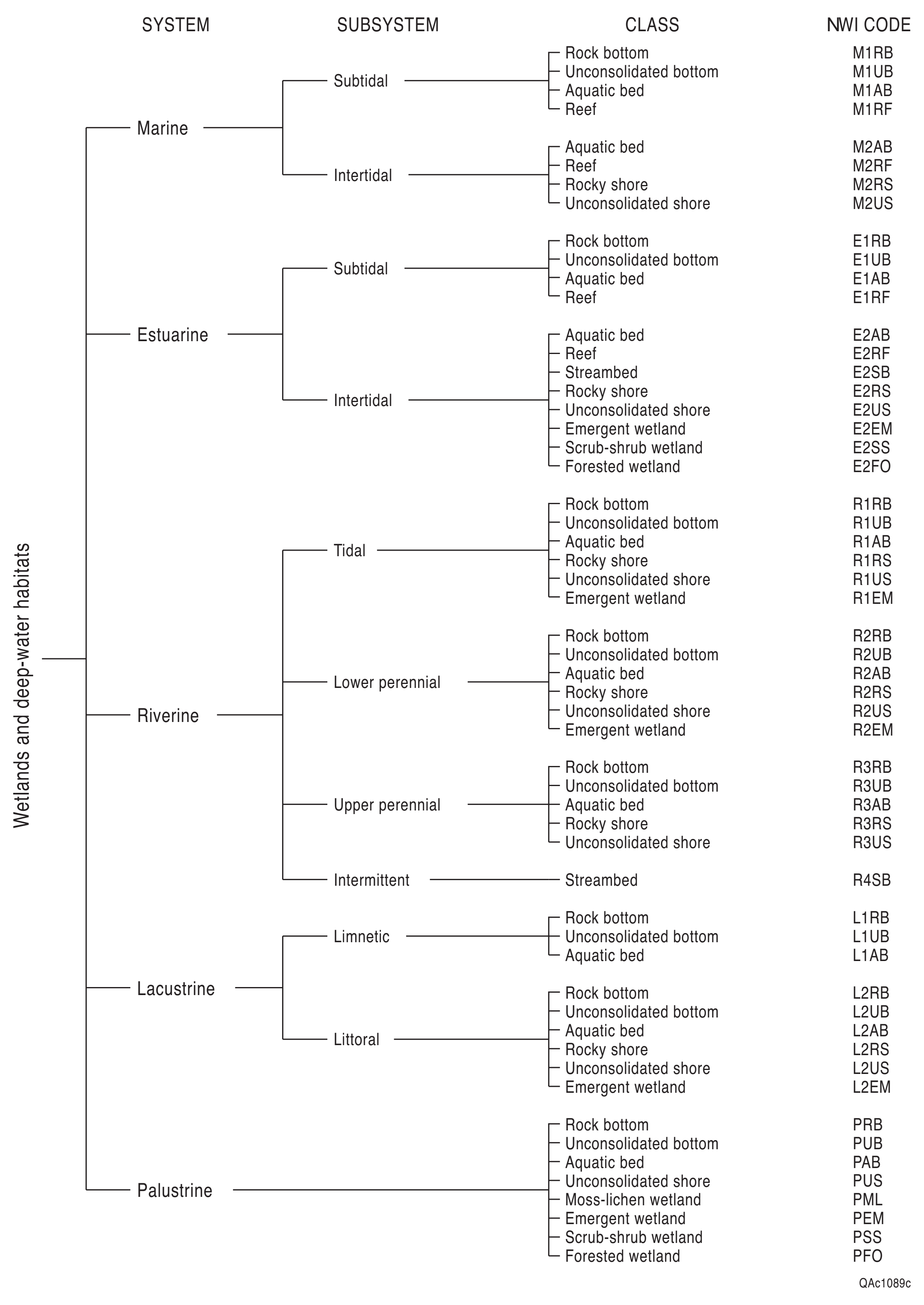

Figure 7. Classification hierarchy of wetlands and deepwater habitats showing systems, subsystems, and classes. From Cowardin et al. (1979).

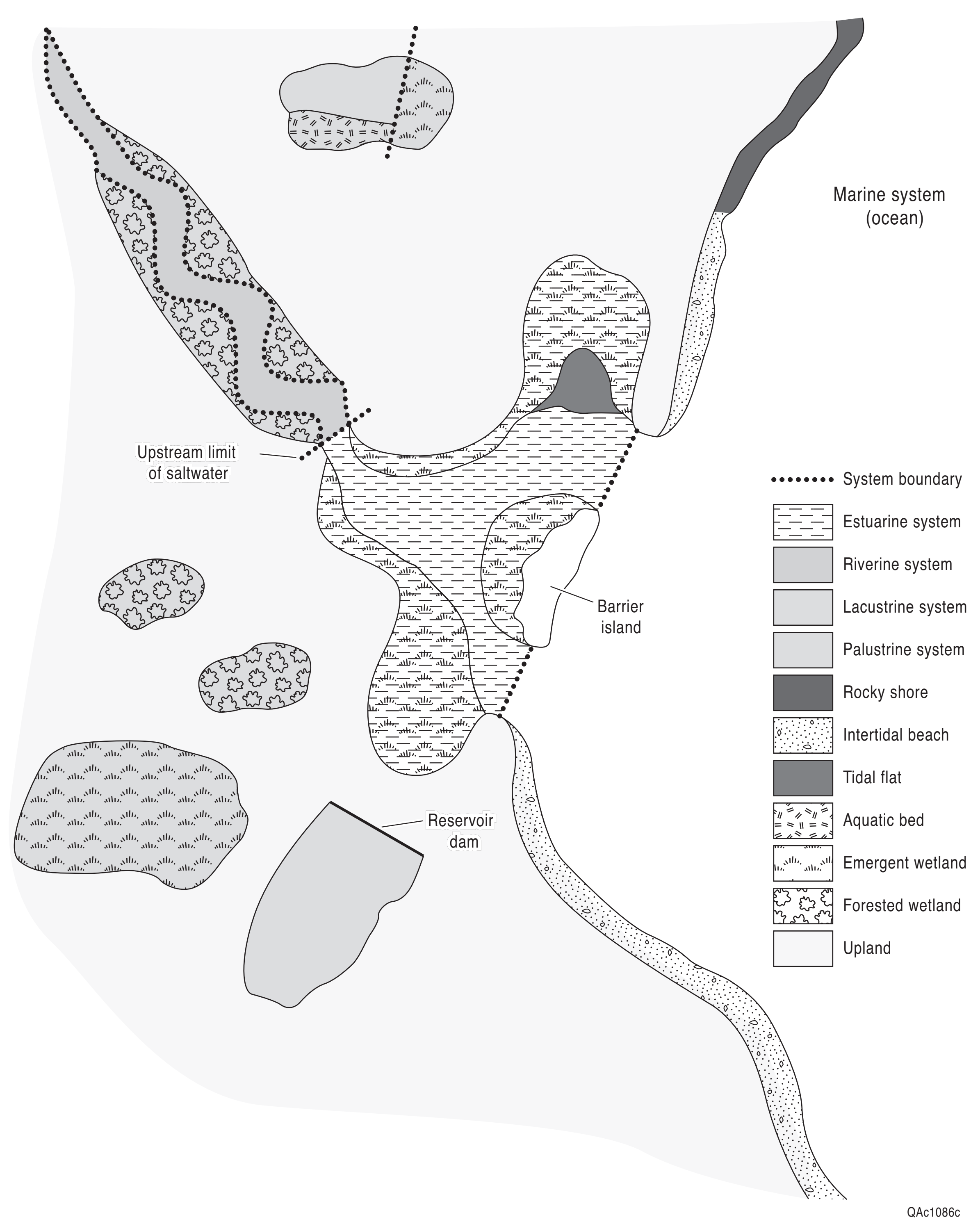

Figure 8. Schematic diagram showing major wetland and deepwater habitat systems. From Tiner (1984).

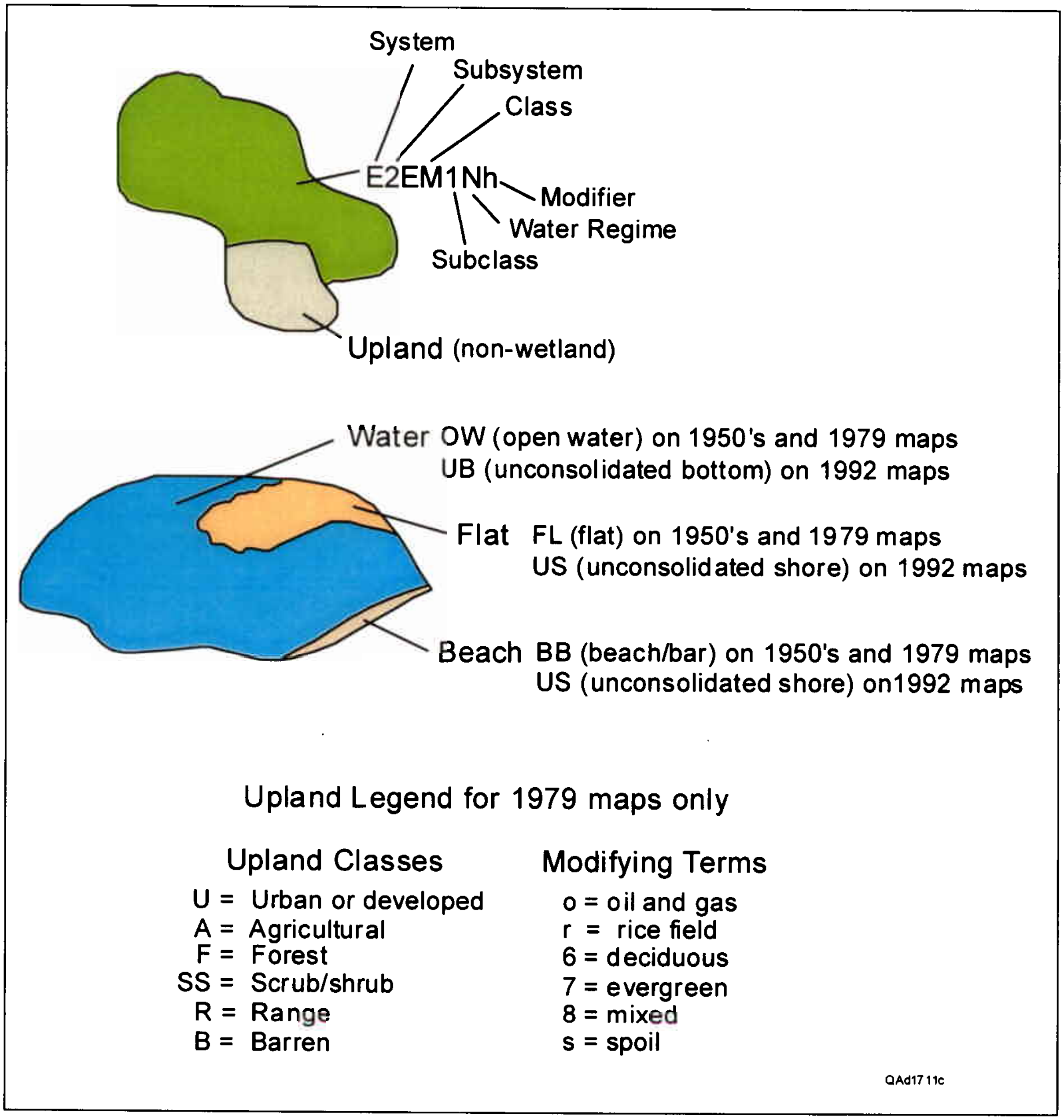

Figure 9. Example of symbology used to define wetland and upland habitats on NWI maps.

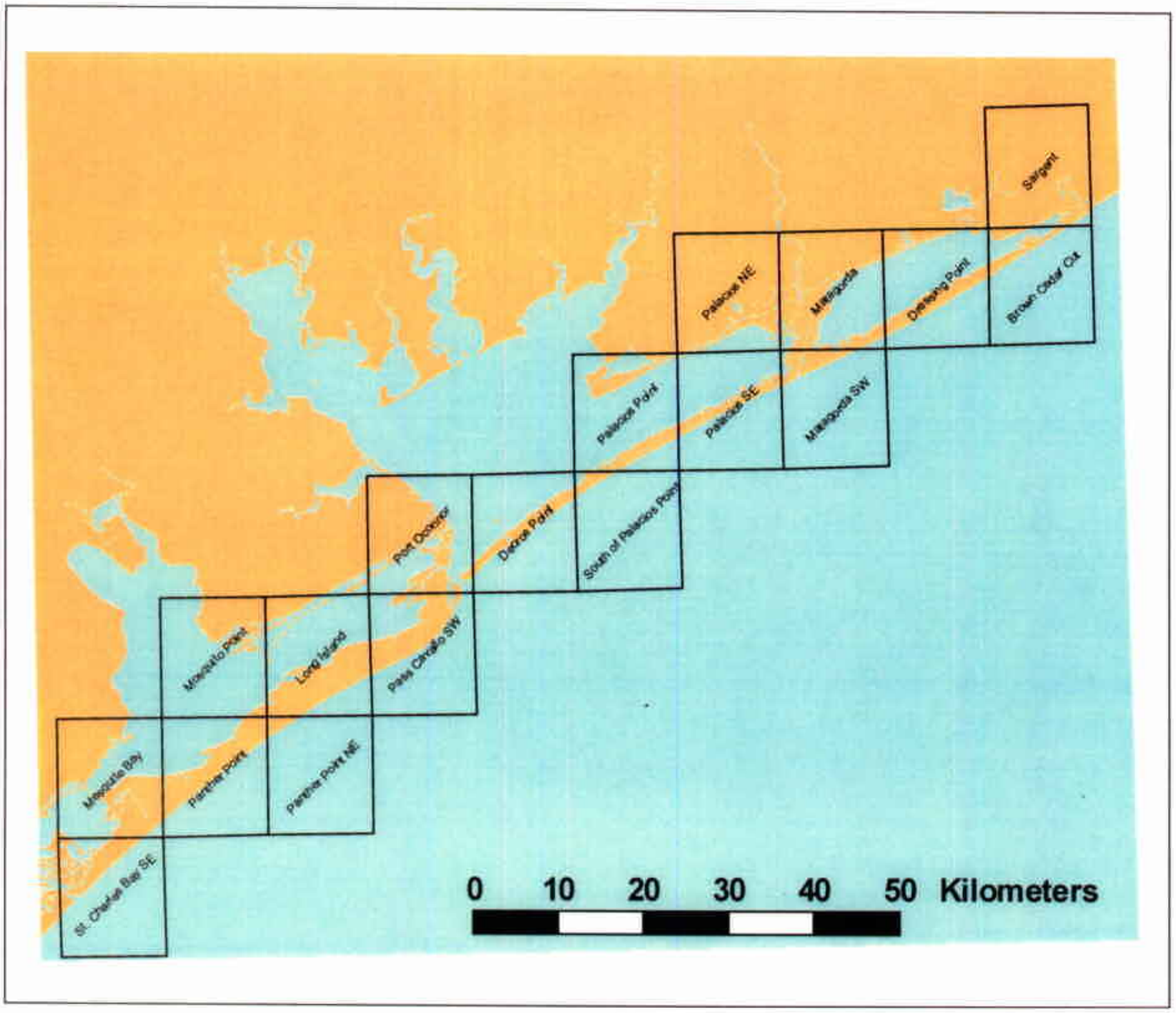

Figure 10. Index map of USGS 7.5-minute quadrangles that encompass the study area.

