STATUS AND TRENDS OF INLAND WETLAND AND AQUATIC HABITATS, FREEPORT AND SAN ANTONIO BAY AREAS

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EXECUTIVE SUMMARY

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Introduction

Wetland and aquatic habitats are essential components of estuarine and inland 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 two investigations designed to determine current status and historical trends of wetlands and associated aquatic habitats along (1) the Texas Gulf coast from the Brazos River southwestward to Caney Creek, an area that includes the San Bernard River valley near Freeport, and (2) San Antonio Bay, the bay system that includes the Guadalupe River delta and extends from Espiritu Santo Bay to the Aransas National Wildlife Refuge. The northern study area is within Brazoria and Matagorda Counties, and the southern study area is within Calhoun and Refugio Counties (Fig. I).

The two study areas are very different. The area near Freeport is part of a delta plain without natural barrier islands. Islands that front this part of the coast were created by the Gulf Intracoastal Waterway (GIWW) that was dredged across this mainland area to connect the Galveston Bay system with the Matagorda Bay system. Included in this area are the Stringfellow and Peach Point Wildlife Management Areas (WMA's). Along this stretch of coast, the Brazos and San Bernard Rivers discharge into the Gulf of Mexico.

The dominant feature of San Antonio Bay is the bayhead delta at the mouth of the Guadalupe River. The delta, situated gulfward of the confluence with the San Antonio River, has been hydrologically modified to manage fresh-water inflow to the bay. The system is characterized by secondary bays, including Hynes Bay and Mission Lake, and expansive brackish- and saltwater ponds and marshes.

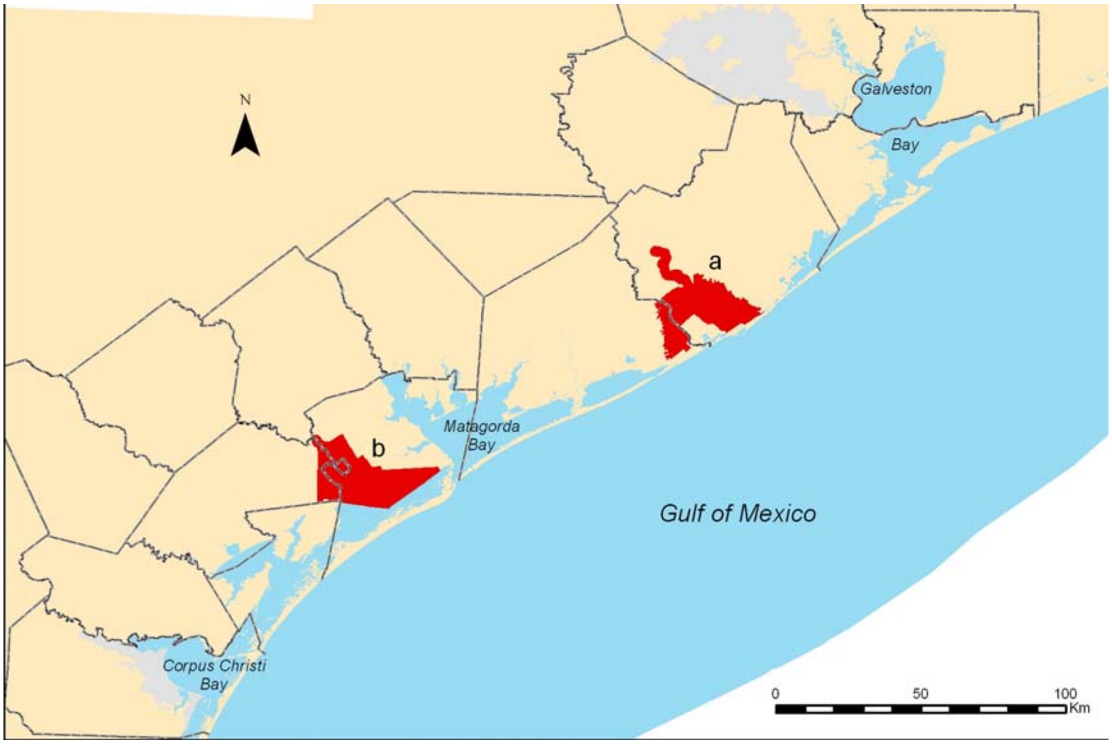

Figure I. Index map of wetland status and trends study areas. (a) Freeport and (b) San Antonio Bay.

Methods

This study of status and trends is based on wetlands interpreted and mapped on recent and historical aerial photographs. Current distribution (status) of wetlands was determined using color infrared (CIR) photographs taken in 2009. 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) (Office of Biological Services, U.S. Fish and Wildlife Service, personal communication, 1983), who mapped the wetlands using methods established as part of the National Wetlands Inventory program. Methods included interpreting and delineating habitats on aerial photographs, field-checking delineations, and transferring delineations to 1:24,000-scale base maps using a zoom transfer scope. The resulting maps were digitized and entered into a GIS, producing GIS maps for the two time periods. Both the 1950's and 1979 series USFWS maps, which are in digital format, were partly revised in this project to be more consistent with wetlands interpreted and delineated on the 2009 photographs.

Methods used to delineate 2009 habitats differed from the earlier methods. The 2009 photographs were scanned to create digital images with a pixel resolution of 0.5 m and registered to USGS Digital Orthophoto Quadrangles (DOQ's). Wetlands and aquatic habitats were mapped through interpretation and delineation of habitats onscreen in a GIS at a scale of 1:5,000. The resulting current-status GIS maps were used to make direct comparisons with the historical GIS maps to determine habitat trends and probable causes of trends.

Wetlands were mapped in accordance with the classification by Cowardin et al. (1979), in which wetlands are classified by system (estuarine, riverine, palustrine, lacustrine), subsystem (reflective of hydrologic conditions), and class (descriptive of vegetation and substrate). Maps for 1979 and 2009 were additionally classified by subclass (subdivisions of vegetated classes only), water regime, and special modifiers. Field sites were examined to characterize wetland plant communities, define wetland map units, and ground-truth delineations. Topographic surveys conducted at several field sites provided data on relative elevation that helped define habitat boundaries and potential frequency of flooding or water regimes.

In analyzing trends, we emphasized wetland classes over water regimes and special modifiers because habitats were mapped only down to class on 1950's photographs. There is a margin of error in interpreting and delineating wetlands on aerial photographs, transferring delineations to base maps, and georeferencing the different vintages of maps to a common base for comparison. Accordingly, we have more confidence in the direction of trends than absolute magnitudes. Probable causes of historical changes are presented in discussions of geographic subareas.

Freeport Area

The Brazos and the San Bernard Rivers cross the Freeport study area and discharge southwest of Freeport into the Gulf of Mexico. In 1929, the lower reach of the Brazos River was diverted so that the mouth of the river now discharges about 10 km down the coast (southwest) from its original location near Surfside (McGowen et al., 1976). The "abandoned" part of the channel has been jettied and dredged to create the Freeport Ship Channel. Historically high rates of erosion have characterized this part of the Texas coast, which is part of the relict deltaic headland of the Colorado and Brazos Rivers (McGowen et al., 1976). Erosion rates have locally exceeded 12 m/yr (Morton and Pieper, 1975; Paine and Morton, 1989; Gibeaut et. al., 2000). Most of the study area extends from the GIWW inland to the coastal-zone management boundary. The boundary extends farthest inland along the entrenched San Bernard River valley. The study area encompasses parts of 10 USGS 7.5′ quadrangles and is located within Brazoria and Matagorda Counties.

Current Status, 2009

Major habitats in the estuarine and palustrine system include salt, brackish, and fresh marshes, forest and scrub/shrub, tidal flats, oyster reefs, and aquatic beds. Estuarine open water is also an important component of the salt and brackish marsh complex.

In 2009, wetland and aquatic habitats were dominated by estuarine marshes (Fig. II), with a total area of about 6,907 ha (17,061 acres), followed by palustrine marshes totaling 5,314 ha (13,723 acres). These marshes make up 62% of the Freeport study area. The other major component of the study area is forest and scrub/shrub. However, owing to interpretational differences, forest area is not emphasized. Other habitats include open water and uplands. The study area was subdivided into geographic subareas—Cedar Lake Creek, San Bernard, Brazos, and Bryan Mound—to allow a more site-specific analysis of status and trends (Figs. III and IV).

The most extensive estuarine emergent wetlands (brackish- and saltwater marshes) occur in the Brazos subarea, where 4,929 ha (12,180 acres) of estuarine marsh was mapped on 2009 photos (Fig. III). Brazos also contains the most palustrine marsh (2,684 ha; 6,632 acres) and estuarine open water (701 ha; 1,732 acres). Of the four subareas, Cedar Lake Creek has the most extensive forests (2,704 ha; 6,682 acres) (Fig. III). Tidal flats are not widely distributed in this coastal area.

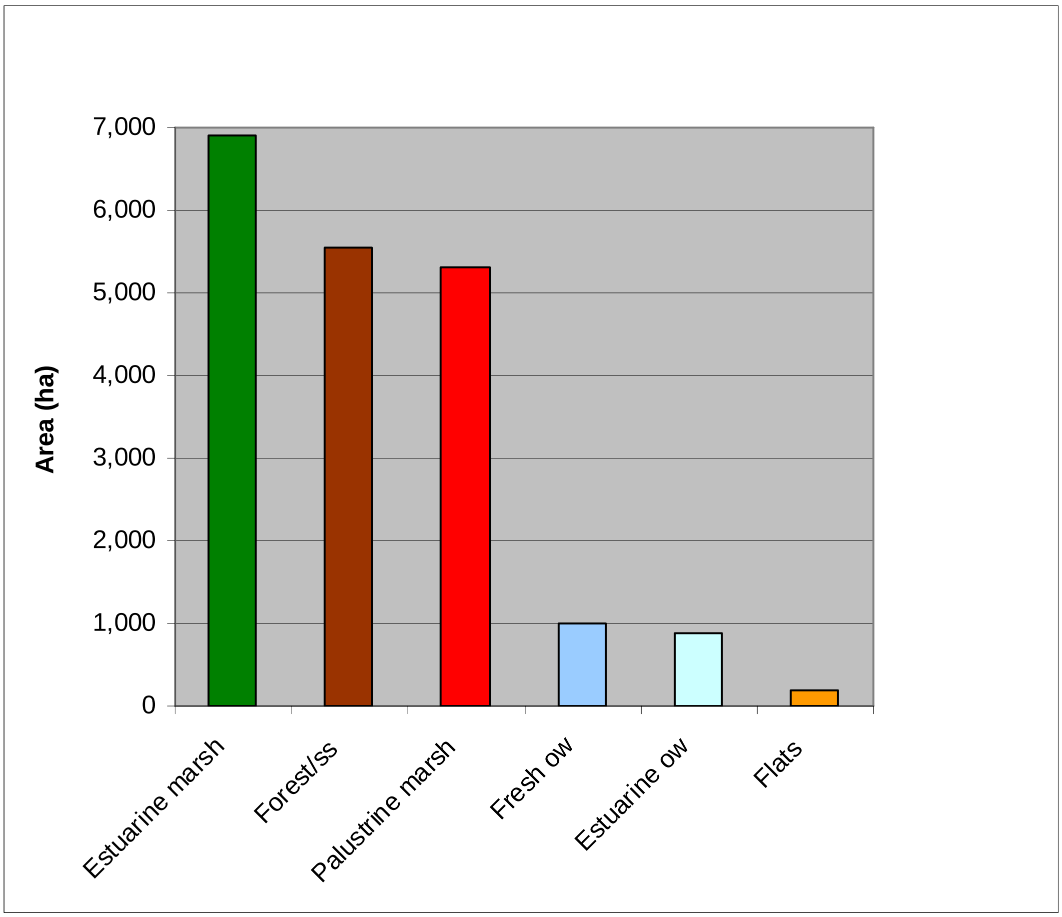

Figure II. Areal distribution of selected habitats in the Freeport study area in 2009.

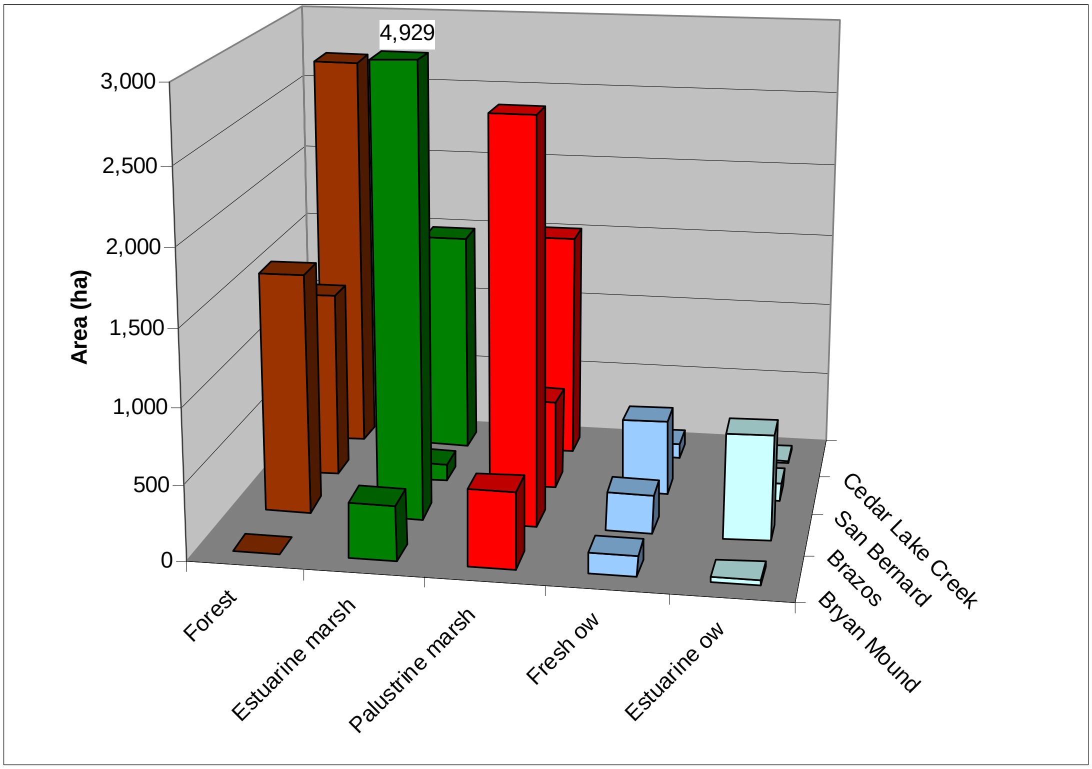

Figure III. Distribution of selected habitats by geographic area in 2009. The most extensive estuarine and palustrine marshes are in the Brazos subarea.

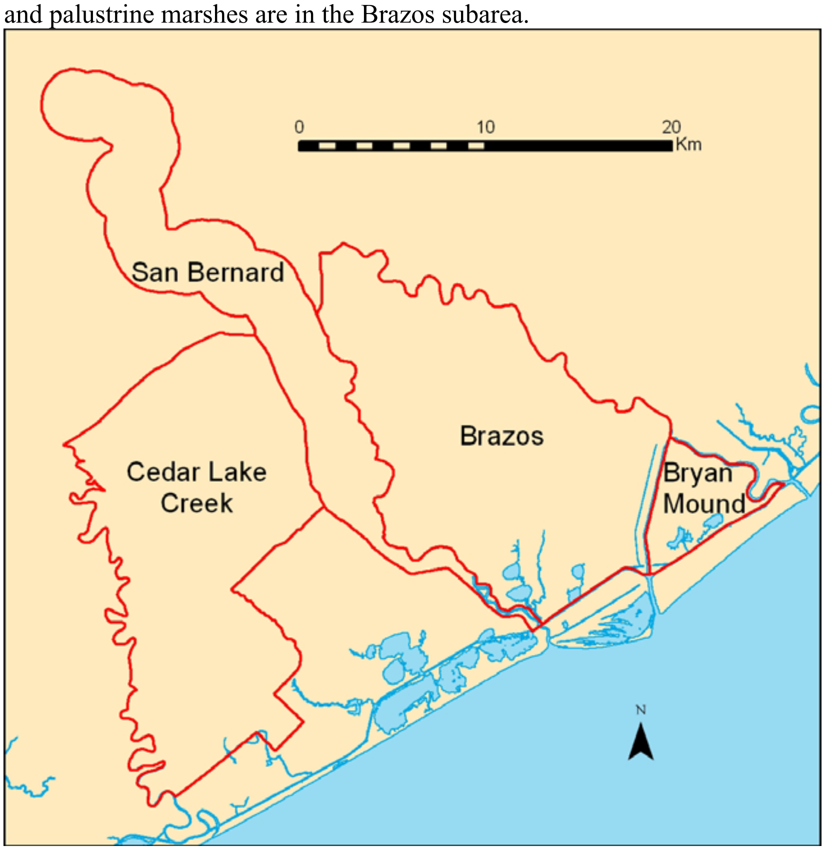

Figure IV. Index map of study area subdivided into the following subareas: Cedar Lake Creek, San Bernard, Brazos, and Bryan Mound.

Wetland Trends and Probable Causes, 1950's–2009

From the 1950's through 2009 within the Freeport study area, there were losses and gains in most habitats. Analyses of spatial and temporal changes show that there was a net gain in estuarine marshes from the 1950's through 2009 (Fig. V). The total area of estuarine marsh increased from 5,238 ha (12,939 acres) in the 1950's to 6,416 ha (15,847 acres) in 1979 to 6,906 ha (17,060 acres) in 2009 (Table I; Fig. V).

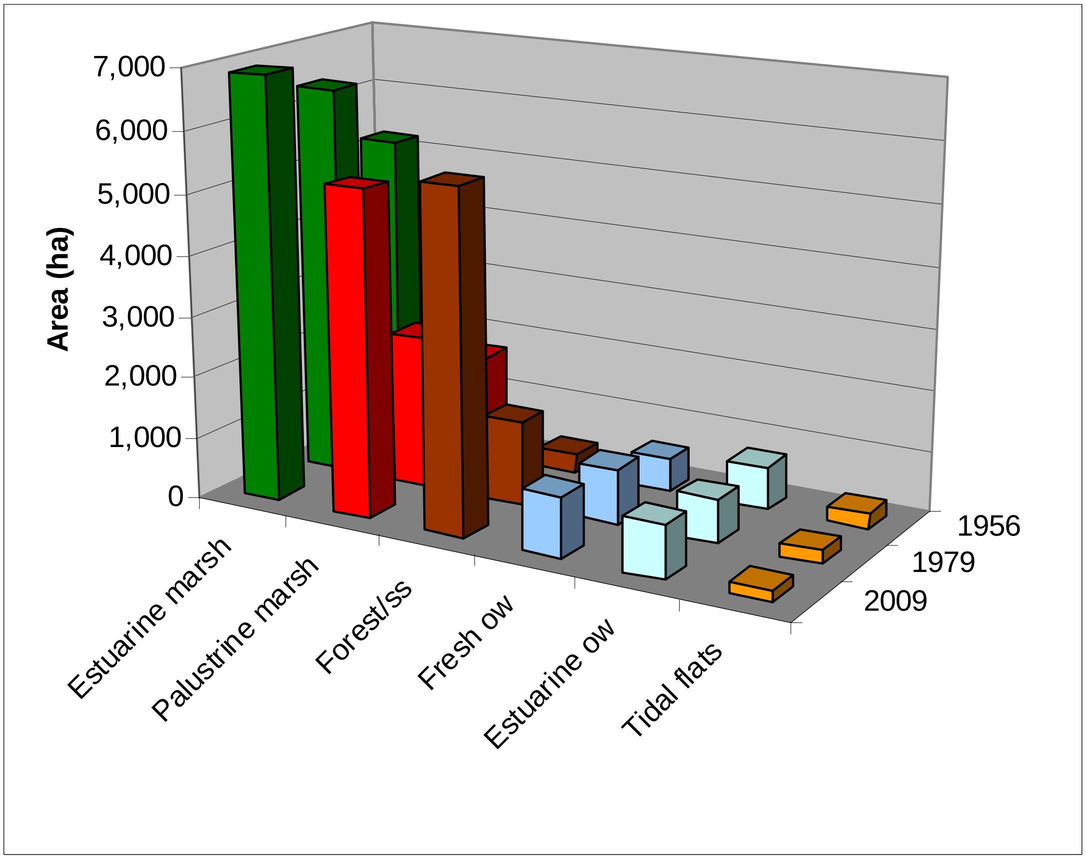

Figure V. Areal distribution of selected habitats in the Freeport study area in the 1950's, 1979, and 2009.

This increase totaled 1,669 ha (4,122 acres) from the 1950's through 2009. During the same time, there was a systematic decrease in tidal flats (E2FL or E2US). The area of flats declined from 249 ha (616 acres) in the 1950's to 219 ha (540 acres) in 1979 to 183 ha (452 acres) in 2009 (Table I). These changes reflect a loss of 66 ha (164 acres) by 2009. Palustrine marshes (PEM) increased in area by 772 ha (1,906 acres) from the 1950's through 1979 and by 2,808 ha (6,935 acres) from 1979 through 2009. The mapped area of forest, including scrub/shrub, increased from the 1950's through 2009 by approximately 5,210 ha (12,868 acres). Distinguishing between upland and wetland forest is difficult, however, and total distribution, as interpreted on aerial photographs, is approximate. The area of fresh open water increased from the earlier years to 2009 by roughly 441 ha (1,090 acres) (Fig. V). Estuarine open water in the study area also increased slightly from the 1950's through 1979 and 2009. Probable causes of changes in habitats are presented in the following sections organized by geographic subarea.

Table I. Total area of major habitats in the Freeport study area in the1950's, 1979, and 2009.

Habitat	1950's		1979		2009	
	(ha)	(acres)	(ha)	(acres)	(ha)	(acres)
Estuarine marsh	5,238	12,939	6,416	15,847	6,907	17,060
Palustrine marsh	1,735	4,285	2,506	6,191	5,314	13,126
Forest/scrub-shrub	346	855	1,377	3,402	5,556	13,723
Fresh open water	550	1,357	895	2,211	991	2,448
Estuarine open water	711	1,756	722	1,783	875	2,161
Tidal flat	249	616	219	540	183	452

The most significant trend, or change, in the **Cedar Lake Creek** subarea was the gain of palustrine marsh from the 1950's through 1979 and 2009. Although losses and gains in marshes were at different locations through time, the total area of marsh habitat, which was about 659 ha (1,628 acres) in the 1950's, increased in size by 74 ha (183 acres) through 1979 but increased by 1,048 ha (2,589 acres) from 1979 through 2009. The net gain from the 1950's through 2009 was 1,122 ha (2,772 acres). This increase in marsh represents a gain of about 274% of this habitat in the Cedar Lake Creek subarea since the 1950's. The increase would be larger except for hay cultivation in wet areas that would otherwise be marshland. Also, there was an overall increase in the area of estuarine marsh from the 1950's through 2009. Most gain of estuarine marsh occurred during the early time period, when 659 ha (1,628 acres) of marsh in 1956 had increased to 1,606 ha (3,967 acres) by 1979. Estuarine marsh area had decreased slightly to 1,495 ha (3,692 acres) by 2009. Long-term change in estuarine marsh between 1956 and 2009 was an increase of 127% of the original resource. Open water increased in area during this period, although the total area of this habitat was relatively small. The 274% increase in palustrine marsh from the 1950's through 2009 occurred as marshes occupied areas of lower elevation, possibly the result of local subsidence. Estuarine marsh also increased as a result of relative sea-level rise, mostly inland from the San Bernard National Wildlife Refuge (SBNWR). GIS overlay analysis of habitat distribution indicates that nearly all marsh gain in the Cedar Lake Creek subarea was the result of conversion to upland habitat. The significant increase in forest area mapped in 2009 is due to interpretational differences. Many large tracts of forest, especially in the Stringfellow Wildlife Management Area (WMA), were not previously mapped.

The **San Bernard** subarea experienced a systematic gain in palustrine marshes between the mid-1950's and 2009. Palustrine marsh increased from a mid-1950's total of 62 ha (154 acres) to 181 ha (448 acres) in 1979, representing an increase of 191%. The subsequent increase to 599 ha (1,479 acres) in 2009 represents an additional 230%. As much as 95% of the gross palustrine-marsh gain over the length of the study occurred where mid-1950's uplands were mapped in 2009 as palustrine marsh. Much of the marsh increase occupied the area between the SBNWR boundary and the San Bernard River. Estuarine-marsh area fluctuated through time. Between the mid-1950's and 1979, marsh numbers decreased from 24 ha (59 acres) to a low of 8 ha (20 acres). By 2009, the area of estuarine marsh had increased more than 1,000% to 116 ha (286 acres). As with palustrine marsh, most estuarine marsh moved into areas previously mapped as upland. Marsh gain occurred between the San Bernard River and the eastern boundary of the SBNWR. Marsh gain in the San Bernard area is attributed to increased rates of relative sea-level rise. The small amount of tidal flat in the San Bernard area was halved between 1956 and 2009, when 28 ha (69 acres) was reduced to 14 ha (35 acres), respectively. Interpretational differences between mapping periods account for most of the gain in forest area.

The most significant trend or change in the **Brazos** subarea was a gain of about 115% of the palustrine-marsh habitat from the 1950's through 2009. The total area of fresh marshes, which covered 1,248 ha (3,083 acres) in the 1950's, had increased by 1.436 ha (3,546 acres) to a total of 2,684 ha (6,629 acres) by 2009. Coincident with the gain of palustrine marsh in this subarea was an increase in estuarine marsh of 1,368 ha (3,380 acres). Other changes included a decline in tidal flats and a systematic increase in open water through time. The 115% increase in palustrine-marsh habitat in the Brazos subarea can be attributed principally to management practices in the Peach Point WMA. Dikes constructed after 1979 impeded the flow of fresh water and converted other habitats to palustrine marsh. Of the newly created marsh, roughly 80% was in areas previously mapped as upland and 19% in areas previously mapped as estuarine marsh. Estuarine-marsh gain was also primarily (77%) from previous uplands and from previous fresh marsh (16%). Movement of salt marsh into uplands and fresh marsh is attributed to relative sea-level rise.

Palustrine marsh experienced a systematic gain in the **Bryan Mound** subarea when 15 ha (38 acres) in the mid-1950's increased to 380 ha (939 acres) in 1979 and further increased to 500 ha (1,234 acres) in 2009. Hydrologic modification in this industrial area had converted salt marsh to fresh marsh by 1979. By 2009, the area of palustrine-marsh increase was mostly (72%) from areas previously mapped as estuarine marsh. Conversion to fresh marsh is evident in the (-)63% loss of the original 994 ha (2,456 acres) of estuarine marsh. In 1979, estuarine marsh had been reduced to 495 ha (1,222 acres) and had been further reduced to a low of 367 ha (908 acres) by 2009. Half of the estuarine-marsh loss had converted to palustrine marsh. Tidal flats lost 14% of the resource between the mid-1950's and 2009. A small area of palustrine flats expanded significantly over the same time period. Expansion occurred in areas mapped as salt marsh in the mid-1950's, fresh marsh and open water in 1979, and 184 ha (454 acres) of palustrine flat in 2009.

San Antonio Bay Area

The dominant feature of San Antonio Bay is the bayhead delta at the mouth of the Guadalupe River. The delta is situated gulfward of the confluence with the San Antonio River and is characterized by several inactive distributary channels. Construction of Traylor Cut in 1935 produced the most active channel (White et al., 1989). The system is characterized by secondary bays, including Hynes Bay and Mission Lake, and expansive brackish- and saltwater ponds and marshes. The mouth of San Antonio Bay opens into Espiritu Santo Bay and is straddled on either side by a relict Pleistocene barrier strandplain. The study area, encompassing parts of 10 USGS 7.5′ quadrangles, is located within Calhoun and Refugio Counties.

Current Status, 2009

In 2009, wetland and aquatic habitats covered 36,139 ha (89,301 acres) within the San Antonio Bay study area. Of the four wetland systems mapped, the palustrine system is the largest. The largest habitats are the open-water and marsh classes (Fig. VI), together covering 23,188 ha (57,299 acres). Emergent vegetated wetlands (E2EM, E2SS, PEM) cover 11,044 ha (27,290 acres), with roughly equal amounts of palustrine and estuarine marsh. Other important habitat classes are seagrass (E1AB3), which in the study area has an area of 2,388 ha (5,898 acres); tidal-flat (E2US), which has 1,725 ha (4,261 acres); and fresh open water, which has 1,506 ha (3,720 acres). The study area was subdivided into geographic subareas—Blackjack, San Antonio River, Guadalupe, Strandplain, Espiritu Santo, and San Antonio Bay—to allow a more site-specific analysis of status and trends (Figs. VII and VIII).The extent of all mapped wetlands, deepwater habitats, and uplands for each year is presented in Appendix 2.

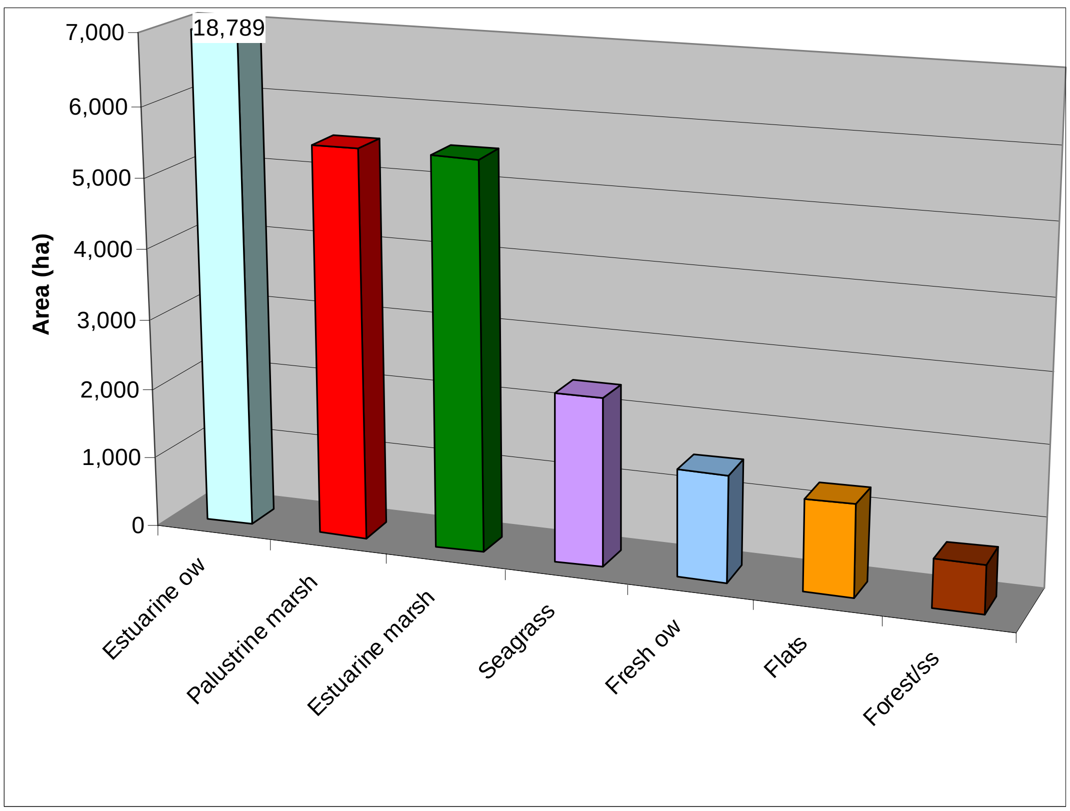

Figure VI. Areal distribution of selected habitats in the San Antonio Bay study area in 2009.

