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V. HISTORICAL TRENDS IN WETLAND HABITATS

A. Methods Used to Analyze Trends

Trends in wetland habitats were determined by analyzing habitat distribution as mapped on 1950's (Fig. 20), 1979 (Fig. 21), and 1992 (Fig. 17) 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.

GIS

GIS-ARC/INFO and ARCVIEW were used to analyze trends. This software allowed for direct comparison between years, generally on a quadrangle by quadrangle basis, but also by major natural system or geographic areas such as the barrier islands, Pleistocene barrier-strandplain, and fluvial-deltaic systems of major rivers. Analyses included tabulation of losses and gains in wetland classes for each area for selected periods. In addition, full-color maps showing basic wetland classes as mapped on 1950's, 1979, and 1992 photographs were prepared to assist in analysis. Supplementary to these maps were full-scale (1:24,000) colored maps showing vegetated-wetland losses and gains for the 1950's-1979 and 1979-1992 periods for each of the quads (Fig. 2). These maps allowed relatively clear visual comparisons of changes to be made on a light table by overlaying them with the prints of the 1950's, 1979, and 1992 map series. 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 ARC/INFO.

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 were that different photointerpreters were involved for different time periods, and for the 1950's and 1979 series, wetlands were interpreted on each set of photographs without reference to photographs taken during preceding or following years. This procedure, in part unavoidable, prevented photointerpreters from selecting the most consistent wetland boundaries, especially along wetland-upland breaks, for different periods. As a result, many changes in the distribution of wetlands from one period to the next are not real but are relicts of the interpretation process.

The most striking example occurred in the Nueces River valley, where certain areas of high palustrine marsh were mapped in the 1950's and 1992, but not in 1979. Adjustments had to be made to account for differences in photointerpretation. Inconsistencies in interpretation seem to have occurred most frequently in high marsh to transitional areas where uplands and wetlands intergrade.

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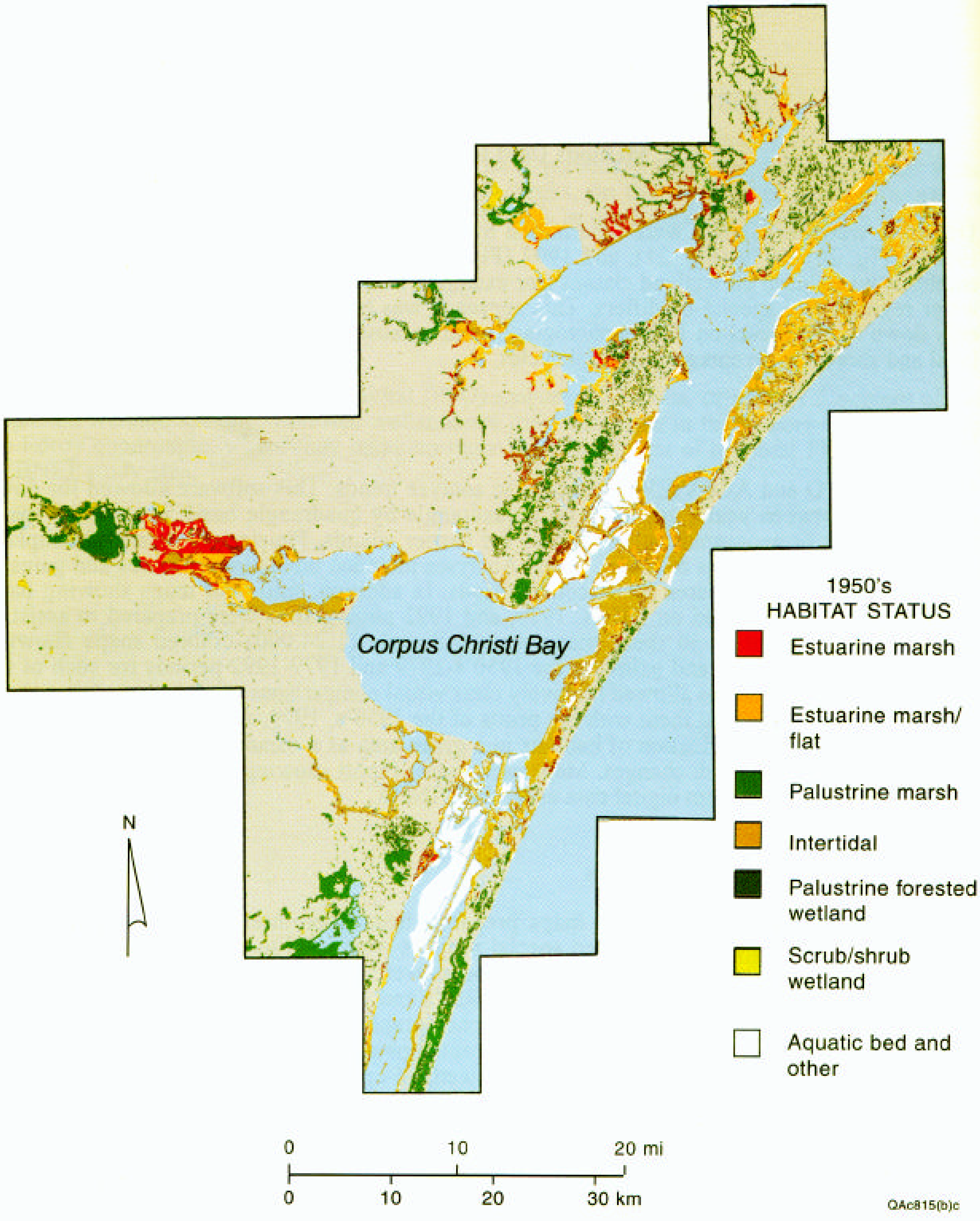


Figure 20. Distribution (1950's) of wetland and aquatic habitats in the CCBNEP study area.

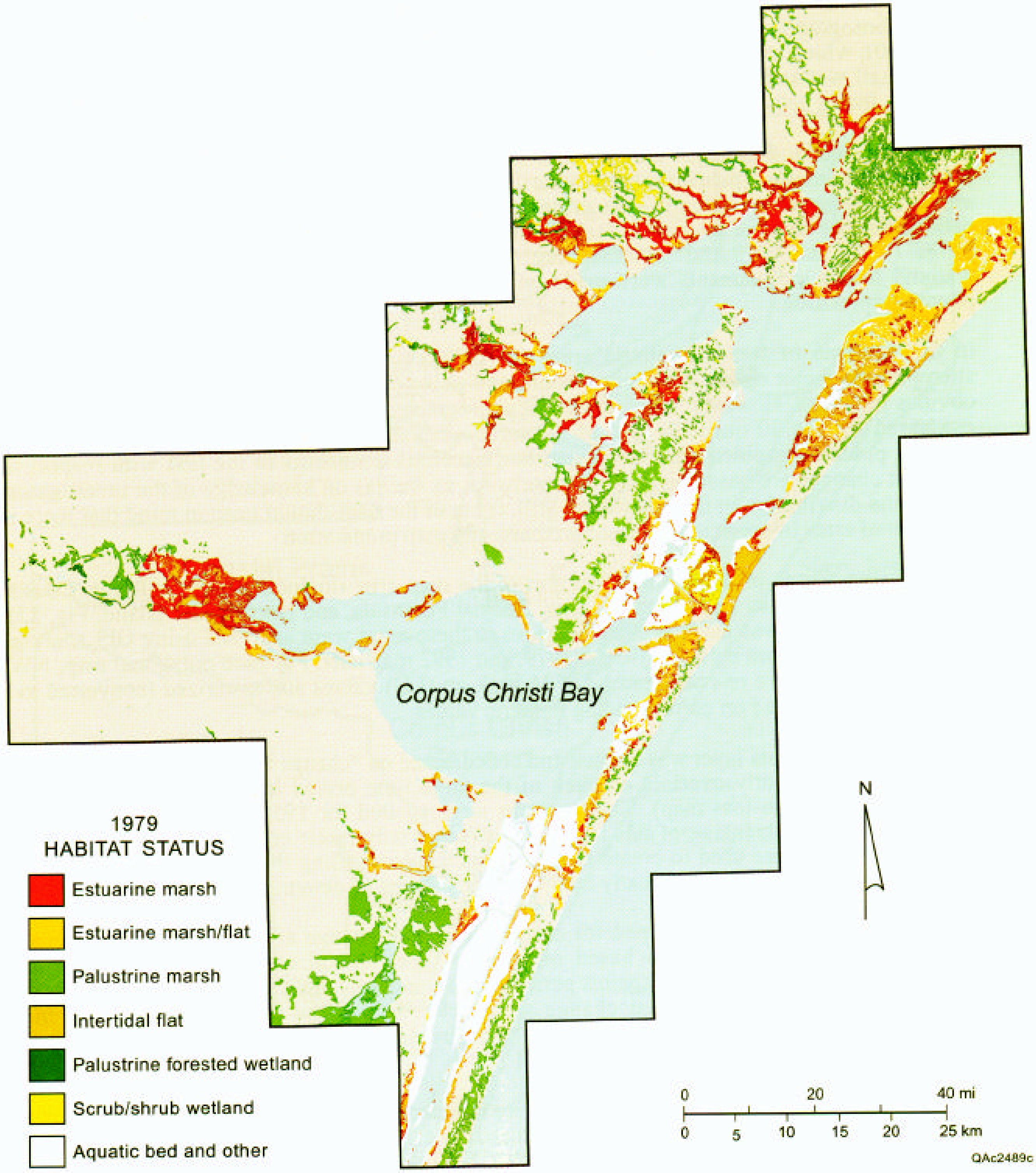


Figure 21. Distribution (1979) of wetland and aquatic habitats in the CCBNEP study area.

Some apparent wetland changes were due to different scales of aerial photographs. The 1950's aerial photographs were at a larger scale (1:24,000) than those taken in 1979 and 1992 (1:65,000), which affected the minimum mapping unit delineated on photographs. Accordingly, more small wetlands were mapped on earlier, larger-scale photographs, accounting for some wetlands losses between earlier and later periods.