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 2001 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 2001 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 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.

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. 7). 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 2001. 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. 9). Symbols for certain habitats changed after 1979; these changes are shown in Figure 9 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 2001 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.

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.

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. 11). 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).

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 regularly flooded (E2USN) to irregularly flooded (E2USP) (Fig. 12). Aquatic beds 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). Three of these species (*Halodule*, *Ruppia*, and *Halophila*) have been identified by the authors in the study area.


2002. 6. 6

Figure 11. Marine beach along the Gulf shoreline. The forebeach (lower beach along the Gulf margin) was mapped as M2USN (marine intertidal unconsolidated shore, regularly flooded), and the backbeach as M2USP (marine intertidal unconsolidated shore, irregularly flooded).


2002. 6. 4

Figure 12. Example of an irregularly flooded tidal flat on the bayward side of Matagorda Island. This sand flat was mapped as estuarine intertidal unconsolidated shore, irregularly flooded (E2USP).

Table 2. Wetland codes and descriptions from Cowardin et al. (1979). Codes listed below were used in mapping wetlands on the 2001 delineations, which varied in some cases from 1950's and 1979 maps (see Fig. 9).

NWI code (water regime)	**NWI description**	**Common description**	**Characteristic vegetation**
M1UB (L)	Marine, subtidal unconsolidated bottom	Gulf of Mexico	Unconsolidated bottom
M2US (P,N,M)	Marine, intertidal unconsolidated shore	Marine beaches, barrier islands	Unconsolidated shore
M2RS (P)	Marine, intertidal rocky shore	Marine breakwaters, beach stabilizers	Jetties
E1UBL (L)	Estuarine, subtidal unconsolidated bottom	Estuarine bays	Unconsolidated bottom
E1AB(L)	Estuarine, subtidal aquatic bed	Estuarine seagrass or algae bed	*Halodule wrightii* *Halophila engelmannii* *Ruppia maritima*
E2US (P,N,M)	Estuarine, intertidal unconsolidated shore	Estuarine bay, tidal flats, beaches	Unconsolidated shore
E2EM (P,N)	Estuarine, intertidal emergent	Estuarine bay marshes, salt and brackish water	*Spartina alterniflora* *Spartina patens* *Distichlis spicata*
E2SS (P)	Estuarine, intertidal scrub-shrub	Estuarine shrubs	*Iva frutescens* *Baccharis halimifolia*
R1UB (V)	Riverine, tidal, unconsolidated bottom	Rivers	Unconsolidated bottom
R1SB (T)	Riverine, tidal, streambed	Rivers	Streambed
R2UB (H)	Riverine, lower perennial, unconsolidated bottom	Rivers	Unconsolidated bottom
R4SB (A,C)	Riverine, intermittent streambed	Streams, creeks	Streambed
L1UB (H,V)	Lacustrine, limnetic, unconsolidated bottom	Lakes	Unconsolidated bottom
L2UB (H,V)	Lacustrine, littoral, unconsolidated bottom	Lakes	Unconsolidated bottom
L2AB (H,V)	Lacustrine, littoral, aquatic bed	Lake aquatic vegetation	*Nelumbo luteaRuppia 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 meadow rims	Swamps, woodlands in floodplains depressions,	*Salix nigra* *Fraxinus spp.* *Ulmus crassifolia* *Celtis spp.*

Emergent areas closest to estuarine waters consist of regularly flooded, salt-tolerant grasses (low salt and brackish marshes) (E2EM1N) (Figs. 13 and 14). These communities are mainly composed of *Spartina alterniflora* (smooth cordgrass), *Batis maritima* (saltwort), *Distichlis spicata* (seashore saltgrass), *Salicornia* spp. (glasswort), *Monanthochloe littoralis* (shoregrass), *Suaeda linearis* (annual seepweed), and *Sesuvium portulacastrum* (sea-purslane) in more saline areas.

In brackish areas, species composition changes to a salt to brackish-water assemblage, including *Schoenoplectus* (formerly *Scirpus*) spp. (bulrush), *Paspalum vaginatum* (seashore paspalum), *Spartina patens* (saltmeadow cordgrass), 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 (Fig. 13).

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) (Fig.15), and in irregularly flooded zones (E2SS1P) between emergent wetland communities and upland habitats, include *Iva frutescens* (big-leaf sumpweed), *Baccharis halimifolia* (sea-myrtle, or eastern false-willow), *Sesbania drummondii* (drummond’s rattle-bush), and *Tamarix* spp. (salt cedar).

Mapping criteria allow classes to be mixed in complex areas where individual classes could not be separated. Most commonly used combinations include the estuarine emergent class and estuarine intertidal flat (E2EM/FL) and wetlands and uplands (PEM/U and POW/U). The E2EM/FL class was used only on 1956 and 1979 maps. In such combinations, each class must compose at least 30 percent of the mapped area (polygon); on the 1950’s and 1979 maps, the wetland class was always listed first (PEM/U) regardless of whether it was most abundant.

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 modifiers (PUBHx or PUBHh). Palustrine

Figure 13. Estuarine intertidal low marsh (E2EM1N) on north Matagorda Island characterized by *Spartina alterniflora* along the water's edge intergrading with *Distichlis spicata* at slightly higher elevations and then into less frequently flooded higher marsh (E2EM1P) characterized by *Spartina patens*, *Borrichia frutescens*, *Spartina spartinae*, and *Iva frutescens*.

Figure 14. Estuarine intertidal low marsh on the bayward side of Matagorda Island, where the dominant vegetation is *Batis maritima*.

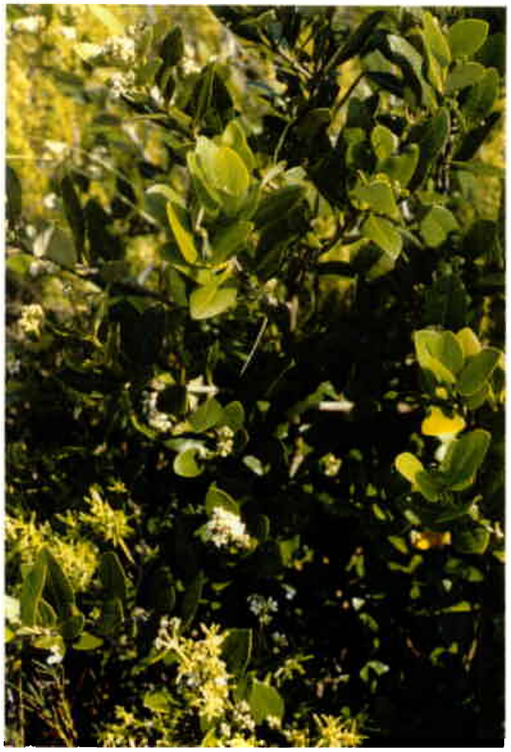

Figure 15. Black mangrove (*Avicennia germinans*) in flower on Matagorda Island. Areas where black mangrove shrubs were dominant in marsh were classified as E2SS3.

Figure 16. Pond and fringing marsh on Matagorda Peninsula mapped in the palustrine system. Vegetation, mapped as PEM1F, is predominantly *Paspalum vaginatum*, *Eleocharis* sp., and *Schoenoplectus pungens* near the pond.

emergent wetlands 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 (Fig 16); seasonally flooded (PEM1C) (Fig. 17) 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 (Figs. 16 and 17). Other species reported include *Schoenoplectus californicus* and *Juncus* sp. (White et al. 1989). 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 (Fig. 5).

Palustrine scrub/shrub wetlands that were mapped (in 1979) are typically seasonally flooded (PSS2C) and may include *Tamarix* spp. (Fig 18), *Baccharis* sp., and *Iva frutescens*. Temporarily and semipermanently flooded scrub/shrub habitats also occur with similar species. Water regimes include both tidally and nontidally influenced areas.

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 in1979 wetlands and none in the 2001 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.

Riverine System

No areas were classified in the riverine system in the study area. The Colorado River channel was mapped as estuarine because only the lower tidally influenced portion is within the study area and ocean-derived salts along the channel exceed 0.5 ppt. (See explanation in last paragraph in preceding Estuarine System).

Figure 17. Palustrine marsh in swale between relict beach ridges on Matagorda Island. This marsh area was mapped as PEM1C. The dominant vegetation in the swale is *Schoenoplectus pungens*.

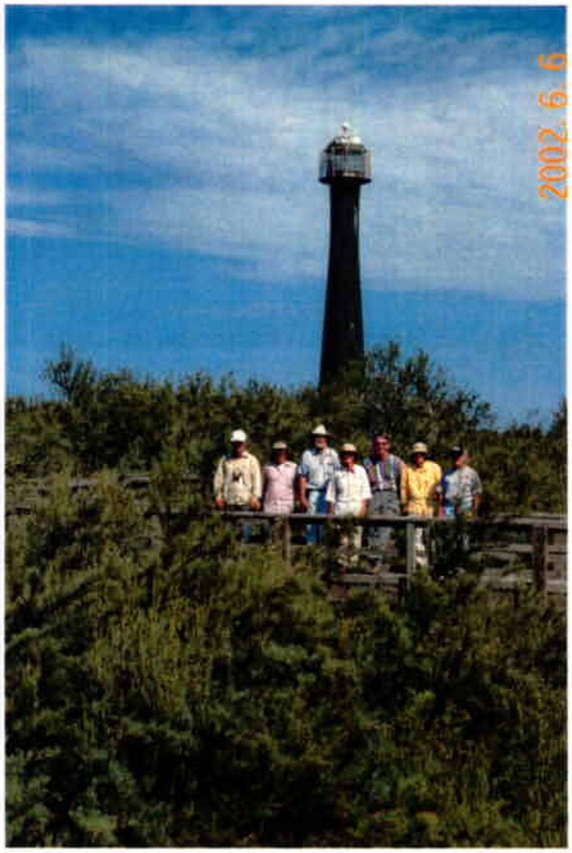

Figure 18. Field crews from BEG's Barrier Island Wetlands Project and Texas Shoreline Change Project standing on boardwalk near relict swale that is seasonally flooded. Shrubs are *Tamarix* (salt cedar). Location is north Matagorda Island.

STATUS OF WETLANDS AND AQUATIC HABITATS IN 2001

In November–December 2001, wetland and aquatic habitats covered about 60,000 ha within the study area (Fig.19, Table 3). This area includes a buffer zone of open water about 1 km wide that parallels the shoreline in the bays and the Gulf. Approximately 14,162 ha within the study area was classified as uplands. Of the three wetland systems mapped, the estuarine system is by far the largest (Fig. 19; Table 3). Emergent vegetated wetlands (E2EM, E2SS, PEM areas) cover about 12,190 ha, 92 percent of which is estuarine marsh. The extent of all mapped wetlands, deepwater habitats, and uplands for each year is presented in the appendix.

Estuarine System

Marshes (Estuarine Intertidal Emergent Wetlands)

The estuarine intertidal emergent wetland habitat (E2EM) (marsh) consists of 11,257 ha of salt and brackish marshes. The regularly flooded estuarine marsh, or low marsh, is most abundant, at 8,693 ha (Fig. 19; Table 3). The irregularly flooded estuarine marsh covers about 2,364 ha. The most extensive estuarine emergent wetlands (salt and brackish marshes) occur (1) on the Colorado River delta; (2) on Matagorda Island, including (a) the relict tidal inlet/washover fan complexes at the southwest end of Matagorda Island, (b) the flood-tidal-delta complex at the north end of the island between Pass Cavallo and Port O'Connor (where black mangroves are also most abundant), and (c) along the bayward side of central Matagorda Island; and (3) along east Matagorda Peninsula (Figs. 20 and 21; Table 4). West Matagorda Peninsula, between Pass Cavallo and the Colorado River Delta, is relatively narrow, and marshes are less extensive than in the other areas. Nevertheless, these marshes are important habitats that fringe Matagorda Bay (Fig. 1), the largest bay system in the area.

