STATUS AND TRENDS OF INLAND WETLAND AND AQUATIC HABITATS, BROWNSVILLE-HARLINGEN AREA

by

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Final Report
Prepared for the

Texas General Land Office
and
National Oceanic and Atmospheric Administration
under GLO Contract No. 11-026

A report of the Coastal Coordination Council pursuant to National Oceanic and Atmospheric Administration Award No. NA10NOS4190207

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

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June 2012

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STATUS AND TRENDS OF INLAND WETLAND AND AQUATIC HABITATS, BROWNSVILLE-HARLINGEN AREA

EXECUTIVE SUMMARY

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Introduction

Wetland and aquatic habitats are essential components of inland environments along the Texas coast. These valuable resources are highly productive biologically and chemically and are part of an ecosystem in which a variety of flora and fauna depend. Scientific investigations of wetland distribution and abundance through time are prerequisites to effective habitat management, thereby ensuring their protection and preservation and directly promoting long-term biological productivity and public use. This report presents results of an investigation designed to determine current status and historical trends of wetlands and associated aquatic habitats in the Brownsville-Harlingen area. The study area is within Cameron, Willacy, and Kenedy Counties (Fig. I).

The Brownsville-Harlingen area, in South Texas, encompasses the long and narrow Laguna Madre. The Laguna Madre grades into broad wind-tidal flats along the mainland and into smaller lagoons and embayments (White et al. 1986). The mainland is characterized by broad beaches, vegetation stabilized dunes, active dune fields, expansive wind-tidal flats, brackish- and salt-water ponds and marshes, and black mangrove communities. Laguna Atascosa National Wildlife Refuge (NWR) is included in the study area. A similar study by White et al. (2005) was conducted on South Padre Island.

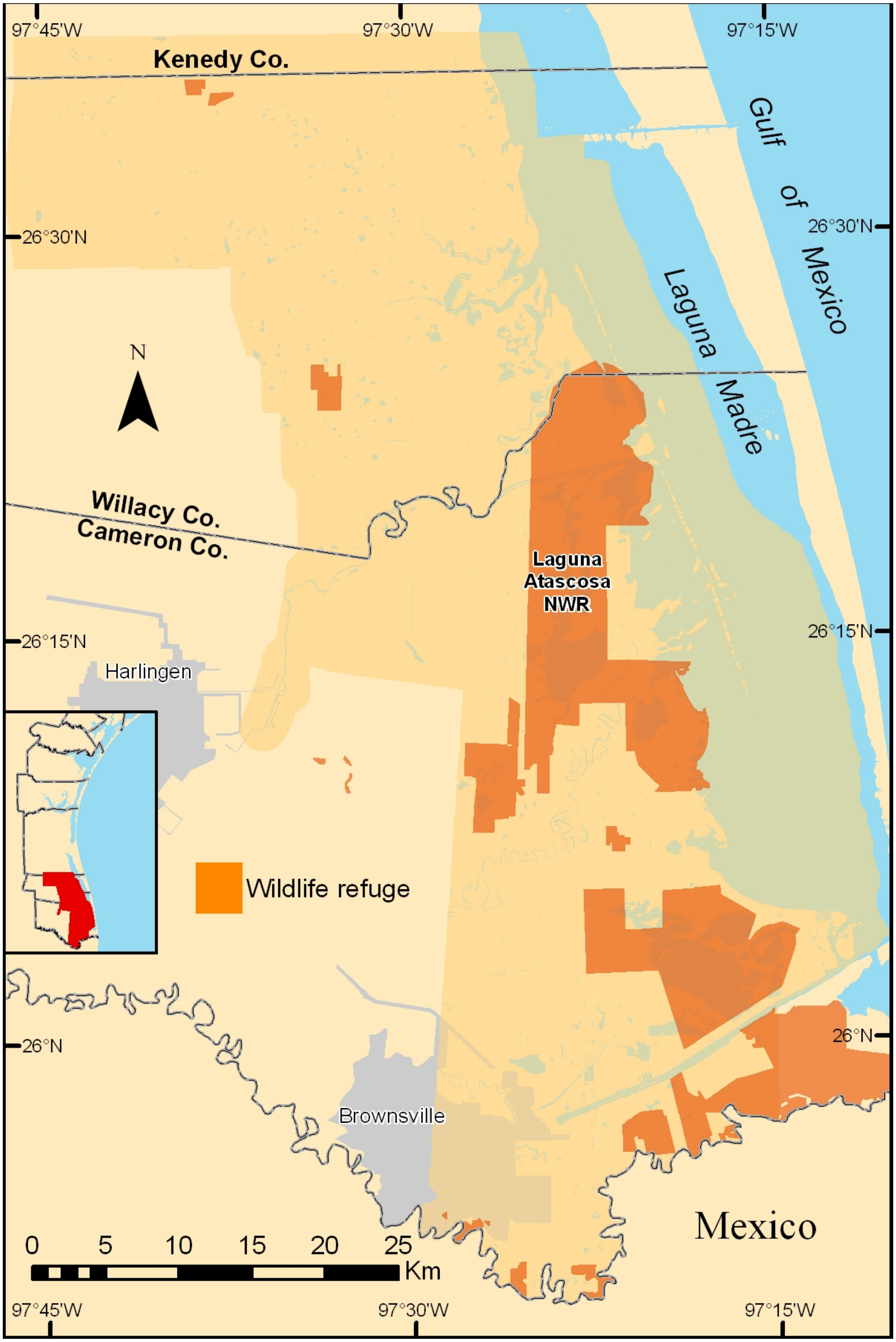

Figure I. Index map of wetland status and trends study area.

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 2010. Historical distribution is based on 1950's black-and-white and 1979 CIR photographs. Mapped wetlands for each period were digitized and entered into a GIS for analysis. The historical GIS maps were obtained from the U.S. Fish and Wildlife Service (USFWS), who mapped the wetlands using methods established as part of the National Wetlands Inventory program. Methods included interpreting and delineating habitats on aerial photographs, field checking delineations, and transferring delineations to 1:24,000-scale base maps using a zoom transfer scope. The resulting maps were digitized and entered into a GIS, producing GIS maps for the two time periods. Both the 1950's and 1979 series USFWS maps, which are in digital format, were partially revised in this project to be more consistent with wetlands interpreted and delineated on the 2010 photographs.

Methods used to delineate 2010 habitats differed from the earlier methods. The 2010 photographs were scanned to create digital images with a pixel resolution of 0.5 m, and registered to USGS Digital Orthophoto Quadrangles (DOQ's). Mapping of wetlands and aquatic habitats was accomplished through interpretation and delineation of habitats on screen in a GIS at a scale of 1:5,000. 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 2010 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, wetland classes were emphasized over water regimes and special modifiers because habitats were mapped only down to class on 1950's photographs. It should also be noted that there is a margin of error in interpreting and delineating wetlands on aerial photographs, transferring delineations to base maps, and georeferencing the different vintages of maps to a common base for comparison. Accordingly, there is more confidence in the direction of trends than absolute magnitudes. Probable causes of historical changes are presented in discussions of geographic subareas.

General Setting of the Brownsville-Harlingen Area

The study area includes inland wetlands from Port Mansfield southward to the Rio Grande and inland to the Coastal Zone Management Program (CMP) boundary. Also included is the Laguna Atascosa NWR, which is bound by the Laguna Madre to the east, the Rio Grande to the south, and the Arroyo Colorado to the north. The study area encompasses parts of 24 USGS 7.5' quadrangles and is located within Cameron, Willacy, and Kenedy Counties.

Unlike estuaries of the central and upper Texas coast where rivers discharge into bays forming typical estuaries diluted by fresh water inflows, the Rio Grande in South Texas discharges into the Gulf of Mexico. Laguna Madre has no major rivers discharging into it. That fact, coupled with the fact that this area receives the least amount of precipitation of all areas along the Texas coast (average annual precipitation in Willacy County is about 70 cm and in Cameron County 68 cm) (Texas Almanac, 2000-2001) contribute to high salinities in Laguna Madre. In addition to high salinity regimes, climate strongly dictates the relative importance of many significant geological processes. Among them, the direction and intensity of persistent southeast winds that control the movement of wave trains approaching shore and the resulting direction of long shore currents and sediment transport. Geologically, the relict Rio Grande Holocene-Modern deltaic system has been retreating for hundreds of years (Brown et al., 1980).

Current Status, 2010

In 2010, wetland, aquatic, and upland habitats covered 251,734 ha (621,783 acres) within the study area, including open water in the Laguna Madre. Approximately 153,511 ha (379,332 acres) within the study area was classified as uplands. Of the four wetland systems mapped, the estuarine system is the largest. The largest habitats are the estuarine open water and seagrass (E1AB3) classes (Fig. II and III), together covering 51,600 ha (127,506 acres). Seagrass beds extend beyond the study area into Laguna Madre. Wind-tidal and algal-flats (E2US and E2AB) cover 12,666 ha (31,298 acres), about 47% of which is algal-flat. Emergent vegetated wetlands (E2EM, E2SS, and PEM) cover 25,538 ha (63,106 acres), roughly 55% of which is palustrine marsh. The extent of all mapped wetlands, deepwater habitats, and uplands for each year is presented in the Appendix.

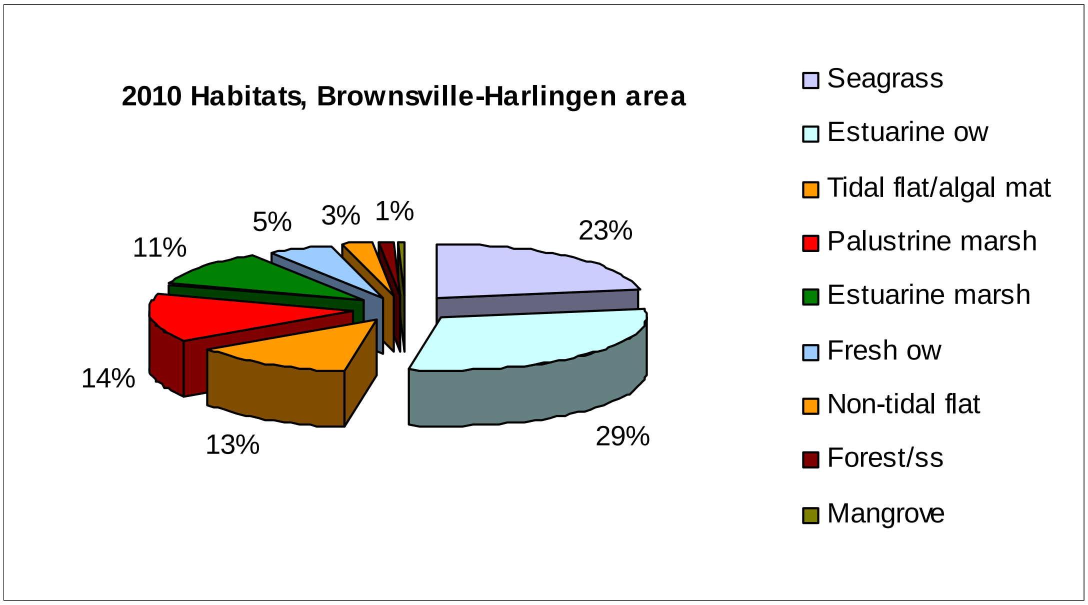

Figure II. Areal distribution of selected habitats in the Brownsville-Harlingen study area in 2010.

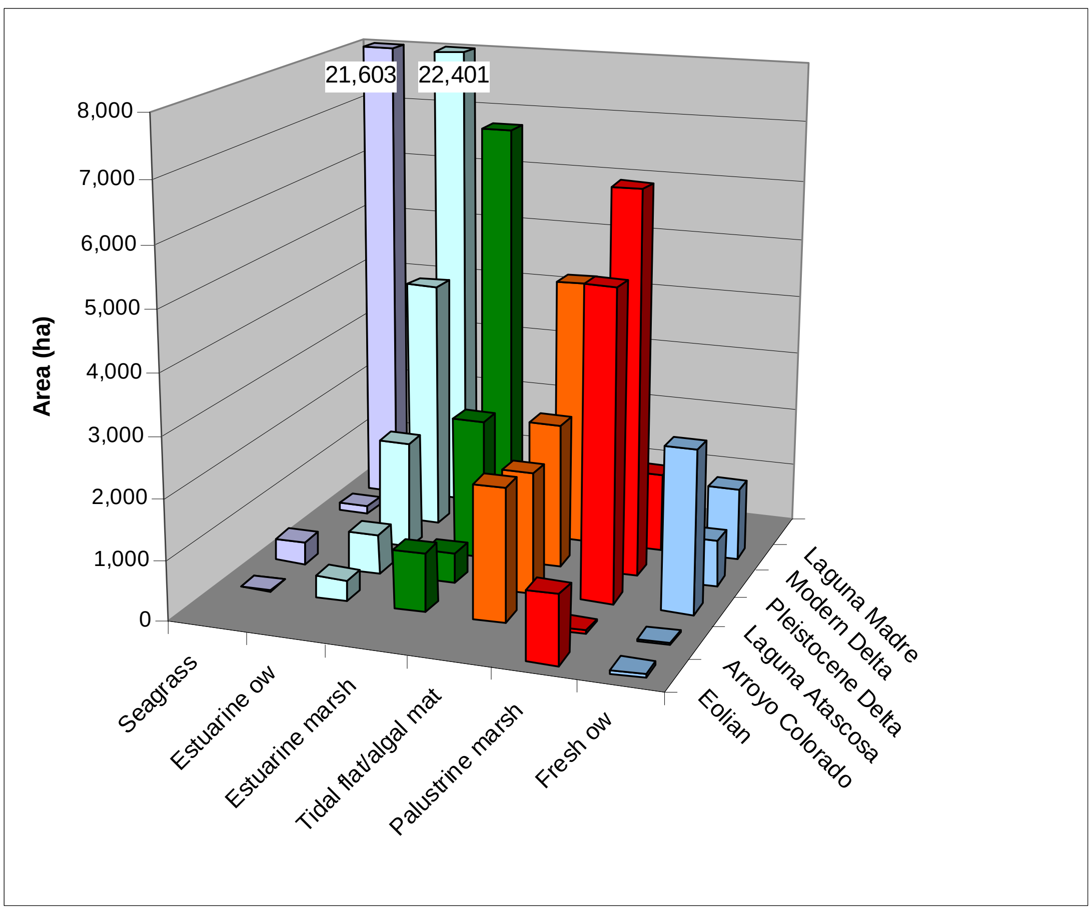

Figure III. Areal extent (ha) of selected habitats by geographic subarea in 2010.

Wetland Trends and Probable Causes, 1950's–2010.

Analysis of trends in wetlands and aquatic habitats from the 1950's through 2010 shows that seagrass decreased from the 1950's to 1979, and increased slightly from 1979 to 2010 (Table I; Fig. IV). Much of the decline in 1979 may have been an apparent and not real decline, as a result of high water levels and turbidities, which can obscure submerged seagrasses on aerial photographs. Seagrass and estuarine open water are, by far, the most extensive habitats. The large difference in area of estuarine open water, which covered an area more than twice as large in 1979, as in the 1950's and 2010 (Table I), appears to be due to higher water levels "captured" in the 1979 aerial photographs that flooded the tidal flats. This was a coast-wide phenomenon. Tidal flats and algal mats declined systematically throughout the study time period. The 1950's total of 15,307 ha (37,807 acres) declined to 14,434 ha (35,651 acres) in 1979, and further declined to 12,666 ha (31,286 acres) in 2010. The broader distribution of flats in the 1950's may be in part related to the mid-1950's drought when estuarine open water was apparently at lower levels than in 1979 and 2010, and when more flats were exposed. This trend is consistent with the coast-wide reduction in tidal flats. The total area of palustrine marsh increased between periods, with the largest jump between the 1950's total of 6,307 ha (15,579 acres) and the1979 total of 13,272 ha (32,782 acres). This is also likely due to drier conditions in the 1950's. Estuarine marsh followed a similar trend with the largest increase from 7,057 ha (17,432 acres) in the 1950's to 9,112 ha (22,506 acres) in 1979. Salt marshes expanded into previous tidal flats and upland areas through time. Forest and palustrine scrub-shrub increased slightly in 1979, then decreased in 2010 losing a total of 283 ha (699 acres) or roughly (-)20% of the original amount. Mangroves, however, could not be adequately mapped separately on the black-and-white 1950's photographs and were included with marshes in most areas. There was a real increase in mangrove distribution from 1979 to 2010, which is explained in the later discussion of subarea trends. More detailed probable causes of changes are presented in the following sections organized by geographic area.

Table I. Areal distribution of selected habitats, 1950's to 2010, in the Brownsville-Harlingen study area. Palustrine, lacustrine, and riverine unconsolidated bottom are combined into fresh open water in the table.

Habitats	***1950's***		***1979***		***2010***	
	(ha)	(acres)	(ha)	(acres)	(ha)	(acres)
Seagrass	36,501	90,158	21,968	54,261	22,129	54,659
Estuarine open water	13,464	33,257	30,236	74,683	29,471	72,793
Tidal flat/algal mat	15,307	37,807	14,434	35,651	12,666	31,286
Palustrine marsh	6,307	15,579	13,272	32,782	14,106	34,841
Estuarine marsh	7,057	17,432	9,112	22,506	10,906	26,938
Fresh open water	4,666	11,526	6,229	15,387	4,769	11,779
Non-tidal flat	1,108	2,736	1,220	3,014	2,596	6,413
Forest/scrub shrub	1,337	3,302	1,436	3,547	1,054	2,604
Mangrove	33	80	139	344	526	1,299

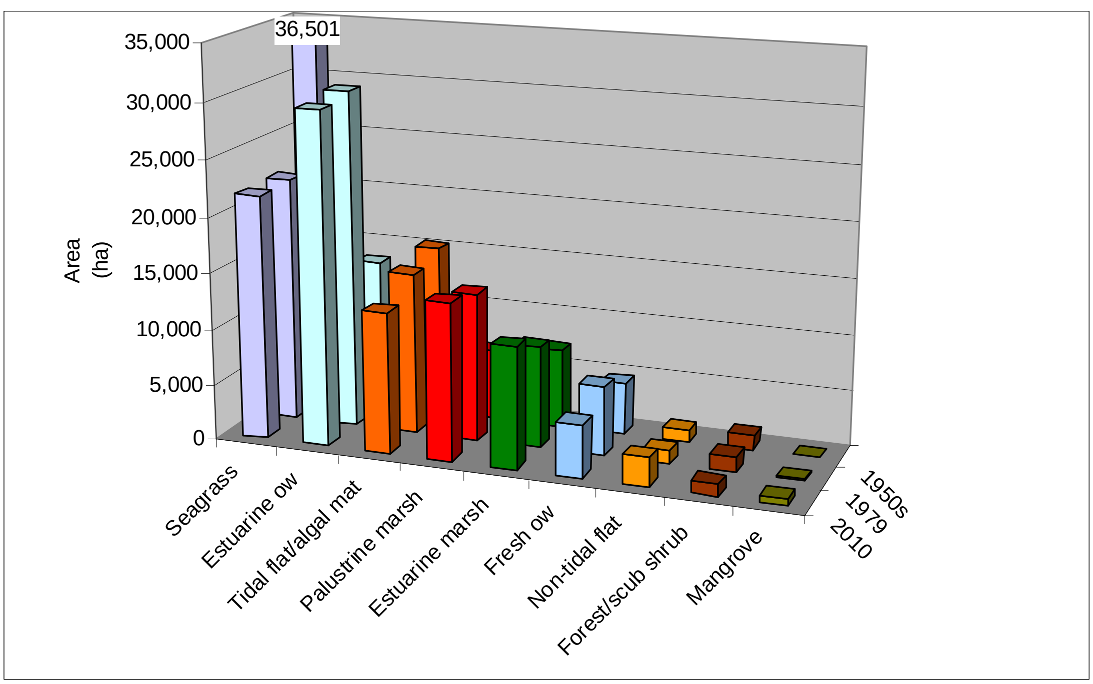

Figure IV. Areal extent (ha) of selected habitats from the 1950's to 2010.

The most significant habitat trends in the **eolian** area (see Fig. 25 in main report) occurred in marshes associated with the local dune system. Palustrine marsh increased from a total of 386 ha (954 acres) in the mid-1950's to 1,387 ha (3,427 acres) in 1979 (259% gain). The mid-1950's to 1979 increase in fresh marsh was due to more extensive mapping in previous upland areas where marshes form in interdune deflation troughs. Drier conditions in the 1950's would limit the formation of marshes in dune depressions. Some change is interpretational where 1950's estuarine marsh was mapped in later time periods as palustrine marsh. The 1979 high of 1,387 ha (3,327 acres), a very wet year in most areas of the coast, was reversed in 2010 when 1,128 ha (2,787 acres) of palustrine marsh was mapped. In 2010 estuarine marsh and tidal flats were not mapped in this area. The area nearest the Laguna Madre had been previously mapped as transitional. The main road to Port Mansfield may form a barrier to salt water intrusion from the Laguna and create fresher conditions through time. Fresh open water and non-tidal flats have increased through the study time period.