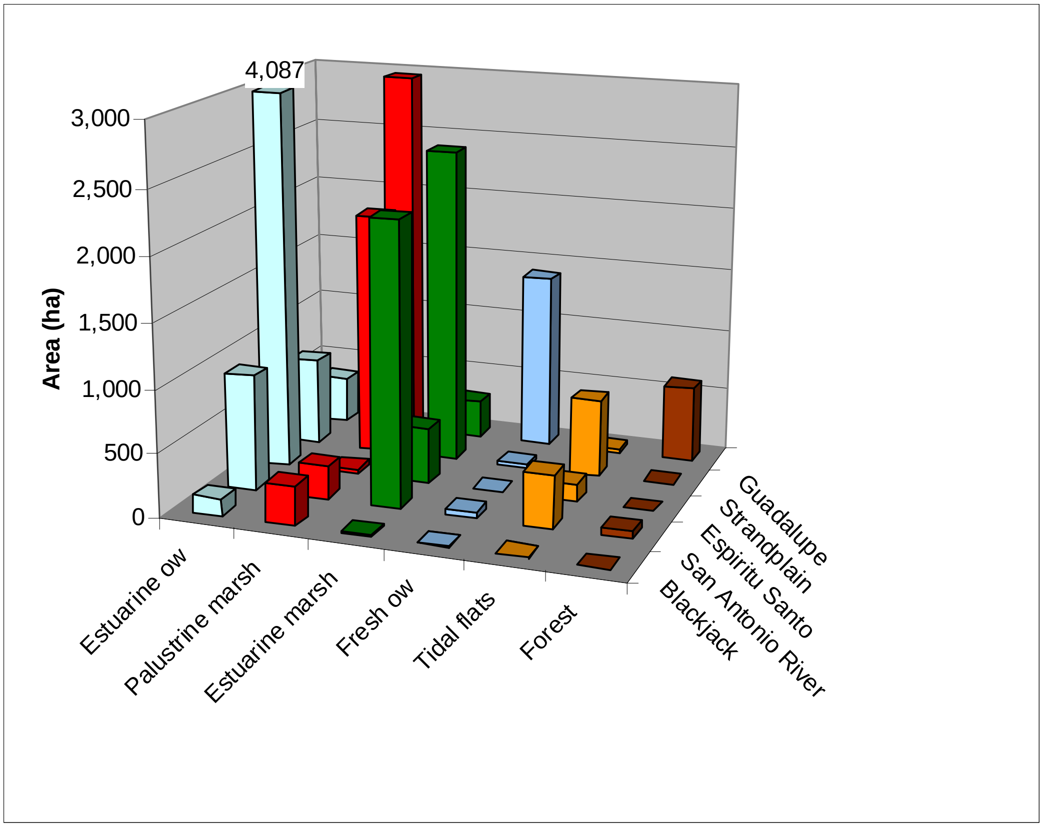

Figure VII. Areal distribution of selected habitats by geographic area in 2009, San Antonio Bay study area.

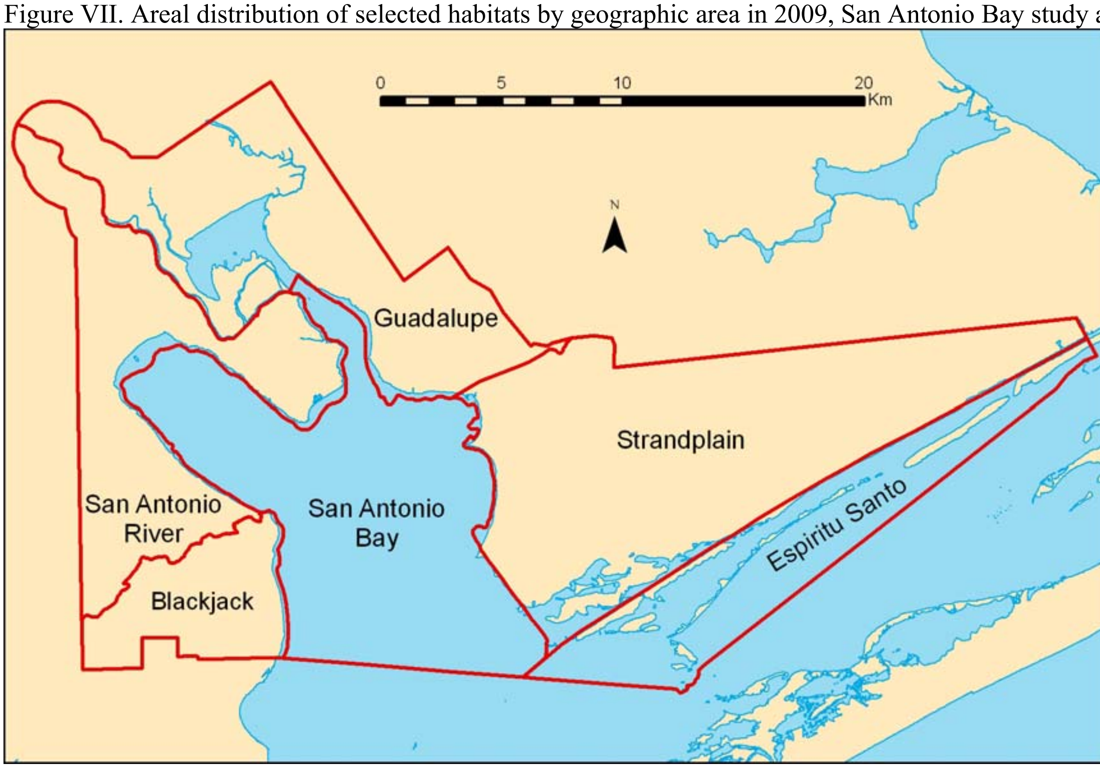

Figure VIII. Index map of study area subdivided into the following subareas: Blackjack, San Antonio River, Guadalupe, Strandplain, Espiritu Santo, and San Antonio Bay.

Wetland Trends and Probable Causes, 1950's–2009.

Analysis of trends in wetlands and aquatic habitats from the 1950's through 2009 shows that palustrine marsh decreased from the 1950's through 1979 and increased from 1979 through 2009 (Table II; Fig. VII). Palustrine marsh is the most extensive habitat. The lesser distribution in 1979 may be partly related to interpretational differences. However, land-management practices and accelerated relative sea-level rise had reduced palustrine-marsh area by 2009. The total area of estuarine marsh increased 58% between the mid-1950's and 1979, remaining relatively stable thru 2009. Estuarine habitats had their largest distribution of 5,508 ha (13,605 acres) in 2009. The difference in total area was larger than that of the 1950's (3,281 ha; 8,103 acres) but relatively consistent with the amount found in 1979 (5,170 ha; 12,771 acres). The large difference in area of estuarine marsh between the mid-1950's and 2009 was mostly interpretational but was also due somewhat to management practices. Tidal flats lost 22% of the original resource of 2,211 ha (5,460 acres), diminishing to 1,725 ha (4,261 acres) in 2009. The tidal-flat low of 1,399 ha (3,456 acres) in 1979 was likely due to wetter ground conditions at the time of photography. The depletion of tidal flats is a coastwide phenomenon. Fresh, open-water area increased through time in the San Antonio Bay area, with the greatest amount of 1,814 ha (4,480 acres) in 1979. Conversely, the amount of forest declined drastically between the mid-1950's and 2009, with a low of 614 ha
(1,516 acres) in 1979. More than 70% of the forest area in 1956 was mapped as palustrine scrub-shrub (PSS); relatively little PSS was mapped in later years. More detailed probable causes of changes are presented in the following sections, organized by geographic area.

Table II. Total area of major habitats in the San Antonio Bay study area in the 1950's, 1979, and 2009.

Habitats	*1950's*		*1979*		*2009*	
	(ha)	(acres)	(ha)	(acres)	(ha)	(acres)
Palustrine marsh	6,547	16,171	4,742	11,713	5,536	13,674
Estuarine marsh	3,281	8,103	5,170	12,771	5,508	13,605
Tidal flats	2,211	5,460	1,399	3,456	1,725	4,261
Fresh open water	1,277	3,154	1,814	4,480	1,506	3,720
Forest/scrub-shrub	1,667	4,117	614	1,516	687	1,697

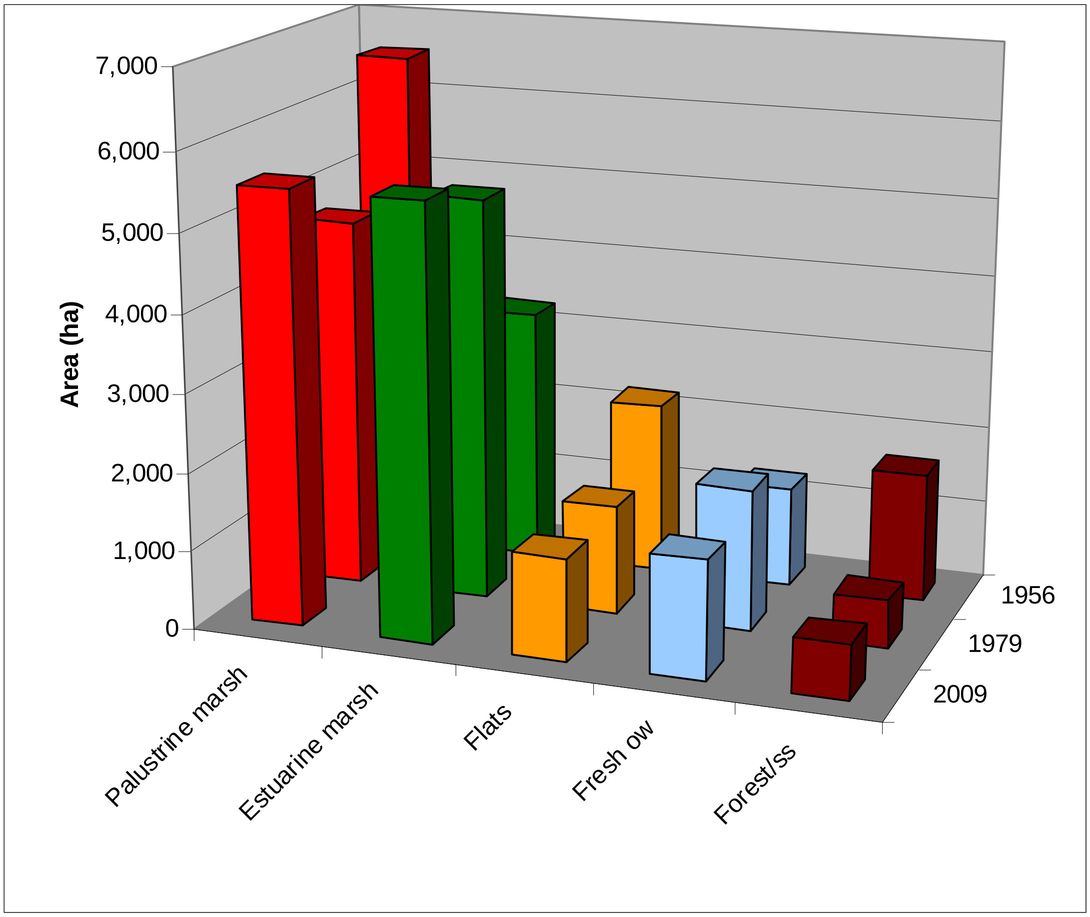

Figure IX. Areal distribution of selected habitats in the San Antonio Bay study area in the 1950's, 1979, and 2009.

The most significant habitat trend in the **Blackjack** subarea is the decrease in palustrine marsh from a total of 464 ha (1,146 acres) in the mid-1950's to 314 ha (775 acres) in 2009 (-32% loss). Wetter ground conditions from high rainfall in 1979 may have inflated palustrine-marsh area to a high of 572 ha (1,410 acres). Estuarine-marsh area remained stable through time. However, location of estuarine marsh in the Blackjack subarea changed. The smallest amount of marsh occurred in 1979, with a total of 108 ha (267 acres). When a tidal inlet to the north of the area had been dammed most of the 131 ha (324 acres) of estuarine marsh had become open water by 1979. Dikes constructed at Webb Point had converted fresh marsh to salt marsh by 2009, returning estuarine marsh area amounts to mid-1950's numbers. A small amount of estuarine open water was reduced by more than half over the length of the study .

In the **San Antonio River** subarea, palustrine marsh decreased by half the original amount through the study . Of the 556 ha (1,373 acres) in 1956, only 266 ha (657 acres) was remaining by 2009. Very little palustrine marsh was mapped in 1979. Conversely, there was a systematic increase in estuarine marsh, with a gain of 452 ha (1,117 acres) from the 1950's through 2009. By 1979, most of the fresh marsh in the upper reaches of Townsend Bayou had been replaced by salt marsh. Tidal-flat area remained stable between the mid-1950's and 1979 at about 180 ha (445 acres), increasing to 415 ha (1,025 acres) by 2009. Most of the increase occurred in areas previously mapped as salt marsh or open water. A large area of tidal-flat increase was along the shoreline of Hynes Bay at Townsend Bayou. This area was mapped as marsh in 1956, open water in 1979, and irregularly exposed flat (E2USM) in 2009, the wettest water regime being assigned to flats. Many flats were mapped in the lower reaches of Townsend Bayou and in the Long Lake area in 2009. Only half of the forest area mapped in the mid-1950's was mapped in 2009.

The **Guadalupe** subarea has experienced relative stability through time. Estuarine marsh, a minor component of the vegetated emergent wetlands in this area, did increase in area by 179%, from 108 ha (266 acres) in the 1950's to 301 ha (743 acres) in 2009. Palustrine marsh is much more abundant in this subarea and increased only slightly by 7%, from 2,777 ha (6,859 acres) in the 1950's to 2,960 ha (7,311 acres) in 2009. Like most of the San Antonio Bay area, forest/scrub-shrub was mapped in 2009 at less than 60% of the original area in the mid-1950's. This change is due primarily to interpretational differences between time periods. Large tracts of palustrine scrub/shrub were mapped in the mid-1950's. What species composed these large scrub/shrub areas is unclear.

The most significant change in the **Strandplain** subarea was the 258% increase in estuarine marsh when 701 ha (1,731 acres) in the mid-1950's had increased to 2,505 ha (6,187 acres) by 2009. Most (39%) salt marsh gain was from previous uplands, primarily along the GIWW. Estuarine marsh also moved into areas mapped in the 1950's as palustrine marsh and tidal flat. Mosquito Point, inland from Welder Flats, was the main area where salt marsh moved into other wetland habitats. The peak estuarine marsh area in 2009 was from mapping of salt marsh at locations farther inland than those mapped in other time periods. Palustrine marsh numbers decreased with a (-)29 % loss between the mid-1950's total of 2,745 ha (6,781 acres) and 2009 total of 1,948 ha (4,812 acres). Following a coastwide trend, tidal flats decreased (-38%) in overall area between the mid-1950's and 2009. The 1950's total of 991 ha (2,448 acres) had increased slightly by 1979 to 939 ha (2,321 acres) but had decreased to 614 ha (1,517 acres) by 2009. Roughly half of the decrease was to salt marsh, mostly regularly flooded salt marsh. Another 23% of the tidal-flat loss area became seagrass. Unlike tidal flats, seagrass expanded in the Strandplain subarea through time. The gain of 142 ha (351 acres) equated to a 33% increase over the original resource amount.

A coastwide trend also occurs in the **Espiritu Santo** subarea, where tidal flats experienced a systematic decrease through time. In the mid-1950's, tidal flats covered 868 ha (2,144 acres), by 1979, the area had been reduced to 219 ha (542 acres), and it had been further reduced to 142 ha (351 acres) by 2009. The GIWW was rechannelized between 1956 and 1979, resulting in 64% of the tidal-flat area being replaced with estuarine open water and seagrass. Uplands also replaced many flats, and by 2009 salt marsh had also moved into previously flat areas. The overall loss of 726 ha (1,794 acres) totals (-)84% of the original resource. Like tidal flats, estuarine marsh also lost area over the span of the study. A high of 608 ha (1,501 acres) was mapped in the mid-1950's, followed by a decrease to 411 ha (1,015 acres) by 1979. A slight increase to 442 ha (1,093 acres) was mapped in 2009. The overall change in salt marsh amounted to a (-)27% loss of the resource. Most (52%) of the marsh-loss area in 1979 had been converted to estuarine open water, but equal amounts of marsh area had been converted to seagrass and upland. Marshes were converted to uplands along the GIWW, where most of the tidal-flat loss had also occurred. Marsh loss to open water and seagrass occurred mainly gulfward of the series of islands, including Blackberry and Dewberry Islands and Long Island. Marsh along the Espiritu Santo Bay side of the islands appears to have been eroded. Erosion along Steamboat Pass has also diminished marshes on Grass Island and the island near South Pass. Overall, seagrass is abundant in the Espiritu Santo subarea, increasing by 22% over the study period. Relatively small numbers of oyster reefs occur here also that increased in area significantly (64%) through time.

STATUS AND TRENDS OF INLAND WETLAND AND AQUATIC HABITATS, FREEPORT AND SAN ANTONIO BAY AREAS

INTRODUCTION

Coastal wetlands on barrier islands 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 is one in a series of wetland status and trends investigations along the Texas coast; two previous investigations complement this study (White et al., 2002, 2005).

Study Areas

Presented here are results of two studies along the Texas Gulf Coast—(1) Freeport southwestward to East Matagorda Bay, an area that includes the Brazos River delta near Freeport, and (2) San Antonio Bay, the bay system that includes the Guadalupe River delta and extends from Espiritu Santo Bay to the Aransas National Wildlife Refuge. The northern study area is within Brazoria and Matagorda Counties, and the southern study area is within Calhoun and Refugio Counties (Fig. 2).

Previous studies of wetland status and trends along the Texas coast by the Bureau of Economic Geology (BEG), for example in the Galveston Bay system (White et al., 1993, 2004), show that substantial losses in wetlands have occurred as a result of subsidence and associated relative sea-level rise. Some of the losses on Galveston Bay barriers have occurred along surface faults that appear to have become active as a result of underground fluid production. In contrast to those of the Galveston Bay system, studies of wetlands on barrier islands in the Matagorda Bay system (White et al., 2002) show that marshes have expanded as a result of relative sea-level rise. Between these two bay systems is the relict Colorado–Brazos River delta complex (McGowen et al., 1976), where extensive wetlands have not been recently studied to determine status and trends, nor have wetlands recently been studied in the San Antonio Bay area. Wetland status and trends and probable causes of trends presented here focus on these two areas, including the Guadalupe River delta in the coastal bend and the Brazos River delta and San Bernard River valley on the central coast. Results help in our understanding of marsh changes on Texas coastal inlands and pinpoint wetlands threatened by development, erosion, faulting, subsidence, and other processes. These data provide site-specific information for implementing management programs for protecting and possibly restoring these valuable natural resources.

Figure 1. Estuarine marsh and open water in the Welder Flats Wildlife Management Area. Plant species include *Borrichia frutescens*, *Spartina* sp., *Salicornia* sp., *Batis maritima* sp., among others.

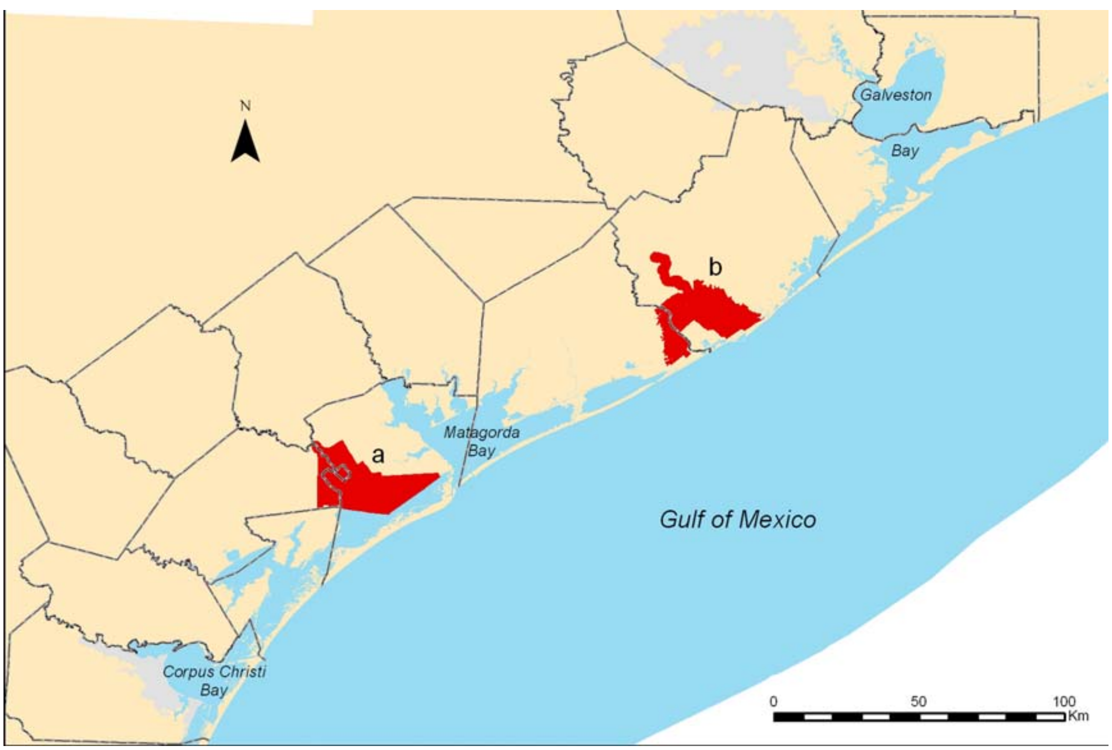

Figure 2. Index map showing the two study areas, (a) San Antonio Bay and (b) Freeport.

METHODS

Mapping and Analyzing Status and Trends

Status and trends of wetlands in the study areas were determined by analyzing the distribution of wetlands mapped on aerial photographs taken in the 1950's, 1979, and 2009. 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 and 2006 aerial photographs. The current status of wetlands in this study is based on photographs contracted by the USDA in 2009. The 1992 and 2006 NWI maps were used as collateral information for interpreting and mapping current wetland distribution.

Wetland Classification and Definition

For purposes of this investigation, wetlands have been classified in accordance with *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):

> 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

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[1] USFWS has prepared a list of hydrophytes and other plants occurring in wetlands of the United States.
[2] NRCS has prepared a list of hydric soils for use in this classification system.

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 observation of vegetation, soil, hydrology, and topography. This information is weighted for seasonality and conditions existing at the time of photography and ground-truthing. Nevertheless, 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-pairs, scale 1:24,000, most of the ones along the Texas coast having been taken in the mid-1950's (Larry Handley, USGS, personal communication, 1997). We think that the photographs covering the Freeport to East Matagorda Bay study area, however, were taken in the early 1950's, on the basis of a comparison of the 1950's wetland delineations with a photograph taken of the Brazos River delta in 1948. The 1979 aerial photographs are NASA color-infrared stereo-pairs, scale 1:65,000, which were taken in November.

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

Photographs used are generally of high quality. Abnormally high precipitation in 1979, however, raised water levels on tidal flats and in many inland fresh to brackish wetlands. Thus, more standing water and wetter conditions were apparent on the 1979 photographs than on the 2009 photographs, which were taken during much drier conditions. Although the 1950's photographs are black and white, they are large scale (1:24,000), which aids in the photointerpretation and delineation process. The 1950's photographs were apparently taken before the severe drought that peaked in 1956 in Texas (Riggio et al., 1987). These differences in wet and dry conditions during the various years affected habitats—especially the palustrine habitat—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 (2009) wetland map units. Revisions of the USFWS data were restricted primarily to estuarine marshes, tidal flats, and areas of open water. The principal reason for the revisions was that in many areas on the historical maps, estuarine, intertidal, emergent wetlands (E2EM) were combined with intertidal flats (E2FL) as a single map unit (E2EM/E2FL). In our revisions, many of these areas were subdivided into E2EM and E2FL where possible at the mapping scale. In addition, because of the larger scale of the 1950's aerial photographs (1:24,000), as compared with that of the 1979 photographs (~1:65,000), smaller wetlands, particularly water features, were mapped on the 1950's photographs. As part of the revisions, many of these smaller water bodies were mapped and added to the 1979 wetland maps.

For revisions, aerial photographs taken in the mid-1950's and 1979 were scanned where necessary and rectified with respect to existing historical maps, and the digital USFWS maps were revised where necessary. Wetlands on the aerial photographs were interpreted, and changes were mapped directly on the screen. The revised data were entered into the GIS.

Current Wetland Distribution (Status)

The current distribution of wetlands and aquatic habitats is based on color infrared (CIR) aerial photographs taken in 2009 under contract with the USDA. Photographs were digital images with a pixel resolution of 0.5 to 1 m and registered to USGS Digital Orthophoto Quads (DOQ's). Interpretation and mapping of wetlands and aquatic habitats were completed by BEG researchers through onscreen delineation of habitats. Delineations were digitized directly into the GIS (ArcGIS) at a scale of 1:5,000. An attempt was made to show about the same amount of detail as that in the historical maps so that accurate comparisons of wetland changes could be made through time. Nevertheless, because of the method used, the current wetland maps show more detail than do the historical maps.

Field Investigations

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

Variations in Classification

Classification of wetlands varied somewhat for the different years. On 1979 and 2009 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. 3–5). 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. 5).

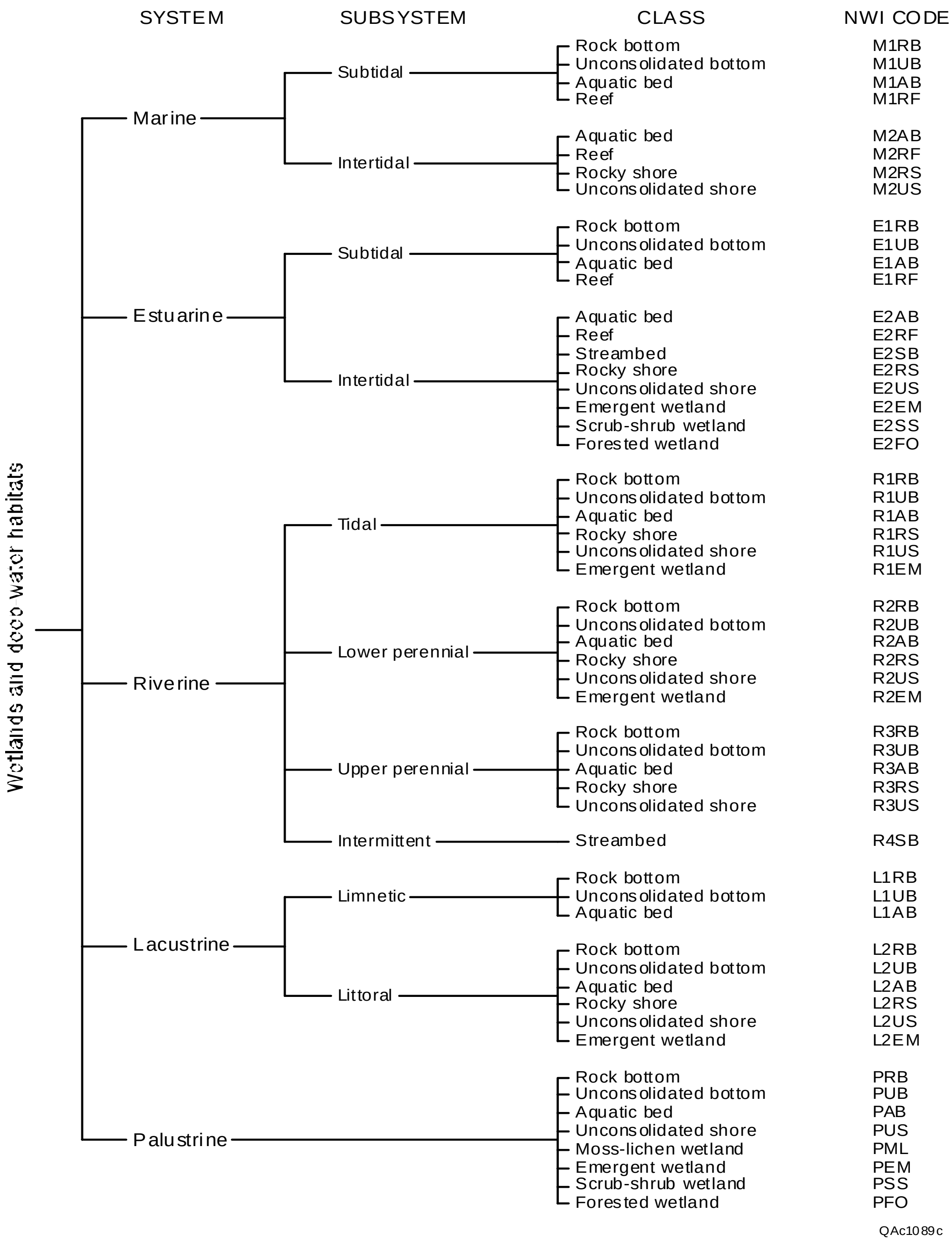


Figure 3. Classification hierarchy of wetlands and deepwater habitats showing systems, subsystems, and classes. From Cowardin et al. (1979).

