STATUS AND TRENDS OF INLAND WETLAND AND AQUATIC HABITATS IN THE CORPUS CHRISTI AREA

by

Thomas A. Tremblay, Jeffrey S. Vincent, and Thomas R. Calnan*

*Coastal Assistance Division, Texas General Land Office

Final Report
prepared for the

Coastal Bend Bays and Estuaries Program, Texas General Land Office,
and
National Oceanic and Atmospheric Administration
under CBBEP Contract No. 0722

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

This investigation was funded by a grant from the National Oceanic and Atmospheric Administration administered by the Texas General Land Office. The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA or any of its subagencies.

Bureau of Economic Geology
Scott W. Tinker, Director
John A. and Katherine G. Jackson School of Geosciences
The University of Texas at Austin
University Station Box X
Austin, TX 78713-8924

March 2008

FIGURES

TABLES

STATUS AND TRENDS OF INLAND WETLAND AND AQUATIC HABITATS IN THE CORPUS CHRISTI AREA

EXECUTIVE SUMMARY

Thomas A. Tremblay[1], Jeffrey S. Vincent[1], and Thomas R. Calnan[2]

[1]Bureau of Economic Geology
John A. and Katherine G. Jackson School of Geosciences
The University of Texas at Austin

[2]Texas General Land Office
Coastal Assistance Division

INTRODUCTION

Wetland and aquatic habitats are essential components of estuarine systems along the Texas coast. These valuable resources are highly productive biologically and chemically and are part of an ecosystem on which a variety of flora and fauna depend. Scientific investigations of wetland distribution and abundance through time are prerequisites to effective habitat management, thereby ensuring their protection and preservation and directly promoting long-term biological productivity and public use. This report presents results of an investigation to determine current status and historical trends of wetlands and associated aquatic habitats in the Corpus Christi area from Lamar Peninsula to Encinal Peninsula. The study area encompasses most of the mainland between the Gulf Intracoastal Waterway (GIWW) and the Texas General Land Office Coastal Management Program boundary, an area that is located within Refugio, Aransas, San Patricio, and Nueces Counties (Fig. I). Natural environments include wetlands, wind-tidal flats, riparian woodlands, and bay shorelines. The methods and classification system used in this report follow those found in the Texas coastal barrier-island report for the Coastal Bend (White et al., 2002).

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 2004. Historical distribution is based on 1950's black-and-white and 1979 CIR photographs. Mapped wetlands for each period were digitized and entered into a GIS for analysis. The historical GIS maps were obtained from the U.S. Fish and Wildlife Service (USFWS), who mapped the wetlands using methods established as part of the National Wetlands Inventory program. Methods included interpreting and delineating habitats on aerial photographs, field checking delineations, and transferring delineations to1:24,000-scale base maps using a zoom transfer scope. Resulting maps were digitized and entered into a GIS, producing GIS maps for the two time periods. Both the 1950's and 1979 series USFWS maps, which are in digital format, were partly revised in this project to be more consistent with wetlands interpreted and delineated on the 2004 photographs.

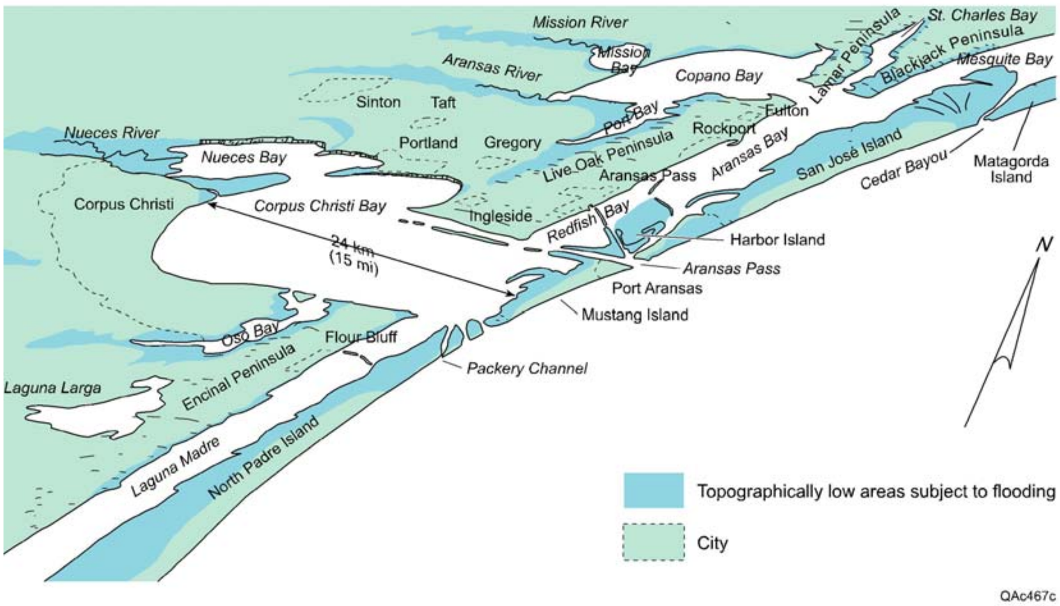

Figure I. Index map showing inland area that was investigated during this study. Modified from Brown et al. (1976).

Methods used to delineate 2004 habitats differed from earlier methods. The 2004 photographs are digital images with a pixel resolution of 1 m and registered to USGS Digital Orthophoto Quadrangles (DOQ's). Wetlands and aquatic habitats were mapped through interpretation and delineation of habitats on screen in a GIS at a scale of 1:5,000. 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 2004 were additionally classified by subclass (subdivisions of vegetated classes only), water regime, and special modifiers. Field sites were examined to characterize wetland plant communities, define wetland map units, and ground-truth delineations. Lidar (light detection and ranging) surveys conducted of the Nueces River Delta provided data on relative elevation that helped define habitat boundaries and potential frequency of flooding, or water regimes.

Current Status, 2004

Major estuarine and palustrine habitats in the study area include salt, brackish, and fresh marshes; tidal flats; and seagrass beds. Areas of estuarine open water are also important components of the salt and brackish-marsh complex.

In 2004 in the study area, wetland and aquatic habitats (excluding open water) were dominated by estuarine marsh at 10,821 ha (26,728 acres), followed by seagrass beds with a total area of 9,975 ha (24,638 acres) and palustrine marsh totaling 5,630 ha (13,906 acres) (Fig. II). Tidal flats, including algal mats, had a total area of 3,040 ha (7,509 acres), and palustrine forest (including scrub/shrub) had an area of 885 ha (2,186 acres). Palustrine open water/flats and Lacustrine habitats totaled 3,753 ha (9,270 acres).

The study area covers the estuarine systems of Corpus Christi Bay and Aransas Bay, and was subdivided into geographic areas—including Lamar Peninsula, Copano Bay mainland, Nueces River, Mission River, Aransas River, Port Bay, Live Oak Ridge, Redfish Bay, coastal prairies, Corpus Christi Bay, and Oso Creek/Encinal Peninsula—to allow a more site-specific analysis of status and trends (Fig. III).

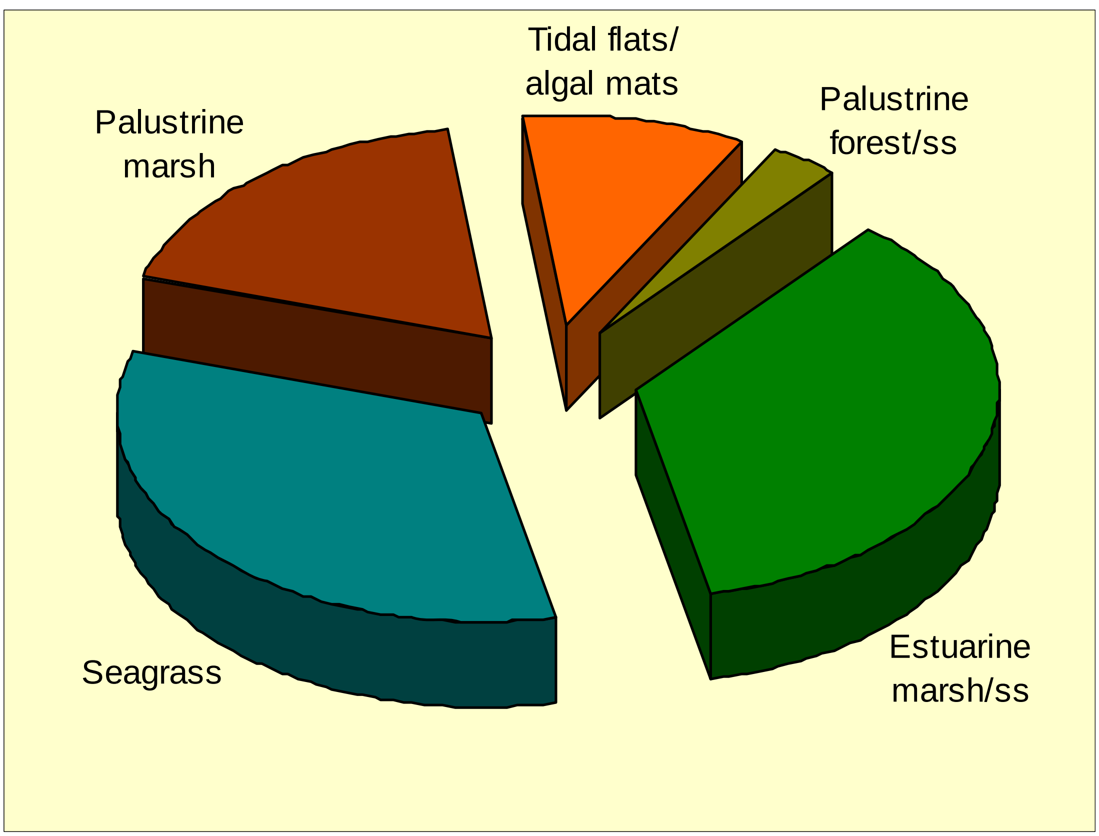

Figure II. Areal extent of selected habitats in the study area in 2004.

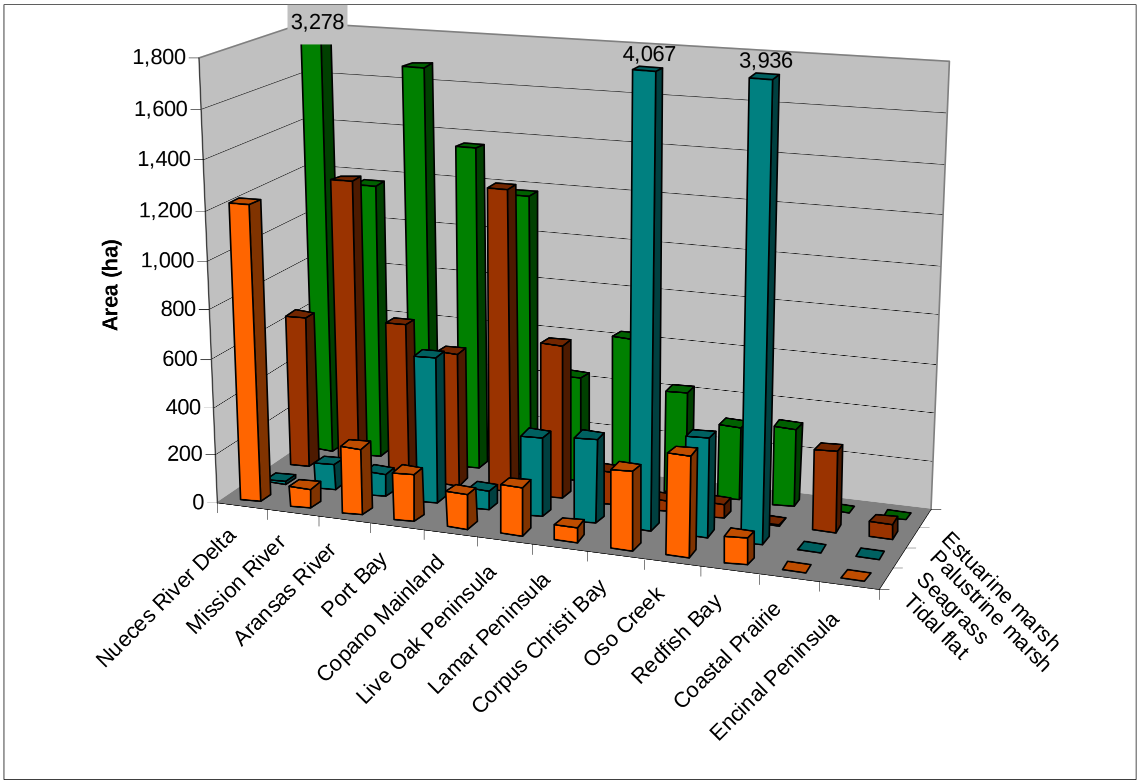

Figure III. Distribution of selected habitats by geographic area in 2004. The most extensive distribution of estuarine marsh is on the Nueces River Delta. Seagrasses are equally abundant in Corpus Christi Bay and Red Fish Bay.

The most extensive estuarine emergent wetlands (salt and brackish marshes) occurred on the Nueces River Delta, where the total area of estuarine marshes in 2004 was 3,278 ha (8,097 acres) (Fig. III). The Aransas-Chiltipin system was a distant second with 1,677 ha (4,142 acres). Port Bay, the Copano mainland, and the Mission River system all had significant amounts of estuarine marsh, where totals areas were 1,361 ha (3,362 acres), 1.182 ha (2,920 acres), and 1,170 ha (2,890 acres), respectively (Fig. III). Seagrass is most extensive in the Corpus Christi Bay/Estuary, followed closely by Redfish Bay, where total areas were 4,067 ha (10,046 acres) and 3,936 ha (9,722 acres), respectively. Seagrasses are abundant in the Laguna Madre. Port Bay and Oso Creek also contain significant amounts of seagrass, with 606 ha (1,497 acres) and 402 ha (993 acres), respectively. Palustrine marshes are equally abundant on the Copano mainland and within the Mission River valley, where total areas were 1,256 ha (3,102 acres) and 1,236 ha (3,053 acres), respectively. The Aransas River with 660 ha (1,630 acres), Nueces River Delta with 647 ha (1,598 acres), Live Oak Peninsula with 640 ha (1,581 acres), and Port Bay containing 561 ha (1,386 acres) all had significant amounts of palustrine marsh (Fig. III). The Nueces River Delta is the site of the largest number of tidal flats and algal mats in the study area, containing 1,221 ha (3,016 acres). Oso Creek is a distant second with 406 ha (1,003 acres) of tidal/algal flats. Palustrine forest and scrub/shrub habitat are relatively scarce, with the largest amount found in the Mission River valley with 269 ha (664 acres), followed by the Copano mainland with 229 ha (566 acres) and the Aransas River with 146 ha (361 acres).

Wetland Trends and Probable Causes, 1950's through 2004

In trend analysis, wetland classes were emphasized over water regimes and special modifiers because habitats were mapped only down to class on 1950's photographs. It should be noted that there is a margin of error in interpreting and delineating wetlands on aerial photographs, transferring delineations to base maps, and georeferencing the different vintages of maps to a common base for comparison. Accordingly, we have more confidence in direction of trends than absolute magnitudes. From the 1950's through 2004 within the study area, some wetland classes underwent substantial net losses and gains, whereas others remained more stable (Fig. IV; Table I). In general, estuarine marshes, combined with scrub/shrub, increased in total area during the period 1950's–1979 and decreased in total area during the period 1979–2004, with a total net gain of 1,956 ha (4,831 acres) from the 1950's through 2004. The average rate of marsh gain during the earlier period was about 126 ha/yr (311 acres/yr) and for the more recent period, a loss of about 38 ha/yr (94 acres/yr). The overall rate of change between the 1950's and 2004 was a gain of about 41 ha/yr (101 acres/yr). Estuarine marsh increased in all of the separately analyzed geographic areas except the Nueces River Delta. A significant proportion of the increase in estuarine marsh in river systems resulted from reclassification to palustrine marsh as a result of the landward movement of the fresh-to-saltwater boundary. In other areas, the primary change was the result of relative sea-level rise, where marshes spread into areas previously occupied by tidal flats. Approximately 43% of the increase in estuarine marsh resulted from spread of marsh into former tidal flats. Marsh loss resulted at Indian Point in Nueces Bay as a result of a combination of the effects of relative sea-level rise and erosion.

Seagrasses increased in total area during each period (1950's–1979 and 1979–2004), with a total net gain of 2,339 ha (5,777 acres) from the 1950's through 2004. Approximately 87% of this gain occurred from 1979 through 2004. The average rate of seagrass gain during the earlier period was about 13 ha/yr (32 acres/yr) and for the more recent period, about 82 ha/yr (202 acres/yr). The overall rate of seagrass change between the 1950's and 2004 was an increase of about 49 ha/yr (120 acres/yr). The geographic area with the largest increase in seagrasses is Corpus Christi Bay; other areas experiencing an increase in seagrasses are Lamar Peninsula, Live Oak Peninsula, Port Bay, and Oso Bay. Expansion frequently occurred in areas previously mapped as tidal flats and open water. In highly saline Oso Bay, freshwater from cooling ponds and drainage channels provided favorable conditions for seagrass expansion. However, human activity on Live Oak Peninsula caused a decline in seagrass area, where community development either removed the habitat entirely or created unfavorable conditions. In Redfish Bay seagrass area remained relatively constant.

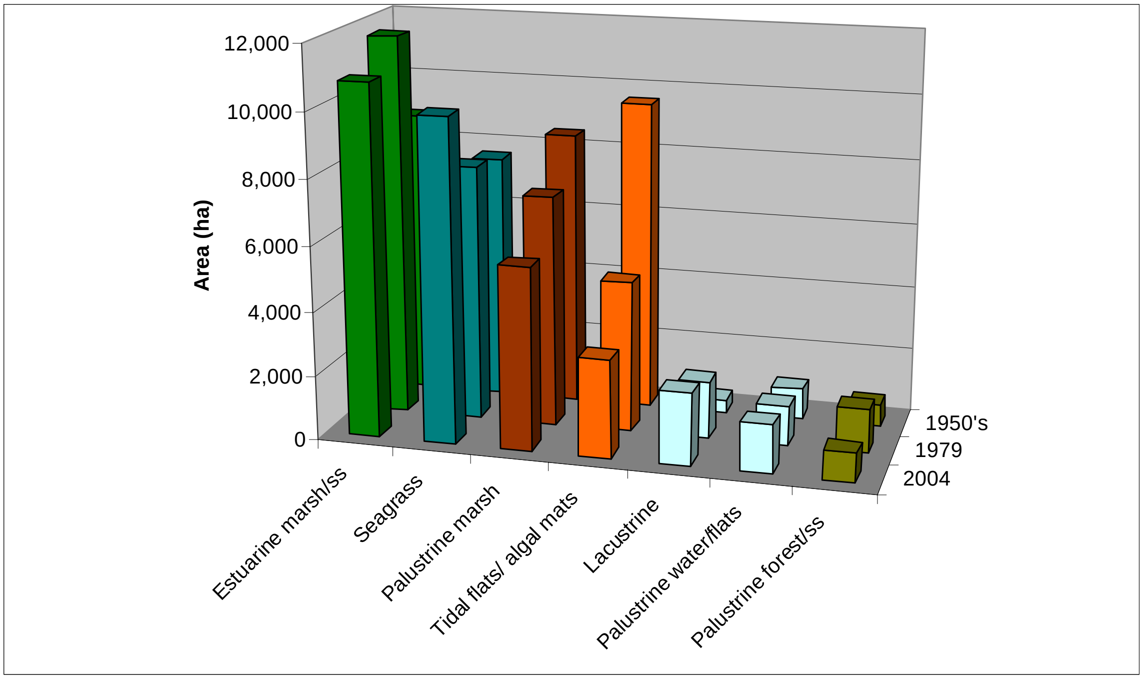

Figure IV. Areal distribution of major habitats in the study area in the 1950's, 1979, and 2004.

Table I. Total area of major habitats in the1950's, 1979, and 2004 in study area.

Habitat	*1950's*		*1979*		*2004*	
	ha	acres	ha	acres	ha	acres
Estuarine marsh/ss	8,856	21,874	11,749	29,020	10,821	26,728
Seagrass	7,611	18,799	7,905	19,525	9,950	24,577
Palustrine marsh	8,489	20,968	7,120	17,586	5,630	13,906
Tidal flats/ algal mats	9,591	23,690	4,672	11,540	3,040	7,509
Lacustrine	383	946	1,762	4,352	2,254	5,567
Palustrine water/flats	957	2,364	1,239	3,060	1,499	3,703
Palustrine forest/ss	683	1,687	1,360	3,359	885	2,186

The most extensive losses in habitats occurred in tidal flats, which underwent a major net decline from the 1950's through 1979 (Fig. IV). Total area of tidal flats decreased by 4,919 ha (12,150 acres) during this period (1950's–1979). During the later period (1979–2004), total area of tidal flats decreased an additional 1,632 ha (4,031 acres). The average rate of tidal-flat loss during the earlier period was about 214 ha/yr (514 acres/yr) and for the more recent period, a loss of about 65 ha/yr (161 acres/yr). Roughly (–)30% of tidal-flat change occurred where estuarine marsh spread into areas previously mapped as tidal flats. In secondary bays of the Copano mainland, marshes spread into previous tidal flats. The same scenario took place on Lamar Peninsula but was compounded by residential development. Both residential and industrial development, as well as the effects of relative sea-level rise, lowered the area of tidal flats on Live Oak Peninsula. Most tidal-flat loss in Port Bay occurred in secondary bays, where relative sea-level rise caused emergent vegetation to spread into previous tidal flats. In Oso Bay, marsh spread into previous flats along the bay margin and in Redfish Bay, seagrasses spread into former flat areas, and dredge material was deposited on other flats. Corpus Christi Bay lost large amounts of flats when industrial areas adjacent to Tule Lake Channel were filled. In Mission and Aransas Rivers, marsh-spread into previous tidal-flat area occurred primarily during the later time period. On the Nueces River Delta tidal-flat area has remained stable.

Palustrine marsh had its largest distribution in the 1950's, at 8,489 ha (20,968 acres), and lowest in the 2004 at 5,630 ha (13,906 acres) (Table I). The average rate of palustrine marsh loss for both time periods was about 60 ha/yr (147 acres/yr). The Copano mainland, Lamar Peninsula, Live Oak Peninsula, coastal prairies, and Port Bay all experienced fluctuations in palustrine marsh area and contain transitional areas dominated by *Spartina spartinae*. The extent to which high marshes are delineated is partly a function of moisture levels at the time photographs are taken. Although some palustrine marsh loss can be attributed to interpretation differences, drier climatic conditions caused by long-term drought had a diminishing effect on the areal extent of palustrine marsh by 2004. At the local level, community development in places like Key Allegro and Aransas Pass contributed to gross losses of wetlands. In some instances, marsh was converted to open water when quarries were excavated for sand resources. The overall trend was characterized primarily by reduction (–84%) of palustrine marsh through conversion to uplands. In Mission and Aransas Rivers, palustrine marsh experienced significant loss over the long term. Most palustrine marsh loss was located in areas that had become estuarine marsh because of landward movement of the salt/freshwater boundary within the river system. On Encinal Peninsula the amount of palustrine marsh remained constant.

Palustrine open water and flats experienced a relatively consistent increase through time. Average rate of gain of palustrine water and flats during the earlier period was about 12 ha/yr (30 acres/yr), and for the more recent period, about 10 ha/yr (26 acres/yr). On Live Oak Peninsula, palustrine open-water totals increased by 280% between the 1950's total of 91 ha (218 acres) and 1979, when open water totaled 346 ha (830 acres). Much higher precipitation levels most likely accounted for the 1979 increase. By 2004, long-term drought had reduced the amount of palustrine open water to 188 ha (470 acres).

Finally, there was a net decrease in the mapped area of palustrine forest and scrub/shrub habitats, decreasing in total area by 202 ha (505 acres) from the 1950's through 2004, a net loss of almost (–)23% since the 1950's. A peak of 1,360 ha (3,400 acres) was mapped in 1979. On Mission and Aransas Rivers, palustrine woodlands increased systematically over time. However, forests, and to a lesser degree scrub/shrub, in the palustrine system are difficult to distinguish from those in the upland system and are, therefore, subject to interpretational differences. Whereas gains and losses of palustrine forest and scrub/shrub were due mostly to photointerpretation, woodlands probably changed little overall, with gains exceeding losses. Woodland acreage on the Copano mainland remained constant over time.

STATUS AND TRENDS OF INLAND WETLAND AND AQUATIC HABITATS IN THE CORPUS CHRISTI BAY AREA

INTRODUCTION

Coastal inland wetlands are essential natural resources that are highly productive biologically and chemically and are part of an ecosystem on 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 in the Corpus Christi area from Lamar to Encinal Peninsula. A previous study of Galveston Bay by the Bureau of Economic Geology (BEG) (White et al., 1993) indicates substantial losses in wetlands due to subsidence and associated relative sea-level rise. Some losses in the Galveston Bay estuary system have occurred along surface faults that have become active as a result of underground fluid production. In contrast to those of the Galveston Bay system, studies of wetlands on barrier islands along the central Texas coast (White et al., 2002) show that marshes have expanded as a result of relative sea-level rise. Down the coast to the southeast of these two bay systems is the Aransas-Corpus Christi-upper Laguna Madre bay system, where extensive wetlands are found. To determine wetland changes through time, wetland status and trends and probable causes of trends on this Coastal Bend estuary system were analyzed. Results of the study help in our understanding of marsh changes in Texas estuaries and pinpoint wetlands threatened by erosion, 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.Big Lake (oxbow) at Welder Wildlife Refuge on the Aransas River. Popular wintering location for waterfowl.

Study Area

The study area includes the estuary system between Lamar and Encinal Peninsula. Included are Lamar Peninsula, Copano Bay mainland, Nueces River drainage, Mission River valley, Aransas River, Port Bay, Live Oak Ridge, Redfish Bay, coastal prairies, Corpus Christi Bay, Oso Creek drainage, and Encinal Peninsula (Figs. 2, 3). The study area from north to south consists of Copano Bay, Aransas Bay, Redfish Bay, Corpus Christi Bay, and upper Laguna Madre. The study area is located in Refugio, Aransas, San Patricio, and Nueces Counties.

General Setting of the Corpus Christi–Aransas Bay System

The geologic framework of the Corpus Christi–Aransas Bay area consists of Modern–Holocene and Pleistocene systems, including the modern wetland system (Fig. 4). Geomorphic features on which various types of coastal wetlands have developed are the result of numerous interacting processes. Physical processes that influence wetlands include rainfall, runoff, water-table fluctuations, streamflow, evapotranspiration, waves and longshore currents, astronomical and wind tides, storms and hurricanes, deposition and erosion, subsidence, faulting, and sea-level rise. These processes have contributed to the development of a gradational array of permanently to infrequently inundated environments ranging in elevation from estuarine subtidal areas to topographically higher wetlands that grade upward from the astronomical-tidal zone through the wind-tidal zone to the storm-tidal zone.

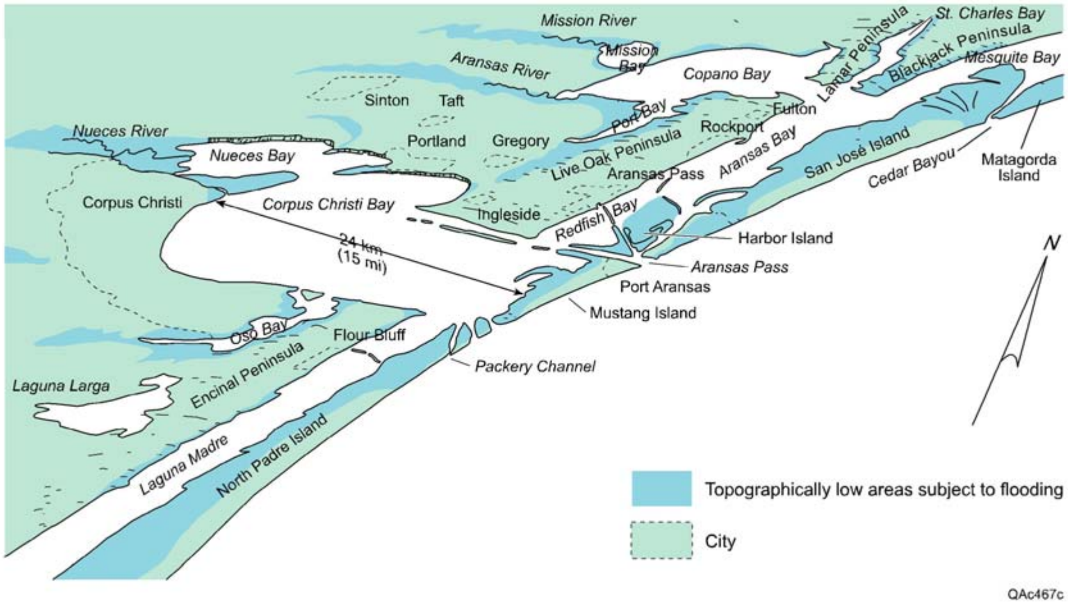

Figure 2. Index map showing inland area that was investigated during this study. Modified from Brown et al. (1976).