In general, wetland changes that seem to have been influenced most by photointerpretation problems are interior (palustrine), temporarily flooded wetlands bordering on being transitional areas. Large apparent gains in palustrine wetlands were documented on barrier islands. We believe that the trend of net gain is real but that it is exaggerated by "undermapping" these areas in the 1950's and 1979 and "overmapping" them in 1992. As explained in a later section on wetland trends, adjustments were made on barrier island marshes to offset changes due to photointerpretation.

In the analysis of trends, wetland areas for different time periods are compared without attempting to factor out all misinterpretations and photo-to-map transfer errors except for major, obvious problems. However, maps and aerial photographs representing each period were visually compared for the 30 quads as part of the trend-analysis process and as part of the effort to identify potential problems in interpretation. Numerous comments in the text with respect to apparent changes are based on these comparisons, as well as on knowledge of the investigators of wetland distribution in the study area. Still, users of the data should keep in mind that there is a margin of error inherent in photointerpretation and map preparation.

In analyzing trends in the southern portion of the map area (including Nueces River, Coastal Prairie, Corpus Christi Bay, Laguna Larga, Encinal Peninsula, and North Padre Island, Fig. 22), a different method was used. Wetland changes in these areas were analyzed using GIS analyses to examine differences between 1950's, 1979, and 1992 map data. For each polygonal map, NWI category classes were re-coded to one of 16 look-up (LU) values and rasterized (converted to a 15 m grid layer) based on corresponding numeric values.

A "raster change" data layer was created and coded based on "change type." The "raster change" layer was subsequently overlaid on each of the three time period layers to create a thematic change map (or gain-loss map). Change maps were created for 1950's-1979, 1979-1992, and 1950's-1992. The advantage of this technique was that only raster cells which were classed as potential change were used to create change maps. Understanding the types of change and the spatial associations of change, greatly facilitated the process of determining actual changes.

Once change maps were developed for each time period, change areas identified by thematic raster polygons were analyzed based on change type, spatial attributes (size, shape and juxtaposition), checked visually against period photos, and, in some cases, on the ground. Raster polygons not representing actual change were deleted from the time-periods change map. Correction of change maps were done on a quad by quad basis and combined into a master 1950's, 1979 and 1992 change map.

Change matrixes for the lower study area were developed by combining master change maps, NWI map data, and system maps. Change matrixes are tables tabulating each category in an NWI map with an associated category in another NWI map (i.e., a table showing to-from values for each LU value in a 1979 to 1992 overlay). Change matrices are extremely useful in determining change dynamics of individual classes. Change matrices were used to further refine what was believed to be actual change. Three change matrices (1950's-1979, 1979-1992, and 1950's –1992) for each system were produced for the lower study area. Analyzing each change matrix resulted in calculation of the "final adjusted change estimate."

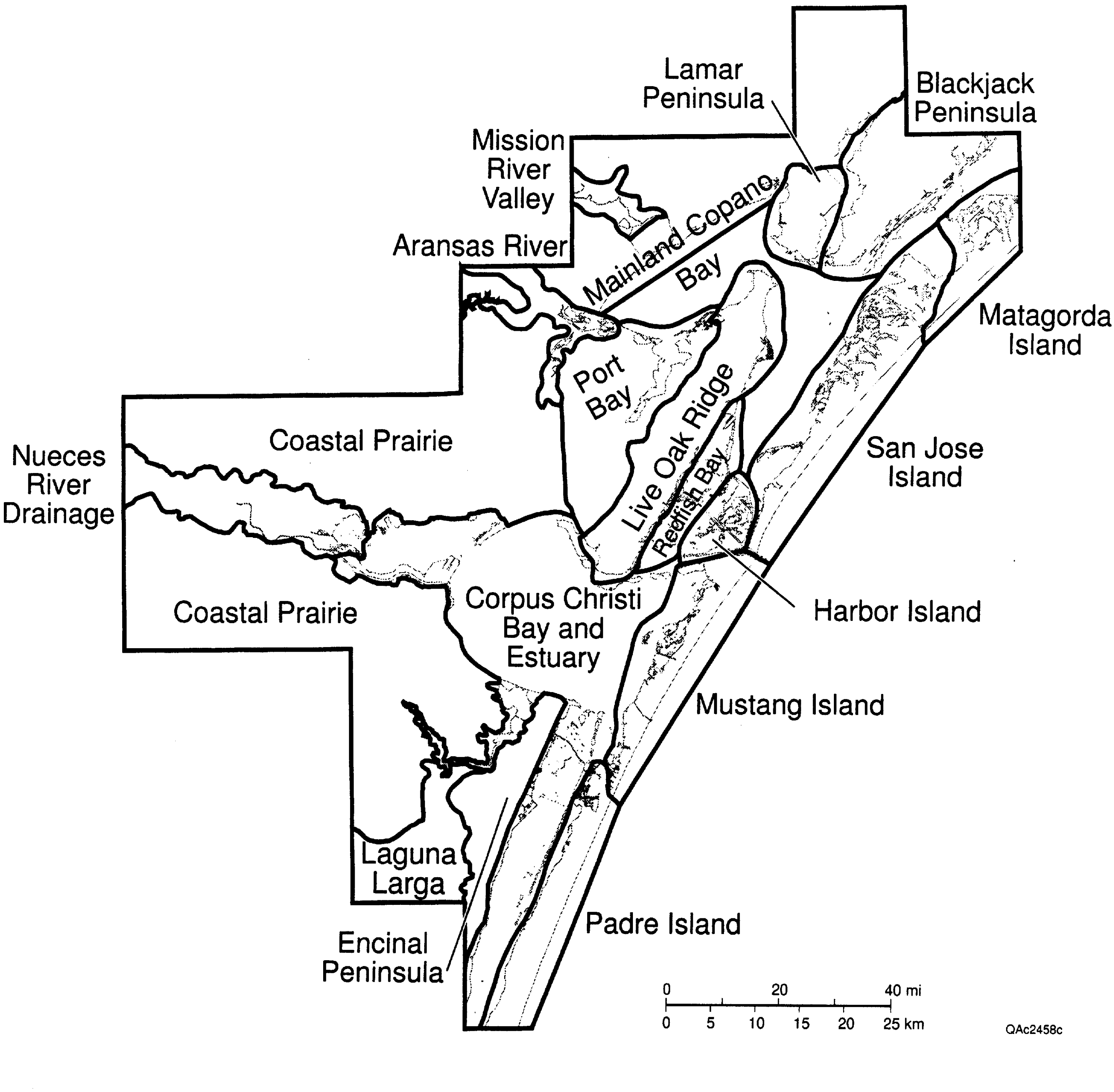


Figure 22. Major natural systems and geographic components analyzed to define wetland trends.

The final adjusted change estimates represented the best professional judgement of the investigators, and required considerable adjustment due to cartographic and photointerpretation errors, and inconsistent classification categories. In general, the 1992 NWI maps are the most accurate when allowance for overdelineation of the PEM1A (temporarily flooded fresh marsh) category is made. Use of change matrices allowed examination of change dynamics. In the southern part of the map area, final estimates of change were based on 1950's-1992 comparisons, with 1979 change derived from the other two periods.

Wetland Codes

As mentioned in the introduction (Fig. 6), some wetland codes used on 1992 maps are different from those used on the 1950's and 1979 maps. In the following discussion of trends, E2FL (instead of E2US used on 1992 maps) is generally used to denote tidal flats, and OW (rather than UB) is used to represent open water.

B. Analysis of Trends by Major Natural Systems

The CCBNEP study area was subdivided into major natural systems and geographic components for analysis of historical trends (Figs. 3 and 22). In general, systems are composed of genetically related environments, sedimentary substrates, and wetland types. This subdivision allowed a more site-specific analysis of trends and their probable causes. Natural systems include barrier islands, Pleistocene barrier-strandplain, major fluvial-deltaic areas, and selected bay and associated mainland areas (Figs. 3 and 22). Emphasis was placed on estuarine and palustrine marshes and tidal flats. In major fluvial-deltaic areas (Nueces River, Aransas-Chiltipin, and Mission), trends in riparian woodlands and forested and scrub-shrub wetlands were examined.

Modern/Holocene Barrier Island System

Modern/Holocene barrier islands include Mustang, San José, and Matagorda Islands, the flood-tidal delta Harbor Island, and North Padre Island (Figs. 3 and 22). Changes in marshes and tidal flats from the 1950's to 1992 varied on modern barrier islands and Harbor Island. The most extensive changes occurred in tidal flats, which decreased significantly in total area on all islands except Matagorda. Loss in tidal flats is a trend occurring throughout the CCBNEP area and can be related to an accelerated rise in relative sea level.

Although there have been real gains in PEM on barrier islands, we found that complex topography on the islands consisting of stabilized dunes and mounds and inter-dune depressions, created a mixture of wetlands and uplands that could not be easily separated on aerial photographs. Ninety percent of palustrine emergent wetlands mapped on 1992 photographs on Mustang Island were composed of PEM1A, which is a high, temporarily flooded interior or fresh marsh. After examining many areas of wetlands mapped on Mustang and North Padre Islands, we concluded that the class PEM1A was too liberally delineated including upland areas on 1992 maps. In addition, this wetland class was too conservatively mapped on the 1979 and 1950's maps by omitting some high marsh areas that should have been included. Based on many field observations on barrier islands, we estimated that this class on 1992 maps consisted, on average, of about 40 percent wetlands and 60 percent uplands. Accordingly, we applied a 60 percent correction to the PEM1A areas on barrier islands. Reducing the area of 1992 PEM1A habitats by 60 percent provided a more realistic assessment of the actual increase in palustrine emergent wetlands on barrier islands from 1979 to 1992.