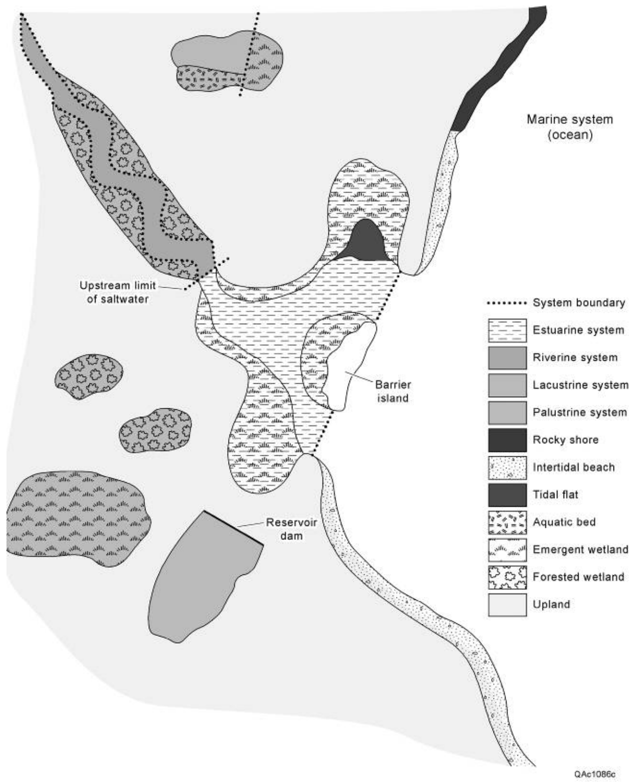


Figure 4. Schematic diagram showing major wetland and deepwater habitat systems. From Tiner (1984).

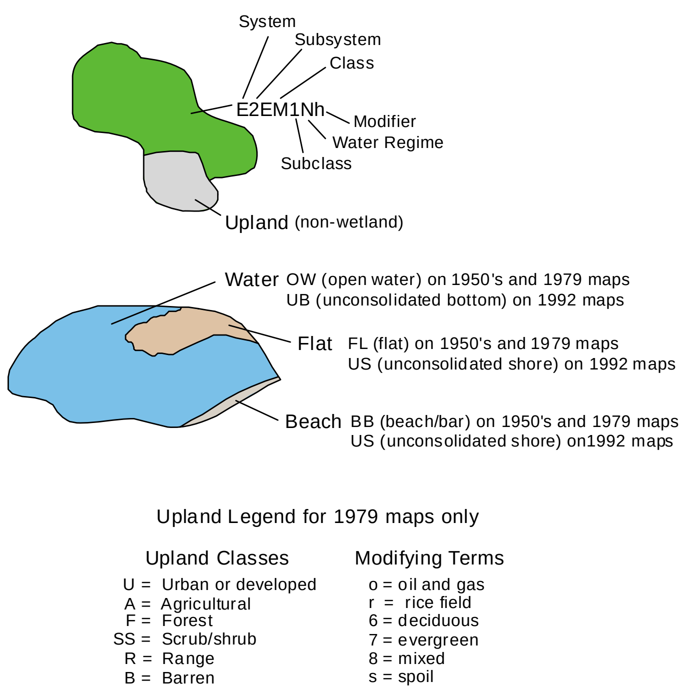


Figure 5. Example of symbology used to define wetland and upland habitats on NWI maps.

Flats and beach/bar classes designated separately on 1950's and 1979 maps were combined into a single class—unconsolidated shore—on 2009 maps, in accordance with updated NWI procedures as exemplified on 1992 NWI wetland maps (Fig. 5). USFWS data for the study area were selected from 7.5′ quadrangles (Figs. 6 and 7) 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 layers corresponding to mapped habitat features for the 1950's, 1979, and 2009. Data can be manipulated as information overlays, whereby scaling and selection features allow parts of the estuary to be selected electronically for specific analysis.

Among the objectives of the GIS are to (1) allow direct historical comparisons of wetland types to gauge historical trends and status of habitats, (2) allow novel comparisons of feature overlays to suggest probable causes of wetland changes, (3) make information on wetlands directly available to managers in a convenient and readily assimilated form—and about as accurate as historical maps—so that accurate comparisons of wetland changes can be made through time (because of the method used, however, the current wetland maps show more detail than do the historical maps), and (4) allow overlays to be combined from wetland studies and other topical studies in a single system that integrates disparate environmental features for planning and management purposes. The GIS is a flexible and valuable management tool for use by resource managers. Users must nonetheless be aware of potential errors—for example, from registration differences—which can arise from direct analysis of GIS overlays.

Map-Registration Differences

Map-registration differences between the historical and recent digital data cause errors when the data sets are overlain and analyzed in a GIS. The 2009 aerial photographs are georeferenced to USGS DOQ's, which show good agreement in registration with the base photographs. However, the historical data sets are not as well registered, and there is an offset in wetland boundaries between historical and 2009 data. When the two data sets are superimposed in a GIS, the offset creates apparent wetland changes that are in reality cartographic errors resulting from a lack of precision in registration. Because re-registration of the USFWS digital data sets was beyond the scope of this project, caution must be used in interpreting changes from direct overlay of the different data sets as layers in a GIS. We tabulated wetland totals separately for each year to determine wetland changes within the given study area. Overlay of the data sets was done primarily to identify significant wetland changes that could be verified by analysis and comparison of aerial photographs.

Figure 6. Index map of USGS 7.5′quadrangles covering the Freeport study area.

Figure 7. Index map of USGS 7.5′ quadrangles covering the San Antonio Bay study area.

Methods Used to Analyze Historical Trends in Wetland Habitats

We determined trends in wetland habitats by analyzing habitat distribution as mapped on 2009, 1979, and 1950's aerial photographs. In analyzing trends, we emphasized wetland classes (for example, E2EM and PEM), with less emphasis on water regimes and special modifiers. This approach was taken because habitats were mapped only down to class level on 1950's photographs and because water regimes can be influenced by local and short-term events, such as tidal cycles and precipitation.

ArcGIS was used to analyze trends. This software allowed for direct comparison, not only between years, but also by geographic areas such as strandplain, river valley, and delta. Analyses included tabulation of losses and gains in wetland classes for each area for selected periods. The GIS allowed cross-classification of habitats in a given area as a means of determining changes and probable cause of such changes. Maps used in this report showing wetland distribution and changes were prepared from digital data using ArcGIS.

Possible Photointerpretation Errors

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

Some apparent wetland changes were due to different scales of aerial photographs. The 1950's aerial photographs were at a scale larger (1:24,000) than those taken in 1979 (1:65,000), affecting 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. Some apparent losses in palustrine wetlands were documented in inland wetlands but appear to be due to the drier conditions when the 2009 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. Nevertheless, users of the data should note that there is a margin of error inherent in photo interpretation and map preparation.

Wetland Codes

As mentioned in the introduction, some wetland codes used on 2009 maps are different from those used on the 1950's and 1979 maps (Fig. 5). In the following discussion of trends, E2US rather than E2FL (used on the 1950's and 1979 maps) is used generally to denote tidal flats, and UB (rather than OW) is used to represent open water.

CLASSIFICATION OF WETLAND AND DEEPWATER HABITATS IN THE STUDY AREAS

Cowardin et al. (1979) defined five major systems of wetlands and deepwater habitats: marine, estuarine, riverine, lacustrine, and palustrine (Fig. 3). Systems are divided into subsystems, which reflect hydrologic conditions, such as intertidal and subtidal for marine and estuarine systems. Subsystems are further divided into class, which describes the appearance of the wetland in terms of vegetation or substrate. Classes are divided into subclasses. Only vegetated classes were divided into subclasses for this project, and only for 1979 and 2009. 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. 5). Symbols for certain habitats changed after 1979; these changes are shown in Figure 6 and are noted in the section on trends in wetland and aquatic habitats. Examples of alphanumeric abbreviations used in the section on status of wetlands apply only to 2009 maps. Much of the following discussion of wetland systems as defined by Cowardin et al. (1979) is modified from White et al. (1993, 1998). Nomenclature and symbols (Appendix) in this discussion are based primarily on 1992 NWI maps.

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

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

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

Table 2. Wetland codes and descriptions from Cowardin et al. (1979). Codes listed were used in mapping wetlands on the 2009 delineations, which varied in some cases from those of 1950's and 1979 maps (see Fig. 5).

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

Estuarine System

The estuarine system consists of many types of wetland habitats. Estuarine subtidal unconsolidated bottom (E1UBL), or *open water*, occurs in the numerous bays and in adjacent salt and brackish marshes. Unconsolidated shore (E2US) includes tidal flats and estuarine beaches and bars. Water regimes for this habitat range primarily from regularly flooded (E2USN) to irregularly flooded (E2USP). Aquatic beds observed in this system are predominantly submerged, rooted vascular plants (E1AB3L) that may include *Halodule wrightii* (shoalgrass), *Ruppia maritima* (widgeongrass), *Thalassia testudinum* (turtlegrass), *Cymodocea filiformis* (manateegrass), and *Halophila engelmannii* (clovergrass). Apparently the most dominant species are *Ruppia maritima* and *Halodule wrightii* (McGowen et al., 1976).

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

In brackish areas, species composition changes from a salt to brackish-water assemblage, including *Schoenoplectus* (formerly *Scirpus*) spp. (bulrush), *Paspalum vaginatum* (seashore paspalum), *Spartina patens* (saltmeadow cordgrass), and *Phyla* sp. (frog fruit), among others. At slightly higher elevations, irregularly flooded estuarine emergent wetlands (E2EM1P) (high salt and brackish marshes) include *Borrichia frutescens* (sea oxeye), *Spartina patens*, *Spartina spartinae* (gulf cordgrass), *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, include *Iva frutescens* (big-leaf sumpweed), *Baccharis halimifolia* (sea-myrtle, or eastern false-willow), *Sesbania drummondii* (drummond's rattle-bush), and *Tamarix* spp. (salt cedar).

Mapping criteria allow classes to be mixed in complex areas where individual classes could not be separated. Most commonly used combinations include the estuarine emergent class and estuarine intertidal flat (E2EM/FL) and wetlands and uplands (PEM/U and POW/U). The E2EM/FL class was used only on 1956 and 1979 maps. In such combinations, each class must compose at least 30 percent of the mapped area (polygon); on the 1950's and 1979 maps, the wetland class was always listed first (PEM/U) regardless of whether it was most abundant. Using historical photographs, we subdivided these classes in most areas on the 1950's and 1979 maps to improve consistency with the 2009 classes, which were mapped individually.

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

Palustrine System

Palustrine areas include the following classes: unconsolidated bottom (open water), unconsolidated shore (including flats), aquatic bed, emergent (fresh or inland marsh), scrub-shrub, and forested. Naturally occurring ponds are identified as unconsolidated bottom, permanently or semipermanently flooded (PUBH or PUBF). Excavated or impounded ponds and borrow pits are labeled (on 1979 maps) with their respective modifiers (PUBHx or PUBHh). Palustrine emergent wetlands are generally equivalent to fresh to brackish or inland marshes that are not inundated by estuarine tides. Semipermanently flooded emergent wetlands (PEM1F) are low, fresh marshes; 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. 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 pennywort), *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.

Note that in many areas, field observations revealed the existence of small depressions or mounds with plant communities and moisture regimes that varied from that which could be resolved on photographs. Thus, some plant species that may typify a low, regularly flooded marsh, for example, may be included in a high-marsh map unit. Differentiation of high- and low-marsh communities is better achieved through field transects that include elevation measurements. Palustrine scrub-shrub wetlands that were mapped are typically temporarily flooded (PSS1A) or seasonally flooded (PSS1C) and may include *Tamarix* spp., *Baccharis* sp., and *Iva frutescens*.

Palustrine forested areas consist primarily of broad-leaved deciduous, temporarily (PFO1A), seasonally (PFO1C), and semipermanently flooded (PFO1F) forested areas. Forests incorporate a large mixture of tree species, including *Liquidambar styraciflua* (sweetgum), *Quercus* spp. (oak), *Salix nigra* (black willow), *Ulmus crassifolia* (cedar elm), *Fraxinus* spp. (ash), *Celtis spp*. (hackberry), and others. Swamp areas are predominately *Taxodium distichum* (bald cypress), *Nyssa aquatica* (water tupelo), and *Sabal minor* (dwarf palmetto).

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* is used to indicate spoil or dredged material.

Riverine System

Several areas were classified in the riverine system in the study area. River channels were mapped as estuarine along the lower-bay-influenced part but were changed to riverine up river within the map area. The change from estuarine to palustrine marshes is at the point where ocean-derived salts along the channel are less than 0.5 ppt. (See explanation in last paragraph in preceding "Estuarine System").

FREEPORT AREA

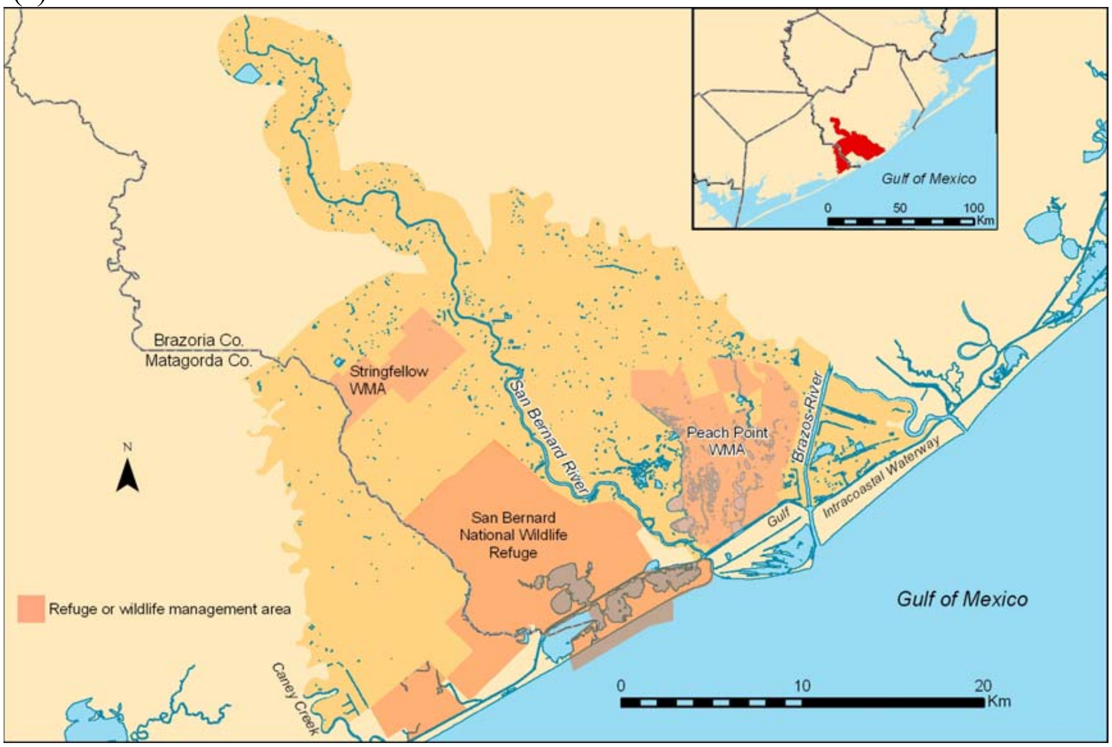
Study Area

The study area encompassing Freeport to East Matagorda Bay includes the inland delta plain between Freeport and East Matagorda Bay (which is southeast of Caney Creek in Fig. 8a). Included in this area are the Stringfellow WMA and Peach Point WMA. Along this stretch of coast, the Brazos and San Bernard Rivers discharge into the Gulf of Mexico. The estuarine system in this area includes Cedar Lake Creek and Jones Creek, the Brazos and San Bernard River valleys, and Bryan Mound. The study area is located within Brazoria and Matagorda Counties. Numerous field sites in the study area were visited during this investigation (Fig. 8b).

General Setting of the Freeport Area

Geologically, habitats in this area were deposited and formed by the Modern–Holocene Brazos–Colorado River deltaic system (Fig. 9a) (McGowen et al., 1976). Today the Brazos and San Bernard Rivers cross this area and discharge southwest of Freeport into the Gulf of Mexico. In 1929, the lower reach of the Brazos River was diverted so that the mouth of the river now discharges about 10 km down the coast (southwest) from its original location near Surfside (McGowen et al. 1976). The “abandoned” part of the channel has been jettied and dredged to create the Freeport Ship Channel. Except for progradation of the Brazos River delta, historically high rates of erosion have characterized this part of the Texas coast, which is part of the relict, retreating, deltaic headland of the Colorado and Brazos Rivers. Erosion rates have locally exceeded 12 m/yr (Morton and Pieper, 1975; Paine and Morton, 1989; Gibeaut et al., 2000). Most of the study area extends from the GIWW inland to the GLO Coastal Management Zone boundary except for near the San Bernard National Wildlife Refuge, which was mapped as part of an earlier study (Fig. 8a).

(a)



(b)

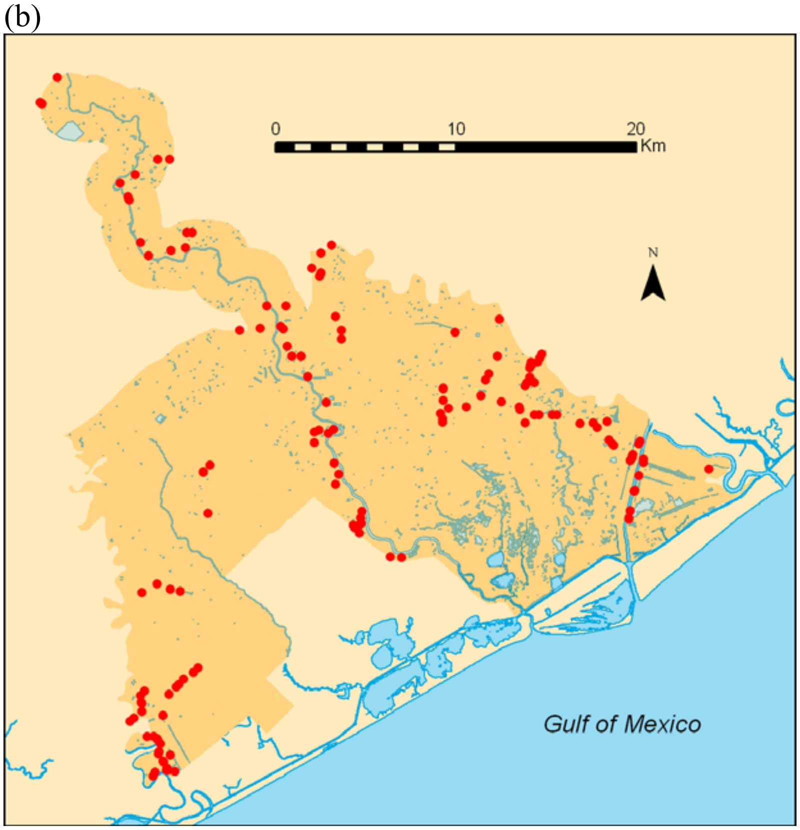


Figure 8. Index map of (a) study area including wildlife refuges and management areas and (b) field sites visited in the Freeport study area.

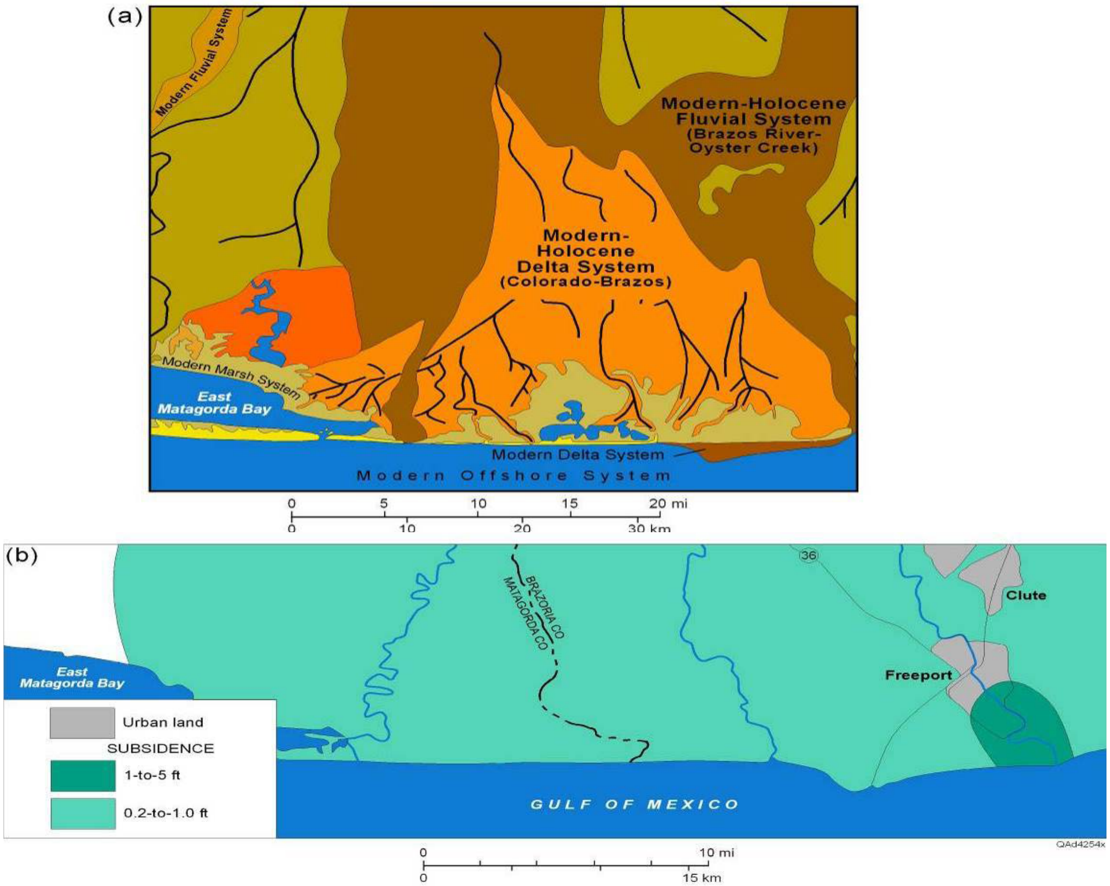


Figure 9. (a) Natural depositional systems in the Freeport area (from McGowen et al., 1976) and (b) subsidence, 1943–1973 (from Gabrysch and Bonnet, 1975). The relict Colorado–Brazos deltaic system filled any existing estuarine system and prograded into the gulf. Today it is retreating through high rates of erosion, except at the mouth of the diverted Brazos River, where a small delta has formed.

Geomorphic features on which various types of wetlands have developed are the result of numerous interacting processes. Physical processes that influence wetlands include astronomical and wind tides, waves and longshore currents, storms and hurricanes, river flow, deposition and erosion, subsidence, faulting, sea-level rise, precipitation, water-table fluctuations, and evapotranspiration. These processes have contributed to development of a gradational array of permanently inundated to infrequently inundated environments ranging in elevation from estuarine subtidal areas to topographically higher intertidal wetlands that grade upward from the astronomical-tidal zone through the wind-tidal zone to the storm-tidal zone. Average tidal range is approximately 0.5 m in the gulf in this area (Freeport Harbor) (U.S. Department of Commerce, 1978).

Relative Sea-Level Rise

Relative sea-level rise (RSLR) is another important process affecting wetland and aquatic habitats. RSLR, as used here, is the relative vertical rise in water level with respect to a datum at the land surface, whether it is caused by a rise in mean water level or subsidence of the land surface. Along the Texas coast, both processes, eustatic sea-level rise and subsidence, are part of the RSLR 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 relative sea-level rise in the Freeport area exceeded 1.1 cm/yr from 1959 through 1971 (Swanson and Thurlow, 1973) and 1.4 cm/yr from 1954 through 1986 (records were incomplete for the years 1954, 1966, and 1984) (Lyles et al., 1988). These short-term rates can be affected by secular variations in sea level caused by climatic factors—such as droughts and periods of higher than normal precipitation—and riverine discharge. Short-term sea-level variations produce temporary adjustments in the longer term trends related to eustatic sea-level rise and subsidence. Subsidence in the Freeport area resulting from groundwater withdrawal and possible hydrocarbon production is as much as 1.5 m (5 ft) (Fig. 9b). High rates of RSLR can cause changes in habitats such as estuarine marshes and wind-tidal flats (White et al., 1998). These types of changes are presented in the discussion of wetland trends.

Status of Wetlands and Aquatic Habitats, Freeport Area, 2009

Estuarine System

Marshes (Estuarine Intertidal Emergent Wetlands)

The estuarine intertidal emergent wetland habitat (E2EM) consists of 6,906 ha of salt and brackish marshes (Figs. 10 and 11). The irregularly flooded estuarine marsh, or *high marsh*, is most abundant at 4,757 ha (Table 3). The regularly flooded estuarine marsh, or *low marsh*, covers 2,151 ha. The most extensive estuarine emergent wetlands (salt and brackish marshes) occur in the Brazos subarea, which is the largest subarea mapped (Figs. 12 and 13; Table 4). Approximately 4,929 ha of estuarine marsh was mapped in the area, compared with 1,495 ha in the Cedar Lake Creek subarea. The estuarine intertidal marsh habitat makes up about 35% of all wetland habitats in the study area.

Tidal Flats (Estuarine Intertidal Unconsolidated Shores)

Estuarine intertidal unconsolidated shores (E2US) include wind-tidal flats, beaches, and algal flats. Approximately 183 ha of E2US was mapped in the study area (Table 3). Tidal flats are most extensive in the Bryan Mound subarea, where 91 ha was mapped, followed by the Brazos area at 77 ha (Table 4). Low, regularly flooded tidal flats are more extensive than high flats (Table 3). Because of the low astronomical tidal range, many flats are flooded only by wind-driven tides. These tidal habitats represent less than 1% percent of the wetland system. The mapped extent of the tidal flats could have been substantially affected by tidal levels at the time aerial photographs were taken. Accordingly, absolute areal extent of flats may vary from that determined using aerial photographs.

Aquatic Beds (Estuarine Subtidal Aquatic Beds)

Estuarine subtidal, rooted, vascular, aquatic beds (E1AB3L) represent areas of submerged vascular vegetation, or *seagrasses*. Accurate delineation of seagrasses on aerial photographs depends on the season in which the photographs were taken and water turbidities, which can obscure seagrass areas. Only 1 ha of seagrasses was mapped in the study area. Most of the subtidal aquatic beds (61 ha) were mapped as floating vascular. Much of the remainder was mapped as unknown submergent (E1AB5) because the type of aquatic bed (algae or seagrass) could not be verified. We assumed that most dark areas in estuarine waters were algal mats and organic material; locally, scattered oyster beds may have been included.

Table 3. Areal extent of mapped wetland and aquatic habitats in 2009, Freeport area.

NWI Code	National Wetlands Inventory Description	Hectares	Acres	Percent
E1AB1	Estuarine Subtidal Aquatic Bed, Algal	5	13	0.01
E1AB3	Estuarine Subtidal Aquatic Bed, Rooted Vascular	1	3	0.00
E1AB4	Estuarine Subtidal Aquatic Bed, Floating Vascular	61	151	0.11
E1AB5	Estuarine Subtidal Aquatic Bed, Unknown Submergent	43	105	0.07
E1UB	Estuarine Subtidal Unconsolidated Bottom	764	1,888	1.34
E2AB1N	Estuarine Intertidal Aquatic Bed, Regularly Flooded	0	1	0.00
E2AB1P	Estuarine Intertidal Aquatic Bed, Irregularly Flooded	1	2	0.00
E2EM1N	Estuarine Intertidal Emergent Wetland, Regularly Flooded	2,151	5,312	3.76
E2EM1P	Estuarine Intertidal Emergent Wetland, Irregularly Flooded	4,757	11,749	8.31
E2SS	Estuarine Intertidal Scrub Shrub	2	4	0.00
E2USM	Estuarine Intertidal Flat, Irregularly Exposed	2	4	0.00
E2USN	Estuarine Intertidal Flat, Regularly Flooded	154	380	0.27
E2USP	Estuarine Intertidal Flat, Irregularly Flooded	27	67	0.05
Subtotal		**7,967**	**19,679**	**13.92**
L1UBH	Lacustrine Limnetic Unconsolidated Bottom, Perm Flooded	33	82	0.06
L1UBK	Lacustrine Limnetic Unconsolidated Bottom, Artificial Flooded	177	437	0.31
Subtotal		**210**	**520**	**0.37**
PAB4	Palustrine Aquatic Bed, Floating Vascular	9	23	0.02
PAB5	Palustrine Aquatic Bed, Unknown Submergent	95	233	0.17
PEM1A	Palustrine Emergent Wetland, Temporarily Flooded	2,873	7,095	5.02
PEM1C	Palustrine Emergent Wetland, Seasonally Flooded	1,594	3,938	2.78
PEM1F	Palustrine Emergent Wetland, Semipermanently Flooded	412	1,017	0.72
PEM1K	Palustrine Emergent Wetland, Artificially Flooded	365	902	0.64
PEM1R	Palustrine Emergent Wetland, Seasonal-Tidal	32	78	0.06
PEM1S	Palustrine Emergent Wetland, Temporary-Tidal	11	26	0.02
PEM1T	Palustrine Emergent Wetland, Semipermanent-Tidal	27	66	0.05
PEM1V	Palustrine Emergent Wetland, Permanent-Tidal	1	3	0.00
PFO1A	Palustrine Forested, Broad-Leaved Deciduous, Temp Flood	4,399	10,865	7.68
PFO1C	Palustrine Forested, Broad-Leaved Decid, Season Flooded	665	1,643	1.16
PFO1R	Palustrine Forested, Broad-Leaved Decid, Seasonal-Tidal	10	24	0.02
PFO1S	Palustrine Forested, Broad-Leaved Decid, Temporary-Tidal	13	31	0.02
PSS1A	Palustrine Scrub/Shrub Wetland, Temporarily Flooded	417	1,031	0.73
PSS1C	Palustrine Scrub/Shrub Wetland, Seasonally Flooded	51	127	0.09
PSS1S	Palustrine Scrub/Shrub Wetland, Temporary-Tidal	1	2	0.00
PUB	Palustrine Unconsolidated Bottom	7	18	0.01
PUBF	Palustrine Unconsolidated Bottom, Semiperm Flooded	11	26	0.02
PUBH	Palustrine Unconsolidated Bottom, Permanently Flooded	178	440	0.31
PUBK	Palustrine Unconsolidated Bottom, Artificially Flooded	28	69	0.05
PUS	Palustrine Unconsolidated Shore	193	476	0.34
Subtotal		**11,390**	**28,134**	**19.90**
R1UBV	Riverine Tidal Unconsolidated Bottom, Permanent-Tidal	322	796	0.56
R2UBH	Riverine Lower Perennial Unconsol Bottom, Perm Flooded	131	324	0.23
R2USA	Riverine Lower Perennial Unconsol Shore, Temp Flooded	3	7	0.00
Subtotal		**456**	**1,127**	**0.80**
U	Upland	37,228	91,953	65.02
Total		**57,252**	**141,413**	**100.00**

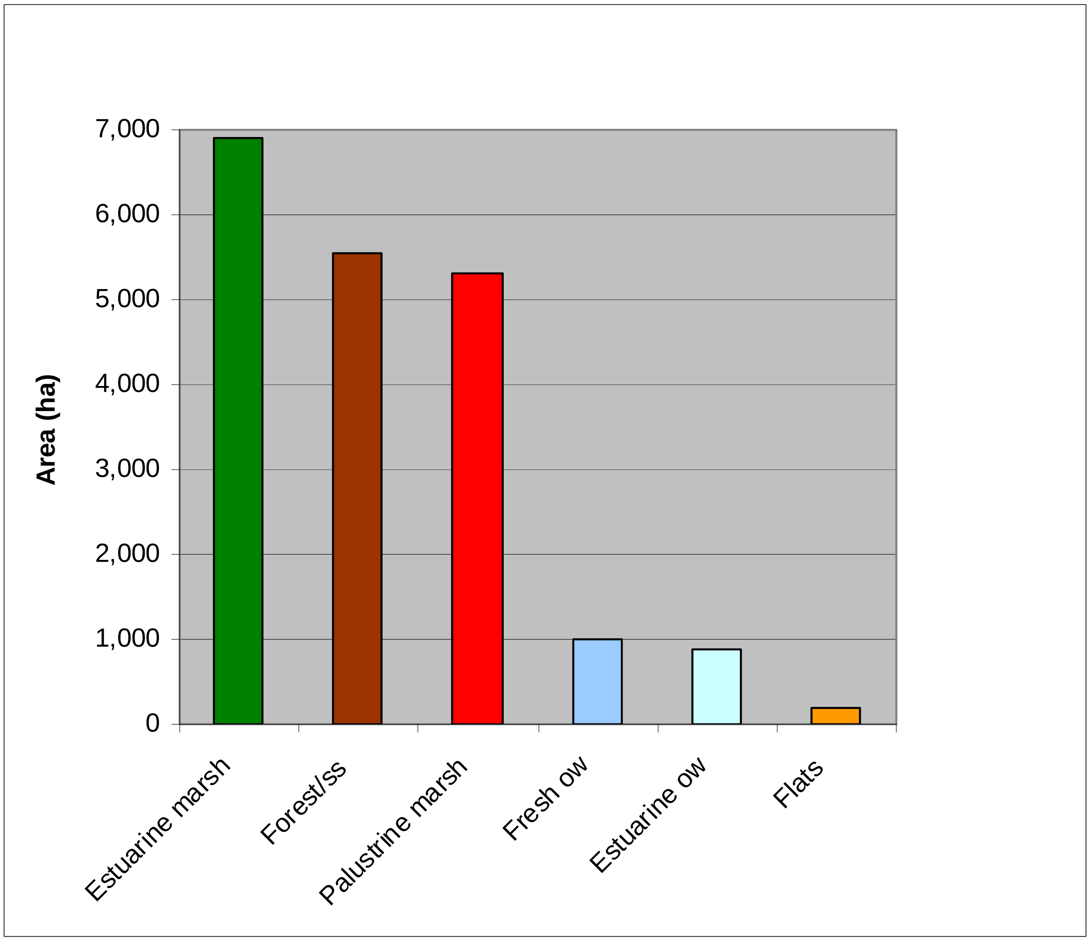


Figure 10. Areal distribution of selected habitats in the Freeport study area.