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

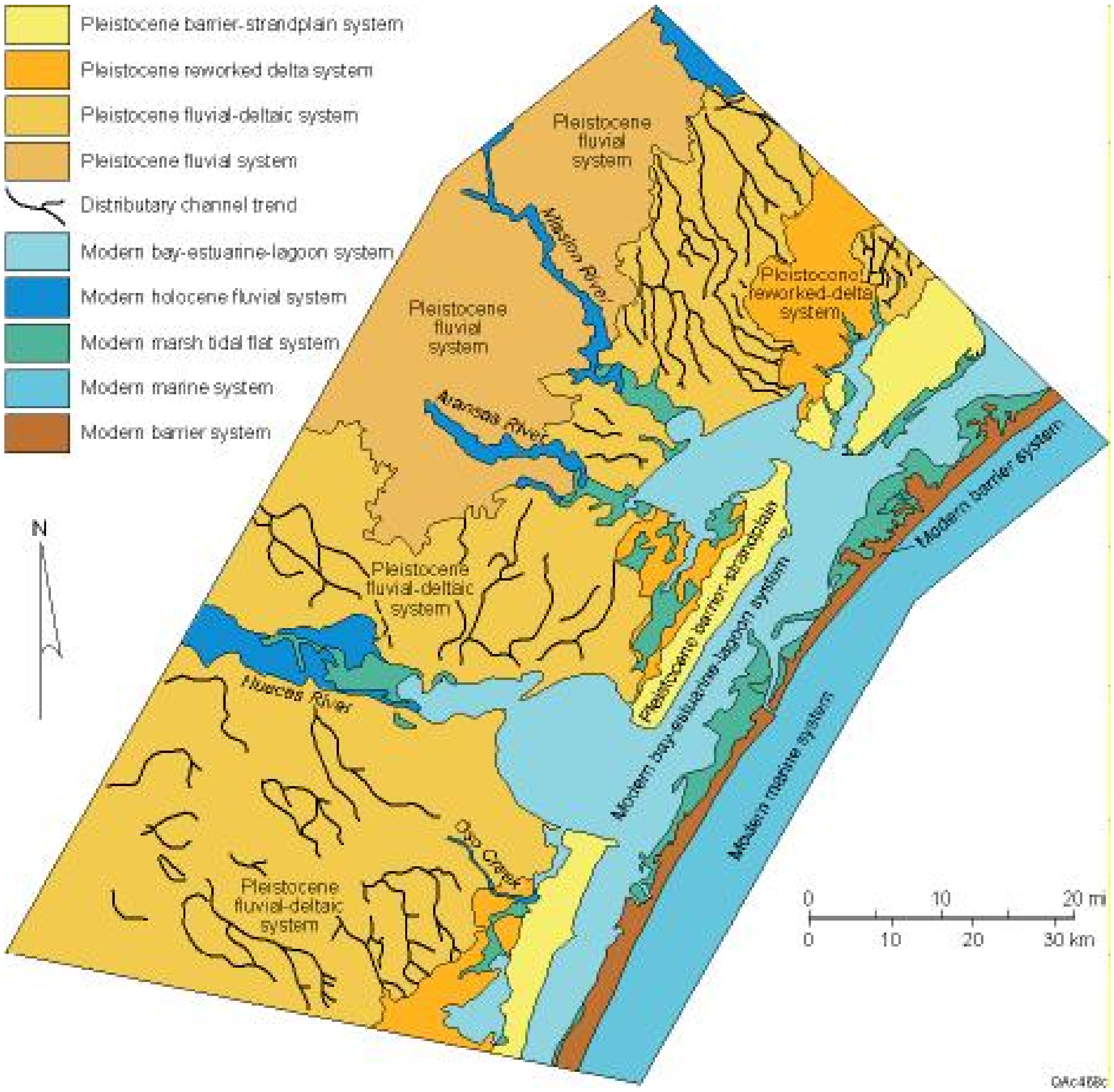

Figure 4. Natural systems in the Corpus Christi–Aransas Bay area. From Brown et al. (1976) and McGowen et al. (1976).

Figure 5. Photo looking south across Rincon Bayou taken during high water levels of February 2007.

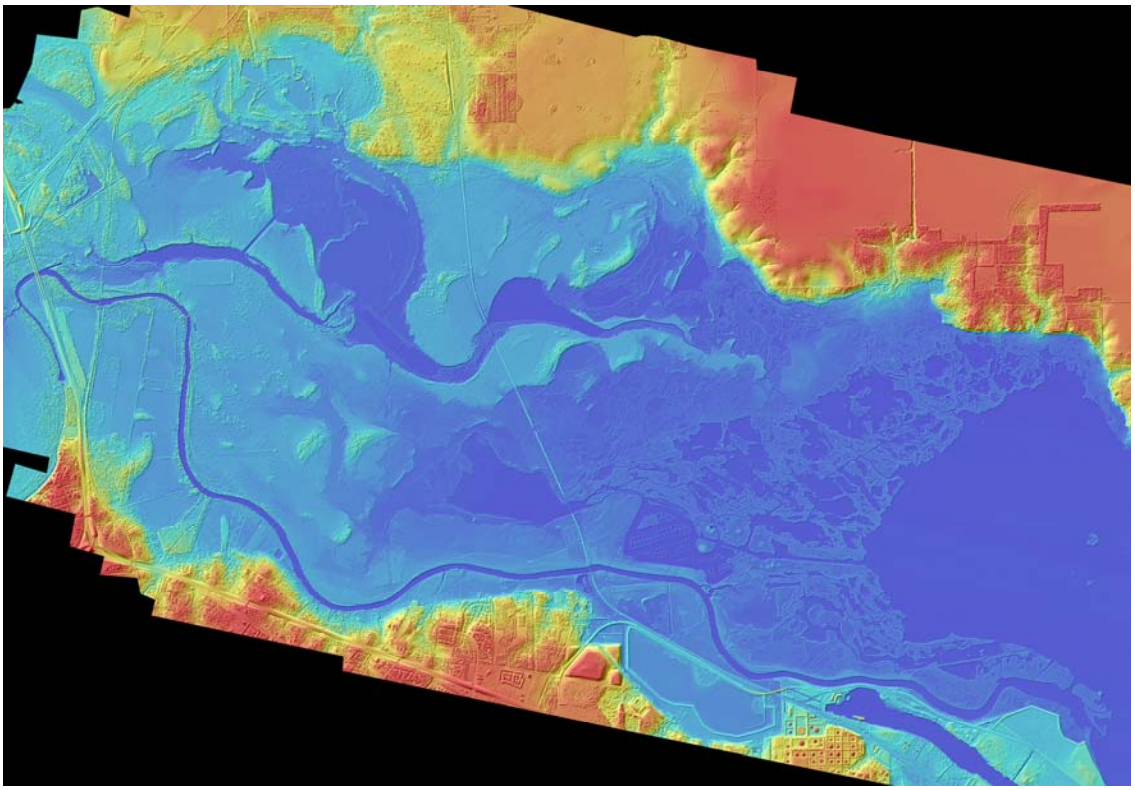

Figure 6. Lidar digital elevation model of the Nueces River Delta (BEG, 2007).

Bay-Estuary-Lagoon Setting

Exchange of marine waters with waters of the estuarine system occurs primarily through the tidal inlet, Aransas Pass, which separates San José Island from Mustang Island. Aransas Pass has been dredged and jettied to create the Corpus Christi Ship Channel (Fig. 2). Intermittent exchange of marine and estuarine water occurs at Cedar Bayou (when open), located at the north end of San José Island. It is a narrow channel that connects the Gulf with Mesquite Bay. Exchange of marine and estuarine waters can also occur through storm washover channels located at the south end of Mustang Island. Packery Channel, located at the south end of Mustang Island (Fig. 2), is dredged and jettied to form a “permanent” inlet to provide boating access to the Gulf of Mexico.

Main sources of freshwater inflow into the estuarine system in the study area are rivers that discharge at the heads of the bays, principally the Nueces, Aransas, and Mission Rivers, which discharge into Nueces Bay, Copano Bay, and Mission Bay, respectively (Fig. 2). The Guadalupe River, which discharges into San Antonio Bay to the northeast, is an important source of freshwater for Aransas Bay (Longley, 1994). Salinities in the bay-estuary-lagoon system vary. Average salinities in Laguna Madre are generally above 30 parts per thousand (ppt), which is in marked contrast to Copano Bay, where average salinities range from about 10 to15 ppt, increasing toward the mouth of the bay. Average salinities are generally highest in Laguna Madre, followed in decreasing order by Corpus Christi, Redfish, Aransas, Nueces, and Copano Bays (Holland et al., 1975; Brown et al., 1976; Hildebrand and King, 1978). Salinities decrease toward the heads of the bays, where they are moderated by freshwater inflows. Astronomical tides along the Gulf shore have a mean diurnal range of 0.5 m and maximum diurnal range of 0.76 m (Collier and Hedgpeth, 1950; Hayes, 1965). Along the bay shore, mean tides are approximately 0.15 m (Watson and Behrens, 1976), although wind-generated tides in the bays can be substantially higher. These numerous interacting processes in Corpus Christi Bay and adjacent bay systems have a major bearing on location and composition of wetland plant communities.

Relative Sea-Level Rise

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

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

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

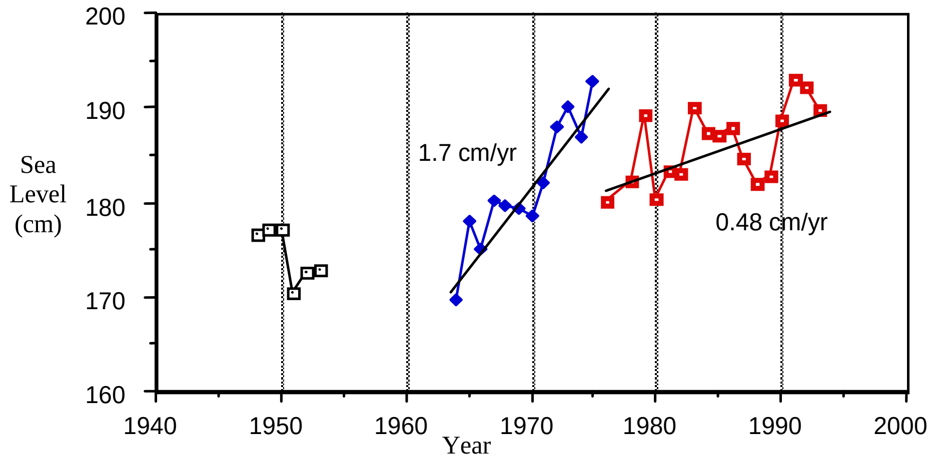

Figure 7. Sea-level rise at the Rockport tide gauge located near the landward margin of Aransas Bay. Tide data from NOAA.

METHODS

Mapping and Analyzing Status and Trends

Status and trends of wetlands in the study area were determined by analyzing the distribution of wetlands mapped on aerial photographs taken in the 1950’s, 1979, and 2004. 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 2004. The 1992 NWI maps were used as collateral information for interpreting and mapping current wetland distribution.

Wetland Classification and Definition

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

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

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

Because the fundamental objective of this project was to determine status and trends of wetlands using aerial photographs, classification and definition of wetlands are integrally connected to the photographs and the interpretation of wetland signatures. Wetlands were neither defined nor mapped in accordance with the *U.S. Army Corps of Engineers Wetland Delineation Manual* (1987) which applies to jurisdictional wetlands.

Interpretation of Wetlands

Historical Wetland Distribution

Historical distribution of wetlands is based on the 1950's and 1979 USFWS wetland maps. Methods used by the USFWS include interpretation and delineation of wetlands and aquatic habitats on aerial photographs through stereoscopic interpretation. Field reconnaissance is an integral part of interpretation. Photographic signatures are compared with the appearance of wetlands in the field by observing vegetation, soil, hydrology, and topography. This information is weighted for seasonality and conditions existing at the time of photography and ground-truthing. Still, field-surveyed sites represent only a small percentage of the thousands of areas (polygons) delineated. Most areas are delineated on the basis of photointerpretation alone, and misclassifications may occur. The 1950's photographs are black-and-white stereo-pair, scale 1:24,000, most of the ones along the Texas coast having been taken in the mid 1950's (Larry Handley, USGS, personal communication, 1997). The 1979 aerial photographs are NASA color-infrared stereo-pair, scale 1:65,000, that were taken in November.

---

[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.

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 are generally of high quality. Abnormally high precipitation in 1979, however, raised water levels on tidal flats and in many inland fresh to brackish wetlands. Thus, more standing water and wetter conditions were apparent on the 1979 photographs than on the 2004 photographs. Although the 1950's photographs are black-and-white, they are large scale (1:24,000), which aids in the photointerpretation and delineation process. There was a severe drought in the 1950's that peaked in 1956 in Texas (Riggio et al., 1987), which may have affected palustrine marshes on the 1950's maps. These differences in wet and dry conditions during the various years affected habitats, especially palustrine, and their interpreted or mapped water regimes.

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

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

Revision of Historical Wetland Maps

As part of this study, researchers at BEG revised USFWS historical wetland maps (1950's and 1979), so that there would be closer agreement between historical map units and current (2004) wetland map units. Revisions of the USFWS data were restricted primarily to the estuarine marshes, tidal flats, and areas of open water. The principal reason for the revisions was that in many areas on the historical maps, estuarine intertidal emergent wetlands (E2EM) were combined with intertidal flats (E2FL) as a single map unit (E2EM/E2FL). In our revisions, these areas were subdivided into E2EM and E2FL.

To accomplish revisions on the USFWS maps, photographs taken in the 1950's and 1979 were scanned and georeferenced with respect to the 1950's and 1979 maps. Wetlands on the digital photos were then analyzed on the computer screen, and changes were mapped directly on the digital wetland maps. Revised data were entered into the GIS.

Current Wetland Distribution

Current distribution of wetlands and aquatic habitats is based on color infrared (CIR) aerial photographs taken in 2004. Interpretation and mapping of wetlands and aquatic habitats were completed by BEG researchers through on-screen delineation of habitats. Delineations were digitized directly into the GIS (ArcMap) at a scale of 1:5,000. Because of the method used, current wetland maps show more detail than do 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 (Figs. 8, 9). Characterization of prevalent plant associations provided vital plant community information for defining mapped wetland classes in terms of typical vegetation associations. In addition, interpretations of wetlands on the Nueces Delta were supported by light detection and ranging (lidar) data acquired by BEG (Gibeaut et al., 2007). The lidar images (Fig. 6) provide detailed elevation data that help differentiate between high and low marshes and flats and areas that are transitional between uplands and wetlands.

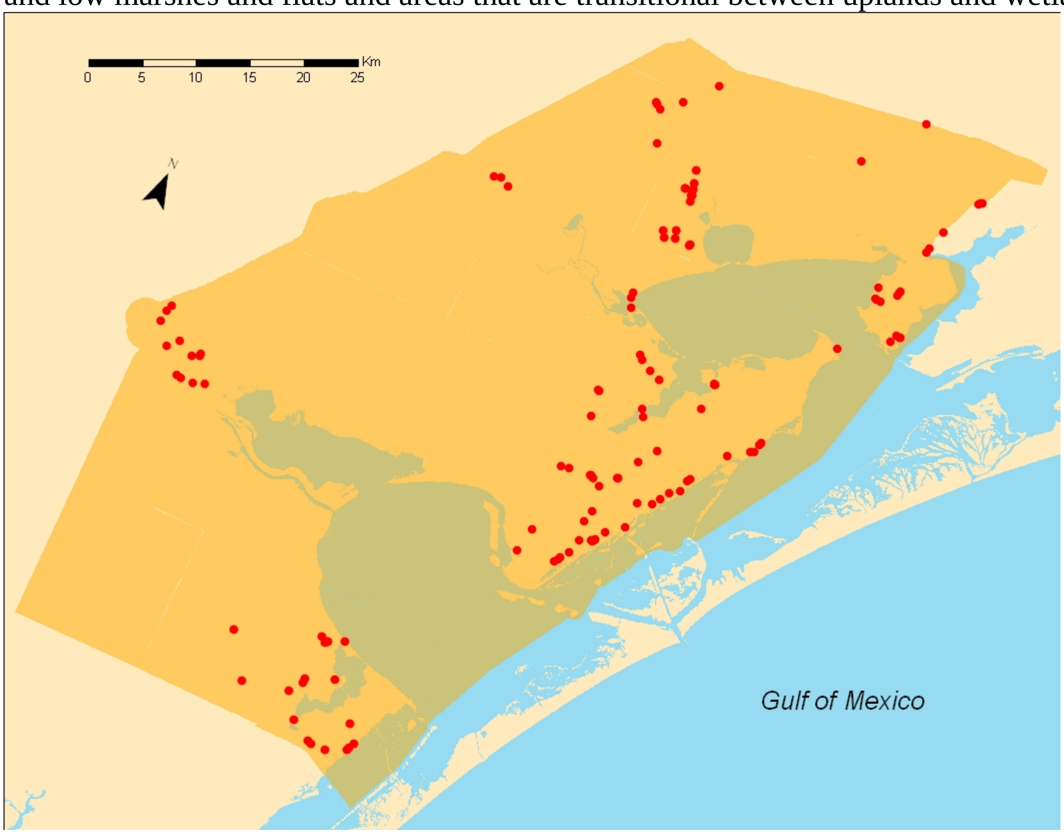

Figure 8. Map of field-survey sites used for ground-truthing aerial photo delineations and collecting field data.

Figure 9. Field crew in all-terrain vehicle at Fennessey Ranch, Mission River.

Variations in Classification

Classification of wetlands varied somewhat for the different years. On 1979 and 2004 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. 10–12). 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. 12). Flats and beach/bar classes designated separately on 1950's and 1979 maps were combined into a single class, unconsolidated shore, on 2004 maps, in accordance with updated NWI procedures as exemplified on 1992 NWI wetland maps (Fig. 10). USFWS data for the study area were selected from parts of 32 7.5-minute quadrangles (Fig. 13) 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 2004. Data can be manipulated as information overlays, whereby scaling and selection functions allow parts of the estuary to be selected electronically for specific analysis. Among objectives of the GIS are to (1) allow direct historical comparisons of wetland types to gauge historical trends and status of habitats, (2) allow novel comparisons of feature overlays to suggest probable causes of wetland changes, (3) make information on wetlands directly available to managers in a convenient and readily assimilated form, and (4) allow overlays to be combined from wetland studies and other topical studies in a single system that integrates disparate environmental features for planning and management purposes. 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 historical and recent digital data. These cause errors when data sets are overlain and analyzed in GIS. The 2004 aerial photographs are georeferenced to USGS DOQ's, and 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 historical and 2004 data. When the two data sets are superimposed in GIS, the offset creates apparent wetland changes that are in reality cartographic errors resulting from a lack of accuracy in registration. Registration of the USFWS digital data sets is complicated and was beyond the scope of this project. Thus, caution must be used in interpreting changes from direct overlay of the different data sets as layers in a GIS. Wetland totals were tabulated separately for each year to determine wetland changes within the given study area. Overlay of the data sets was done primarily to identify significant wetland changes that could be verified by analyzing and comparing aerial photographs.

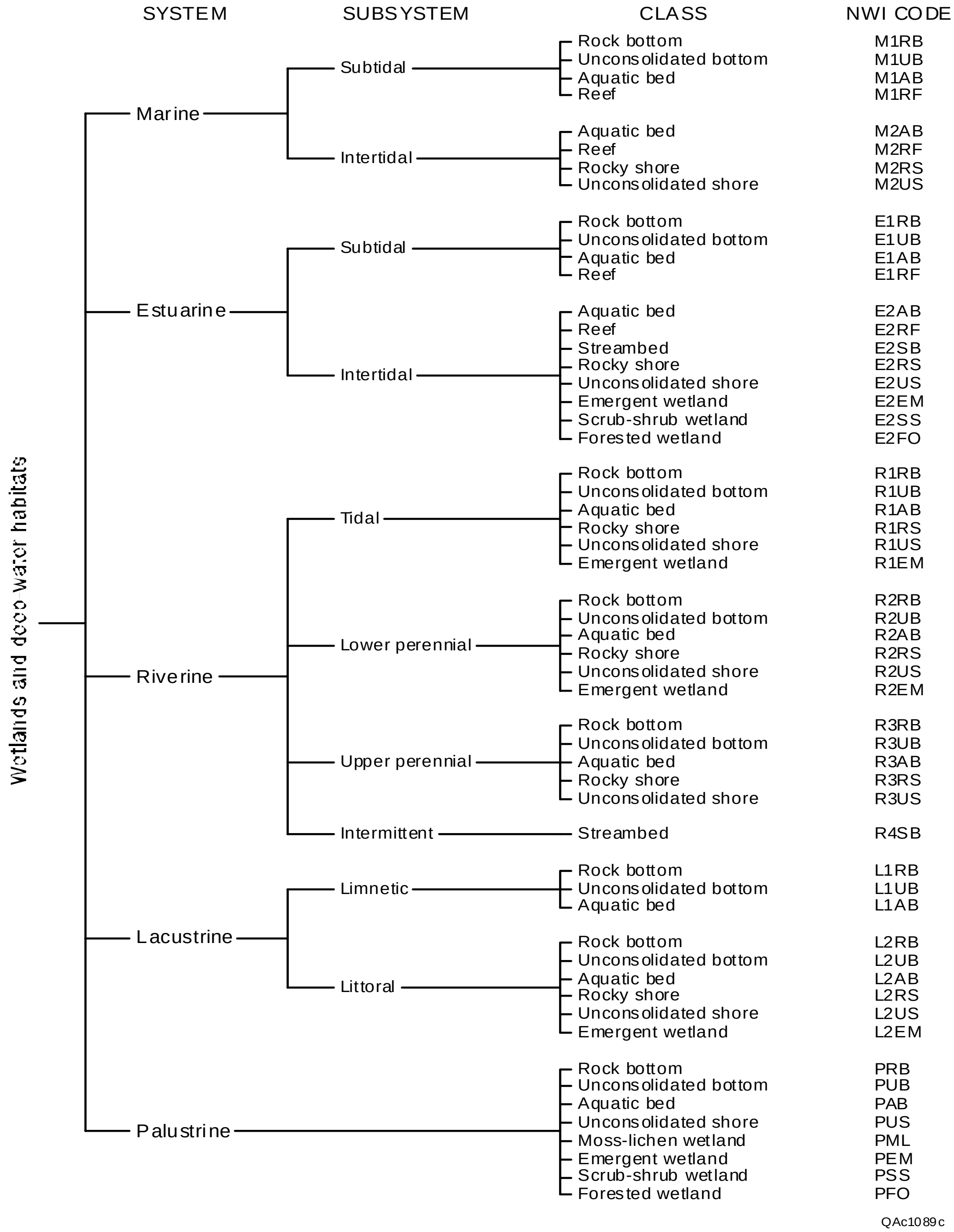

Figure 10. Classification hierarchy of wetlands and deepwater habitats showing systems, subsystems, and classes. From Cowardin et al. (1979).

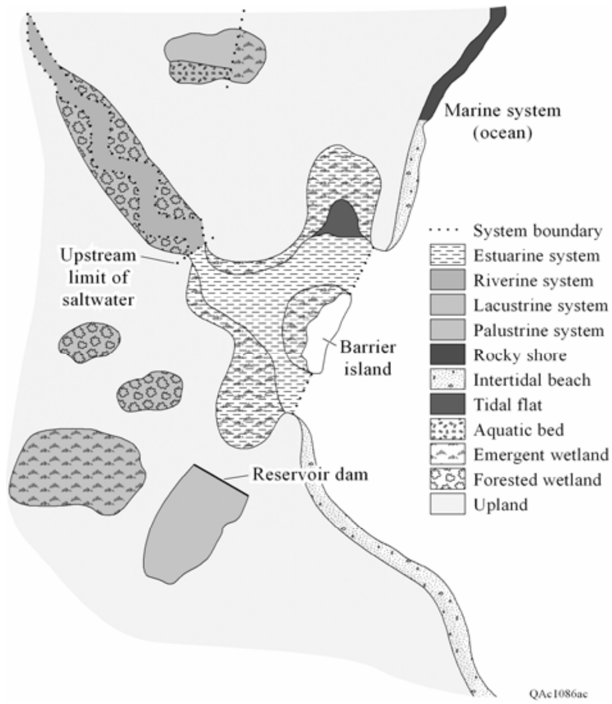

Figure 11. Schematic diagram showing major wetland and deepwater habitat systems. From Tiner (1984).

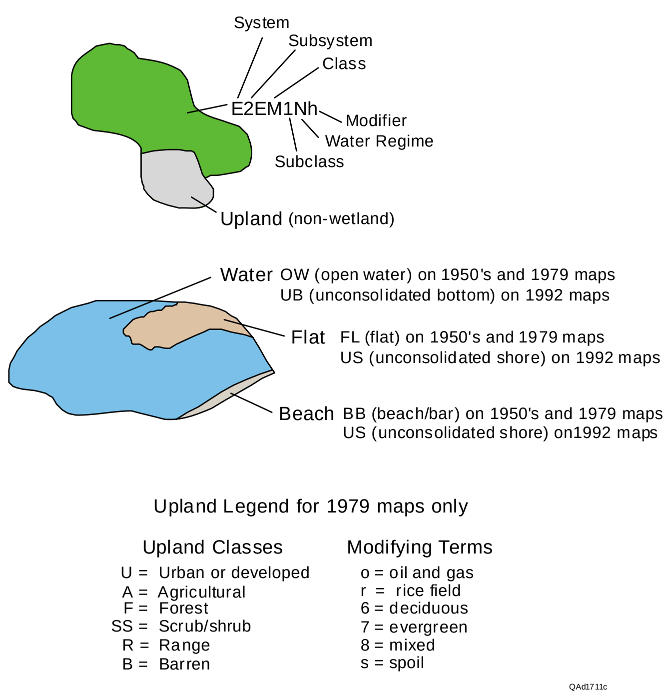

Figure 12. Example of symbology used to define wetland and upland habitats on NWI maps.

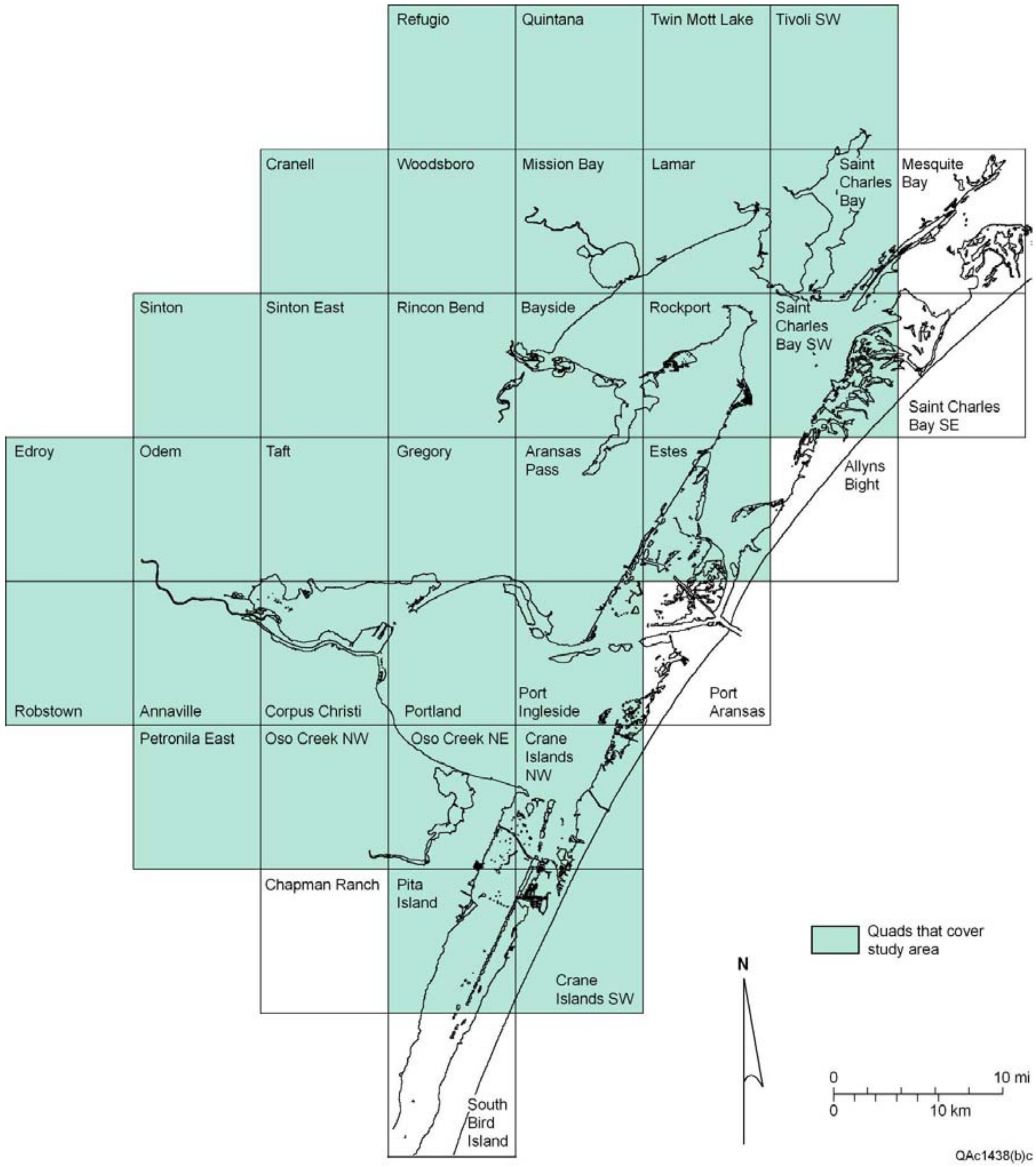

Figure 13. U.S. Geological Survey 7.5-minute quadrangles that encompass the bay systems mapped in this investigation.

CLASSIFICATION OF WETLAND AND DEEPWATER HABITATS IN STUDY AREA

Cowardin et al. (1979) defined five major systems of wetlands and deepwater habitats: marine, estuarine, riverine, lacustrine, and palustrine (Fig. 10). Systems are divided into subsystems, which reflect hydrologic conditions, such as intertidal and subtidal for marine and estuarine systems. Subsystems are further divided into class, which describes the appearance of the wetland in terms of vegetation or substrate. Classes are divided into subclasses, although only vegetated classes were divided into subclasses for this project, and only for 1979 and 2004. 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. 12). Symbols for certain habitats changed after 1979; these changes are shown in Figure 12 and are noted in the section on trends in wetland and aquatic habitats. Examples of alphanumeric abbreviations used in the section on status of wetlands apply only to 2004 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 1979 NWI maps.

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

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

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

Table 2. Wetland codes and descriptions from Cowardin et al. (1979). Codes listed below were used in mapping wetlands on 2004 delineations, which varied in some cases from 1950's and 1979 maps (see Fig. 12).