Mustang Island

Marshes. *1950's-1979***.** The total area of estuarine and palustrine emergent wetlands (marshes) expanded from the 1950's to 1979 on Mustang Island (Table 13). Estuarine marshes increased in area by 70 ha, and undifferentiated mixtures of estuarine emergent wetlands and flats (E2EM/FL) increased by 380 ha. Most gains occurred on the southern half of Mustang Island as broad tidal flats became more extensively vegetated. Among the notable increases in salt/brackish marsh on the northern end of the island was at the Port Aransas sewage treatment plant where emergent vegetation increased on flats (Fig. 23). The gain in E2EM/FL at the expense of E2FL in this and the surrounding area encompasses approximately 140 ha, but review of aerial photographs indicates less than half of the area had emergent vegetation. Accordingly, the actual increase in area of emergent vegetation on flats at the sewage treatment site is closer to 70 ha. Applying this adjustment reduces the total increase in E2EM/FL on Mustang Island to 310 ha (Table 13). This adjustment increased the E2FL class by 70 ha.

Net gain in fresh or nontidal marsh (PEM) was 85 ha, as gross losses of about 145 ha were offset by gains of 230 ha. Increases occurred mostly in central parts of the vegetated barrier flat primarily south of Wilson’s Cut in the Crane Island NW quadrangle. Losses occurred near Port Aransas, some possibly in part due to development on the southern edge of the city; in the absence of 1979 photographs losses were partly verified using 1982 photographs.

*1979 to 1992***.** Marshes continued to expand from 1979 to 1992 on Mustang Island (Table 14). Net gain in estuarine marshes (E2EM + E2EM/FL) was about 470 ha, some of which occurred in the outfall of the sewage treatment plant at Port Aransas. Confirmation of the spread of emergent vegetation on wind-tidal flats was provided by aerial photographic analysis (Fig. 23). The 1979 E2EM/FL class was adjusted as explained previously. Unadjusted gains in PEM show an increase of almost 1,500 ha from 1979 to 1992. Adjustments of the PEM1A class, as mentioned in the introduction to this section on barrier islands, still yields an increase in PEM of about 420 ha on Mustang Island (Table 14).

Table 13. Net change in marshes and intertidal flats from 1950's-1979, Mustang Island.

Habitat	1950's (ha)	1979 (ha)	1979 Adjusted	Adjusted Net Change
E2EM	181	251	251	70
E2EM/FL	169	549	479	310
PEM	183	268	268	85
Total EM	**533**	**1068**	**998**	**465**
E2FL	3708	1278	1348	-2360

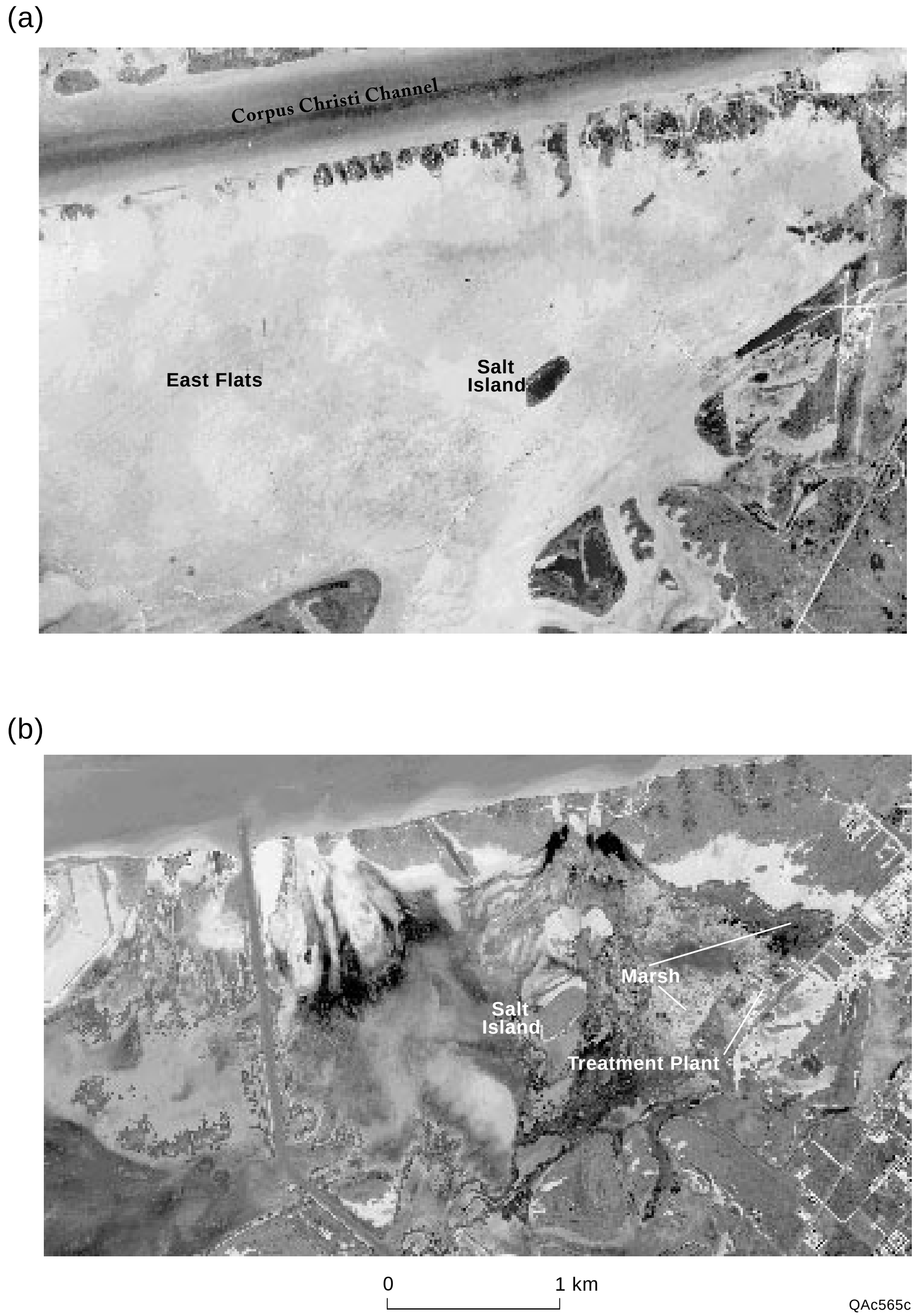


Figure 23. Development of a brackish marsh on a wind-tidal flat at the discharge site of a sewage treatment plant at Port Aransas. Aerial photographs were taken in (a)1958 and (b)1994.

Table 14. Net change in marshes and intertidal flats from 1979-1992, Mustang Island.

Habitat	1979 (ha)	1992 (ha)	1979 Adjusted	1992 Adjusted	Adjusted Net Change
E2EM	251	1203	251	1203	952
E2EM/FL	549	0	479	0	-479
PEM	268	1728	268	691	423
Total EM	**1068**	**2931**	**998**	**1894**	**896**
E2FL	1278	1343	1348	1343	-5

Estuarine intertidal flats (E2FL, E2US). *1950's-1979.* From the mid-1950's to 1979, tidal flats underwent the most extensive changes (net loss) of any habitat on Mustang Island. There was a net loss of almost 2,400 ha. More than 55 percent of gross losses were due to permanent inundation and conversion of the intertidal flats to subtidal aquatic beds and open water. Approximately 23 percent of the loss was to upland rangeland or grassland, and 21 percent was to emergent vegetation (E2EM) and emergent vegetation/intertidal flats (E2EM/FL).

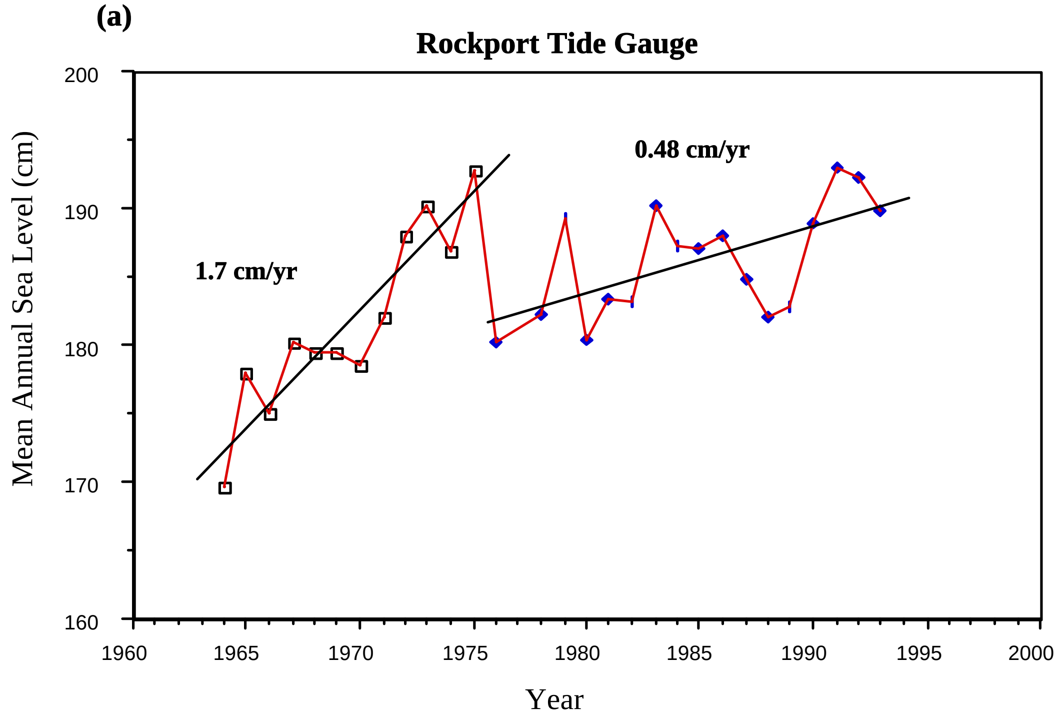
1979-1992. From 1979 to 1992, tidal flats were more stable in terms of net change. There were gains and losses resulting in a negligible net loss of less than 10 ha (Table 14). Of the gross losses more than 50 percent were converted to E2EM from an expansion of emergent vegetation, primarily *S.alterniflora*, over regularly flooded flats.