Table 4. Areal extent (ha) of selected habitats for the four subareas in 2009.

	Cedar Lake Creek	San Bernard	Brazos	Bryan Mound	Totals
Forest	2,704	1,253	1,599	0	5,556
Estuarine marsh	1,495	116	4,929	367	6,907
Palustrine marsh	1,531	599	2,684	500	5,314
Fresh open water	93	504	256	138	991
Estuarine open water	23	119	701	34	877
Tidal flats	0	14	77	91	182

Open Water (Estuarine Subtidal Unconsolidated Bottom)

Estuarine subtidal, unconsolidated bottom (E1UBL), or *open water*, includes water features in the Peach Point WMA, the lower reaches of rivers, the GIWW, and other smaller water areas. The total area of estuarine open water is 877 ha, which is about 4% of all wetland habitats in the study area.

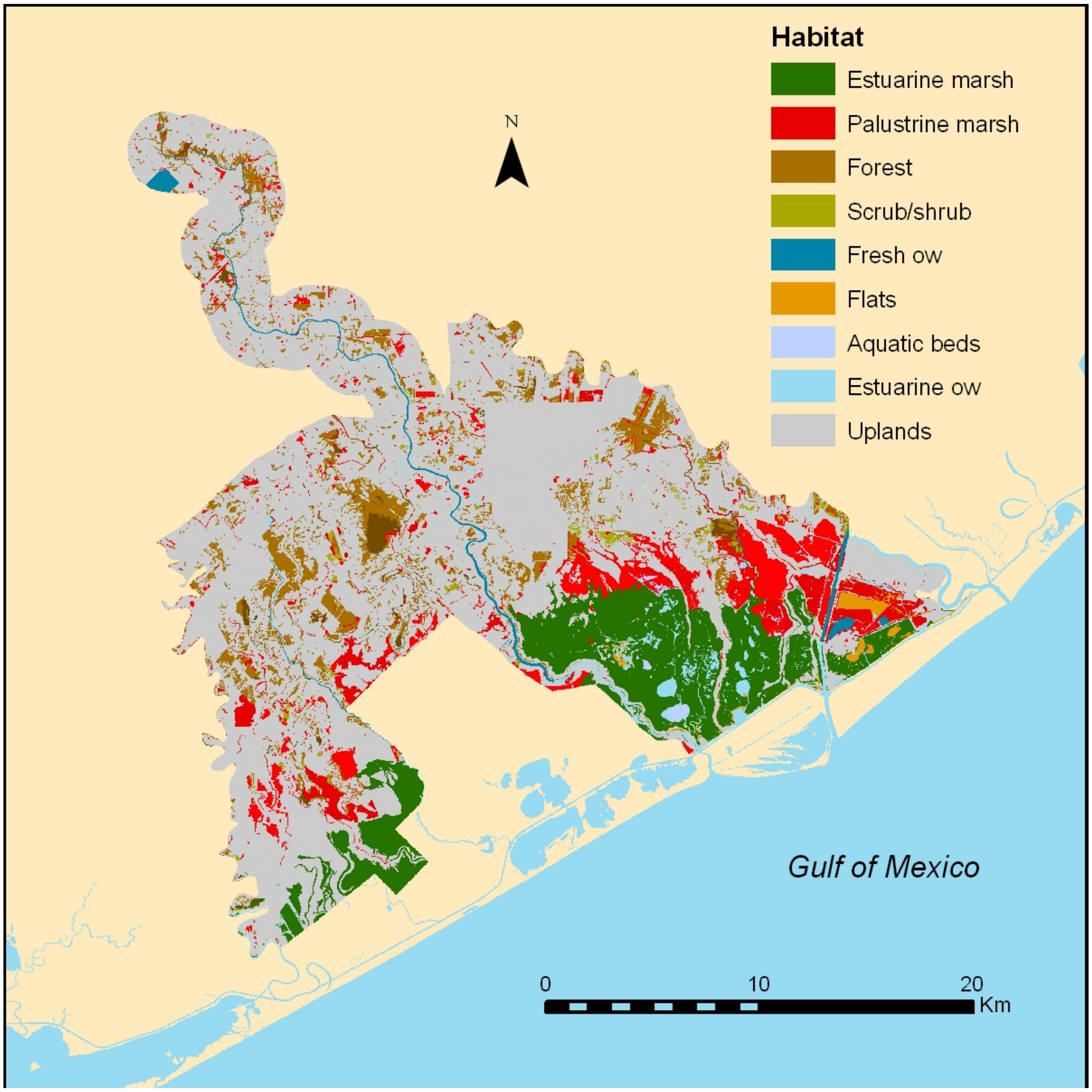


Figure 11. Distribution of major habitats in 2009 in the Freeport study area.

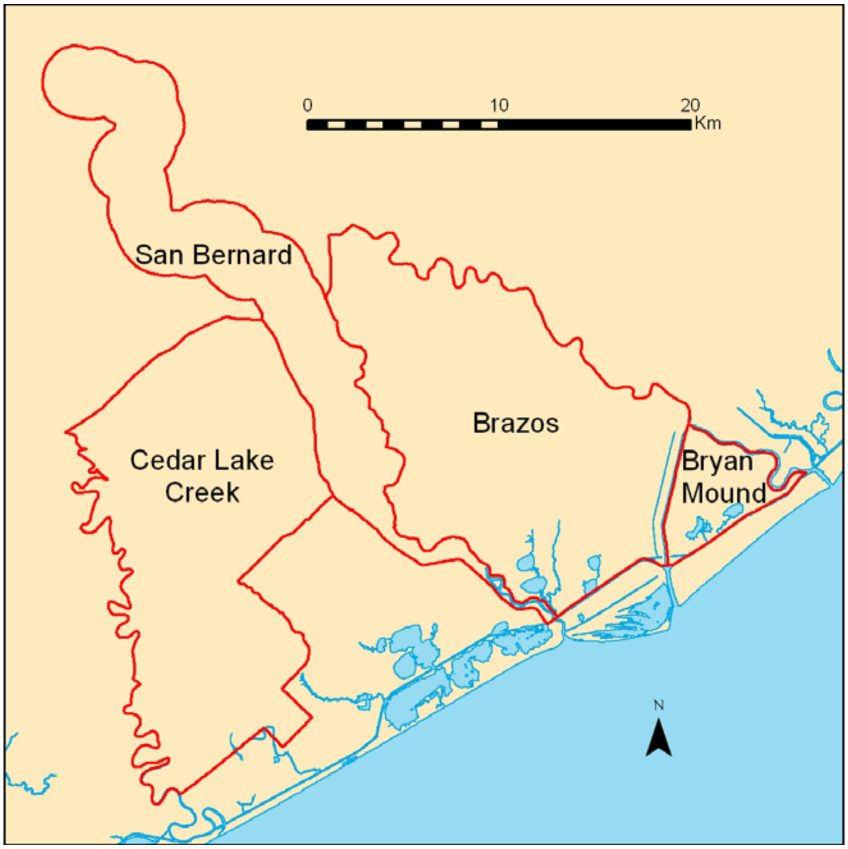


Figure 12. Index map of study area subdivided into the following subareas: Cedar Lake Creek, San Bernard, Brazos, and Bryan Mound.

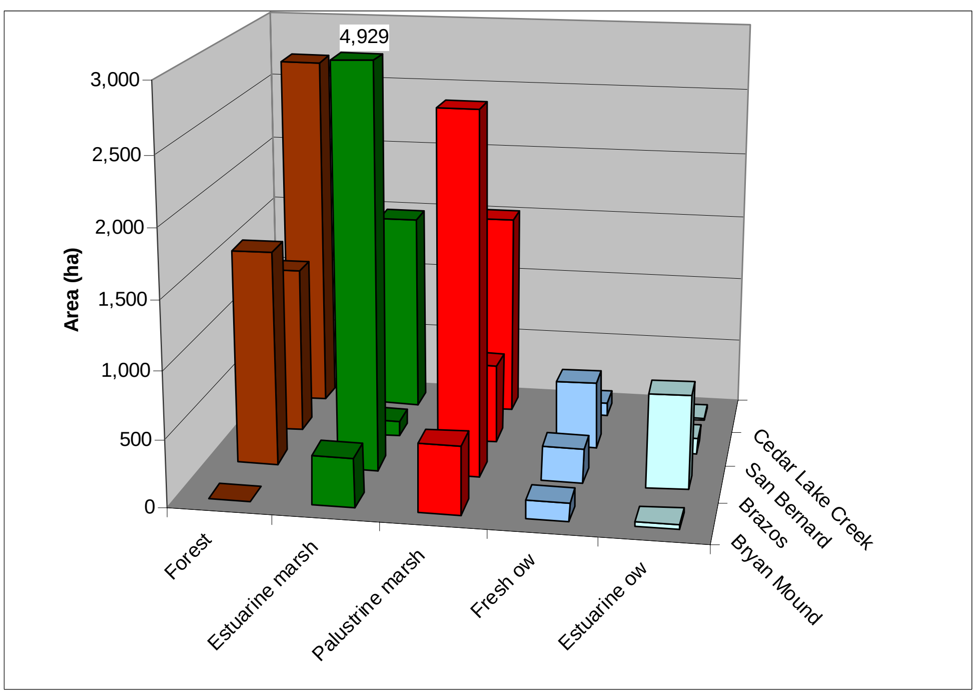


Figure 13. Distribution of selected habitats by geographic subareas (Cedar Lake Creek, San Bernard, Brazos, and Bryan Mound) in 2009. The most extensive estuarine and palustrine marshes are in the Brazos subarea.

Palustrine System

Marshes (Palustrine Emergent Wetlands)

Palustrine emergent wetlands (PEM), or *inland fresh-water marshes*, cover 5,314 ha (Fig. 10; Table 4) and represent 27% of all wetland habitats. The broadest distribution of palustrine emergent wetlands is in the Brazos subarea, where more than 2,684 ha was mapped along the inland margins of the estuarine system (Fig. 14). Typically we classified palustrine marshes into one of four water regimes: (1) temporarily flooded, (2) seasonally flooded, (3) semipermanently flooded, and (4) artificially flooded. Most extensive in the map area were those that were temporarily flooded. Palustrine marshes in the Brazos subarea account for approximately half of this habitat mapped in the study area.

Forest (Palustrine Forested and Scrub-Shrub Wetlands)

Palustrine forested wetlands (PFO), comprising fluvial woodlands and swamps, cover a 5,086-ha area (Figs. 10 and 15; Table 4). Forests were classified primarily as temporarily flooded, broad-leaved deciduous trees. Palustrine scrub-shrub (PSS) habitat covers 469 ha. Owing to difficulty in distinguishing forest regrowth from scrub-shrub, the two classes were combined for analysis.

Figure 14. Seasonally flooded palustrine marsh (PEM1C) on a tributary of Jones Creek, Brazos subarea.

Figure 15. Seasonally flooded palustrine forest (PFO1C) on Jones Creek, Brazos subarea.

Open Water (Palustrine Unconsolidated Bottom and Aquatic Beds)

Palustrine unconsolidated bottom (PUB), or *open water*, and palustrine aquatic beds (PAB) are generally fresh to brackish water ponds. The total mapped area of these habitats was only 327 ha, roughly 54% of which were excavated ponds (Table 3).

Flats (Palustrine Unconsolidated Shore)

Palustrine unconsolidated shore (PUS), or *flat habitats*, are generally found in conjunction with fresh to brackish water ponds. The total mapped area of these habitats was only 193 ha, almost 95% of which were flats in artificially flooded, dredged-material disposal areas (Table 3).

Lacustrine and Riverine Systems

Open Water (Lacustrine Unconsolidated Bottom)

Lacustrine unconsolidated bottom (L1UB), or *lakes*, include lakes and inland reservoirs greater than 20 acres (8.33 ha). Lakes, covering 210 ha, are further classified according to depth. Most lakes are found in the industrial area around Bryan Mound (Fig. 16).

Figure 16. Artificially flooded lacustrine unconsolidated bottom (L1UBK) on the flank of Bryan Mound.

River (Riverine Tidal and Lower Perennial)

Riverine tidal unconsolidated bottom (R1UB) and lower perennial unconsolidated bottom (R2UB) and unconsolidated shore (R2US), or *rivers*, cover 457 ha. Lower perennial rivers compose about 29% of all rivers in the study area.

Historical Trends in Wetland and Aquatic Habitats, Freeport Area

General Trends in Wetlands within the Study Area

Analysis of trends in wetlands and aquatic habitats in the Freeport study area shows that there was a net gain in estuarine marshes from the 1950's through 2009. The total area of marshes increased from 5,238 ha in the 1950's to 6,416 ha in 1979 and 6,907 ha in 2009 (Table 5; Figs. 17 and 18). This increase amounted to 1,669 ha from the 1950's through 2009. During the same time, tidal flats decreased systematically (E2FL or E2US). The area of flats declined from 249 ha in the 1950's to 219 ha in 1979 to 183 ha in 2009 (Table 5). These changes reflect losses of 30 ha and 36 ha for each period, respectively. Palustrine marshes (PEM) increased in area by 771 ha from the 1950's through 1979 and by 2,808 ha from 1979 through 2009. The mapped area of forest and scrub/shrub increased from the 1950's through 2009 by approximately 5,210 ha. Wetland forest is difficult to distinguish from upland forest, however, and total distribution as interpreted on aerial photographs is approximate. The area of estuarine open water increased slightly from the earlier years through 2009 (Table 5). Fresh open water in the study area also increased from the 1950's through 1979 and 2009.

Probable causes of changes in habitats are presented in the following sections organized by geographic subarea.

Table 5. Area (ha) of selected habitats in the Freeport study area, mid-1950's, 1979, and 2009.

Habitat	*1950's*	*1979*	*2009*
Estuarine marsh	5,238	6,416	6,907
Palustrine marsh	1,735	2,506	5,314
Forest/ss	346	1,377	5,556
Fresh open water	550	895	991
Estuarine open water	711	722	875
Tidal flats	249	219	183

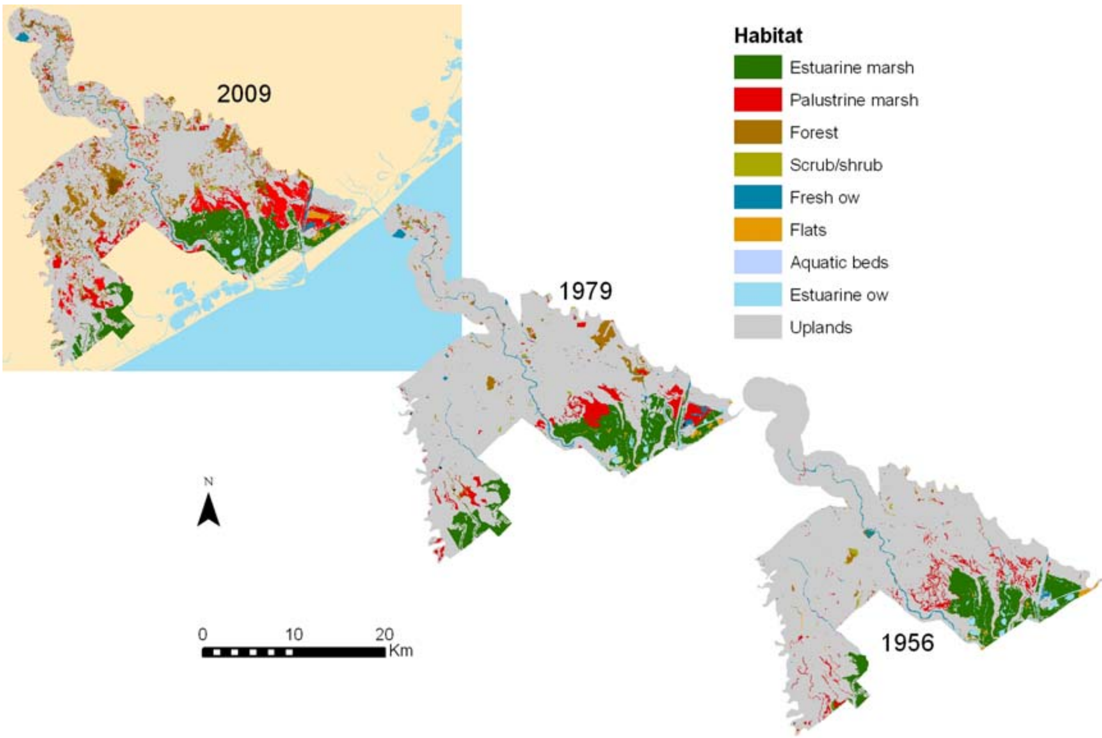


Figure 17. Map showing distribution of major wetland and aquatic habitats in 2009, 1979, and the 1950's in the Freeport study area.

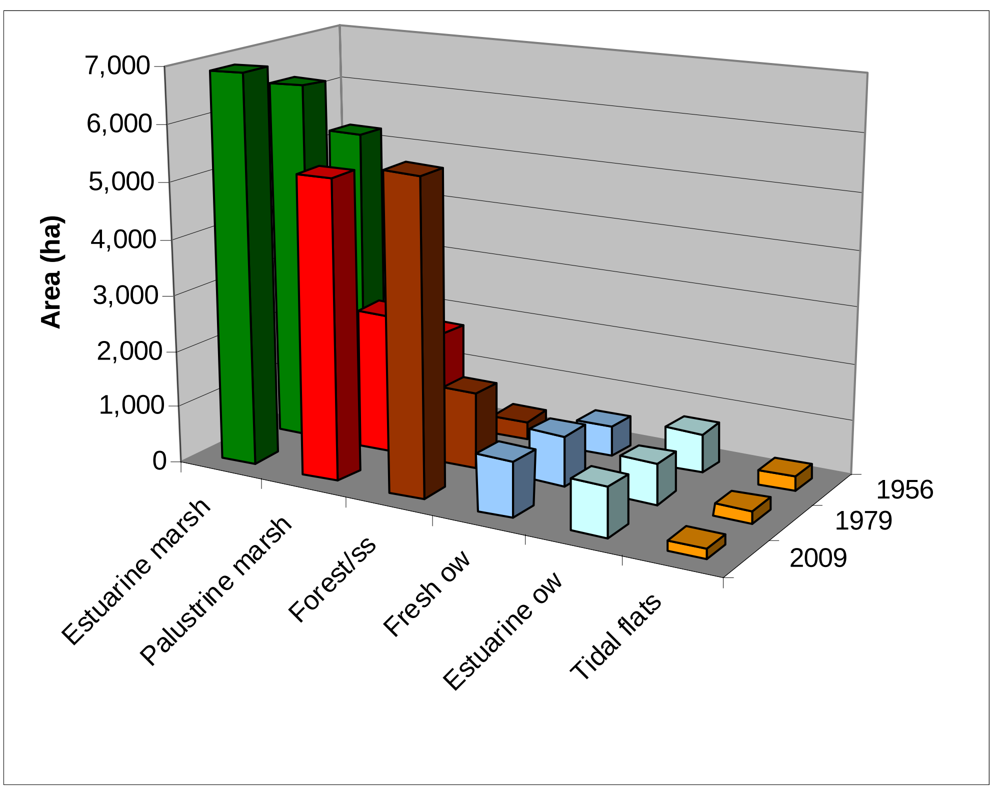


Figure 18. Areal extent of major habitats in the Freeport study area in the 1950's, 1979, and 2009.

Analysis of Habitat Trends by Geographic Area

As noted previously, the study area was subdivided into major natural areas and geographic components for analysis of historical trends (Fig 12). The subareas are presented from southwest to northeast in the following order: (1) Cedar Lake Creek, (2) San Bernard, (3) Brazos, and (4) Bryan Mound. This subdivision allowed a more site-specific analysis of trends and their probable causes. Estuarine and palustrine marshes are emphasized.

Cedar Lake Creek

The most significant trend, or change, in the **Cedar Lake Creek** subarea was the gain of palustrine marsh from the 1950's through 1979 and 2009 (Fig. 19). Although there were losses and gains in marshes at different locations through time, the total area of marsh habitat, which was about 659 ha in the 1950's, increased in size by 74 ha through 1979 but increased by 1,048 ha from 1979 through 2009. The net gain from the 1950's through 2009 was 1,122 ha. This increase in marsh represents a gain of about 274% of this habitat in the Cedar Lake Creek subarea since the 1950's. The increase would be larger except for hay cultivation in wet areas that would otherwise be marshland. Also, there was an overall increase in the area of estuarine marsh from the 1950's through 2009 (Fig. 20). Most gain of estuarine marsh occurred during the early time period, when 659 ha of marsh in 1956 had increased to 1,606 ha by 1979. Estuarine marsh area had decreased slightly to 1,495 ha by 2009. Long-term change in estuarine marsh between 1956 and 2009 was an increase of 127% of the original resource. Open water increased in area during this period, although the total area of this habitat was relatively small.

The 274% increase in palustrine marsh from the 1950's through 2009 occurred as marshes occupied areas of lower elevation, possibly the result of local subsidence. Estuarine marsh also increased as a result of relative sea-level rise, mostly inland from the San Bernard National Wildlife Refuge (SBNWR) (Fig. 21). GIS overlay analysis of habitat distribution indicates that nearly all marsh gain in the Cedar Lake Creek subarea was the result of conversion from upland habitat. The significant increase in forest area mapped in 2009 is due to interpretational differences. Many large tracts of forest, especially in the Stringfellow Wildlife Management Area (WMA), were not previously mapped.

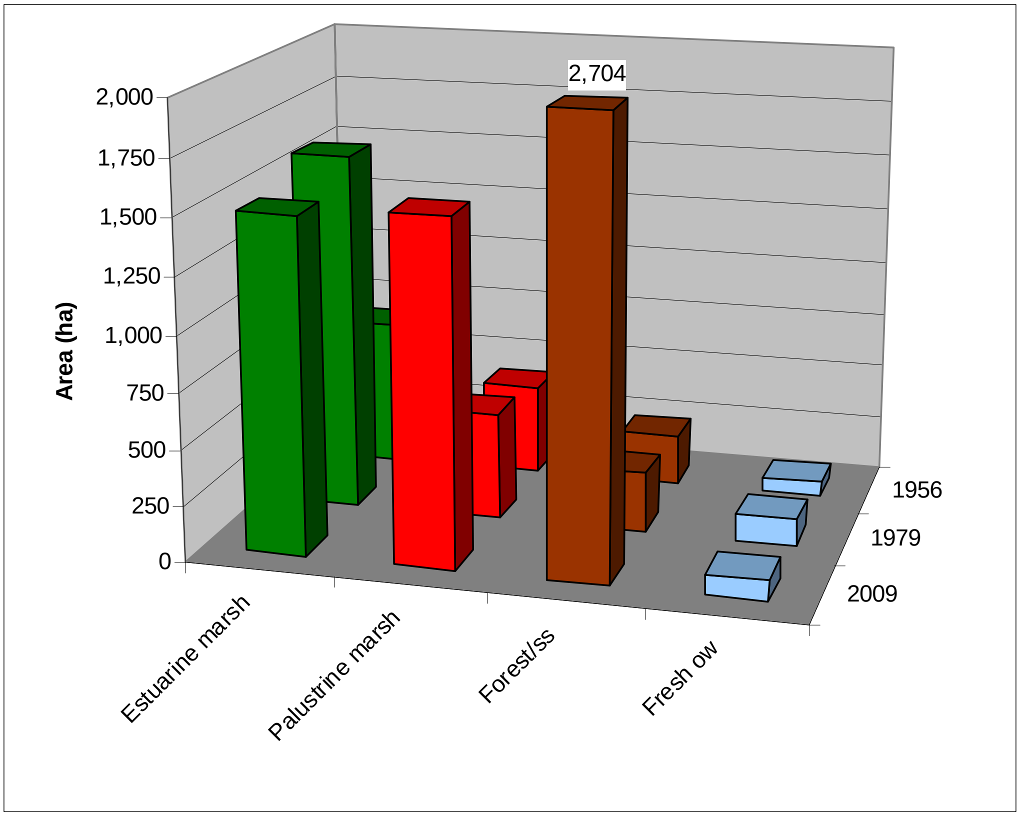


Figure 19. Areal extent of major habitats on the Cedar Lake Creek subarea in the 1950's, 1979, and 2009.

Figure 20. Irregularly flooded estuarine marsh (E2EM1P) near Caney Creek. *Spartina spartinae* is the dominant species.

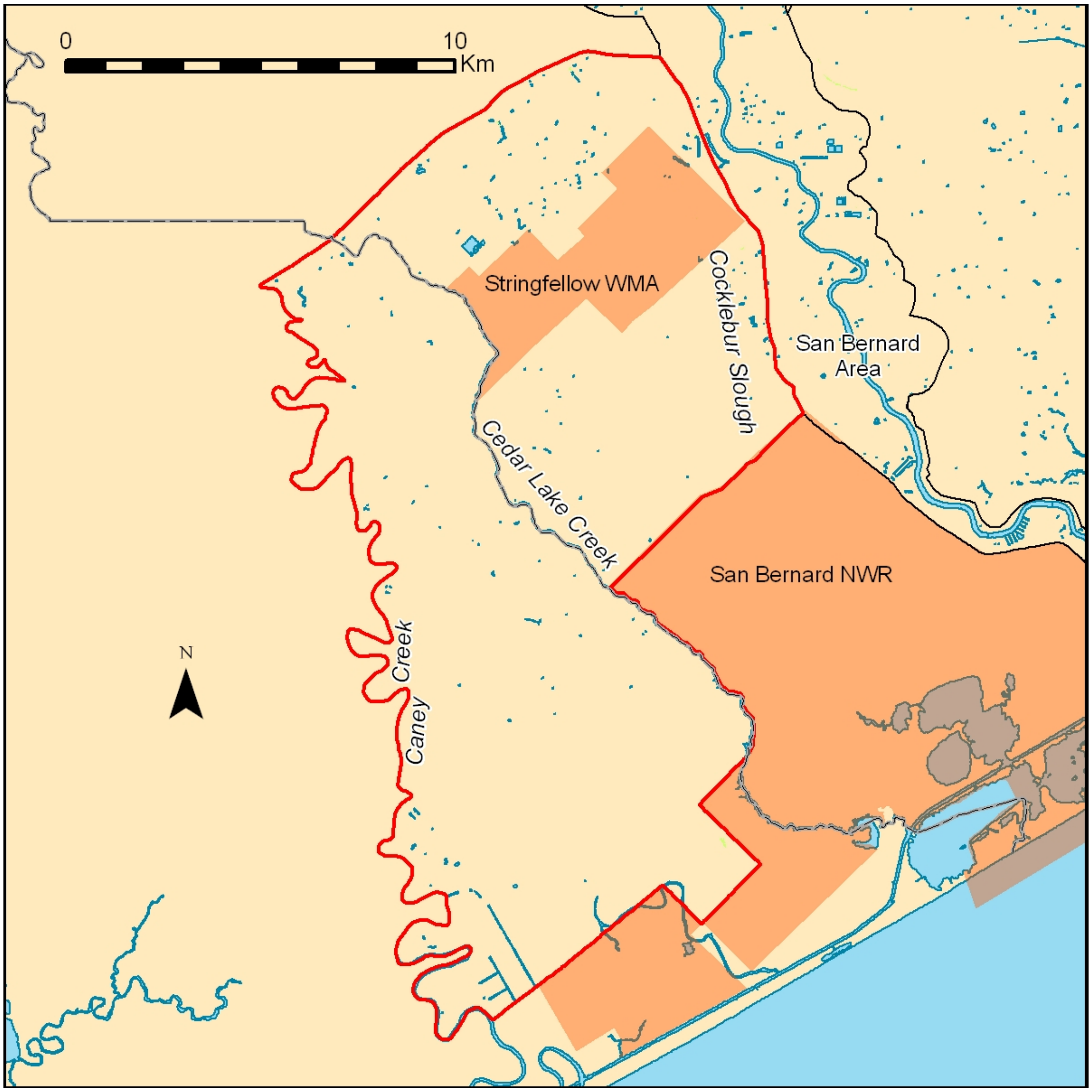


Figure 21. Index map showing features in the Cedar Lake Creek subarea.