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

Marine System

Marine areas include unconsolidated bottom (open water), unconsolidated shore (beaches), and rocky shore (jetties). Mean range of Gulf tides is about 0.5 m. Nonvegetated open water overlying the Texas Continental Shelf is classified as marine subtidal unconsolidated bottom (M1UBL) (Table 2). Unconsolidated shore is mostly irregularly flooded shore or beach (M2USP), with a narrow zone of regularly flooded shore (M2USN). 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). This system is not represented in the study area.

Estuarine System

The estuarine system consists of many types of wetland habitats. Estuarine subtidal unconsolidated bottom (E1UBL), or open water, occurs in the numerous bays and in adjacent salt and brackish marshes. Unconsolidated shore (E2US) includes tidal flats and estuarine beaches and bars. Water regimes for this habitat range primarily from irregularly flooded (E2USP) to regularly flooded (E2USN) to irregularly exposed (E2USM) (Fig. 15). In Figure 15 north winds have pushed water into areas not normally flooded. Aquatic beds (Fig. 16) observed in this system are predominantly submerged, rooted vascular plants (E1AB3L) that may include *Halodule wrightii* (shoalgrass), *Ruppia maritima* (widgeongrass), *Thalassia testudinum* (turtlegrass), *Syringodium filiforme* (manateegrass), and *Halophila engelmannii* (clovergrass) (Pulich et al., 1997).


Figure 14. Example of high tidal flats (E2US1P) in Mullens Bayou.

Figure 15. Example of wind-tidal flats (E2USP) near Peary Place, Oso Bay.

Figure 16. Seagrass (*Halodule wrightii*) exposed by low tides in a shallow pond at Italian Bend, Port Bay.

Emergent areas closest to estuarine waters consist of regularly flooded, salt-tolerant grasses (low salt and brackish marshes) (E2EM1N) (Fig. 17). These communities are composed mainly of *Spartina alterniflora* (smooth cordgrass), *Batis maritima* (saltwort), *Distichlis spicata* (seashore saltgrass), *Sporobolus virginicus* (coastal dropseed), *Salicornia* spp. (glasswort), *Monanthochloe littoralis* (shoregrass), *Suaeda linearis* (annual seepweed), and *Sesuvium portulacastrum* (sea-purslane) in more saline areas.

In brackish areas, species composition changes to a salt- to brackish-water assemblage, including *Schoenoplectus* (formerly *Scirpus*) spp. (bulrush), *Bolboschoenus robustus* (sturdy bulrush), *Paspalum vaginatum* (seashore paspalum), *Spartina patens* (saltmeadow cordgrass) (Figs. 18, 19), and *Phyla* sp. (frog fruit), among others. At slightly higher elevations, irregularly flooded estuarine emergent wetlands (E2EM1P) (high salt and brackish marshes) include *Borrichia frutescens* (sea oxeye), *Spartina patens*, *Spartina spartinae* (gulf cordgrass), *Distichlis spicata*, *Fimbrystylis castanea* (marsh fimbry), *Aster* spp. (aster), and many others.

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

The estuarine system extends landward to the point where ocean-derived salts are less than 0.5 ppt (during average annual low flow) (Cowardin et al., 1979). Mapping these boundaries is subjective in the absence of detailed, long-term salinity data, characterizing water and marsh features. Vegetation types, proximity and connection to estuarine water bodies, salinities of water bodies, and location of artificial levees and dikes are frequently used as evidence to determine the boundary between estuarine and adjacent palustrine systems. In general, a pond or emergent wetland was placed in the palustrine system if there was an upland break that separated it from the estuarine system.

Figure 17. *Spartina alterniflora*, E2EM1N, at the mouth of the Aransas River.

Figure 18. E2EM1P composed of *Borrichia frutescens* and *Bolboschoenus robustus* along the banks of Mullens Bayou.

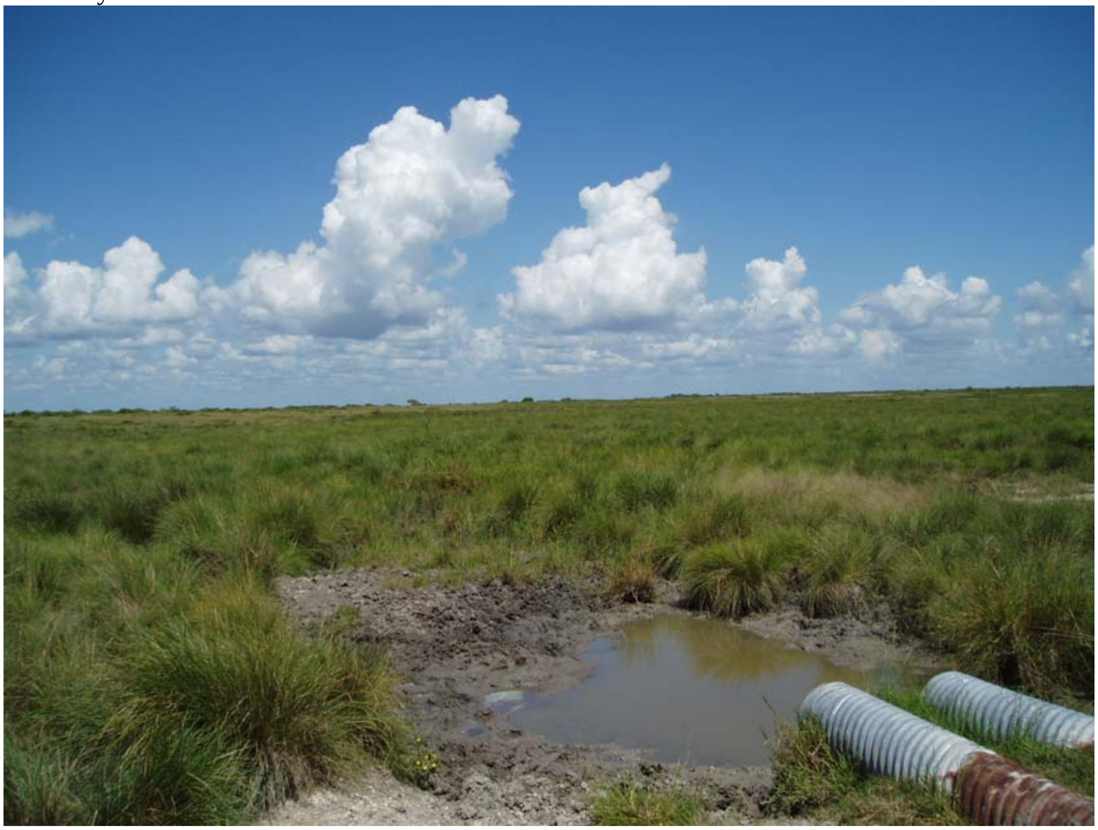

Figure 19. *Spartina spartinae* mapped as E2EM1P. Drainage pipes empty into high marsh near Swan Lake.

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 emergent wetlands (Figs. 20, 21) are generally equivalent to fresh to brackish or inland marshes that are not inundated by estuarine tides. Semipermanently flooded emergent wetlands (PEM1F) are low, fresh marshes; seasonally flooded (PEM1C) and temporarily flooded (PEM1A) palustrine emergent wetlands are high, fresh marshes.

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

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

Palustrine scrub/shrub wetlands are limited in extent but where mapped are typically seasonally flooded and are dominated by *Salix nigra* (black willow), *Parkinsonia aculeata* (retama), *Acacia smalli* (huisache), and *Sesbania drummondii*. Temporarily and semipermanently flooded scrub/shrub habitat also occurs with similar species (Fig. 22). Water regimes include both tidally and nontidally influenced areas. *Tamarix spp*. is labeled as PSS2A or PSS2C, depending on water conditions present (Table 2).

Palustrine forested areas, consisting of temporarily (PFO1A) and seasonally (PFO1C) flooded forested areas, incorporate a large mixture of tree species, including *Salix nigra*, *Parkinsonia aculeata*, *Acacia smalli*, *Fraxinus spp*. (ash), *Ulmus crassifolia* (cedar elm), *Celtis spp*. (hackberry), *Ehretia anacua,* and others (Fig. 23).

Lacustrine System

Water bodies greater than 8 ha are included in this system, with both limnetic and littoral subsystems represented. 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" indicates spoil or dredged material.

Riverine System

Three riverine subsystems occur in the study area: tidal (R1), lower perennial (R2), and intermittent (R4). Major rivers discharging directly into the bay system are the Nueces, Aransas, and Mission.

Figure 20. Example of palustrine marsh on Live Oak Ridge. Vegetation includes *Typha* sp., *Spartina spartinae*, and other species.

Figure 21. Example of palustrine marsh in Mullens Bayou. Vegetation includes *Schoenoplectus californicus*, *Borrichia frutescens*, among others.

Figure 22. Palustrine scrub/shrub wetland (PSS) along channel on Live Oak Ridge. Species include *Tamarix* sp. and *Celtis* sp., among others.

Figure 23. Palustrine forested wetlands (PFO) on Fennessey Ranch. Trees include *Anacua*, *Celtis*, and *Ulmus crassifolia*, among others. Trees rim accretionary swales of the Mission River.

STATUS OF WETLANDS AND AQUATIC HABITATS IN 2004

Major estuarine habitats in the study area include salt and brackish marshes, seagrass beds, tidal flats, and riparian forests. Areas of open water are also important components of the salt and brackish marsh complex. The palustrine system consists of marshes, flats, and open water that are not tidally influenced and are typically characterized by freshwater marsh assemblages. Forested and scrub/shrub wetland habitats are found primarily along rivers, bayous, creeks, and oxbow lakes.

In 2004, wetland and aquatic habitats covered about 108,279 ha within the study area (Fig.25, Table 3). Approximately 231,844 ha within the study area was classified as uplands. Of the three wetland systems mapped, the estuarine system is by far the largest (Fig. 26, Table 3). Emergent vegetated wetlands (E2EM, E2SS, PEM, PFO, PSS areas) cover 17,366 ha, 62% of which is estuarine marsh. The extent of all mapped wetlands, deepwater habitats, and uplands for each year is presented in the appendix. The study area was subdivided into geographic areas—Lamar Peninsula, Copano mainland, Mission River, Aransas River, Live Oak Peninsula, coastal prairies, Port Bay, Redfish Bay, Nueces River Delta, Corpus Christi Bay, Oso Creek, and Encinal Peninsula—to allow a more site-specific analysis of status and trends (Figs. 24, 25).

The most extensive estuarine emergent wetlands (salt and brackish marshes) occurred on the Nueces River Delta, where the total area of estuarine marshes in 2004 was 3,278 ha (Fig. 27). The Aransas-Chiltipin system was a distant second, with 1,677 ha. Port Bay, the Copano mainland, and the Mission River system all had significant amounts of estuarine marsh, where totals areas were 1,361 ha, 1.182 ha, and 1,170 ha, respectively (Fig. 27). Seagrass is most extensive in the Corpus Christi Bay/Estuary, followed closely by Redfish Bay, where total areas were 4,067 ha and 3,936 ha, respectively. Seagrasses are abundant in the Laguna Madre. Port Bay and Oso Creek also contain significant amounts of seagrass, with 606 ha and 402 ha, respectively. Estuarine scrub/shrub is a relatively minor component of emergent vegetated wetlands but contains a component of black mangrove that is found with increasing frequency throughout the Texas coast. Palustrine marshes are equally abundant on the Copano mainland and within the Mission River valley, where total areas were 1,256 ha and 1,236 ha, respectively. The Aransas River with 660 ha, Nueces River Delta with 647 ha, Live Oak Peninsula with 640 ha, and Port Bay containing 561 ha all had significant amounts of palustrine marsh (Fig. 27). The Nueces River Delta is the site of the largest number of tidal flats and algal mats in the study area, containing 1,221 ha. Oso Creek is a distant second, with 406 ha of tidal/algal flats. Palustrine forest and scrub/shrub habitat are relatively scarce, with the largest amount found in the Mission River valley with 269 ha, followed by the Copano mainland with 229 ha and the Aransas River with 146 ha.

Figure 24. Map showing boundaries of the different geographic areas investigated.

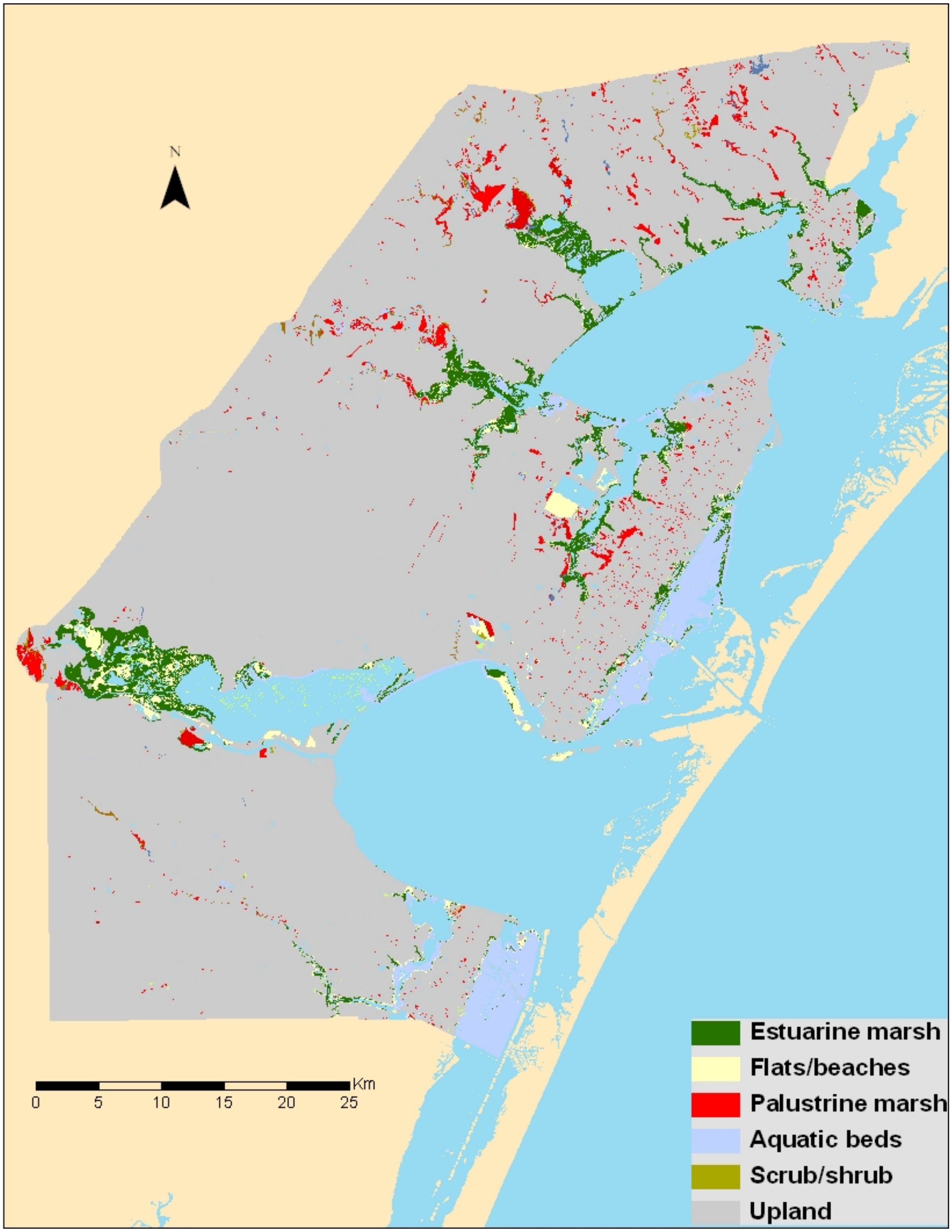

Figure 25. Map of major habitats in Corpus Christi Bay area in 2004.

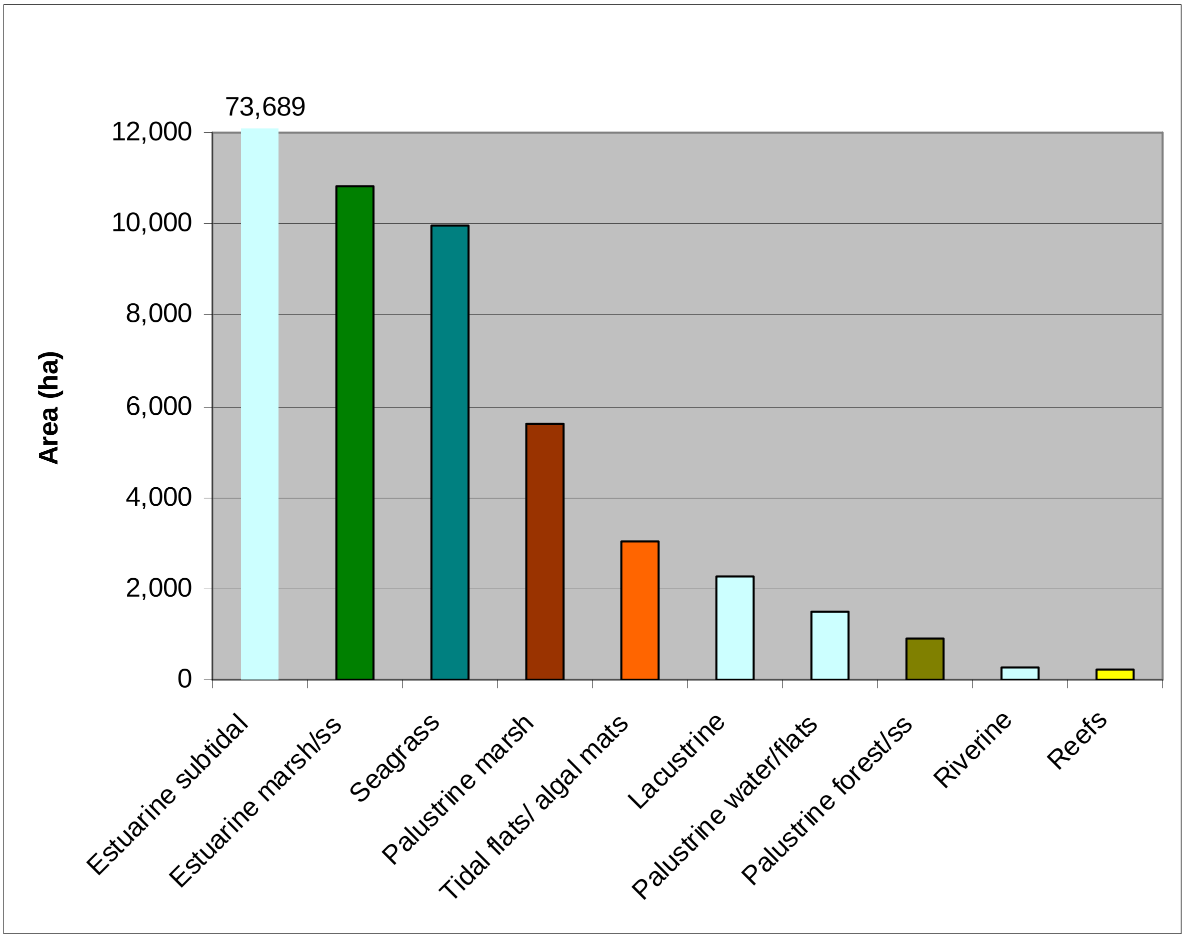

Figure 26. Areal extent of selected habitats in the study area in 2004.

Table 3. Areal extent of mapped wetland and aquatic habitats in 2004, excluding uplands.

NWI Code	National Wetlands Inventory Description	Hectares	Acres	Percent
E1AB3	Estuarine Subtidal Aquatic Bed, Rooted Vascular	9,975	24,638	9
E1AB5	Estuarine Subtidal Aquatic Bed, Unknown Submergent	377	931	0
E1AB6	Estuarine Subtidal Aquatic Bed, Unknown Surface	252	622	0
E1UB	Estuarine Subtidal Unconsolidated Bottom	73,060	180,458	68
E2AB1M	Estuarine Intertidal Aquatic Bed, Algal Irr. Exposed	136	336	0
E2AB1N	Estuarine Intertidal Aquatic Bed, Algal Reg. Flooded	475	1,174	0
E2AB1P	Estuarine Intertidal Aquatic Bed, Algal Irr. Flooded	215	532	0
E2EM1N	Estuarine Intertidal Emergent Wetland, Reg. Flooded	5,631	13,909	5
E2EM1P	Estuarine Intertidal Emergent Wetland, Irr. Flooded	5,164	12,755	5
E2RF2M	Estuarine Intertidal Reef, Irregularly Exposed	5	12	0
E2SS3	Estuarine Intertidal Scrub/Shrub	25	62	0
E2USM	Estuarine Intertidal Flat, Irregularly Exposed	107	264	0
E2USN	Estuarine Intertidal Flat, Regularly Flooded	801	1,979	1
E2USP	Estuarine Intertidal Flat, Irregularly Flooded	1,304	3,222	1
Subtotal		**97,528**	**240,894**	**90**
L1UB	Lacustrine Limnetic Unconsolidated Bottom	162	399	0
L2AB5	Lacustrine Littoral Aquatic Bed, Unknown Submergent	183	453	0
L2UB	Lacustrine Littoral Unconsolidated Bottom	998	2,466	1
L2USK	Lacustrine Littoral Flat, Artificially Flooded	911	2,249	1
Subtotal		**2,254**	**5,567**	**2**
PAB, K	Palustrine Aquatic Bed, Artificially Flooded	8	20	0
PAB4F	Palustrine Aquatic Bed, Floating Vascular	49	121	0
PAB5	Palustrine Aquatic Bed, Unknown Submergent	202	499	0
PEM1A	Palustrine Emergent Wetland, Temporarily Flooded	2,744	6,779	3
PEM1C	Palustrine Emergent Wetland, Seasonally Flooded	1,394	3,443	1
PEM1F	Palustrine Emergent Wetland, Semiperm. Flooded	644	1,592	1
PEM1K	Palustrine Emergent Wetland, Artificially Flooded	174	430	0
PEM1R	Palustrine Emergent Wetland, Seasonal-Tidal	367	906	0
PEM1S	Palustrine Emergent Wetland, Temporary-Tidal	268	662	0
PEM1T	Palustrine Emergent Wetland, Semipermanent-Tidal	38	94	0
PFO1A	Palustrine Forested, Temporarily Flooded	500	1,235	0
PSS1A	Palustrine Scrub/Shrub	386	953	0
PUB	Palustrine Unconsolidated Bottom	813	2,008	1
PUS	Palustrine Flat	428	1,057	0
Subtotal		**8,016**	**19,799**	**7**
R1UB	Riverine Tidal Unconsolidated Bottom	21	52	0
R2UB	Riverine Lower Perennial Unconsolidated Bottom	244	603	0
R4UB	Riverine Intermittent Unconsolidated Bottom	6	15	0
Subtotal		**271**	**669**	**0**
Total		**108,069**	**266,930**	**100**

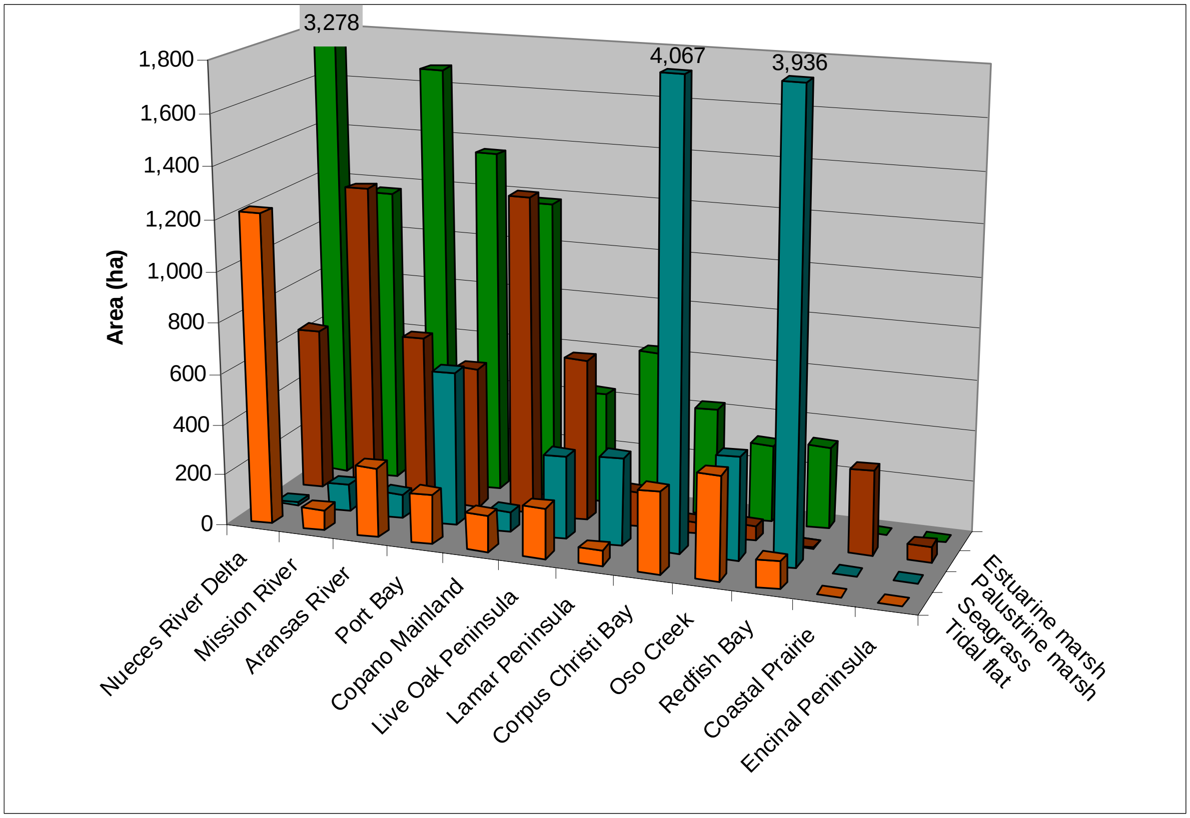

Figure 27. Distribution of selected habitats by geographic area in 2004. The most extensive distribution of estuarine marshes and tidal flats is on the Nueces River Delta.

Table 4. Areal extent (in hectares) of selected habitats by geographic area in 2004.

Location	*Tidal/algal flat*	*Estuarine marsh*	*Palustrine marsh*	*Seagrass*	**Total**
Nueces River Delta	1,221	3,278	647	9	**5,155**
Mission River	82	1,170	1,236	108	**2,596**
Aransas River	276	1,677	660	95	**2,708**
Port Bay	195	1,361	561	606	**2,723**
Copano mainland	141	1,182	1,256	79	**2,658**
Live Oak Peninsula	197	440	640	327	**1,604**
Lamar Peninsula	62	629	136	346	**1,173**
Corpus Christi Bay	315	425	44	4,067	**4,851**
Oso Creek	406	307	58	402	**1,173**
Redfish Bay	107	324	1	3,936	**4,368**
Coastal prairies	0	2	329	0	**331**
Encinal Peninsula	0	0	61	0	**61**

Estuarine System

Marshes (Estuarine Intertidal Emergent Wetlands)

The estuarine intertidal emergent wetland habitat (E2EM) in the study area consists of 10,821 ha of salt- and brackish-water marshes. This number includes 25 ha of estuarine scrub/shrub wetlands (E2SS). The low marsh, or regularly flooded estuarine marsh, is most abundant at 5,631 ha (Fig. 26; Table 3). The higher, irregularly flooded estuarine marsh covers about 5,164 ha. The most extensive estuarine marshes (Fig. 27) occur at the mouth of the Nueces River, where relatively broad areas of marsh have spread over the distal part of the delta. Other areas containing significant amounts of estuarine marsh are the (1) Aransas River Delta and Mud Flats; (2) Port Bay, including Swan Lake, Italian Bend, and McCampbell Slough; 3) the Copano mainland at Copano Creek and Mullens Bayou; and (4) the Mission River Delta. Lesser, but still significant, numbers of estuarine marshes are found in all geographic areas other than the coastal prairies.

Tidal Flats (Estuarine Intertidal Unconsolidated Shores and Aquatic Beds)

Estuarine intertidal unconsolidated shores (E2US) include wind-tidal flats and some algal flats (Fig. 14). Estuarine intertidal aquatic beds (E2AB) include well defined algal flats with distinct signatures on the aerial photographs. Approximately 3,040 ha of E2US/E2AB was mapped in the study area (Table 3). Tidal flats are most extensive on the Nueces River delta, followed by the bayhead of Oso Bay, and spoil islands in Corpus Christi Bay. (Fig. 27; Table 4). High, irregularly flooded tidal flats are more extensive than low flats (Fig. 26). 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 22% of the intertidal wetland system (excluding subtidal habitats and the E1 map units). The mapped extent of the tidal flats can be substantially affected by tidal levels at the time aerial photographs were taken (Fig. 15). Accordingly, absolute areal extent of flats may vary from that determined using aerial photographs.

Scrub/Shrub (Estuarine Intertidal Scrub/Shrub)

Estuarine scrub/shrub wetlands (E2SS) have a total area of 25 ha , a negligible amount of the estuarine intertidal vegetated classes. It should be noted that scattered mangrove shrubs are rare but are found in increasing numbers in many estuarine marshes, particularly on the barrier islands bordering Corpus Christ Bay. Mangroves were not mapped separately. This habitat has its broadest distribution in Redfish Bay, where *Avicennia germinans* is found at a few locations. Sherrod and McMillan (1981) noted that mangroves in this Coastal Bend area are one of the three major concentrations along the Texas coast and are typically mixed with *Spartina, Batis,* and *Salicornia*.