Tidal Flats (Estuarine Intertidal Unconsolidated Shores)

Estuarine intertidal unconsolidated shores (E2US) include wind-tidal flats, beaches, and algal flats. Approximately 2,290 ha of E2US was mapped in the study area (Table 3). Tidal flats are most extensive on Matagorda Island, followed by west Matagorda Peninsula, east Matagorda Peninsula, and the Colorado River Delta (Fig. 20; Table 4). High, irregularly flooded tidal flats are slightly more extensive than low flats (Fig. 12). Because of the low astronomical tidal range, many flats are flooded only by wind-driven tides and are, thus, designated as wind-tidal flats (McGowen et al. 1976). These tidal habitats represent about 17 percent 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.

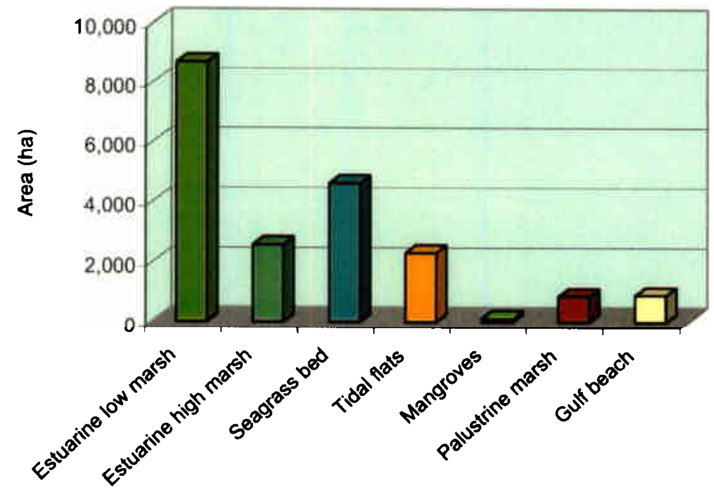

Figure 19. Areal extent of selected habitats in the study area in 2001.

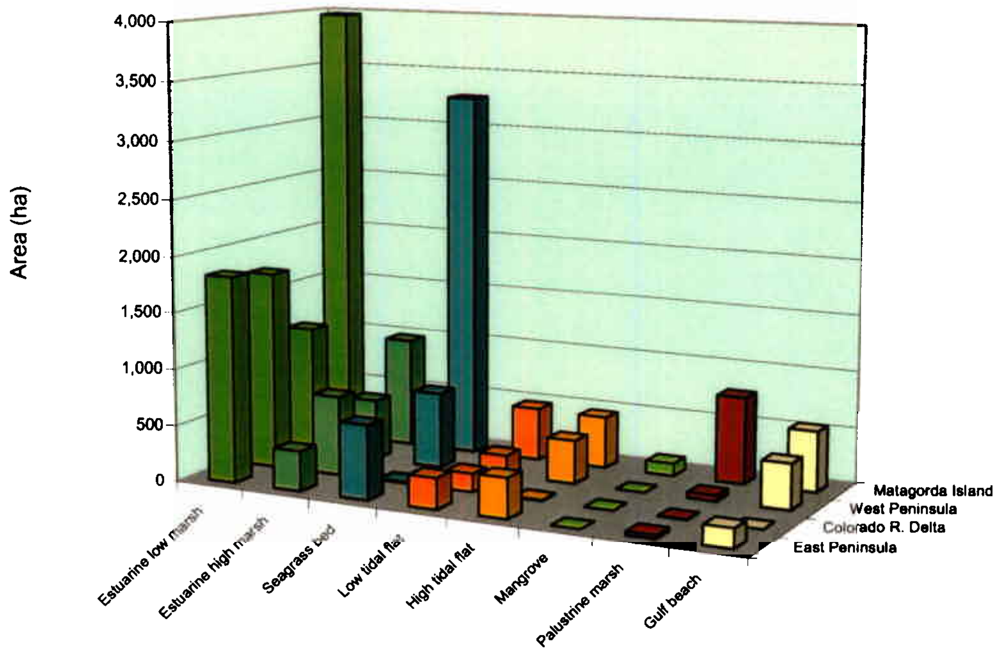

Figure 20. Areal extent of habitats in 2001 for different geographic areas.

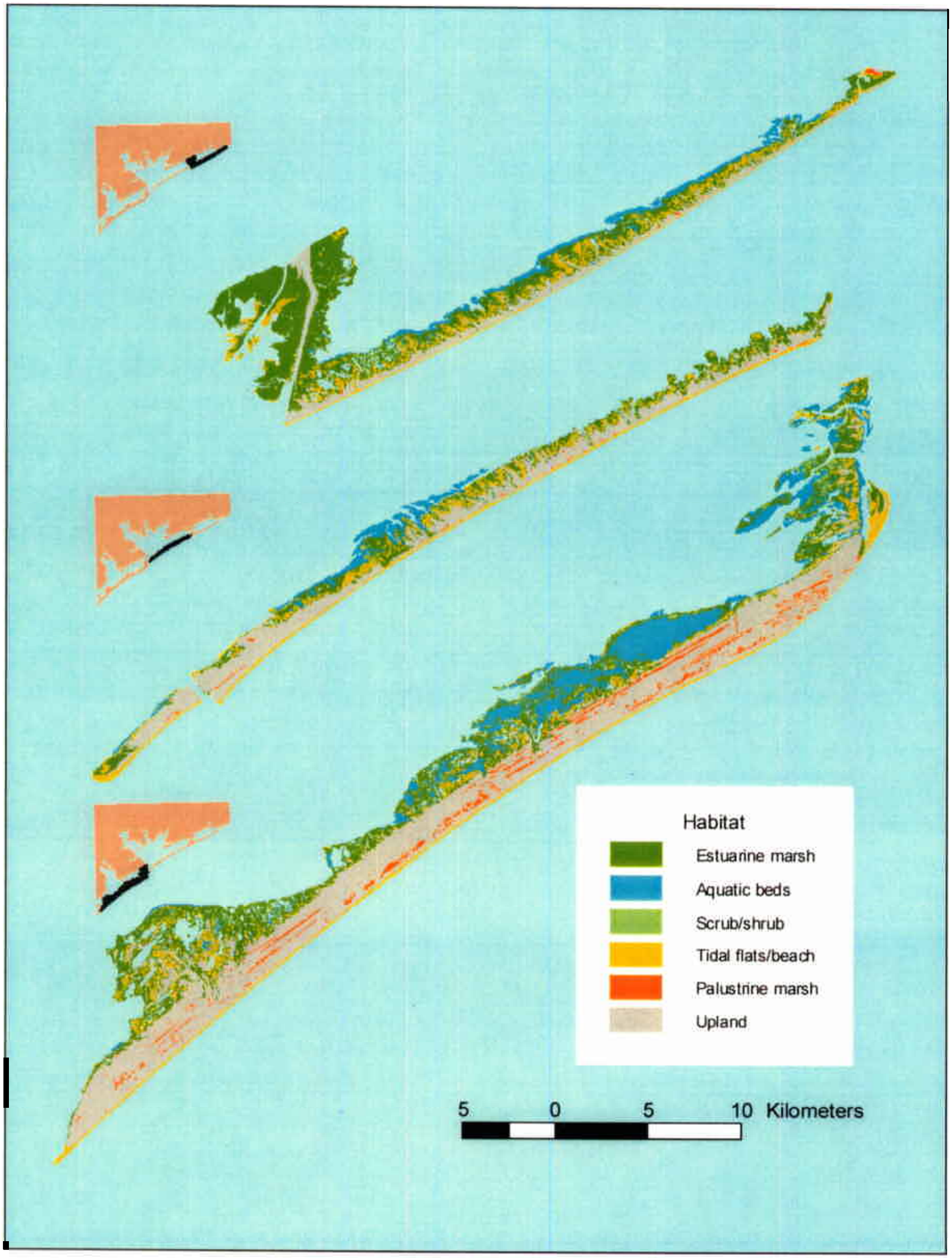

Figure 21. Maps of habitats in 2001 for different geographic areas. From the top they are east Matagorda Peninsula and Colorado River Delta (discussed as separate areas), west Matagorda Peninsula, and Matagorda Island.

Table 3. Areal extent of mapped wetland and aquatic habitats in 2001

NWI Code	National Wetlands Inventory Description	Hectares	Acres	Percent
E2EM1N	Estuarine Intertidal Emergent Wetland, Regularly Flooded	8,693	21,46	11.71
E2EM1P	Estuarine Intertidal Emergent Wetland, Irregularly Flooded	2,564	6,330	3.45
E2SS3	Estuarine Intertidal Scrub/Shrub Wetland	112	276	0.15
E1AB	Estuarine Subtidal Aquatic Bed	4,607	11,374	6.21
E2USN	Estuarine Intertidal Flat, Regularly Flooded	1,086	2,680	1.46
E2USP	Estuarine Intertidal Flat, Irregularly Flooded	1,204	2,972	1.62
E2RF2M	Estuarine Intertidal Reef, Mollusk	15	37	0.02
E1UB	Estuarine Subtidal Unconsolidated Bottom	24,480	60,440	2.98
Subtotal		**42,759**	**105,573**	**57.62**
PEM1A	Palustrine Emergent Wetland, Temporarily Flooded	415	1,025	0.56
PEM1C	Palustrine Emergent Wetland, Seasonally Flooded	337	831	0.45
PEM1F	Palustrine Emergent Wetland, Semi-Permanently Flooded	50	123	0.07
PEM1K	Palustrine Emergent Wetland, Artificially Flooded	19	48	0.03
PUB	Palustrine Unconsolidated Bottom	36	90	0.05
Subtotal		**857**	**2,117**	**1.16**
M2USN	Marine Intertidal Unconsolidated Shore, Regularly Flooded)	235	580	0.32
M2USP	Marine Intertidal Unconsolidated Shore, Irregularly Flooded)	889	2,194	1.20
M2RS2P	Marine Intertidal Rock Shore, Rubble (granite jetties)	7	17	0.01
M1UB	Marine Subtidal Unconsolidated Bottom	15,306	7,791	20.62
Subtotal		**16,437**	**40,583**	**22.15**
U	Upland	14,162	34,965	19.08
Total		**74,215**	**183,237**	**100.00**

Table 4. Areal extent (in hectares) of selected habitats by geographic area in 2001.

Habitat	East Peninsula	Colorado River Delta	West Peninsula	Matagorda Island
Estuarine marsh	2,185	2,463	1,673	4,936
Seagrass bed	655	12	671	3,269
Tidal flat	631	171	561	927
Mangrove	0	0	0	112
Palustrine marsh	33	0	51	773
Gulf beach	174	0	409	540

Mangroves (Estuarine Intertidal Scrub/Shrub)

Estuarine scrub/shrub wetlands (E2SS) (mostly black mangrove habitat) have a total area of 112 ha, or about 1 percent of the estuarine intertidal vegetated classes. It should be noted that scattered mangrove shrubs are a common component of many estuarine marshes, particularly in the flood-tidal delta area of Pass Cavallo between Espiritu Santo and Matagorda Bays. Only in areas where the mangrove shrubs were dominant were they mapped separately as E2SS habitat. This habitat has its broadest distribution on the islands between Matagorda and Espiritu Santo Bays, where *Avicennia germinans* is abundant. This area is included as part of Matagorda Island, the only area in which E2SS was mapped on the 2001 photographs (Fig. 21; Table 4). Sherrod and McMillan (1981) noted that mangroves in this 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. 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 2001 imagery but are obscured by turbidities in some areas and could not be mapped in total. Densities of the mapped seagrass ranged from very dense to patchy. Seagrass beds throughout the study area covered 4,607 ha in 2001 and are the second most extensive habitat after estuarine marshes (excluding open water). The largest distribution of seagrasses is along the margins of and in the numerous shallow lagoons on the bayward side of Matagorda Island, including the flood-tidal-delta complex between Port O'Connor and Pass Cavallo. Seagrass beds mapped along Matagorda Island have an area of 3,269 ha and account for about 71 percent of this habitat in the study area. Seagrass beds along east and west Matagorda Peninsula are similar in total area, covering 655 ha and 671 ha, respectively (Fig. 20; Table 4). In the area of the Colorado River delta, only 12 ha of seagrass habitat was mapped.

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 a strip of bay water about 1 km wide paralleling the bay shoreline. This area was included primarily for cartographic purposes to help standardize the study area for each time period. Including this zone, the total area of estuarine open water mapped in the study area is 24,480 ha.

Oyster Reefs (Estuarine Reefs)

Oyster reefs (E2RF2M) mapped on the 2001 photographs amounted to just 15 ha and are mostly on the west edge of the Colorado River Delta. Only those that were very near the water's surface and were clearly visible were mapped. A large reef at the south end of Matagorda Island was not fully mapped or coded because it extended away from the island out of the study area (the outline of the reef, however, is shown on maps).

Palustrine System

Marshes (Palustrine Emergent Wetlands)

Palustrine emergent wetlands (PEM), or inland "freshwater marshes," cover 821 ha (Fig. 19) and represent only 7 percent of emergent vegetated wetlands. The broadest distribution of palustrine emergent wetlands is on Matagorda Island (Figs. 20 and 21), where swales between relict beach ridges (Figs. 3, 6, and 17) provide topographic lows in which water ponds and supports hydrophytic vegetation. Typically, palustrine marshes were classified into one of three water regimes: (1) temporarily flooded, (2) seasonally flooded, or (3) semi-permanently flooded. Most extensive in the map area were those that were temporarily flooded or seasonally flooded. Palustrine marshes on Matagorda Island account for approximately 90 percent of this habitat mapped in the study area. As mentioned previously, dry conditions over the years preceding 2001 when the aerial photographs were taken scaled down the extent of palustrine marshes mapped.