San Bernard

This **San Bernard** area experienced a systematic gain in palustrine marshes between the mid-1950's and 2009. Palustrine marsh increased from a mid-1950's total of 62 ha to 181 ha in 1979, representing an increase of 191% (Fig. 22). The subsequent increase to 599 ha in 2009 represents an additional 230% increase. As much as 95% of the gross palustrine-marsh gain over the length of the study occurred where mid-1950's uplands were mapped in 2009 as palustrine marsh. Much of the marsh increase occupied the area between the SBNWR boundary and the San Bernard River (Figs. 17 and 23). Estuarine-marsh area fluctuated through time. Between the mid-1950's and 1979, marsh numbers decreased from 24 ha to a low of 8 ha. By 2009, the area of estuarine marsh had increased more than 1,000% to 116 ha. The small amount of tidal flat in the San Bernard area was halved between 1956 and 2009, when 28 ha was reduced to 14 ha, respectively.

As with palustrine marsh, most estuarine marsh moved into areas previously mapped as upland. Marsh gain occurred between the San Bernard River and the eastern boundary of the SBNWR. Marsh gain in the San Bernard subarea is attributed to increased rates of relative sea-level rise. Interpretational differences between mapping periods account for most of the gain in forest area (Fig. 24).

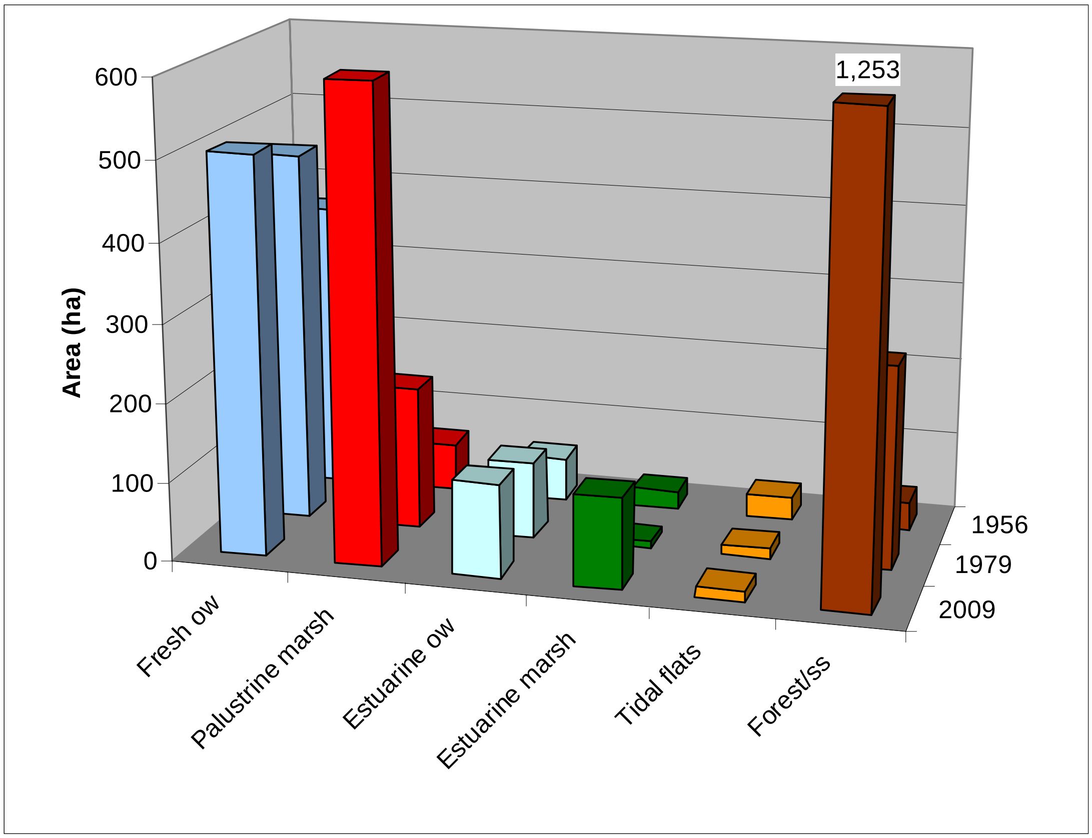


Figure 22. Areal extent of major habitats in the San Bernard subarea in the mid-1950's, 1979, and 2009.

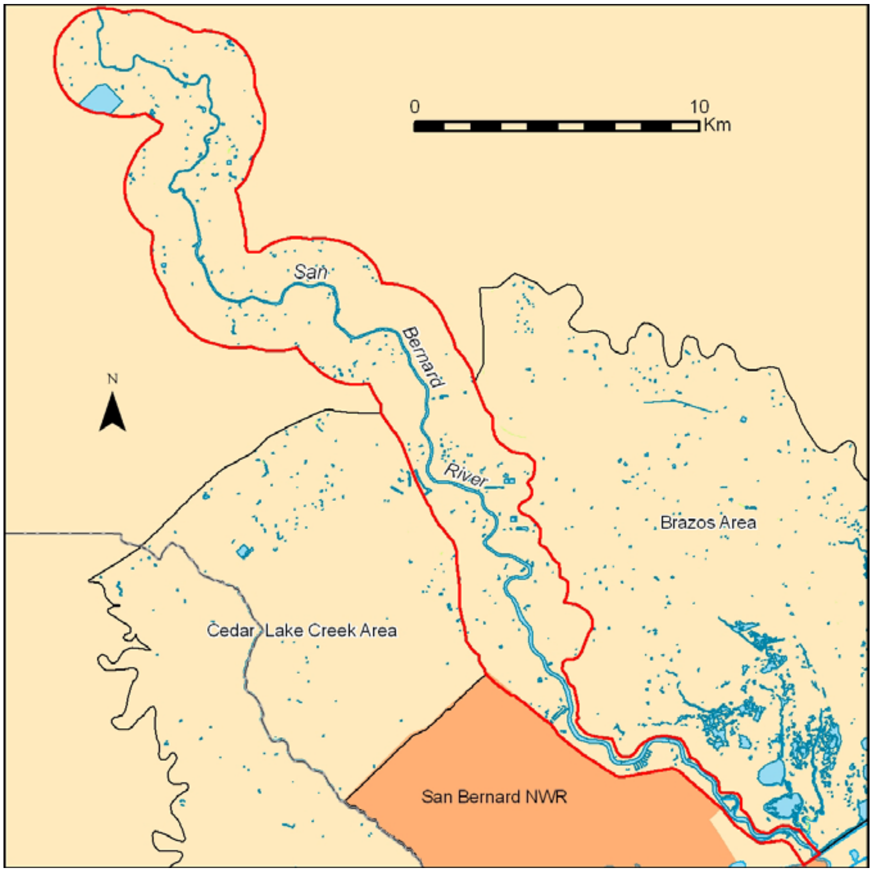


Figure 23. Index map showing features in the San Bernard subarea.


Figure 24. Riparian forest along a tributary of the San Bernard River.

Brazos

The most significant trend, or change, in the **Brazos** subarea was a gain of about 115% of the palustrine-marsh habitat from the 1950's through 2009. The total area of fresh marshes, which covered 1,248 ha in the 1950's, had increased by 1.436 ha, to a total of 2,684 ha by 2009 (Fig. 25). Coincident with the gain of palustrine marsh in this subarea was an increase in estuarine marsh of 1,368 ha (3,380 acres). Other changes included a decline in tidal flats and a systematic increase in open water through time.

The 115% increase in palustrine-marsh habitat in the Brazos subarea can be attributed principally to management practices in the Peach Point WMA (Fig. 26). Dikes constructed after 1979 impeded the flow of fresh water and converted other habitats to palustrine marsh. Of the newly created marsh, roughly 80% was in areas previously mapped as upland, and 19% was in areas previously mapped as estuarine marsh. Estuarine marsh gain was also primarily (77%) from previous uplands and from previous fresh marsh (16%). Movement of salt marsh into uplands and fresh marsh is attributed to relative sea-level rise.

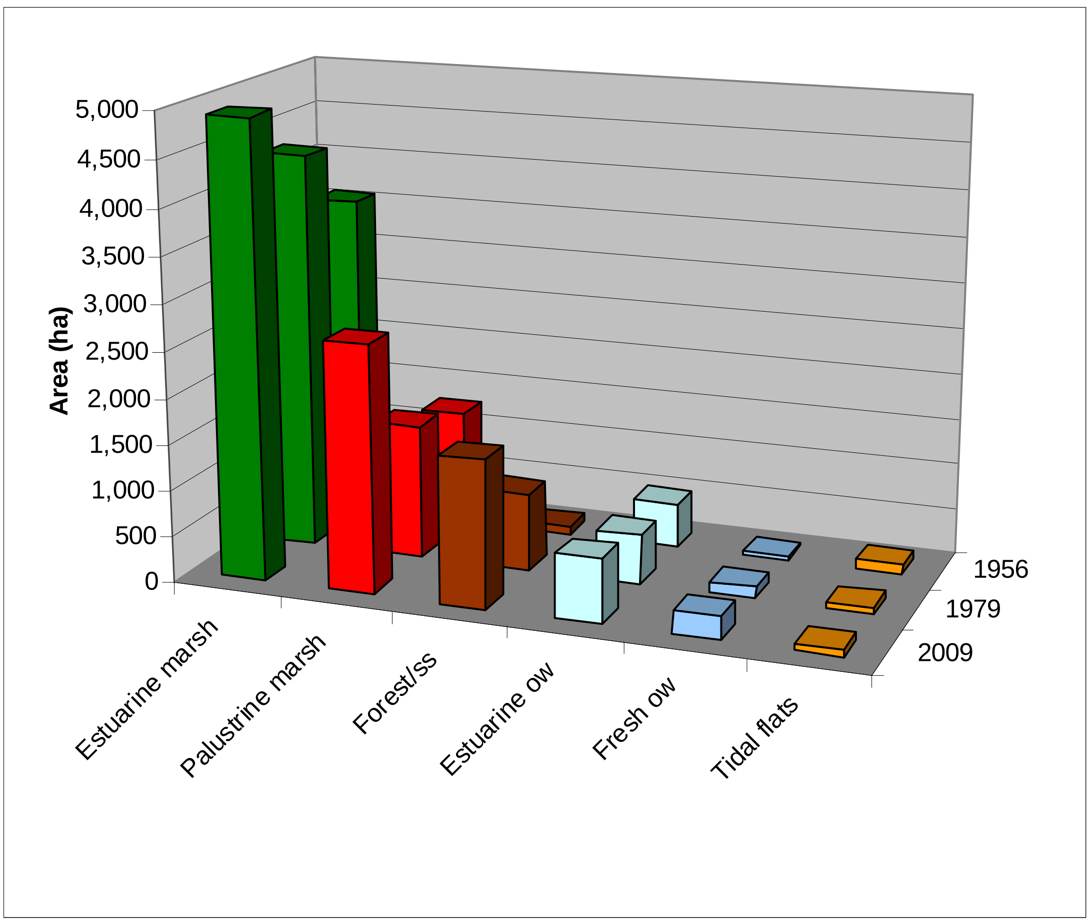


Figure 25. Areal distribution of major habitats in the Brazos subarea in the 1950's, 1979, and 2009.

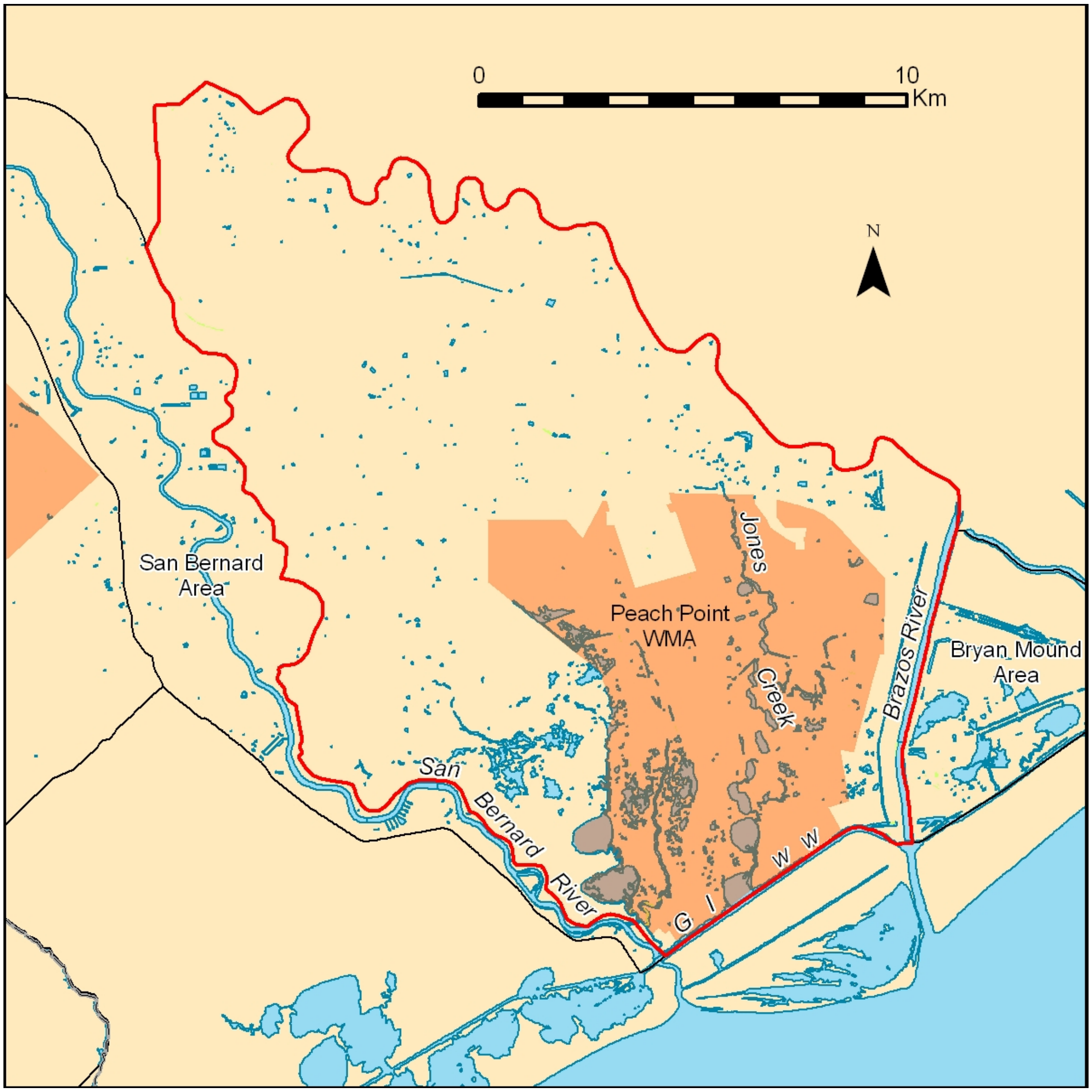


Figure 26. Index map showing features in the Brazos subarea.

Bryan Mound

Palustrine marsh experienced a systematic gain in the **Bryan Mound** subarea when 15 ha in the mid-1950's increased to 380 ha in 1979 and further increased to 500 ha in 2009 (Fig. 27). In 1979, estuarine marsh had been reduced from the original 994 ha to 495 ha and had been further reduced to a low of 367 ha by 2009. Tidal flats lost 14% of the resource between the mid-1950's and 2009. A small area of palustrine flats expanded significantly over the same time period. Expansion occurred in areas mapped as salt marsh in the mid-1950's, fresh marsh and open water in 1979, and palustrine flat in 2009.

Diking in this industrial area had converted salt marsh to fresh marsh by 1979 (Fig. 28). By 2009, the area of palustrine marsh increase was mostly (72%) from areas previously mapped as estuarine marsh. Conversion to fresh marsh is evident in the (-) 63% loss of the original estuarine-marsh resource. Half of the estuarine-marsh loss area had converted to palustrine marsh.

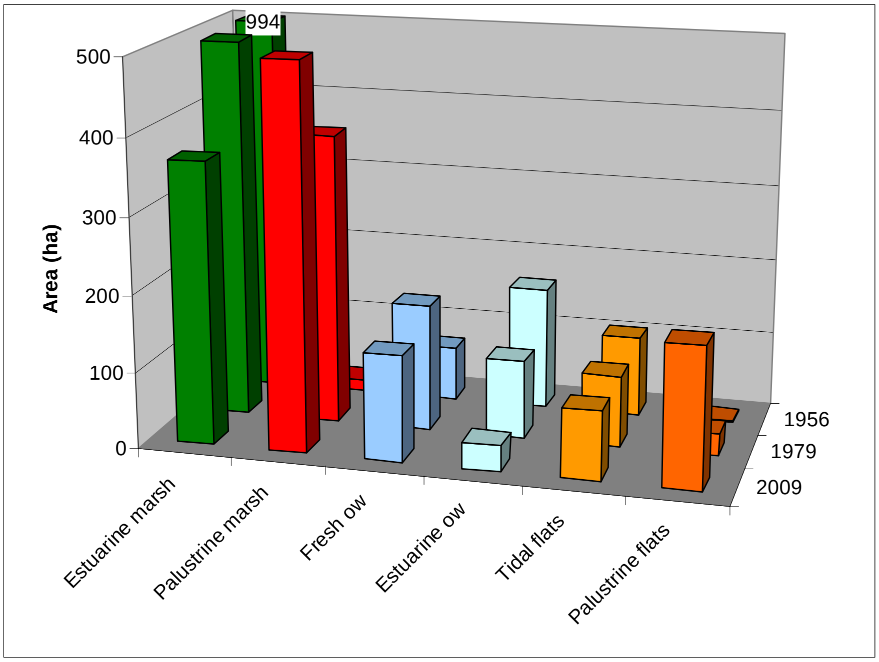


Figure 27. Areal distribution of major habitats in the Bryan Mound subarea in the 1950's, 1979, and 2009.

Figure 28. Index map showing features in the Bryan Mound subarea.

Summary and Conclusions, Freeport Area

The most significant trend, or change, in the **Cedar Lake Creek** area was the gain of palustrine marsh from the 1950's through 1979 and 2009. Although there were losses and gains in marshes at different locations through time, the total area of marsh habitat, which was about 659 ha in the 1950's, had increased in size by 74 ha through 1979 but had increased by 1,048 ha from 1979 through 2009. The net gain from the 1950's through 2009 was 1,122 ha. This increase in marsh represents a gain of about 274% of this habitat in the Cedar Lake Creek subarea since the 1950's. The increase would be larger except for hay cultivation in wet areas that would otherwise be marshland. Also, there was an overall increase in the area of estuarine marsh from the 1950's through 2009. Most gain of estuarine marsh occurred during the early time period when 659 ha of marsh in 1956 had increased to 1,606 ha by 1979. Estuarine marsh area had decreased slightly to 1,495 ha by 2009. Long-term change in estuarine marsh between 1956 and 2009 was an increase of 127% of the original resource. Open water increased in area during this period, although the total area of this habitat was relatively small.

The 274% increase in palustrine marsh from the 1950's through 2009 occurred as marshes occupied areas of lower elevation, possibly the result of local subsidence. Estuarine marsh also increased as a result of relative sea-level rise, mostly inland from the SBNWR. GIS overlay analysis of habitat distribution indicates that nearly all marsh gain in the Cedar Lake Creek subarea was the result of conversion from upland habitat. The significant increase in forest area mapped in 2009 is due to interpretational differences. Many large tracts of forest, especially in the Stringfellow WMA, were not previously mapped.

The **San Bernard** subarea experienced a systematic gain in palustrine marshes between the mid-1950's and 2009. Palustrine marsh increased from a mid-1950's total of 62 ha to 181 ha in 1979, representing an increase of 191%. The subsequent increase to 599 ha in 2009 represents an additional 230% increase. As much as 95% of the gross palustrine-marsh gain over the length of the study occurred where mid-1950's uplands were mapped in 2009 as palustrine marsh. Much of the marsh increase occupied the area between the SBNWR boundary and the San Bernard River. Estuarine-marsh area fluctuated through time. Between the mid-1950's and 1979, marsh numbers decreased from 24 ha to a low of 8 ha. By 2009, the area of estuarine marsh had increased more than 1,000% to 116 ha. The small amount of tidal flat in the San Bernard area was halved between 1956 and 2009, when 28 ha was reduced to 14 ha, respectively.

As with palustrine marsh, most estuarine marsh moved into areas previously mapped as upland. Marsh gain occurred between the San Bernard River and the eastern boundary of the SBNWR. Marsh gain in the San Bernard area is attributed to increased rates of relative sea-level rise. Interpretational differences between mapping periods account for most of the gain in forest area.

The most significant trend, or change, in the **Brazos** subarea was a gain of about 115% of the palustrine-marsh habitat from the 1950's through 2009. The total area of fresh marshes, which covered 1,248 ha in the 1950's, had increased by 1,436 ha to a total of 2,684 ha by 2009. Coincident with the gain of palustrine marsh in this subarea was an increase in estuarine marsh of 1,368 ha. Other changes included a decline in tidal flats and a systematic increase in open water through time.

The 115% increase in palustrine-marsh habitat in the Brazos subarea can be attributed principally to management practices in the Peach Point WMA. Dikes constructed after 1979 impeded the flow of fresh water and converted other habitats to palustrine marsh. Of the newly created marsh, roughly 80% was in areas previously mapped as upland, and 19% was in areas previously mapped as estuarine marsh. Estuarine-marsh gain was also primarily (77%) from previous uplands and from previous fresh marsh (16%). Movement of salt marsh into uplands and fresh marsh is attributed to relative sea-level rise.

Palustrine marsh experienced a systematic gain in the **Bryan Mound** subarea when 15 ha in the mid-1950's increased to 380 ha in 1979 and further increased to 500 ha in 2009. In 1979, estuarine marsh had been reduced from the original 994 ha to 495 ha and had been further reduced to a low of 367 ha by 2009. Tidal flats lost 14% of the resource between the mid-1950's and 2009. A small area of palustrine flats expanded significantly over the same time period. Expansion occurred in areas mapped as salt marsh in the mid-1950's, fresh marsh and open water in 1979, and palustrine flat in 2009.
Hydrologic modification in this industrial area had converted salt marsh to fresh marsh by 1979. By 2009, the area of palustrine-marsh increase was mostly (72%) from areas previously mapped as estuarine marsh. Conversion to fresh marsh is evident in the (-) 63% loss of the original estuarine-marsh resource. Half of the estuarine-marsh-loss area had converted to palustrine marsh.

SAN ANTONIO BAY AREA

Study Area

The dominant feature of San Antonio Bay is the bayhead delta at the mouth of the Guadalupe River. The delta, situated gulfward of the confluence with the San Antonio River, is characterized by several inactive distributary channels. Construction of Traylor Cut in 1935 produced the most active channel (White et al., 1989). The system is characterized by secondary bays, including Hynes Bay and Mission Lake, and expansive brackish- and saltwater ponds and marshes (Fig. 29). The mouth of San Antonio Bay opens into Espiritu Santo Bay and is straddled on either side by a relict Pleistocene barrier strandplain. Included in this area are the Guadalupe Delta WMA and Welder Flats WMA. The study area encompasses parts of 10 USGS 7.5′ quadrangles and is located within Calhoun and Refugio Counties.

General Setting of the San Antonio Bay Area

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

Estuarine and palustrine marshes inhabit the Guadalupe Delta, with estuarine marshes predominantly adjacent to Hynes and Guadalupe Bays (Fig. 29). Salinities are highest in Hynes Bay, lower in Guadalupe Bay, and lowest in Mission Lake. The gulfward half of the delta is characterized by shallow open water, algal and tidal flats, and salt marsh. The inland half of the delta contains fresh-water marshes, lacustrine flats, and shallow fresh-water lakes. The Ingleside barrier strandplain lies landward of Espiritu Santo Bay and is the site of most marshes outside of the Guadalupe Delta WMA (Fig. 30).

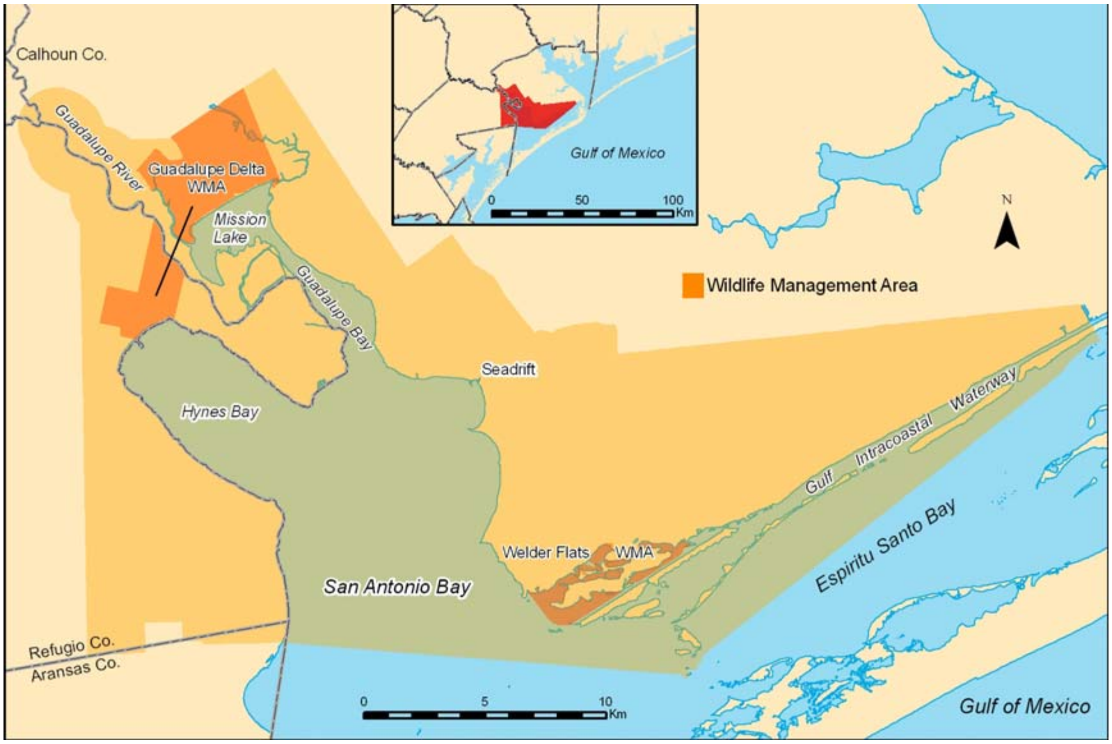


Figure 29. Index map of San Antonio Bay study area.

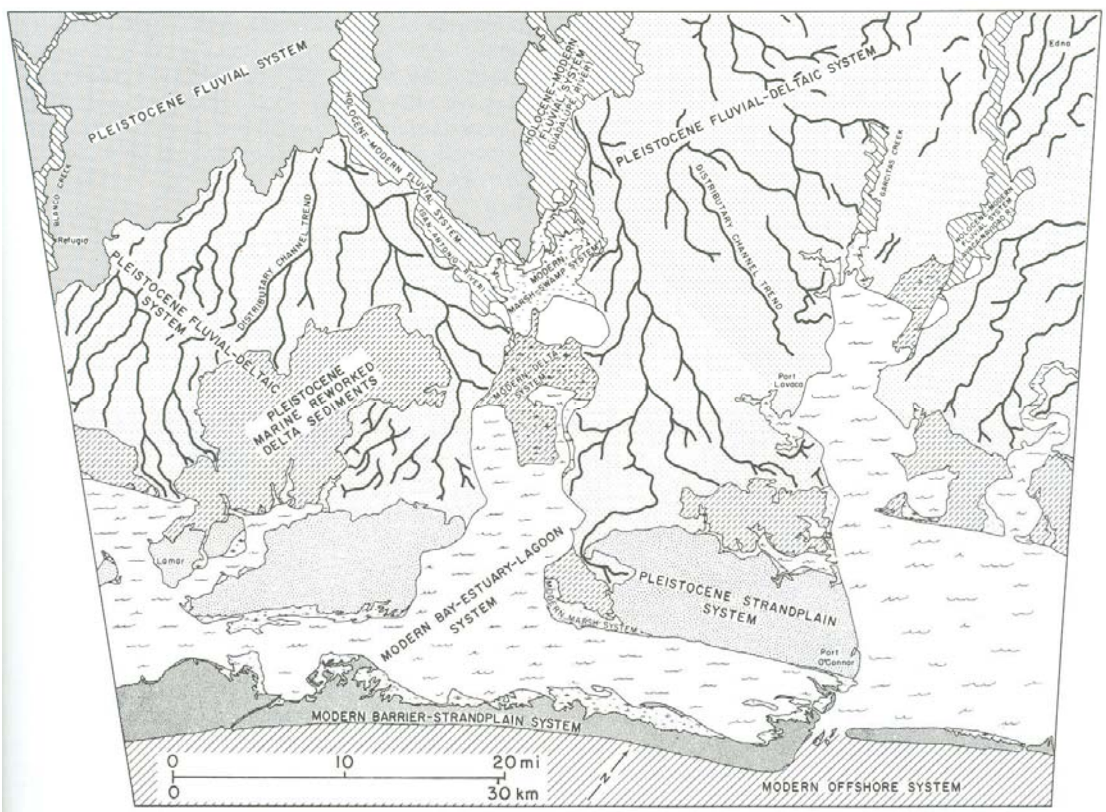


Figure 30. Natural systems of the San Antonio Bay area (from McGowen et al., 1976).

Relative Sea-Level Rise

Relative sea-level rise (RSLR), as discussed more completely previously in the Freeport section, is another important process affecting wetland and aquatic habitats. Along the Texas coast, both processes—eustatic sea-level rise and subsidence—are part of the RSLR equation. Subsidence, especially associated with withdrawal of groundwater and oil and gas, is the overriding component (White and Morton, 1997). Over the past century, sea level has risen worldwide (eustatic) 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). High rates of RSLR can cause changes in habitats, such as estuarine marshes and wind-tidal flats (White et al., 1998). The tide gauge at Rockport provides the longest continuous record of sea-level variations near the southwest end of the study area. The average rate of sea-level rise from the 1950's through 1993 (with data missing in the late 1950's and early 1960's) is about 0.40 cm/yr. Rates of sea-level rise recorded by the tide gauge reached a high of 1.7 cm/yr from the mid-1960's to mid-1970's; this time coincides with a maximum change in some habitats, such as wind-tidal flats (White et al., 1998). These relationships in the bay area are presented in the discussion of wetland trends.