Seagrass Beds (Estuarine Subtidal Aquatic Beds)

Estuarine subtidal rooted vascular aquatic beds (E1AB3L) represent areas of submerged vascular vegetation, or seagrasses (Fig. 16). Accurate delineation of seagrasses on aerial photographs depends 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 2004 imagery but are obscured by turbidities in some areas and could not be mapped in total. Densities of mapped seagrass ranged from very dense to patchy. Seagrass beds throughout the study area covered 9,950 ha in 2004 and are the second-most-extensive habitat (excluding open water). The largest distribution of seagrasses is in Redfish Bay and in the Laguna Madre part of the Corpus Christi Bay and estuary system (Figs. 29); the areal extent of seagrasses are similar in these bays, accounting for 40% and 41% of this habitat, respectively. Half of the remaining resource is in Port and Oso Bays. For additional data on Coastal Bend seagrass, see Pulich et al. (1997),.

Open Water (Estuarine Subtidal Unconsolidated Bottom)

Estuarine subtidal unconsolidated bottom (E1UBL), or open water, consists primarily of Corpus Christi, Nueces, Copano, and Aransas Bays, the northern tip of upper Laguna Madre, and associated secondary bays and tidal lakes (Fig. 24). The total area of estuarine open water, including subtidal algae and subtidal unknown bottom mapped in the study area, is 73,689 ha, roughly 68% of the wetland and aquatic habitat system (Table 3).

Oyster Reefs (Estuarine Reefs)

Oyster reefs (E1RF2L and E2RF2M) mapped on the 2004 photographs amounted to 238 ha. Only those reefs that were very near the water’s surface and were clearly visible on the NAIP imagery were mapped; thus, many were not mapped. In Nueces Bay mapping was supplemented using data gathered through a contemporaneous NOAA benthic mapping study (NOAA, 2007).

Palustrine System

Marshes (Palustrine Emergent Wetlands)

Palustrine emergent wetlands (PEM) (Fig. 24), or inland “freshwater marshes,” cover 5,630 ha (Fig. 26) and represent 33% of emergent vegetated wetlands and 52% of the marsh (emergent wetland) system in the study area. Broadest distributions of palustrine emergent wetlands are on the Copano mainland and in the Mission River valley (Figs. 25, 27). In these areas marshes occupy the upper reaches and drainages of rivers, creeks, and bayous (Fig. 4). Flowing artesian wells and oxbow lakes on Fennessey Ranch and Packer Flats provide suitable habitat for large areas of marsh. Palustrine marshes were classified into one of three water regimes:

(1) temporarily flooded, (2) seasonally flooded, or (3) semipermanently flooded. Most extensive marshes were those that are temporarily flooded. Palustrine marshes on the Copano mainland and in the Mission River valley each account for almost 22% of this habitat; the Nueces River Delta and Aransas River, both about 12%; Live Oak Peninsula at 11%; and Port Bay at 10%.

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

Palustrine scrub/shrub and forested wetlands compose 885 ha, or about 5% of the vegetated wetland system (Fig. 22). Forested wetlands are most extensive in the Mission River valley and on the Copano mainland, where 269 ha (30%) and 229 ha (26%) were mapped, respectively. The Aransas River contains 146 ha (17%) of forested wetlands. Most areas of scrub/shrub and forest occur along rivers, bayous, and creeks; on the margins of reservoirs; and in small depressions.

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

Palustrine unconsolidated bottom (PUB), or open water, generally consists of small, fresh- to brackish-water ponds, and palustrine unconsolidated shore consists of small unvegetated flats. The total mapped area of these habitats together is 1,499 ha, approximately 1,072 ha of water and 428 ha of flats. The largest area of palustrine water habitat is on the coastal prairies, where 238 ha was mapped.

Lacustrine System

Open Water and Flats (Lacustrine Unconsolidated Bottom, Unconsolidated Shore, and Aquatic Bed)

Lakes and reservoirs represent the lacustrine unconsolidated bottom, unconsolidated shore, and algal beds (L2UB, L2US, and L2AB). All components were mapped as littoral, generally shallower than 6 ft. (1.8 m) depth (Fig. 11). The total area of this habitat in the study area is 2,092 ha. Almost 42% of this habitat occurs in Port Bay, the site of industrial settling ponds (Fig. 25 and Table 4).

HISTORICAL TRENDS IN WETLAND HABITATS

Methods Used to Analyze Trends

Trends in wetland habitats were determined by analyzing habitat distribution as mapped on 2004, 1979, and 1950's aerial photographs (Fig. 28). In analyzing trends, wetland classes (for example, E2EM and PEM) were emphasized, 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-ArcGIS was used to analyze trends. This software allowed for direct comparison, not only between years, but also by each geographic area. 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 ArcMap.

Possible Photointerpretation Errors

As mentioned previously, existing maps prepared from photointerpretation as part of the USFWS-NWI program and associated special projects were used to determine trends. Among the shortcomings of the photointerpretation process is that different photo-interpreters were involved for different time periods, and interpretation of wetland areas can vary somewhat among interpreters. As a result, some changes in the distribution of wetlands from one period to the next may not be real but, rather, relicts of the interpretation process. Inconsistencies in interpretation seem to have occurred most frequently in high marsh to transitional areas where uplands and wetlands intergrade.

Some apparent wetland changes were due to different scales of aerial photographs. The 1950's aerial photographs were at a scale (1:24,000) larger than that of 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 in the Corpus Christi Bay area, but much of this change we think is due to drier conditions when the 2004 photographs were taken.

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

Wetland Codes

Some wetland codes used on 2004 maps are different from those used on the 1950's and 1979 maps (Fig. 12). In the following discussion of trends, E2US rather than E2FL (used on the 1950's and 1979 maps) is generally used to denote tidal flats, and UB (rather than OW) is used to represent open water.

Wetland Trends and Probable Causes, 1950's through 2004

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 2004 within the study area, some wetland classes underwent substantial net losses and gains, whereas others remained more stable (Table 5; Figs. 28 and 29).

Table 5. Total area (ha) of major habitats in the 1950's, 1979, and 2004 in study area.

Habitat	*1950's*	*1979*	*2004*
Estuarine marsh/ss	8,856	11,749	10,821
Seagrass	7,611	7,905	9,950
Palustrine marsh	8,489	7,120	5,630
Tidal flats/algal mat	9,591	4,672	3,040
Lacustrine	383	1,762	2,254
Palustrine water/flat	957	1,239	1,499
Palustrine forest/ss	683	1,360	885

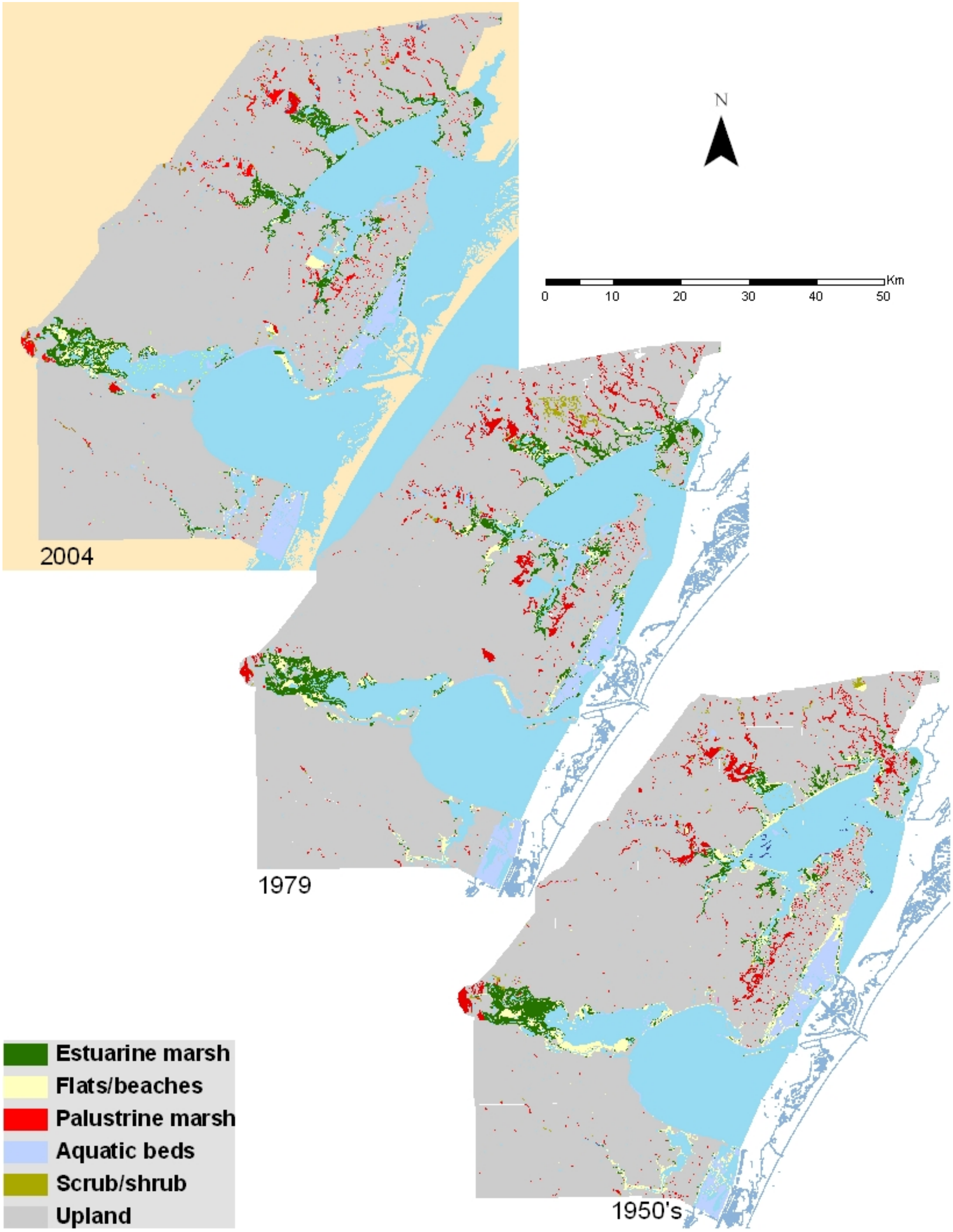

Figure 28. Map showing distribution of major wetland and aquatic habitats in 2004, 1979, and 1950's in study area.

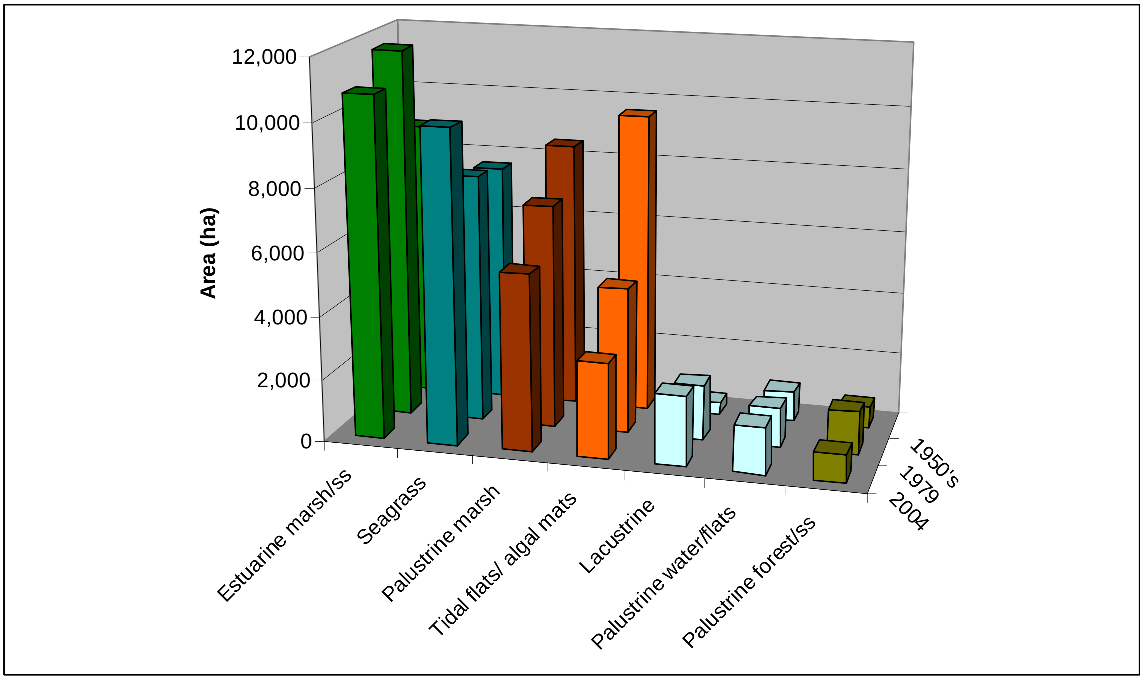

Figure 29. Areal distribution of major habitats in the study area in the 1950's, 1979, and 2004.

In general, estuarine marshes, combined with scrub/shrub, increased in total area during 1950's through 1979 and decreased in total area during 1979 through 2004, with a total net gain of 1,956 ha (4,831 acres) from the 1950's through 2004. The average rate of marsh gain during the earlier period was about 126 ha/yr (311 acres/yr) and for the more recent period, a loss of about 38 ha/yr (94 acres/yr). Overall rate of change between the 1950's and 2004 was a gain of about 41 ha/yr (101 acres/yr). Seagrasses increased in total area during each period (1950's–1979 and 1979–2004), with a total net gain of 2,339 ha (5,777 acres) from the 1950's through 2004. Approximately 87% of this gain occurred from 1979 through 2004, indicating that the rate of gain increased from 1979 through 2004. Average rate of seagrass gain during the earlier period was about 13 ha/yr (32 acres/yr) and for the more recent period, about 82 ha/yr (202 acres/yr). Overall rate of seagrass change between the 1950's and 2004 was a gain of about 49 ha/yr (120 acres/yr).

The most extensive losses in habitats occurred in tidal flats, which underwent a major net decline from the 1950's through 1979 (Fig. 29). Total area of tidal flats decreased by 4,919 ha (12,150 acres) during this period (1950's–1979). During the later period (1979–2004), total area of tidal flats decreased an additional 1,632 ha (4,031 acres). Average rate of tidal-flat loss during the earlier period was about 214 ha/yr (419 acres/yr), and for the more recent period, a loss of about 65 ha/yr (161 acres/yr). Palustrine marsh had its largest distribution in the 1950's, at 8,489 ha (20,968 acres), and lowest in the 2004, at 5,630 ha (13,906 acres) (Table 5). Average rate of palustrine marsh loss between both time periods was about 60 ha/yr (147 acres/yr). Conversely, palustrine open water and flats experienced a relatively consistent rate increase through time. Average rate of palustrine water and flats gain during the earlier period was about 12 ha/yr (30 acres/yr), and for the more recent period, a gain of about 10 ha/yr (26 acres/yr). Finally, there was a net increase in the mapped area of lacustrine habitats, increasing in total area by 1,379 ha (3,406 acres) from the 1950's through 1979, and by 492 ha (1,215 acres) from 1979 through 2004, a net change of almost +489% since the 1950's.

Analysis of Wetland Trends by Geographic Area

As in previous sections, the study area was subdivided into major natural areas and geographic components for analysis of historical trends (Fig. 27). The Corpus Christi Bay area is presented from northeast to southwest in the following order: (1) Copano mainland, (2) Lamar Peninsula, (3) Mission River valley, (4) Aransas River, (5) Live Oak Peninsula, (6) coastal prairies, (7) Port Bay, (8) Redfish Bay, (9) Nueces River Delta, (10) Corpus Christi Bay and Estuary, (11) Oso Bay, and (12) Encinal Peninsula. The subdivision allowed a more site-specific analysis of trends and their probable causes. Estuarine marshes, seagrass beds, palustrine marshes, and tidal flats are emphasized.

Copano Mainland

The coastal plain system encompasses mainland areas inland from Corpus Christi Bay and Copano Bay (Fig. 31). Most of the area is characterized by cropland and rangeland. In addition to broad, flat, coastal prairies, however, it includes small, entrenched, intertidal to supratidal valleys, creeks, and bayous along the northern and western shore of Copano Bay.

General Trends. The most significant wetland trend on the Copano mainland was the long-term loss of palustrine marsh. The overall marsh total (1950's–2004) experienced a 29% loss because the area of marshes decreased from 1,769 ha in the mid-1950's to 1,256 ha by 2004. In 1979 the quantity of palustrine marsh was highest at 2,054 ha. Estuarine marshes on the Copano mainland experienced a net gain through time. Through the overall time interval, estuarine marshes experienced a 14% increase, when 1,041 ha in the mid-1950's increased to 1,182 ha by 2004 (Fig. 30). Like the palustrine marshes, the 1979 estuarine marsh area was most extensive, with a total of 1,747 ha. Palustrine forest and scrub/shrub habitat remained consistent throughout the study time period, with 223 ha mapped in the 1950's and 229 ha mapped in 2004. Again, the largest amount of palustrine forest and scrub/shrub was mapped in 1979. Large tracts of rangeland in the Mission Bay and Lamar quadrangles between Copano Creek and the Mission River were mismapped as palustrine scrub/shrub in 1979 (Fig. 32). Tidal flats, the remaining dominant habitat type on the Copano mainland, was overmapped in the 1950's when a strip of subtidal bay sand was misinterpreted as a flat. This misclassification may have been partly due to low tides. The 1950's total of 613 ha was reduced to 237 ha by 1979, finally reaching a low of 141 ha in 2004. When adjusted to correct for the misinterpreted bay margin, the long-term (1950's–2004) tidal flat loss is roughly 22%.

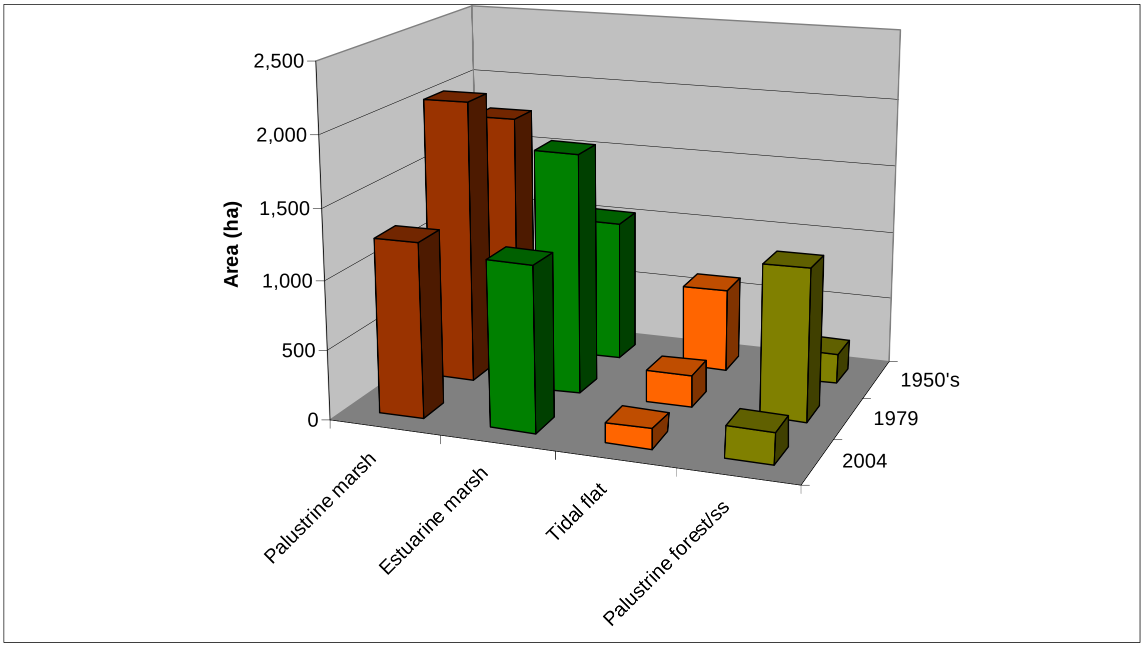

Figure 30. Areal extent of major habitats on the Copano mainland in the 1950's, 1979, and 2004.

Probable Causes of Trends. Interpretational differences between time periods results in varied amounts of marsh. Although there were many gross gains of palustrine marsh, the overall trend was characterized by a reduction of marsh through conversion to uplands. High marshes and prairie grasslands have developed in these transitional areas, and distinction and classification depend on the amount of moisture at the time of the photography. Wetlands mapped in 1979 are generally more extensive than other time periods because of a high amount of precipitation that year. Wetlands in all time periods are also affected by drainage ditches constructed before the 1950's to reduce flooding and ponding of water (Fig. 32). Conversion of marsh to uplands may have been the result of long-term drought that has persisted in Texas through much of the past decade. Most estuarine marsh gain occurred where flats in secondary bays along Copano Bay were converted to marsh. Relative sea-level rise has allowed other habitats to move into previous tidal-flat areas. The upper reaches of Copano Creek also experienced expansion of estuarine marsh into previous palustrine marsh and upland areas. The area between Copano Creek and the Mission River in Mission Bay and Lamar quadrangles has numerous relict, subtle entrenchments that slope toward Copano Bay (Fig. 32). Several of these topographically lower features were interpreted in 1979 to contain palustrine scrub/shrub, although dense scrub/shrub is not apparent on 1979 NASA photography. Most of the real loss of tidal flats was due to the spread of emergent vegetation in secondary bays at Mullens Bayou and the adjacent mouth of Mission Bay and at the mouth of Copano Creek. Marsh-spread into flats had progressed significantly by 1979 and continued through 2004.

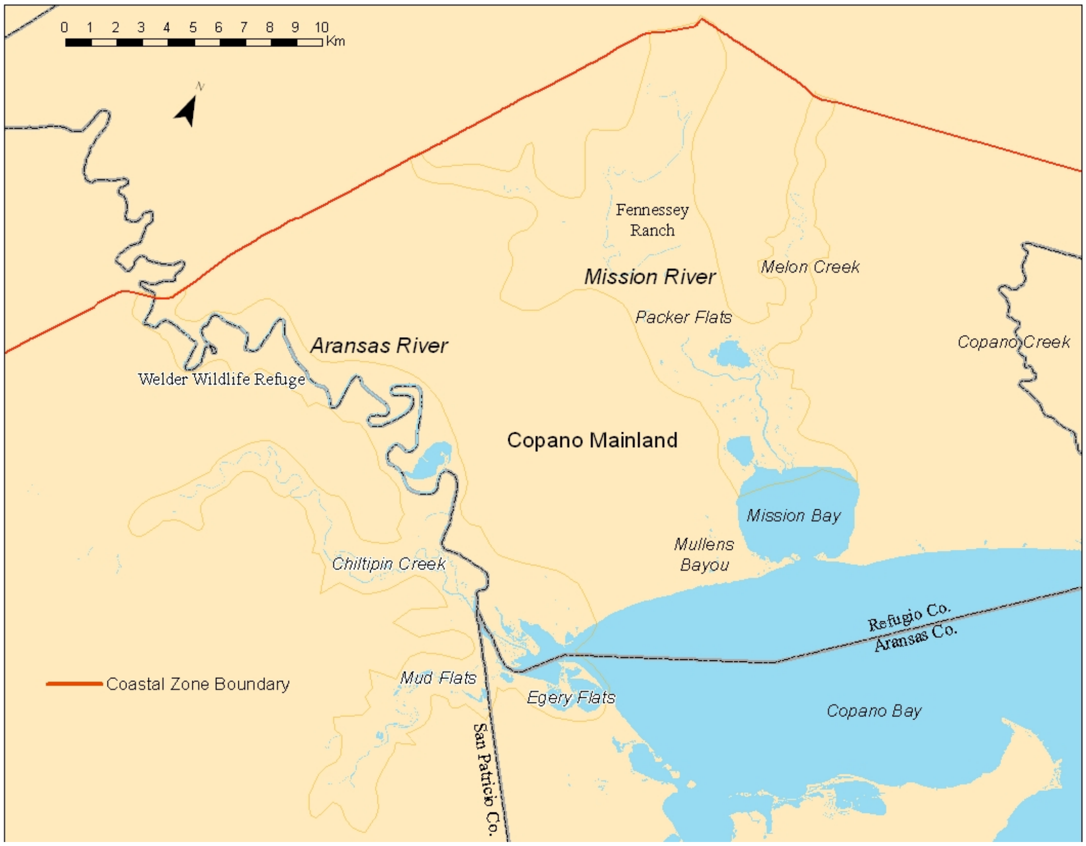

Figure 31. Locator map showing place names and geographic features in north part of study area.

Figure 32. Drainage ditches in marshes in the Lamar quadrangle. Photo October 1952.

Lamar Peninsula

Lamar Peninsula is located on a Pleistocene strandplain that consists of a series of sand ridges characterized by a network of pothole wetlands and live oak mottes.

General Trends. The most significant wetland trend on Lamar Peninsula has been the long-term loss of palustrine marsh. The overall marsh total (1950’s–2004) experienced a 77% loss as the area of marshes decreased from 583 ha in the mid-1950’s to 136 ha by 2004. In 1979 the quantity of palustrine marsh was lowest of the three time periods at 88 ha. Wide-ranging quantities of palustrine marsh reported in individual time periods can be attributed to interpretational differences (Fig. 33). From a total area of 391 ha of tidal flat mapped on 1950’s photographs, only 182 remained in 1979, a loss of 209 ha, or about 54% of the 1950’s resource. Loss of tidal flats continued with a net loss of 120 ha from 1979 through 2004, or an additional 66% loss. In contrast to the overall decline in tidal flats, total areas of seagrass beds and estuarine marshes increased from the 1950’s through 2004. From the 1950’s through 1979, seagrasses decreased by 100 ha, then increased 201 ha by 2004, primarily from their spread into areas previously mapped as tidal flats. Although losses and gains occurred in estuarine marsh throughout the peninsula, overall change was a net gain of 157 ha from the 1950’s through 2004. The large amount of estuarine marsh (1,266 ha) mapped in 1979 was mostly interpretational.

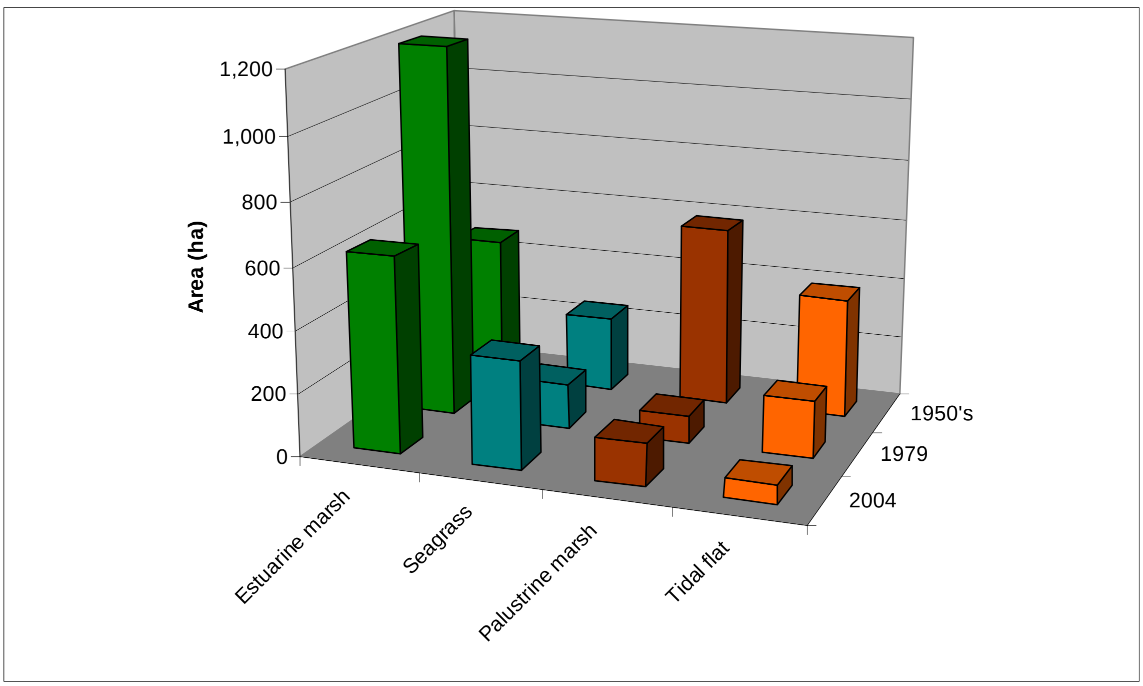

Figure 33. Areal extent of major habitats on Lamar Peninsula in the 1950’s, 1979, and 2004.

Probable Causes of Trends. The long-term trend was characterized primarily by reduction of palustrine marsh through conversion to uplands. This phenomenon occurs along a topographically low transitional area that connected St. Charles Bay and the secondary bay at the mouth of Copano Creek (Fig. 34). In the 1950's and 1979, this area, characterized by *S. spartinae*, was mapped as marsh. Some marsh conversion to uplands was the result of residential/commercial development. But most change was interpretational. The low amount of palustrine marsh in 1979 is an interpretational artifact, where transitional areas were mapped as estuarine marsh in the 1950's. There is little evidence that vegetation composition and tidal communication have been different since the 1950's. However, by 2004 the long-term drought experienced throughout the Texas coast had altered the moisture regime significantly. Ground conditions during 2004 photography justified classifying this transitional area as upland**.** White et al. (1998) noted that shrubs, such as *Iva frutescens*, had become more common locally (Fig. 35). A similar area just southwest has been further altered by community development.

Development north of Newcomb Point contributed to losses of estuarine marsh and flats (Fig. 36). Housing development altered the flats, converting some areas to uplands for houses and roads and some to boat channels. Gain of estuarine marsh and loss of tidal flats in several of the small bays encompassing the peninsula since the 1950's can be explained largely by relative sea-level rise (Fig. 37). Most tidal-flat loss was due to the spread of low estuarine marsh (E2EM1N) and, to a lesser degree, by open water and seagrass. Conversion occurred as topographically low flats became submerged and slightly higher flats became more frequently flooded, contributing to a spread of marsh vegetation. Higher marshes also expanded into adjacent uplands in some instances. Much of the long-term increase in seagrasses from the 1950's through 2004 occurred through expansion into the open waters of St. Charles Bay. The low amount of seagrass mapped in 1979 may have been due to turbidity in the bay.