Open Water (Palustrine Unconsolidated Bottom)

Palustrine unconsolidated bottom (PUB), or open water, habitats are generally small-fresh to brackish water ponds. The total mapped area of this habitat was only 36 ha, more than 60 percent occurring on Matagorda Island.

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 fore beach and irregularly flooded backbeach (Figs. 3 and 11). The total area of this habitat in the study area is 1,124 ha. This habitat is most extensive on Matagorda Island and west Matagorda Peninsula (Fig. 20). A buffer zone approximately 1 km wide of marine subtidal unconsolidated bottom (M1UB), or marine open water, was included along the Gulf shoreline, primarily to standardize the size of the map area for each time period analyzed.

HISTORICAL TRENDS IN WETLAND HABITATS

Methods Used to Analyze Trends

Trends in wetland habitats were determined by analyzing habitat distribution as mapped on 2001, 1979, and 1950's aerial photographs (Fig. 22). 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 ArcView were used to analyze trends. This software allowed for direct comparison not only between years, but also by geographic areas such as the barrier island, peninsula, and delta. Analyses included tabulation of losses and gains in wetland classes for each area for selected periods. 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 photointerpreters were involved for different time periods, and interpretation of wetland areas can vary somewhat among interpreters. As a result, some changes in the distribution of wetlands from one period to the next may not be real but, rather, relicts of the interpretation process. Inconsistencies in interpretation seem to have occurred most frequently in high marsh to transitional areas where uplands and wetlands intergrade.

Some apparent wetland changes were due to different scales of aerial photographs. The 1950's aerial photographs were at a scale (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 2001 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

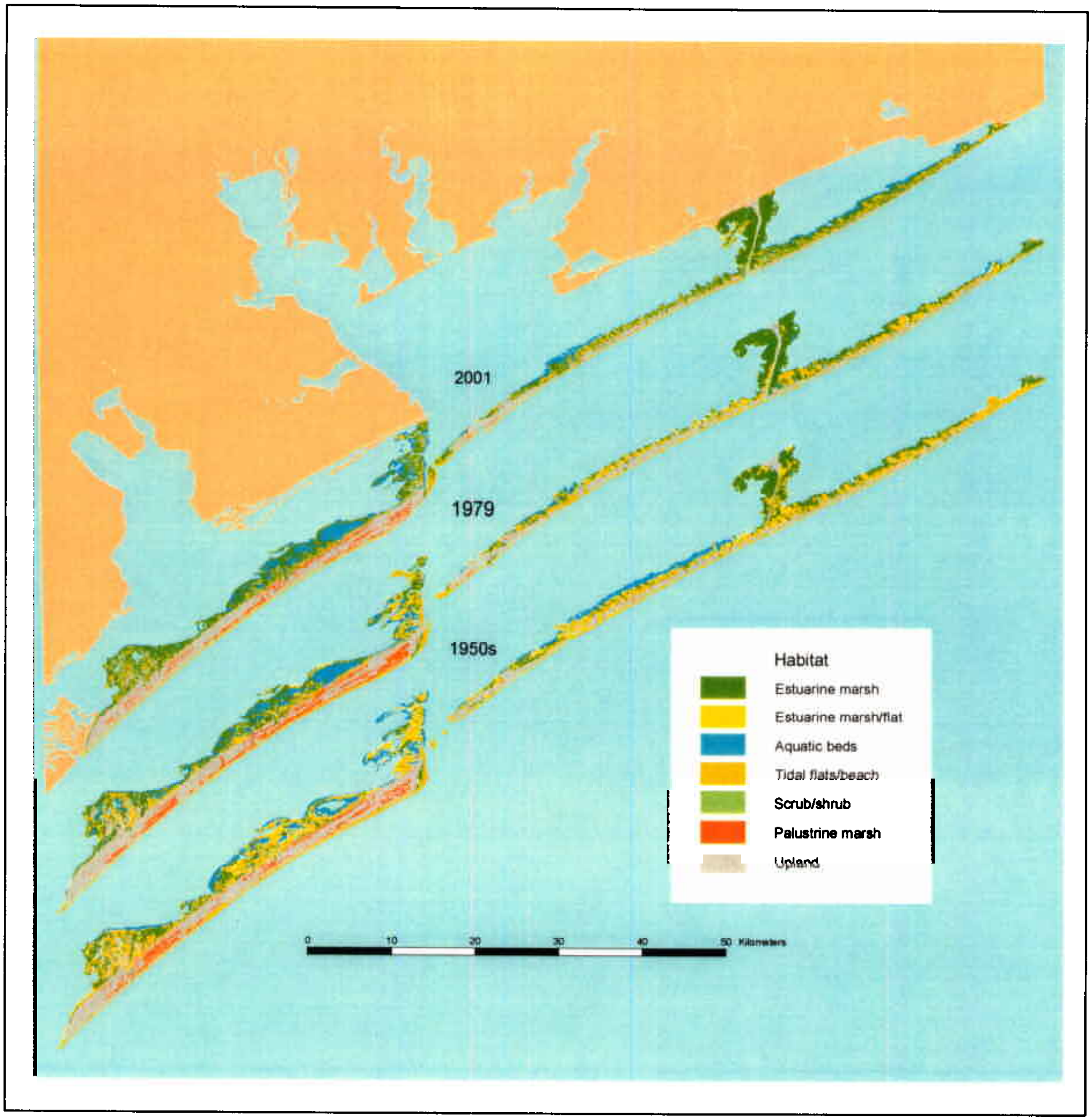

Figure 22. Map showing distribution of major wetland and aquatic habitats in 2001, 1979, and the1950's in study area.

potential problems in interpretation. Still, users of the data should keep in mind that there is a margin of error inherent in photo interpretation and map preparation.

Wetland Codes

As mentioned in the introduction, some wetland codes used on 2001 maps are different from those used on the 1950's and 1979 maps (Fig. 9). 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.

General Trends in Wetlands within the Study Area

Analysis of trends in wetlands and aquatic habitats from the 1950's through 2001 shows that there were slight systematic net gains in estuarine marshes during each period. The total area of marshes[3] increased from 10,751 ha in the 1950's to 11,069 ha in 1979 to 11,257 in 2001 (Fig. 23). These increases amounted to 318 ha from the 1950's through 1979, and 188 ha from 1979 through 2001. During the same time, there was a larger systematic decrease in tidal flats (E2FL or E2US). The area of flats declined from 3,131 ha in the 1950's to 2,942 ha in 1979 to 2,289 ha in 2001 (Fig. 23). These changes reflect losses of 1,188 ha and 654 ha for each period, respectively. Palustrine marshes (PEM) increased in area from the 1950s through 1979 by 995 ha and decreased by a slightly larger amount of 1,113 ha from 1979 through 2001. Seagrass beds declined by about 830 ha from the 1950's through 1979, but increased by a similar amount (915 ha) from1979 through 2001. Estuarine scrub/shrub wetlands (primarily mangroves) could not be adequately mapped separately and were included with marshes on the black-and-white 1950's photographs, so the true distribution during that year cannot be determined. In 1979, mangroves had a total area of 143 ha and a slightly smaller area of 112 ha in 2001. Probable causes of changes are presented in the following sections organized by geographic area.

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. 21). The areas are presented from northeast to southwest in the following order (1) east Matagorda Peninsula, (2) Colorado River Delta, (3) west Matagorda Peninsula, and (4) Matagorda Island. This subdivision allowed a more site-specific analysis of trends and their probable causes. Estuarine and palustrine marshes, tidal flats, mangroves, and seagrass beds are emphasized.

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[3] Total areas of estuarine marsh for the 1950's and 1979 periods include the E2EM/FL class.

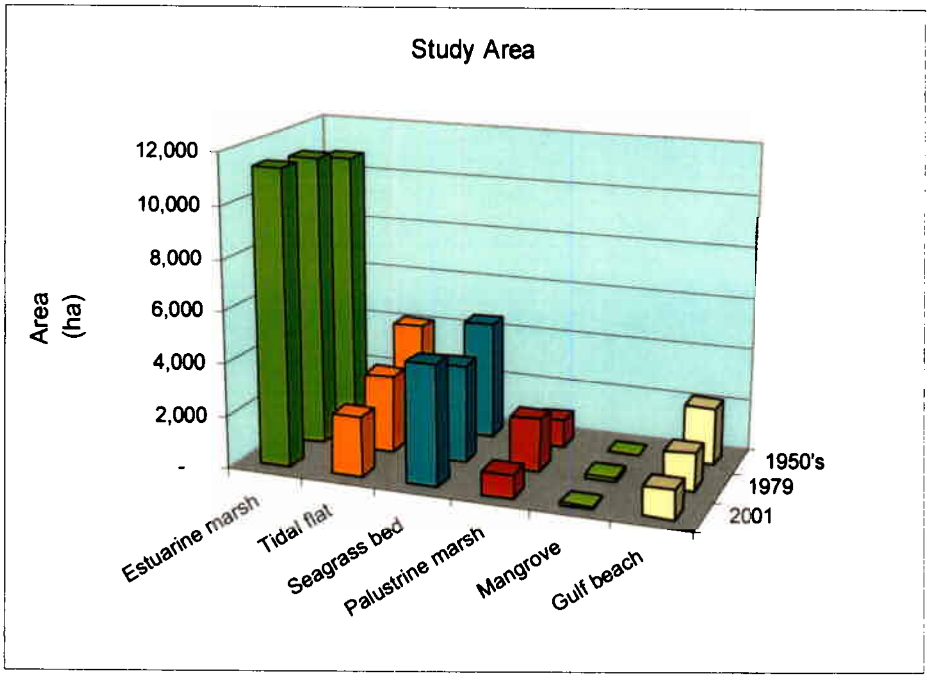

Figure 23. Areal extent of major habitats in study area in the1950's, 1979, and 2001.

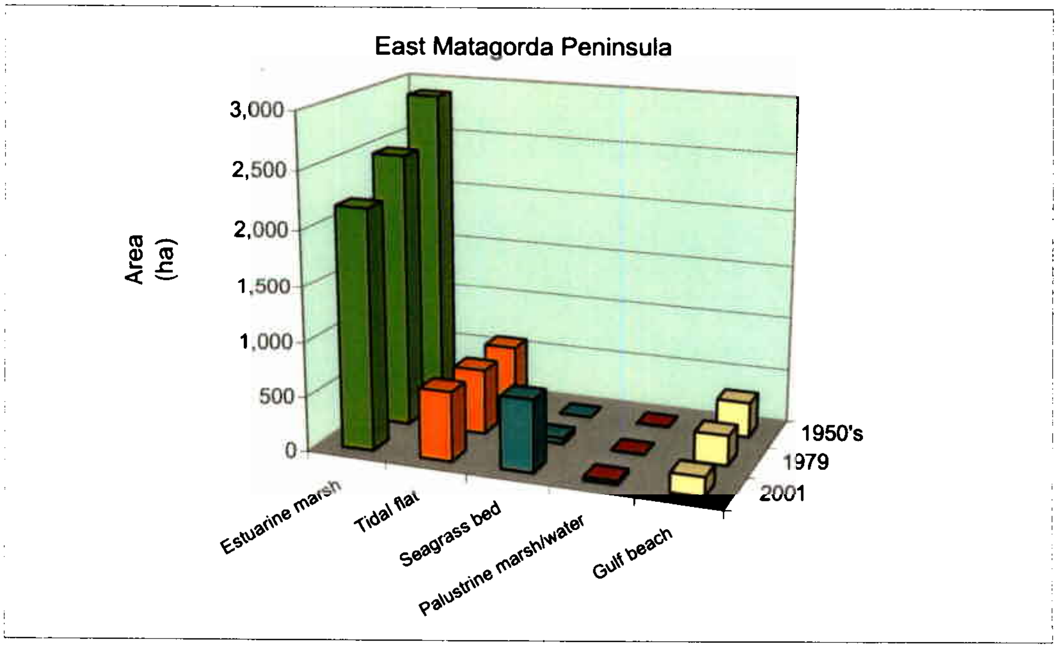

Figure 24. Areal extent of major habitats on east Matagorda Peninsula in the 1950's, 1979, and 2001.

East Matagorda Peninsula

General Trends. The most significant trend, or change, on east Matagorda Peninsula was a systematic decline in estuarine marshes. The total area of marsh habitat, which covered about 2,900 ha in the 1950's, decreased in size by 406 ha from the1950's through 1979, and by 303 ha from 1979 through 2001 (Fig. 24). This decrease represents a 25-percent loss of the marsh habitat on the east peninsula since the 1950's. The area of Gulf beach also decreased in total area by 50 ha and 96 ha for the two periods, respectively. Tidal flats remained relatively unchanged, with slight increases in total area of 6 ha and 37 ha. Seagrass beds, however, had a significant increase in total area of 51 ha from the 1950's through 1979, and 604 ha from1979 through 2001. No seagrass beds were mapped in this area on 1950's photographs. Mapped palustrine marsh areas amounted to only 29 ha in 2001.