Status of Wetlands and Aquatic Habitats, San Antonio Bay Area, 2009

In 2009, wetland, aquatic, and upland habitats covered 59,010 ha within the San Antonio Bay study area. Approximately 22,696 ha within the study area was classified as uplands. Of the four wetland systems mapped, the palustrine system is the largest (Figs. 31 and 32; Table 6). The largest area is the open-water class, covering 18,718 ha. Emergent vegetated wetlands (E2EM, E2SS, PEM) cover 11,044 ha, about 50% of which is palustrine marsh. Other important habitats are seagrass (E1AB3), which in the study area covers almost 2,388 ha and tidal flats (E2US), covering 1,725 ha. Oyster reefs are also present in the bay. The extent of all mapped wetlands, deepwater habitats, and uplands for each year is presented in the appendix. Field-site locations visited during this study are shown in Figure 33.

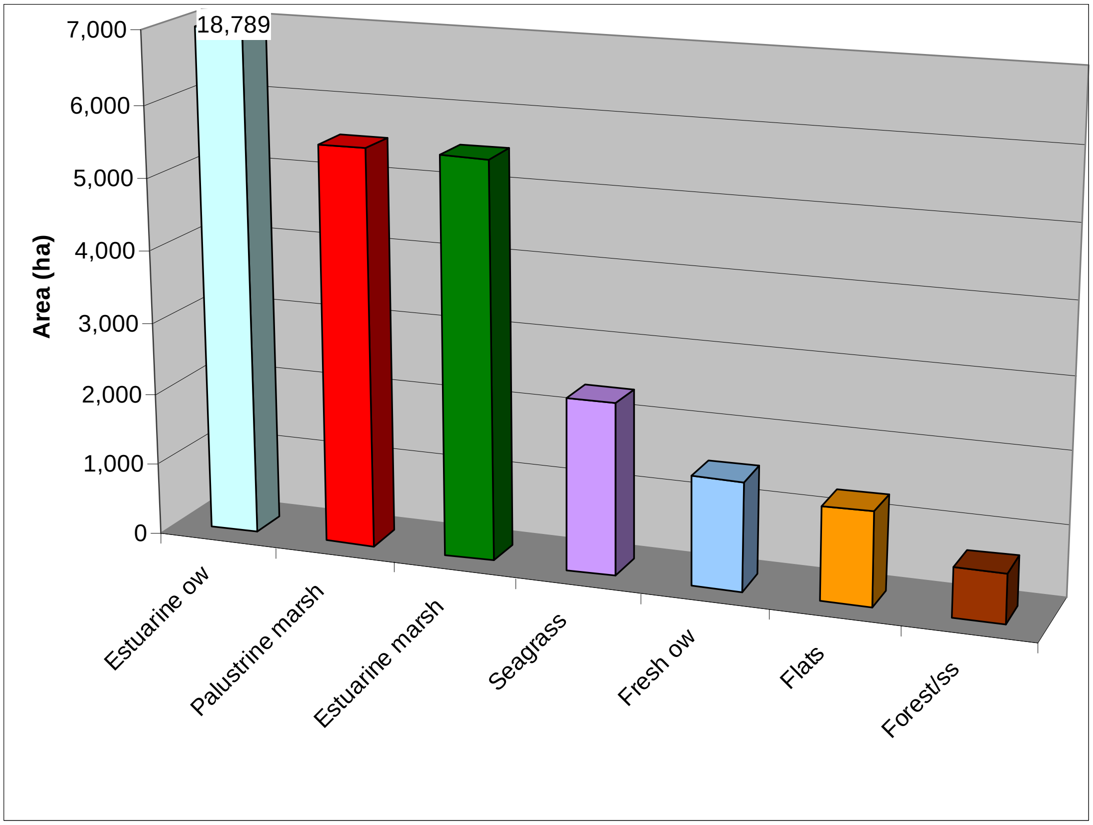


Figure 31. Areal distribution of selected habitats in 2009 in San Antonio Bay.

Estuarine System

Marshes (Estuarine Intertidal Emergent Wetlands)

The estuarine intertidal emergent wetland habitat (E2EM) consists of 5,506 ha of salt and brackish marshes. Unlike most wetlands on the Texas coast, in San Antonio Bay irregularly flooded marshes are most abundant (White et al., 2002, 2004; Tremblay et al., 2008; Tremblay and Calnan, 2010) (Table 6). The irregularly flooded marshes cover 2,911 ha and the regularly flooded marshes, 2,595 ha. The most extensive estuarine emergent wetlands are in the Strandplain subarea, where 46% of this habitat occurs and the San Antonio River subarea, where 41% occurs (subareas are shown in Fig. 34). Locally, salt-marsh assemblages fringe open bays (Figs. 35 and 36).

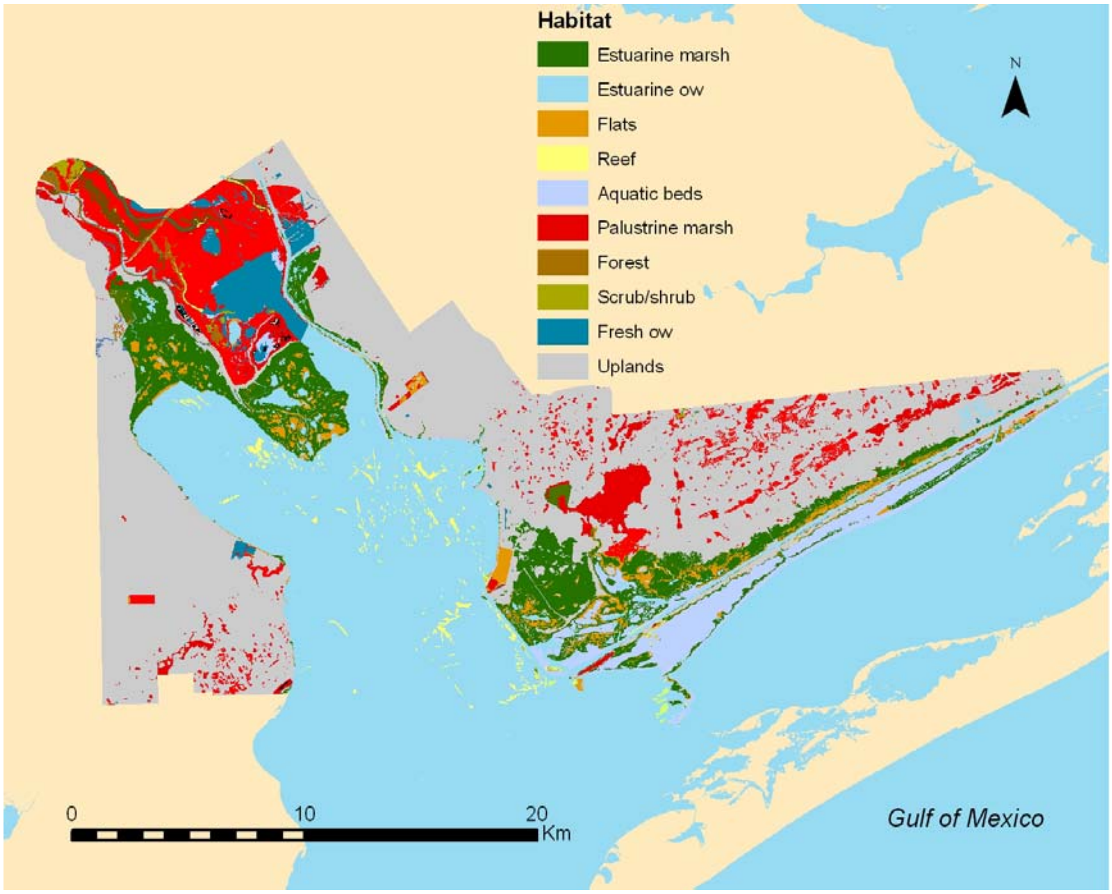


Figure 32. Map of habitats in 2009 for the San Antonio Bay study area.

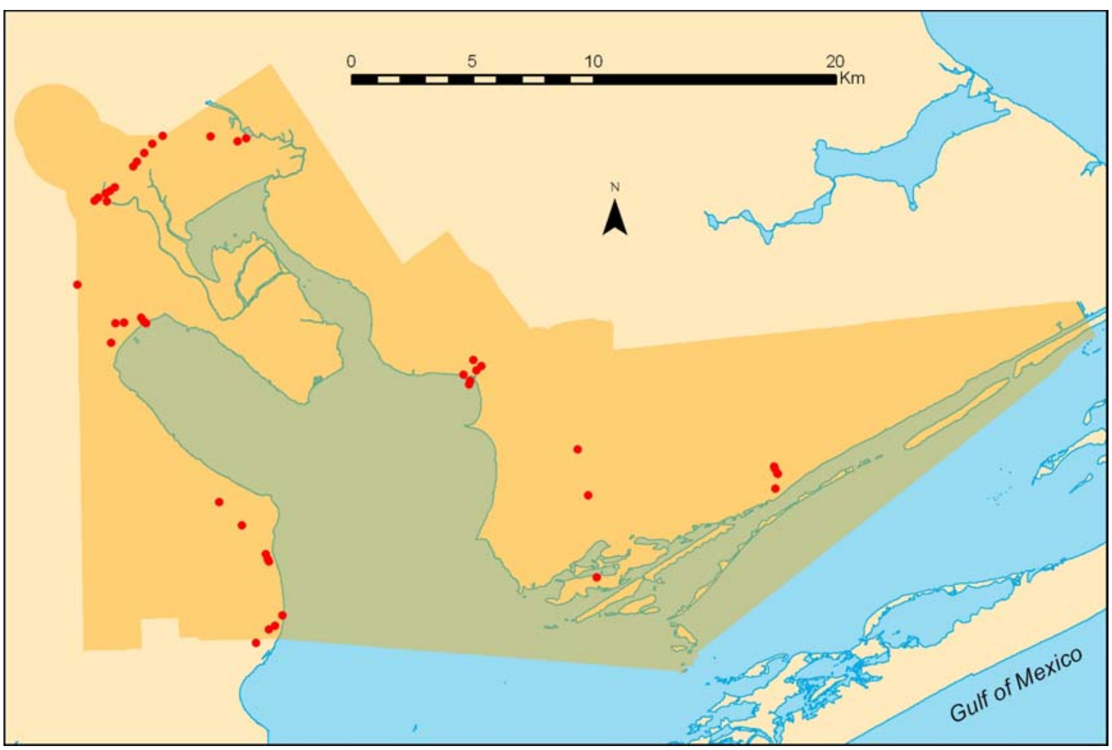


Figure 33. Field-site locations in the San Antonio Bay study area.

Table 6. Areal extent of mapped wetland and aquatic habitats in the San Antonio Bay area in 2009 and percentage that each habitat represents in the study area.

NWI Code	National Wetlands Inventory Description	Hectares	Acres	Percent
E1AB1	Estuarine Subtidal Aquatic Bed, Algal	4	10	0.01
E1AB3	Estuarine Subtidal Aquatic Bed, Rooted Vascular	2,388	5,898	4.05
E1AB5	Estuarine Subtidal Aquatic Bed, Unknown Submergent	23	58	0.00
E1AB6	Estuarine Subtidal Aquatic Bed, Unknown Surface	1	2	0.00
E1RF2L	Estuarine Subtidal Reef, Mollusk	42	104	0.07
E1UB	Estuarine Subtidal Unconsolidated Bottom	18,718	46,234	31.72
E2AB1N	Estuarine Intertidal Aquatic Bed, Algal Regularly Flooded	6,259	15,466	13.52
E2AB1P	Estuarine Intertidal Aquatic Bed, Algal Irregularly Flooded	1,594	3,939	3.44
E2EM1N	Estuarine Intertidal Emergent Wetland, Regularly Flooded	2,595	6,410	4.40
E2EM1P	Estuarine Intertidal Emergent Wetland, Irregularly Flooded	2,911	7,190	4.93
E2RF2M	Estuarine Intertidal, Reef, Mollusk	418	1,032	0.71
E2SS3	Estuarine Intertidal Scrub/Shrub Wetland	2	4	0.00
E2USM	Estuarine Intertidal Flat, Irregularly Exposed	99	244	0.17
E2USN	Estuarine Intertidal Flat, Regularly Flooded	531	1,312	0.90
E2USP	Estuarine Intertidal Flat, Irregularly Flooded	338	835	0.57
Subtotal		**28,410**	**70,171**	**48.14**
L1UBH	Lacustrine Limnetic Unconsolidated Bottom, Perm Flooded	251	620	0.43
L1UBV	Lacustrine Limnetic Unconsolidated Bottom, Perm-Tidal	767	1,894	1.30
L2AB5	Lacustrine Littoral Aquatic Bed	5	13	0.00
L2AB5V	Lacustrine Littoral Aquatic Bed, Permanent-Tidal	48	117	0.08
L2UBF	Lacustrine Littoral Unconsol Bottom, Semiperm Flooded	15	38	0.03
L2UBK	Lacustrine Littoral Unconsolidated Bottom, Artificial Flood	40	98	0.07
Subtotal		**1,126**	**2,781**	**1.91**
PAB1F	Palustrine Aquatic Bed, Algal, Semipermanently Flooded	25	62	0.04
PAB4F	Palustrine Aquatic Bed, Float Vascular, Semiperm Flood	6	14	0.01
PAB4K	Palustrine Aquatic Bed, Floating Vascular, Artificially Flood	1	2	0.00
PAB5	Palustrine Aquatic Bed, Unknown Submergent	43	105	0.07
PAB5V	Palustrine Aquatic Bed, Unknown Submergent, Perm-Tidal	18	44	0.03
PEM1A	Palustrine Emergent Wetland, Temporarily Flooded	2,755	6,808	4.67
PEM1C	Palustrine Emergent Wetland, Seasonally Flooded	2,084	5,150	3.53
PEM1F	Palustrine Emergent Wetland, Semipermanently Flooded	500	1,235	0.85
PEM1K	Palustrine Emergent Wetland, Artificially Flooded	60	148	0.10
PEM1R	Palustrine Emergent Wetland, Seasonal-Tidal	31	76	0.05
PEM1S	Palustrine Emergent Wetland, Temporary-Tidal	23	58	0.04
PEM1T	Palustrine Emergent Wetland, Semipermanent-Tidal	45	110	0.08
PEM1V	Palustrine Emergent Wetland, Permanent-Tidal	38	95	0.06
PFO1A	Palustrine Forested, Broad-Leaved Decid, Temp Flooded	197	487	0.33
PFO1C	Palustrine Forested, Broad-Leaved Decid, Season Flooded	366	904	0.62
PSS1A	Palustrine Scrub/Shrub Wetland, Temporarily Flooded	24	59	0.04
PSS1C	Palustrine Scrub/Shrub Wetland, Seasonally Flooded	100	246	0.17
PUB	Palustrine Unconsolidated Bottom	28	69	0.05
PUBC	Palustrine Unconsolidated Bottom, Seasonally Flooded	0.3	0.7	0.00

PUBF	Palustrine Unconsolidated Bottom, Semiperm Flooded	17	41	0.03
PUBH	Palustrine Unconsolidated Bottom, Permanently Flooded	119	294	0.20
PUBK	Palustrine Unconsolidated Bottom, Artificially Flooded	13	32	0.02
PUS	Palustrine Unconsolidated Shore	76	188	0.13
PUSC	Palustrine Unconsolidated Shore, Seasonally Flooded	9	22	0.02
PUSK	Palustrine Unconsolidated Shore, Artificially Flooded	91	224	0.15
Subtotal		**6,667**	**16,469**	**11.30**
R1UBV	Riverine Tidal Unconsolidated Bottom, Permanent-Tidal	25	63	0.04
R2AB4	Riverine Lower Perennial Aquatic Bed, Floating Vascular	8	20	0.01
R2UBH	Riverine Lower Perennial Unconsol Bottom, Perm Flooded	77	191	0.13
Subtotal		**111**	**274**	**0.19**
U	Upland	22,695	56,057	38.46
Total		**59,010**	**145,756**	**100.00**

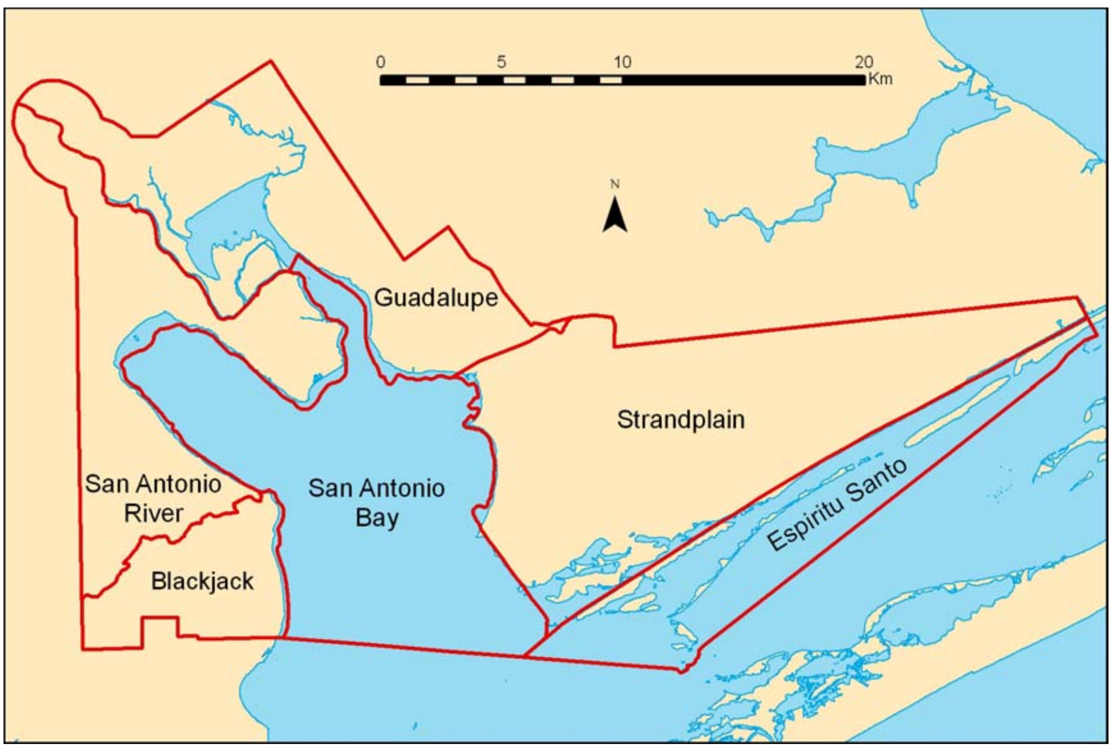


Figure 34. Index map of study area subdivided into the following subareas: Blackjack, San Antonio River, Guadalupe, Strandplain, Espiritu Santo, and San Antonio Bay.

Figure 35. Regularly flooded estuarine marsh (E2EM1N) at Welder Flats WMA. Dominant species is *Batis maritima*.

Figure 36. High salt marsh (E2EM1P) at upland contact, Lane Road, Strandplain subarea. Dominant species is *Spartina spartinae*.

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

Estuarine intertidal unconsolidated shores (E2US) include tidal flats and bay beaches. Estuarine intertidal aquatic beds (E2AB) are tidal flats in which blue-green algae have formed algal mats on the surface. Approximately 968 ha of E2US and 399 ha of E2AB was mapped in the study area (Figure 31; Table 6). E2US areas, mapped as irregularly exposed ("M" water regime) (Table 6), were included in Table 7 and Figure 32. These areas are relatively small, totaling about 99 ha. Low, regularly flooded tidal flats are more extensive than high, irregularly flooded flats (Table 6). A much larger area of low, regularly flooded aquatic beds (flats with algal mats) were mapped than high, irregularly flooded aquatic beds (Table 6). Together, tidal and algal flats represent approximately 19% of the intertidal wetland system (excluding subtidal habitats and the E1 map units). The mapped extent of the tidal flats could have been affected substantially by tidal levels at the time the aerial photographs were taken (Fig. 37). Accordingly, absolute areal extent of flats may vary from that determined using aerial photographs.

Figure 37. Wetland gradient at Welder Flats WMA. Right to left, flooded low flat (E2USN), regularly flooded salt marsh (E2EM1N), irregularly flooded flat (E2USP), and irregularly flooded salt marsh (E2EM1P).

Table 7. Areal extent (ha) of selected habitats by geographic subarea in 2009, San Antonio Bay.

	Blackjack	San Antonio River	Guadalupe	Strandplain	Espiritu Santo	Totals
Estuarine open water	139	923	374	696	4,087	6,219
Palustrine marsh	314	266	2,960	1,984	40	5,528
Estuarine marsh	14	2,234	301	2,505	442	5,496
Fresh open water	6	51	1,401	23	5	1,486
Tidal flats	8	421	29	617	142	1,217
Forest	0	63	607	9	0	679

Oyster Reefs (Estuarine Reefs)

Intertidal oyster reefs (E2RF2M) mapped on 2007 photographs totaled 418 ha and are almost entirely in San Antonio Bay (Fig. 32). Reefs in San Antonio Bay were incorporated from NOAA's benthic habitat atlas—Coastal Bend Texas Benthic Habitat— San Antonio Bay data set (2007). Subtidal oyster reefs (E1RF2L) mapped on the 2009 photographs totaled 42 ha in Espiritu Santo Bay. Only those that were near the water's surface and that were clearly visible were mapped (Fig. 38). Reefs were mapped in 1979 (7 ha) but were not mapped by USFWS on the 1950's photographs. Without the historical data, we were unable to document spatial and temporal trends in the reefs.

Figure 38. Intertidal oyster reefs (E2RF2M) in San Antonio Bay near Seadrift.

Aquatic Beds (Estuarine Subtidal Aquatic Beds)

Estuarine subtidal, rooted, vascular, aquatic beds (E1AB3L) represent areas of submerged, rooted, vascular vegetation, or *seagrasses*. 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 visible in most of the 2009 photographs but are obscured by turbidities in some areas and could not be mapped in total. Densities of the mapped seagrass ranged from very dense to patchy (Fig. 39). Within the study area, about 2,388 ha of seagrass beds was mapped. Seagrasses are most extensive in the Espiritu Santo subarea and to a lesser degree in the Strandplain subarea (Fig. 34).

Figure 39. Seagrass in GIWW at end of Lane Road, Strandplain subarea of San Antonio Bay.

Open Water (Estuarine Subtidal Unconsolidated Bottom)

Estuarine subtidal unconsolidated bottom (E1UBL), or *open water*, includes the bays, GIWW, and ponds within the marsh complexes. The total area of estuarine open water mapped in the study area is 18,718 ha. If the subtidal reefs and nonseagrass algal beds (E1RF and E1AB) are included, the total is 18,789 ha (Fig. 31; Table 6).

Palustrine System

Marshes (Palustrine Emergent Wetlands)

Palustrine emergent wetlands (PEM), or *inland, nontidal fresh-water* marshes, cover 5,536 ha (Fig 31; Table 6) and represent 50% of emergent vegetated wetlands. The broadest distribution is in the Guadalupe subarea, where 2,960 ha occurs, followed by the Strandplain subarea where 1,948 ha was mapped (Fig. 32; Table 7). Relatively little marsh was mapped in the rest of the study area. Much of the PEM in the Guadalupe subarea is in the Guadalupe Delta WMA (Fig. 40). Palustrine marshes often occur in isolated depressions along the Ingleside barrier strandplain and on the active Guadalupe River delta. These marshes typically were classified into one of three water regimes: (1) temporarily flooded, (2) seasonally flooded, or (3) semipermanently flooded. Roughly half of palustrine marshes were mapped as temporarily flooded, the driest water regime.

Figure 40. Temporarily flooded, persistent emergent marsh (PEM1A) along Highway 35 boundary of Guadalupe Delta WMA. Dominant species is *Aster spinosus*.

Open Water and Flats (Palustrine Unconsolidated Bottom and Shore)

Palustrine unconsolidated bottom (PUB), or *open water*, habitats are generally small fresh- to brackish-water ponds (Fig. 41). The total mapped area of this habitat was 177 ha. Palustrine flats are often associated with open water and cover 176 ha. Many of these habitats are either excavated (x modifier) or impounded (h modifier). For analysis purposes, palustrine, lacustrine, and riverine unconsolidated bottom and aquatic bed habitats were combined into fresh open water (Table 7).

Figure 41. Palustrine unconsolidated bottom (PUB) or fresh-water pond in Hynes Unit of Guadalupe Delta WMA.

Forest (Palustrine Forested and Scrub-Shrub Wetlands)

Palustrine forested wetlands (PFO), comprising fluvial woodlands and swamps, cover a 563-ha area (Fig. 31; Table 6). Forests were classified as broad-leaved, deciduous trees (Fig. 42). Palustrine scrub-shrub (PSS) habitat covers 124 ha. Owing to difficulty in distinguishing forest regrowth from scrub-shrub, the two classes were combined for analysis.

Figure 42. Palustrine forest (PFO) adjacent to Highway 35 border of Guadalupe Delta WMA.

Lacustrine and Riverine Systems

Open Water and Flats (Lacustrine Unconsolidated Bottom and Shore)

Lacustrine unconsolidated bottom (L1UB and L2UB), or *lakes*, and lacustrine aquatic bed (L2AB), or *algal mats*, include lakes and inland reservoirs greater than 20 acres (8.33 ha). Lakes and algal mats associated with lakes cover 1,126 ha. Lakes are further classified according to depth. Mission Lake accounts for about 66% of the total lacustrine open-water and algal-mat area.

River (Riverine Tidal and Lower Perennial)

Riverine tidal unconsolidated bottom (R1UB) and lower perennial unconsolidated bottom (R2UB) and aquatic beds (R2AB), or *rivers*, cover 111 ha. (Fig. 43). Lower perennial rivers compose about 69% of all rivers in the study area.

Figure 43. Riverine unconsolidated bottom and aquatic beds adjacent to Highway 35 border of Guadalupe Delta WMA.

Historical Trends in Wetlands and Aquatic Habitats, San Antonio Bay

General Trends in Wetlands within the Study Area

Analysis of trends in wetlands and aquatic habitats from the 1950's through 2009 shows that palustrine marsh decreased from the 1950's through 1979 and increased from 1979 through 2009 (Figs. 44 and 45; Table 8). Palustrine marsh is the most extensive habitat. The lesser distribution in 1979 may be partly related to interpretational differences. However, by 2009, land-management practices and accelerated relative sea-level rise had reduced palustrine-marsh area. The total area of estuarine marsh increased 58% between the mid-1950's and 1979, remaining relatively stable through 2009. Estuarine-marsh habitats had their largest distribution of 5,508 ha in 2009. The difference in total area was larger than that of the 1950's (3,281 ha) but relatively consistent with that found in 1979 (5,170 ha). The large difference in area of estuarine marsh between the mid-1950's and 1979 was mostly interpretational but was due somewhat to management practices. Combined palustrine and estuarine-marsh totals show a net gain through time (Fig. 46). Tidal flats lost 22% of the original resource of 2,211 ha, diminishing to 1,725 ha in 2009. The tidal-flat low of 1,399 ha in 1979 was likely due to wetter ground conditions because of higher rainfall at the time of photography. The depletion of tidal flats is a coastwide phenomenon. Fresh open-water area increased through time in the San Antonio Bay, with the greatest area of 1,814 ha occurring in 1979. Conversely, the amount of forest declined drastically between the mid-1950's and 2009, with a low of 614 ha in 1979. More than 70% of the forest area in 1956 was mapped as palustrine scrub-shrub (PSS), relatively little PSS being mapped in later years. More detailed probable causes of changes are presented in the following sections organized by geographic area.

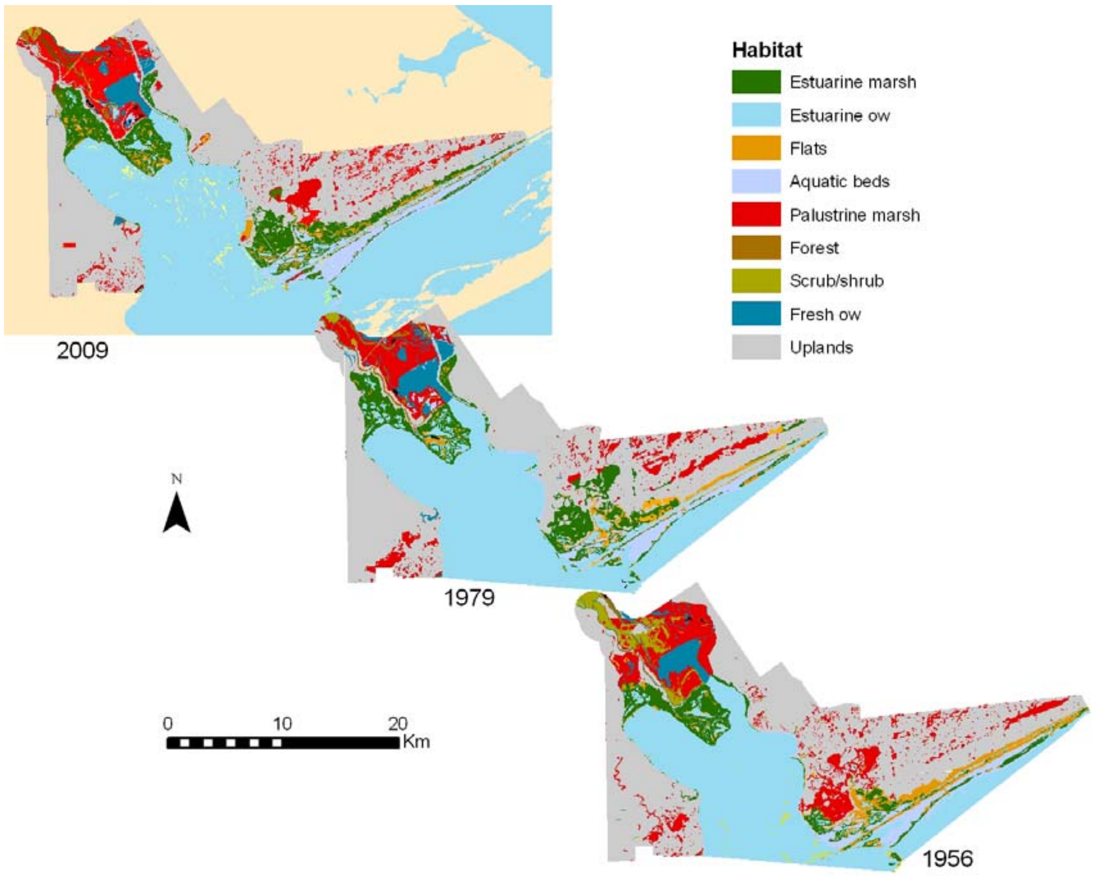


Figure 44. Maps showing distribution of major wetland and aquatic habitats in 2009, 1979, and the 1950's in the San Antonio Bay study area.