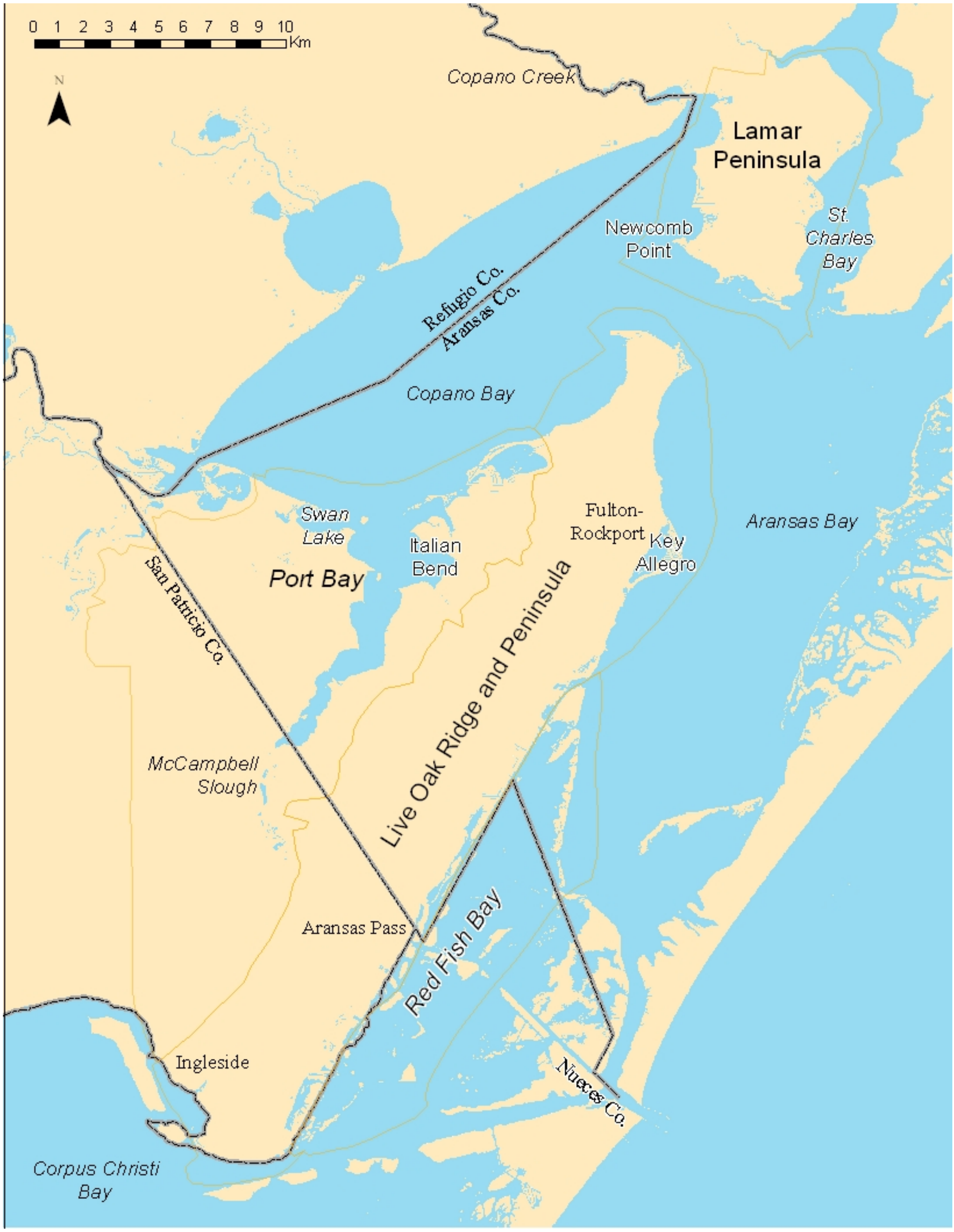

Figure 34. Locator map showing place names and geographic features in the central part of study area.

Figure 35. Transitional area on Lamar Peninsula between St. Charles Bay and the NE corner of Copano Bay. *Spartina spartinae* interspersed with *Andropogon*.

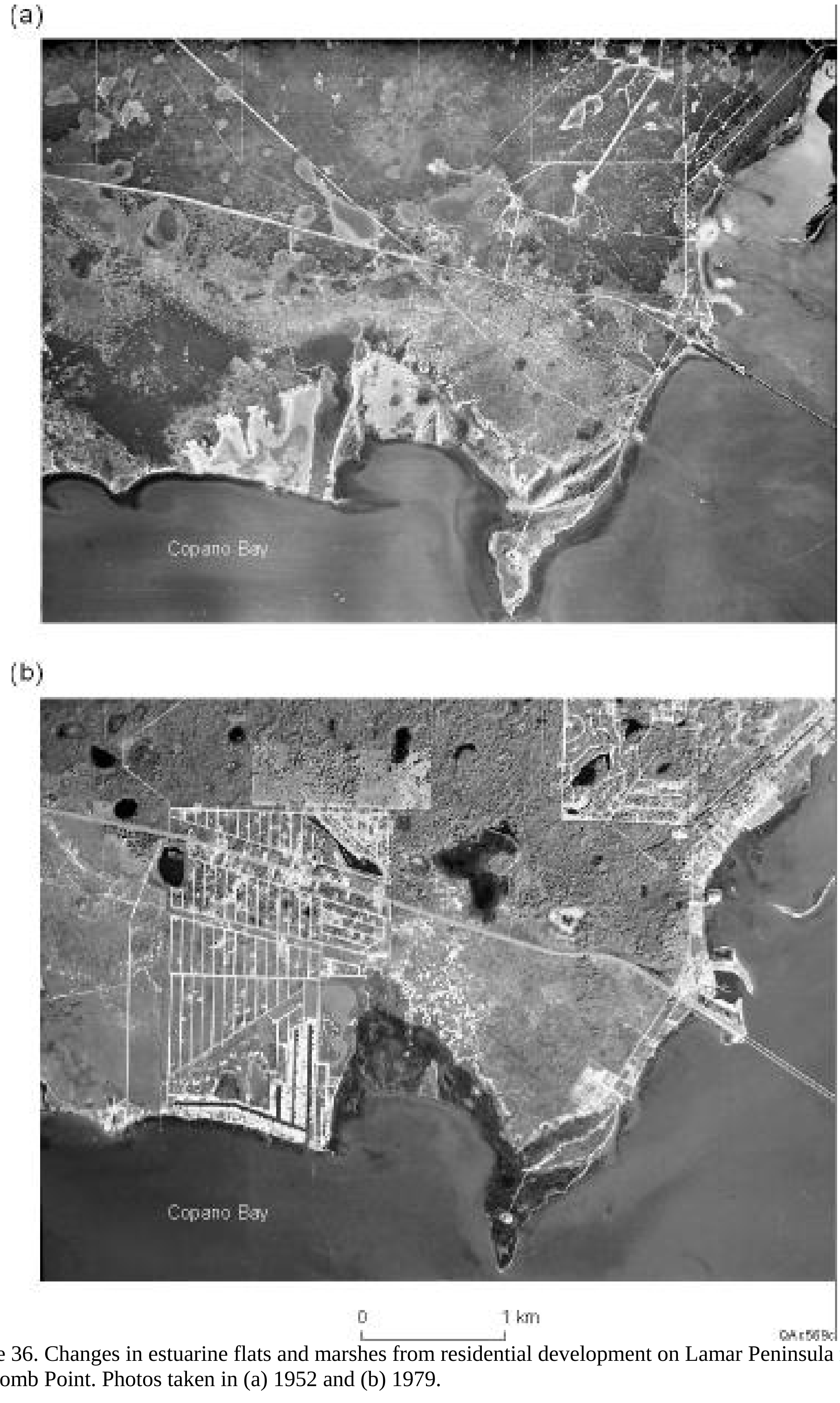

Figure 36. Changes in estuarine flats and marshes from residential development on Lamar Peninsula near Newcomb Point. Photos taken in (a) 1952 and (b) 1979.

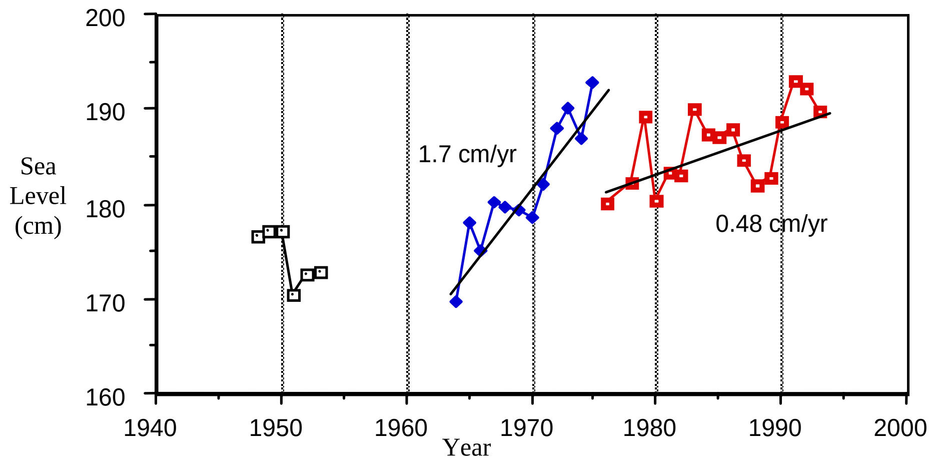

Figure 37. Sea-level rise at the Rockport tide gauge located near the landward margin of Aransas Bay. Tide data from NOAA.

Mission River Valley

The Mission River is one of the fluvial-deltaic systems that lies within valleys entrenched during the most recent Pleistocene sea-level lowstand (Brown et al. 1976). Riparian woodlands consist of forested and scrub/shrub wetlands, as well as other forested areas that are within entrenched river valleys.

General Trends. The most significant trend in the Mission River valley was the gain of estuarine marsh. A large increase of area between the mid-1950's total of 573 ha and 1979 total of 976 ha represents a 70% gain of the resource (Fig. 38). Estuarine marshes continued to increase from 1979 through 2004 to a total of 1,170 ha, an additional 20% increase. Tidal-flat area remained constant between the 1950's and 1979, with a small increase of 6 ha. During the later time period, flats decreased in area from the 1979 total of 308 ha to 82 ha in 2004, representing a 73% decrease. Palustrine marsh experienced a systematic decrease in area through time. In the mid-1950's, palustrine marsh occupied 1,726 ha, 1,428 ha by 1979, and was reduced in area to 1,236 ha by 2004. Consistent decreases of 17% and 14% led to an overall loss of 28% of the resource across the study time period. Like the estuarine marsh habitat, palustrine forest and scrub/shrub habitats experienced a systematic increase through time, although in much smaller numbers. The largest increase occurred in the initial time period when 171 ha of forest/scrub/shrub in the 1950's grew to 249 ha in 1979, a 46% increase. The later addition of 20 ha represented an additional 8% increase by 2004.

Probable Causes of Trends. Wetland habitat changes during the mid-1950's through 1979 were partly due to the conversion of palustrine marsh to estuarine marsh at the confluence of the Mission River and Melon Creek (Fig. 31). Estuarine marsh was mapped up the river valley in 1979 farther than was mapped in the 1950's. Conversion of palustrine marsh to estuarine marsh accounted for roughly 49% of the gross gain in estuarine marsh during this time period. Movement of the estuarine/palustrine boundary farther upriver in 2004 reflects landward migration of the saltwater wedge. Gross increases in estuarine marsh were also shown in flats (+28%) and uplands (+18%).

Tidal flats lost nearly two-thirds of the original amount between 1979 and 2004, after a slight increase in the early time period. In analyzing trends, more than 71% of the flat loss can be attributed to spreading of estuarine marsh, most of which was low, or regularly flooded, marsh (E2EM1N). Flats were also lost when seagrasses became established in shallow ponds on the Mission River delta (Fig. 39). Loss of flats to marsh may be partly due to sea-level rise, contributing to more frequent inundation of flats and subsequent expansion of emergent vegetation.

Palustrine marsh experienced gross gains and losses through time, resulting in a net decrease of the resource. Placement of the estuarine/palustrine interface within the river valley, as discussed earlier, contributed to the gross loss of palustrine marsh over time. A large oxbow lake on Fennessey Ranch was mapped as lacustrine littoral aquatic beds (L2AB) in the 1950's and 1979 but mapped as semipermanently flooded, palustrine marsh in 2004, contributing to the gross increase in palustrine marsh (Fig. 40). The dominant marsh species encountered during field verification was *Schoenoplectus californicus*. The unusual photo signature on the November 2004 imagery may have been caused by floating vegetation, i.e., lily pads. Riparian woodland (palustrine forest and scrub/shrub) in the entrenched Mission River fluvial-deltaic system increased in area systematically through time. Forests, and to a lesser degree scrub/shrub, in the palustrine system are difficult to distinguish from those in the upland system and are therefore subject to interpretational differences. Woodlands most likely changed little overall, with gains exceeding losses.

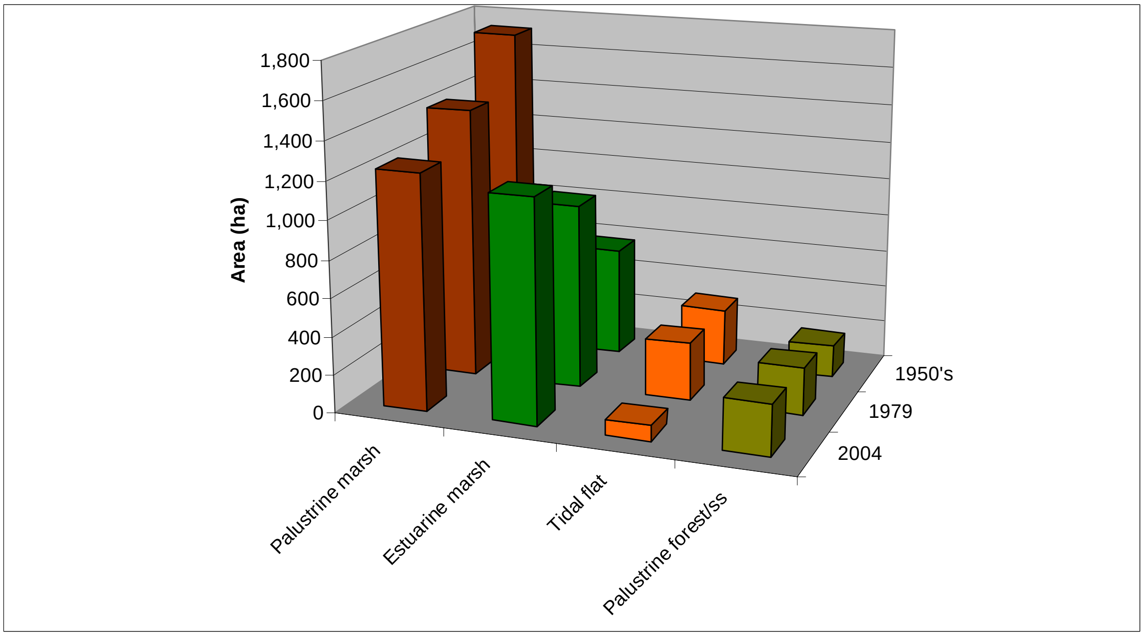

Figure 38. Areal extent of major habitats in the Mission River valley in the 1950's, 1979, and 2004.

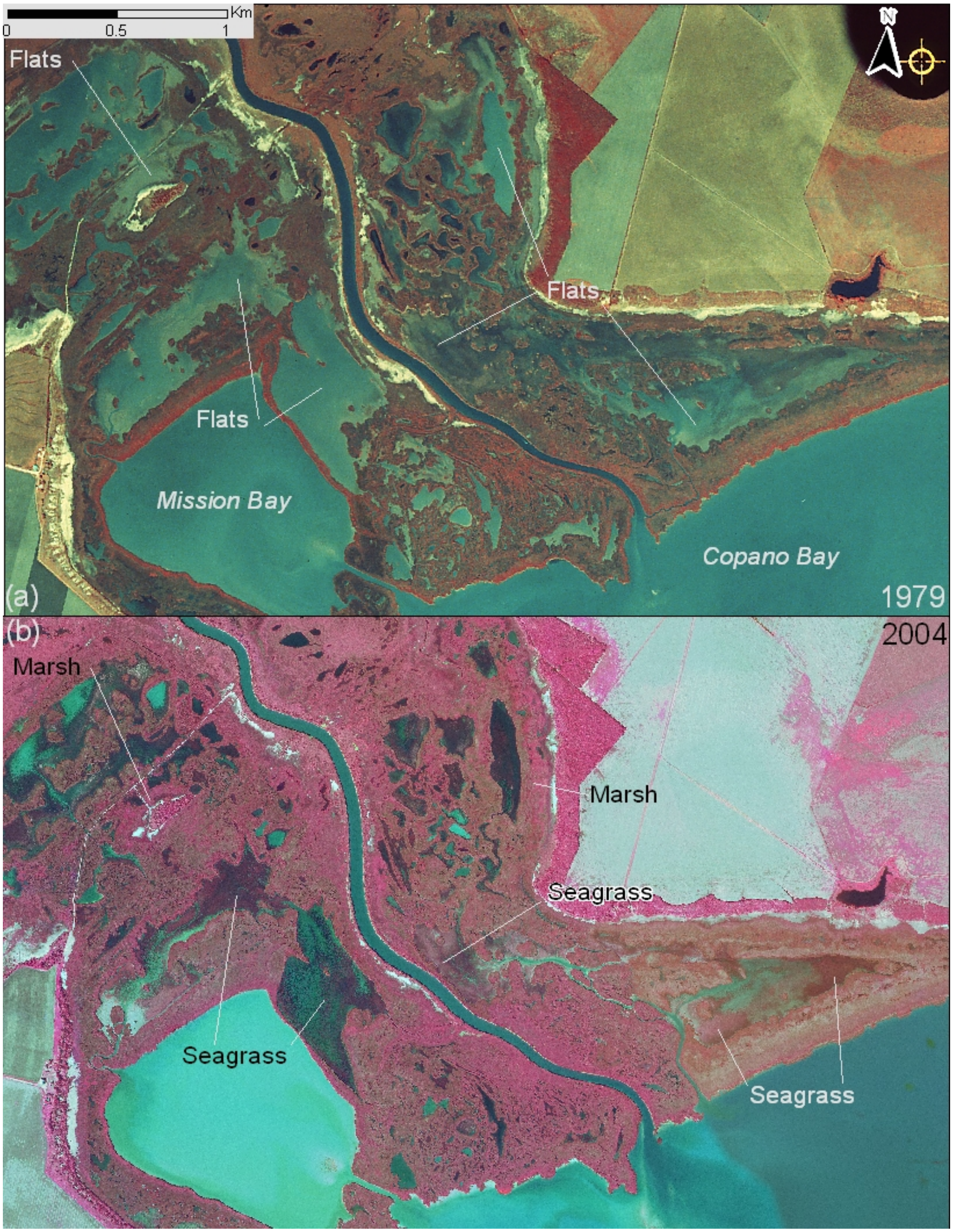

Figure 39. Shallow ponds on the Mission River Delta previously mapped as E2FLN and E2FLM, mapped as marsh and seagrass beds in 2004.

Figure 40. McGuill Lake on Fennessey Ranch. Previously mapped as lacustrine aquatic bed, mapped as semipermanently flooded palustrine marsh and open water in 2004.

Aransas River

General Trends. In the Aransas River–Chiltipin Creek fluvial-deltaic area, the most significant change was a systematic increase in estuarine marsh since the 1950's. The 748 ha of marsh mapped in the1950's increased to 1,186 ha by 1979, a 59% gain. By 2004 estuarine marsh had gained an additional 41%, totaling 1,677 ha (Fig. 41). This change, from the 1950's through 2004, amounted to a net gain of estuarine marsh of over 124% in the Aransas River area since the 1950's. Tidal flats also experienced a systematic loss through time. The 1950's corrected total of 673 ha changed little by 1979, when 661 ha was mapped. Although gross gains and losses of flat occurred in the early time period, much of the loss was due to an interpretational error at the bay margin. By 2004, tidal flats occupied only 276 ha, a significant 58% loss of the 1979 tidal flat total. Palustrine marsh experienced a significant loss (–45%) between the 1950's and 1979, when 1,068 ha was reduced to 587 ha. By 2004, palustrine marsh area had recovered slightly to 660 ha . In contrast to the decline in palustrine marsh were major increases in open water and seagrasses. Combined totals of seagrasses and open water increased from 701 ha in the 1950's to 930 ha by 1979 and 1,022 ha by 2004, an overall increase of 46%. Palustrine forest and scrub/shrub increased systematically within the fluvial-deltaic system through time. Only 24 ha was mapped in the 1950's, increasing to 94 ha in 1979 and 146 ha by 2004. Although gains and losses of palustrine forest and scrub/shrub are due mostly to photointerpretation, woodlands are thought to have had more gains than losses through time.

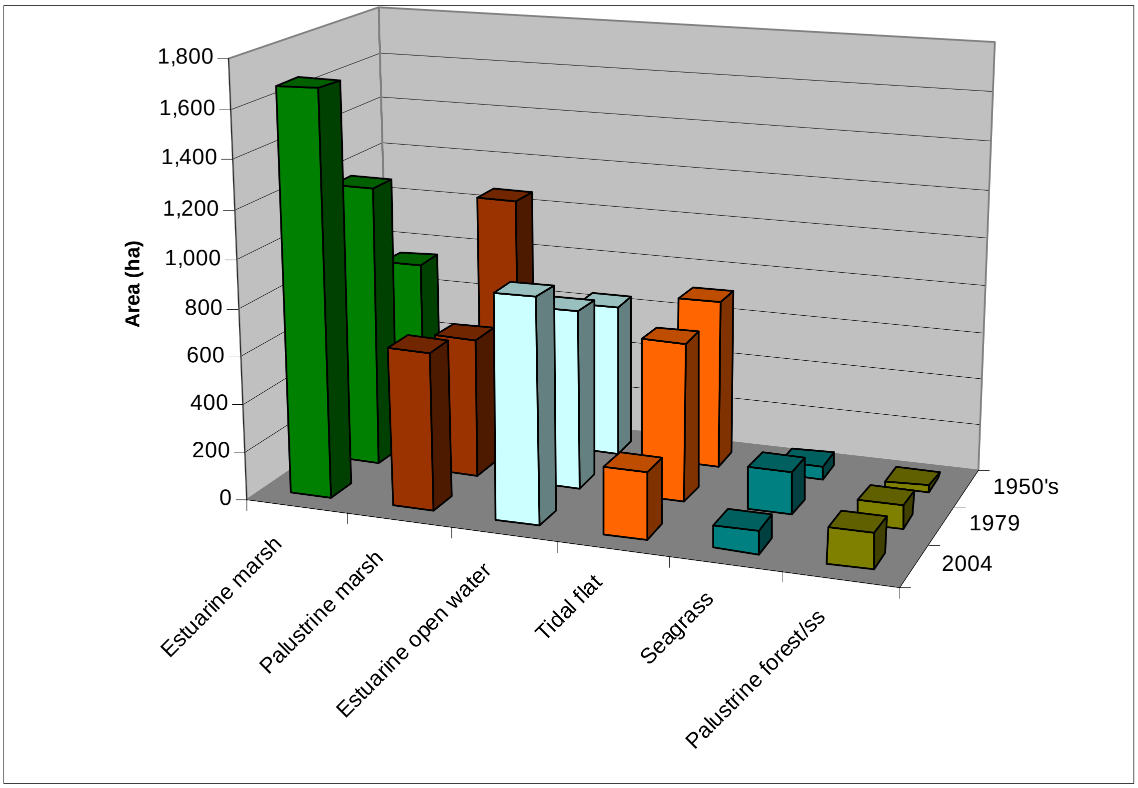

Figure 41. Areal extent of major habitats in the Aransas River area in the 1950's, 1979, and 2004.

Probable Cause of Trends. Wetland habitat changes during the mid-1950's through 1979 were partly due to conversion of palustrine marsh to estuarine marsh at the confluence of the Aransas River and Chiltipin Creek (Fig. 31). Estuarine marsh was mapped up the river valley in 1979 farther than was mapped in the 1950's. Conversion of palustrine marsh to estuarine marsh accounted for roughly 33% of the gross gain in estuarine marsh during this time period. Movement of the estuarine/palustrine boundary farther upriver in 2004 reflects migration of the saltwater wedge farther upriver. In the later time period, estuarine marsh continued to spread into flats and uplands at the mouth of Chiltipin Creek and into flats and open water at Mud Flats. Uplands and tidal flats accounted for 26% and 24%, respectively, of gross marsh gain between the 1950's and 2004. Tidal flats lost most area during 1950's through 2004. Roughly 41% of tidal-flat loss was to estuarine marsh, 36% of which was lower, or regularly flooded marsh (E2EM1N). Palustrine marsh lost acreage in the early time period when the freshwater-saltwater boundary shifted landward. Most palustrine marsh loss (~48%) was located in areas that became estuarine marsh.

Egery Flats, just off Copano Bay, was mapped as seagrass in 1979 and unknown surface aquatic beds (E1AB6) in 2004 (Fig. 42). Combined with aquatic beds on the north side of the mouth of the Aransas River, E1AB6 accounted for 25% of the loss of tidal flats between the 1950's and 2004. As mentioned in the Copano mainland section, tidal flats were misinterpreted along the bay shoreline on the 1950's photography, resulting in an overestimate of tidal-flat area. After correction, open-water inundation and seagrass displacement accounted for ~ 26% of the loss of flats. Estuarine open water had flooded farther up Mud Flats and into the delta area of Chiltipin Creek by 1979. Open water had also inundated parts of the lower Aransas River Delta by 1979, where seagrass became established by 2004. Formation of shallow open-water areas and seagrass beds in former tidal-flat habitats is thought to be the result of relative sea-level rise in fluvial-deltaic systems of the Corpus Christi Bay area.

Figure 42. Floating algae at Egery Flats.

Live Oak Peninsula/Ridge

Live Oak Peninsula and Ridge are located on the Pleistocene strandplain. Because of the complex topography consisting of relict beach ridges, interridge swales, deflation troughs, and stabilized dunes, delineation between palustrine marshes and ponds and uplands is difficult.

General Trends. The most significant change in wetland habitats on the Live Oak Peninsula is the dramatic loss of tidal flats through time. For analysis purposes, the peninsula was partitioned, isolating the western shoreline from the remainder of the peninsula. Severe loss of tidal flats occurs in the adjacent Port Bay region of the peninsula, which is discussed elsewhere (Fig. 34). The 1950's total of 1,154 ha decreased significantly by 1979, when only 338 ha was mapped, representing a 71% loss. By 2004 only 188 ha of flats was mapped. Most tidal-flat loss occurred on the east margin of Live Oak Ridge landward of Redfish Bay. The long-term loss of flats, 1950's through 2004, was (–)83% of the original resource (Fig. 43). As is the case in many wetland areas along the Texas coast, tidal-flat loss was offset on Live Oak Peninsula by gains in estuarine marsh. An original area of 275 ha of estuarine marsh in the 1950's grew to a peak of 479 ha in 1979. By 2004 the amount of marsh had lowered slightly to 440 ha. Outside of the 8% decrease from the 1979 acreage, estuarine marsh increased overall by 60% between the 1950's and 2004. Palustrine open-water totals increased by 280% between the 1950's total of 91 ha and 1979, when open water totaled 346 ha. Much higher precipitation levels, discussed later, most likely accounted for the 1979 increase. Conversely, palustrine marsh exhibited a systematic loss through time. The 1950's total of 990 ha was reduced to 962 ha by 1979 and further reduced in 2004 to 640 ha. From the 1950's through 2004, palustrine marsh area was reduced in area by 35%. The 1950's total of 670 ha of seagrass experienced a steep decline (–49%) during the early time period owing to development of the Key Allegro community at Frandolig Island. Seagrasses established at different locations along the shoreline of the peninsula, after declining in area to 340 ha in1979, but overall acreage remained relatively constant, with a loss of 13 ha by 2004.

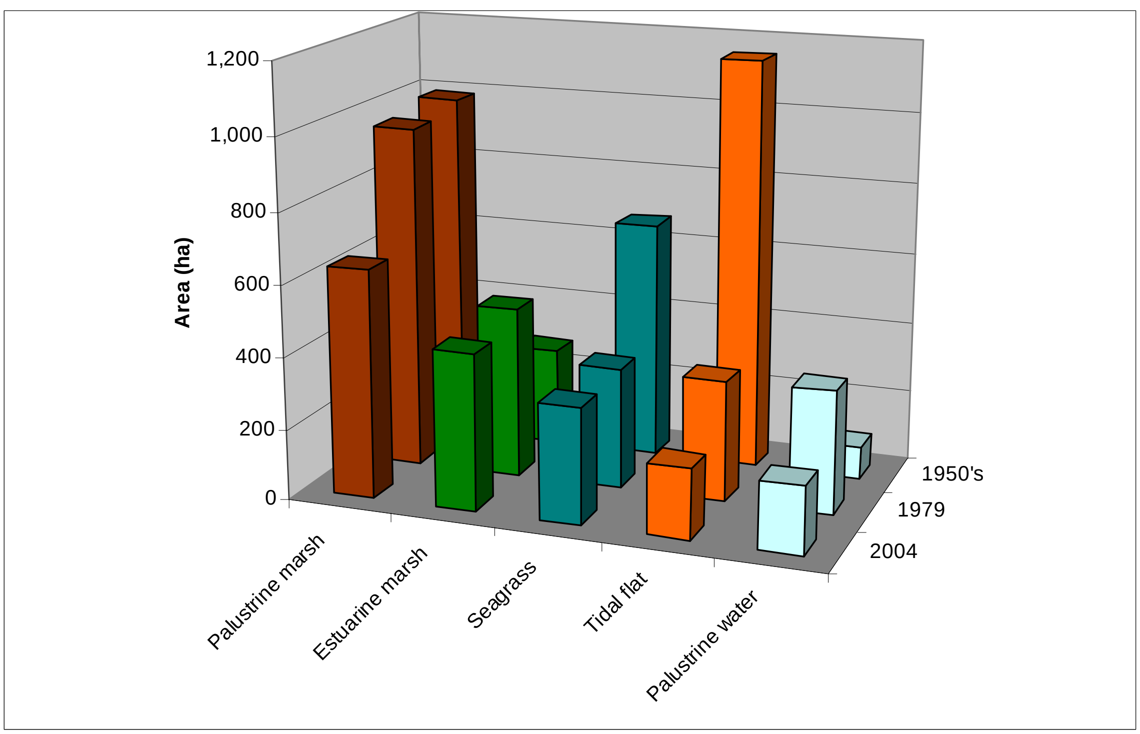

Figure 43. Areal extent of major habitats on Live Oak Peninsula in the 1950's, 1979, and 2004.