In the **Pleistocene delta** area, there was a systematic decline in tidal/algal flats with a loss of 2,203 ha (5,544 acres) from the 1950's to 2010, or about 48% of the original 1950's resource. The overall decrease in flats from the 1950's to 2010 has several causes. Relative sea level rise, caused by both subsidence and eustatic sea-level change, led to some tidal flats being flooded by open water and others being replaced by estuarine marsh. Forest and palustrine scrub-shrub also declined in area by 576 ha (1,423 acres). The 1950's total of 585 ha (1,446 acres) decreased slightly to 527 ha (1,302 acres) in 1979, then fell precipitously to 9 ha (22 acres) in 2010. The forested areas range from woodlands to shrubby vegetation to marshland depending upon ground moisture conditions at the time of photography. By 2010 many of these areas had been cleared, presumably for grazing. A significant increase in palustrine marsh occurs between the 1950's and 1979. This is likely due to fewer marshes being mapped during drought conditions in the mid-1950's. Many of the inland palustrine marshes mapped in 1979 were mapped as intermittently flooded depressions or were omitted altogether from the 1950's mapping. The decline in palustrine marsh from a total of 8,032 ha (19,848 acres) in 1979 to the 2010 total of 6,434 ha (15,899 acres) was due primarily to clearing for agricultural purposes. Estuarine marsh comprises a large percentage of the vegetated wetland habitats in the Pleistocene delta area and has maintained relatively stable acreage through time. The 1950's total of 2,273 ha (5,617 acres) dropped slightly to 2,055 ha (5,078 acres) in 1979, then increased to a high of 2,349 ha (5,805 acres) in 2010. In many locations, estuarine marsh moved into previous tidal flat areas. This phenomenon is common along much of the Texas coast. Although mangroves represent a small area overall and weren't mapped in the 1950's, mangroves increased in area from 3 ha (7 acres) in 1979 to 68 ha (168 acres) in 2010. Mangroves frequently form in narrow strips at the boundary between salt marsh and open water. Estuarine open water increased from the 1950's to 2010 by approximately 52%. The majority of the increase occurred where open water moved into previous tidal flat habitat.

The **Arroyo Colorado Delta** area, which encompasses the northern tip of Laguna Atascosa NWR, has experienced relatively minor change over time. Tidal flats decreased in area by 17%, from 2,673 ha (6,605 acres) in 1950's to 2,211 ha (5,464 acres) in 2010. A high percentage of the loss of flats resulted from conversion to uplands where dredge material was deposited along the north bank of the Arroyo Colorado Cutoff. The estuarine marsh habitat increased 32% over the study time period from 735 ha (1,816 acres) in 1950's to 1,179 ha (2,913 acres) in 1979, then decreased to 973 ha (2,404 acres) in 2010. Palustrine marshes comprise a relatively small percentage of the wetland habitat in the Arroyo Colorado Delta. The large increase in palustrine marsh between the 1950's and 1979 is interpretational. Estuarine open water area remained stable, while mangroves expanded, with a high of 69 ha (171 acres) in 1979.

The **Laguna Atascosa** area, which contains a large part of the Laguna Atascosa NWR, has experienced change in several habitat types over time. The most significant change is the 95% increase in palustrine marsh between the 1950's and 2010. Palustrine marsh systematically increased from a total of 2,645 ha (6,536 acres) in the 1950's to 3,103 ha (7,668 acres) in 1979, and increased again in 2010 to 5,167 ha (12,768 acres). Over three quarters of the increase in palustrine marsh was in areas mapped as upland in the 1950's. Most of this increase resulted from marsh management practices in Laguna Atascosa NWR. Areas mapped in 1979 as "transitional" in the Submerged Lands report (White et al., 1986) were managed for wildlife habitat in the form of fresh water wetlands in 2010. Tidal flats/algal mats experienced a systematic loss of acreage throughout the study time period. An initial 2,877 ha (7,109 acres) in the 1950's was reduced to 2,158 ha (5,333 acres) in 1979, then further reduced to 2,016 ha (4,982 acres) in 2010 or 30% loss of the resource during the study time period. Analysis of tidal flat change shows that most of the loss occurred when tidal flat was submerged by open water and seagrass. Conversely, non-tidal flats, consisting primarily of palustrine and lacustrine flats, increased systematically through time. As a result of managing wetlands towards a fresher system, the 1950's total of 205 ha (507 acres) increased to 511 ha (1,263 acres) by 1979, then jumped to 1,415 ha (3,497 acres) by 2010, representing a nearly 600% increase. A sharp decrease in estuarine marsh occurred when the 1950's total of 1,666 ha (4,117 acres) was reduced to 552 ha (1,364 acres) in 1979. The systematic decline continued in 2010 when salt marsh acreage declined to 504 ha (1,245 acres). Refuge management practices had converted much of the 1950's salt marsh to fresh marsh by 2010. Forest/scrub shrub habitat declined systematically in the Laguna Atascosa area when 414 ha (1,023 acres) in the 1950's declined to 235 ha (581 acres) by 1979, then to 139 ha (344 acres) by 2010. In many cases, 1950's scrub-shrub was mapped in 2010 as palustrine marsh.

Another area that experienced change in many habitats is the **modern delta**. The southernmost part of the Brownsville-Harlingen study area experienced a large gain in estuarine marsh through time. While comprising the largest vegetated wetland habitat, drought conditions during the mid-1950's kept marsh area low, resulting in only 1,912 ha (4,725 acres). By 1979, 4,861 ha (12, 012 acres) of salt marsh was mapped, and in 2010 estuarine marsh acreage increased to 6,974 ha (17,233 acres). The increase in the later time period was 44% of the 1979 amount. Roughly 86% of the area converted to estuarine marsh between the 1950's and 2010 was formerly upland. Much of the estuarine marsh increase between 1979 and 2010 was in areas mapped as transitional in the Submerged Lands report. The next most abundant habitat in the modern delta is tidal flats/algal mats which weren't mapped as extensively in the 1950's as in later time periods. The 1950's total of 2,517 ha (6,220 acres) is roughly half that mapped in 1979 when tidal flats covered 5,330 ha (13,171 acres). A large low lying area south of the Brownsville ship channel was flooded during the 1950's time period and mapped in 1979 and 2010 as flat. By 2010, tidal flats/algal mats were reduced to 4,485 ha (11,083 acres). The later time period trend towards a decrease in tidal flat/algal mat habitat follows the coastwide trend of tidal flat loss through time. Palustrine marsh habitat on the modern delta covered 1,584 ha (3,914 acres) in the 1950's, half that amount in 1979 at 705 ha (1,742 acres), rebounding to 1,319 ha (3,259 acres) in 2010. Although relatively small in comparison to other habitat acreage, forest/scrub shrub is most abundant in the modern delta compared to the other geographic subareas. In the 1950's, forest covered 293 ha (724 acres), increasing to 630 ha (1,557 acres) by 1979, and increasing further to 871 ha (2,152 acres) by 2010. Most of the increase is interpretational, where riparian forests were not mapped in earlier time periods. Mangrove is a relatively small habitat in area on the modern delta, but has grown significantly through time. In the 1950's only 8 ha (20 acres) was mapped. By 1979 mangrove area had grown slightly to 23 ha (57 acres), but by 2010 mangrove acreage had grown to 215 ha (531 acres). This expansion is an exponential increase from the original 1950's resource. Most of the expansion in mangrove occurred along the shores of San Martin Lake. A planting project at Bahia Grande also contributed to the expansion.

The **Laguna Madre** area covers 46,036 ha (113,757 acres) with varying amounts of open water and seagrass. The largest extent of seagrass occurred in the 1950's when 35,368 ha (87,396 acres) were mapped. In 1979, the amount of seagrass dropped to 21,139 ha (52,236 acres), but rebounded slightly to 21,603 ha (53,382 acres) in 2010. Conversely, the smallest amount of estuarine open water was in the 1950's with only 7,567 ha (18,699 acres) mapped. In 1979, open water covered a much larger area of 23,611 ha (58,344 acres) and slightly less open water was mapped in 2010 with 22,401 ha (55,354 acres). Following the coastwide trend, tidal flats/algal mat acreage decreased over the study time period. A high of 2,467 ha (6,096 acres) was mapped in the 1950's followed by a severe decline to 627 ha (1,549 acres) in 1979. The 2010 total rebounded to 1,538 ha (3,801 acres). The decline in tidal flats represents a 38 % loss of the original amount. Nearly half of the loss of tidal flats in the Laguna Madre area was in areas that had converted to seagrass between the 1950's and 2010 with much of the loss area converting to open water. While not covering a large area in the Laguna Madre, mangroves increased from 25 ha (62 acres) in 1979 to 134 ha (587 acres) in 2010.

STATUS AND TRENDS OF INLAND WETLAND AND AQUATIC HABITATS, BROWNSVILLE-HARLINGEN AREA

INTRODUCTION

Coastal inland wetlands are essential natural resources that are highly productive biologically and chemically and are part of an ecosystem in which a variety of flora and fauna depend (Fig. 1). Scientific investigations to determine status and trends of wetlands assist in their protection and preservation, directly benefiting long-term biological productivity and public use. This report is one in a series of wetland status and trends investigations along the Texas Coast; a barrier island wetland investigation on South Padre Island was completed in 2005 (White et al. 2005).

Presented here are the results of a study along the Texas Gulf coast, inland of the barrier system, in the Brownsville-Harlingen area. The study site extends from the Rio Grande through Cameron and Willacy Counties and slightly into Kenedy County (Fig. 2).

Figure 1. Upland to lagoon transect. Habitats from left to right- irregularly flooded flats, regularly flooded flats, salt marsh/mangrove, and open water/seagrass. View is to the north from the observation platform south of Stover Cove, Laguna Atascosa NWR.

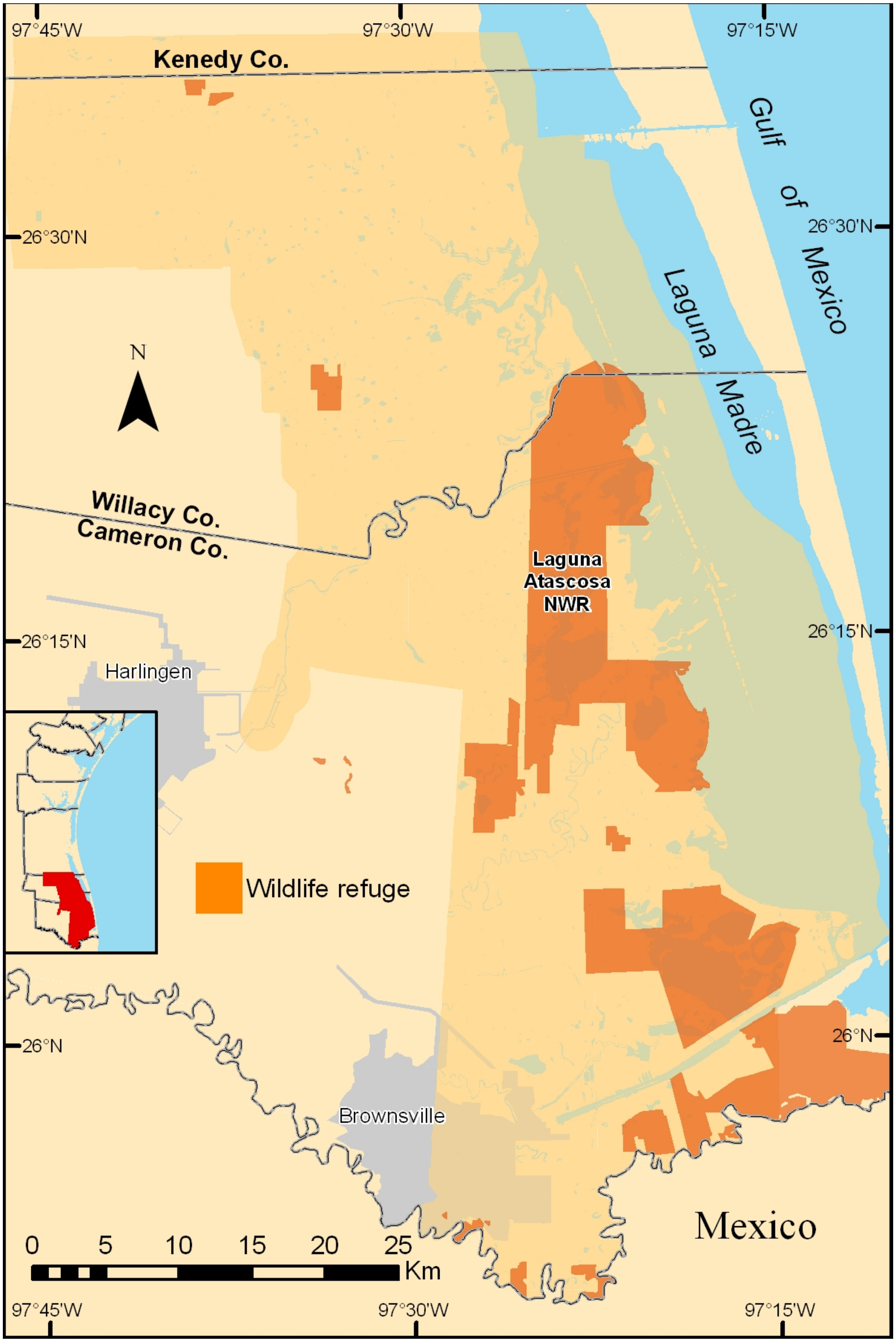

Figure 2. Index map showing the Brownsville-Harlingen study area.

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 and 2004), show that substantial losses in wetlands have occurred due to subsidence and associated relative sea-level rise. Some of the losses on Galveston Bay barriers have occurred along surface faults that appear to have become active as a result of underground fluid production. In contrast to those of the Galveston Bay system, studies of wetlands in the Matagorda Bay system (White et al. 2002; Tremblay and Calnan, 2010) show that marshes have expanded as a result of relative sea-level rise. Wetlands have been recently studied on South Texas barrier islands to determine status and trends (White et al. 2005), but inland wetlands have not been recently studied. Wetland status and trends and probable causes of trends presented here focus on the inland wetlands of South Texas including Laguna Atascosa NWR. Results help in our understanding of marsh changes on Texas coastlines, and pinpoint wetlands threatened from 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.

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 2010. 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 2006 aerial photographs. The current status of wetlands in this study is based on photographs contracted by the USDA in 2010. 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 were classified in accordance with *The Classification of Wetlands and Deepwater Habitats of the United States* by Cowardin et al. (1979). This is the classification used by the USFWS in delineating wetlands as part of the NWI.

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

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

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

Interpretation of Wetlands

Historical Wetland Distribution

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

Methods used by the USFWS NWI program involved transferring wetlands mapped on aerial photographs to USGS 7.5-minute-quadrangle base maps, scale 1:24,000,

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

using a zoom-transfer scope. Wetlands on the completed maps were then digitized and the data entered into a GIS. As in the photointerpretation process, there is a margin of error involved in the transfer and digitization process.

Photographs used are generally of high quality. Abnormally high precipitation in 1979, however, raised water levels on tidal flats and in many island fresh to brackish wetlands. Thus, more standing water and wetter conditions were apparent on the 1979 photographs than on the 2010 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 palustrine, and their interpreted, or mapped, water regimes.

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

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

Revision of Historical Wetland Maps

As part of this study, researchers at BEG revised USFWS historical wetland maps (1950's and 1979) so that there would be closer agreement between the historical map units and the current (2010) wetland map units. Revisions of the USFWS data were restricted primarily to the estuarine marshes, tidal flats, and areas of open water. The principal reason for the revisions was that in many areas on the historical maps, estuarine intertidal emergent wetlands (E2EM) were combined with intertidal flats (E2FL) as a single map unit (E2EM/E2FL). In our revisions, many of these areas were subdivided into E2EM and E2FL where possible at the mapping scale. In addition, because of the larger scale of the 1950's aerial photographs (1:24,000) as compared with the 1979 photographs (~1:65,000), smaller wetlands, particularly water features, were mapped on the 1950's photographs. As part of the revisions, many of these smaller water bodies were mapped and added to the 1979 wetland maps.

To accomplish the revisions, maps made in 1980 and 1986 were scanned where necessary, rectified with respect to the existing historical maps, and the digital USFWS maps revised where necessary. Mapped wetlands were interpreted and changes mapped directly on 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 2010 under contract with the USDA, and supplemented with other recent photographs. Photographs were digital images with a pixel resolution of 0.5 to 1 meter and registered to USGS Digital Orthophoto Quads (DOQ's). Interpretation and mapping of wetlands and aquatic habitats were completed by BEG researchers through on-screen delineation of habitats. Delineations were digitized directly into the GIS (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 in order to make accurate comparisons of wetland changes through time. Still, because of the method used, the current wetland maps show more detail than do the historical maps.

Field Investigations (see Figure 12)

Field investigations were conducted (1) to characterize wetland plant communities through representative field surveys and (2) to compare various wetland plant communities in the field with corresponding "signatures" on aerial photographs to define wetland classes, including water regimes, for mapping purposes. Characterization of prevalent plant associations provided vital plant community information for defining mapped wetland classes in terms of typical vegetation associations. Field investigations were conducted from October to December, 2011.

Variations in Classification

Classification of wetlands varied somewhat for the different years. On 1979 and 2010 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

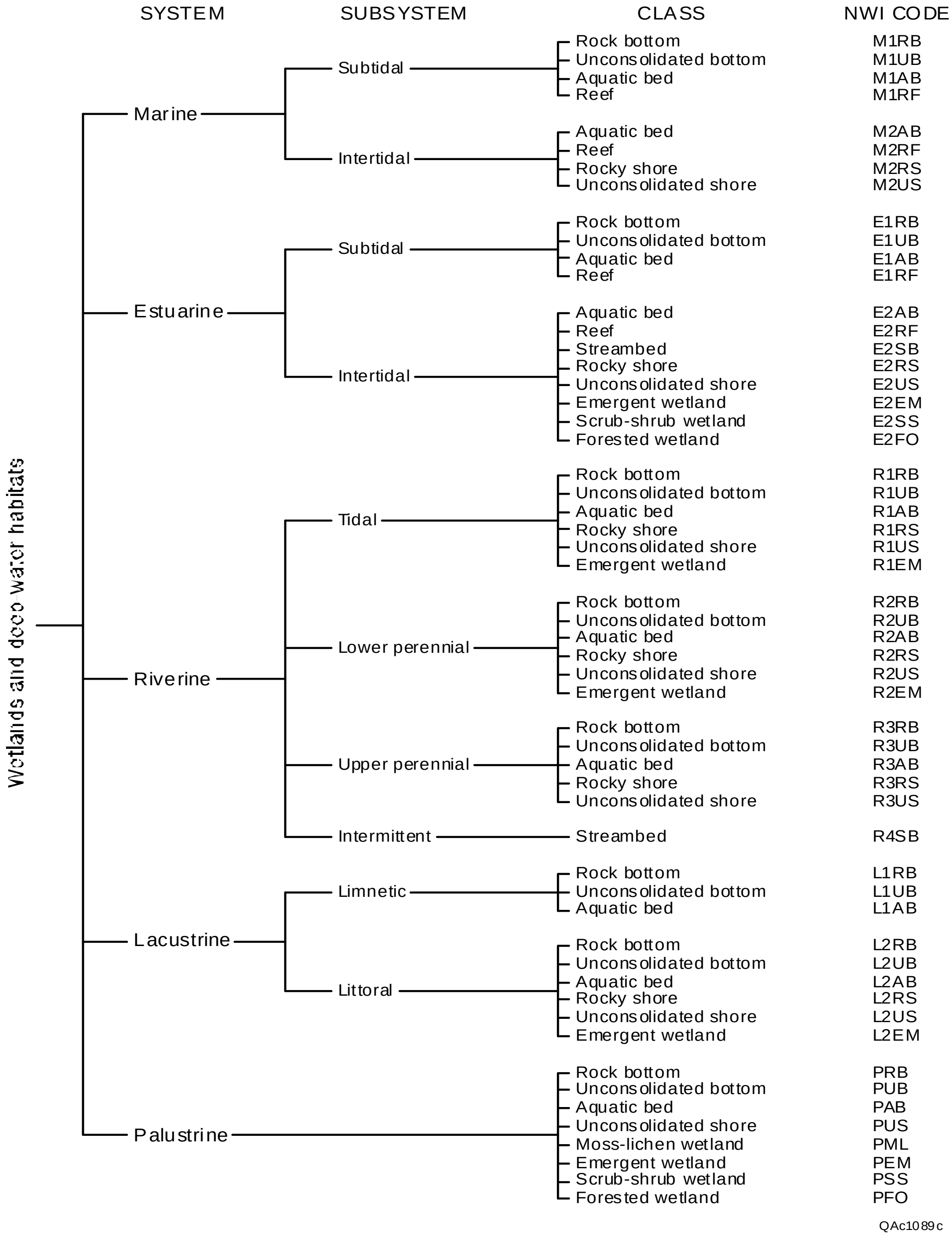

Figure 3. Classification hierarchy of wetlands and deepwater habitats showing systems, subsystems, and classes. From Cowardin et al. (1979).

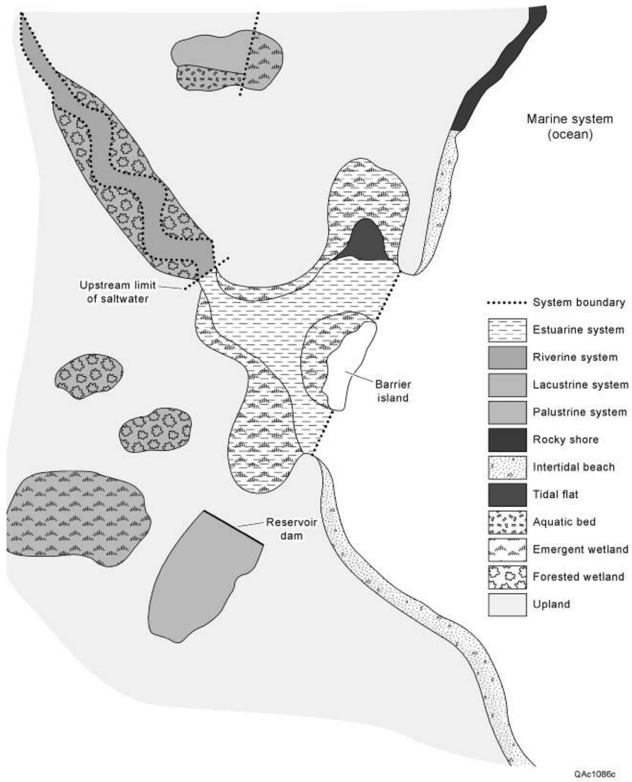

Figure 4. Schematic diagram showing major wetland and deepwater habitat systems. From Tiner (1984).