Table 8. Areal distribution (ha) of selected habitats, 1950's through 2009, in the San Antonio Bay study area.

Habitats	1950's	1979	2009
Palustrine marsh	6,547	4,742	5,536
Estuarine marsh	3,281	5,170	5,508
Tidal/algal flat	2,211	1,399	1,307
Fresh open water	1,277	1,814	1,506
Forest/scrub shrub	1,667	614	687

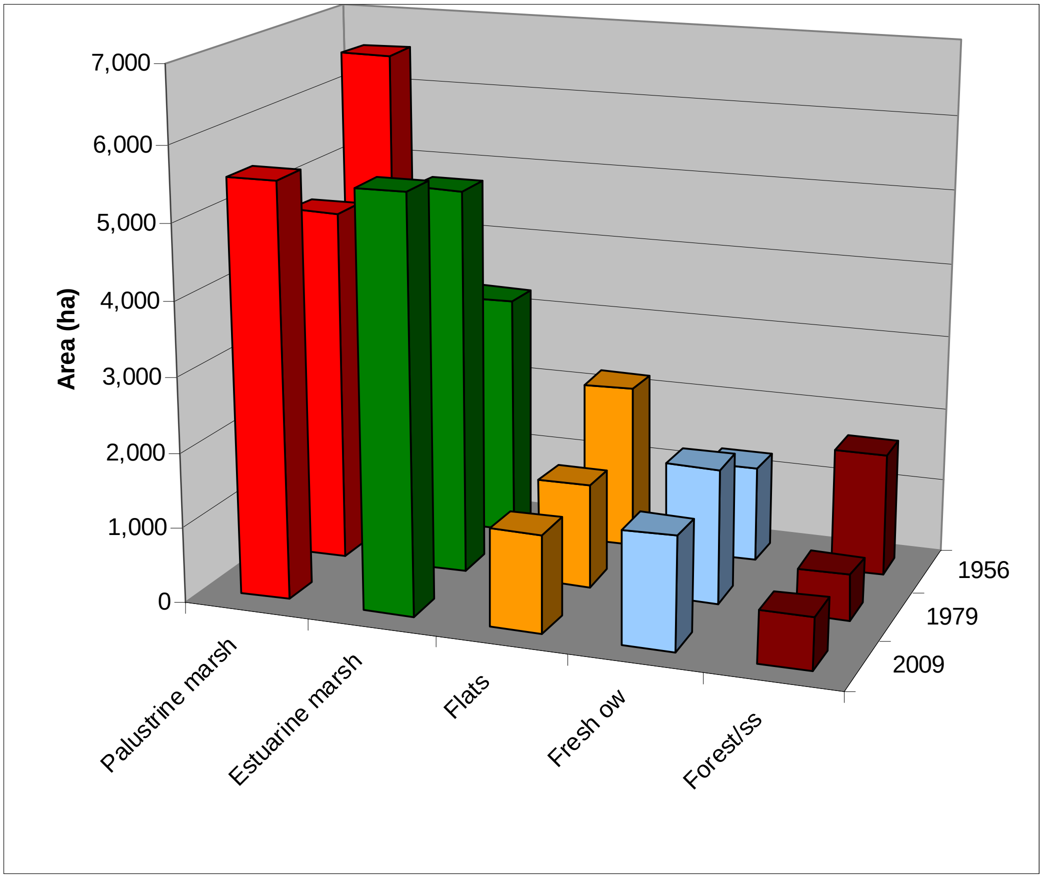


Figure 45. Areal extent of selected habitats from the 1950's through 2009 in the San Antonio Bay study area. Palustrine marsh is the most extensive habitat. Estuarine marsh is also widely distributed in the study area.

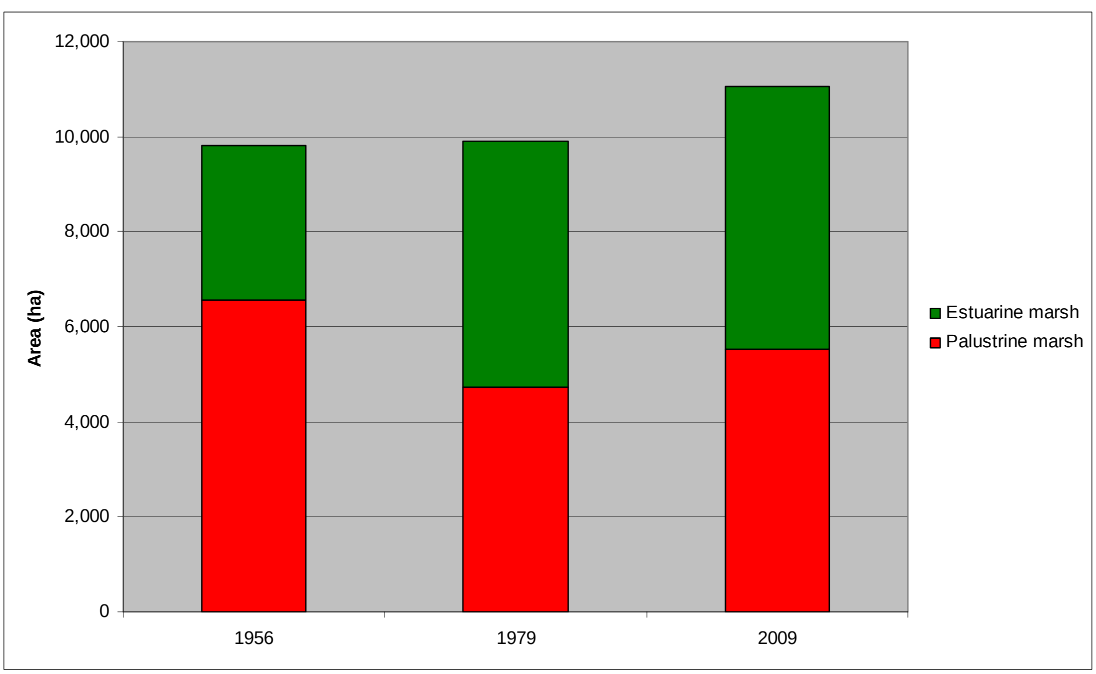


Figure 46. Combined marsh totals in the mid-1950's, 1979, and 2009.

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. 47): (1) Blackjack, (2) San Antonio River, (3) Guadalupe, (4) Strandplain, (5) Espiritu Santo, and (6) San Antonio Bay. This subdivision allowed a more site-specific analysis of trends and their probable causes. Palustrine marshes, estuarine marshes, tidal flats, open water, and forests are emphasized.

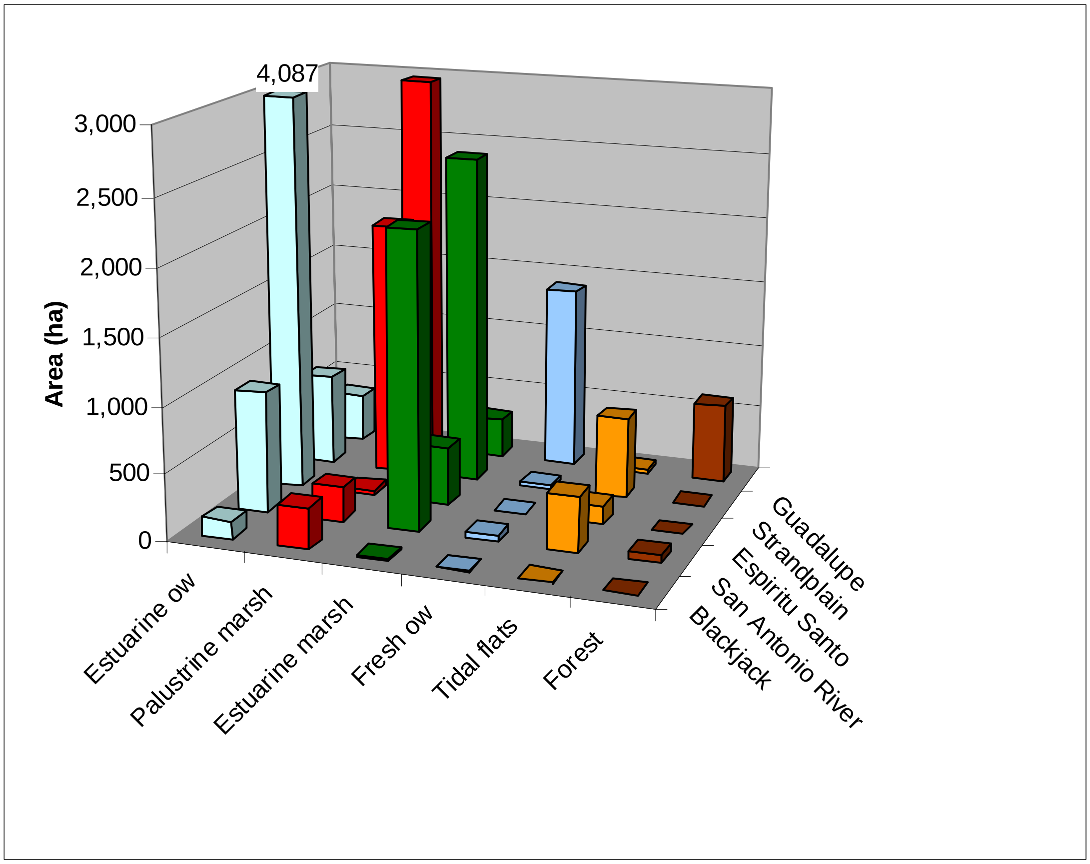


Figure 47. Areal distribution of habitats in the separate geographic subareas of the San Antonio Bay study area.

Blackjack

The most significant habitat trend in the **Blackjack subarea** is the decrease in palustrine marsh from a total of 464 ha in the mid-1950's to 314 ha in 2009 (-32% loss) (Fig. 48). Wetter ground conditions because of higher rainfall in 1979 may have inflated palustrine-marsh area to a high of 572 ha. Estuarine-marsh area remained stable through time. However, location of estuarine marsh in the Blackjack subarea changed. The lowest amount of marsh occurred in 1979, with a total of 108 ha. Because a tidal inlet to the north of the area had been dammed, most of the

131 ha of estuarine marsh had become open water by 1979. Dikes constructed at Webb Point had converted fresh marsh to salt march by 2009, returning estuarine area amounts to mid-1950's numbers (Figs. 49 and 50). A small amount of estuarine open water was reduced by more than half over the length of the study .

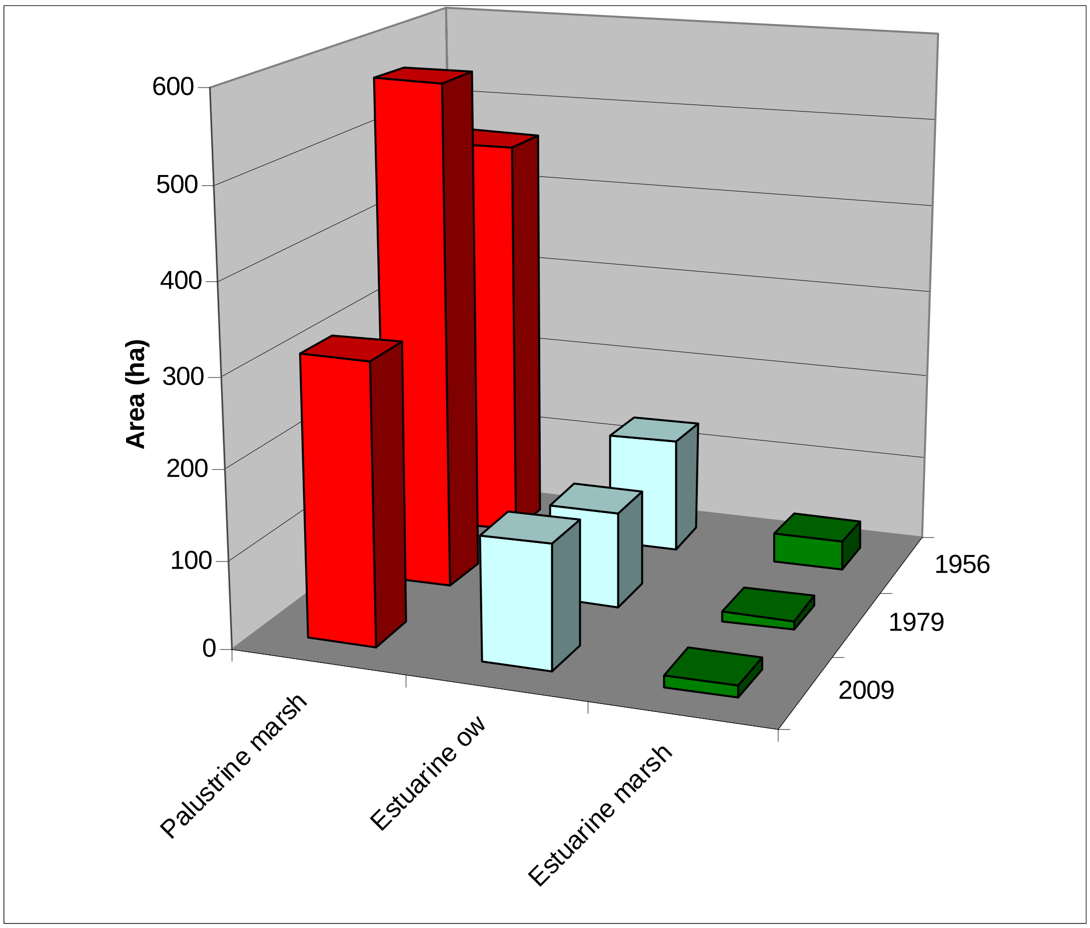


Figure 48. Areal extent of major habitats in the Blackjack subarea in the 1950's, 1979, and 2009.

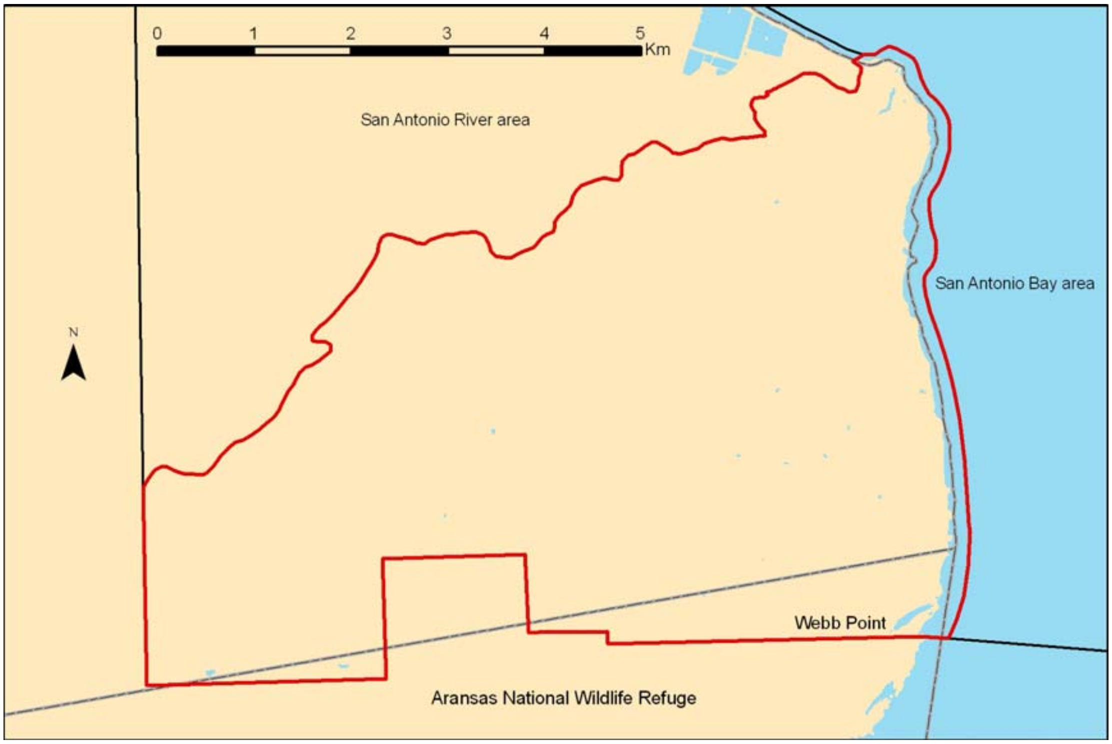


Figure 49. Index map showing features in the Blackjack subarea.

Figure 50. Palustrine marsh near Webb Point. View from Aransas National Wildlife Refuge headquarters building.

San Antonio River

In the **San Antonio River** subarea, palustrine marsh lost over half of the original amount during the study time period. Of the 556 ha in 1956, only 266 ha was remaining by 2009 (Fig. 51). Very little palustrine marsh was mapped in 1979. Conversely, there was a systematic increase in estuarine marsh, with a gain of 452 ha from the 1950's through 2009, or about 25% of this resource with an area of 1,782 ha in the 1950's. By 1979, most of the fresh marsh in the upper reaches of Townsend Bayou had been replaced by salt marsh (Figs. 52 and 53). Tidal-flat area remained stable between the mid-1950's and 1979 at about 180 ha, increasing to 415 ha by 2009. Most of the increase occurred in areas previously mapped as salt marsh or open water. A large area of tidal-flat increase was along the shoreline of Hynes Bay at Townsend Bayou. This area was mapped as marsh in 1956, open water in 1979, and irregularly exposed flat (E2USM) in 2009, the wettest water regime assigned to flats (Fig. 54). Many flats were mapped in the lower reaches of Townsend Bayou and in the Long Lake area in 2009. Only half of the forest area mapped in the mid-1950's was mapped in 2009.

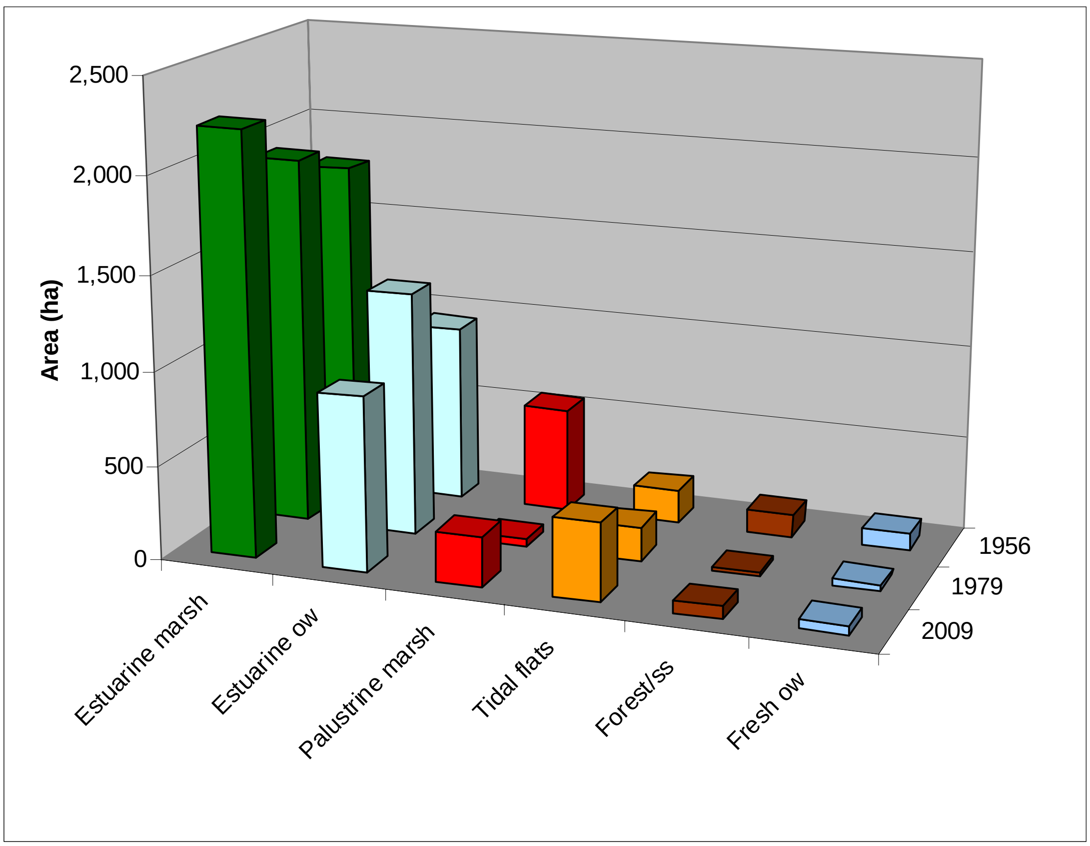


Figure 51. Areal extent of habitats in the 1950's, 1979, and 2009 in the San Antonio River subarea.

Figure 52. Index map showing features in the San Antonio River subarea.

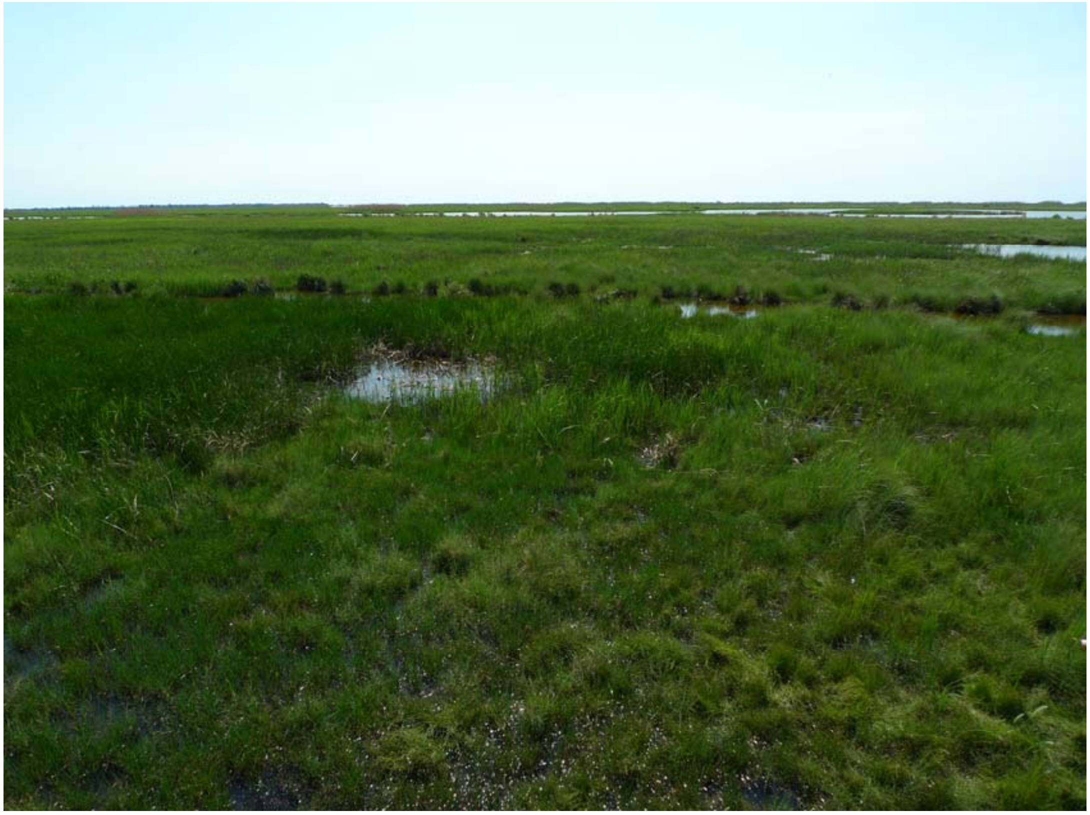


Figure 53. *Spartina* sp. in regularly flooded estuarine marsh (E2EM1N), Hynes Unit, Guadalupe Delta WMA.


Figure 54. Irregularly exposed tidal flat (E2USM) at the head of Hynes Bay.

Guadalupe

The **Guadalupe** subarea has experienced relative stability through time partly because of the establishment of the Guadalupe Delta WMA (Fig. 55). Estuarine marsh, a minor component of the vegetated emergent wetlands in this area, nevertheless increased in area by 179%, from 108 ha in the 1950's to 301 ha in 2009 (Fig. 56). Palustrine marsh is much more abundant in this subarea and increased only slightly by 7%, from 2,777 ha in the 1950's to 2,960 ha in 2009 (Fig. 57). Like most of the San Antonio Bay area, forest/scrub-shrub was mapped in 2009 at less than 60% of the original amount. Again, this change is due primarily to interpretational differences between time periods. Large tracts of palustrine scrub/shrub were mapped in the mid-1950's. What species composed these large scrub/shrub areas is unclear.

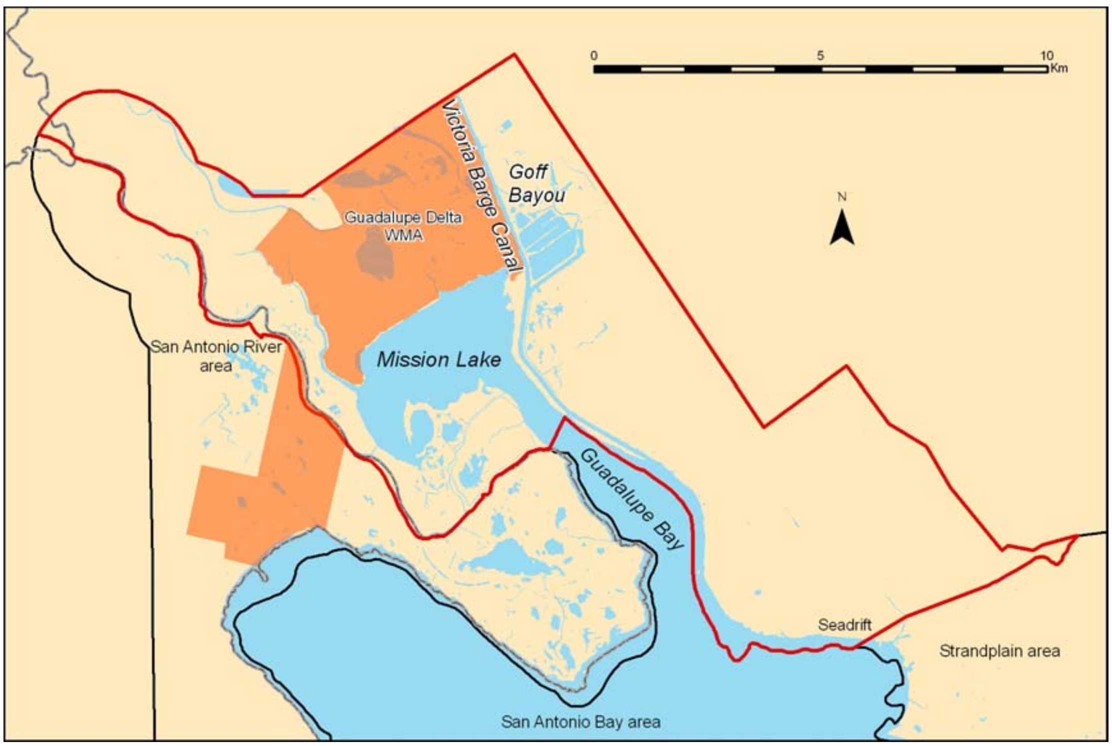


Figure 55. Index map showing features in the Guadalupe subarea.

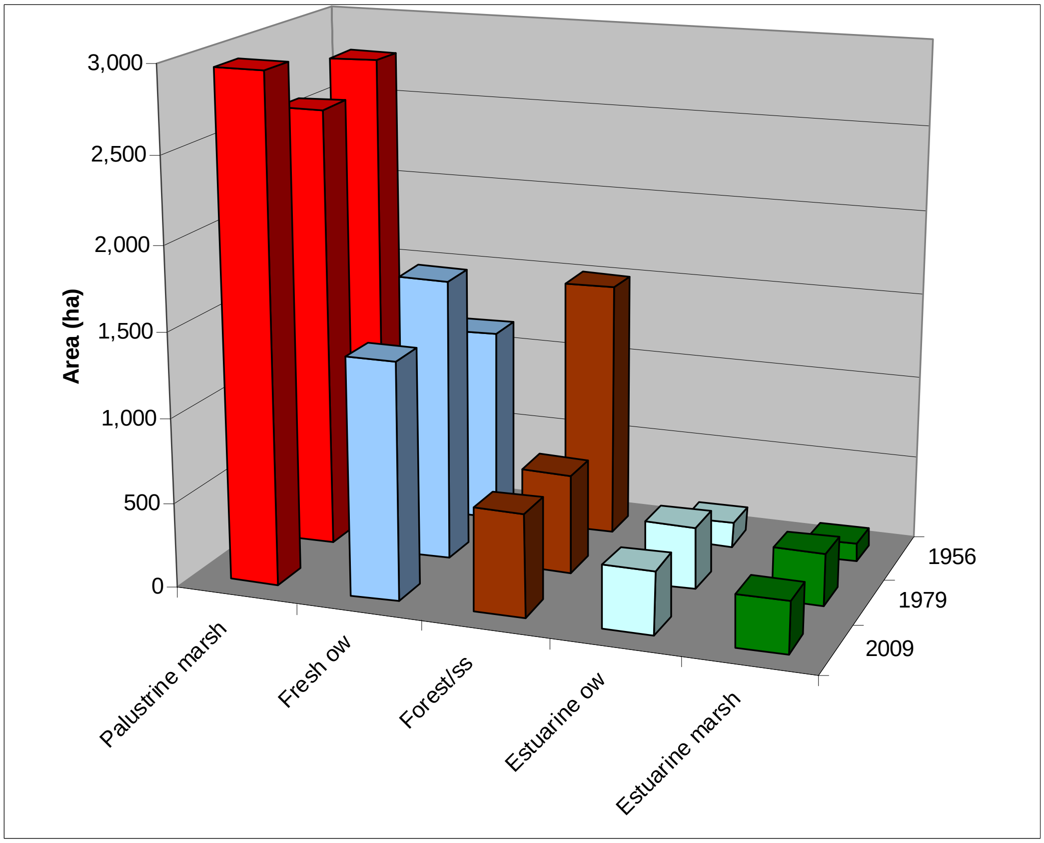


Figure 56. Distribution of selected habitats in the 1950's, 1979, and 2009 in the Guadalupe subarea.

Figure 57. Impounded palustrine marsh at Guadalupe Delta WMA.