Probable Causes of Changes. *1950's-1979-1992.* From the 1950's to 1979, marshes increased in area on Mustang Island by approximately 465 ha. Most of the increase occurred in estuarine emergent wetlands. Salt marshes probably expanded on wind-tidal flats because flats became more frequently flooded from a relative rise in sea level (Fig. 24). Growth of emergent vegetation across flats was confirmed by comparing aerial photographs taken in the 1950's and 1979. Increases in estuarine (brackish) marsh near the sewage treatment plant was likely the result of treated water discharges and more frequent flooding of flats, creating favorable conditions for the growth and spread of emergent vegetation (Fig. 23). Increases in palustrine emergent wetlands on Mustang Island were less extensive and were due in part to wetter conditions in 1979 compared to the mid-1950's. Near Port Aransas, losses in PEM, part of which are interpretational, were less than 10 ha and appear to be due primarily to commercial property development.

Estuarine marshes on Mustang Island continued to expand from 1979 to 1992, although the rate of relative sea-level rise during this period was much slower (Fig. 24). Upper margins of tidal flats appear to have become more frequently flooded, thereby promoting the growth and spread of emergent vegetation (Fig. 25).

Palustrine emergent wetlands in mid-island areas expanded dramatically from 1979 to 1992. Whereas some of the gains in PEM were the result of photo-interpretative changes in classes such as E2EM to PEM, much of the gain was due to expansion of PEM into former upland areas. Although this increase in PEM may in many areas reflect differences in interpretation of historical and recent aerial photographs, there is evidence that island soils have become wetter since the 1950's and 1960's due to both higher levels of precipitation and rising sea level.

(a)



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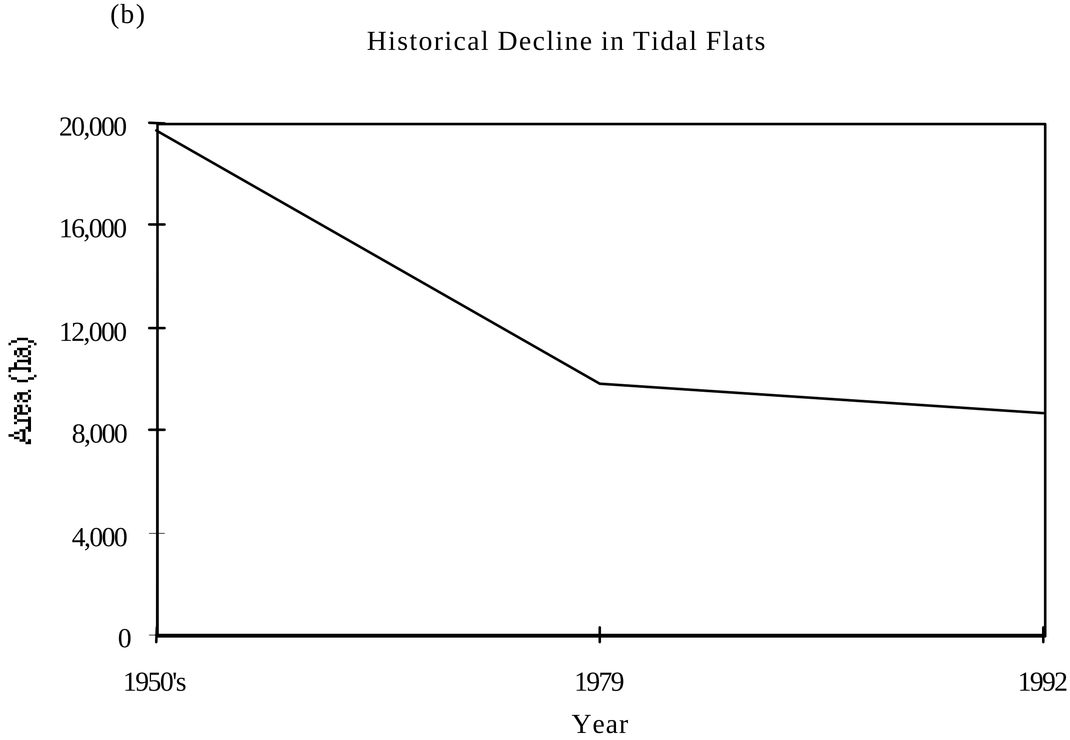


Figure 24. Relationship between (a) rate of relative sea level rise and (b) decline in area of estuarine intertidal flats in the study area.

(a)

(b)

Figure 25. Changes on the bayward side of Mustang Island including Shamrock Island from (a) 1952 to (b) 1994. The breach in Shamrock Island spit apparently occurred during Hurricane Celia in 1970. A rise in relative sea level has contributed to a spread of marsh vegetation over flats and dredged material islands since the 1950's.

From the 1950's to 1979, the most extensive losses of tidal flats, more than 1,400 ha, were due to their conversion to subtidal areas. Flooding and permanent inundation of flats is in agreement with findings by White et al. (1983) and Pulich et al. (1997), and is attributed to an accelerated rise in relative sea level from the mid-1960's to the mid 1970's (Fig. 24). Coinciding with this rise in sea level was a spread of seagrass beds and shallow open water into these formerly intertidal areas. Conversion of tidal flats to uplands occurred in some areas and was most extensive at the southern end of the island where a mixture of broad barren flats and active dunes in the 1950's became vegetated by 1979 and were mapped as upland rangeland (UA). Additional changes from flats to uplands occurred along Fish Pass where dredged material was placed on flats along the channel forming upland mounds. Similar changes occurred along a channel dredged across East Flats southwest of Port Aransas.

From the 1950's to 1992, the loss in intertidal flats amounted to approximately 2,365 ha, or about 5 ha more than from the 1950's to 1979 (Table 13). The smaller net change in estuarine intertidal flats from 1979 to 1992, is attributed in part to a slower rise in sea level (Fig. 24), and to the fact that by 1979 a large percentage (65 percent) of the 1950's flats had already been replaced by other habitats (Tables 14 and 15).

Table 15. Net change in marshes and tidal flats from the 1950's-1992, Mustang Island.

Habitat	1950's (ha)	1992 (ha)	1992 Adjusted	Adjusted Net Change
E2EM	181	1203	1203	1022
E2EM/FL	169	0	0	-169
PEM	183	1728	691	508
Total EM	**533**	**2931**	**1894**	**1361**
E2FL	3708	1343	1343	-2365

Among the reasons for loss of some habitats was shoreline erosion. Williams (1997) concluded that the northwest shoreline of Shamrock Island (Fig. 25), a natural sand and shell spit formed and nourished by southwesterly moving currents and sediments on the western shore of Mustang Island, had retreated as much as 156 m between 1938 and 1995. He also concluded that material eroded from the northwest shoreline was deposited along the southwest shore of the spit, indicating a redistribution of sediment rather than a loss. Williams (1997) noted that transport of sediment feeding the spit from the northeast was interrupted by a channel dredged around 1951 across the neck of the spit connecting to Mustang Island. The spit was breached and separated from Mustang Island by Hurricane Celia in 1970 (White et al. 1978). Rates of shoreline erosion on Shamrock Island correlate well with rates of relative sea level rise; the most rapid rate of erosion and sea level rise occurred between the mid-1960's to 1975 (Fig. 26). About three ha of estuarine marsh was lost between 1979 and 1992 due to erosion of the northeastern part of the spit. Additional apparent losses in E2EM were due to conversion of E2EM to E2SS, a change partly due to photointerpretation.

San José Island

Marshes. *1950's-1979.* Overall, there was a net loss in marshes on San José Island between the 1950's and 1979 because of a large loss in E2EM/FL (Table 16). Analysis of 1950's aerial photographs, however, indicated that about 30 percent of the area of E2EM/FL had little