Probable Cause of Trends. The 25-percent decline in estuarine marsh habitat on east Matagorda Peninsula can be attributed principally to (1) active surface faults that intersect wetlands, (2) erosion along the Gulf shoreline at the northeast end of the Peninsula near Mitchell's Cut, and (3) bay shoreline erosion. The most extensive loss of marsh occurred at the southwest end of the peninsula near the Colorado River Delta, where a major fault intersects wetlands and has caused marsh losses exceeding 200 ha (Fig. 25). On the fault's downthrown side, which is toward the Gulf, marshes have been replaced by open water (see Fig. 29), indicating a rate of subsidence and relative sea-level rise that exceeded marsh vertical accretion on the downthrown side of the fault. Marsh loss is not as great on the upthrown side of the fault. The fault apparently extends to the northeast into East Matagorda Bay and affects marshes to the southeast beyond the visible extent of the fault trace, as shown on Figure 25. The length of the visible part of the fault is about 5 km. The average length of 40 faults that cross wetlands mapped along the upper Texas coast (White and Morton, 1997) is about 3.8 km, with the longest being a little over 13 km. Of the 40 faults mapped on the upper coast, about 25 percent were 5 km or more in length, indicating that the fault crossing Matagorda Peninsula is among the longest. Additional active faults that intersect the peninsula to the northeast were mapped (Fig. 26). These faults also have affected marshes but to a lesser extent. One is downthrown toward a nearby oil and gas field, suggesting a possible association with oil and gas production, as reported for some faults on the upper Texas coast by White and Morton (1997). Over time, the fault traces have become more visible on sequential aerial photographs indicating that fault movement has occurred since the 1950's, when the fault traces were not visible. The faults appear to be surface extensions of faults mapped in the subsurface (Hentz et al. 1997), as has been reported in studies of faults on the upper coast (White and Morton, 1997).

Additional estuarine marsh losses on east Matagorda Peninsula can be attributed to high rates of erosion along the Gulf shoreline at the northeast end of the peninsula near Mitchell's Cut. Substantial marsh loss has occurred in this area since the 1950's (Fig. 27). Rates of erosion exceed 7.5 m/yr (25 ft/yr) (Gibeaut et al. 2001). Additional marsh losses occurred along bay shorelines that are also in an erosional state. Although bay shoreline erosion rates are not as high as those along the Gulf shoreline, marsh habitats occur at the bay shoreline along most of the peninsula and are directly affected by erosion. The loss in total area of marine unconsolidated shore (Gulf beach) since the 1950's is apparently a reflection of both beach erosion and an

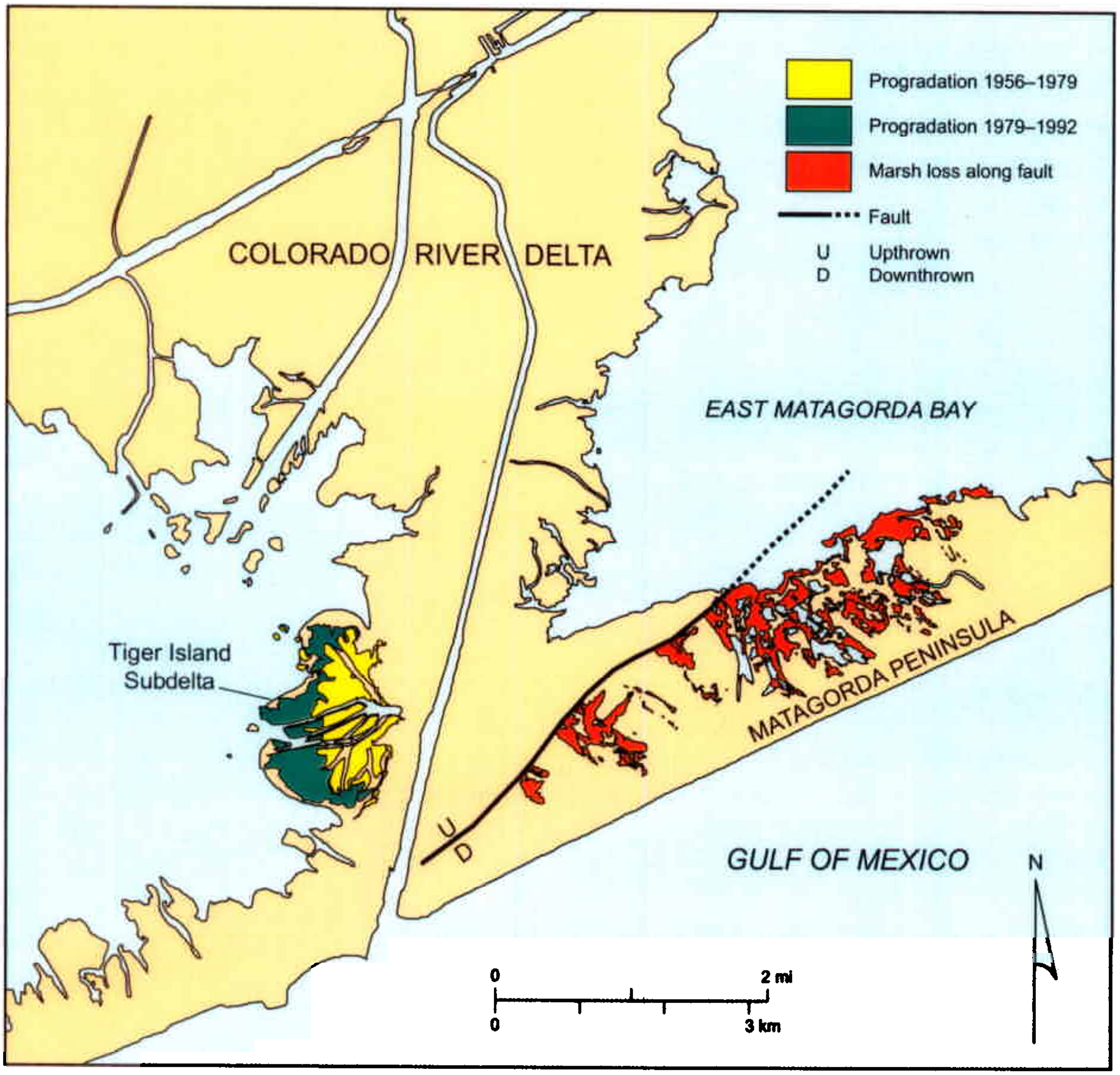

Figure 25. Marsh loss along a fault on east Matagorda Peninsula and marsh gain on a subdelta of the Colorado River Delta since the 1950's. Marsh loss due primarily to submergence on the drownthrown side of the fault, exceeded marsh gain resulting from progradation on Tiger Island subelta.

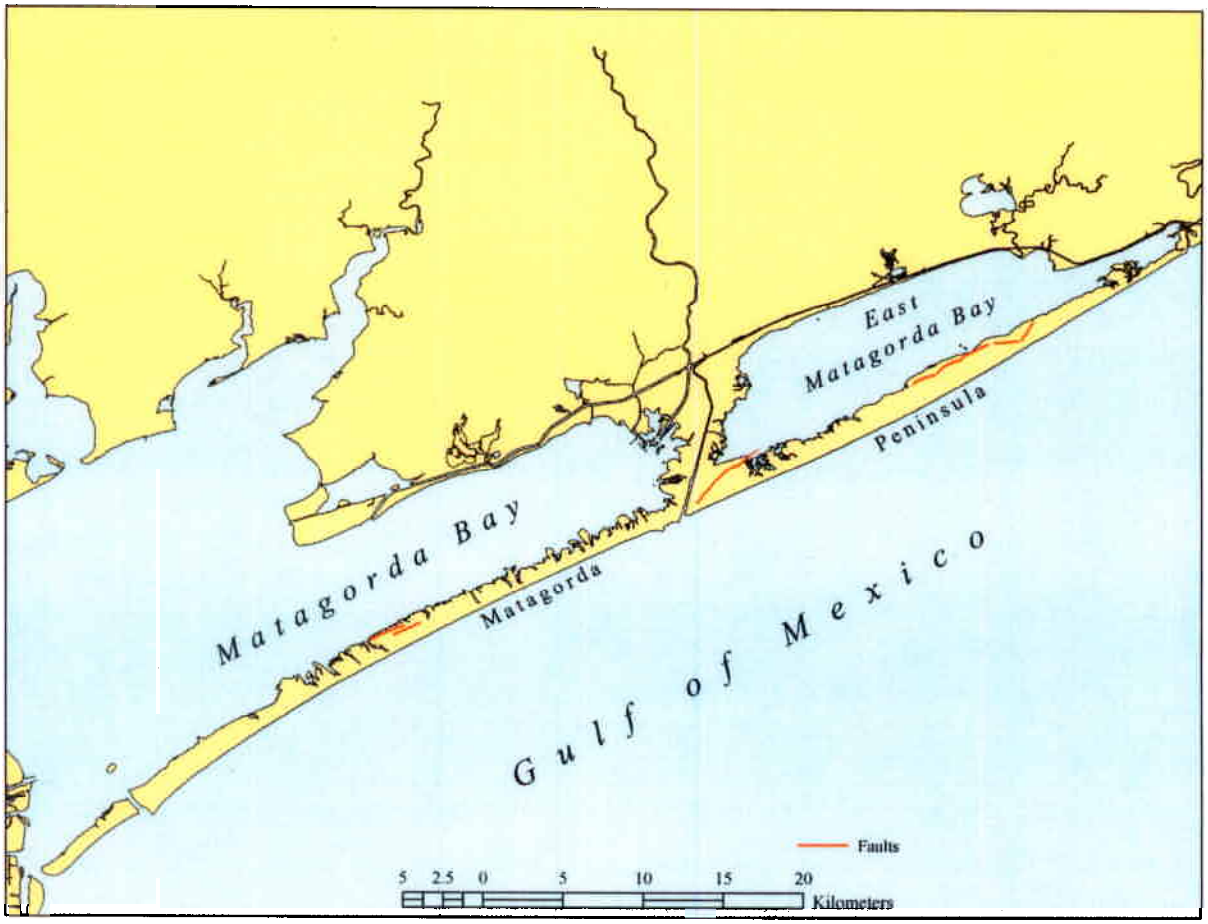

Figure 26. Index map of active faults that intersect wetlands on Matagorda Peninsula. These faults were identified and mapped using 2001 aerial photographs.

Figure 27. Loss of estuarine marsh since the 1950's due to erosion of the northeast end of Matagorda Peninsula at Mitchell's Cut. Loss shown in red. Erosion rates in this area are as high as 8m/yr (27 ft/yr). Photograph taken in 2001 by ALS, Inc.

increase in low dunes and vegetation on the backbeach that were mapped as uplands in later years (1979 and 2001). Palustrine marshes have very limited distribution on east Matagorda Peninsula (Fig. 24). This habitat was not mapped in this area in the 1950's or 1979. Of the 29 ha mapped in 2001, more than 65 percent occurred in a leveed dredged-material-containment site along the Intracoastal Waterway at the northeast end of the peninsula. This area was mapped as a lacustrine flat in 1979 and as estuarine marsh and upland in the 1950's.

The increase in seagrass beds since the 1950's is not fully understood. No seagrasses were mapped on 1950's photographs along east Matagorda Peninsula. The increase in area in later years may be a response to natural coastal cycles and processes (Pulich et al. 1997).

Colorado River Delta

General Trends. The most significant trend on the Colorado River delta from the 1950's through 2001 was an increase in estuarine marsh (Fig. 28). The estuarine marsh habitat, which makes up most of the delta, increased in total area from 2,112 ha in the 1950's, to 2,345 in 1979, to 2,463 in 2001. From the 1950's through 2001, the net increase in marsh was 352 ha, reflecting a gain of about 17 percent. Other habitats did not change significantly, except for oyster reefs. In the 1950's a total area of 243 ha was mapped. In following years much smaller areas were mapped (32 ha in 1979 and 5 ha in 2001) (Fig. 28).

Probable Causes of Trends. The principal gain in estuarine marsh since the 1950's occurred in the southwest corner of the delta on Tiger Island subdelta that formed at the mouth of an artificial channel. The formation of this subdelta through time can be seen in Figure 25 and by comparing Figures 29, 30, and 31. Since the 1950's (Fig. 31), when the channel was cut, until 1979 (Fig. 30), the subdelta prograded about 800 m, creating 90 ha of marsh. The subdelta continued to prograde until the early 1990's, extending the edge of the marsh another 500 m into the bay and increasing the area of marsh by an additional 80 ha. In 1991, as part of the Colorado River Diversion Project (Wilber and Bass, 1998), a dam (visible in Fig. 29) was constructed across Tiger Island Channel, causing progradation and marsh development at this subdelta to cease. Additional small marsh areas have developed near the mouth of the Colorado River diversion channel at the upper west side of the delta (Fig. 29). New marshes in this area appear to have developed primarily along islands and shoals resulting from disposal of material dredged from the channel. Total additional estuarine marsh in this area is about 110 ha.

Countering the growth of marshes on the west side of the delta was marsh erosion on the east side. Erosion of the delta margin in this area occurred at rates averaging about 1.5 m/yr from 1956 through mid-1995, accounting for a marsh loss of about 50 ha. For the period 1957 through 1972, McGowen and Brewton (1975) estimated erosion rates of approximately 2 m/yr on the east side of the delta. Some interior marshes on the east half of the delta were also lost to submergence and erosion. This half of the delta no longer receives sediments from the Colorado River and is in a destructional phase, geologically (Kanes, 1970, and Manka and Steinmetz, 1971).