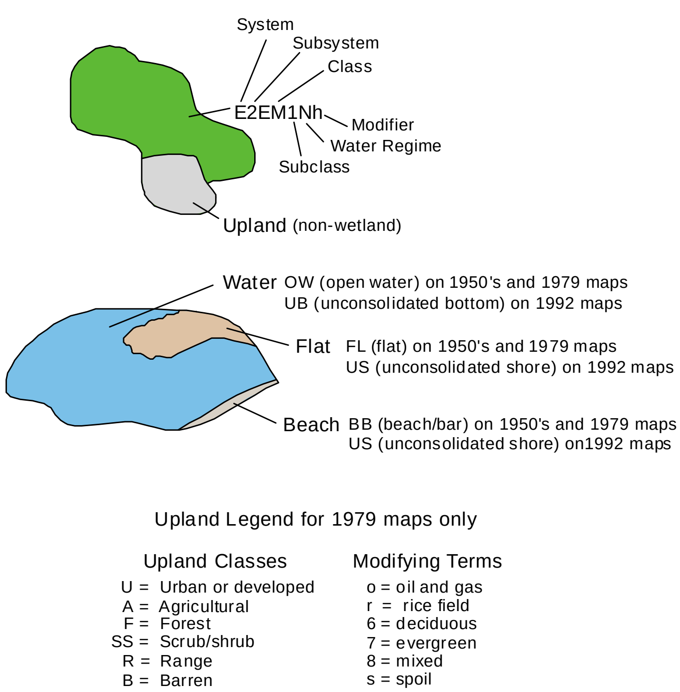

Figure 5. Example of symbology used to define wetland and upland habitats on NWI maps.

habitats using a modified Anderson et al. (1976) land-use classification system (Fig. 5). Flats and beach/bar classes designated separately on 1950's and 1979 maps were combined into a single class, unconsolidated shore, on 2010 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-minute quadrangles (Fig. 6) 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 2010. Data can be manipulated as information overlays, whereby scaling and selection features allow portions of the estuary to be selected electronically for specific analysis.

Among the objectives of the GIS are to (1) allow direct historical comparisons of wetland types to gauge historical trends and status of habitats, (2) allow novel comparisons of feature overlays to suggest probable causes of wetland changes, (3) make information on wetlands directly available to managers in a convenient and readily assimilated form, and about the same amount of accuracy as that in the historical maps in order to make accurate comparisons of wetland changes through time (however, because of the method used, 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. Still, users must be aware of potential errors, for example from registration differences, which can arise from direct analysis of GIS overlays.

Map-Registration Differences

There are map-registration differences between the historical and recent digital data. These cause errors when the data sets are overlain and analyzed in a GIS. The 2010 aerial photographs are georeferenced to USGS DOQ's. There is good agreement in registration with these base photographs. However, the historical data sets are not as well registered, and there is an offset in wetland boundaries between the historical and the 2010 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. Re-registration of the USFWS digital data sets was beyond the scope of this project. Thus, caution must be used in interpreting changes from direct overlay of the different data sets as layers in a GIS. Wetland totals were tabulated separately for each year to determine wetland changes within the given study area. Overlay of the data sets was done primarily to identify significant wetland changes that could be verified by analyzing and comparing aerial photographs.

Figure 6. Index map of USGS 7.5' quadrangles covering the Brownsville-Harlingen study area.

Methods Used to Analyze Historical Trends in Wetland Habitats

Trends in wetland habitats were determined by analyzing habitat distribution as mapped on 2010, 1979, and 1950's aerial photographs. In analyzing trends, emphasis was placed on wetland classes (for example, E2EM and PEM), with less emphasis on water regimes and special modifiers. This approach was taken because habitats were mapped only down to class level on 1950's photographs, and because water regimes can be influenced by local and short-term events, such as tidal cycles and precipitation.

ArcGIS was used to analyze trends. This software allowed for direct comparison, not only between years, but also by geographic areas such as the Laguna Madre, eolian area, and deltas. 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), which affected the minimum mapping unit delineated on photographs. Accordingly, a larger number of small wetland areas were mapped on earlier, larger-scale photographs, accounting for some wetland losses between earlier and later periods.

In general, wetland changes that seem to have been influenced the most by photointerpretation problems are interior (palustrine), temporarily flooded wetlands bordering on being transitional areas. Some apparent losses in palustrine wetlands were documented in inland wetlands, but appear to be due to drier conditions when the 2010 photographs were taken.

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

Wetland Codes

As mentioned in the introduction, some wetland codes used on 2010 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 generally used to denote tidal flats, and UB (rather than OW) is used to represent open water.

CLASSIFICATION OF WETLAND AND DEEPWATER HABITATS IN THE BROWNSVILLE-HARLINGEN AREA

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 2010. 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 5 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 2010 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.
(G)	Intermittently exposed
(J)	Intermittently flooded
(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.
(V)*	Permanently flooded—Tidal

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

Table 2. Wetland codes and descriptions from Cowardin et al. (1979). Codes listed below were used in mapping wetlands on the 2010 delineations, which varied in some cases from 1950's and 1979 maps (see Fig. 6).

NWI code (water regime)	**NWI description**	**Common description**	**Characteristic vegetation**
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*
E2AB (L,M,N,P)	Estuarine, intertidal aquatic bed	Estuarine algae bed	
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,N)	Estuarine, intertidal scrub-shrub	Estuarine shrubs	*Avicennia germinans* *Iva frutescens* *Baccharis halimifolia*
R1UB (V)	Riverine, tidal, unconsolidated bottom	Rivers	Unconsolidated bottom
R2UB (F,G,H)	Riverine, lower perennial, unconsolidated bottom	Rivers	Unconsolidated bottom
L1UB (H)	Lacustrine, limnetic, unconsolidated bottom	Lakes	Unconsolidated bottom
L2UB (F,G,H,K)	Lacustrine, littoral, unconsolidated bottom	Lakes	Unconsolidated bottom
L2US (A,C,J,K)	Lacustrine, littoral, unconsolidated shore	Lake flats	Unconsolidated shore
L2AB (F,G)	Lacustrine, littoral, aquatic bed	Lake aquatic vegetation	*Nelumbo lutea* *Ruppia maritima*
PUB (F,G,H,K)	Palustrine, unconsolidated bottom	Pond	Unconsolidated bottom
PAB (A,C,F,G,H,K)	Palustrine, aquatic bed	Pond, aquatic beds	*Nelumbo lutea*
PEM (A,C,F,J,K)	Palustrine emergent	Fresh-water marshes, meadows, depressions, or drainage areas	*Schoenoplectus californicus* *Typha spp.*

PSS (A,C,J)	Palustrine scrub-shrub	Willow thicket, river banks	*Salix nigra* *Parkinsonia aculeata* *Sesbania drummondii*
PFO (A)	Palustrine forested	Swamps, woodlands in floodplains depressions, meadow rims	*Salix nigra* *Fraxinus spp.* *Ulmus crassifolia* *Celtis spp.*
PUS (A,C,J,K)	Palustrine unconsolidated shore	Pond, flats	Unconsolidated shore

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), *Thalassia testudinum* (turtlegrass), *Syringodium filiforme* (manateegrass), and *Halophila engelmannii* (clovergrass). All species have been reported in lower Laguna Madre (Handley et al. 2006). Apparently, the most abundant species in the southern end of Laguna Madre are *Thalassia testudinum*, *Syringodium filiforme*, and *Halodule wrightii* (Handley et al. 2006). Estuarine intertidal aquatic beds (E2AB) also occur in smaller numbers.

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

In brackish areas, species composition changes to a salt to brackish-water assemblage, including *Schoenoplectus* (formerly *Scirpus*) spp. (bulrush), *Paspalum vaginatum* (seashore paspalum), *Spartina patens* (saltmeadow cordgrass), and *Phyla* sp. (frog fruit), among others. At slightly higher elevations, irregularly flooded estuarine emergent wetlands (E2EM1P) (high salt and brackish marshes) include *Borrichia frutescens* (sea oxeye), *Spartina patens*, *Spartina spartinae* (gulf cordgrass), *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 maps, we subdivided these classes in most areas on the 1979 maps to improve the consistency with the 2010 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), and scrub/shrub. Naturally occurring ponds are identified as unconsolidated bottom, permanently or semipermanently flooded (PUBH or PUBF). Excavated or impounded ponds and borrow pits are labeled (on 1979 maps) with their respective modifiers (PUBHx or PUBHh). Palustrine emergent wetlands are generally equivalent to fresh to brackish or inland marshes that are not inundated by estuarine tides. Palustrine aquatic beds (PAB) occur in small numbers in the study area. 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 penny-wort), *Phyla* sp. (frog fruit)

Aster spinosus (spiny aster), *Paspalum* spp. (paspalum), *Panicum* spp. (panic), *Polygonum* sp. (smartweed), *Andropogon glomeratus* (bushy bluestem), and *Cynodon dactylon* (Bermuda grass) to mention a few.

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

Palustrine forested areas consist of broad-leaved deciduous, temporarily flooded (PFO1A) areas. Forests incorporate a large mixture of tree species, including *Salix nigra* (black willow), *Fraxinus* spp. (ash), *Celtis spp*. (hackberry), *Sabal minor* (dwarf palmetto) and others.

Lacustrine System

Water bodies greater than 8 ha are included in this system, with both limnetic and littoral subsystems represented. Most lakes in the Brownsville-Harlingen area are associated with Laguna Atascosa NWR. Nonvegetated water bodies are labeled limnetic or littoral unconsolidated bottom (L1UB or L2UB) (L1OW or L2OW in 1950's and 1979 data sets), depending on water depth. The impounded modifier (h) is used on bodies of water impounded by levees or artificial means, and the modifier "s" to indicate spoil or dredged material. Lacustrine littoral unconsolidated shore (L2US) and aquatic beds (L2AB) are frequently found in impounded dredge material areas.

Riverine System

Few areas were classified in the riverine system in the study area. The Rio Grande channel was mapped as estuarine along the lower marine influenced portion but was 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). Only the more inland length of the Arroyo Colorado is classified as riverine tidal unconsolidated bottom (R1UB). All other stream and channel segments are mapped in 2010 as riverine lower perennial unconsolidated bottom (R2UB).

FLUVIAL-DELTAIC AND BAY-ESTUARY-LAGOON SYSTEMS

Study Area

The study area includes inland areas from Port Mansfield southward to the Rio Grande, and from the Laguna Madre to the CMP boundary. Also included is the Laguna Atascosa NWR (Fig. 7). The study area encompasses parts of 24 USGS 7.5' quadrangles (Fig. 6), and is located within Willacy, Cameron, and Kenedy Counties.

General Setting of the Fluvial-Deltaic and Bay-Estuary-Lagoon Systems

Unlike estuaries of the central and upper Texas coast, where rivers discharge into bays forming typical estuaries diluted by fresh water inflows, the Rio Grande in South Texas discharges into the Gulf of Mexico. Laguna Madre has no major rivers discharging into it, and that fact, coupled with the fact that this area receives the least amount of precipitation of all areas along the Texas coast (average annual precipitation in Willacy County is about 70 cm and in Cameron County 68 cm) (Texas Almanac, 2000-2001), contribute to high salinities in Laguna Madre. Salinities at the southern end of Laguna Madre typically range from 23-36 parts per thousand (ppt) and are influenced by exchange of Gulf water through Brazos Santiago Pass (White et al., 1986). Salinities in South Bay average between 25 and 35 ppt. In the northern part of the study area near Mansfield Channel, salinities typically range from 20 to 40 ppt and average about 38 ppt.

In addition to high salinity regimes, climate strongly dictates the relative importance of many significant geological processes. Among them, the direction and intensity of persistent southeasterly winds that control the movement of wave trains approaching shore and the resulting direction of long shore currents and sediment transport. Geologically, the eroding, relict Rio Grande Holocene-Modern deltaic system has been retreating for hundreds of years (Brown et al., 1980) (Fig. 8).

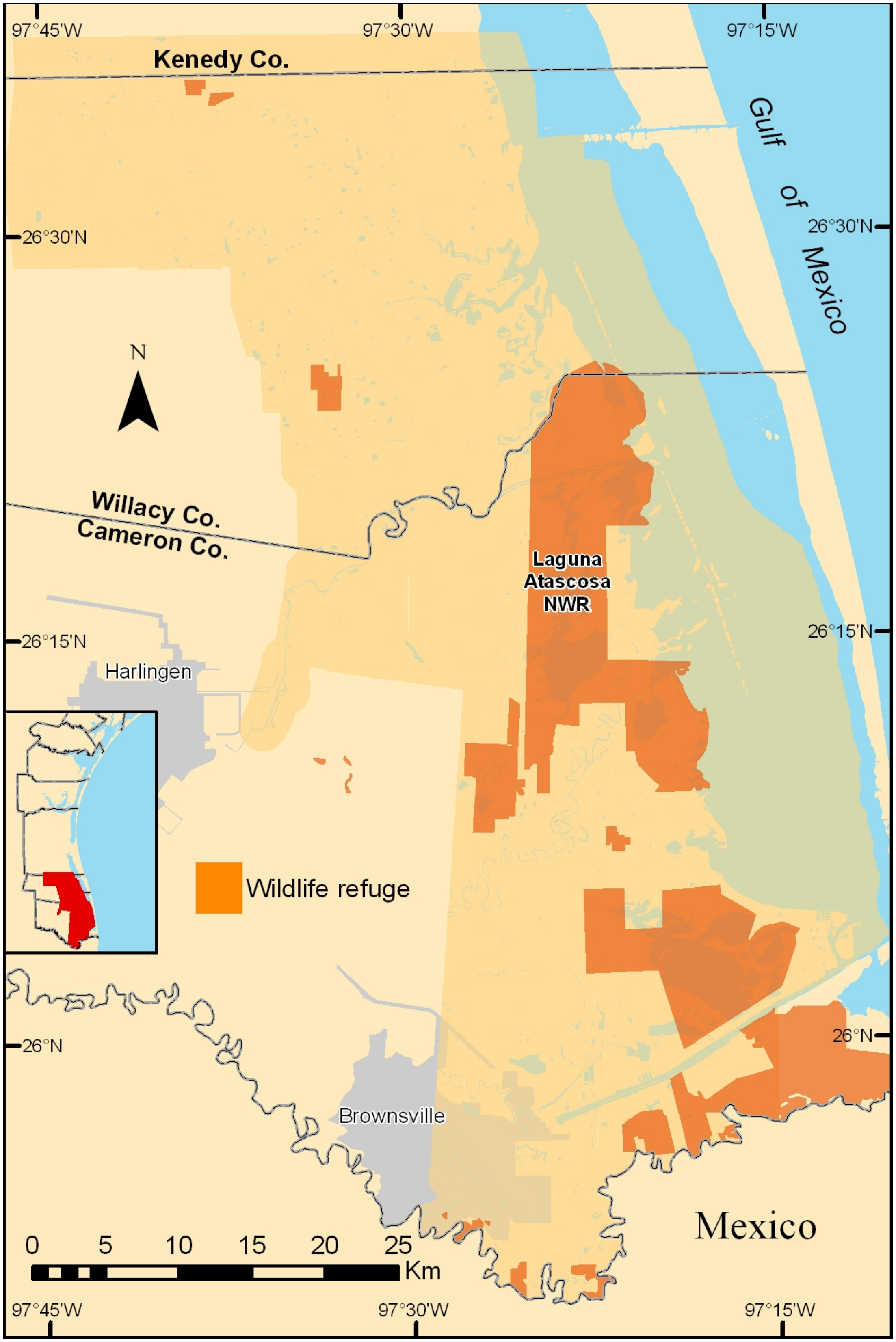

Figure 7. Index map showing the Brownsville-Harlingen study area.

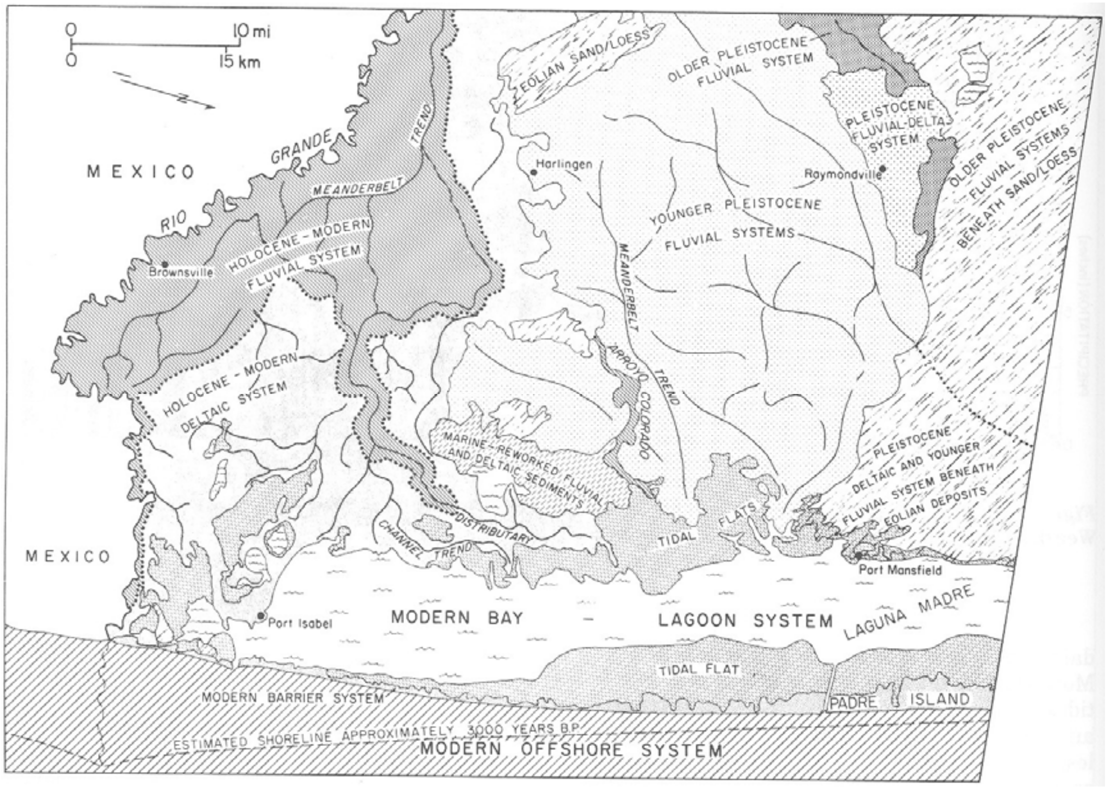

Figure 8. Natural systems of the Brownsville-Harlingen area (from Brown et al., 1980).

The dry climate and the prevailing southeasterly winds lead to vegetation fragmentation and blowouts that are the sources of active dunes that migrate to the northwest (Fig. 9). Left behind the migrating dunes are deflation flats and troughs that are topographic lows in which higher moisture levels support marsh vegetation, such as *Schoenoplectus pungens*. In contrast to deflation that can create depressions for marsh development, migrating active dunes can fill the depressions and cover the vegetation. Low amounts of rainfall in this area produce higher lagoon salinities that inhibit the growth of some marshes, like broad stands of *Spartina alterniflora* that are typical in the central and upper Texas coast. In the Brownsville-Harlingen area, *Spartina alterniflora* has limited distribution. It grows along with *Avicennia germinans* (black mangrove) and other salt marsh plants at the mouth of Bahia Grande where tidal flow through Brazos Santiago Pass (the tidal inlet/ship channel between Padre Island and Brazos Island) moderates salinities.

In this semi-arid climate, the most extensive habitats are broad wind-tidal flats. Astronomical tides in lower Laguna Madre average about 0.3 m (Diener, 1975). The range in tides caused by persistent winds, however, can be much higher than the astronomical tides, flooding much broader flats.

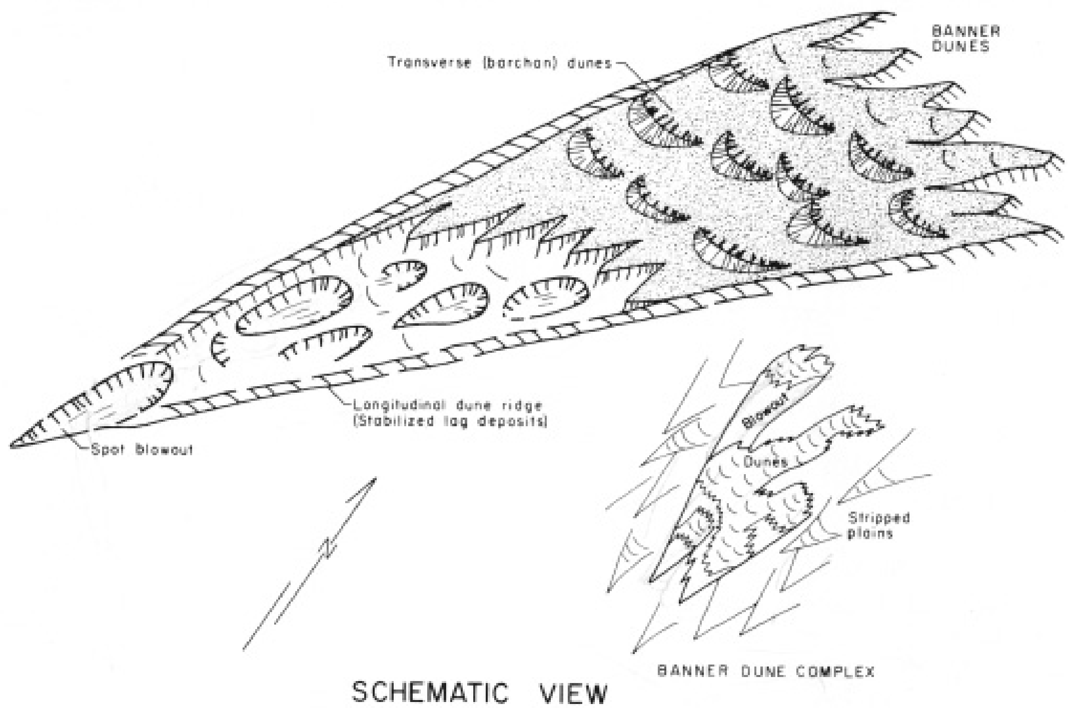

Figure 9. Active banner dune, found primarily in the eolian subregion of the study area. (from Brown and others, 1980).