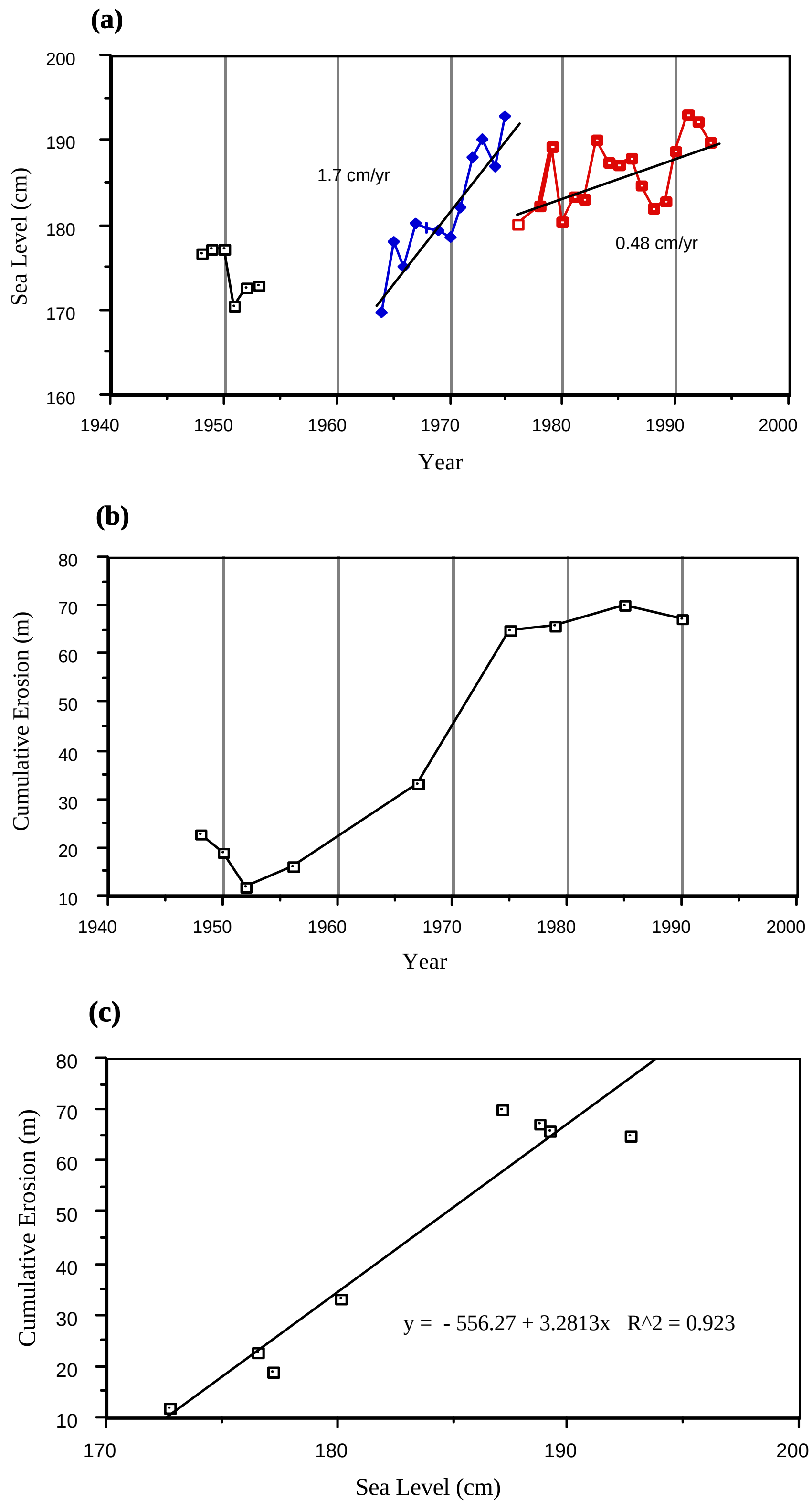


Figure 26. Relationship between sea level rise and erosion as shown by (a) sea level rise at the Rockport tide gauge, (b) shoreline erosion at one transect on Shamrock Island, and (c) high correlation (r^2=0.923). Tide data from NOAA; shoreline erosion data from Williams (1997).

emergent vegetation and could have more accurately been mapped as E2FL. Reduction of the E2EM/FL class by 30 percent reduces the net loss to 194 ha. Adding this loss to the 643 ha gain in E2EM (Table 16) yields a net gain in salt and brackish marshes of about 450 ha. We believe this is a more realistic approximation of the change that occurred on San José Island. Comparison of aerial photographs from the 1950's and 1979 shows an increase in emergent vegetation on intertidal flats. An increase of about 140 ha in fresh marsh (PEM) occurred in mid-island areas and in swales between vegetation stabilized dunes.

1979-1992. Marsh habitat on San José Island increased by more than 2,000 ha from 1979 to 1992, with estuarine marshes (E2EM + E2EM/FL) accounting for most of the gain (Table 17). More than 70 percent of the increase in E2EM wetlands occurred in areas formerly mapped as E2EM/FL and E2FL, indicating expansion of vegetation over intertidal flats. We believe the 2,000 ha gain is somewhat high because of inclusion of tidal flats in the E2EM class on the 1992 NWI maps. Nevertheless, the trend toward the spread of emergent vegetation over areas formerly mapped as flats is real and can be verified on sequential aerial photographs (Fig. 27). Palustrine emergent wetlands had an unadjusted gain of almost 500 ha, but a reduction of PEM1A areas by 60 percent (as discussed in the introduction to barrier islands) reduced the gain to 68 ha.

Table 16. Net change in marshes and intertidal flats from the 1950's-1979, San José Island.

Habitat	1950's (ha)	1979 (ha)	1950's Adjusted	Adjusted Net Change
E2EM	100	743	100	643
E2EM/FL	3460	2228	2422	-194
PEM	184	326	184	142
Total EM	**3744**	**3297**	**2706**	**591**
E2FL	3799	2977	4837	-1860

Table 17. Net change in marshes and intertidal flats from 1979-1992, San José Island.

Habitat	1979 (ha)	1992 (ha)	1992 Adjusted	Adjusted Net Change
E2EM	743	5097	5097	4354
E2EM/FL	2228	0	0	-2228
PEM	326	816	394	68
Total EM	**3297**	**5913**	**5491**	**2194**
E2FL, E2US	2977	2724	2724	-253

Estuarine Intertidal Flat. *1950's-1979*. Unadjusted net loss of E2FL on San José Island was more than 800 ha. It is estimated, however, that about 30 percent (1,038 ha) of E2EM/FL areas mapped on 1950's photographs should have been E2FL as noted above in the discussion of marshes. This adjustment increases the net loss in estuarine flat to 1,860 ha (Table 16).

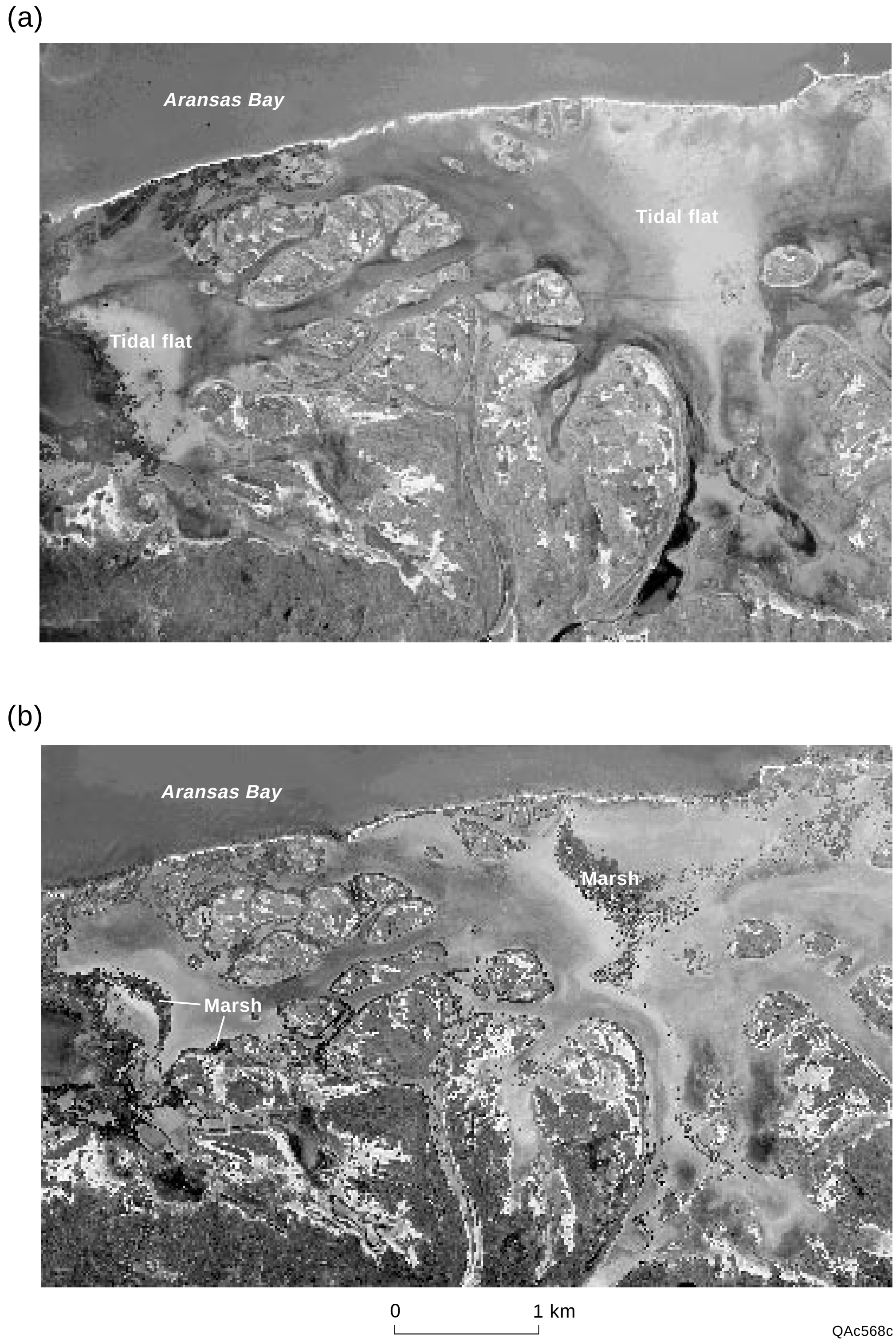


Figure 27. Example of the spread of marsh vegetation on tidal flats on San Jose Island from (a) 1979 to (b) 1994.

1979-1992. Losses of estuarine intertidal flats continued from 1979 to 1992, but at a slower rate than from the 1950's to 1979. There was a net loss of about 250 ha in E2FL, but additional losses occurred in areas mapped as E2EM/FL in 1979.

Probable Cause of Changes. *1950's-1979-1992*. Causes for changes are similar to those in Mustang Island. Some changes are interpretational, but gains in salt/brackish marsh are part of the trend toward more frequent flooding of wind-tidal flats and spread of emergent vegetation, especially *S. alterniflora* (Fig. 27). Gains in fresh marsh are partly interpretational and partly due to wetter conditions in 1979 and 1992 compared to the 1950's. As on Mustang Island, PEM1A areas appear to have been too liberally delineated on 1992 aerial photographs and were reduced by 60 percent. Still, there was a net gain in PEM.

Similar to Mustang Island, the major cause of loss in estuarine intertidal flats on San José Island (Table 18) was apparently a rise in relative sea level from the mid-1960's to 1979. Relative sea level rose about 25 cm during this period and flooded much of the intertidal flat habitat. From the 1950's to 1979, approximately 57 percent of the flats were converted to seagrass beds and open water and 25 percent to estuarine emergent marsh (E2EM, E2EM/FL). Most of the gross gain in intertidal flats from the 1950's to 1979 occurred in areas previously mapped as E2EM/FL, and is due more to interpretation than to loss of emergent vegetation. Continuing loss of tidal flats from 1979 to 1992 was in part due to the spread of emergent vegetation over flats (Fig. 27).

Table 18. Net change in marshes and intertidal flats from the 1950's-1992, San José Island.