Probable Cause of Trends. Most tidal-flat loss occurred on the east margin of Live Oak Ridge landward of Redfish Bay. Industrial development along the GIWW had displaced many of the tidal flats along Redfish Bay by 1979. Development of Key Allegro on Frandolig Island had also displaced many flats by that time (Fig. 44). As much as 43% of the long-term loss of tidal flats was due to upland development. Alteration of flats through channelization along the GIWW contributed to a 31% gross loss of flats to open water. Channelization, in turn, allowed low marsh (E2EM1N) to move into former flat areas. Spread of emergent vegetation accounted for roughly 23% of long-term gross flat loss.

Gain of estuarine marsh was the predominant trend between the 1950's and 1979, when 61% of marsh gain occurred in previous flats. By 2004 some of the areas mapped as marsh in 1979, possibly because of wetter ground conditions at the time, had reverted back to upland. A transitional area to the south of Aransas Pass mapped as marsh in 1979 was under construction during field verification (Fig. 45). Large tracts of Live Oak Peninsula are transitional areas dominated by *Spartina spartinae*. These areas are frequently delineated into different wetland systems, depending on local climatic conditions and water levels when aerial photographs were taken. Topography of the Pleistocene sand ridge is unique, characterized by hundreds of potholes that have fluctuating seasonal and annual water regimes dependent upon precipitation. Many more pothole wetlands were mapped in the 1950's, whereas fewer, but larger, individual potholes were mapped in 1979. In a study of pothole wetlands on the strandplain, including Live Oak Peninsula, Collins (1987) reported that average rainfall in 1956 was almost 44 cm less than in 1979. Most palustrine marsh loss over the long term was due to drought conditions, which by 2004 had dried up many prairie potholes. On the local level, community development in places like Key Allegro and Aransas Pass contributes to gross losses of wetlands. In some instances, marsh was converted to open water when quarries were excavated for sand resources.

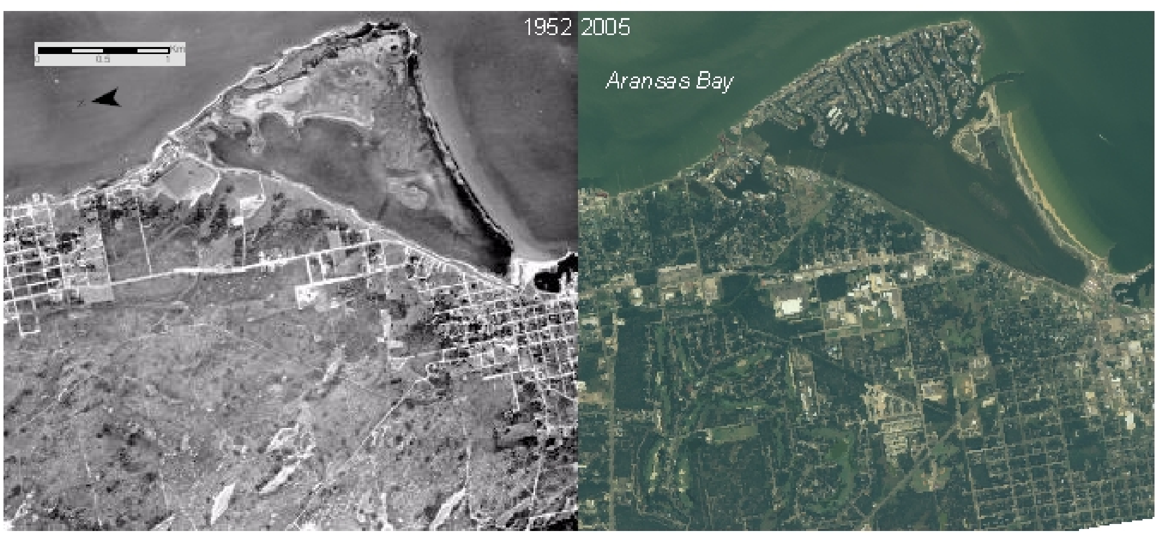

Figure 44. Urban development 1952–2005 contributed to the loss of seagrass, intertidal flats, and estuarine and palustrine marshes on Key Allegro, Live Oak Peninsula.

Figure 45. Construction site west of Aransas Pass municipal airport. The area is marsh (E2EM1P) on 1979 NASA photography.

Coastal Prairie

General Trends. The largest of the geographic areas, the coastal prairies, are two geographically distinct areas. The area north of Corpus Christi Bay comprises approximately 65,957 ha, and the area south of Corpus Christi Bay is approximately 57,731 ha. Figure 24 shows the extent and location of the geographic region in relation to other geographic regions. Uplands comprise most of the habitat classification (>99% of total area) for this area, but the upland category did not significantly change in the number of hectares from the 1950's through 2004. Figure 46 shows that palustrine marsh habitat did experience some changes during the 1950's through 2004, with 530 ha in the 1950's slightly increasing to 537 ha in 1979, but then decreasing to 329 ha in 2004 (–38% change overall). The most common habitat to which palustrine marsh changed was upland habitat, and the single largest areal change was 36 ha, with most remaining changes occurring within less than 1 ha. The single largest palustrine marsh gain was 102 ha (97% of palustrine marsh gains) within an industrial site where process water impoundments of Sherwin Aluminum were converted to palustrine marsh. In 1956 0.50 ha of estuarine marsh was within the study area, and by 2004 it had increased to 1.75 ha (250% increase). The largest patch of estuarine marsh is 1 ha in size and is located south of Tule Lake Channel, with one edge of the polygon being the border of the coastal-prairie study region.

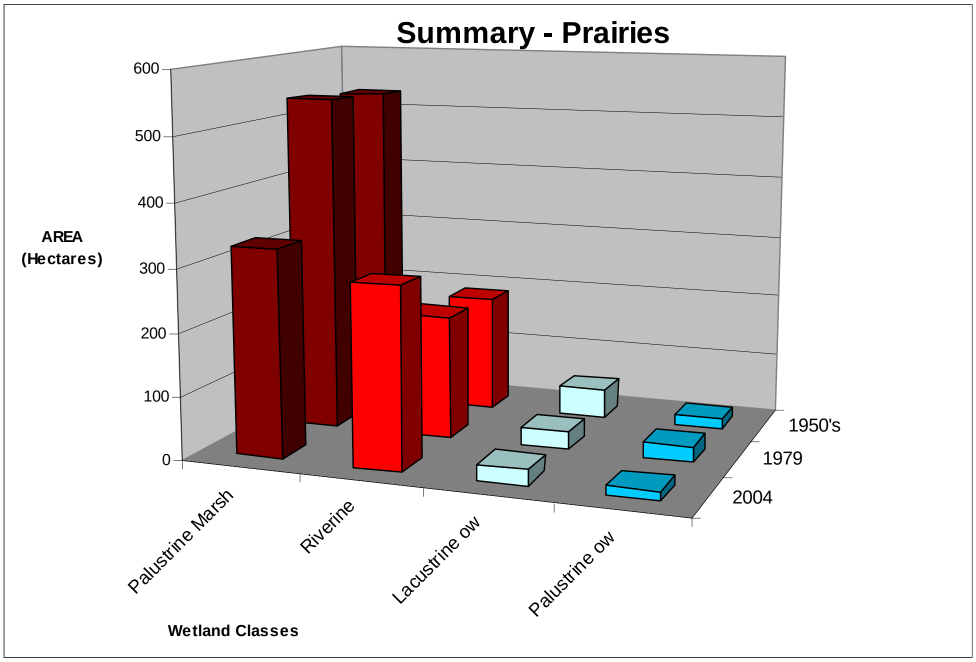

Figure 46. Areal extent of major habitats in coastal prairies in the 1950's, 1979, and 2004.

Probable Causes of Trends. The largest cause of palustrine marsh loss is infilling of palustrine marsh and conversion to upland, or, as in the case of the Sherwin Aluminum property, impoundments converted to palustrine marsh.

Port Bay

In Port Bay wetland trends in higher areas are among the most complex to determine because of variable moisture levels and gently sloping landscapes characterized by topographically high marsh and transitional areas. Vegetation in many areas is dominated by *S. spartinae*, and delineation on aerial photographs was inconsistent from year to year.

General Trends. The most significant change in wetland habitats in Port Bay is the systematic loss of tidal flats. The high of 930 ha mapped in the 1950's was reduced to 372 ha by 1979. Tidal flats were overmapped along the shore of Copano Bay in the 1950's, as discussed earlier. After correction, the 1950's through 1979 tidal-flat loss was roughly 56%. The trend continued into 2004, when only 195 ha of tidal flats was mapped, an additional 48% decline. The overall long-term loss of tidal flats results in a 77 % loss of the original resource, after correction (Fig. 47). Most tidal-flat loss occurred along the Live Oak Peninsula shore of Port Bay and in McCampbell Slough (Fig. 34).

Palustrine marsh also suffered a systematic decrease in area through time. Between the 1950's and 1979, only 52 ha of marsh was lost. The more substantial loss occurred in the later time period, when 939 ha of palustrine marsh mapped in 1979 was reduced to 561 ha by 2004, a 40% decline. Nearly all long-term palustrine marsh loss was to uplands, mostly along the Live Oak Peninsula shore and south of McCampbell Slough.

Estuarine marshes make up the largest wetland class in Port Bay. In the 1950's estuarine marsh covered 1,205 ha; by 1979 the area of estuarine marsh had increased to a high of 1,780 ha, an increase of 48%. Higher precipitation levels expanded the boundaries of marsh in several areas, including Swan Lake, Italian Bend, and McCampbell Slough. By 2004, estuarine marsh area had been reduced to 1,361 ha, down 24%. Long-term change in estuarine marsh in Port Bay was a 13% net gain in area. Of the marsh-area increase, 69% was from areas mapped previously as tidal flat.

Relatively few seagrass beds were mapped in the 1950's, with only 136 ha mapped. Seagrasses flourished between the 1950's and 1979, spreading along the shoreline of Port Bay and into Swan Lake, reaching their height in 1979, when 811 ha were mapped. In 2004, 606 ha of seagrass was mapped, representing a long-term increase, but a 25% decrease from 1979. Seagrasses occupied the northern shoreline of Port Bay and Swan Lake in 1979 and 2004. By 2004, seagrasses had invaded previous tidal-flat areas as sea-level rise inundated flats, resulting in a net long-term gain of seagrass.

Probable Cause of Trends. The largest loss of tidal flats occurred between the 1950's and 1979. Following the coastwide trend, loss of flats was accompanied by a spread of emergent vegetation. Most loss to marsh expansion was at the mouth of Port Bay near Italian Bend and at the head of the bay in McCampbell Slough. Approximately 54% of long-term tidal-flat loss was to estuarine marsh, 68% of which was low marsh (E2EM1N). Seagrass spread into roughly 14% of the area once occupied by tidal flats, and open water spread into another 13% of the area that had previously been flats (Fig. 48). Movement of these habitats into tidal flats is likely due to relative sea-level rise.

Much of the landscape in the Port Bay area is transitional between uplands and high estuarine marsh or drier palustrine marsh. Palustrine marsh habitat is topographically high, infrequently flooded marsh bordering on upland prairie classification. Often characterized by vegetation communities dominated by *Spartina spartinae*, the extent to which high marshes are delineated is partly a function of moisture level at the time photographs are taken. Although some palustrine marsh loss can be attributed to interpretation differences, drier climatic conditions caused by long-term drought had a diminishing effect on areal extent of palustrine marsh by 2004. An example of the difficulty encountered when attempting to pick the upland/marsh boundary is the area south of McCampbell Slough, which was mapped extensively s palustrine marsh in the 1950's, should have been mapped as marsh in 1979, and was mapped as upland in 2004. An area with similar topographic and vegetative characteristics southwest of Swan Lake was correctly mapped as palustrine marsh in 1979, could have been mapped as marsh in the 1950's, and was mapped as upland in 2004. Most estuarine marsh movement into tidal flats occurred along the Live Oak Peninsula shore of Port Bay and in McCampbell Slough. Relative sea-level rise has increased the level of flooding, allowing marsh to establish in these bay-shore areas.

Whereas the long-term trend is toward a gain in estuarine marsh, local losses were documented. An example of this loss occurred when a dam constructed prior to 1979 across an entrenched drainage into Swan Lake on the edge of Copano Bay flooded about 70 ha of estuarine marsh (Fig. 49). From 1979 through 2004 marsh vegetation increased along the margins of the lake, offsetting some of the 1950's through 1979 marsh loss due to impoundment. In one area west of Rockport and inland of Italian Bend, an area mapped as estuarine marsh in 1979 was mapped as upland in the 1950's and 2004. It is a complex area consisting primarily of upland "pimple" mounds and intermound depressions supporting a vegetation community dominated by *Spartina spartinae*.

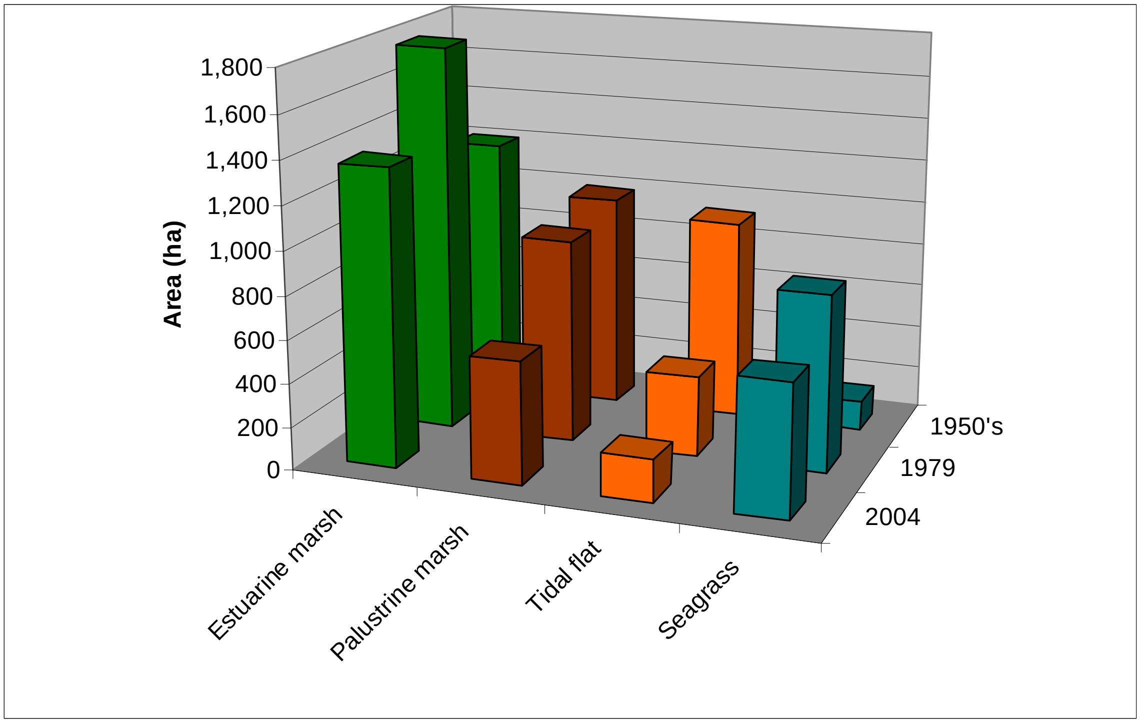

Figure 47. Areal extent of major habitats in Port Bay in the 1950's, 1979, and 2004.

Figure 48. Movement of seagrass into tidal flats at Italian Bend, Port Bay.

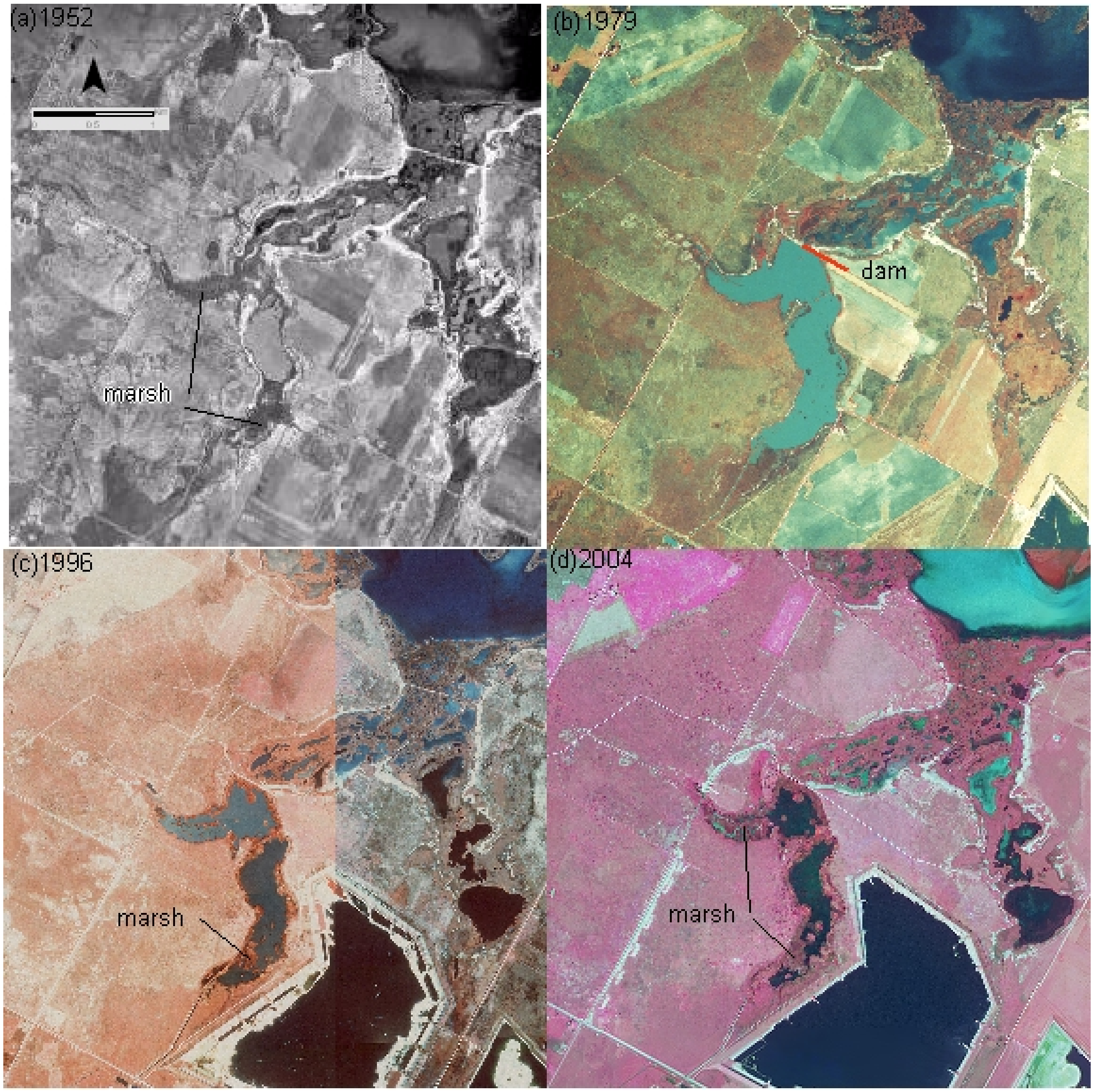

Figure 49. Marsh change from impoundment west of Port Bay, 1952–2004.

Redfish Bay

General Trends. The Redfish Bay area consists almost entirely of estuarine habitats. As in many locations around Corpus Christi Bay, the most significant wetland habitat trend in Redfish Bay is the systematic loss of tidal flats. In the 1950's a relatively large area of flats was mapped. The 1950's total of 768 ha was reduced in 1979 to 219 ha, a 72% loss. By 2004 the tidal-flat area was reduced to only 107 ha, a further 51% decrease. Most change to tidal flats occurred on the islands separating Redfish Bay from Aransas and Corpus Christi Bay and along navigation channels between Harbor Island and the GIWW (Fig. 34).

Estuarine marsh in Redfish Bay increased in area over the long term. In the 1950's only 163 ha of marsh had been mapped, but by 1979 a high of 352 ha was reached before decreasing slightly to 324 ha. Between the 1950's and 2004 amount of estuarine marsh in Redfish Bay nearly doubled (Fig. 50). Most change occurred on islands separating Redfish Bay from Aransas and Corpus Christi Bays and on spoil islands along the GIWW.

Seagrasses cover most of Redfish Bay but did not change much in total area through time, decreasing by only 7% between the 1950's and 2004.

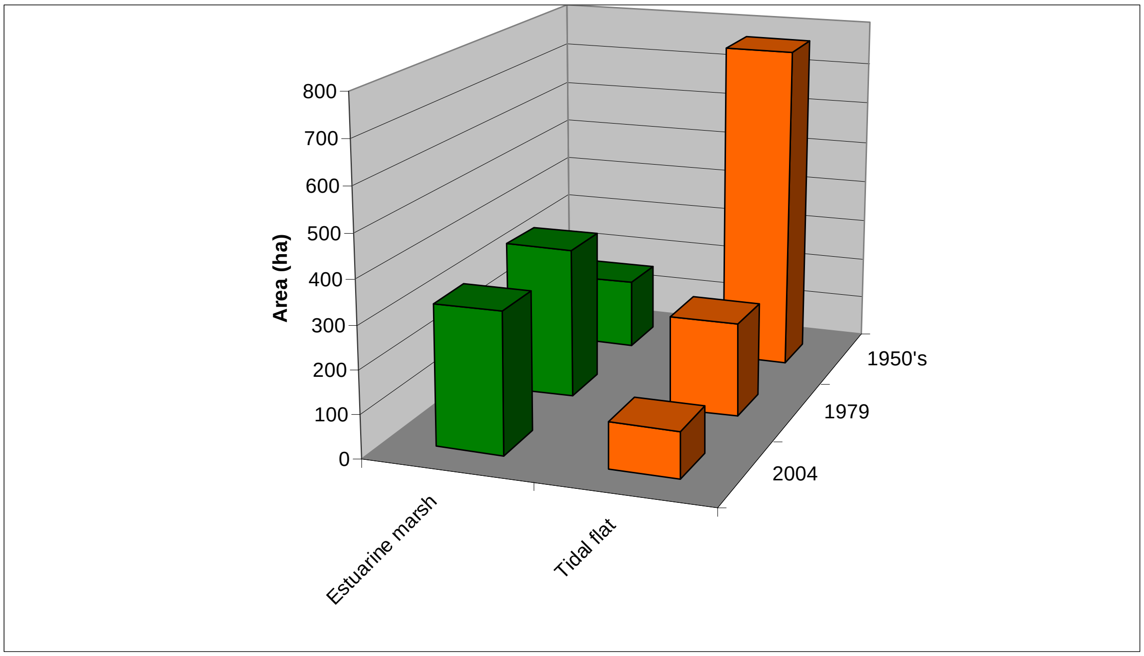

Figure 50. Areal extent of selected habitats in Redfish Bay in the 1950's, 1979, and 2004.

Probable Cause of Trends. Tidal-flat loss in Redfish Bay occurred mostly during the 1950's through 1979 as a result of relative sea-level rise, which inundated some flats and increased the frequency of flooding of others. Seagrasses spread into 47% of the area that was once flats, and open water spread into another 16% of previous flat area. Some loss, roughly 11%, along Aransas Channel and the spoil island to the north, was the result of dredging of the channel in the late 1950's and disposing of dredge material on the flats. By 1979, inundation of the margins of the dredged material had led to expansion of emergent vegetation. Between the 1950's and 2004, low marsh expanded into 25% of the area that was once occupied by tidal flats. Approximately 65% of gross gains in estuarine marsh over the length of the study time period were in areas formerly mapped as tidal flats. Marsh movement into former seagrass areas accounted for another 27% of gross marsh gain.

Nueces River Delta

General Trends. Figure 51 shows habitat classes that had the greatest change during the study time period. Palustrine marsh incurred the largest loss from 1956 through 2004. In 1956 there was 936 ha of palustrine marsh, and in 2004 there was 647 ha, which represents a 31% loss of palustrine habitat. Estuarine marsh represented more than 38% of the total habitat in the Nueces River Delta in 1956 (4,041 ha) but had declined 12% in 1979 to 3,543 ha, and had declined another 8% to 3,278 ha by 2004. Estuarine flats have remained basically stable during the study time period, comprising 1,137 ha in 1956, 1,061 ha in 1979 and 1,220 ha in 2004. Whereas overall change in area of estuarine flats has remained relatively stable, the pattern of spatial distribution has been diverse through the study time period. This aspect of spatial distribution will be further explored later. Upland habitat is found along upward, sloping margins of the riverine terrace. In 1956 uplands comprised 2,510 ha, increased to 3,188 ha in 1979, and declined slightly to 2,752 ha in 2004.

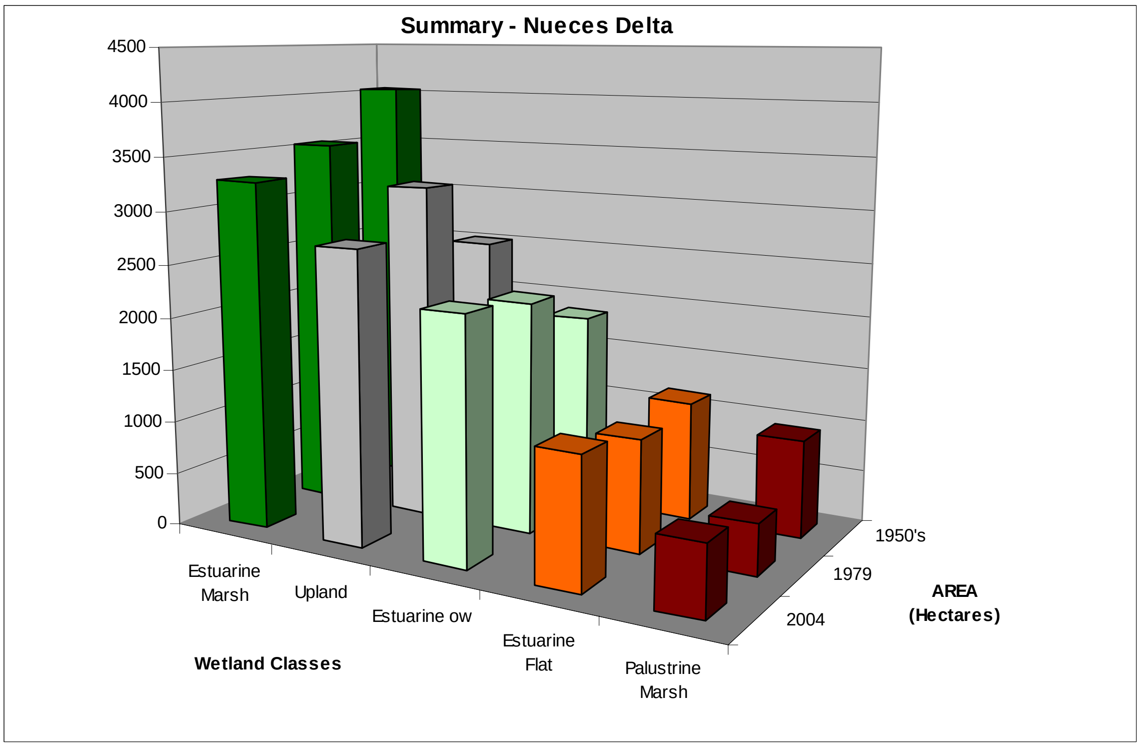

Figure 51. Areal extent of major habitats in Nueces Delta in the 1950's, 1979, and 2004.

Probable Causes of Trends. Total area of estuarine flats has remained relatively stable throughout the 48-year period, as shown in Figure 51, but spatial distribution of the estuarine flats has changed over time. Probable causes of these changes are thought to be partly interpretational and partly due to localized seasonal flooding of the delta. The Nueces River Delta receives a median of two flood events annually, one in May and another in September (Texas Department of Water Resources, 1982). It is thought that 1979 imagery was acquired during a period of one of the annual flooding events, thus resulting in a decrease in the area of estuarine flats. Indeed, in 1979, there was a slight drop in hectares of estuarine flats.

Estuarine marsh loss is thought to be due to a combination of marsh inundation and the spread of other habitats and interpretational differences, an example of which is found in the distal part of the delta, where marsh became inundated with open water owing to relative sea-level rise (Morton et al., 2000). In the same part of the delta, tidal flats have become established in previous marshes. Prior historical studies of shoreline change in this area show that shorelines had been accreting between 1930 and 1982 at a rate of approximately 21 ft per year for a total of 1,075 linear feet (Morton and Paine, 1984; Gibeaut et al., 2000). These data are in contrast to those of this study for the time period of 1979 through 2004, which show the estuarine marsh to be eroding along the shore of Nueces Bay. Figure 52 is a transparent overlay of the 1979 imagery with the 2004 NAIP imagery and shows changes along the shore during the 25-year period of 1979 through 2004.

Figure 52. Comparison of 1979 and 2004 imagery showing different shoreline positions.

A transect in Figure 52 shows the difference in shoreline lengths as approximately 43 m. Whereas certain areas show less erosion, there are areas where large tracts of marsh have eroded. Probable causes of the reversal of accretion from historical studies may be relative sea-level rise, alteration of sediment budget within the estuary, and/or water-induced erosion by wind or motorboat activity.

Figure 53 shows an area of estuarine flat from a 1959 Tobin aerial photomosaic that was classified as estuarine marsh and the same area in the 2004 NAIP imagery that was classified as estuarine flat. Correcting for this misinterpretation reduces long-term loss of estuarine marsh by about 200 ha.