Relative Sea-Level Rise

Relative sea-level rise (RSLR), as discussed more completely previously in the Freeport to East Matagorda Bay 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 on a worldwide (eustatic) basis at about 0.12 cm/yr, with a rate in the Gulf of Mexico and Caribbean region of 0.24 cm/yr (Gornitz et al. 1982; Gornitz and Lebedeff, 1987). Adding compactional subsidence to these rates yields a relative sea-level rise that locally exceeds 1.2 cm/yr (Swanson and Thurlow, 1973; Penland et al. 1988). Relative sea-level rise in South Texas (Port Isabel) averaged 3.38 mm/yr from 1944 to 1999 (NOAA, NOS). High rates of RSLR can cause changes in habitats, such as estuarine marshes and wind-tidal flats (White et al. 1998). The Port Isabel tide gauge shows that RSLR rates are lower along the South Texas Gulf Coast than the middle or upper coast. Still, this lower RSLR rate can have an impact through time, as discussed in the sections on probable cause of habitat trends.

Status of Wetlands and Aquatic Habitats, 2010

In 2010, wetland, aquatic, and upland habitats covered 251,735 ha within the Brownsville-Harlingen study area (Fig. 10 and 11; Table 3). Approximately 153,511 ha within the study area was classified as uplands. Of the four wetland systems mapped, the estuarine system is the largest (Fig. 10; Table 3). Habitats with the greatest area are the open water and seagrass classes, together covering 51,600 ha. Seagrass beds and open water extend beyond the study area into Laguna Madre. Wind-tidal and algal-flat classes together cover 12,666 ha. Emergent vegetated wetlands (E2EM, E2SS, PEM) cover 25,538 ha, about 55% of which is palustrine marsh. 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 12.

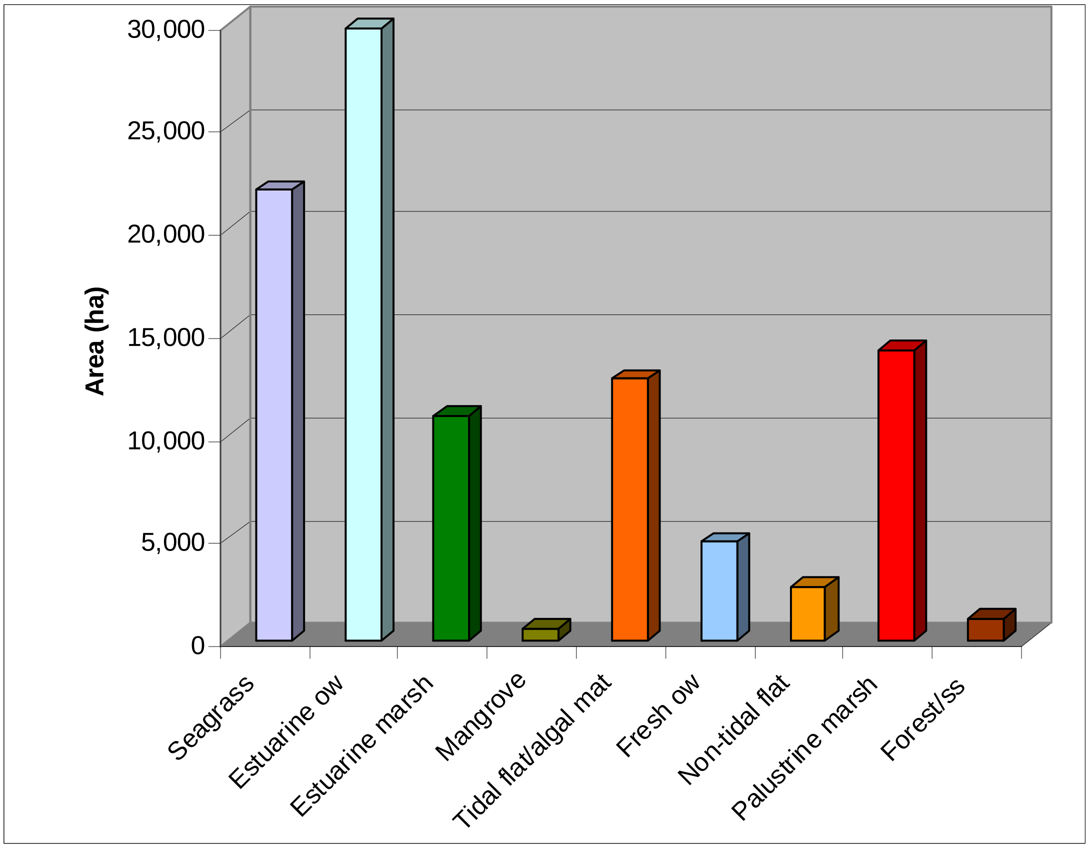

Figure 10. Areal distribution of selected habitats in 2010.

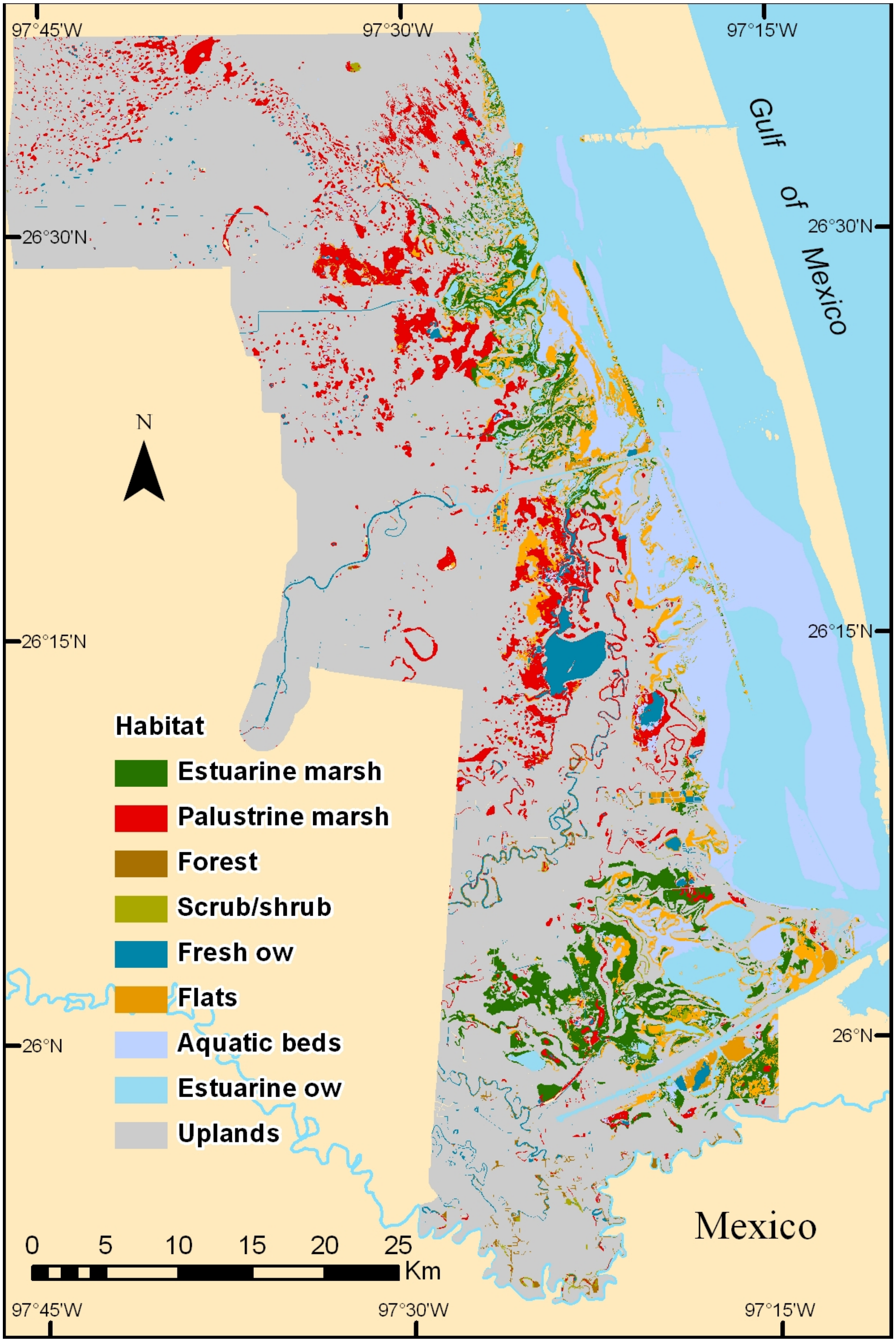

Figure 11. Map of habitats in 2010 for the Brownsville-Harlingen study area.

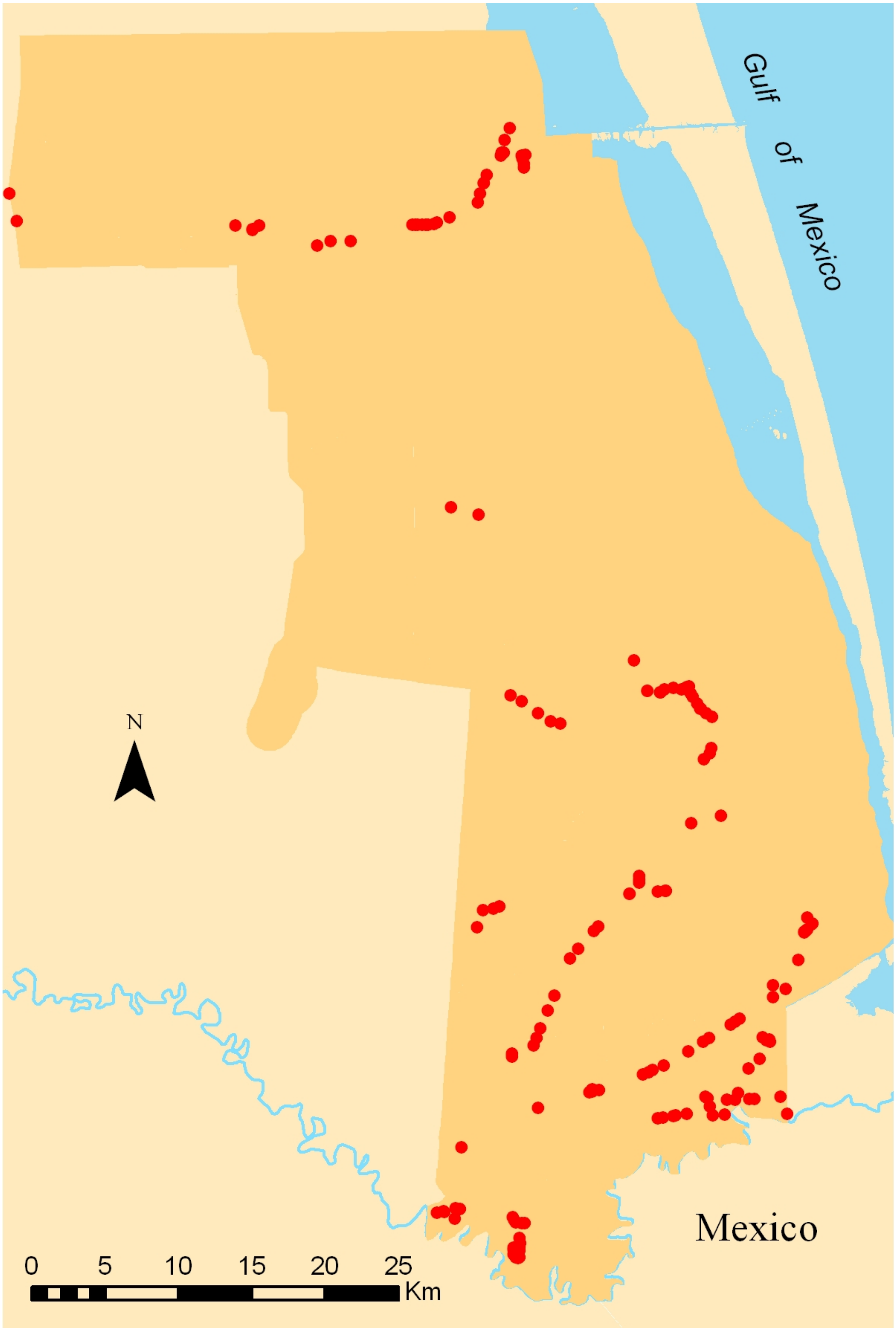

Figure 12. Field site locations in the Brownsville-Harlingen study area.

Estuarine System

Marshes (Estuarine Intertidal Emergent Wetlands)

The estuarine intertidal emergent wetland habitat (E2EM) consists of 10,906 ha of salt and brackish marshes. Unlike the central and upper coast, where the regularly flooded marshes are more abundant (White et al. 2002; 2004), irregularly flooded marshes are more abundant in these south Texas coastal wetlands (Table 3). The irregularly flooded marshes cover 9,143 ha and the regularly flooded marshes only 1,763 ha. The most extensive estuarine emergent wetlands are on the modern delta where 64% of this habitat occurs (Fig. 13: Table 4). The next highest amount occurs on the Pleistocene delta with 22% of the resource (areas are shown in Figs. 11 and 25). Locally, salt marsh assemblages cover the Arroyo Colorado delta (Fig. 11).

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

Estuarine intertidal unconsolidated shores (E2US) include tidal flats and lagoon beaches (Figs. 14 and 15). Estuarine intertidal aquatic beds (E2AB) are tidal flats in which blue-green algae have formed algal mats on the surface (Fig. 16). Approximately 5,660 ha of E2US and 5,952 ha of E2AB were mapped in the study area (Figure 10; Table 3). E2US areas, mapped as irregularly exposed (“M” water regime) (Table 3), were included with open water (E1UB) in Table 4 and Figure 10. These areas are relatively small, totaling about 977 ha. High, irregularly flooded tidal flats are much more extensive than low, regularly flooded flats (Table 3). Because of the low astronomical tidal range, many flats are flooded only by wind-driven tides and are, thus, designated as wind-tidal flats (Brown et al. 1980). A much larger area of low, regularly flooded aquatic beds (flats with algal mats) were mapped than high, irregularly flooded aquatic beds (Table 3). Together, tidal and algal flats, represent approximately 53% of the intertidal wetland system (excluding subtidal habitats and the E1 map units). The mapped extent of the tidal flats can be substantially affected by tidal levels at the time the aerial photographs were taken. Accordingly, absolute areal extent of flats may vary from that determined using aerial photographs.

Table 3. Areal extent of mapped wetland and aquatic habitats in the Brownsville-Harlingen area in 2010, 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	71	175	0.03
E1AB3	Estuarine Subtidal Aquatic Bed, Rooted Vascular	22,129	54,659	8.79
E1AB4	Estuarine Subtidal Aquatic Bed, Floating Vascular	49	120	0.02
E1AB5	Estuarine Subtidal Aquatic Bed, Unknown Submergent	292	722	0.12
E1AB6	Estuarine Subtidal Aquatic Bed, Unknown Surface	2	4	0.00
E1UBL	Estuarine Subtidal Unconsolidated Bottom	28,083	69,395	11.16
E2AB1M	Estuarine Intertidal Aquatic Bed, Irregularly Exposed	199	492	0.08
E2AB1N	Estuarine Intertidal Aquatic Bed, Algal Regularly Flooded	3,931	9,709	1.56
E2AB1P	Estuarine Intertidal Aquatic Bed, Algal Irregularly Flooded	1,791	4,432	0.71
E2AB3	Estuarine Intertidal Aquatic Bed, Rooted Vascular	31	77	0.01
E2EM1N	Estuarine Intertidal Emergent Wetland, Regularly Flooded	1,763	4,354	0.70
E2EM1P	Estuarine Intertidal Emergent Wetland, Irregularly Flooded	9,143	22,584	3.63
E2SB	Estuarine Intertidal, Streambed	1	2	0.00
E2SS3	Estuarine Intertidal Scrub/Shrub Wetland	305	755	0.04
E2SS3N	Estuarine Intertidal Scrub/Shrub, Regularly Flooded	102	252	0.05
E2SS3P	Estuarine Intertidal Scrub/Shrub, Irregularly Flooded	118	291	0.12
E2USM	Estuarine Intertidal Flat, Irregularly Exposed	975	2,408	0.39
E2USN	Estuarine Intertidal Flat, Regularly Flooded	1,054	2,604	0.42
E2USP	Estuarine Intertidal Flat, Irregularly Flooded	5,660	13,980	2.25
Subtotal		**75,699**	**186,977**	**30**
L1UBH	Lacustrine Limnetic Unconsolidated Bottom, Perm Flooded	1,779	4,394	0.71
L2AB1F	Lacustrine Littoral Aquatic Bed, Algal, Semiperm Flooded	63	156	0.03
L2AB3	Lacustrine Littoral Aquatic Bed, Rooted Vascular	135	333	0.05
L2AB4	Lacustrine Littoral Aquatic Bed, Floating Vascular	16	40	0.01
L2AB5	Lacustrine Littoral Aquatic Bed, Unknown Submergent	47	116	0.02
L2UBF	Lacustrine Littoral Unconsol Bottom, Semiperm Flooded	245	606	0.10
L2UBG	Lacustrine Littoral Unconsol Bottom, Intermittent Exposed	426	1,052	0.17
L2UBH	Lacustrine Littoral Unconsol Bottom, Permanent Flooded	84	207	0.03
L2UBK	Lacustrine Littoral Unconsol Bottom, Artificially Flooded	221	547	0.09
L2USA	Lacustrine Littoral Unconsol Shore, Temporarily flooded	36	90	0.01
L2USC	Lacustrine Littoral Unconsol Shore, Seasonally Flooded	35	86	0.01
L2USJ	Lacustrine Littoral Unconsol Shore, Intermittent Flooded	116	285	0.05
L2USK	Lacustrine Littoral Unconsol Shore, Artificially Flooded	683	1,688	0.27
Subtotal		**3,887**	**9,600**	**1**
PAB1A	Palustrine Aquatic Bed, Algal, Temporarily Flooded	1	1	0.00
PAB1C	Palustrine Aquatic Bed, Algal, Seasonally Flooded	20	49	0.01
PAB1F	Palustrine Aquatic Bed, Algal, Semipermanently Flooded	43	106	0.02
PAB1H	Palustrine Aquatic Bed, Algal, Permanently Flooded	14	34	0.01
PAB1K	Palustrine Aquatic Bed, Algal, Artificially Flooded	1	2	0.00
PAB3F	Palustrine Aquatic Bed, Rooted Vascular, Semiperm Flood	11	28	0.00
PAB3G	Palustrine Aquatic Bed, Rooted Vascular, Intermit Exposed	1	3	0.00
PAB4F	Palustrine Aquatic Bed, Float Vascular, Semiperm Flood	160	394	0.06
PAB5	Palustrine Aquatic Bed, Unknown Submergent	252	622	0.10

PAB5K	Palustrine Aquatic Bed, Unknown Submergent, Artif Flood	5	12	0.00
PAB6	Palustrine Aquatic Bed, Unknown Surface	24	60	0.01
PEM1A	Palustrine Emergent Wetland, Temporarily Flooded	6,571	16,230	2.61
PEM1C	Palustrine Emergent Wetland, Seasonally Flooded	5,472	13,516	2.17
PEM1F	Palustrine Emergent Wetland, Semipermanently Flooded	1,676	4,139	0.67
PEM1K	Palustrine Emergent Wetland, Artificially Flooded	16	41	0.01
PEM1J	Palustrine Emergent Wetland, Intermittently Flooded	371	915	0.15
PFO1A	Palustrine Forested, Broad-Leaved Decid, Temp Flooded	727	1,797	0.29
PSS1A	Palustrine Scrub/Shrub Wetland, Temporarily Flooded	285	705	0.11
PSS1C	Palustrine Scrub/Shrub Wetland, Seasonally Flooded	11	27	0.00
PSS1J	Palustrine Scrub/Shrub Wetland, Intermittently Flooded	29	71	0.01
PSS3	Palustrine Scrub/Shrub Wetland, Broad-Leave Evergreen	1	3	0.00
PUBG	Palustrine Unconsolidated Bottom, Intermittently Exposed	83	204	0.03
PUBC	Palustrine Unconsolidated Bottom, Seasonally Flooded	2	5	0.00
PUBF	Palustrine Unconsolidated Bottom, Semiperm Flooded	625	1,544	0.25
PUBH	Palustrine Unconsolidated Bottom, Permanently Flooded	314	775	0.12
PUBK	Palustrine Unconsolidated Bottom, Artificially Flooded	70	172	0.03
PUSJ	Palustrine Unconsolidated Shore, Intermittently Flooded	10	25	0.00
PUSC	Palustrine Unconsolidated Shore, Seasonally Flooded	204	503	0.08
PUSK	Palustrine Unconsolidated Shore, Artificially Flooded	279	689	0.11
Subtotal		**18,171**	**44,882**	**7**
R1UBV	Riverine Tidal Unconsolidated Bottom, Permanent-Tidal	287	709	0.11
R2UBF	Riverine Low Perennial Unconsol Bottom, Semiperm Flood	12	31	0.00
R2UBG	Riverine Low Peren Unconsol Bottom, Intermit Exposed	2	5	0.00
R2UBH	Riverine Lower Perennial Unconsol Bottom, Perm Flooded	166	410	0.07
Subtotal		**468**	**1,155**	**0**
U	Upland	153,511	379,173	61
Total		**251,734**	**621,783**	**100.00**