Habitat	1950's (ha)	1992 (ha)	1950's Adjusted	1992 Adjusted	Adjusted Net Change
E2EM	100	5097	100	5097	4997
E2EM/FL	3460	0	2422	0	-2422
PEM	184	816	184	394	210
Total EM	**3744**	**5913**	**2706**	**5491**	**2785**
E2FL	3799	2724	4837	2724	-2113

Matagorda Island

Marshes. *1950's-1979*. In the marsh system, there was an apparent gain of about 60 ha in salt marsh (E2EM) (Table 19). However, the most extensive changes were in the E2EM/FL class, a net loss of 150 ha. Combining this class with E2EM yields a net loss in estuarine marsh of about 70 ha. Gross gains and losses were more substantial, with about 70 percent of gains occurring in estuarine subtidal and intertidal environments (changes in part due to photointerpretation). About 45 percent of the gross losses were to upland rangeland, 30 percent to subtidal classes (E1AB and E1OW), and 20 percent to emergent vegetation (E2EM). Comparison of photographs reveals some gain of emergent vegetation as it spread across tidal flats, but there was also some loss in emergent vegetation near the north margin of Mesquite Bay on the north side of Bray Cove. Palustrine emergent wetlands had a net loss of only 4 ha.

1979-1992. Net changes in marsh habitats were minor from 1979 to 1992. Losses in estuarine marshes (E2EM+E2EM/FL) were less than 50 ha (Table 20). A net gain of less than 20 ha occurred in palustrine marshes after adjustments to the PEM1A class as explained in the introduction to barrier islands. Overall, net change in emergent wetlands was a loss of 35 ha.

Table 19. Net change in marshes and intertidal flats from the 1950's-1979, Matagorda Island.

Habitat	1950's (ha)	1979 (ha)	Net change
E2EM	176	238	62
E2EM/FL	1858	1708	-150
PEM	103	99	-4
Total EM	**2137**	**2045**	**-92**
E2FL	86	109	23

Table 20. Net change in marshes and intertidal flats from 1979-1992, Matagorda Island.

Habitat	1979 (ha)	1992 (ha)	1992 Adjusted	Adjusted Net Change
E2EM	238	1898	1898	1660
E2EM/FL	1708	0	0	-1708
PEM	99	229	112	13
Total EM	**2045**	**2127**	**2010**	**-35**
E2FL	109	557	557	448

Estuarine Intertidal Flats. *1950's-1979*. Net loss in E2FL was only 23 ha from the 1950's to 1979. Losses were mostly due to conversion of flats to subtidal areas (E1AB and E1OW) and to estuarine marsh (E2EM and E2EM/FL).

1979-1992. An apparent net gain of more than 400 ha in estuarine flat occurred between 1979 and 1992. About 60 percent of the change occurred in subtidal habitats suggesting lower tides in 1992 compared to 1979. Most of the remaining 40 percent occurred in areas formerly mapped as E2EM/FL, indicating more detailed differentiation of the E2EM and E2FL (E2US) classes in 1992.

Probable Causes of Changes. *1950's-1979-1992*. From 1950's to 1979, there were losses in emergent vegetation on the north side of Bray Cove and Mesquite Bay. Losses apparently resulted from construction of a levee/road complex that cut off intertidal connections forming an impoundment that submerged marsh vegetation. Between 1979 and 1992 emergent vegetation increased in this area after the intertidal connection was restored. Although verified on aerial photographs, the quantitative extent of this change could not be determined because the area was mapped as E2EM/FL on both the 1950's and 1979 maps.

Marshes had minimal net losses during both periods but losses are questionable because of photointerpretation inconsistencies and map registration problems. Comparison of historical and recent photographs indicate a spread of intertidal vegetation in several areas. Overall, from the 1950's to 1992, there was a loss of approximately 125 ha of marsh and a gain of more than 470 ha of estuarine intertidal flat (Table 21).

Table 21. Net change in marshes and intertidal flats from the 1950's-1992, Matagorda Island.

Habitats	1950's (ha)	1992 (ha)	1992 Adjusted	Adjusted Net Change
E2EM	176	1898	1898	1722
E2EM/FL	1858	0	0	-1858
PEM	103	229	112	9
Total EM	**2137**	**2127**	**2010**	**-127**
E2FL	86	557	557	471

Harbor Island

Marshes. *1950's-1979.* The trend in marsh habitat on Harbor Island from the 1950's to 1979 was one of net gain (Table 22). For purposes of the Harbor Island anlaysis, estuarine intertidal scrub/shrub (E2SS, consisting mostly of black mangroves) was combined with estuarine emergent vegetation (marsh). This is because of inconsistencies in delineation of E2SS on the 1950's and 1979 maps; E2SS could not be adequately subdivided on the black and white 1950's aerial photographs from which the 1950's maps were prepared. E2SS was mapped, however, on the 1979 color-infrared aerial photographs and shown on the 1979 maps. Total gain in E2EM and E2SS was approximately 800 ha, most of which (678 ha) was E2SS. Although, there were gains and losses in the E2EM/FL class, overall there was a net loss of about 50 ha. Combining this loss with the 800 ha gain noted previously yields a net gain of 750 ha. Increases in estuarine emergent vegetation (and scrub/shrub) occurred primarily as marsh vegetation spread across estuarine intertidal flats. The palustrine emergent wetland class is negligible on Harbor Island.

Table 22. Net change in marshes and intertidal flats from the 1950's-1979, Harbor Island.

Habitat	1950's (ha)	1979 (ha)	Net Change
E2EM, E2SS	27	830	803
E2EM/FL	261	210	-51
PEM	2	0	-2
Total EM	**290**	**1040**	**750**
E2FL	2365	357	-2008

1979-1992. From 1979 to 1992 there was an apparent net decline in estuarine marshes (E2EM, E2EM/FL, and E2SS) on Harbor Island (Table 23). This is a reversal in the trend of net gain from the 1950's to 1979. However, analysis of aerial photographs indicates photointerpretion inconsistencies. There is evidence of a continuing spread of emergent vegetation over intertidal flats at a much slower rate than that occurring from the 1950's to 1979. Use of the E2EM/FL class in 1979 accounts for some of the apparent loss.

Table 23. Net change in marshes and intertidal flats from 1979-1992, Harbor Island.

Habitat	1979 (ha)	1992 (ha)	Net Change
E2EM	152	831	679
E2EM/FL	210	0	-210
E2SS	678	40	-638
PEM	0	29	29
Total EM&SS	**1040**	**900**	**-140**
E2FL	357	295	-62

Estuarine Intertidal Flats. *1950's-1979*. There was a net loss of approximately 2,000 ha of estuarine intertidal flats on Harbor Island from the 1950's to 1979. The most extensive losses occurred on the western half toward Redfish Bay.

1979-1992. The area of estuarine intertidal flat continued to decrease after 1979, but at a much slower rate than during the earlier period. From 1979 to 1992 the net decline in this habitat was about 60 ha.

Probable Causes of Changes. *1950's-1979-1992*. Harbor Island is one of the best examples of changes that occur from a rise in sea level (Figs. 24 and 28). Broad tidal flats became permanently flooded between the 1950's and 1979 promoting expansion of seagrass beds. Salt-marsh vegetation, including *Avicennia germinans* spread on topographically higher flats and mounds.

There is photographic evidence indicating a continuing spread of estuarine marsh from 1979 to 1992, although digital data indicate a loss. Photo analysis shows that some areas mapped as E2EM/FL in 1979 should have been mapped as E2FL, which would have produced a larger gain in E2EM from 1979 to 1992. The change in E2SS to E2EM habitats from 1979 to 1992 is both interpretational and real. Extreme low temperatures in 1983 killed many black mangroves. Still, much of the difference in area of E2SS in 1979 and 1992 is due to aerial photographic quality and interpretation differences. From the 1950's to 1992, relative rise in sea level contributed to a net gain of 610 ha of marsh and a loss of more than 2,000 ha of estuarine intertidal flat (Table 24).

Table 24. Net change in marshes and intertidal flats from the 1950's-1992, Harbor Island.

Habitat	1950's (ha)	1992 (ha)	Net Change
E2EM, E2SS	27	871	844
E2EM/FL	261	0	-261
PEM	2	29	27
Total EM	**290**	**900**	**610**
E2FL	2365	295	-2070