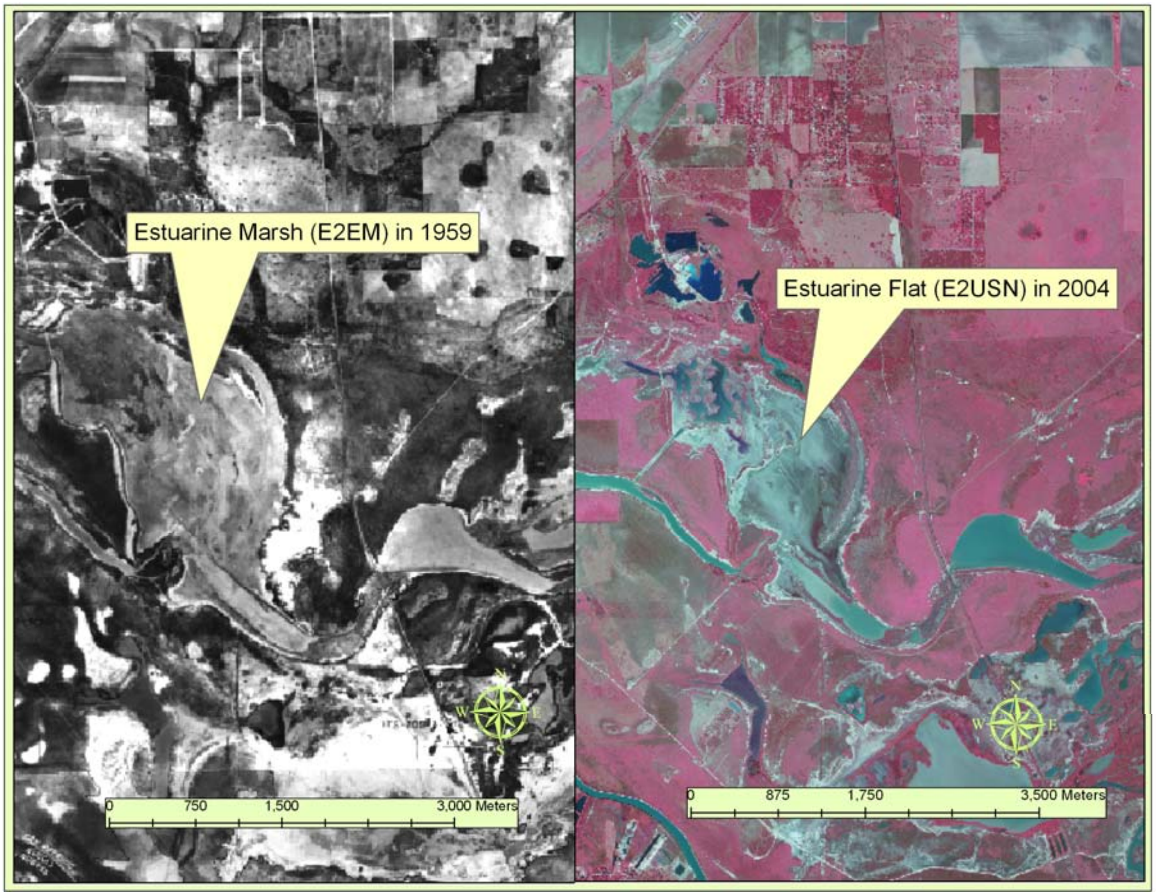

Figure 53. Comparison of 1959 and 2004 imagery. The same area was mapped as marsh in the 1950's and as estuarine flats in 2004.

Corpus Christi Bay Area

General Trends. Most of the 44,655 ha within this geographic region is water as encompassed by Corpus Christi and Nueces Bays. It is along the shores of the bays that estuarine marsh occurs, along with shellfish reefs and estuarine flats. The greatest habitat change within the Corpus Christi Bay is seagrasses. Figure 54 shows the major habitat classes that have experienced change within the three time periods. In the 1950's there was 2,158 ha of estuarine flats, and in 1979 this figure had declined to 787 ha (64% loss). It had declined an additional 60% in 2004 to 315 ha, for a total loss of 85%. Two areas with the highest change in estuarine flats: the area immediately north of the Tule Lake Channel and Indian Point are discussed later.

Area of estuarine marsh increased dramatically within the time period. In 1956, 1979, and 2004 there was 238, 307, and 424 ha respectively, which represents an overall 78% increase of estuarine marsh within Corpus Christi Bay.

Habitat with the greatest gain is seagrasses, with an overall gain of 88% over the entire study time period. In the 1950's there was 2,160 ha of seagrasses, increasing 31% to 2,838 ha in 1979, and an additional 43% increase to 4,067 ha in 2004. Seagrasses also encompass more of the Corpus Christi geographic region than any other habitat, with approximately 9% of the total area, excluding open water.

Uplands also increase within the Corpus Christi geographic region, from 1,748 ha in the 1950's to 2,734 ha in 1979 (56% increase), but decreased from 1979 through 2004 to 2,440 ha (12% decline), for an overall 40% increase during the entire study time period.

Shoreline along the City of Corpus Christi north of the Nueces River has been highly modified over time. The 1958 shoreline position was south of what is now the Tule Lake Channel. Through time, the area progressed from open water to tidal flats and to upland by 2004. Figure 55 shows a comparison of the north part of the City of Corpus Christi between a 1958 black-and-white Tobin aerial photo and 2004 NAIP imagery. The area north of the Tule Lake Channel, approximately 926 ha, was originally estuarine open water, flats, and marsh in the 1950's, but by 2004, most of the area had been classified as upland (803 ha), lacustrine flat (41 ha), and palustrine flat—impounded (101 ha).

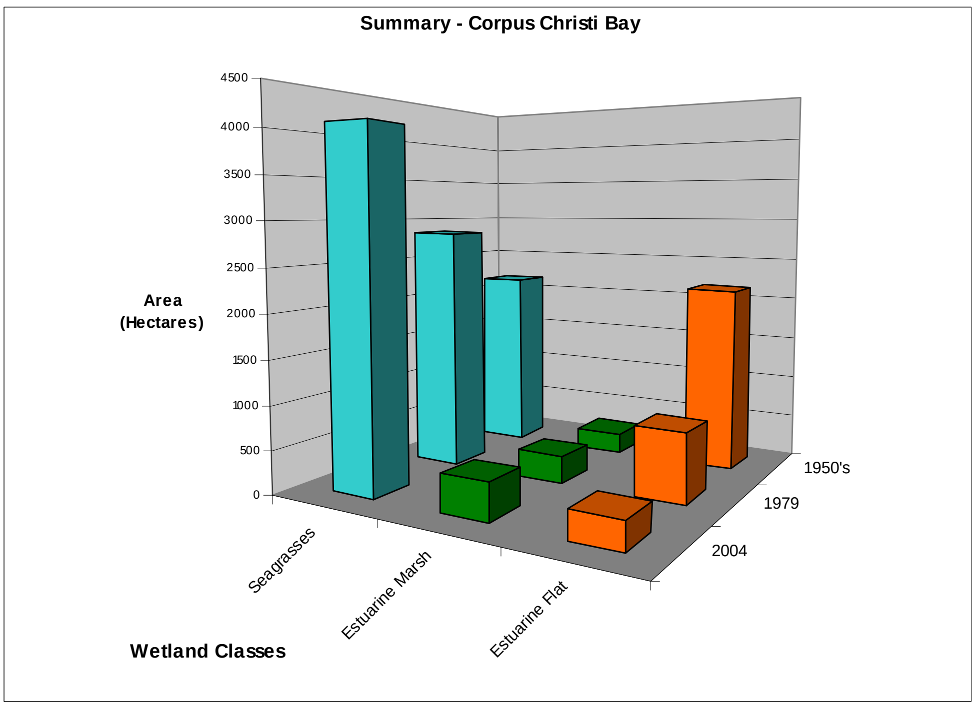

Figure 54. Areal extent of major habitats in Corpus Christi Bay in the 1950's, 1979, and 2004.

Figure 55. (a) 1958 Tobin aerial photo of Corpus Christi showing the area north of the Tule Lake Channel being part of the Nueces Bay and (b) 2004 NAIP imagery of the city of Corpus Christi.

Spatial distribution of estuarine marsh gains and losses is concentrated in a few places within the Corpus Christi Bay region, and the most visible change is along the highway on the north side of the bridge at Indian Point. Figure 56 shows marsh loss at Indian Point and a deltaic fan positioned across from Indian Point. Marsh loss from the 1950’s through

2004 resulted in conversion to open water (18 ha), followed in area by uplands (10 ha), and seagrasses (9 ha). Figure 56 at Indian Point shows loss of estuarine tidal flats and location of the 1958 shoreline. Position of the present shoreline shows progressive erosion along the Nueces Bay side of Indian Point. This loss of shoreline along the Nueces Bay side is also supported by a historical study of shoreline change (Morton and Paine, 1984), where 100 linear feet of erosion was measured along the Nueces Bay side at Indian Point from 1930 through 1974. As shoreline erodes, estuarine marsh is lost, with the exception of areas with higher topographic relief.

Figure 56 also shows tidal flats becoming inundated with water over time.

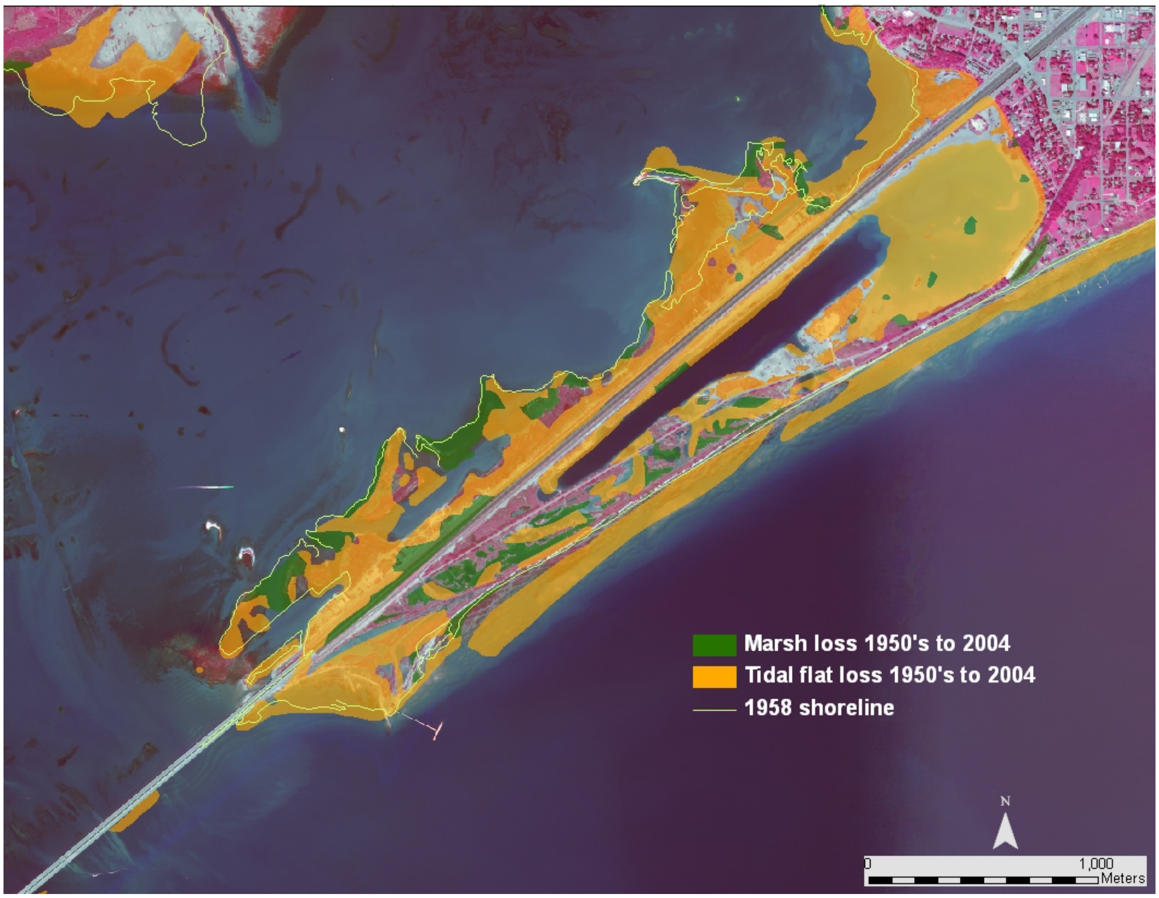

Figure 56. Estuarine marsh and tidal-flat loss at Indian Point, 1950’s to 2004; 1958 shoreline shown in yellow.

Probable Causes of Trends. In the area immediately north of the Tule Lake Channel and adjacent to the City of Corpus Christi, the most prominent cause of changes has been human modification of the landscape by infilling with either dredged material and/or rock, sand, and mud material. The area north of Indian Point, which changed from estuarine flats to open water with a limited amount of marsh change in this area, is, like the other areas of Nueces Bay, the result of relative sea-level rise and erosion.

Oso Bay and Encinal Peninsula

General Trends. This system encompasses Oso Bay and associated adjacent lowlands and the Pleistocene barrier-strandplain system of Encinal Peninsula (Fig. 57). For discussion purposes, the two systems will be treated as a single unit. In terms of percent change, estuarine marsh changed most dramatically over the study time period. A relatively small 81 ha of marsh in the 1950's grew to 112 ha by 1979, a 38% increase. Between 1979 and 2004, marsh had increased in area an additional 174%, to 307 ha. Marsh expansion occurred where freshwater inflows into the bay/creek system had created a more suitable environment for emergent vegetation. Overall, estuarine marsh grew 279% by 2004 from the original 1950's resource (Fig. 58). Tidal-flat change in Oso Bay followed a familiar trend. In the 1950's flats occupied 837 ha, and by 1979 the number of flats had been reduced to 518 ha, a 38% loss. Losses continued into 2004, when 406 ha of flats was mapped, representing an additional 22% loss. Whereas tidal flats declined systematically in Oso Bay, rate of decline decreased in the later time period. Most flat loss occurred along the periphery of Oso Bay and further inland within the channels of the narrow Oso Creek valley. Seagrass spread dramatically in Oso Bay and Oso Creek between the 1950's and 2004. In the 1950's, only 27 ha of seagrass was mapped, but by 2004 seagrass acreage had expanded to 402 ha. Seagrass was not mapped in 1979, possibly because of turbidity caused by heavy precipitation. Most seagrass increase occurred in Oso Bay. Palustrine marsh acreage was relatively low and remained constant through the long term, ranging from a 1950's high of 128 ha, to 119 ha by 2004, with a 1979 low of 83 ha.

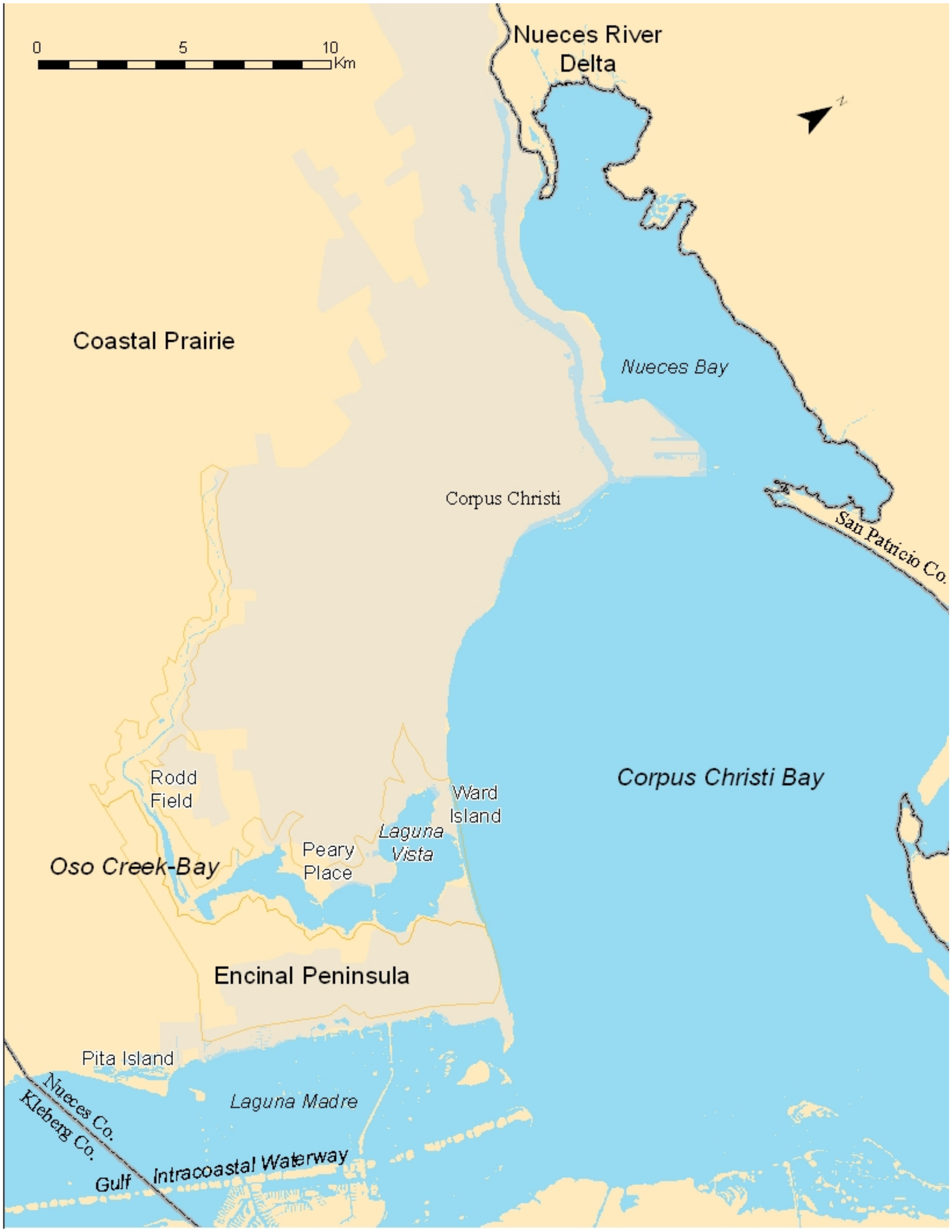

Figure 57. Locator map showing place names and geographic features in south part of study area.

Probable Cause of Trends.
Three sites in the Oso Bay/Creek area produced most of the gross increase in estuarine marsh. Effluent from a wastewater treatment plant and drainage from an adjacent golf course inland of Laguna Vista combined to provide favorable conditions for marsh

expansion (Fig. 59). Most expansion of marsh into flats at this site occurred during the 1950’s but continued at a slower rate through 2004. Another area of flat loss to marsh was at the discharge point of a drainage channel southwest of Peary Place (Fig. 60). The channel discharges onto a small fan delta, where marshes have spread at the apex of the delta since 1979. Freshwater inflow from the drainage channel, along with possible nutrient loading from fertilizers used at the up-channel golf course, allowed marsh to spread into the otherwise highly saline bay. Salinities as high as 23 ppt have been reported at the bend in Oso Creek near Rodd Field (Hildebrand and King, 1978). The bend in the creek near Rodd Field is the location of the largest gross gain in estuarine marsh (Fig. 61). Like in the Peary Place location, marsh expansion occurred primarily from 1979 through 2004. Another similarity is the proximity of a golf course. Marshes spread adjacent to and downstream of the section of creek bordering the golf course. The pace of urban development in the area between Oso Creek and Corpus Christi Bay is one of the highest in the study area. Runoff from creek-side neighborhoods and the golf course most likely provide a more favorable environment for spread of emergent marsh vegetation. Over the length of the study period, 57% of the gross gain in estuarine marsh came from areas previously mapped as tidal flat.

Roughly 29% of gross loss of tidal flats between the 1950’s and 2004 was to estuarine marsh, 75% of which was low or regularly flooded marsh (E2EM1N). Another 27% of gross loss of flats was to uplands, and 22% to open water.

The relatively small amount of seagrass mapped in the 1950’s was restricted to the mouth of Oso Bay. In 2004, seagrass was mapped to varying degrees along most of the bay shoreline and into lower reaches of Oso Creek. Outflow from the large cooling pond at the sharp right-angle bend of the creek has scoured the creek bed, increasing water depth considerably. Patches of seagrass occupy the deepened creek channel downstream of the cooling pond and along the creek bank downstream of the fan delta. Seagrass has also spread on either side of Ward Island at the mouth of Oso Bay. Seagrass-spread appears to be associated with locations of freshwater inflows into the bay.

Over the study time period gross gains and losses of palustrine marsh were experienced. Marsh expanded into previous flats of a shallow oxbow lake on the west bank of the creek near Rodd Field. The oxbow continued to retain moisture into the later time period, when marsh expanded farther into the lake. A large flat at the west edge of the Naval Air Station has experienced palustrine marsh expansion through time. Some of the gain is interpretational owing to estuarine marsh classification in the 1950’s. Construction of roads and runways prevented saltwater exchange and enhanced moisture retention along artificial barriers. Most change in palustrine marsh on Encinal Peninsula was associated with construction of retention and cooling ponds at the south end of the peninsula.

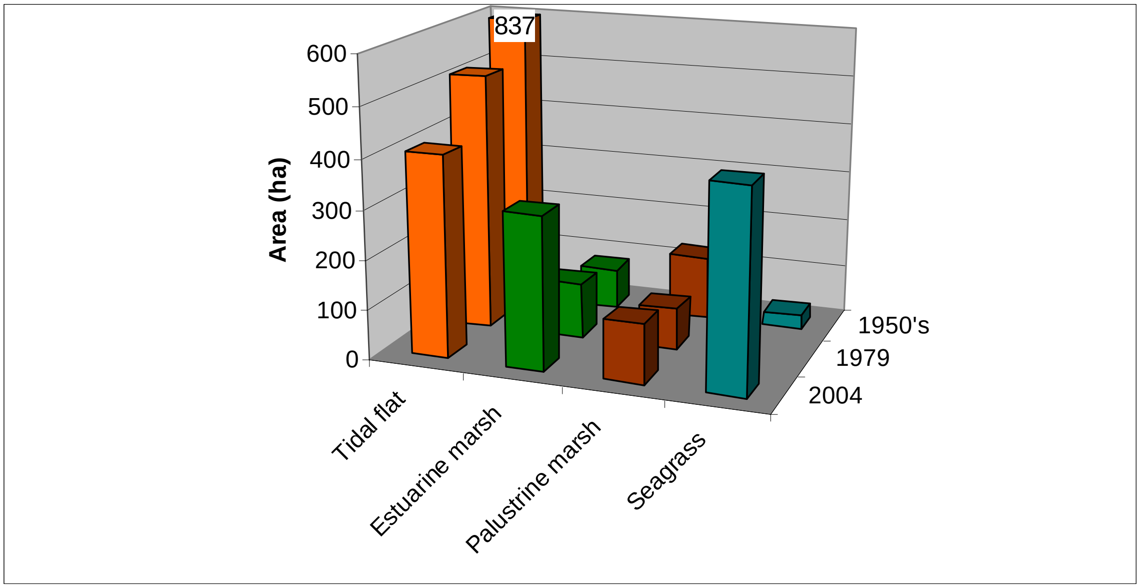

Figure 58. Areal extent of major habitats in Oso Bay and Encinal Peninsula in the 1950's, 1979, and 2004.

Figure 59. Marsh movement into tidal flats at Laguna Vista, Oso Bay, 1958–2004.

Figure 60. Algal flats (E2AB1M) southwest of Peary Place, Oso Bay. Marsh and high algal flats have developed at the outlet of a drainage channel. Yellow dot is where inset photo was taken, looking north.

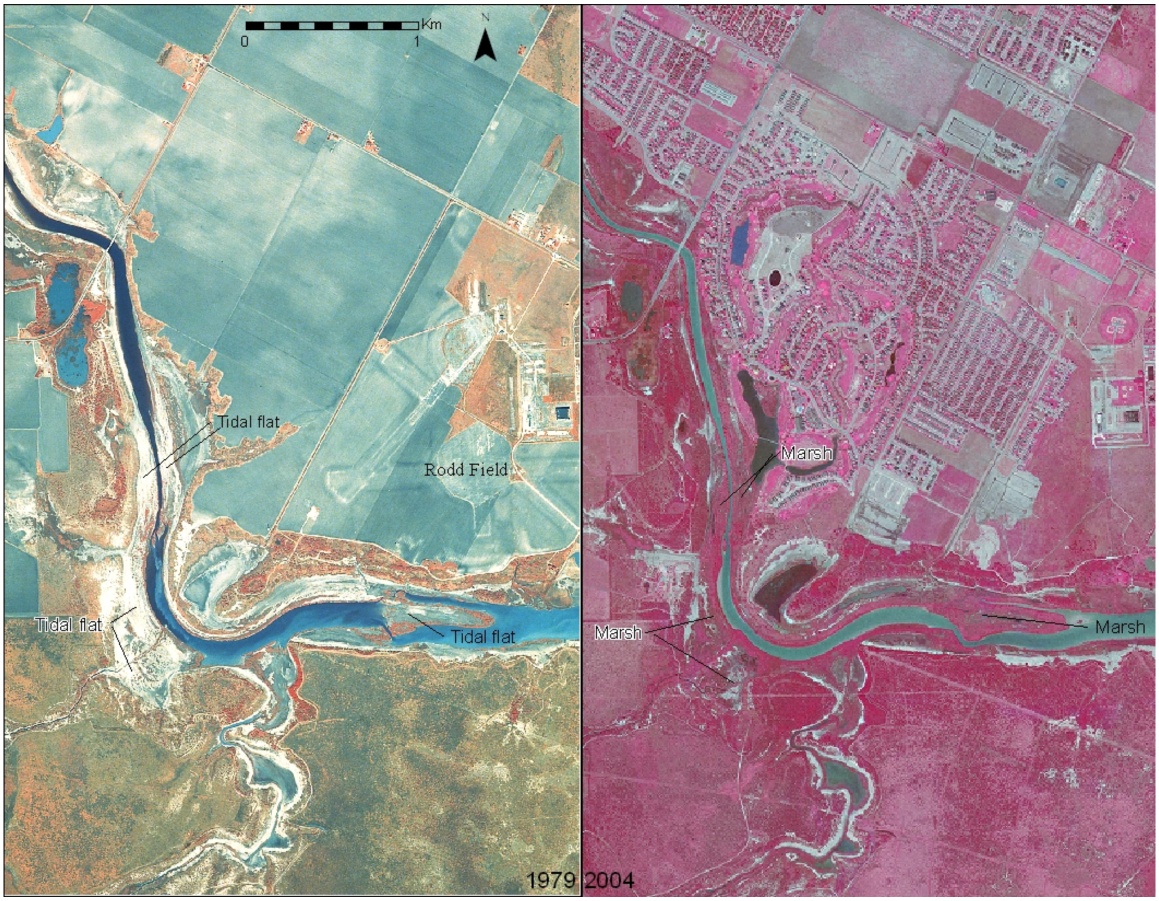

Figure 61. Marsh expansion into tidal flats at Rodd Field, Oso Creek, 1979–2004.

SUMMARY AND CONCLUSIONS

Inland wetlands and aquatic habitats in the Corpus Christi Bay area are dominated by estuarine open water, which in 2004 encompassed an area of almost 73,060 ha, accounting for about 68% of mapped wetland and aquatic habitats. The second-most-extensive habitats were emergent vegetated wetlands, with an area of 17,366 ha, comprising about 16% of wetland and aquatic habitats. Seagrasses covered an area of 9,975 ha, or about 9% of wetland and aquatic habitats. Among other mapped classes (excluding open water and uplands), palustrine habitats are most abundant, at 8,016 ha (7%).

Examination of wetland distribution in 12 geographic subareas within the study area (Lamar Peninsula, Copano mainland, Mission River, Aransas River, Live Oak Peninsula, coastal prairies, Port Bay, Redfish Bay, Nueces River Delta, Corpus Christi Bay, Oso Creek, and Encinal Peninsula) shows that the Nueces River Delta has the largest distribution of estuarine marshes and tidal/algal flats, with 30% and 41%, respectively. The largest distribution of seagrass or aquatic beds occurs in Corpus Christi Bay, where 41% was mapped. Palustrine marshes are equally abundant on the Copano mainland and within the Mission River valley, both representing 22% of the habitat. Palustrine forest and scrub/shrub habitat is relatively scarce, with the largest amount found in the Mission River valley at roughly 42%.

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 different vintages of maps to a common base for comparison. Accordingly, we have more confidence in direction of trends than absolute magnitudes.

From the 1950's through 2004 within the study area, some wetland classes underwent substantial net losses and gains, whereas others remained more stable. Historically, losses and gains in habitats have occurred throughout the study area, but the overall trend in vegetated estuarine emergent wetlands (marshes and scrub/shrub) is one of net gain, as revealed by an increase in estuarine marsh-scrub/shrub habitat of 8,856 ha in the 1950's to 10,821 ha by 2004. The marsh-scrub/shrub high amount occurred in 1979, when totals reached 11,749 ha. Average rate of marsh-scrub/shrub habitat change fluctuated, from a gain of about 126 ha/yr during the earlier period to a loss of about 38 ha/yr during the later one. The long-term (1950's through 2004) marsh-scrub/shrub habitat change rate was a gain of about 41 ha/yr. Total area of tidal/algal flats decreased by 4,919 ha from the 1950's through 1979 and continued to decrease from 1979 through 2004, when 1,632 ha was lost. Average rate of tidal-flat loss decreased dramatically through time, from about 214 ha/yr during the earlier period to 65 ha/yr during the later period. Seagrass beds increased by 294 ha in total area from the 1950's through 1979 and continued to increase by 2,045 ha from 1979 through 2004, reflecting a net gain of 2,339 ha since the 1950's. Palustrine marshes decreased in total area by 1,369 ha between the 1950's and 1979 and decreased by 1,490 ha between 1979 and 2004. Average rate of tidal-flat loss remained constant, at about 60 ha/yr. There was an increase in the area of lacustrine habitats, primarily cooling ponds and fluctuations in amount of palustrine forest/scrub shrub.