Strandplain

The most significant change in the **Strandplain** subarea was the 258% increase in estuarine marsh, when 701 ha in the mid-1950's had increased to 2,505 ha by 2009 (Fig. 58). Most (39%) salt-marsh gain was from previous uplands, primarily along the GIWW (Fig. 59). Estuarine marsh also moved into areas mapped in the 1950's as palustrine marsh and tidal flat. Mosquito Point, inland from Welder Flats, was the main location for movement of salt marsh into other wetland habitats (Fig. 60). The peak estuarine-marsh area in 2009 resulted from mapping of salt marsh at locations farther inland than those mapped in other time periods. This extensive salt-marsh delineation resulted in a lower amount of palustrine-marsh area in 2009. Palustrine-marsh numbers decreased with a (-)29% loss between the mid-1950's total of 2,745 ha and 2009 total of 1,948 ha. Following a coastwide trend, tidal flats decreased (-38%) in overall area between the mid-1950's and 2009. The 1950's total of 991 ha had increased slightly by 1979 to 939 ha and had decreased to 614 ha by 2009. Roughly half of the decrease was to salt marsh, mostly low salt marsh. Another 23% of the tidal-flat loss area was replaced by seagrass. Unlike tidal flats, seagrass expanded in the Strandplain area through time. The gain of 142 ha equated to a 33% increase over the original resource amount.

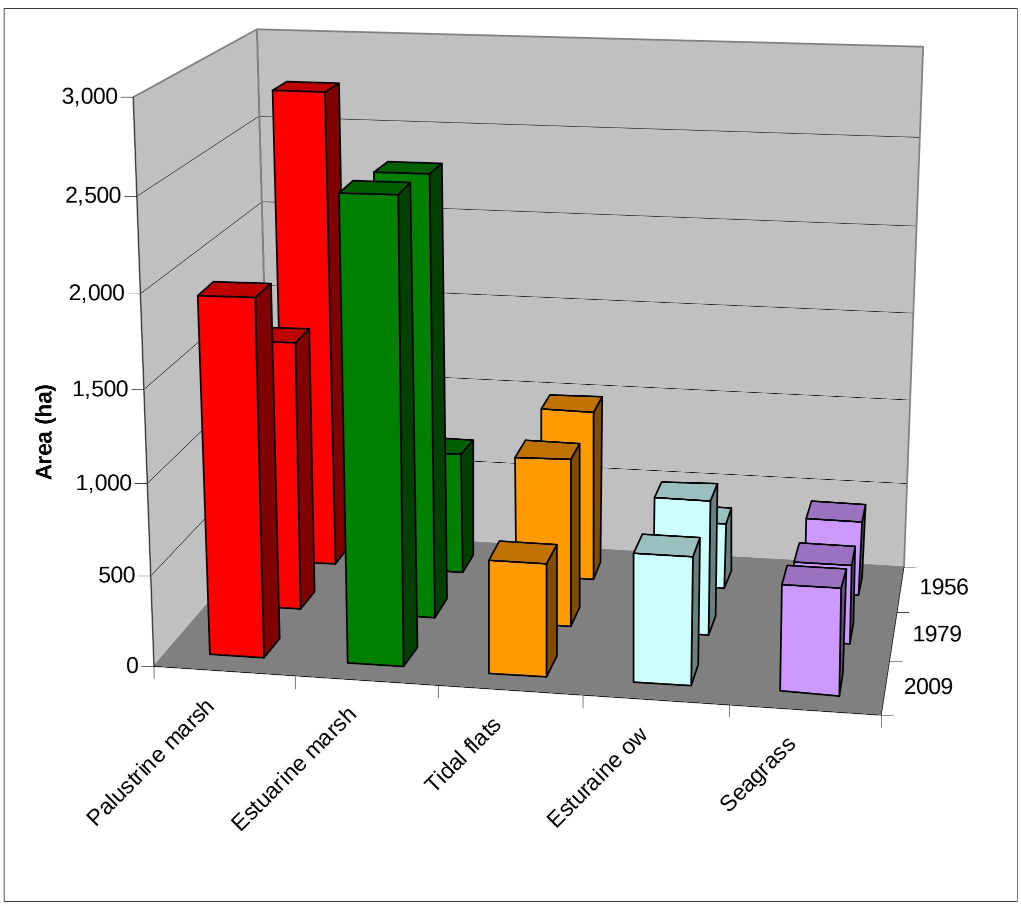


Figure 58. Areal distribution of selected habitats in the 1950's, 1979, and 2009 in the Strandplain subarea.

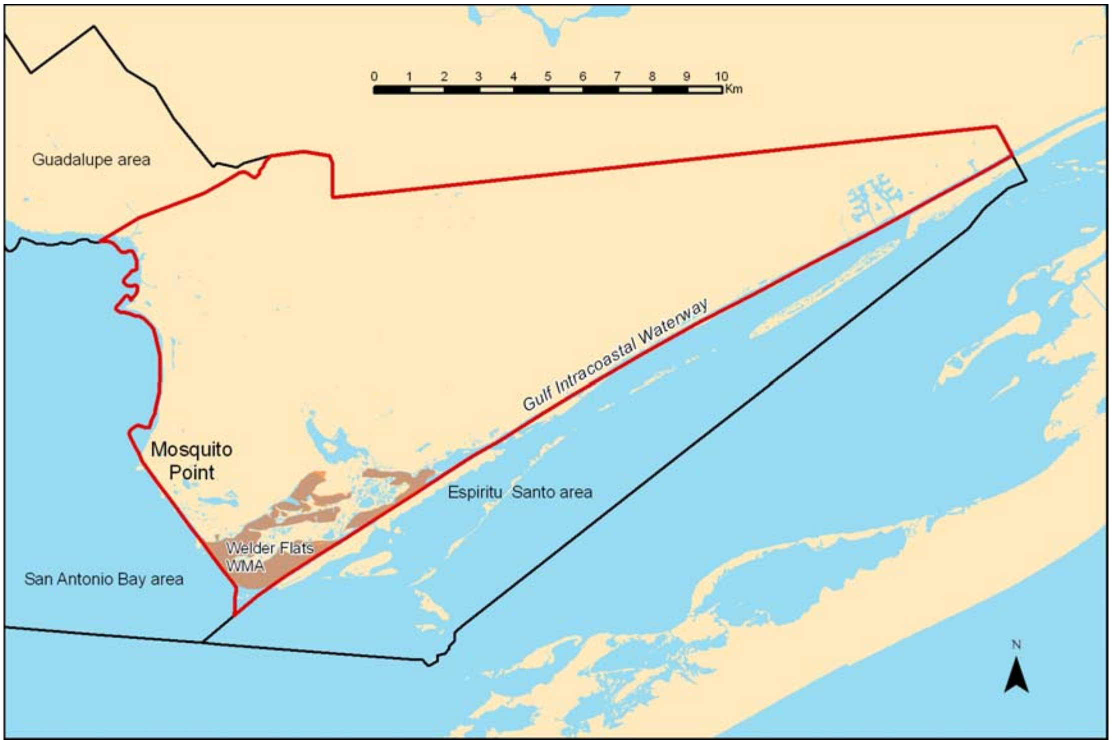


Figure 59. Index map showing features in the Strandplain subarea.


Figure 60. Salt marsh and estuarine open water at Welder Flats WMA.

Espiritu Santo

A coastwide trend also occurs in the **Espiritu Santo** subarea, where tidal flats experienced a systematic decrease through time. In the mid-1950's tidal flats covered 868 ha, and by 1979 the number had been reduced to 219 ha and had been further reduced to 142 ha by 2009 (Fig. 61). The GIWW was realigned between 1956 and 1979, causing tidal-flat area to be replaced with estuarine open water and seagrass (Fig. 62). About 64% of the tidal-flat loss area was replaced by these subtidal habitats in 1979. Uplands replaced many flats, and by 2009 salt marsh had also moved into previously flat areas. The loss of 726 ha amounts to (-)84% of the original resource. Like tidal flats, estuarine marsh also lost area over the length of the study. A high of 608 ha was mapped in the mid-1950's, followed by a drop to 411 ha by 1979, with a slight increase to 442 ha in 2009. The overall change in salt marsh amounted to a (-)27% loss of the resource. Most (52%) of the marsh loss area in 1979 had been converted to estuarine open water, and equal amounts of marsh-loss area had been converted to seagrass and upland. Marsh loss to upland occurred along the GIWW, where most of the tidal-flat loss also occurred. Marsh loss to open water and seagrass occurred mainly gulfward of the series of islands, including Blackberry Island, Dewberry Island, and Long Island along the GIWW. Marsh along the Espiritu Santo Bay side of the islands appears to have been eroded. Erosion along Steamboat Pass has also diminished marshes on Grass Island and the island near South Pass. Seagrass is abundant in the Espiritu Santo area, increasing by 22% over the length of the study. Relatively small numbers of oyster reefs occur here also, increasing in area significantly (64%) through time.

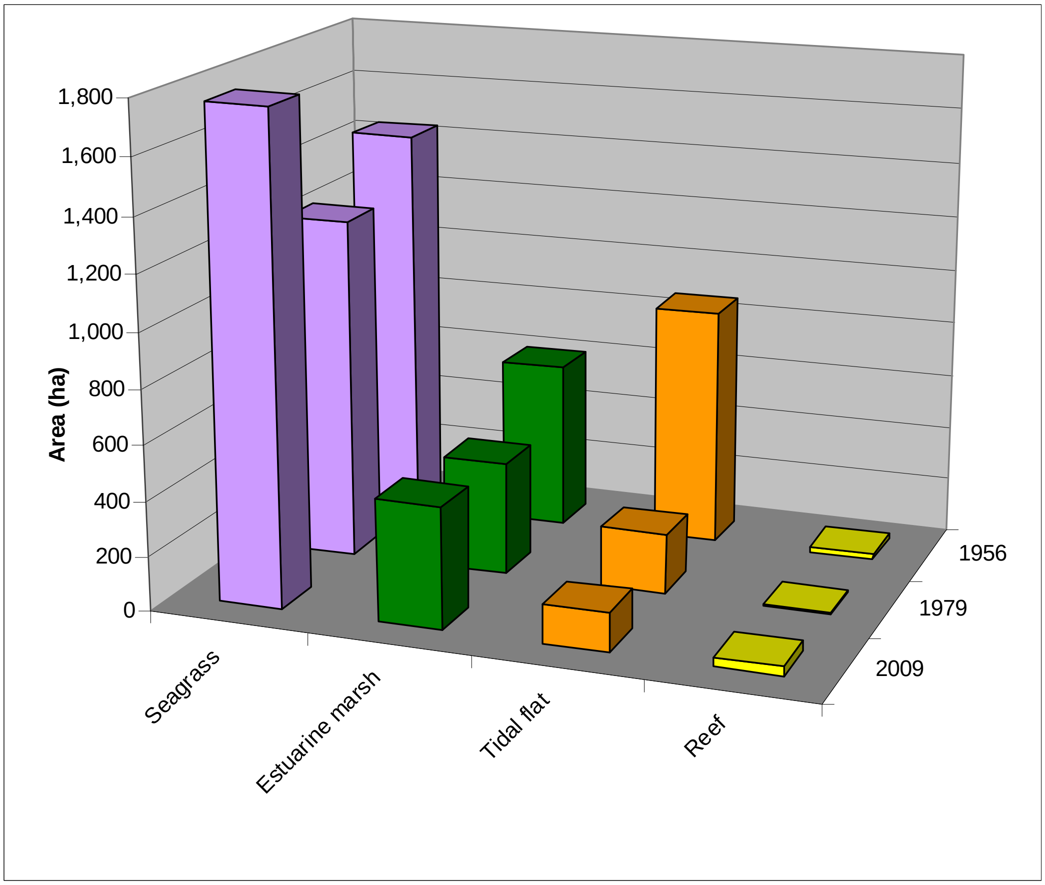


Figure 61. Distribution of selected habitats in the 1950's, 1979, and 2009 in the Espiritu Santo subarea.

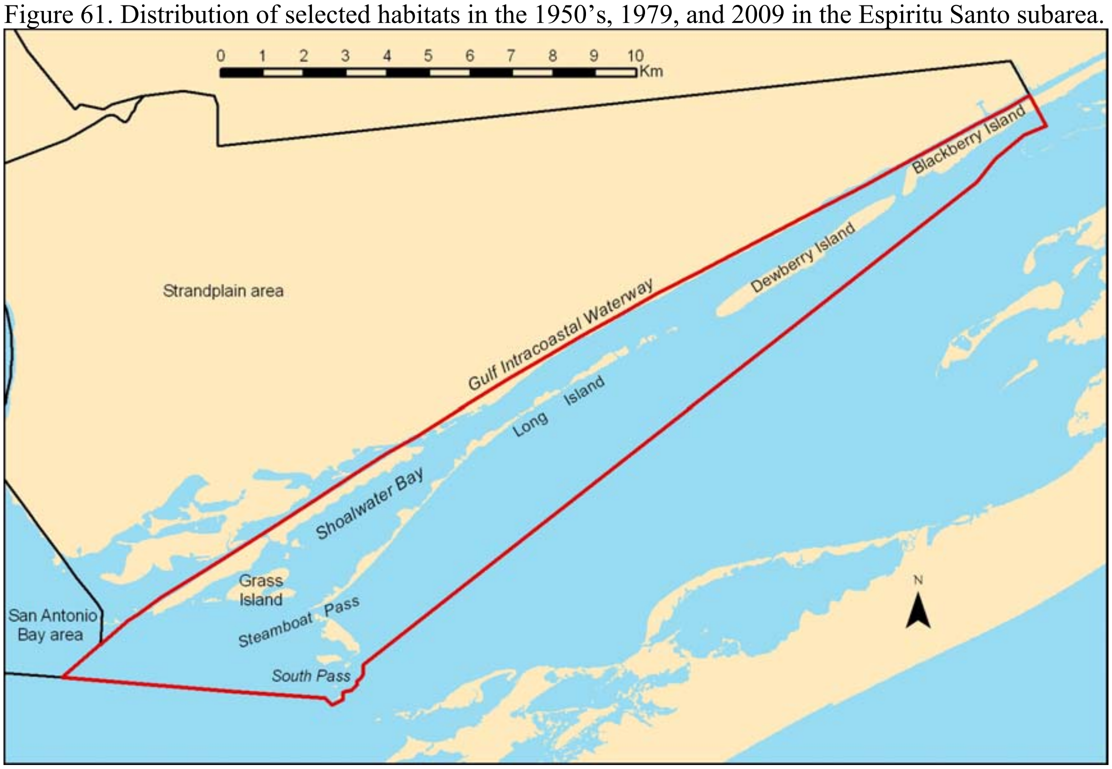


Figure 62. Index map showing features in the Espiritu Santo subarea.

San Antonio Bay Subarea

The **San Antonio Bay** subarea, covering roughly 13,100 ha, is predominantly estuarine subtidal unconsolidated bottom (E1UB), or *open water*. Most of the estuarine intertidal reef (E2RF) in the San Antonio Bay study area is found in this subarea. In the mid-1950’s only 113 ha of reef was mapped in the bay. No reefs were mapped in 1979, and 406 ha was mapped in 2009. As noted in the 2009 status section, intertidal reefs were incorporated from NOAA’s benthic habitat atlas (NOAA, 2007).

Summary and Conclusions, San Antonio Bay Area

The most significant habitat trend in the **Blackjack** subarea is the decrease in palustrine marsh from a total of 464 ha in the mid-1950’s to 314 ha in 2009 (-32% loss). Wetter ground conditions in 1979 may have inflated palustrine-marsh area to a high of 572 ha. Estuarine-marsh area remained stable through time, although the location of estuarine marsh in the Blackjack subarea changed. The lowest area of marsh occurred in 1979 with a total of 108 ha. When a tidal inlet to the north of the area had been dammed, most of the 131 ha of estuarine marsh had become open water by 1979. Dikes constructed at Webb Point had converted fresh marsh to salt marsh by 2009, returning estuarine area amounts to mid-1950’s numbers. A small amount of estuarine open water was reduced by more than half over the 50-year length of the study.

In the **San Antonio River** subarea, palustrine marsh lost over half of the original area through the study time period. Of the 556 ha in 1956, only 266 ha remained by 2009. Very little palustrine marsh was mapped in 1979. Conversely, there was a systematic increase in estuarine marsh with a gain of 452 ha from the 1950’s through 2009, or about 25% of this resource, with an area of 1,782 ha in the 1950’s. By 1979, most of the fresh marsh in the upper reaches of Townsend Bayou had been replaced by salt marsh. Tidal-flat area remained stable between the mid-1950’s and 1979 at about 180 ha but had increased to 415 ha by 2009. Most of the increase occurred in areas previously mapped as salt marsh or open water. A large area of tidal flat increased along the shoreline of Hynes Bay at Townsend Bayou. This area was mapped as marsh in 1956, open water in 1979, and irregularly exposed flat (E2USM) in 2009—the wettest water regime assigned to flats. Many flats were mapped in the lower reaches of Townsend Bayou and in the Long Lake area in 2009. Only half of the forest area mapped in the mid-1950’s was mapped in 2009.

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Antonio Bay area, forest/scrub-shrub was mapped in 2009 at less than 60% of the original amount. Again, this change is due primarily to interpretational differences between time periods. Large tracts of palustrine scrub/shrub were mapped in the mid-1950's. What species composed these large scrub/shrub areas is unclear.

The most significant change in the **Strandplain** subarea was the 258% increase in estuarine marsh when 701 ha in the mid-1950's had grown to 2,505 ha by 2009. Most (39%) salt-marsh gain was from previous uplands, primarily along the GIWW. Estuarine marsh also moved into areas mapped in the 1950's as palustrine marsh and tidal flat. Mosquito Point, inland from Welder Flats, was the main location of the movement of salt marsh into other wetland habitats. The peak estuarine-marsh area in 2009 resulted from mapping of salt marsh at locations farther inland than those mapped in other time periods. This extensive salt-marsh delineation resulted in a lower amount of palustrine-marsh area in 2009. Palustrine-marsh numbers decreased with a (-)29% loss between the mid-1950's total of 2,745 ha and 2009 total of 1,948 ha. Following a coastwide trend, tidal flats decreased (-38%) in overall area between the mid-1950's and 2009. The 1950's total of 991 ha had increased slightly by 1979 to 939 ha and had decreased to 614 ha by 2009. Roughly half of the decrease was to salt marsh, mostly low salt marsh. Another 23% of the tidal-flat loss area was to seagrass. Unlike tidal flats, seagrass expanded in the Strandplain area through time. The gain of 142 ha equated to a 33% increase over the original resource amount.

A coastwide trend occurs in the **Espiritu Santo** subarea where tidal flats experienced a systematic decrease in area through time. In the mid-1950's tidal flats covered 868 ha, and by 1979 the number had been reduced to 219 ha and had been further reduced to 142 ha by 2009. The GIWW was realigned between 1956 and 1979, causing tidal-flat area to be replaced with estuarine open water and seagrass. About 64% of the tidal-flat loss area was replaced by these subtidal habitats in 1979, and by 2009 uplands and salt marsh had moved into previously flat areas. The loss of 726-ha totals (-)84% of the original resource. Like tidal flats, estuarine marsh also lost area over the length of the study. A high of 608 ha was mapped in the mid-1950's, followed by a drop to 411 ha by 1979 and a slight increase to 442 ha in 2009. The overall change in salt marsh amounted to a (-)27% loss of the resource. Most (52%) of the marsh-loss area in 1979 had been converted to estuarine open water, with equal amounts of marsh-loss area converted to seagrass and upland. Marsh loss to upland occurred along the GIWW, where most of the tidal-flat loss also occurred. Marsh loss to open water and seagrass occurred mainly gulfward of the series of islands along the GIWW, including Blackberry, Dewberry, and Long Island. Marsh along the Espiritu Santo Bay side of the islands appears to have been lost to erosion. Erosion along Steamboat Pass has also diminished marshes on Grass Island and the island near South Pass. Seagrass is abundant in the Espiritu Santo area, increasing by 22% over the length of the study time period. Relatively small numbers of oyster reefs occur here also and increased in area significantly (64%) through time.

The **San Antonio Bay** subarea, covering a roughly 13,100-ha area, is predominantly estuarine subtidal unconsolidated bottom (E1UB), or *open water*. Most of the estuarine intertidal reef (E2RF) in the San Antonio Bay study area is found in this subarea. In the mid-1950's only 113 ha of reef was mapped in the bay. No reefs were mapped in 1979, and 406 ha was mapped in 2009. As noted in the 2009 status section, intertidal reefs were incorporated from NOAA's benthic habitat atlas (2007).

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 distributions for historical periods are based on maps from the U.S. Fish and Wildlife Service prepared as part of the National Wetland Inventory program and special projects. The authors thank researcher Sojan Mathew for his help during joint field campaigns. Also, thanks go to George Bush for vehicle support. We thank Lana Dieterich of the Bureau of Economic Geology for assistance in editing the text. The authors appreciate the support of Melissa Porter, GLO, for her assistance in presenting the proposals to the Coastal Coordination Council and administrating the contracts once approved.

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.

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, 131 p.

Federal Interagency Committee for Wetland Delineation, 1987, 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, Cooperative technical publication, 76 p., appendices.

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

Gibeaut, J. C., White, W. A., Hepner, T., Gutierrez, R., Tremblay, T. A., Smyth, R. C., and Andrews, J. R., 2000, Texas Shoreline Change Project, Colorado River to Brazos River: The University of Texas at Austin, Bureau of Economic Geology, map.

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.

Lyles, S. D., Hickman, L. E., Jr., and DeBaugh, H. A., Jr., 1988, Sea level variations for the United States, Rockville Maryland: National Oceanic and Atmospheric Administration, National Ocean Service, 182 p.

McGowen, J. H., Brown, L. F., Jr., Evans, T. J., Fisher, W. L., and Groat, C. G., 1976, Environmental geologic atlas of the Texas Coastal Zone–Bay City–Freeport area: The University of Texas at Austin, Bureau of Economic Geology, Special Publication, 98 p.

Morton, R. A., and Pieper, M. J., 1975, Shoreline changes on Brazos Island and South Padre Island (Mansfield Channel to mouth of Rio Grande), An analysis of historical changes of the Texas Gulf Shorline: The University of Texas at Austin, Bureau of Economic Geology, Geological Circular 75-2, 39 p.

NOAA, 2007, Coastal Bend Texas benthic habitat mapping: San Antonio Bay.

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

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.

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.

Shew, D. M., Baumann, R. H., Fritts, T. H., and Dunn, L. S., 1981, Texas barrier island region ecological characterization: environmental synthesis papers: 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.

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.

Tremblay, T. A., and Calnan, T. R., 2010, Status and trends of inland wetland and aquatic habitats, Matagorda Bay Area: 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. 09-046, a report of the GLO Coastal Coordination Council pursuant to National Oceanic and Atmospheric Administration Award No. NA08NOS4190458, 71 p. + CD-ROM.

Tremblay, T. A., Vincent, J. S., and Calnan, T. R., 2008, Status and trends of inland wetland and aquatic habitats in the Corpus Christi Area: 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 CBBEP contract no. 0722, a report of the GLO Coastal Coordination Council pursuant to National Oceanic and Atmospheric Administration Award No. NA04NOS4190058, 89 p. + CD-ROM.

U.S. Department of Commerce, 1978, Tide current tables 1979, Atlantic coast of North America: National Oceanic and Atmospheric Administration, National Ocean Survey, 293 p.

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.

White, W. A., Calnan, T. R., Morton, R. A., Kimble, R. S., Littleton, T. G., McGowen, J. H., and Nance, H. S., 1988, Submerged lands of Texas, Bay City–Freeport area: sediments, geochemistry, benthic macroinvertebrates, and associated wetlands: The University of Texas at Austin, Bureau of Economic Geology Special Publication, 130 p.

White, W. A., Calnan, T. R., Morton, R. A., Kimble, R. S., Littleton, T. G., McGowen, J. H., and Nance, H. S., 1989, Submerged lands of Texas, Port Lavaca area: sediments, geochemistry, benthic macroinvertebrates, and associated wetlands: The University of Texas at Austin, Bureau of Economic Geology Special Publication, 165 p.

White, W. A., and Morton, R. A., 1997, Wetland losses related to fault movement and hydrocarbon production, southeastern Texas coast: Journal of Coastal Research, v. 13, no. 4, p. 1305-1320.

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., Waldinger, R. L, and Calnan, T. R., 2004, Status and trends of wetland and aquatic habitats on Texas Barrier Islands, Upper Texas Coast, Galveston and Christmas Bays: 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. 03-057, 67 p

.

White, W. A., Tremblay, T. A., Waldinger, R. L, Hepner, T. L., and Calnan, T. R., 2005, Status and trends of wetland and aquatic habitats on Texas Barrier Islands, Freeport to East Matagorda Bay and South Padre Island: 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. 04-044-045, 100 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 1

Total habitat areas for 2009, 1979, and 1950’s determined from GIS data sets of Freeport study area

2009 Habitat	Hectares	1979 Habitat	Hectares	1950's Habitat	Hectares
E1AB1	5	E1OWL.	643	E1OW.	694
E1AB3	1	E1OWLH.	28		
E1AB4	61	E1OWLX.	51	E1RF.	17
E1AB5x	43				
		E2EM1N.	2,148	E2EM.	5,238
E1UBLx	764	E2EM1NX.	1		
		E2EM1P.	4,267	E2FL.	249
E2AB1N	0				
E2AB1P	1	E2FL3N.	74	L1OW.	112
		E2FL5PS.	7		
E2EM1Nx	2,151	E2FLM.	45	L2FO.	26
E2EM1Px	4,757	E2FLN.	50		
		E2FLP.	26	PEM.	1,735
E2SS	2				
		E2RF2M.	15	PFL.	25
E2USM	1				
E2USNs	154	L1OWH.	110	PFO.	175
E2USPs	27	L1OWHH.	111		
		L1OWHHX.	5	POW.	51
L1UBHx	33	L1OWHX.	17		
L1UBKhs	210			PSS.	145
		L2AB4H.	2		
PAB4Fx	9	L2AB6H.	10	R1OW.	357
PAB5x	95				
		L2FLC.	2	R1SB.	6
PEM1Ax	2,873	L2FLY.	1		
PEM1Cx	1,594			R2AB.	7
PEM1Fx	412	L2OWH.	2		
PEM1Khs	365			R2OW.	29
PEM1R	32	PAB5H.	1		
PEM1S	11	PAB6FH.	1	R2SB.	5
PEM1T	27				
PEM1V	1	PEM1A.	1,269	R4SB.	6
		PEM1C.	649		
PFO1Ah	4,399	PEM1CD.	10	U.	48,429
PFO1C	665	PEM1CH.	54		
PFO1F	0	PEM1F	0		
PFO1R	10	PEM1F.	342		
PFO1S	13	PEM1FX.	1		
		PEM1H.	22		
PSS1Ah	417	PEM1R.	79		

PSS1Ch	51
PSS1S	1
PUB	7
PUBFh	11
PUBHx	178
PUBKh	28
PUSh	193
R1UBVx	322
R2UBH	131
R2USA	3
U	37,228

PEM1S.	42
PEM1Y.	34
PEM1YH.	3
PFLAHX.	1
PFLY.	0
PFLYN.	28
PFO6A.	779
PFO6C.	114
PFO6F.	7
PFO6S.	246
PFO6Y.	87
POWF.	28
POWFH.	11
POWFHX.	4
POWFX.	17
POWG.	1
POWGH.	0
POWH.	49
POWHH.	29
POWHHX.	7
POWHX.	79
PSS6A.	55
PSS6B.	0
PSS6C.	37
PSS6F.	1
PSS6R.	6
PSS6S.	6
PSS6Y.	39
R1FLR.	6
R1OW.	39
R1OWV.	305
R1OWVX.	2
R2OWH.	67
U.	39,170
UA.	2,747
UB.	1
UBS.	32
UF6.	827
UR.	1,451
UU.	838
UUO.	68

APPENDIX 2

Total habitat areas for 2009, 1979, and 1950’s determined from GIS data sets of San Antonio Bay study area

2009 Habitat	Hectares	1979 Habitat	Hectares	1950's Habitat	Hectares
E1AB1	4	E1AB2L.	1,736	E1AB.	1,957
E1AB3	2,388				
E1AB5	22	E1OWL.	19,852	E1OW.	18,315
E1AB5x	1	E1OWLH.	2		
E1AB6	1	E1OWLX.	160	E2EM.	3,281
		E1OWX.	14		
E1RF2L	42			E2FL.	2,072
		E1RF2M.	7		
E1UBL	17,988			E2RF.	138
E1UBLs	0	E2AB6M.	16		
E1UBLx	730			L1OW.	1,010
		E2EM1N.	2,554		
E2AB1N	327	E2EM1P.	2,596	PAB.	2
E2AB1P	12	E2EM1Y.	5		
				PEM.	6,547
E2EM1N	2,595	E2FL5P.	50		
E2EM1P	2,911	E2FLM.	44	PFL.	57
		E2FLN.	676		
E2RF2M	418	E2FLP.	606	PFO.	483
E2SS	1	E2SS4P.	15	POW.	73
E2USM	99	L1AB4H.	1	PSS.	1,183
E2USN	531	L1AB6H.	58		
E2USP	338	L1AB6V.	10	R1AB.	2
		L1ABL.	19		
L1UBH	251			R1OW.	135
L1UBV	767	L1OWH.	202		
		L1OWHH.	223	R2OW.	54
L2AB5	5	L1OWV.	1,006		
L2AB5V	47			R2SB.	1
		L2AB2V.	15		
L2UBFh	15	L2AB6H.	12	U.	23,671
L2UBKh	40				
		PAB4H.	7		
PAB1F	25	PAB5H.	4		
PAB4F	5	PAB6F.	18		
PAB4Khs	1	PAB6H.	13		
PAB5	43	PAB6HH.	6		
PAB5V	18	PABH.	0		
PEM1A	2,755	PEM1A.	82		

PEM1C	2,084
PEM1F	500
PEM1Khs	60
PEM1R	31
PEM1S	23
PEM1T	45
PEM1V	38
PFO1A	197
PFO1C	366
PSS1A	24
PSS1C	100
PUB	28
PUBCx	0
PUBFh	17
PUBHx	119
PUBKh	13
PUS	76
PUSCx	9
PUSKhs	91
R1UBV	25
R2AB4x	8
R2UBH	77
U	22,696

PEM1C.	1,666
PEM1CD.	463
PEM1F.	95
PEM1FHX.	3
PEM1FX.	1
PEM1R.	1,693
PEM1T.	94
PEM1V.	3
PEM1Y.	641
PEM1YHX.	0
PFLC.	26
PFLV.	5
PFO6C.	25
PFO6R.	208
PFO6Y.	255
POWF.	37
POWFH.	0
POWFHX.	3
POWFX.	4
POWG.	12
POWGH.	1
POWGHX.	7
POWGX.	4
POWH.	48
POWHH.	6
POWHHX.	3
POWHX.	1
POWV.	7
PSS6C.	10
PSS6Y.	116
R1OWV.	34
R2OWH.	50
U.	1,008
UA.	20,675
UAR.	579
UBS.	10
UF6.	753
UU.	445