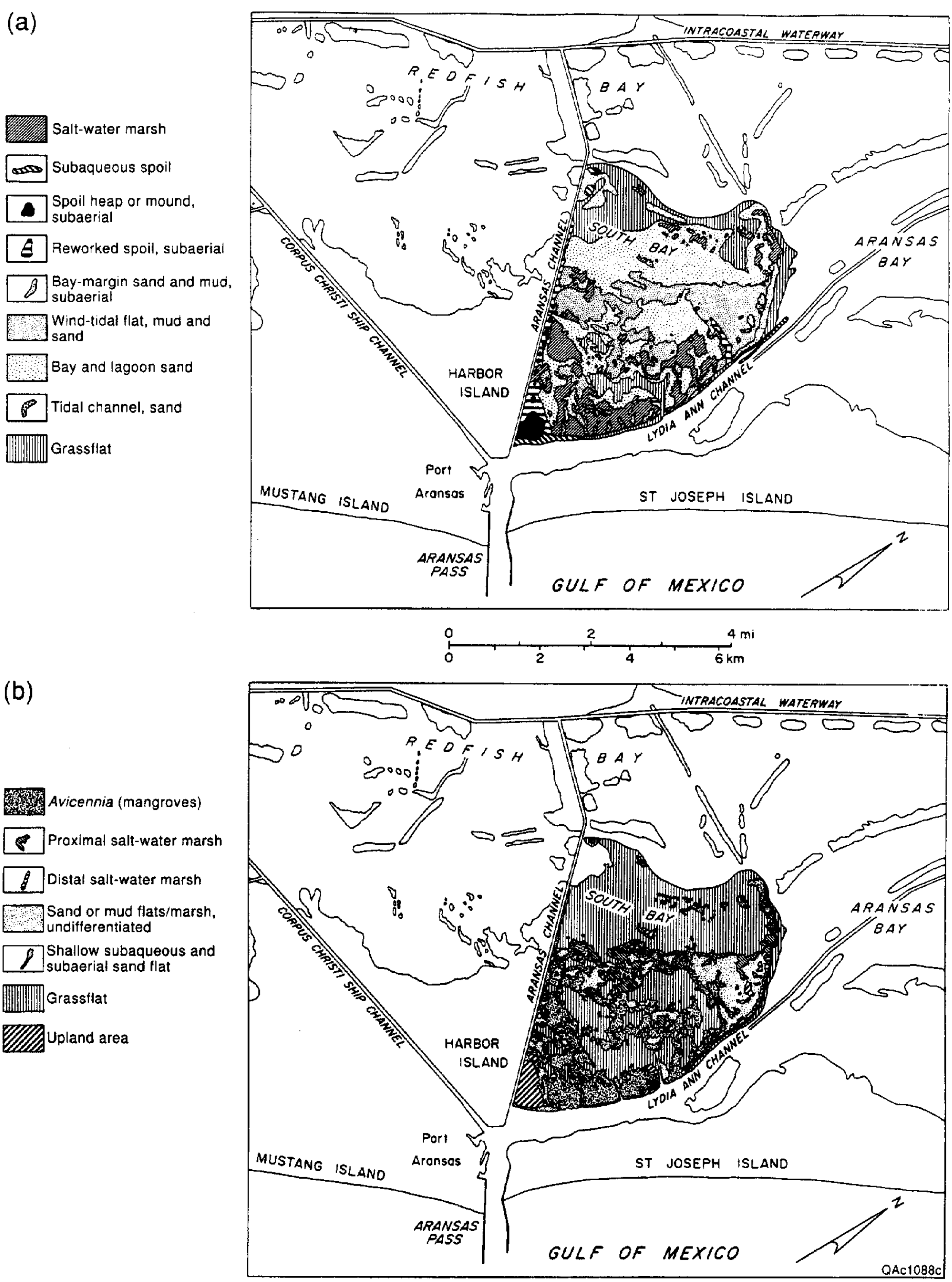


Figure 28. North Harbor Island environments (a) in 1958 (from Brown et al. 1976) and (b) in 1979 (from White et al. 1983).

North Padre Island

Marshes. *1950's-1992.* Tables 25-27 present habitat changes for this region. It appears that PEM marshes have increased in area on North Padre Island. The net gain was estimated at 663 ha. As on other barrier islands, we estimated, based on ground-truthing, that about 40 percent of the area classified as PEM1A on the 1992 photos was actually PEM wetlands. The rest would be more appropriately called wetland/upland transitional area. Areas totaling about 360 ha classified as seasonally flooded marsh (PEM1C), wetter than PEM1A, remained constant in area although not in spatial distribution. About 80 percent of the increase in PEM1A was classified as U in the 1950's. There was a net gain of about 87 ha of E2EM; 37 ha from E2FL and 51 ha from U. This expansion of E2EM occurred along the Laguna Madre shore of the island. This change analysis did not include the South Bird Island quadrangle for which no 1992 data were available. Also, the 1950's data exhibited serious cartographic errors that made a 1950's-1979 comparison untenable. The available photos of South Bird Island and Pita Island gave no indication that wetland trends on the two quads differed.

Table 25. Net change in marshes and intertidal flats from the 1950's-1979, North Padre Island.

Habitat	1950's (ha)	1979 (ha)	1950's Adjusted	1979 Adjusted	Adjusted Net Change
E2EM	18	7	82	77	-6
E2EM/FL	40	58	36	45	9
PEM	360	458	335	548	213
Total EM	**419**	**523**	**454**	**671**	**217**
E2FL	793	284	669	300	-369

Table 26. Net change in marshes and intertidal flats from 1979-1992, North Padre Island.

Habitat	1979 (ha)	1992 (ha)	1979 Adjusted	1992 Adjusted	Adjusted Net Change
E2EM	7	169	77	169	92
E2EM/FL	58	0	45	0	-45
PEM	458	1951	549	999	450
Total EM	**523**	**2120**	**671**	**1168**	**497**
E2FL	284	197	300	197	-103

Table 27. Net change in marshes and intertidal flats from the 1950's-1992, North Padre Island.

Habitat	1950's (ha)	1992 (ha)	1950's Adjusted	1992 Adjusted	Adjusted Net Change
E2EM	18	169	82	169	87
E2EM/FL	40	0	36	0	-36
PEM	360	1951	335	999	663
Total EM	**419**	**2120**	**454**	**1168**	**714**
E2FL	793	197	669	197	-472

Estuarine Intertidal Flats. *1950's-1992*. There was a loss of 521 ha of E2FL; 230 ha went to upland, 223 ha to E1OW, and 37 ha to E2EM. About 49 ha of E2FL were gained, 26 ha from E1OW and 22 ha from U, so the net change was a 472 ha loss of E2FL.

Probable Causes of Changes. *1950's-1992*. About 453 ha of E2FL loss was due to residential development (Padre Isles), i.e., dredge and fill conversion to E1OW (canals) and uplands (Fig. 29). Other losses of E2FL along the Laguna Madre shore may be the result of several active processes. A rise in relative sea level plus vegetative stabilization of dunes, resulting in less sand blowing into the bay, may have caused submergence of some E2FL. A study of historical changes in the upper Laguna Madre shoreline on the South Bird Island quad attributed shoreline progradation between 1941 and the late 1970's to the effects of below average rainfall and heavy grazing pressure upon island vegetation (Prouty and Prouty 1989). Since 1979 and stabilization of active dune fields, the shoreline has been eroding. Rising relative sea level may also have caused expansion of PEM on the island. As sea level rises, the island’s freshwater lens also rises and the island may be getting wetter.

Pleistocene Barrier–Strandplain System

The Pleistocene barrier-strandplain system consists of a series of Pleistocene sand ridges characterized by a network of pothole wetlands and live oak mottes. A major component of this barrier-strandplain system is Live Oak Peninsula/Ridge, located at the heart of the CCBNEP study area (Figs. 3 and 22). To the northeast are Blackjack and Lamar Peninsulas, and to the southwest is Encinal Peninsula (Fig. 22). Because of the complex topography consisting of relict beach ridges, inter-ridge swales, deflation troughs, and stabilized dunes, this system is host to one of the most complex array of palustine marshes and ponds that exist in the CCBNEP area. This complex interrelationship between wetlands and uplands was simplified for mapping purposes by using combinations of classes that do not spatially differentiate wetlands from uplands (Fig. 30).

Live Oak Peninsula/Ridge

Marshes. *1950's-1979*. There were losses and gains in salt and brackish marshes (E2EM, E2EM/FL) on Live Oak Peninsula and Ridge from the 1950's to 1979, but overall, there was a net gain of almost 400 ha (Table 28, E2EM+E2EM/FL). Increases occurred primarily along the margins of Redfish Bay and to a lesser extent on the Port Bay side of the peninsula.

Table 28. Net change in marshes and intertidal flats from the 1950's-1979, Live Oak Ridge/Peninsula.

Habitat	1950's (ha)	1979 (ha)	1950's Adjusted	1979 Adjusted	Adjusted Net Change
E2EM	207	472	207	472	265
E2EM/FL	228	356	228	356	128
PEM	995	938	995	938	-57
PEM/U	1233	37	432	13	-419
POW/U	0	1606	0	562	562
POW, PFL	243	306	243	306	63
Total EM + POW	**2906**	**3715**	**2105**	**2647**	**542**
E2FL	1084	214	1084	214	-870

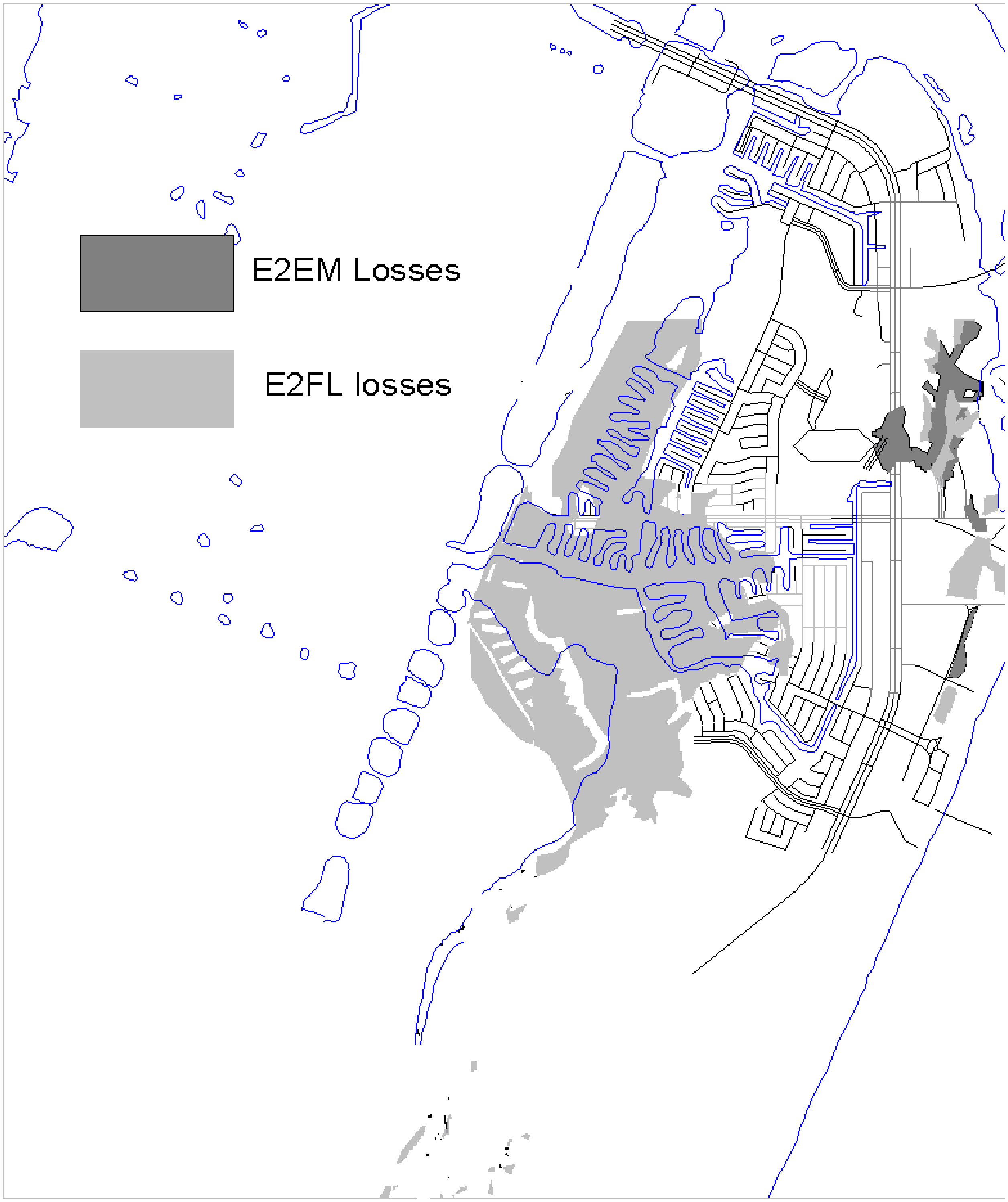


Figure 29. Padre Isles residential development and loss of E2FL and E2EM since the 1950's