Analysis of habitat distribution by geographic subarea reveals local differences in historical trends. The most significant wetland trend on the Copano mainland was the long-term loss of 29% of palustrine marsh from the 1950's through 2004. Interpretational differences between time periods result in varied amounts of marsh. Whereas there were many gross gains of palustrine marsh, the overall trend was characterized by a reduction of palustrine marsh through conversion to uplands. Conversion of marsh to uplands may have been the result of long-term drought that has persisted in Texas through much of the past decade.

Estuarine marshes on the Copano mainland experienced a net gain of 14% through the overall study time interval. Like palustrine marshes, the estuarine marsh area was most extensive in 1979. Most estuarine marsh gain occurred where flats in secondary bays along Copano Bay were converted to marsh. Relative sea-level rise has allowed other habitats to move into previous tidal-flat areas.

Palustrine forest and scrub/shrub habitat remained consistent throughout the study time period. Again, the largest amount of palustrine forest and scrub/shrub was mapped in 1979. Large tracts of rangeland in Mission Bay and Lamar quadrangles, between Copano Creek and the Mission River, were mismapped as palustrine scrub/shrub in 1979.

Tidal flats, the remaining dominant habitat type on the Copano mainland, was overmapped in the 1950's. When adjusted to correct for the misinterpreted bay margin, long-term (1950's through 2004) tidal-flat loss is roughly 22%. Most real loss of tidal flats resulted in spread of emergent vegetation in secondary bays. Marsh movement into flats had progressed significantly by 1979 and continued through 2004.

Lamar Peninsula, located on a Pleistocene strandplain, had a long-term loss of palustrine marsh. Overall marsh total (1950's through 2004) experienced a 77% loss, with the lowest quantity mapped in 1979. Wide-ranging quantities of palustrine marsh reported in individual time periods can be attributed to interpretational differences. Overall trend was characterized primarily by reduction of palustrine marsh through conversion to uplands. Some marsh conversion to uplands was the result of residential/commercial development, but most change was interpretational. The low amount of palustrine marsh in 1979 is an interpretational artifact in which transitional areas were mapped as estuarine marsh in the 1950's. Little evidence suggests that vegetation composition and tidal communication were different since the 1950's. However, by 2004 the long-term drought experienced throughout the Texas coast had altered the moisture regime significantly.

Tidal flats lost about 54% of the 1950's resource by 1979 and continued with an additional 66% loss between 1979 and 2004. Housing development altered flats, converting some areas to uplands for houses and roads and some to boat channels. The gain of estuarine marsh and loss of tidal flats in several small bays encompassing the Peninsula since the 1950's can be largely explained by a relative rise in sea level. Most tidal-flat loss was due to spread of low estuarine marsh (E2EM1N) and, to a lesser degree, open water and seagrass. Conversion occurred as topographically low flats became submerged and slightly higher flats became more frequently flooded, contributing to a spread of marsh vegetation. In some instances, higher marshes also expanded into adjacent uplands.

In contrast to overall decline in tidal flats, total areas of seagrass beds and estuarine marshes increased from the 1950's through 2004. From the 1950's through 1979 seagrass numbers decreased then increased by 2004, primarily through spreading into areas previously mapped as tidal flats. The low amount of seagrass mapped in 1979 may have been due to turbidity. Although losses and gains occurred in estuarine marsh throughout the peninsula, overall change was a net gain from the 1950's through 2004.

The Mission River is a fluvial-deltaic system that lies within an entrenched valley. The most significant trend in the Mission River valley was the gain of estuarine marsh. A large increase of marsh area between the mid-1950's and 1979 represents a 70% gain of the resource. Estuarine marshes continued to increase from 1979 through 2004, gaining an additional 20%. Wetland habitat changes during the mid-1950's through 1979 were due partly to the conversion of palustrine marsh to estuarine marsh at the confluence of the Mission River and Melon Creek. Conversion of palustrine marsh to estuarine marsh accounted for roughly 49% of the gross gain in estuarine marsh during this time period. Gross increases in estuarine marsh were also from flats (+28%) and upland (+18%).

Tidal-flat area remained constant between the 1950's and 1979, with a small increase. During the later time period, from 1979 through 2004, flats decreased in area 73%. In analyzing trends, more than 71% of the flat loss can be attributed to spread of estuarine marsh, most of which was low or regularly flooded marsh. Flats were also lost when seagrasses became established in the shallow ponds on the Mission River Delta. Loss of flats to marsh may be partly due to sea-level rise contributing to more frequent inundation of flats and subsequent expansion of emergent vegetation.

Palustrine marsh experienced gross gains and losses, resulting in a systematic decrease in area through time. Consistent net decreases led to an overall loss of 28% of the resource over the study time period. Differences in placement of the estuarine/palustrine interface within the river valley, as discussed earlier, contributed to the gross loss of palustrine marsh through time.

Like the estuarine marsh habitat, palustrine forest and scrub/shrub habitats experienced a systematic increase through time, although in much smaller numbers. The largest increase occurred in the initial time period, between the 1950's and 1979, when forest/scrub-shrub gained 46%, increasing 8% by 2004. Forests, and to a lesser degree scrub/shrub, in the palustrine system are difficult to distinguish from those in the upland system and are therefore subject to interpretational differences. Woodlands most likely changed little overall, with gains exceeding losses.

In the Aransas River–Chiltipin Creek fluvial-deltaic area, the most significant change was a systematic increase in estuarine marsh since the 1950's. Marsh areas mapped in the 1950's increased 59% by 1979 and another 41% by 2004. This change amounted to a net gain of estuarine marsh of more than 124% in the Aransas River area since the 1950's. Wetland habitat changes during the mid-1950's through 1979 resulted partly from conversion of palustrine marsh to estuarine marsh at the confluence of the Aransas River and Chiltipin Creek. Estuarine marsh was mapped up the river valley in 1979 farther than in the 1950's. Conversion of palustrine marsh to estuarine marsh accounted for roughly 33% of the gross gain in estuarine marsh during this time period. In the later time period estuarine marsh continued to spread into flats and uplands at the mouth of Chiltipin Creek and into flats and open water at Mud Flats. Uplands and tidal flats accounted for 26% and 24%, respectively, of gross marsh gain between the 1950's and 2004.

Palustrine marsh experienced a significant loss (–45%) between the 1950's and 1979, when 1,068 ha was reduced to 587 ha. Most palustrine marsh loss (~48%) was located in areas that became estuarine marsh. By 2004, palustrine marsh area had recovered slightly to 660 ha.

Tidal flats also experienced a systematic loss through time. The 1950's acreage changed little by 1979. By 2004, tidal flats were reduced by 58% from the 1979 resource. Tidal flats lost most area to emergent vegetation during the time span of the 1950's through 2004. Roughly 41% of tidal-flat loss was due to estuarine marsh, 36% of which was lower or regularly flooded marsh. In contrast to the decline in tidal flats were major increases in open water and seagrasses. Combined open water and seagrass totals increased 46% over the length of the study time period. Spreading of subtidal habitats accounted for roughly 51% of long-term gross loss of tidal flats. Formation of shallow open-water areas and seagrass beds in former tidal-flat habitats is thought to be the result of relative sea-level rise in fluvial-deltaic systems of the Corpus Christi Bay area.

Palustrine forest and scrub/shrub increased systematically over time within the fluvial-deltaic system. Whereas gains and losses of palustrine forest and scrub/shrub were due mostly to differences in photointerpretation, woodlands are thought to have had more gains than losses.

Live Oak Peninsula and Ridge, located on the Pleistocene strandplain, experienced a dramatic loss of tidal flats over time. The 1950's total had decreased 71% by 1979, so that by 2004 only a relatively few flats had been mapped. Most tidal-flat loss occurred on the east margin of Live Oak Ridge landward of Redfish Bay. Long-term loss of flats from the 1950's through 2004 was (–)83% of the original resource. Industrial development along the GIWW had filled many of the tidal flats along Redfish Bay by 1979. As much as 43% of the long-term loss of tidal flats was due to upland development.

Channelization along GIWW flooded flats resulted in a 31% gross loss of flats to open water. Channelization, in turn, allowed low marsh (E2EM1N) to move into former flats. Emergent vegetation eventually spread into 23% of areas occupied by flats. As is the case in many wetland areas along the Texas coast, tidal-flat loss was offset on Live Oak Peninsula by gains in estuarine marsh.

Estuarine marsh area peaked in 1979. Approximately 61% of gross marsh gain occurred in previous tidal-flat areas. By 2004 the area of marsh had decreased slightly. Except for an 8% decrease from the 1979 acreage, estuarine marsh increased overall by 60% between the 1950's and 2004. Rising relative sea levels may have allowed marsh to spread into previous tidal flats.

Palustrine open water increased by 280% between the 1950's and 1979. Much higher precipitation levels, discussed later, most likely accounted for the 1979 increase. Conversely, palustrine marsh exhibited a systematic loss through time. From the 1950's through 2004, palustrine marsh was reduced in area by 35%. Large tracts of Live Oak Peninsula are transitional wetland areas dominated by *Spartina spartinae*, and these areas are frequently delineated into different wetland systems, depending on local climatic conditions and water levels when aerial photographs were taken. Topography of the Pleistocene sand ridge is unique, characterized by hundreds of potholes that have fluctuating seasonal and annual water regimes dependent upon precipitation. Many more pothole wetlands were mapped in the 1950's, whereas fewer, but larger, individual potholes were mapped in 1979. Most palustrine marsh loss over the long term was due to drought conditions, which by 2004 had dried up many prairie potholes. Locally, community development in places like Key Allegro and Aransas Pass have contributed to gross losses of wetlands. In some instances, marsh was converted to open water when quarries were excavated for sand resources.

The 1950's total of seagrass experienced a steep decline (–49%) during the early time period owing to development of the Key Allegro community at Frandolig Island. Seagrasses became established at different locations along the shoreline of the peninsula after declining in area in1979. Overall, seagrass acreage remained relatively constant, with a small loss by 2004.

Uplands, which make up most of the habitat classification in the coastal prairies, did not significantly change in area from the 1950's through 2004. Palustrine marsh habitat did experience some changes during the 1950's through 2004, with a slight increase from the 1950's through 1979, but then decreasing by 2004 for a net loss of 38%. The most common habitat to which palustrine marsh changed was uplands. In 1956 0.50 ha of estuarine marsh was within the study area, but by 2004 that increased to 1.75 ha (250% increase). Largest causes of palustrine marsh loss were from filling and conversion to uplands, i.e., impoundments for industrial waste. The largest area of palustrine marsh gain was in such an impoundment.

The most significant change in aquatic habitats in Port Bay was the systematic loss of tidal flats, with the high mapped in the 1950's reduced by roughly (–)56% by 1979. Following the coastwide trend, flats were converted to emergent vegetation, with the greatest change occurring at the mouth of Port Bay near Italian Bend and at the head of the bay in McCampbell Slough. The trend continued into 2004, with an additional 48% decline. The overall, long-term loss of tidal flats results in a 77% loss of original resource. Most tidal-flat loss occurred along the Live Oak Peninsula shore of Port Bay and in McCampbell Slough. Approximately 54% of long-term tidal-flat loss resulted in conversion to estuarine marsh, 68% of which was to low marsh (E2EM1N). Seagrass-spread into tidal flats accounted for roughly 14% of the area once occupied by flats, with open water accounting for another 13%. Movement of other habitats, such as seagrasses and marsh, into tidal flats is likely due to relative sea-level rise.

Palustrine marsh also suffered a systematic decrease in area through time. Between time periods, location of palustrine marsh changed, but gross gains and losses resulted in a small net area loss. More substantial loss occurred later, when palustrine marsh mapped in 1979 was reduced 40% by 2004. Nearly all long-term palustrine marsh loss was to uplands, mostly along the Live Oak Peninsula shore and south of McCampbell Slough. Whereas some palustrine marsh loss can be attributed to interpretation differences, drier climatic conditions caused by long-term drought had reduced the areal extent of palustrine marsh by 2004.

Estuarine marshes make up the largest wetland class in Port Bay. In the 1950's through 1979, area of estuarine marsh increased 48%. Higher precipitation levels in 1979 expanded the boundaries of estuarine marsh in several areas, including Swan Lake, Italian Bend, and McCampbell Slough. By 2004, estuarine marsh area had been reduced 24%. Over the long term, estuarine marsh in Port Bay gained 13%. Of this increase, 69% was from areas mapped previously as tidal flat. Most estuarine marsh movement into tidal flats occurred along the Live Oak Peninsula shore of Port Bay and in McCampbell Slough. Relative sea-level rise has increased the level of flooding, allowing marsh to become established in these bay-shore areas. Although there has been a long-term gain in estuarine marsh, local losses have been documented.

Seagrass area was at its height in Port Bay in 1979, whereas relatively few seagrass beds were mapped in the 1950's. Seagrass flourished between the 1950's and 1979, spreading along the shoreline of Port Bay and into Swan Lake. In 2004, seagrass decreased in area by 25% from the 1979 total. Seagrasses occupied the northern shoreline of Port Bay and Swan Lake in 1979 and 2004. As mentioned earlier, by 2004 seagrasses had moved into areas that had previously been tidal flats, resulting in a net long-term (1950's through 2004) gain of seagrass.

The Redfish Bay area consists almost entirely of estuarine habitats. As in many locations around Corpus Christi Bay, the most significant habitat trend in Redfish Bay is the systematic loss of tidal flats. In the 1950's a relatively large number of flats were mapped, but the area had been reduced by 72% by 1979. Most of this loss resulted from relative sea-level rise, which inundated some flats and increased the frequency of flooding of others. By 2004 the tidal-flat area had been reduced by 51%, with most changes occurring on the islands separating Redfish Bay from Aransas and Corpus Christi Bays and along navigation channels between Harbor Island and the GIWW. Over the long term, seagrasses occupied 47% of the area once occupied by flats, with open water occupying another 16%. Some loss, roughly (–)11%, along Aransas Channel and the dredged material island to the north, was the result of dredging in the late 1950's and disposing of dredge material on the flats. By 1979, inundation of the margins of the dredged material led to expansion of emergent vegetation. From the 1950's through 2004, low marsh expanded into 25% of the area once occupied by flats.

Estuarine marsh in Redfish Bay increased in area over the long term. In the 1950's only a small amount of marsh had been mapped, but by 1979 the habitat area had reached its peak, before reducing slightly by 2004. Between the 1950's and 2004 the net area of estuarine marsh in Redfish Bay nearly doubled. Most change occurred on the islands separating Redfish Bay from Aransas and Corpus Christi Bays and on dredged material islands along the GIWW. Approximately 65% of the increase in estuarine marsh over the length of the study was in areas formerly mapped as tidal flats. Marsh expansion into former seagrass areas accounted for another 27% of gross marsh gain.

Seagrasses cover most of Redfish Bay and did not change much in total area through time, with a net change of only (–7% between the 1950's and 2004.

In the Nueces River Delta, palustrine marsh incurred the largest loss of habitat during the overall, 1956 through 2004 time period, resulting in a 31% loss of resource. Estuarine marsh declined 12% from the 1950's through 1979 and had declined another 8% by 2004. Estuarine tidal flats remained basically stable during the study time period. Whereas overall change in area of estuarine flats has remained relatively stable, the pattern of spatial distribution has been diverse. Probable causes of these changes are thought to be partly interpretational and partly localized seasonal precipitation-induced flooding of the delta. The 1979 imagery was probably acquired during an annual flooding event, thus resulting in a decrease in the area of estuarine flats in 1979. It is also thought that classification inaccuracies due to different analysts and quality of imagery contribute to classification error. Estuarine marsh loss is thought to be the result of a combination of habitat loss and interpretational differences. An example of marsh habitat loss is found in the distal part of the delta, where marsh became inundated with open water owing to relative sea-level rise. In the same part of the delta, tidal flats have become established in areas previously occupied by marsh. From 1979 through 2004, estuarine marsh eroded along the shore of Nueces Bay. Although certain areas show less erosion, there are places where large areas of marsh have eroded. Probable causes of erosion may be relative sea-level rise, alteration of sediment budget within the estuary, and/or water-induced erosion by wind or motorboat activity.

The Corpus Christi Bay area contains Corpus Christi and Nueces Bay. It is along the shores of the bays that estuarine marsh occurs, along with shellfish reefs and seagrasses. The greatest habitat change within the Corpus Christi Bay is the seagrasses. Between the 1950's and 1979, flats had declined 64% and had declined an additional 60% by 2004, for a total loss of 85% of the habitat. Two areas with the highest change in estuarine flats: the area immediately north of the Tule Lake Channel and at Indian Point. Estuarine marsh increased by 78% within the Corpus Christi Bay area. The habitat with the greatest gain is seagrasses, with an overall gain of 88% from 1950's through 2004. The shoreline along the City of Corpus Christi north of the Nueces River has been highly modified over time. The 1958 shoreline position was south of what is now the Tule Lake Channel. Through time, the area changed from open water to tidal flats, and it had changed to uplands by 2004. In the area immediately north of the Tule Lake Channel and adjacent to the City of Corpus Christi, the main cause of changes has been human modification of the landscape by infilling with dredged material and/or rock, sand, and mud material. Spatial distribution of estuarine-marsh gains and losses is concentrated in a few places within the Corpus Christi Bay region; the most visible change is along the highway on the north side of the bridge at Indian Point. Marsh loss from 1950's through 2004 resulted in conversion to open water, uplands, and seagrasses. Position of the present shoreline, when compared with that of the 1958 shoreline, shows progressive erosion along the Nueces Bay side of Indian Point. As the shoreline erodes, estuarine marsh is lost. During the same time interval (1950's–2004), tidal flats became inundated with water. The area north of Indian Point has changed from estuarine flats to open water, with a limited area of marsh as a result of relative sea-level rise and erosion.

In terms of percent change in habitats, estuarine marsh changed most dramatically over the study time period in Oso Bay and associated adjacent lowlands and the Pleistocene barrier-strandplain system of Encinal Peninsula. A relatively small area of marsh in the 1950's had grown 38% by 1979. Between 1979 and 2004, marsh had increased in area 174%. Marsh expansion occurred where freshwater inflows into the bay/creek system created a more suitable environment for emergent vegetation. Overall, by 2004, estuarine marsh had grown 279% from the original 1950's resource. Three sites in the Oso Bay/Creek area produced most of the gross increase in estuarine marsh. Over the length of the study period, 57% of the gross gain in estuarine marsh came from areas previously mapped as tidal flat.

Tidal-flat change in Oso Bay follows a familiar trend. From the 1950's through 1979, flats were reduced by 38%, and an additional 22% had been lost by 2004. Whereas tidal flats declined systematically in Oso Bay, rate of decline decreased in the later time period. Most flat loss occurred along the periphery of Oso Bay and farther inland within channels of the narrow Oso Creek valley. Roughly 29% of the gross loss of tidal flats between the 1950's and 2004 was to estuarine marsh, 75% of which was low or regularly flooded marsh (E2EM1N). Another 27% and 22% of the gross loss of flats were to uplands and open water, respectively.

Seagrass spread dramatically in Oso Bay and Oso Creek between the 1950's and 2004. In the 1950's only a small amount of seagrass was mapped, but by 2004 seagrass acreage had expanded exponentially. The relatively small amount of seagrass mapped in the 1950's was restricted to the mouth of Oso Bay. No seagrass was mapped in 1979, possibly because of turbidity caused by heavy precipitation during the time aerial photographs were taken. Most seagrass increases occurred in Oso Bay. In 2004, seagrass was mapped to varying degrees along most of the bay shoreline and into the lower reaches of Oso Creek. Seagrass has also spread on either side of Ward Island at the mouth of Oso Bay. Increases in seagrasses appear to be associated with location of freshwater inflows into the bay.

Palustrine marsh acreage was relatively low and remained constant over the long term. Over the study time period gross gains and losses of palustrine marsh were experienced. However, most change in palustrine marsh on Encinal Peninsula was associated with the construction of retention and cooling ponds at the south end of the peninsula.

ACKNOWLEDGMENTS

This investigation was funded by the National Oceanic and Atmospheric Administration through the Texas Coastal Management Program administered by the Texas General Land Office. Wetland distribution for historical periods is based on maps from the U.S. Fish and Wildlife Service prepared as part of the National Wetland Inventory program and special projects. We are grateful to Sally Morehead of UTMSI for logistical support and Sally Crofutt for providing an all-terrain vehicle for access to Fennessey Ranch. The authors also appreciate the support of Ben Rhame, GLO, for his assistance in presenting the proposal to the Coastal Coordination Council and administrating the contracts. We thank Joel Lardon of the Bureau of Economic Geology for assistance in preparing illustrations and Lana Dieterich for editorial comments. Also, thanks go to George Bush for vehicle support.

REFERENCES

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

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

Bureau of Economic Geology, 2007, Lidar dataset, February.

Collier, W. J., and Hedgpeth, J., 1950, An introduction to the hydrography of tidal waters of Texas: University of Texas, Austin, Institute of Marine Science Publications, v. 1, no. 2, p. 125-194.

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

Cowardin, L. M., Carter, V., Golet, F. C., and LaRoe, E. T., 1979, Classification of wetlands and deepwater habitats of the United States: U.S. Department of Interior, Fish and Wildlife Service, Washington, D.C., USA 131 p.

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

Gibeaut, J. C., Tremblay, T. A., and White, W. A., 2000, Coastal hazards atlas of Texas: a tool for hurricane preparedness and coastal management—volume 1, the southeast coast: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the Texas Coastal Coordination Council, pursuant to National Oceanic and Atmospheric Administration Award No. NA770Z0202, 69 p.

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

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

Hayes, M. O., 1965, Sedimentation on a semiarid, wave-dominated coast (South Texas), with emphasis on hurricane effects: The University of Texas at Austin, Ph.D. dissertation, 350 p.

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

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

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

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

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

Morton, R. A., Ward, G. H., and White, W. A., 2000, Rates of sediment supply and sea-level rise in a large coastal lagoon: Marine Geology, v. 167, p. 261-284.

NOAA, 2007, Coastal bend Texas benthic habitat mapping: Corpus Christi Bay.

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

Pulich, Warren, Jr., Blair, Catherine, and White, W. A., 1997, Current status and historical trends of seagrasses in the Corpus Christi Bay National Estuary Program study area: Corpus Christi Bay National Estuary Program, Publication CCBNEP-20, 131 p.

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

Sherrod, C. L., and McMillan, Calvin, 1981, Black mangrove, *Avicennia germinans*, in Texas: past and present distribution: The University of Texas Marine Science Institute at Port Aransas, Contributions in Marine Science, v. 24, p. 115-131.

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

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

Texas Department of Water Resources, 1982, The influence of freshwater inflows upon the major bays and estuaries of the Texas gulf coast: Texas Department of Water Resources, LP-115, 53 p.

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

U.S. Army Corps of Engineers, 1987, USACE wetlands delineation manual, Environmental Laboratory, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS, USA, Technical Report Y-87-1.

U.S. Fish and Wildlife Service, 1983, Unpublished digital data of wetland maps of the Texas coastal zone prepared from mid-1950's and 1979 aerial photographs: Office of Biological Services, U.S. Fish and Wildlife Service.

U.S. Soil Conservation Service, Soil Survey Staff, 1975, Soil taxonomy: a basic system of soil classification for making and interpreting soil surveys: U.S. Soil Conservation Service, Agricultural Handbook 436, 754 p.

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

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

White, W. A., Tremblay, T. A., Hinson, James, Moulton, D. W., Pulich, W. J., Jr., Smith, E. H., and Jenkins, K. V., 1998, Current status and historical trends of selected estuarine and coastal habitats in the Corpus Christi Bay National Estuary Program study area: Corpus Christi Bay National Estuary Program, CCBNEP-29, 161 p.

White, W. A., Tremblay, T. A., Waldinger, R. L, and Calnan, T. R., 2002, Status and trends of wetland and aquatic habitats on Texas barrier islands, Matagorda Bay and San Antonio Bay: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the Texas General Land Office and National Oceanic and Atmospheric Administration under GLO Contract No. 01-241-R, 66 p.

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

APPENDIX: Total habitat areas for 2004, 1979, and 1950's from GIS data of study area.

2004		*1979*		*1950's*	
Habitats	**Hectares**	**Habitats**	**Hectares**	**Habitats**	**Hectares**
E1AB1	31	E1AB2L.	7,905	E1AB.	7,611
E1AB3	9,950	E1AB6L.	408		
E1AB3x	25	E1AB7L.	3	E1OW.	72,602
E1AB4	2	E1OWL.	74,691		
E1AB5	319	E1OWLH.	88	E1RF.	170
E1AB5x	24	E1OWLX.	164		
E1AB6	252			E2BB.	59
		E2AB2M.	9		
E1RF2L	233	E2AB6M.	4	E2EM.	8,839
E1UB	72,209	E2BBP.	1	E2FL.	9,527
E1UBs	0				
E1UBx	851	E2EM1N.	5,233	E2RF.	75
		E2EM1P.	6,514		
E2AB1M	136			E2RS.	1
E2AB1N	456	E2FL6N.	18		
E2AB1Ns	19	E2FLM.	304	E2SB.	3
E2AB1P	193	E2FLMH.	12		
E2AB1Ps	22	E2FLN.	2,440	E2SS.	17
		E2FLP.	1,827		
E2EM1N	5,514	E2FLPH.	32	L1OW.	139
E2EM1Nd	3	E2FLUH.	26		
E2EM1Nh	10			L2AB.	105
E2EM1Ns	96	E2RF2M.	3		
E2EM1Nx	9			L2FL.	61
E2EM1P	5,079	E2SS3N.	2		
E2EM1Pd	7			L2OW.	79
E2EM1Ps	78	L1AB2H.	21		
		L1OWH.	132	PAB.	0
E2RF2M	5	L1OWHH.	23		
		L1OWHHX.	1,057	PEM.	8,489
E2SS	24	L1OWHx.	11		
E2SS3	1	L1OWV.	83	PFL.	418
E2USM	107	L2AB5.	25	PFO.	266
E2USN	784	L2AB5h.	75		
E2USNs	17	L2AB6F.	57	POW.	538
E2USNx	0	L2AB7G.	18		
E2USP	1,212	L2AB7H.	34	PSS.	417
E2USPs	92	L2AB7T.	13		
				R1FL.	8
L1UBH	24	L2FLC.	10		
L1UBHx	57	L2FLH.	17	R1OW.	170
L1UBV	81	L2FLR.	45		
		L2FLU.	27	R1SB.	14
L2AB5	120				

L2AB5h	64	L2OWF.	82	R2OW.	326
		L2OWFHX.	7		
L2UB	21	L2OWG.	14	R2SB.	14
L2UBFx	880	L2OWGh.	11		
L2UBKh	98			R4OW.	1
		PAB4F.	21		
L2USKh	130	PAB5HH.	16	R4SB.	18
L2USKhs	780	PAB6FHX.	1		
		PAB7F.	11	U.	230,741
PAB	2	PAB7FD.	1		
PAB1Khs	6	PAB7T.	9		
PAB4F	41				
PAB4Fx	8	PEM1A.	1,613		
PAB5	49	PEM1AHX.	217		
PAB5h	11	PEM1Ad.	10		
PAB5x	142	PEM1Ah.	6		
		PEM1Ax.	3		
PEM1A	2,577	PEM1C.	2,874		
PEM1Ad	52	PEM1CD.	13		
PEM1Ah	52	PEM1CH.	3		
PEM1Ax	63	PEM1CHX.	1		
PEM1C	1,150	PEM1CX.	1		
PEM1Cd	11	PEM1Cd.	30		
PEM1Ch	120	PEM1Ch.	8		
PEM1Cx	113	PEM1F.	531		
PEM1F	481	PEM1FD.	3		
PEM1Fh	32	PEM1FH.	3		
PEM1Fx	132	PEM1FHX.	0		
PEM1Khs	174	PEM1FU.	22		
PEM1R	367	PEM1FX.	2		
PEM1S	268	PEM1Fh.	3		
PEM1T	38	PEM1Fx.	16		
		PEM1R.	806		
PFO1A	500	PEM1S.	22		
		PEM1T.	115		
PSS1A	383	PEM1Y.	817		
PSS1Ah	2	PEM1YHX.	0		
PUB	95	PFLC.	20		
PUBCh	42	PFLJ.	10		
PUBCx	10	PFLR.	48		
PUBFh	65	PFLY.	22		
PUBHx	502	PFLYX.	7		
PUBKh	44				
PUBKhs	53	PFO1A.	172		
PUBT	3	PFO1R.	4		
		PFO6.	1		
PUS	216	PFO65.	1		
PUSCx	55	PFO6A.	66		
PUSKhs	101	PFO6C.	13		
PUSh	56	PFO6F.	1		

		PFO6R.	18
R1UBV	21	PFO6S.	47
		PFO6Y.	34
R2AB5	1	PFOGY.	3
R2UBH	244	POW.	34
		POWF.	440
R2USA	0	POWFH.	9
		POWFHX.	26
R4SB	1	POWFX.	223
		POWFh.	38
R4UB	6	POWFhx,	0
		POWFhx.	13
U	231,844	POWFx.	26
		POWG.	15
		POWGH.	3
		POWGHX.	7
		POWGX.	7
		POWGhx.	3
		POWH.	54
		POWHH.	24
		POWHHX.	3
		POWHX.	94
		POWHx.	30
		POWT.	21
		PSS1A.	194
		PSS1Ax.	0
		PSS6A.	633
		PSS6C.	248
		PSS6CD.	10
		PSS6R.	86
		PSS6S.	6
		R1FLR.	17
		R1OWV.	139
		R2OWH.	301
		R2FLA.	4
		R4SB.	17
		R4OW.	0
		U.	64,434
		UA.	127,347
		UAR.	96
		UB.	43
		UBS.	453

UF6.	9,074
UF7.	1
UU.	24,742
UUO.	1,851
UUO/A.	563
UUO/F6.	140
UUOA.	51
UUo.	9