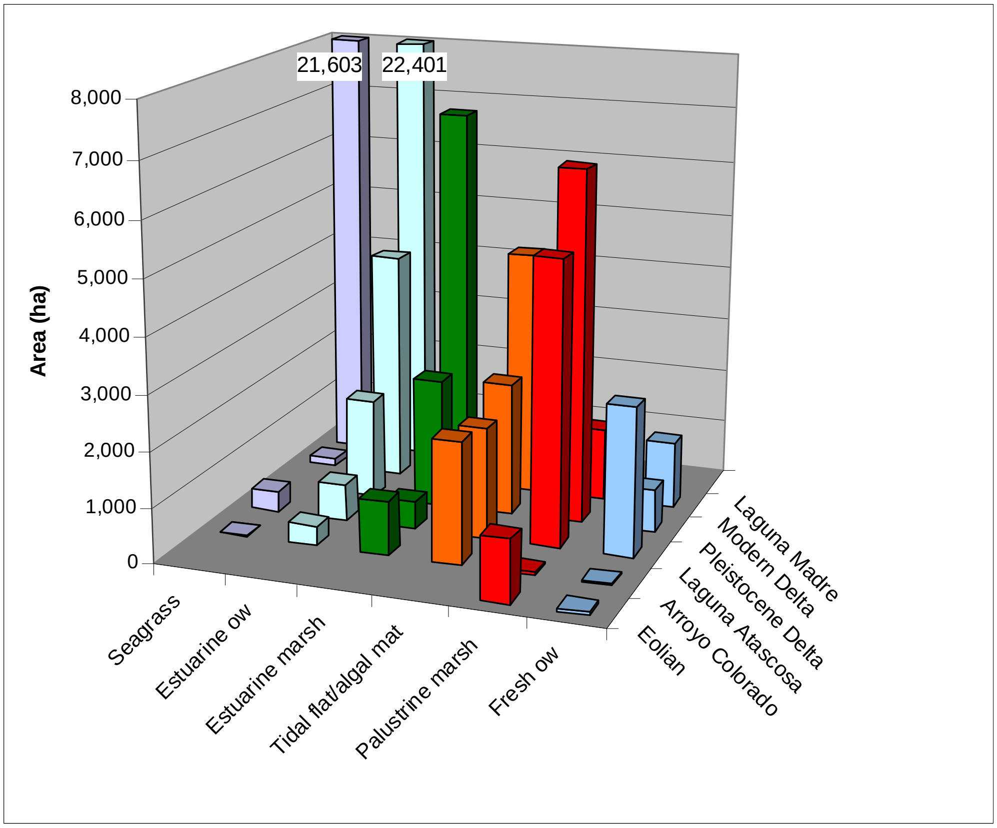

Figure 13. Areal distribution (ha) of selected habitats by geographic subarea in 2010.

Table 4. Areal extent (ha) of selected habitats by geographic subarea in 2010. See Figure 25 for location of different subareas.

Habitat	Laguna Madre	Modern Delta	Pleistocene Delta	Laguna Atascosa	Arroyo Colorado	Eolian
Seagrass	21,603	146		378	2	
Estuarine ow	22,401	4,210	1,830	674	355	
Estuarine marsh	106	6,974	2,349	504	973	
Tidal flat/algalmat	1,538	4,485	2,416	2,016	2,211	
Palustrine marsh	2	1,319	6,434	5,167	54	1,128
Fresh ow		1,206	769	2,709	32	54
Total	**45,650**	**18,340**	**13,798**	**11,448**	**3,627**	**1,182**


Figure 14. Regularly flooded tidal flat (E2USN) at tidal inlet, Laguna Atascosa NWR, see figure 7.


Figure 15. Irregularly flooded tidal flat (E2USP) with narrow strip of mangrove on Laguna Madre.


Figure 16. Regularly flooded algal mat (E2AB1N) on Laguna Madre.

Mangroves (Estuarine Intertidal Scrub/Shrub)

Estuarine scrub/shrub wetlands (E2SS) (mostly *Avicennia germinans* or black mangrove habitat with some red mangrove or *Rhizophora mangle* reported) have a total area of 526 ha, or about 2% of the estuarine intertidal classes (Fig. 10). With respect to the vegetated intertidal wetlands, it represents about 5% of the total. Scattered mangrove shrubs are a common component of many estuarine marshes (E2EM), particularly on the margins of Laguna Madre and along the shore of San Martin Lake. Only in areas where the mangrove shrubs were dominant and extensive enough were they mapped separately as E2SS habitat. This habitat has its broadest distribution on the margins of San Martin Lake and the mouth of Bahia Grande, and in narrow strips at several locations at the margins of Laguna Madre and around spoil islands along the Gulf Intracoastal Waterway (Fig. 17). Sherrod and McMillan (1981) noted that mangroves in this area are one of the three major concentrations along the Texas coast and are typically mixed with *Spartina*, *Batis*, and *Salicornia*.

Figure 17. Mangrove (E2SS3) along the margins of Laguna Madre.

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 is dependent on the season in which the photographs were taken and water turbidities, which can obscure seagrass areas. Seagrasses are visible in most of the 2010 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. 18). Within the study area, about 22,129 ha of seagrass beds was mapped. Seagrasses extend along most of the Laguna Madre (Fig. 11). Distributions of seagrass in other mapped subareas are minimal, covering 378 ha in the Laguna Atascosa area and 146 ha in the modern delta subarea (Table 4).

Figure 18. Darker patches offshore in Laguna Madre are seagrass beds (E1AB3L).

Open Water (Estuarine Subtidal Unconsolidated Bottom)

In addition to the shallow lagoons and ponds within the marsh complexes, estuarine subtidal unconsolidated bottom (E1UBL), or open water, is primarily found in the Laguna Madre. The total area of estuarine open water mapped in the study area is 28,083 ha. If the irregularly exposed tidal flats (E2USM) and subtidal aquatic beds (E1AB) are included, the total is 29,471 ha (Table 3).

Palustrine System

Marshes (Palustrine Emergent Wetlands)

Palustrine emergent wetlands (PEM), or inland, non-tidal "freshwater" marshes, cover 14,106 ha (Fig 10; Table 3), and represent 55% of emergent vegetated wetlands. The broadest distribution is in the Pleistocene delta subarea where 6,434 ha occur, followed by the Laguna Atascosa subarea where 5,167 ha were mapped (Fig. 13; Table 4). The modern delta and eolian subareas have the next highest fresh marsh totals with 1,319 ha and 1,128 ha, respectively. Although brackish vegetation occurs in many of these areas, it was mapped as palustrine to be consistent with previous mapping. Palustrine marshes in the Brownsville-Harlingen area often occur in isolated depressions deflated by the wind (Fig. 19). These marshes typically were classified into one of three water regimes: (1) temporarily flooded, (2) seasonally flooded, or (3) semi-permanently flooded. More than 47% of palustrine marshes were mapped as temporarily flooded, the driest water regime, in this dry South Texas area.

Figure 19. Seasonally flooded palustrine marsh (PEM1C) in depression near Estacas Lake, see figure 29. Dominant species are *Aster spinosus* and *Typha* sp.

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. 20). The total mapped area of this habitat was 1,093 ha. If aquatic beds (PAB) are included, the total is 1,546 ha (Figs. 10 and 21; Table 3). For analysis purposes, palustrine, lacustrine, and riverine unconsolidated bottom and aquatic bed habitats were combined into fresh open water. Palustrine flats are often associated with open water and cover 1,387 ha. Many of these habitats are either impounded (h modifier), or associated with spoil (s modifier).

Figure 20. Excavated pond (PUBHx) near Estacas Lake, see figure 29.

Figure 21. Palustrine semipermanently flooded floating vascular aquatic bed (PAB4F) in resaca (oxbow lake) near Rio Grande.

Forest (Palustrine Forested and Scrub-Shrub Wetlands)

Palustrine forested wetlands (PFO), comprising fluvial woodlands and swamps, cover a 727 ha area (Fig. 10; Table 3). Forests were classified as broad-leaved, deciduous trees. Palustrine scrub-shrub (PSS) habitat covers 327 ha (Fig. 22). Owing to difficulty in distinguishing forest regrowth from scrub-shrub, the two classes were combined for analysis.

Figure 22. Seasonally flooded palustrine scrub-shrub (PSSIC) in meander scar near Estacas Lake, see figure 29. Dominant species is *Sesbania drummondii*.

Lacustrine and Riverine Systems

Open Water and Flats (Lacustrine Unconsolidated Bottom and Shore)

Lacustrine unconsolidated bottom (L1UB and L2UB), or *lakes*, include lakes and inland reservoirs greater than 20 acres (8.33 ha). Lakes are further classified according to depth. Laguna Atascosa proper accounts for nearly half of the 2,756 ha. total lake acreage. Lacustrine unconsolidated shore and aquatic bed (L2US and L2AB), or *algal mats*, cover 1,131 ha.

River (Riverine Tidal and Lower Perennial)

Riverine tidal unconsolidated bottom (R1UB) and lower perennial unconsolidated bottom (R2UB), or *rivers*, cover 468 ha. Tidal rivers compose about 61% of all rivers in the study area.

Historical Trends in Wetlands and Aquatic Habitats

General Trends in Wetlands within the Study Area

Analysis of trends in wetlands and aquatic habitats from the 1950's through 2010 shows that seagrass decreased from the 1950's to 1979, and increased slightly from 1979 to 2010 (Figs. 23 and 24; Table 5). Much of the decline in 1979 may have been an apparent and not real decline, as a result of high water levels and turbidities, which can obscure submerged seagrasses on aerial photographs. Seagrass and estuarine open water are, by far, the most extensive habitats. The large difference in area of estuarine open water, which covered an area more than twice as large in 1979 as in the 1950's and 2010 (Table 5), appears to be due to higher water levels "captured" in the 1979 aerial photographs that flooded the tidal flats. This was a coast wide phenomenon. Tidal flats and algal mats declined systematically throughout the length of the study time period. The 1950's total of 15,307 ha declined to 14,434 ha in 1979, and further declined to 12,666 ha in 2010. The broader distribution of flats in the 1950's may be in part related to the mid-1950's drought when estuarine open water was apparently at lower levels than in 1979 and 2010. Accordingly, more flats would be exposed at that time. The present sea-level rise rate may exceed the rate of aggradation of sediment in flats and lead to flooding (Morton and Holmes, 2009). This trend is consistent with the coast wide reduction in tidal flats. The total area of palustrine marsh increased between periods, with the largest jump between the 1950's total of 6,307 ha and the1979 total of 13,272 ha. This is also likely due to drier conditions in the 1950's. Estuarine marsh followed a similar trend with the largest increase from 7,057 ha in the 1950's to 9,112 ha in 1979. Salt marshes expanded into previous tidal flats and upland areas through time. Forest and palustrine scrub-shrub increased slightly in 1979, then decreased in 2010 losing a total of 283 ha or roughly (-)20% of the original amount. Mangroves, however, could not be adequately mapped separately on the black-and-white 1950's photographs and were included with marshes in most areas. There was a real increase in mangrove distribution from 1979 to 2010, which is explained in the later discussion of subarea trends. More detailed probable causes of changes are presented in the following sections organized by geographic area.

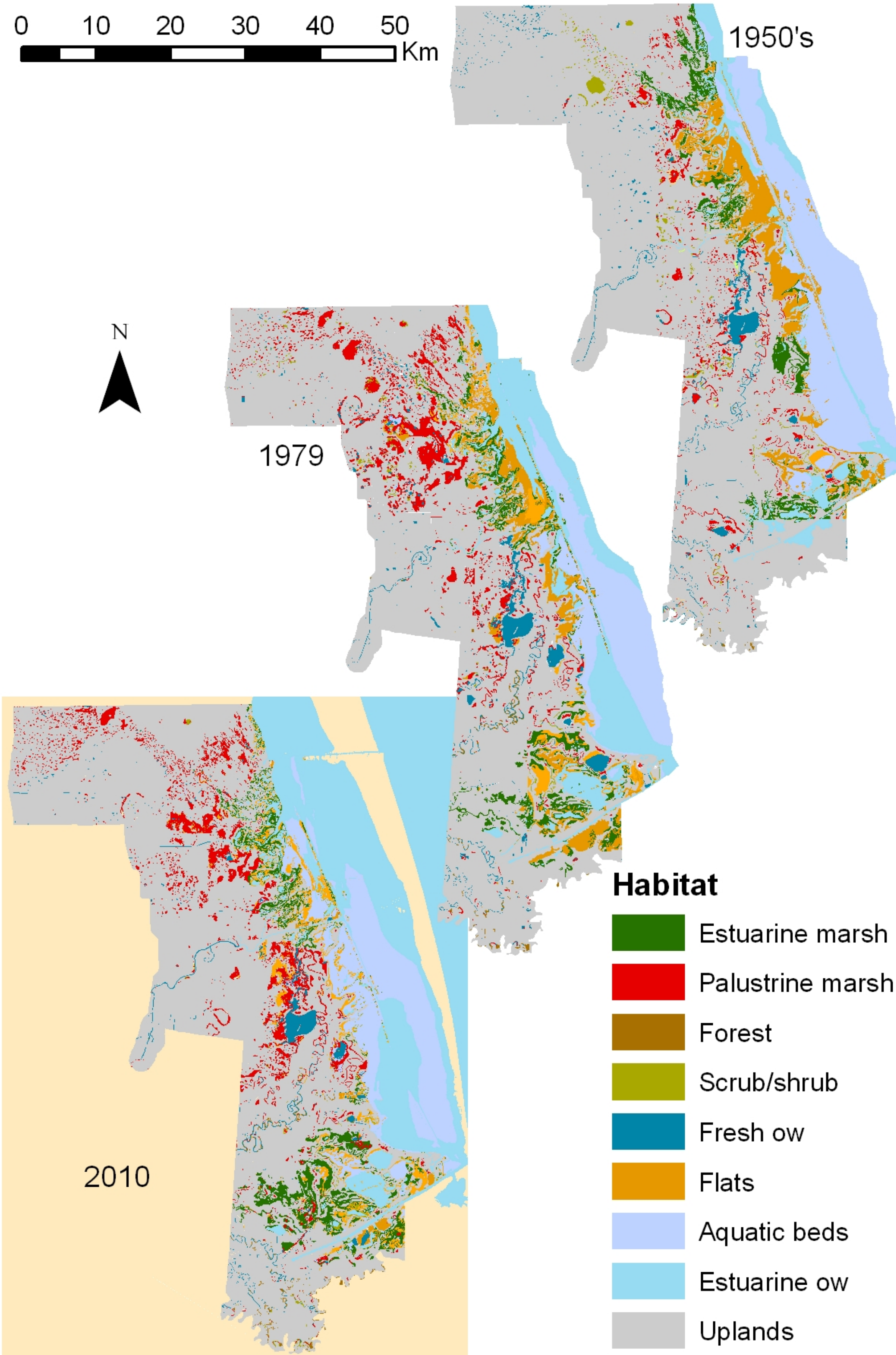

Figure 23. Maps showing distribution of major wetland and aquatic habitats in 2010, 1979, and the 1950's in the Brownsville-Harlingen study area. Seagrass shown only within map area in Laguna Madre.

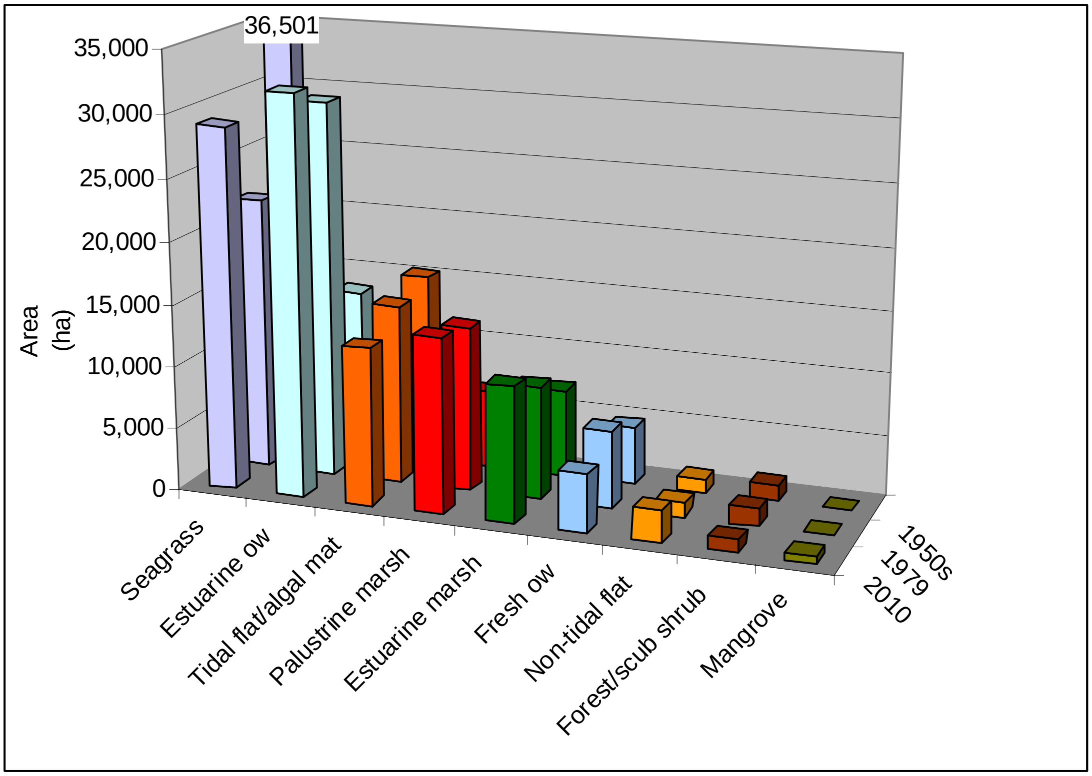

Figure 24. Areal extent of selected habitats from the 1950's to 2010 in the Brownsville-Harlingen study area. Seagrass and estuarine open water are the most extensive habitats. The broader distribution of tidal flats and algal mats in the 1950's may be, in part, related to the mid-1950's drought, when estuarine open water was apparently at lower levels than in 1979 and 2010.

Table 5. Areal distribution (ha) of selected habitats, 1950's to 2010.

Habitats	*1950's*	*1979*	*2010*
Seagrass	36,501	21,968	22,129
Estuarine open water	13,464	30,236	29,471
Tidal flat/algal mat	15,307	14,434	12,666
Palustrine marsh	6,307	13,272	14,106
Estuarine marsh	7,057	9,112	10,906
Fresh open water	4,666	6,229	4,769
Non-tidal flat	1,108	1,220	2,596
Forest/scrub shrub	1,337	1,436	1,054
Mangrove	33	139	526

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. 25). The areas are presented in the following order: (1) eolian area; (2) Pleistocene delta; (3) Arroyo Colorado delta; (4) Laguna Atascosa area; (5) modern delta; and (6) Laguna Madre area. This subdivision allowed a more site-specific analysis of trends and their probable causes. Estuarine tidal flats, estuarine marshes, mangroves, seagrasses, and palustrine marshes are emphasized.