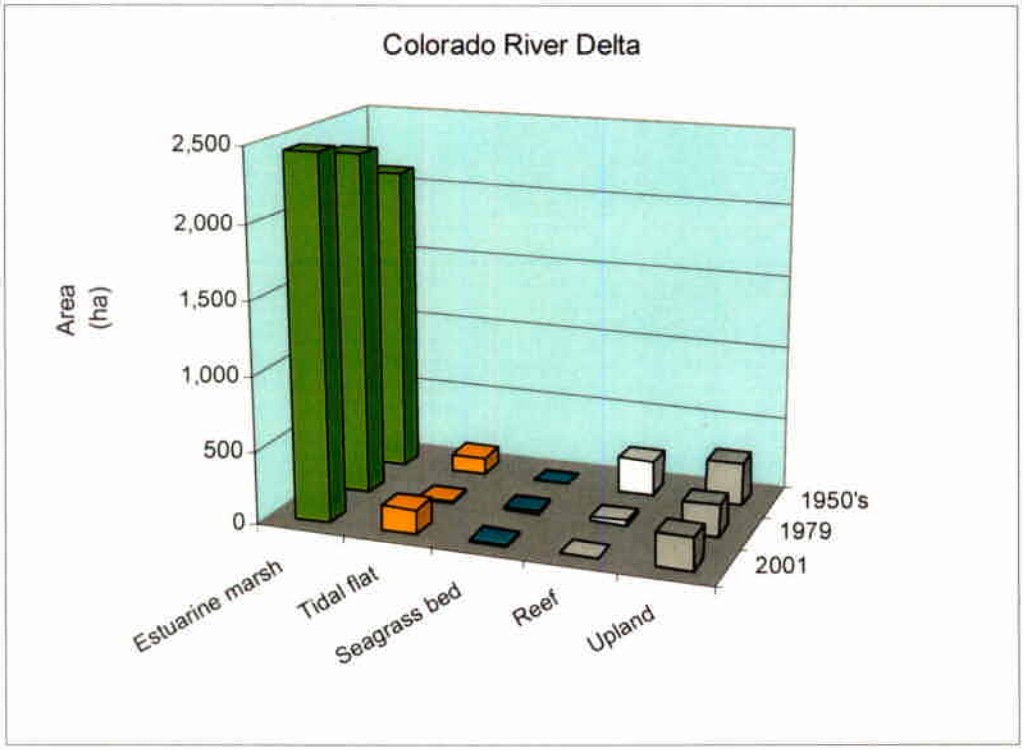

Figure 28. Areal extent of major habitats on the Colorado River Delta in the 1950's, 1979, and 2001.

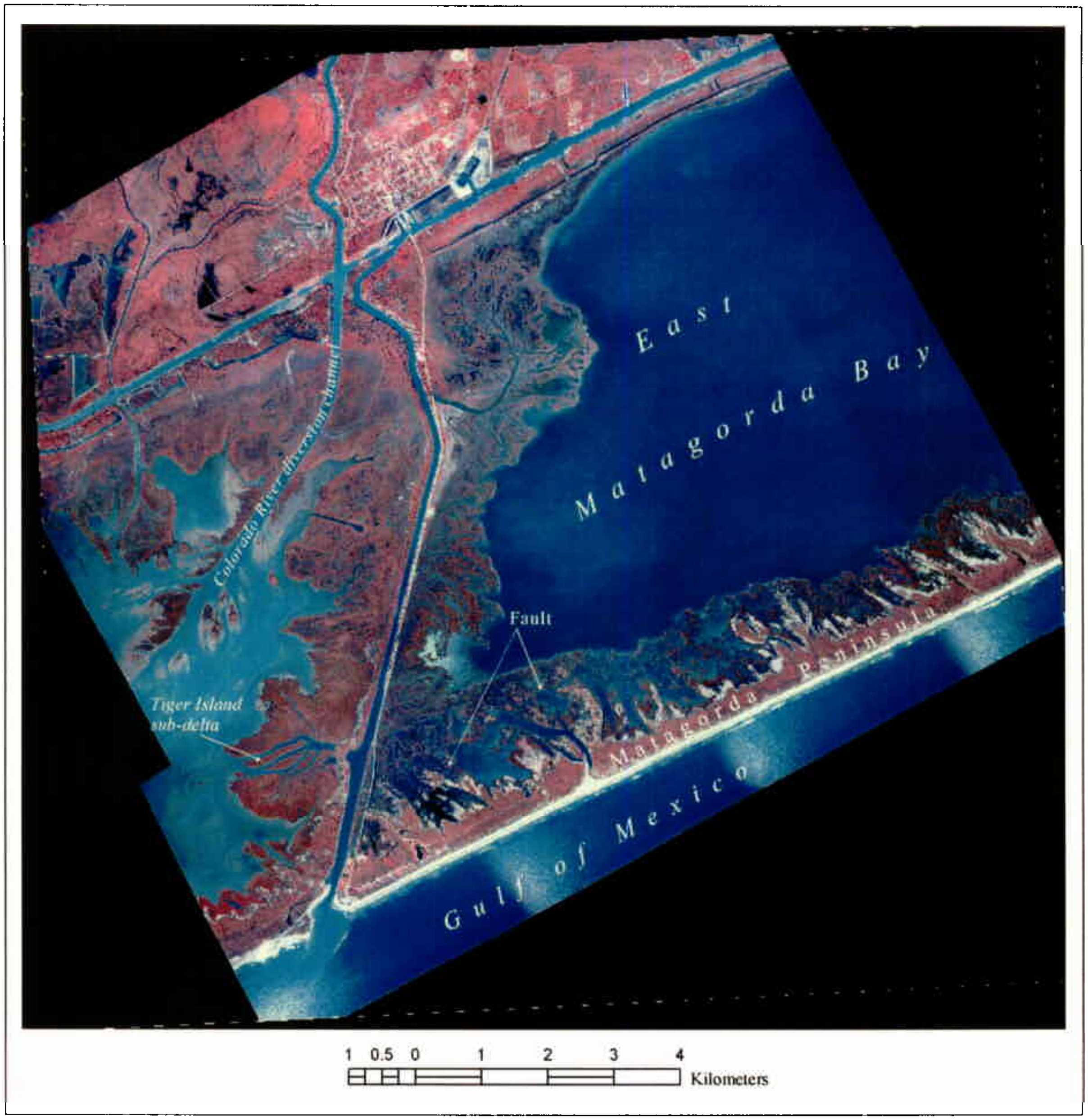

Figure 29. The Colorado River Delta in 2001. Gains in estuarine marsh at Tiger Island subdelta in the southwest corner of the delta were offset by losses along the active surface fault on Matagorda Peninsula southeast of the delta. Aerial photographs from ALS, Inc.

Figure 30. The Colorado River Delta in 1979. Compare this figure with Figure 29 to see changes in the Tiger Island subdelta. Also note changes associated with the diversion channel shown in Figure 29. Photograph from NASA.

Figure 31. The Colorado River Delta in 1956. Compare with Figures 29 and 30 to see growth of Tiger Island subdelta through time. Also note that the active fault shown in Figures 29 and 30 is not visible in the 1956 photograph. Photomosaic from Tobin Surveys, Inc.

The apparent loss in oyster reefs from the 1950's is due principally to low tidal levels on the 1950's photographs, which allowed large areas of exposed reefs to be mapped on the west side of the delta. Higher tidal levels in 1979 and 2001 limited the area of reefs that could be mapped. Although dredging of the Colorado River diversion channel probably caused a loss in some reefs, it could not be quantified.

West Matagorda Peninsula

General Trends. In contrast to east Matagorda Peninsula where there was a systematic loss of estuarine marshes through time, there was a systematic gain in estuarine marshes on west Matagorda Peninsula. The total estuarine marsh habitat increased from 1,154 ha in the 1950's to 1,320 ha in 1979, to 1,673 ha in 2001 (Fig. 32). This is an increase of about 45 percent from the 1950's through 2001. Other significant trends were losses in tidal flats and seagrass beds (Fig. 32). Tidal flats declined in area from a high in the 1950's of 1,225 ha, to 789 ha and 561 ha in 1979 and 2001, respectively, indicating a loss of 54 percent from the 1950's through 2001. Seagrass beds declined in area from the 1950's through 1979. The trend was reversed from 1979 through 2001 when seagrass beds increased in total area but still showed a substantial loss of about 54 percent from the 1950's through 2001 (Fig. 32). The marine unconsolidated shore habitat (Gulf beach) also decreased in total area from the 1950's through 2001.

Probable Causes of Trends. Much of the gain in marshes and loss in seagrass beds occurred as a result of a single event, Hurricane Carla, a Category 5 hurricane, that struck the Texas coast between Port O'Connor and Port Lavaca on September 11, 1961. The hurricane eroded the beach and dunes, opened and scoured existing washover channels, and transported sand and shell bayward, depositing it in washover fans that eventually became the sites of new marshes. The largest additions of marsh from this process occurred mostly at the northeast end of the peninsula near the Colorado River Delta (Fig. 33) and in central areas of the peninsula. Additional gains in marsh area occurred at the peninsula's southwest end as it accreted toward Pass Cavallo through time (Fig. 34).

The systematic loss in tidal flats can be attributed in part to an accelerated rate of relative sea-level rise from the 1960's through late 1970's, which correlates with a loss in tidal flats. It appears that gains in estuarine marsh in some areas previously mapped as flats are part of a trend toward more frequent flooding of the flats and a spread of emergent vegetation, especially *S. alterniflora*, as a result of sea-level rise. A similar trend was reported by White et al. (1998) on Mustang Island and San José Island (Fig. 35).

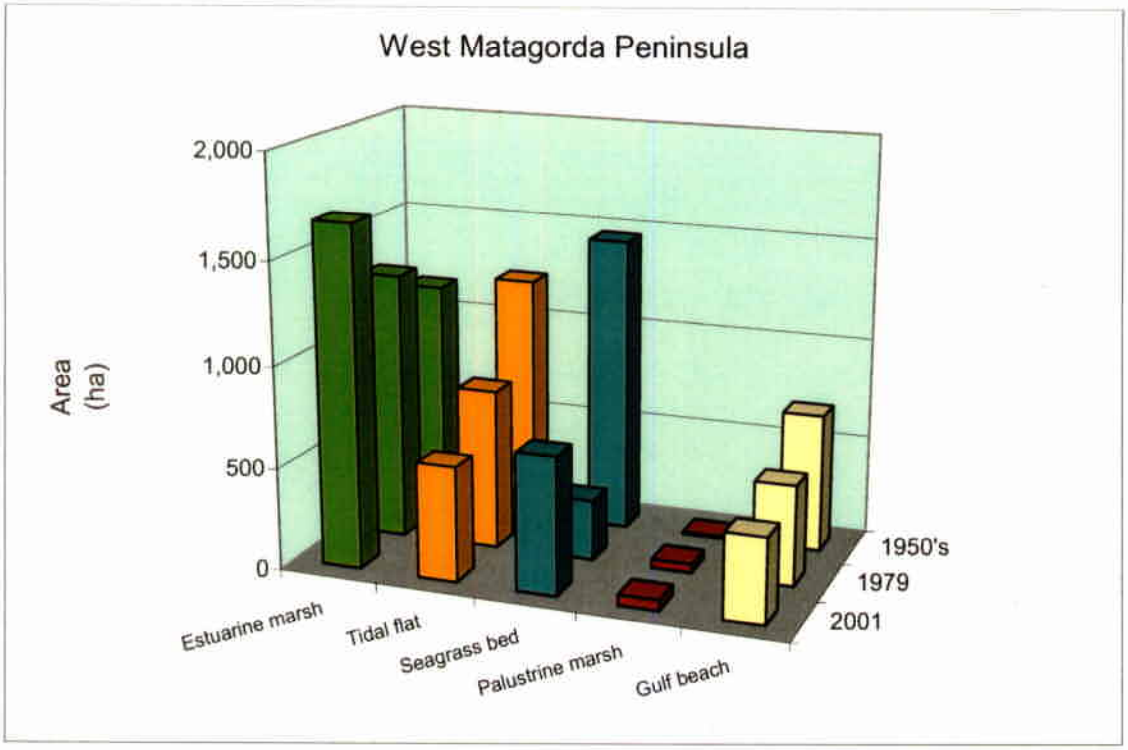

Figure 32. Areal extent of major habitats on west Matagorda Peninsula in the 1950's, 1979, and 2001.