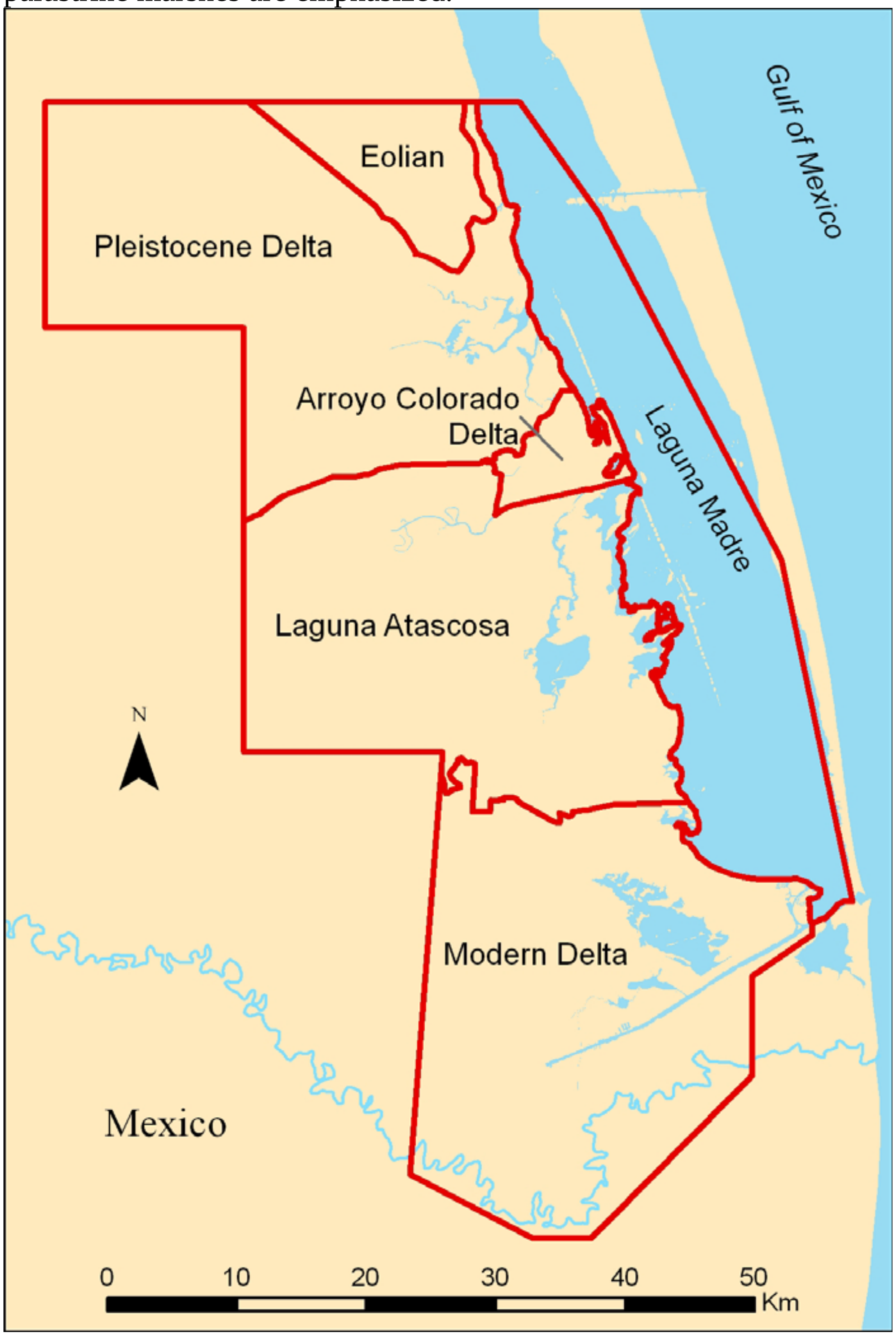

Figure 25. Index map of study area geographic subareas.

Eolian Subarea

General Trends and Probable Cause of Trends. The most significant habitat trends in the eolian subarea occurred in marshes associated with the local dune system (Fig. 26). Palustrine marsh increased from a total of 386 ha in the mid-1950's to 1,387 ha in 1979 (259% gain) (Fig. 27; Table 6). The mid-1950's to 1979 increase in fresh marsh was due to wetter ground conditions in 1979 and thus more extensive mapping in previous upland areas where marshes form in interdune deflation troughs. Drier conditions in the 1950's would limit the formation of marshes in dune depressions. Some change is interpretational where 1950's estuarine marsh was mapped in later time periods as palustrine marsh (Fig. 28). The 1979 high acreage was reversed in 2010 when 1,128 ha of palustrine marsh was mapped. The long-term palustrine marsh gain rate is 14 ha/yr between 1956 and 2010. In 2010 estuarine marsh and tidal flats were not mapped in this area. The area nearest the Laguna Madre had been previously mapped as transitional. The main road to Port Mansfield may form a barrier to salt water intrusion from the Laguna and create fresher conditions through time. Fresh open water and non-tidal flats have increased through the study time period.

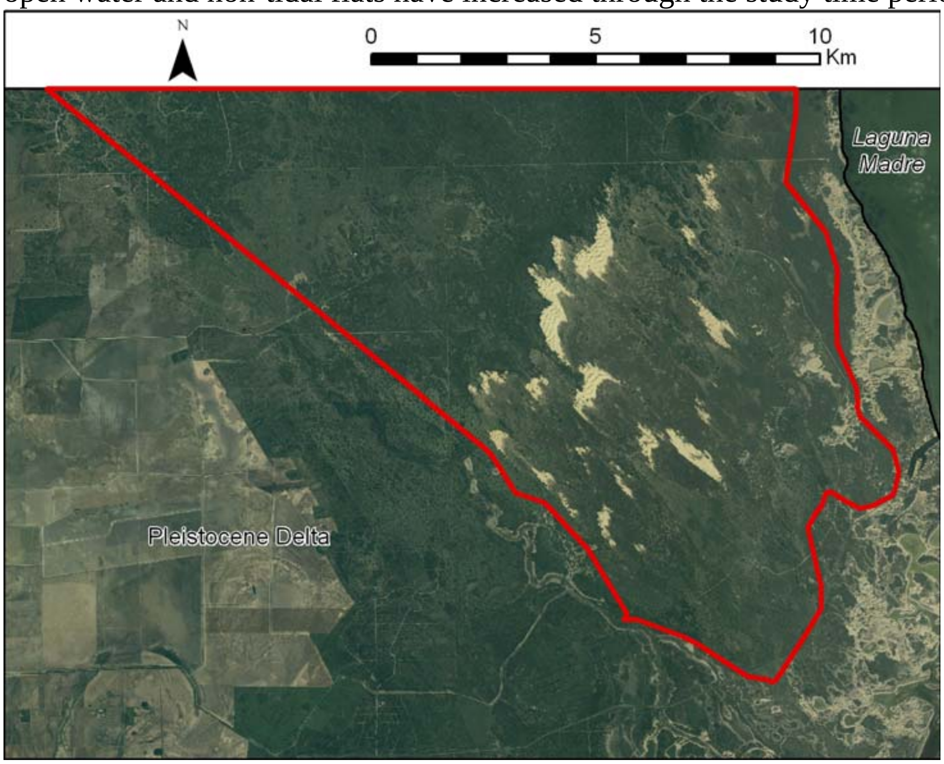

Figure 26. Index map showing "banner" dunes in the eolian subarea. See figure 9.

Table 6. Area (ha) of selected habitats in the 1950's, 1979, and 2010, eolian subarea.

	1950's	1979	2010
Tidal and algal flats	153	164	
Fresh open water	19	20	54
Estuarine marsh	317	110	
Scrub shrub (PSS)	44	44	35
Palustrine marsh	386	1,387	1,128

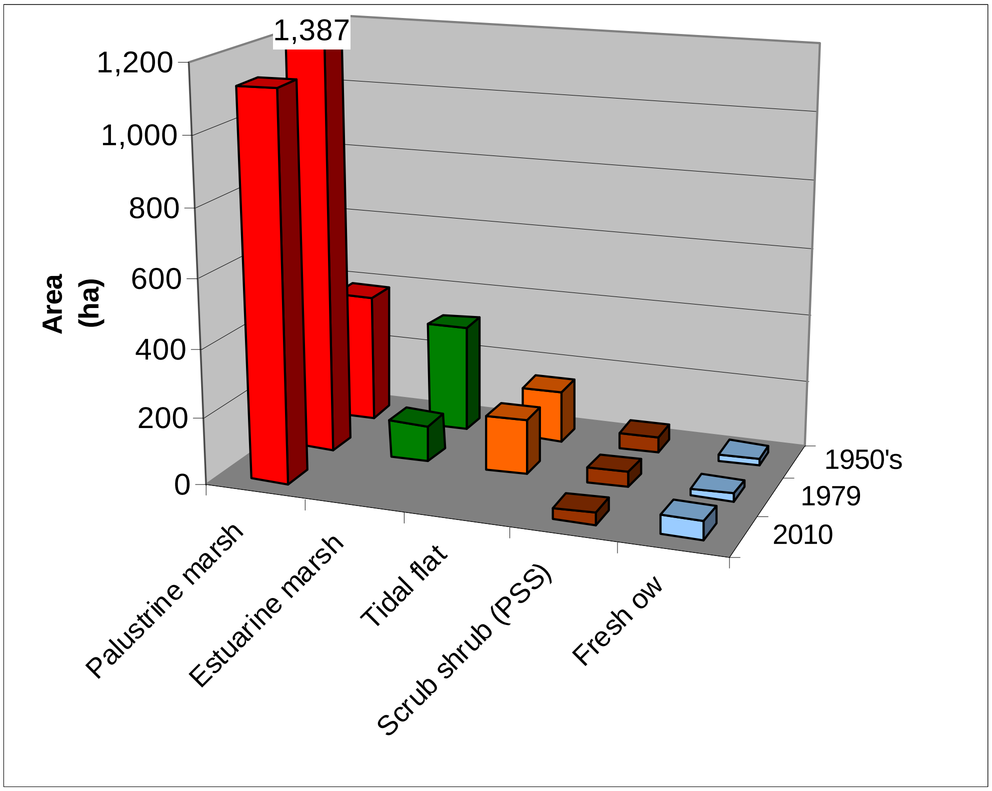

Figure 27. Areal extent of major habitats in the eolian subarea in the 1950's, 1979, and 2010.

Figure 28. Field photo of temporarily flooded palustrine marsh (PEM1A)at the edge of the eolian subarea, see figure 26. Dominanat species is *Spartina spartinae*.

Pleistocene Delta

General Trends and Probable Cause of Trends. In the Pleistocene delta subarea (Fig. 29), there was a systematic decline in tidal/algal flats with a loss of 2,203 ha from the 1950's to 2010, or about 48% of the original 1950's resource (Fig 30; Table 7). Between 1956 and 1979 the tidal flat loss rate was (-)65 ha/yr. In the later time period, 1979 to 2010, the loss rate was reduced to (-)23 ha/yr. The overall decrease in flats from the 1950's to 2010 has several causes. Relative sea level rise, caused by both subsidence and eustatic sea-level change, led to some tidal flats being flooded by open water and from replacement of the flats by estuarine marsh. Forest and palustrine scrub-shrub also declined in area by 576 ha. The 1950's total of 585 ha decreased slightly to 527 ha in 1979, then fell precipitously to 9 ha in 2010. The forested areas range from woodlands to shrubby vegetation to marshland depending upon ground moisture conditions at the time of photography (Fig. 31). By 2010 many of these areas had been cleared, presumably for grazing. A significant increase in palustrine marsh occurs between the 1950's and 1979, probably due to fewer marshes being mapped during drought conditions in the mid-1950's. Many of the inland palustrine marshes mapped in 1979 were mapped as intermittently flooded depressions (ponds) or were omitted altogether from the 1950's mapping. The decline in palustrine marsh from a total of 8,032 ha in 1979 to the 2010 total of 6,434 ha was due primarily to clearing for agricultural purposes (Fig. 32). Estuarine marsh comprises a large percentage of the vegetated wetland habitats in the Pleistocene delta subarea and has maintained relatively stable acreage through time (Fig. 33; Table 7). The 1950's total of 2,273 ha dropped slightly to 2,055 ha in 1979, then increased to a high of 2,349 ha in 2010. In many locations, estuarine marsh moved into previous tidal flat areas, a phenomenon that is common along much of the Texas coast. Although mangroves represent a small area overall and weren't present in the 1950's, mangroves increased in area from 3 ha in 1979 to 68 ha in 2010. Mangroves frequently form in narrow strips at the boundary between salt marsh and open water. Estuarine open water increased from the 1950's to 2010 by approximately 52%. The majority of the increase occurred where open water moved into previous tidal flat habitat.

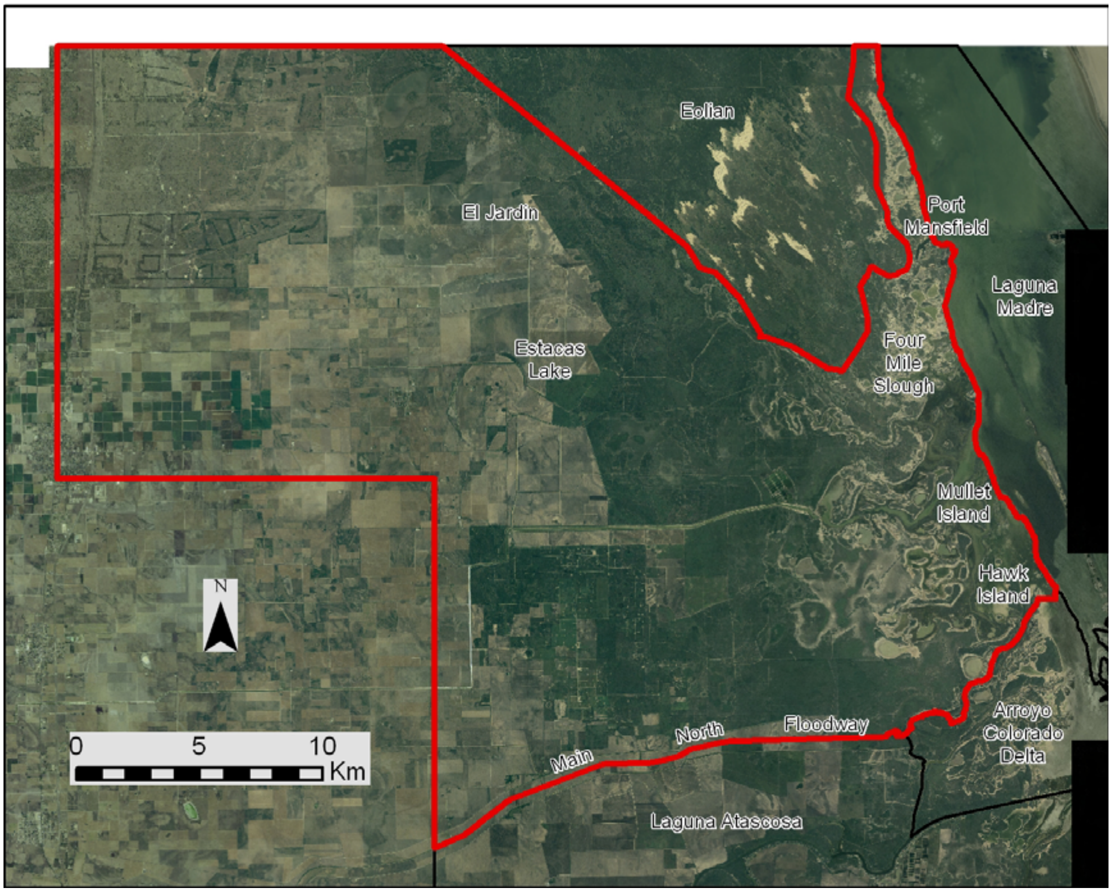

Figure 29. Index map showing features in the Pleistocene delta subarea.

Table 7. Area (ha) of selected habitats in the 1950's, 1979, and 2010, Pleistocene delta subarea.

	1950's	1979	2010
Tidal and algal flats	4,619	3,899	2,416
Seagrass	153	24	
Estuarine marsh	2,273	2,055	2,349
Mangrove		3	68
Palustrine marsh	1,681	8,032	6,434
Forest/scrub shrub	585	527	9
Estuarine open water	738	1,524	1,830
Non-tidal flats	116	499	301

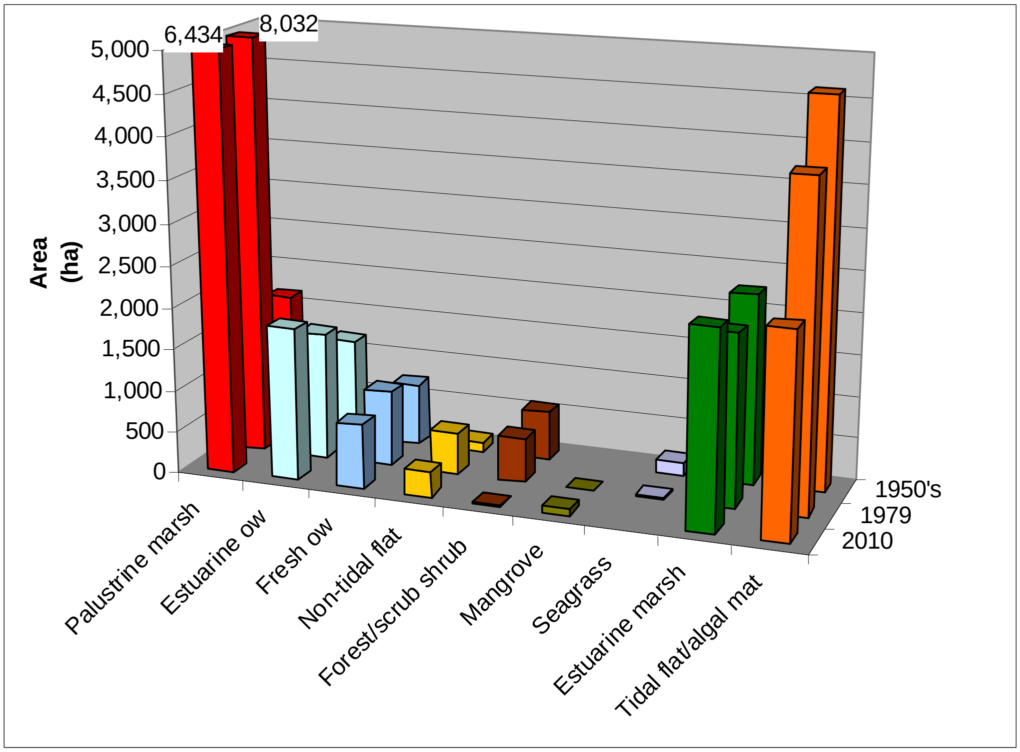

Figure 30. Areal extent of habitats in the 1950's, 1979, and 2010 in the Pleistocene delta subarea.

Figure 31. Palustrine forested area (PFO1A) in recently flooded depression. Dominant species is *Salix nigra* (black willow).


Figure 32. Cattle grazing in temporarily flooded palustrine marsh (PEM1A). Dominant species is *Spartina spartinae*. *Batis maritima* is present in grazed areas.


Figure 33. High salt marsh (E2EM1P) at intersection of Highway 186 and creek, inland from Fourmile Slough, see figure 29. Dominant vegetation is *Borrichia frutescens* and *Batis maritima*.

Arroyo Colorado Delta

General Trends and Probable Cause of Trends. The Arroyo Colorado Delta subarea, which encompasses the northern tip of Laguna Atascosa NWR, has experienced relatively minor change over time (Fig. 34). Tidal flats decreased in area by 17%, from 2,673 ha in 1950's to 2,211 ha in 2010 (Fig. 35; Table 8). During the early time period, 1956 to 1979, tidal flat loss rate was (-)14 ha/yr. In the later period, from 1979 to 2010 the loss rate was reduced to (-)5 ha/yr. A high percentage of the loss of flats was from conversion to uplands, where dredge material was deposited along the north bank of the Arroyo Colorado Cutoff. The estuarine marsh habitat increased 32% over the entire study time period from 735 ha in 1950's to 1,179 ha in 1979, then decreased to 973 ha in 2010. Palustrine marshes comprise a relatively small percentage of the wetland habitat in the Arroyo Colorado Delta. The large increase in palustrine marsh between the 1950's and 1979 is interpretational. Estuarine open water area remained stable through time. Mangroves have expanded through time, with a high of 69 ha in 1979.

Figure 34. Index map showing features in the Arroyo Colorado Delta subarea and Laguna Atascosa NWR.

Table 8. Area (ha) of selected habitats in the 1950's, 1979, and 2010, Arroyo Colorado Delta subarea.

	1950's	1979	2010
Tidal and algal flats	2,673	2,357	2,211
Estuarine open water	367	204	355
Estuarine marsh	735	1,179	973
Mangrove	25	69	46
Palustrine marsh	9	44	54

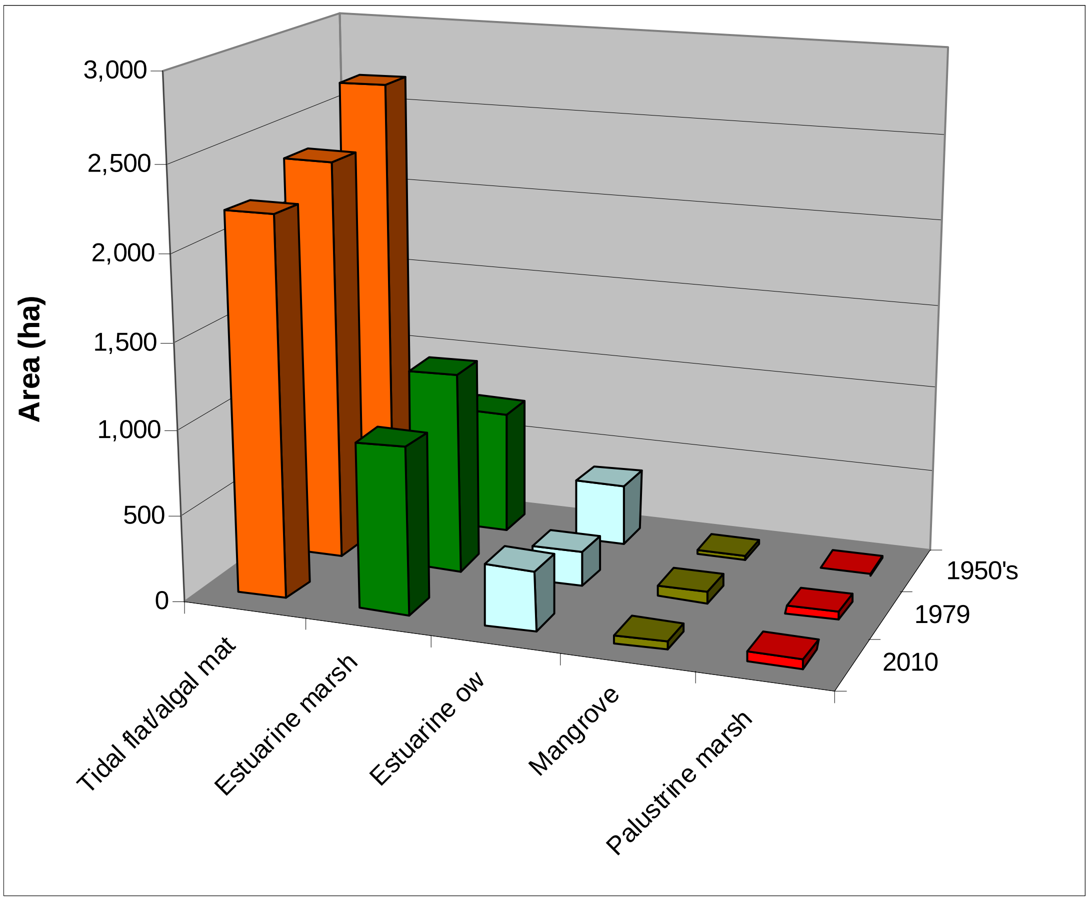

Figure 35. Areal distribution of selected habitats in the 1950's, 1979, and 2010, in the Arroyo Colorado Delta subarea.