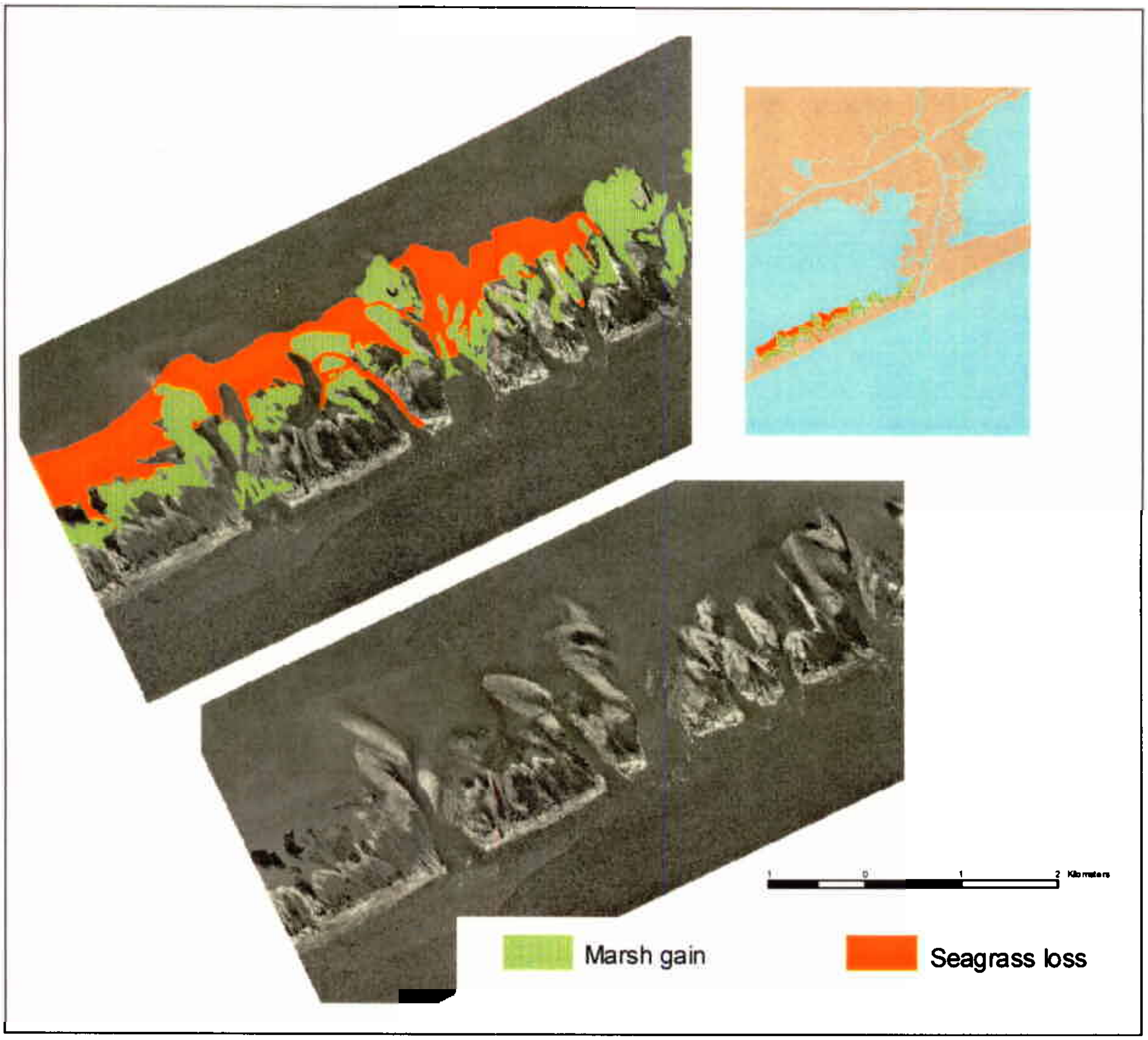

Figure 33. Changes in estuarine marsh and seagrass habitats as a result of Hurricane Carla. This photograph, taken in September 1961 a few days after Hurricane Carla made landfall, shows open channels and washover fans deposited in Matagorda Bay. Marsh gain and seagrass loss based on changes in habitats from the 1950's to 1979.

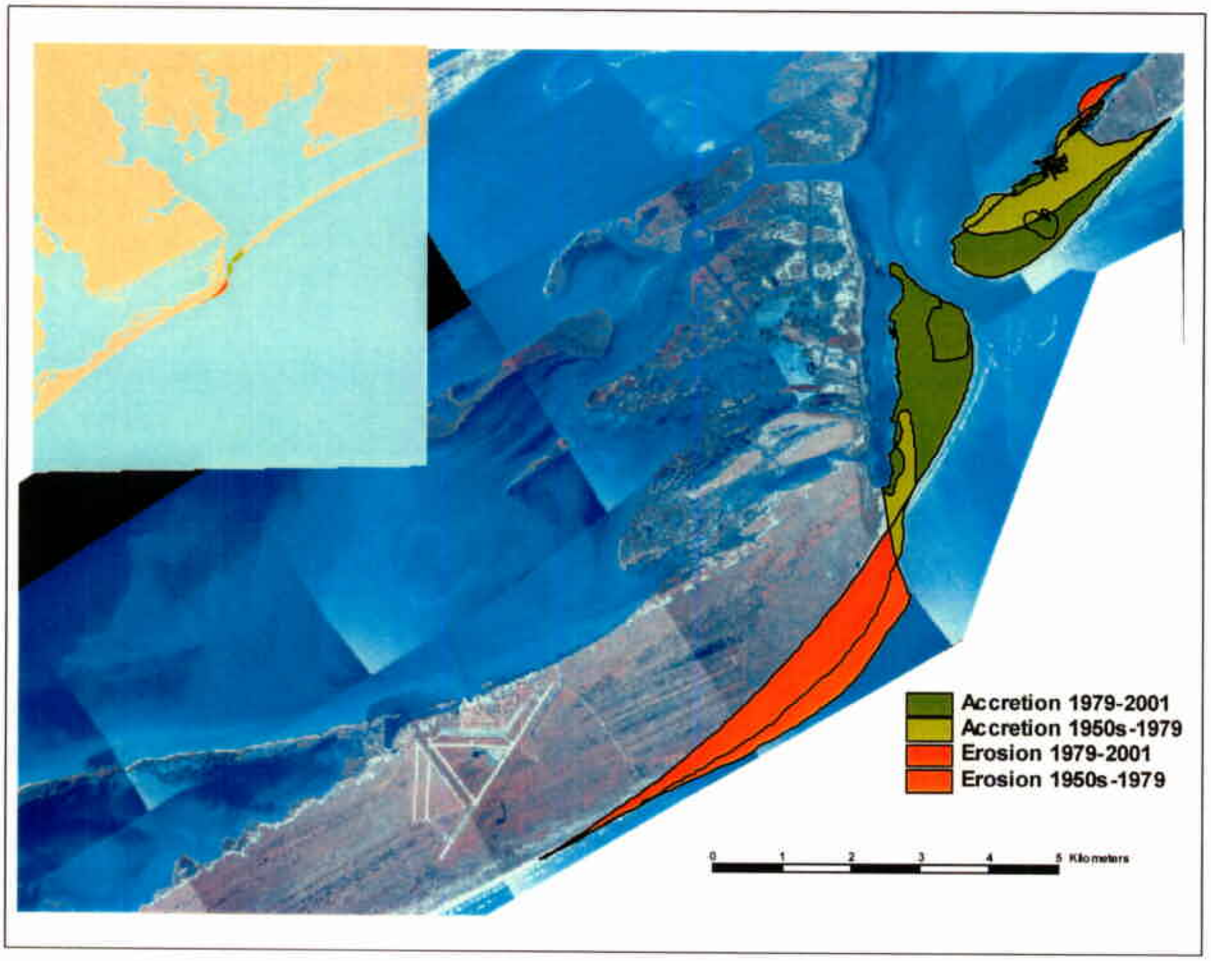

Figure 34. Changes at Pass Cavallo between Matagorda Island and west Matagorda Peninsula. Matagorda Peninsula accreted toward Matagorda Island adding new marsh habitat and greatly reducing the width of the pass since the 1950's. Across the pass, erosion of Matagorda Island, resulted in marsh loss where the island was eroded and marsh gain from spit development down drift in Pass Cavallo.

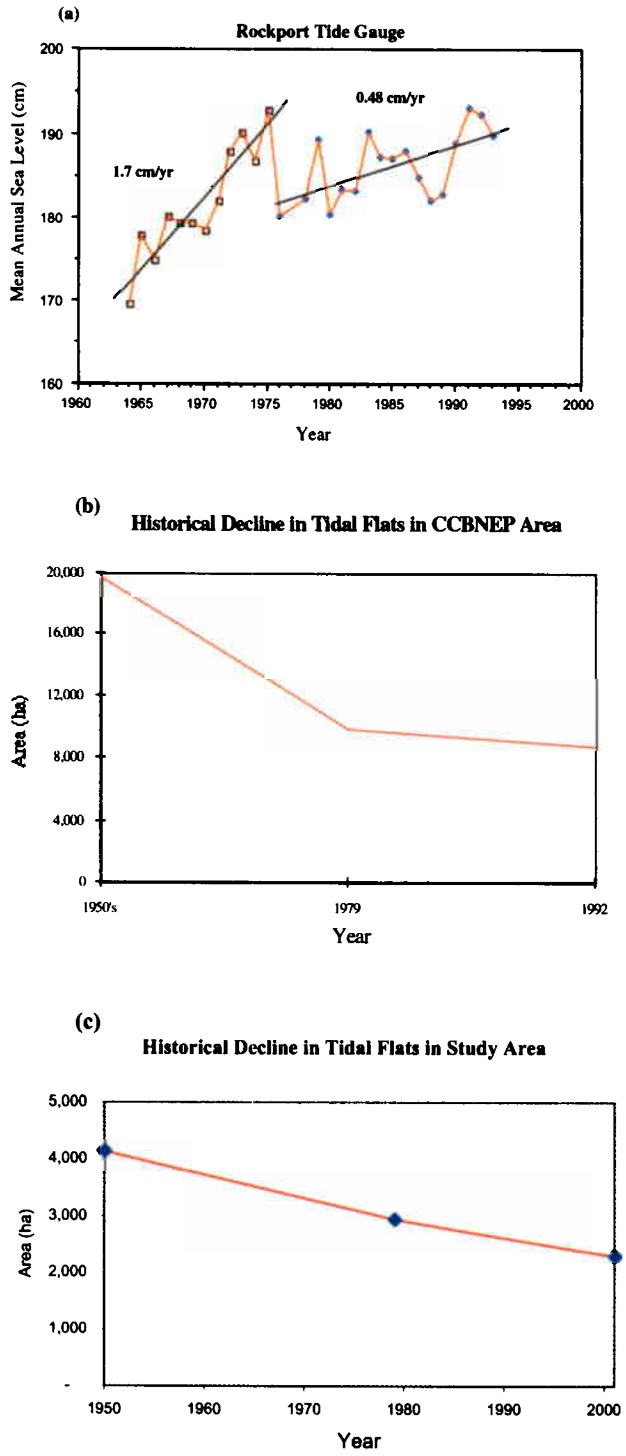

Figure 35. Relationship between (a) rate of relative sea-level rise, (b) decline in area of estuarine intertidal flats, as documented by White et al. (1998) in the Corpus Christi Bay National Estuary Program study area, which included Mustang and San José Islands, and (c) decline in area of estuarine intertidal flats in study area.

Loss of seagrass beds largely occurred as a result of Hurricane Carla's storm surge that overwashed the peninsula and deposited sediment in the bay (Fig. 33). The seagrass beds did not recover along the peninsula near the Colorado River Delta, perhaps partly because of the artificial channel from the Colorado River at the Tiger Island subdelta, which probably caused higher turbidities at this end of the bay. Seagrass beds mapped on the 2001 photographs are located along the peninsula, approximately 20 km southwest of the delta.

The systematic decline in area of Gulf beach can be attributed in large part to a narrowing of the beach as a result of the growth and expansion of vegetation on the backbeach and erosion along the Gulf shoreline. Some of the shoreline along the peninsula, however, actually accreted, mostly along a stretch up current from the jetties at the mouth of Matagorda Ship Channel near Pass Cavallo. The beach accreted on the northeast side of the jetties but eroded to the southwest, in the direction of littoral drift.

Matagorda Island

General Trends. The most significant change or trend on Matagorda Island was a systematic loss in tidal flats from the 1950's through 2001 (Fig. 36). Tidal flats decline from total areas of 2,214 ha in the 1950's to 1,642 ha in 1979 to 927 ha in 2001. This decline amounts to a loss of almost 60 percent of this habitat since the 1950's. The total areas of estuarine marshes and seagrass beds remained relatively unchanged from the 1950's through 2001, with marshes increasing in area by 345 ha and seagrass beds by 212 ha since the 1950's (Fig. 36). Palustrine marshes, however, had their highest distribution in 1979 and lowest in 2001. The estuarine scrub/shrub habitat (primarily mangroves) had total areas of 143 ha in 1979 and 112 ha in 2001. Only 2 ha of estuarine scrub/shrub was mapped in the 1950's. The total area of Gulf beach mapped declined systematically from 1,157 in the 1950's to 673 in 1979 to 540 in 2001. This decline represents a 53-percent reduction in the area of beach mapped in the 1950's as compared with that mapped in 2001.

Probable Causes of Trends. The loss of 60 percent of tidal-flat habitat from the 1950's through 2001 on Matagorda Island can be explained in part by a relative rise in sea level. As mentioned previously, a similar trend was reported on Mustang and San José Islands to the southwest (Fig. 35). Areas mapped as tidal flats in the 1950's were converted in large part to open water, seagrass beds, and marshes, as topographically low flats became submerged and slightly higher flats became more frequently flooded contributing to a spread of marsh vegetation. Although estuarine marshes had a small net gain in area from the 1950's through 2001 (Fig. 36), significant losses were concentrated in some areas on the island, for example (1) at the north end at Pass Cavallo where severe erosion of the island cut into estuarine marshes mapped on 1950's photographs (Fig. 34) and (2) along the bay shore just northeast of the relict tidal inlet/washover fan complex at the south end of the island where marshes were submerged and replaced by open water (Fig. 37). There were losses and gains throughout the island, resulting in a net gain in estuarine marsh overall (Fig. 36).