Laguna Atascosa Subarea

General Trends and Probable Cause of Trends. The Laguna Atascosa subarea, which contains a large part of the Laguna Atascosa NWR, has experienced change in several habitat types over time (Fig. 36). The most significant change is the 95% increase in palustrine marsh between the 1950's and 2010. Palustrine marsh systematically increased from a total of 2,645 ha in the 1950's to 3,103 ha in 1979, and almost doubled in 2010 to 5,167 ha (Fig. 37; Table 9). From 1956 to 1979, fresh marsh gained 20 ha/yr and from 1979 to 2010 fresh marsh gained 67 ha/yr. Over three quarters of the increase in palustrine marsh was in areas mapped as upland in the 1950's. Most of this increase resulted from marsh management practices in Laguna Atascosa NWR. Areas mapped as "transitional" in the Submerged Lands report (White et al., 1986) were managed to encourage the establishment of wildlife habitat in the form of fresh water wetlands (Fig. 38). Tidal flats/algal mats experienced a systematic loss of acreage throughout the study time period. An initial 2,877 ha in the 1950's was reduced to 2,158 ha in 1979, then further reduced to 2,016 ha in 2010. This represents a 30% loss of the resource across the study time period. Flat loss rates are (-)31 ha/yr in the earlier time period and (-)5 ha/yr in the later time period. Analysis of tidal flat change shows most of the loss occurred when tidal flat was submerged by open water and an accompanying increase in seagrass (Figs. 39 and 40). Conversely, non-tidal flats, consisting primarily of palustrine and lacustrine flats, increased systematically through time. As a result of the management of wetlands towards a fresher system, the 1950's total of 205 ha increased to 511 ha by 1979, then to 1,415 ha by 2010, representing a nearly 600% increase. A sharp decrease in estuarine marsh occurred, as the 1950's total of 1,666 ha was reduced to 552 ha in 1979. The systematic decline continued in 2010 when salt marsh acreage reduced to 504 ha. The initial loss rate of (-)48 ha/yr continued into the later time period when salt marsh was lost at a rate of (-)2 ha/yr. Refuge management practices had converted much of the 1950's salt marsh to fresh marsh by 2010. Forest/scrub shrub habitat declined systematically in the Laguna Atascosa area, when 414 ha in the 1950's declined to 235 ha by 1979, then further lowered to 139 ha by 2010. In many cases, 1950's scrub-shrub was mapped in 2010 as palustrine marsh.

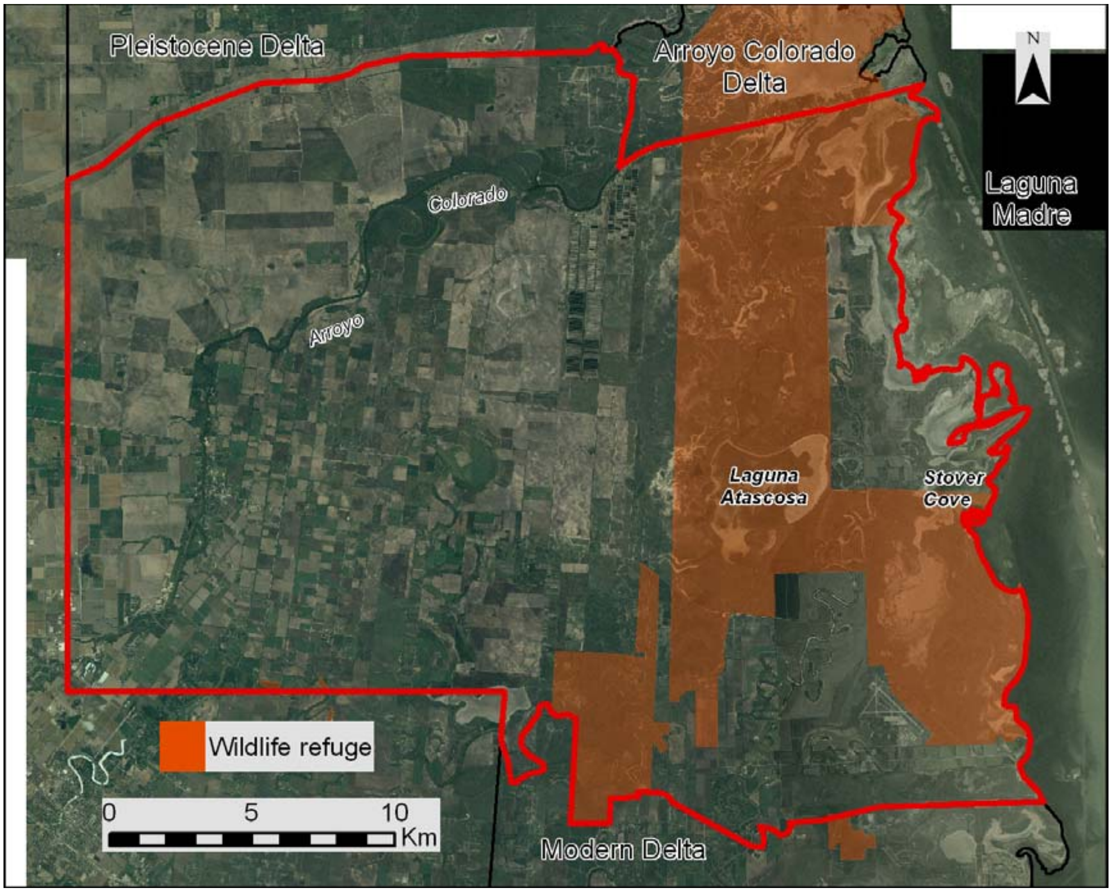

Figure 36. Index map showing features in the Laguna Atascosa subarea.

Table 9. Area (ha) of selected habitats in the 1950's, 1979, and 2010, Laguna Atascosa subarea.

	1950's	1979	2010
Tidal and algal flats	2,877	2,158	2,016
Seagrass	97	486	378
Estuarine marsh	1,666	552	504
Non-tidal flats	205	511	1,415
Palustrine marsh	2,645	3,103	5,167
Forest/scrub shrub	414	235	139
Estuarine open water	492	426	674
Fresh open water	2,820	3,772	2,709

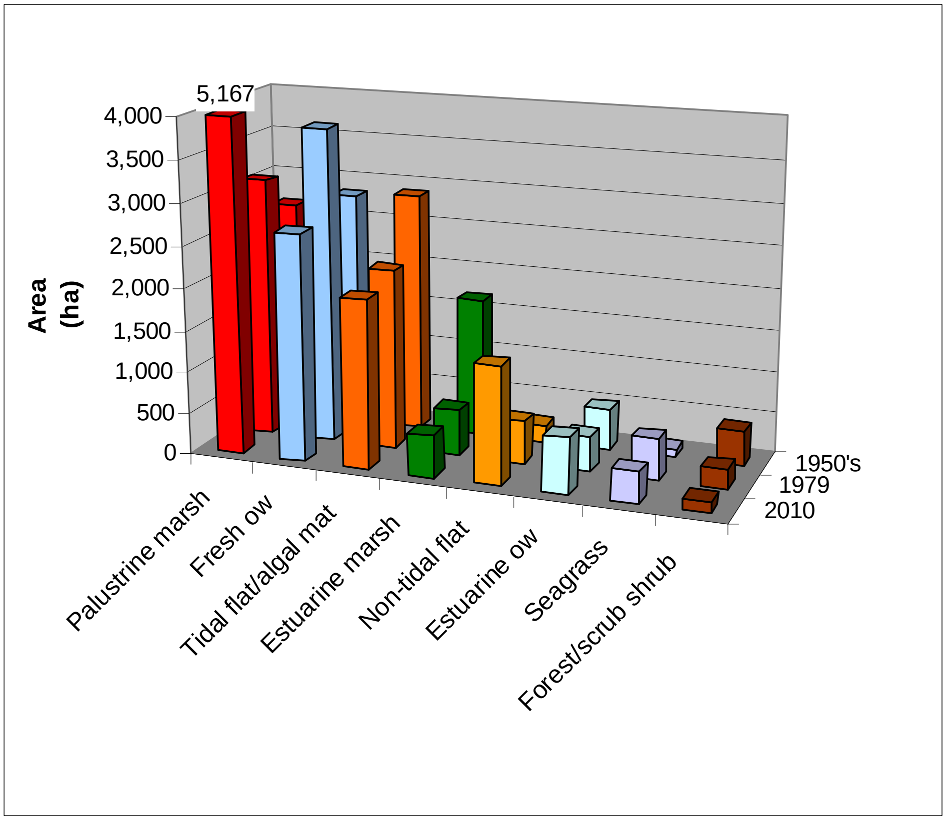

Figure 37. Areal extent of habitats in the 1950's, 1979, and 2010 in the Laguna Atascosa subarea.

Figure 38. Transitional impounded fresh marsh (PEM1Ah) and lacustrine aquatic beds (L2AB) in Laguna Atascosa NWR.


Figure 39. Irregularly flooded tidal flat (E2USP) with mangrove/salt marsh fringing the Laguna Madre.


Figure 40. Dry lake bed at Laguna Atascosa NWR. View is looking north from observation deck.

Modern Delta

General Trends and Probable Cause of Trends. Another area that experienced change in many habitats is the modern delta (Fig. 41). The southernmost part of the Brownsville-Harlingen study area experienced a large gain in estuarine marsh through time. While comprising the largest vegetated wetland habitat, drought conditions during the mid-1950's kept salt marsh acreage low, resulting in only 1,912 ha. By 1979, 4,861 ha of salt marsh was mapped, and in 2010 estuarine marsh acreage increased to 6,974 ha (Fig. 42; Table 10). The increase during the later time period was 44% of the 1979 amount. Salt marsh increased at a rate of 128 ha/yr between 1956 and 1979 and increased again by 2010 at a rate of 68 ha/yr. Roughly 86% of the area converted to estuarine marsh between the 1950's and 2010 was mapped as upland in the 1950's. This change is likely interpretational and due to drier ground conditions at the time of the 1950's photography. Much of the estuarine marsh increase between 1979 and 2010 was in areas mapped as transitional in the Submerged Lands report (Fig. 43). The next most abundant habitat in the modern delta is tidal flats/algal mats, which weren't mapped as extensively in the 1950's as in later time periods (Fig. 44). The 1950's total of 2,517 ha is roughly half that mapped in 1979 when tidal flat area was 5,330 ha. A large low lying area south of the Brownsville Ship Channel was flooded during the 1950's time period and mapped in later years as flat. By 2010, tidal flats/algal mats had decreased in area by 4,485 ha. The trend during the later time period towards a decrease in tidal flat/algal mat habitat follows the coastwide trend of tidal flat loss through time. Palustrine marsh habitat on the modern delta covers a smaller area with 1,584 ha mapped in the 1950's, half that amount in 1979 at 705 ha, and rebounding to 1,319 ha in 2010. Although relatively small in comparison to other habitat acreage, forest/scrub shrub is most abundant in the modern delta compared to the other geographic subareas (Fig. 45). In the 1950's, forest covered 293 ha, increasing to 630 ha by 1979, and increasing further to 871 ha by 2010. Most of the increase is interpretational because riparian forests were not mapped in earlier time periods. Mangrove covers a relatively small area on the modern delta, but has grown significantly through time. In the 1950's, only 8 ha was mapped, but by 1979 the area had grown slightly to 23 ha, and to 215 ha by 2010. Most of the expansion in mangrove occurred along the shores of San Martin Lake. A planting project at Bahia Grande also contributed to the expansion (Fig. 46).

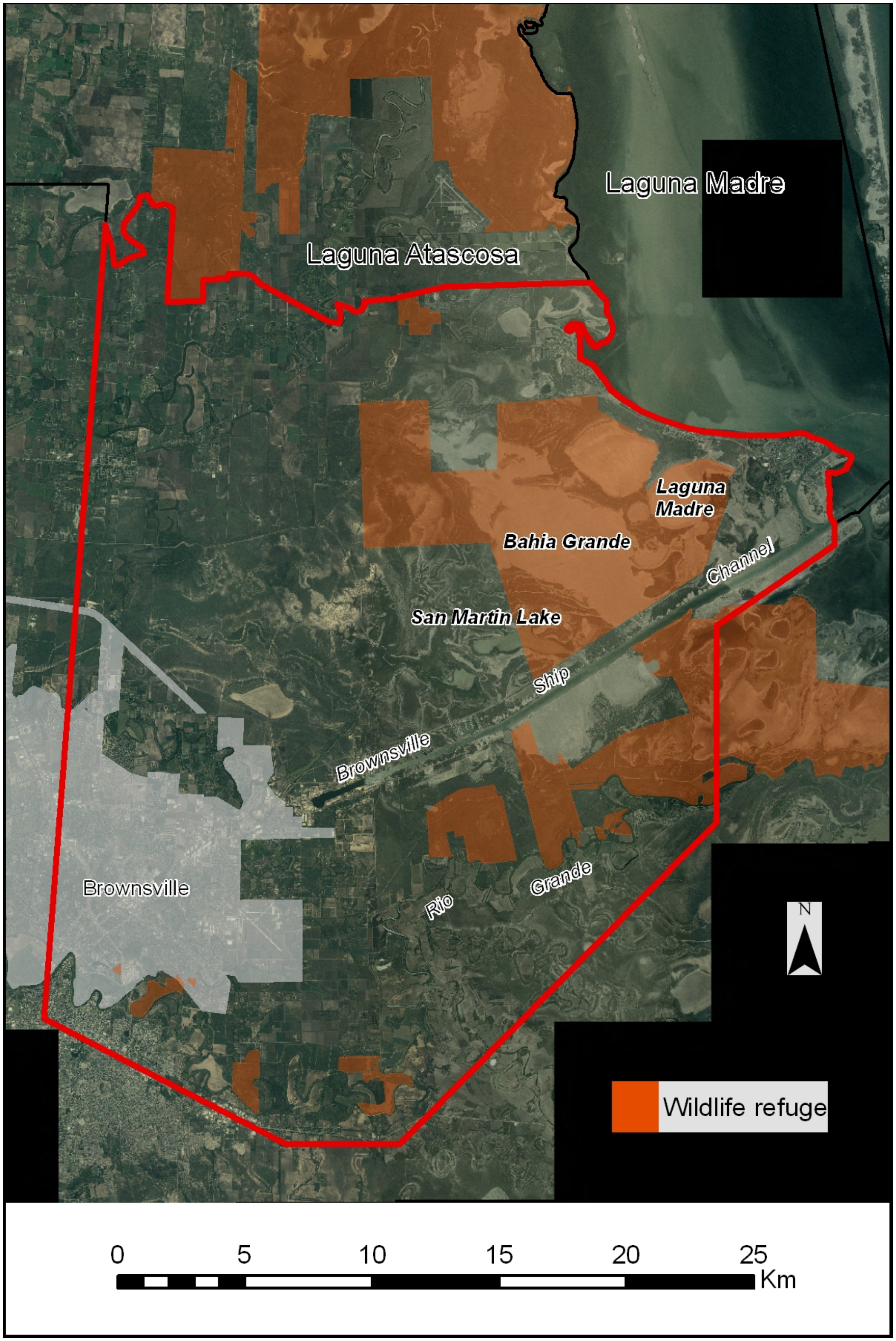

Figure 41. Index map showing features in the modern delta subarea.

Table 10. Area (ha) of selected habitats in the 1950's, 1979, and 2010, modern delta subarea.

	1950's	1979	2010
Tidal and algal flats	2,517	5,330	4,485
Seagrass	876	319	146
Estuarine marsh	1,912	4,861	6,974
Non-tidal flats	771	210	723
Palustrine marsh	1,584	705	1,319
Forest/scrub shrub	293	630	871
Estuarine open water	3,795	4,343	4,210
Fresh open water	1,085	1,529	1,206
Mangrove	8	23	215

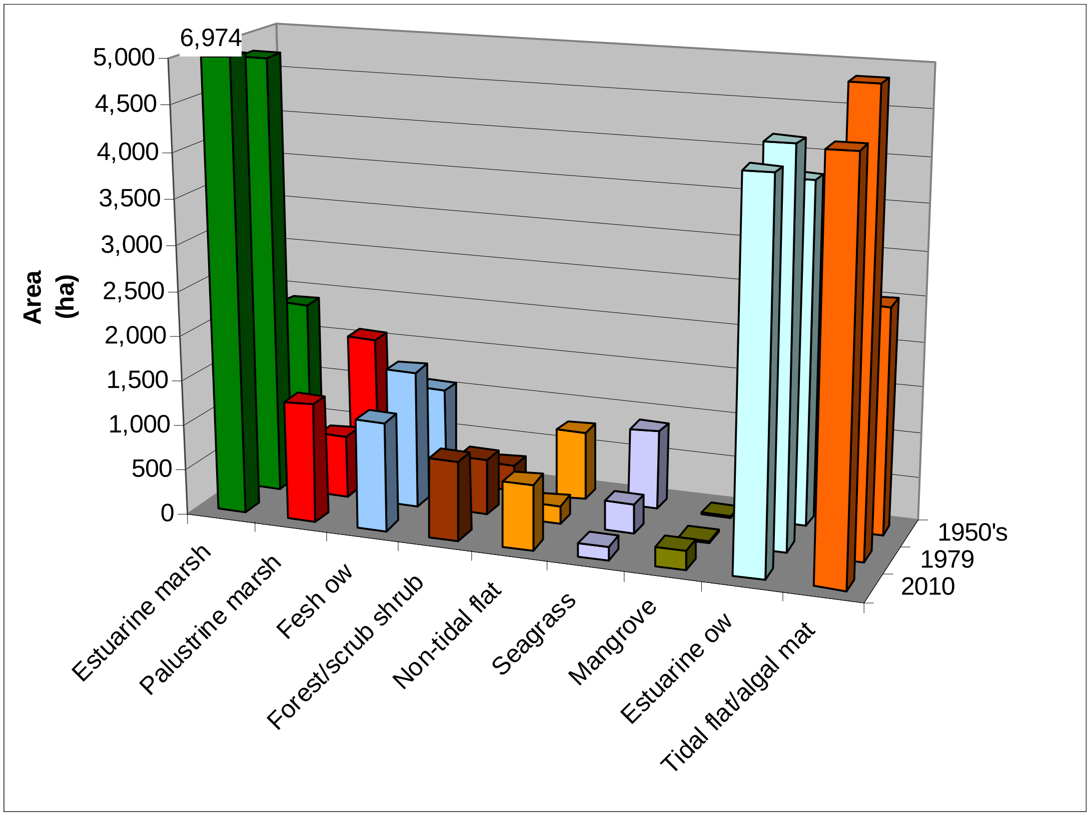

Figure 42. Areal extent of habitats in the 1950's, 1979, and 2010 in the modern delta subarea.

Figure 43. Irregularly flooded salt marsh (E2EM1P) south of the Brownsville ship channel, Laguna Atascosa NWR. Species include *Distichlis spicata*, *Batis maritima*, and *Salicornia sp*.

Figure 44. Regularly flooded tidal flat (E2USN) where Highway 48 crosses Laguna Madre, Laguna Atascosa NWR.


Figure 45. Riparian forest (PFO1A) on Resaca de la Palma, south of the Rio Grande Valley airport.

Figure 46. Mangrove (E2SS3) among irregularly flooded tidal flats (E2USP) along Highway 48 near the mouth of Bahia Grande.

Laguna Madre Subarea

General Trends and Probable Cause of Trends. The Laguna Madre subarea covers 46,036 ha with varying amounts of open water and seagrass (Figs. 47 and 48). The greatest extent of seagrass occurred in the 1950's, when 35,368 ha were mapped. In 1979, the amount of seagrass decreased to 21,139 ha, but rebounded slightly to 21,603 ha in 2010 (Fig. 49; Table 11). Conversely, the smallest amount of estuarine open water was in the 1950's with only 7,567 ha. In 1979, open water covered a much larger area of 23,611 ha, and slightly less open water was mapped in 2010 with 22,401 ha. Following the coastwide trend, tidal flats/algal mat acreage decreased over the study time period with a high of 2,467 ha in the 1950's followed by a severe decline to 627 ha in 1979. The 2010 total rebounded to 1,538 ha. The decline in tidal flats represents a 38 % loss of the original amount. Nearly half of the loss of tidal flats in the Laguna Madre subarea was in areas that had converted to seagrass between the 1950's and 2010 with much of the loss converting to open water. While not covering a large area in the Laguna Madre, mangroves expanded from 25 ha in 1979 to 134 ha in 2010.

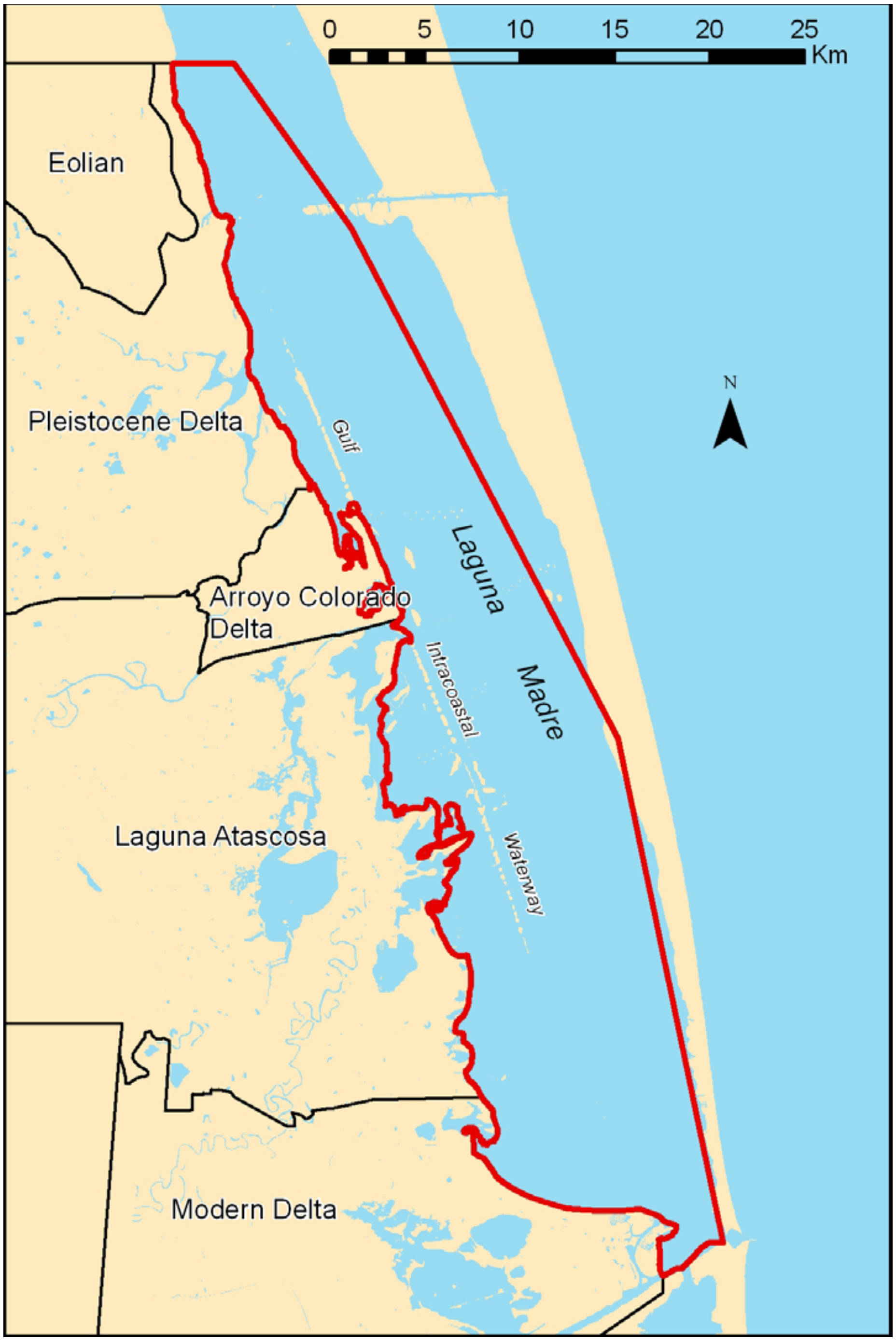

Figure 47. Index map showing features in the Laguna Madre subarea.

Table 11. Area (ha) of selected habitats in the 1950's, 1979, and 2010, Laguna Madre subarea.

	1950's	1979	2010
Tidal and algal flats	2,467	627	1,538
Estuarine open water	7,567	23,611	22,401
Estuarine marsh	154	356	106
Mangrove		25	134
Seagrass	35,368	21,139	21,603

Figure 48. Laguna Madre from observation platform in Laguna Atascosa NWR. View looking south towards Laguna Heights.

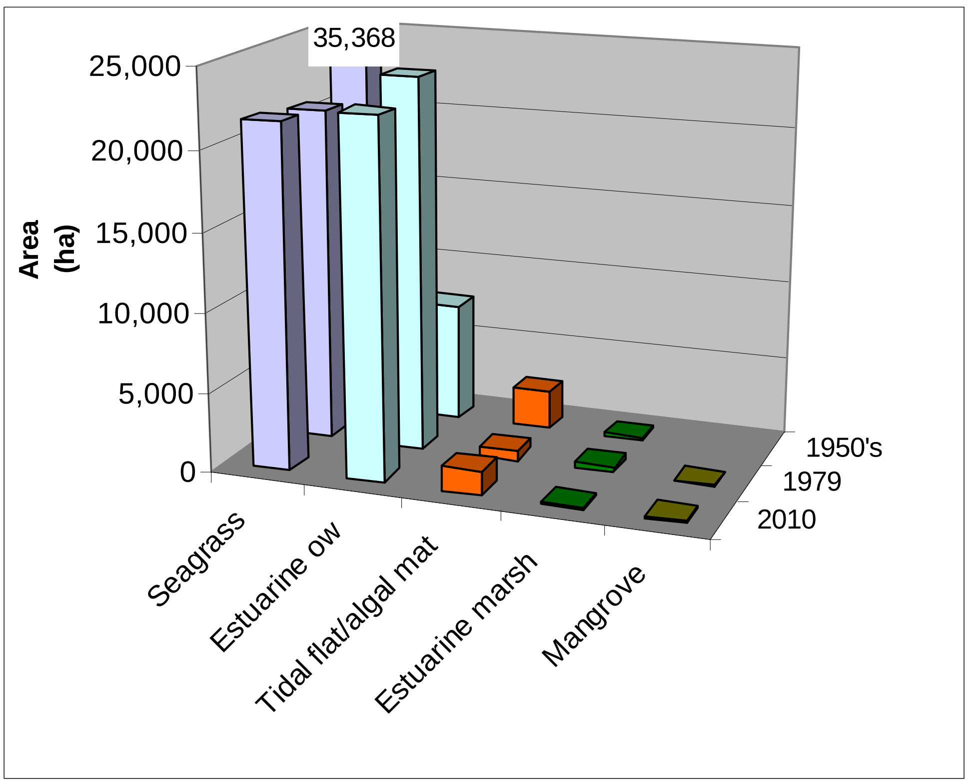

Figure 49. Areal extent of major habitats in the Laguna Madre subarea in the 1950's, 1979, and 2010.

Summary and Conclusions

The most significant habitat trends in the **eolian** subarea occurred in marshes associated with the local dune system. Palustrine marsh increased 259% between the mid-1950's and 1979. The mid-1950's to 1979 increase in fresh marsh was due to wetter ground conditions in 1979 and thus more extensive mapping in previous upland areas where marshes form in interdune deflation troughs. Drier conditions in the 1950's would limit the formation of marshes in dune depressions. Some change is interpretational where 1950's estuarine marsh was mapped in later time periods as palustrine marsh. The 1979 high acreage was reversed in 2010 when fewer palustrine marshes were mapped. The long-term palustrine marsh gain rate is 14 ha/yr between 1956 and 2010. In 2010 estuarine marsh and tidal flats were not mapped in this area. The area nearest the Laguna Madre had been previously mapped as transitional. The main road to Port Mansfield may form a barrier to salt water intrusion from the Laguna Madre and create fresher conditions through time. Fresh open water and non-tidal flats have increased through the study time period.

In the **Pleistocene delta** subarea, there was a systematic decline in tidal/algal flats with a loss of about 48% of the original 1950's resource by 2010. Between 1956 and 1979 the tidal flat loss rate was (-)65 ha/yr. In the later time period, 1979 to 2010, the loss rate was reduced to (-)23 ha/yr. The overall decrease in flats from the 1950's to 2010 has several causes. Relative sea level rise, caused by both subsidence and eustatic sea-level change, led to some tidal flats being flooded by open water and from replacement of the flats by estuarine marsh. Forest and palustrine scrub-shrub showed a systematic decline with a small loss in area from the 1950's to 1979, then fell precipitously by 2010. The forested areas range from woodlands to shrubby vegetation to marshland depending upon ground moisture conditions at the time of photography. By 2010 many of these areas had been cleared, presumably for grazing. A significant increase in palustrine marsh occurs between the 1950's and 1979, probably due to fewer marshes being mapped during drought conditions in the mid-1950's. Many of the inland palustrine marshes mapped in 1979 were mapped as intermittently flooded depressions (ponds) or were omitted altogether from the 1950's mapping. The decline in palustrine marsh from 1979 to 2010 was due primarily to clearing for agricultural purposes. Estuarine marsh comprises a large percentage of the vegetated wetland habitats in the Pleistocene delta subarea and has maintained relatively stable acreage through time. The 1950's total dropped slightly by 1979, then increased to a high in 2010. In many locations, estuarine marsh moved into previous tidal flat areas, a phenomenon that is common along much of the Texas coast. Although mangroves represent a small area overall and weren't present in the 1950's, mangroves increased in area between 1979 and 2010. Mangroves frequently form in narrow strips at the boundary between salt marsh and open water. Estuarine open water increased from the 1950's to 2010 by approximately 52%. The majority of the increase occurred where open water moved into previous tidal flat habitat.

The **Arroyo Colorado Delta** subarea, which encompasses the northern tip of Laguna Atascosa NWR, has experienced relatively minor change over time. Tidal flats decreased in area by 17% from the mid-1950's to 2010. During the early time period, 1956 to 1979, tidal flat loss rate was (-)14 ha/yr. In the later period, from 1979 to 2010 the loss rate was reduced to (-)5 ha/yr. A high percentage of the loss of flats was from conversion to uplands, where dredge material was deposited along the north bank of the Arroyo Colorado Cutoff. The estuarine marsh habitat increased 32% over the entire study time period from the mid-1950's to 2010 with a peak acreage in 1979. Palustrine marshes comprise a relatively small percentage of the wetland habitat in the Arroyo Colorado Delta. The large increase in palustrine marsh between the 1950's and 1979 is interpretational. Estuarine open water area remained stable through time. Mangroves have expanded through time, with the high acreage in 1979.

The **Laguna Atascosa** subarea, which contains a large part of the Laguna Atascosa NWR, has experienced change in several habitat types over time. The most significant change is the 95% increase in palustrine marsh between the 1950's and 2010. Palustrine marsh area systematically increased from the mid-1950's to 1979, then almost doubled by 2010. From 1956 to 1979, fresh marsh gained 20 ha/yr and from 1979 to 2010 fresh marsh gained 67 ha/yr. Over three quarters of the increase in palustrine marsh was in areas mapped as upland in the 1950's. Most of this increase resulted from marsh management practices in Laguna Atascosa NWR. Areas mapped as "transitional" in the Submerged Lands report were managed to encourage the establishment of wildlife habitat in the form of fresh water wetlands. Tidal flats/algal mats experienced a systematic loss of acreage throughout the study time period. The initial mid- 1950's amount was reduced by 1979, then further reduced in 2010. This represents a 30% loss of the resource across the study time period. Flat loss rates are (-)31 ha/yr in the earlier time period and (-)5 ha/yr in the later time period. Analysis of tidal flat change shows most of the loss occurred when tidal flat was submerged by open water and an accompanying increase in seagrass. Conversely, non-tidal flats, consisting primarily of palustrine and lacustrine flats, increased systematically through time. As a result of the management of wetlands towards a fresher system, the 1950's total increased by 1979, and increased again in 2010, representing a nearly 600% increase. A sharp decrease in estuarine marsh occurred, as the 1950's total was reduced by 1979. The systematic decline continued in 2010 when salt marsh acreage was further reduced. The initial loss rate of (-)48 ha/yr continued into the later time period when salt marsh was lost at a rate of (-)2 ha/yr. Refuge management practices had converted much of the 1950's salt marsh to fresh marsh by 2010. Forest/scrub shrub habitat declined systematically in the Laguna Atascosa area, when the 1950's acreage declined by 1979, then further lowered by 2010. In many cases, 1950's scrub-shrub was mapped in 2010 as palustrine marsh.

Another area that experienced change in many habitats is the **modern delta**. The southernmost part of the Brownsville-Harlingen study area experienced a large gain in estuarine marsh through time. While comprising the largest vegetated wetland habitat, drought conditions during the mid-1950's kept salt marsh acreage low. By 1979, salt marsh area had increased, and increased further by 2010. The increase during the later time period was 44% of the 1979 amount. Salt marsh increased at a rate of 128 ha/yr between 1956 and 1979 and increased again by 2010 at a rate of 68 ha/yr. Roughly 86% of the area converted to estuarine marsh between the 1950's and 2010 was mapped as upland in the 1950's. This change is likely interpretational and due to drier ground conditions at the time of the 1950's photography. Much of the estuarine marsh increase between 1979 and 2010 was in areas mapped as transitional in the Submerged Lands report. The next most abundant habitat in the modern delta is tidal flats/algal mats, which weren't mapped as extensively in the 1950's as in later time periods. The 1950's total acreage was roughly half that mapped in 1979. A large low lying area south of the Brownsville Ship Channel was flooded during the 1950's time period and mapped in later years as flat. By 2010, tidal flats/algal mats area had decreased further. The trend during the later time period towards a decrease in tidal flat/algal mat habitat follows the coastwide trend of tidal flat loss through time. Palustrine marsh habitat on the modern delta covers a small area in the 1950's, half that amount in 1979, but rebounded by 2010. Although relatively small in comparison to other habitat acreage, forest/scrub shrub is most abundant in the modern delta compared to the other geographic subareas. The 1950's forest cover increased by 1979, and increasing further by 2010. Most of the increase is interpretational because riparian forests were not mapped in earlier time periods. Mangrove covers a relatively small area on the modern delta, but has grown significantly through time. Most of the expansion in mangrove occurred along the shores of San Martin Lake. A planting project at Bahia Grande also contributed to the expansion.

The **Laguna Madre** subarea covers a large area with varying amounts of open water and seagrass. The greatest extent of seagrass occurred in the 1950's, then decreases by 1979, and rebounds slightly by 2010. Conversely, the smallest amount of estuarine open water was in the 1950's. In 1979, open water covered a much larger area, then decreases slightly in 2010. Following the coastwide trend, tidal flats/algal mat acreage decreased over the study time period with a high in the 1950's followed by a severe decline in 1979, rebounding in 2010. The decline in tidal flats represents a 38 % loss of the original amount. Nearly half of the loss of tidal flats in the Laguna Madre subarea was in areas that had converted to seagrass between the 1950's and 2010 with much of the loss converting to open water. While not covering a large area in the Laguna Madre, mangroves expanded between 1979 and 2010.

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. The author thanks Dr. Gene Paull and Javier Garcia, UT Brownsville, for their help during joint field campaigns. Also, thanks go to Kenneth Edwards for vehicle support. I thank Cathy Brown and John Ames of the Bureau of Economic Geology for assistance in preparing illustrations. The author appreciates the support of Melissa Porter, GLO, for her assistance in presenting the proposals to the Coastal Coordination Council and administrating the contracts once approved. Thanks to Tom Calnan, USFWS, for reviewing the draft.

REFERENCES

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

Brown, L. F., Jr., Brewton, J. L., Evans, T. J., McGowen, J. H., White, W. A., Groat, C. G., and Fisher, W. L., 1980, Environmental geologic atlas of the Texas Coastal Zone, Brownsville–Harlingen Area: The University of Texas at Austin, Bureau of Economic Geology, Special Publication, 140 p.

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

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

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.

Handley, L., Altsman, D., and DeMay, R., eds., 2007, Seagrass status and trends in the Northern Gulf of Mexico: 1940–2002: U.S. Geological Survey Scientific Investigations Report 2006–5287, 267 p.

Morton, R. A., and C. W. Holmes, 2009, Geological processes and sedimentation rates of wind-tidal flats, Laguna Madre, Texas: Gulf Coast Association of Geological Societies Transactions, v. 59, p. 519-538.

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.

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

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

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

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.

Texas Almanac 2000-2001, Millennium Edition: Dallas Morning News, 672 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, 71 pU.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. Fish and Wildlife Service, 1983, Unpublished digital data of wetland maps of the Texas coastal zone prepared from mid-1950's and 1979 aerial photographs: Office of Biological Services, U.S. Fish and Wildlife Service.

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

White, W. A., Calnan, T. R., Morton, R. A., Kimble, R. S., Littleton, T. G., McGowen, J. H., Nance, H. S., and Schmedes, K.E., 1986, Submerged lands of Texas, Brownsville – Harlingen area: sediments, geochemistry, benthic macroinvertebrates, and associated wetlands: The University of Texas at Austin, Bureau of Economic Geology Special Publication, 138 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., and Tremblay, T. A., 1995, Submergence of wetlands as a result of human-induced subsidence and faulting along the upper Texas Gulf Coast: Journal of Coastal Research, v. 11, no. 3, p. 788-807.

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 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 nos. 04-044 and 04-045, a report of the Coastal Coordination Council pursuant to National Oceanic and Atmospheric Administration Award No. NA03NOS4190102, 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

Total habitat areas for 2010, 1979, and 1950's determined from GIS data sets of the Brownsville-Harlingen study area.

2010		**1979**		**1950's**	
Habitat	**Hectares**	**Habitat**	**Hectares**	**Habitat**	**Hectares**
E1AB1L	71	E1AB.	390	E1AB.	36,501
E1AB3Lx	22,129	E1AB6L.	21,578		
E1AB4	49			E1OW.	13,458
E1AB5x	292	E1OW.	867		
E1AB6	2	E1OWL.	28,943	E2EM.	4,727
		E1OWLX.	207		
E1UBLx	28,083			E2FL.	14,165
		E2AB2M.	9		
E2AB1Mh	199	E2AB6L.	13	E2SS.	33
E2AB1Ns	3,931	E2AB6M.	26		
E2AB1Ps	1,791			L1AB.	1
E2AB3L	31	E2EM.	4,387		
		E2EM1M.	16	L1OW.	2,828
E2EM1Nx	1,763	E2EM1N.	718		
E2EM1Px	9,143	E2EM1NX.	2	L2AB.	401
		E2EM1P.	3,990		
E2SB	1			L2FL.	357
		E2FL.	6,895		
E2SS3Ns	102	E2FL6N.	1,122	L2OW.	141
E2SS3Ps	118	E2FLM.	219		
E2SS3s	305	E2FLN.	3,456	PAB.	8
		E2FLP.	2,913		
E2USMx	975			PEM.	5,715
E2USNx	1,054	E2SS.	29		
E2USPx	5,660	E2SS3N.	110	PFL.	305
L1UBHx	1,779	L1AB.	16	PFO.	109
L2AB1F	63	L1OW.	1,672	POW.	1,249
L2AB3Gh	135	L1OWFH.	23		
L2AB4Fh	16	L1OWG.	8	PSS.	277
L2AB5h	47	L1OWH.	779		
		L1OWHH.	1,494	R1OW.	287
L2UBFx	245	L1OWHhx.	27		
L2UBGh	426	L1OWHHX.	52	R1SB.	1
L2UBHh	84	L1OWVH.	73		
L2UBKhx	221			R2OW.	116
		L2AB.	18		

L2USAh	36	L2AB6F.	70	U.	166,334
L2USCh	35	L2AB6H.	132		
L2USJhs	116				
L2USKhs	683	L2FLC.	159		
		L2FLRH.	22		
PAB1Ah	1	L2FLY.	103		
PAB1Chs	20				
PAB1Fhs	43	L2OW.	28		
PAB1H	14	L2OWF.	11		
PAB1Khs	1	L2OWH.	73		
PAB3Fh	11				
PAB3Gh	1	PAB.	93		
PAB4Fx	160	PAB6F.	6		
PAB5Khs	5	PAB6G.	16		
PAB5x	252	PAB6GH.	1		
PAB6	24	PAB7G.	2		
		PAB7HH.	7		
PEM1Ax	6,571				
PEM1Cx	5,472	PEM.	1,742		
PEM1Fx	1,676	PEM1A.	510		
PEM1Jx	371	PEM1AD.	5		
PEM1Khs	16	PEM1C.	1,935		
		PEM1CD.	29		
PFO1A	727	PEM1CH.	9		
		PEM1CX.	5		
PSS1Ax	285	PEM1F.	1,909		
PSS1Cx	11	PEM1FD.	19		
PSS1Jx	29	PEM1FH.	10		
PSS3	1	PEM1FHX.	1		
		PEM1FX.	1		
PUBCh	2	PEM1Y.	7,002		
PUBFx	625	PEM1YD.	88		
PUBGx	83	PEM1Yh.	1		
PUBHx	314	PEM1YH.	4		
PUBKx	70	PEM1Yhx.	1		
		PEM1YHX.	1		
PUSAx	895				
PUSCx	204	PFL.	630		
PUSJx	10	PFLC.	60		
PUSKhs	279	PFLY.	18		
		PFLYH.	7		
R1UBV	287				
		PFO.	629		
R2UBFx	12	PFO6A.	1		
R2UBGx	2	PFO6F.	3		
R2UBHx	166	PFO6Y.	1		
UPLAND	153,511	POW.	864		
		POWF.	159		
		POWFh.	2		

POWFH.	51
POWFhx.	6
POWFHX.	52
POWFx.	1
POWFX.	29
POWG.	285
POWGH.	18
POWGHH.	1
POWGhx.	2
POWGHX.	29
POWGX.	10
POWH.	65
POWHH.	14
POWHHX.	8
POWHX.	14
PSS.	189
PSS1Y.	3
PSS6A.	34
PSS6C.	325
PSS6F.	27
PSS6Y.	224
R1OW.	234
R2OW.	3
U.	84,655
UA.	62,809
UB.	178
UBD	1
UBD.	587
UBS.	793
UF6.	4,155
UU.	912
UUO.	30