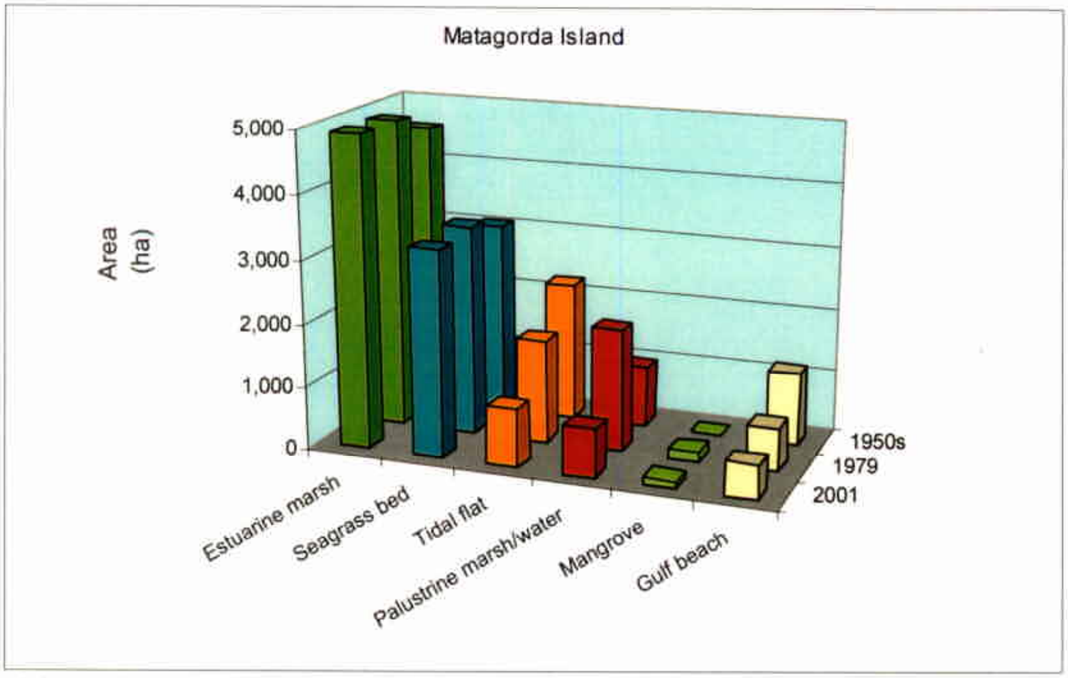

Figure 36. Areal extent of major habitats on Matagorda Island in the 1950's, 1979, and 2001.

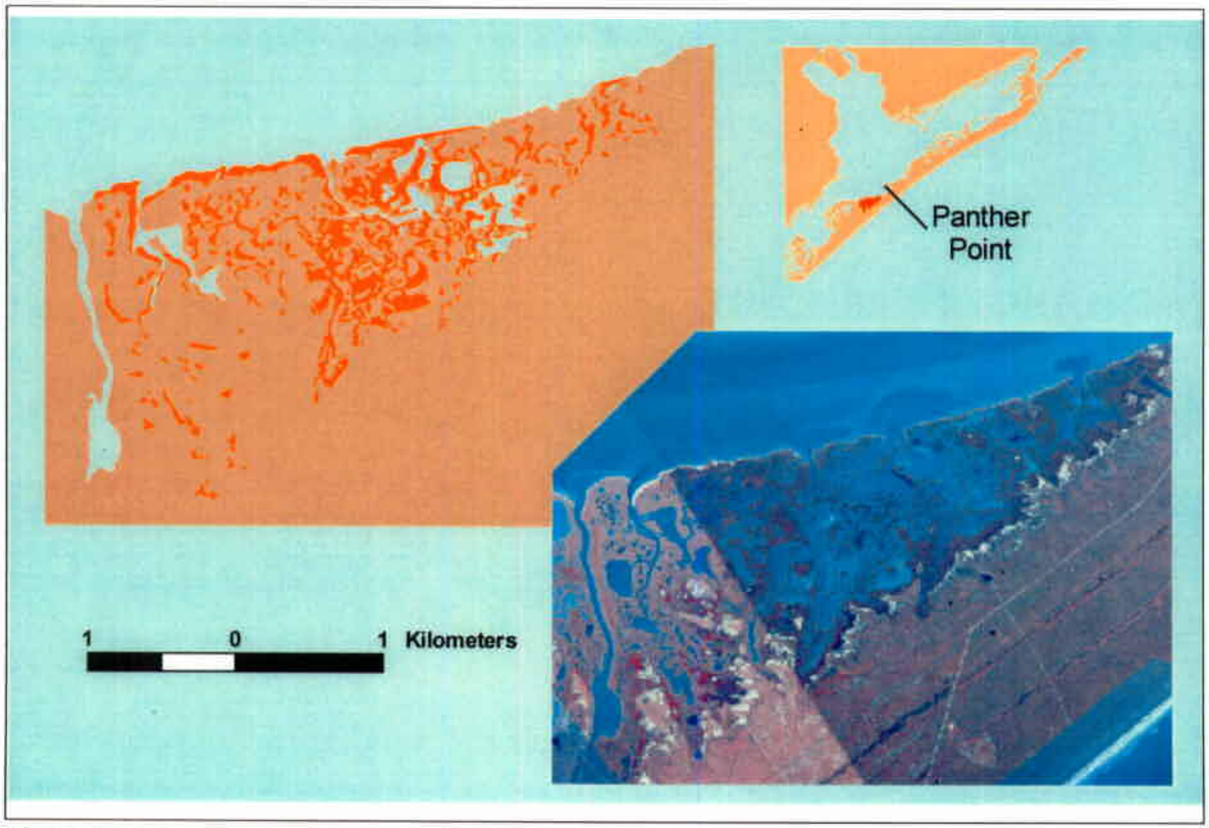

Figure 37. Loss of estuarine marsh (shown in red) due to submergence and conversion to open water since the 1950's on the southwest end of Matagorda Island near Panther Point. Photograph taken in 2001 by ALS, Inc.

Figure 38. Photograph taken in 1992 of a spit that developed at the north end of Matagorda Island in Pass Cavallo. Prominent accretionary ridges and intervening swales are visible in the photograph. View is gulfward.

The Pass Cavallo area is dynamic, and losses in estuarine marsh due to erosion were partly offset by accretion. Sediment that had eroded from the east end of Matagorda Island was transported into Pass Cavallo and deposited in a large bayward-projecting spit, much of which became vegetated through time (Figs. 34 and 38). Across Pass Cavallo, Matagorda Peninsula accreted toward Matagorda Island, reducing the width of Pass Cavallo from more than 3,500 m in the 1950's to about 550 m in 2001 (Fig. 34). Much of the spit accretion on Matagorda Island apparently occurred in 1980 during Hurricane Allen, judging from a comparison of photographs taken in 1979 and 1982.

Not all losses in estuarine marsh in the Pass Cavallo area were due to erosion or submergence. There were also "apparent" losses that resulted from differences in photo interpretation of the marsh habitat. For example, some areas on the north tip of the island near Pass Cavallo, which were mapped as estuarine marsh in the 1950's and 1979, were too dry in 2001 to map as marsh. This difference produced an apparent marsh loss relative to the earlier years.

The increase in estuarine scrub/shrub habitat (mostly mangroves) on Matagorda Island since the 1950's can be attributed to the fact that mangroves could not be adequately mapped on the black-and-white 1950's aerial photographs. The distinct bright-red signatures of mangroves on 1979 and 2001 CIR aerial photographs allowed them to be readily mapped for those years. The apparent loss of about 30 ha of mangrove between 1979 and 2001 appears to be in part the result of interpretation. Mangrove shrubs were mapped with the marsh habitat in many areas where they could not be separated at the mapping scale. Possibly contributing to an actual difference in distribution in 1979 and 2001, however, was the occurrence of freezing temperatures in 1983 and the late1980's, which killed mangroves along much of the Texas coast. Although mangroves have made a significant recovery since then, they may not have reached their pre-1980's distribution.

The apparent increase in palustrine marshes from the 1950's through 1979 and decrease from 1979 through 2001 is primarily due to wetter conditions in 1979. The topographically low swales between relict beach ridges on Matagorda Island (Figs. 3 and 6) ponded water and supported extensive fresh- to brackish-water marsh vegetation. Much drier conditions in 2001 limited the extent of these marshes, so fewer were mapped. In future, wetter times, the swales will be flooded and marshes will become reestablished.

The systematic decrease in the total area mapped as Gulf beach from the 1950's through 2001 (Fig. 36) can be attributed primarily to (1) expansion of vegetation on the backbeach (including low sand dunes) and in barren sand flats washed over by storm tides along the backbeach; (2) local erosion of the beach, including the Pass Cavallo area (Fig. 34); and (3) to differences in classification at the southwest end of the island at Cedar Bayou. In the area along Cedar Bayou, an area mapped as estuarine tidal flat on 1979 photographs was mapped as marine beach on the1950's and 2001 photographs.

SUMMARY AND CONCLUSIONS

Wetlands and aquatic habitats on central Texas Gulf coast barriers and delta are dominated by estuarine emergent wetlands (salt and brackish marshes), which in 2001 encompassed 11,257 ha and represented 67 percent of the vegetated wetland and aquatic classes (marshes, mangroves, and seagrass beds). Among other mapped classes (excluding open water), seagrass beds are most abundant at 4,607 ha, followed by tidal flats (2,289 ha), Gulf beaches (1,124 ha), palustrine marshes (857 ha), and scrub/shrub wetlands, primarily mangroves (112 ha).

Examination of wetland distribution in four geographic subareas within the study area (east Matagorda Peninsula, Colorado River Delta, west Matagorda Peninsula, and Matagorda Island) show that Matagorda Island, including a complex of islands at its north end, has the largest distribution of each major habitat mapped, including 44 percent of estuarine marshes, 71 percent of seagrass beds, 40 percent of tidal flats, 100 percent of mangrove habitats, 90 percent of palustrine marshes, and 48 percent of Gulf beaches. Estuarine marshes in other areas are most abundant on the Colorado River Delta, followed by east Matagorda Peninsula and west Matagorda Peninsula.

Historically, losses and gains in habitats have occurred throughout the study area, but the overall trend in vegetated wetlands is one of net gain, as revealed by slight increases in estuarine marshes of 318 ha from the 1950’s through 1979 and 188 ha from 1979 through 2001. The average rate of marsh gain, however, decreased from about 14 ha/yr during the earlier period to 9 ha/yr during the later one. The total area of tidal flats decreased by 1,188 ha from the 1950’s through 1979 and 654 ha from 1979 through 2001. The average rate of tidal-flat loss decreased through time, from about 50 ha/yr during the earlier period to 30 ha/yr during the later period. Seagrass beds decreased in total area from the 1950’s to 1979 (– 830 ha), but increased by a larger amount from 1979 through 2001 (+ 915 ha), reflecting a net gain of 85 ha. Palustrine marshes increased in total area by almost 1,000 ha between the 1950’s and 1979 but decreased by a similar amount between 1979 and 2001. Mangroves decreased slightly in total area from 1979 through 2001. Trends in mangrove distribution from the 1950’s could not be determined because they were not mapped separately from marshes. There was a systematic decline in the area of mapped Gulf beaches, which decreased in total area by 730 ha and 308 ha, for the 1950’s through 1979 and 1979 through 2001 periods, respectively.

Analysis of habitat distribution by geographic subarea reveals local differences in historical trends. There were systematic net losses of estuarine marshes on east Matagorda Peninsula but net gains on the Colorado River Delta, West Matagorda Peninsula, and Matagorda Island. Losses on east Matagorda Peninsula were due primarily to submergence of marsh vegetation on the downthrown side of active faults that intersect marshes and to erosion of the Gulf and bay shorelines. Net marsh gains on the Colorado River Delta were due to delta progradation and marsh development on its west side, although marshes were lost because of erosion on its east side. A net increase of estuarine marshes on west Matagorda Peninsula was due in large part to deposition of washover fans by Hurricane Carla in 1961 that became the sites on which new marshes developed by 1979. Additional increases in estuarine marsh occurred at the southwest end of the peninsula from accretion into Pass Cavallo. Although there was a minor net gain in estuarine marsh on Matagorda Island, locally there were losses because of submergence of marshes in interior areas and marsh erosion along the bay margin. The systematic loss of tidal flats occurred primarily on west Matagorda Peninsula and Matagorda Island. These losses appear to be explained in part by a rise in relative sea level, causing the flats to be replaced by other habitats, such as open water, seagrass beds, and marshes. Seagrass beds underwent a substantial reduction along west Matagorda Peninsula, primarily from burial by washover fans deposited during Hurricane Carla, but increased in area on east Matagorda Peninsula, resulting in a net gain for the study area. Palustrine marshes on Matagorda Island had their largest distribution in 1979, when wetter than normal conditions contributed to their expansion, followed by drier than normal conditions in 2001, leading to their presumably temporary decline. The systematic decline in mapped Gulf beaches that occurred on both Matagorda Peninsula and Matagorda Island 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.

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APPENDIX

Total habitat areas for 2001, 1979, and 1950’s determined from GIS data sets of the study area.

2001

Habitats	**Hectares**
E1AB	4607
E1UB	24480
E2EM1N	8693
E2EM1P	2564
E2RF2M	15
E2SS3	112
E2USN	1086
E2USP	1204
M1UB	15306
M2RS2P	7
M2USN	235
M2USP	889
PEM1A	415
PEM1C	337
PEM1F	50
PEM1K	19
PUB	36
U	14162

1979

Habitats	**Hectares**
E1AB	227
E1AB2L	3457
E1AB2M	8
E1OW	312
E1OWL	24227
E1RFM	4
E2AB2L	68
E2AB2M	21
E2BB	8
E2EM1N	7666
E2EM1P	1785
E2EM1N/E2FLN	1174
E2EM1P/E2FLP	444
E2FLM	340
E2FLN	1457
E2FLP	1146
E2RF2M	32
E2SS	4
E2SS3N	121
E2SS3N/E2FLN	18
L2FLYHS	21
M1OWL	15208
M2BBN	32
M2BBP	1399
PEM1A	13
PEM1AD	3
PEM1C	319
PEM1F	107
PEM1Y	1375
POWF	65
POWGH	1
POWGHX	1
POWH	101
POWHX	1
PSS2C	3
PSS6C	1
U	3
UA	11104
UB	129
UBD	2
UBS	14
UF6	5
UR	1470
UU	354
UUO	3

1950’s

Habitats	**Hectares**
E1AB	3844
E1ABFL	543
E1ABOW	135
E1OW	23612
E2BB	19
E2EM	6615
E2EMP	129
E2EMPU	7
E2EMFL	4001
E2FL	4094
E2FL/E2AB	36
E2RF	5
E2SS	2
M1OW	14811
M2BB	2162
PEM	931
PEMFL	22
POW	42
U	12963