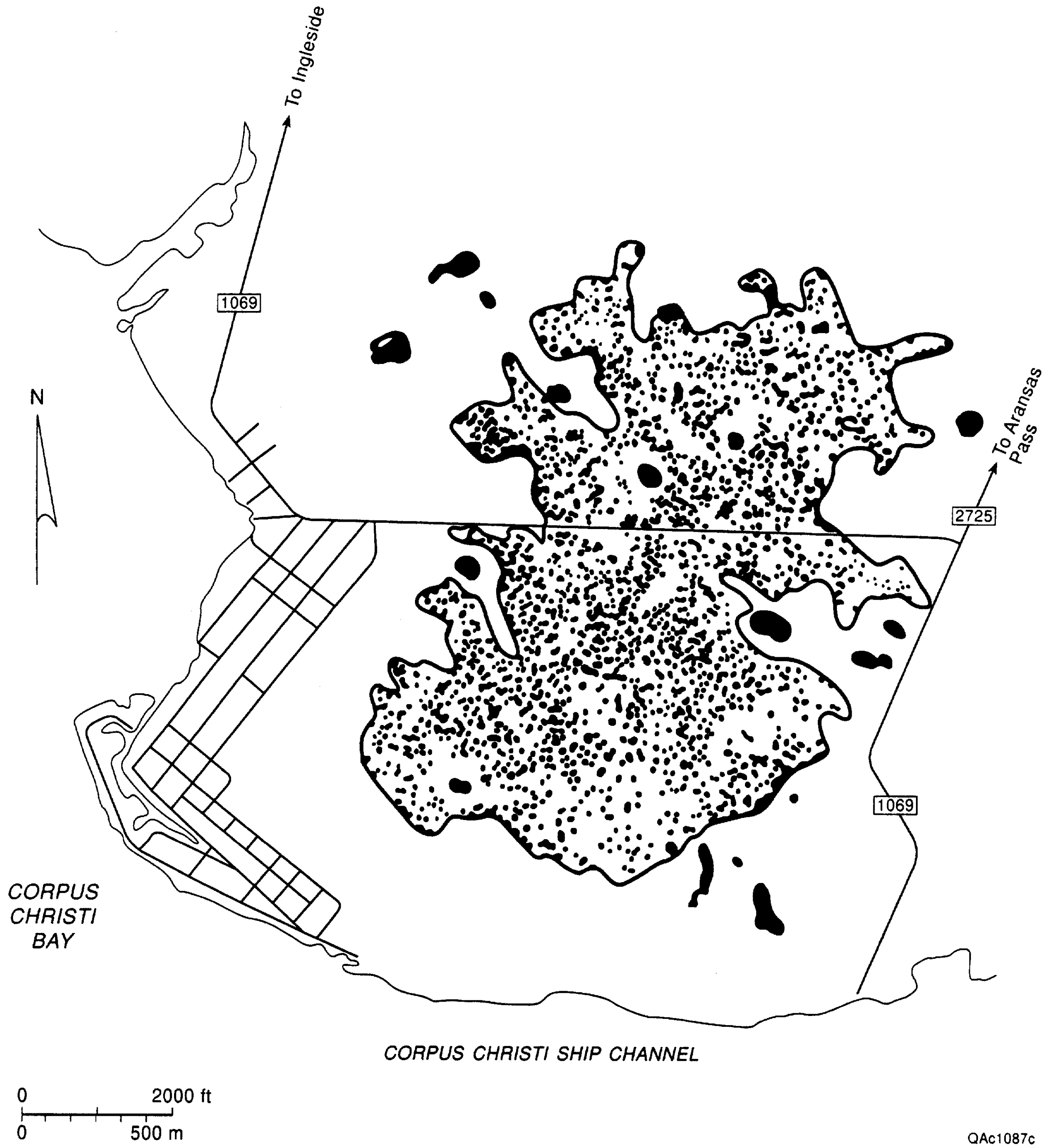


Figure 30. Example of the complexity of areas mapped as wetland/uplands undifferentiated (PEM/U and POW/U) on Live Oak Ridge. Within the irregularly shaped area defined by the dark line, the dark circles represent ponds and marshes that are surrounded by upland live oak mottes (white areas). On wetland maps these areas are defined only by the outer boundary. From White et al. (1983).

A straight comparison of 1950's and 1979 palustrine emergent wetland (PEM) digital data shows a loss of about 1,250 ha. However, a large part of the PEM resource (1,233 ha) in the 1950's was mapped as palustrine emergent wetlands and uplands undifferentiated (PEM/U), which is a complex mixture of numerous, small isolated wetland depressions surrounded by uplands (Fig. 30). Because of much wetter conditions in 1979, many depressions were filled with water and were mapped as palustrine open water and uplands undifferentiated (POW/U) (Table 28). Collins (1987), in a study of the pothole wetlands on the barrier-strandplain including Live Oak Peninsula, reported that average rainfall in 1956 was almost 44 cm less than in 1979. By 1992, most ponds had reverted back to marshes. Thus, depressions may be characterized by marsh or open water depending on local climatic conditions and water levels when aerial photographs were taken. Accordingly, the unadjusted loss of almost 1,200 ha of PEM/U from the 1950's to 1979 (Table 28), was not a permanent loss but rather a temporary conversion from marsh to open water. The 1979 increase in POW/U of 1,600 ha more than offset the loss. If we consider POW/U mapped in 1979 as equivalent to PEM/U mapped in the 1950's, and if we further assume that the wetland portion of these units is approximately 35 percent of the whole, then the net change in total PEM and PEM/U from the 1950's to 1979 is a gain of 86 ha (or about 150 ha including POW and PFL).

If only change in the PEM class on Live Oak Peninsula is considered, there is a resulting net loss of marsh of 57 ha. Of the gross loss of PEM, 52 ha was converted to open water by excavation for development. Because of drier conditions in 1956 compared to 1979, Collins (1987) concluded that NWI data underestimated the number and size of palustrine wetlands in the 1950's relative to 1979. Nevertheless, he noted the data showed a considerable decline in number and area of pothole wetlands on Live Oak Peninsula. A difference in this study and the one by Collins, is that we used digital data in a GIS to focus only on Live Oak Peninsula and exclude areas south of Port Bay in the Aransas Pass quadrangle that were included in Collin’s analysis. We found that an area of more than 400 ha of high marsh south of Port Bay mapped in the 1950's and 1992 should have also been mapped in 1979 (see later section on Port Bay area). This omission in the 1979 NWI data exaggerated the loss in palustrine wetlands reported by Collins whose study was based on a comparison of the 1979 and 1956 data. Still, we agree that the 1950's data probably underestimated pothole wetlands on Live Oak Peninsula.

1979-1992. There was an apparent net loss in estuarine marsh (E2EM + E2EM/FL) of about 270 ha from 1979 to 1992 on Live Oak Peninsula (Table 29). There were losses and gains in the E2EM class, although most of the estuarine marsh loss occurred in the E2EM/FL class, which was not mapped in 1992. In one area west of Rockport near Port Bay, approximately 100 ha of land mapped as E2EM in 1979, was mapped as upland in 1992. This is a complex area consisting primarily of upland “pimple” mounds and inter-mound depressions supporting a vegetation community dominated by *Spartina spartinae* .

Palustrine wetlands declined in area between 1979 and 1992 on Live Oak Peninsula. For reasons discussed previously, areas of palustrine open water (POW, POW/U and PUB) were combined with areas of emergent vegetation (PEM, PEM/U, and U/PEM) because of the unique topography of this Pleistocene sand ridge characterized by hundreds of potholes that have fluctuating seasonal and annual water regimes dependent on precipitation. In addition, the complexed areas (as explained previously) were assumed to contain approximately 35 percent wetlands. With these considerations, net adjusted loss in palustrine wetlands was about 155 ha from 1979 to 1992. Overall, net change in emergent wetlands was a decline of more than 400 ha (Table 29), which is a reversal in the net gain from 1950's to 1979 (Table 28).

Estuarine Intertidal Flats. *1950's-1979*. Tidal flats declined by 870 ha from the 1950's to 1979 (Table 28). Losses in flats occurred on the eastern margin of the Live Oak Ridge landward of the GIWW and Redfish Bay.

Table 29. Net change in marshes and intertidal flats from 1979-1992, Live Oak Ridge/Peninsula.

Habitat	1979 (ha)	1992 (ha)	1979 Adjusted	1992 Adjusted	Adjusted Net Change
E2EM	472	558	472	558	86
E2EM/FL	356	0	356	0	-356
PEM	938	1405	938	1405	467
PEM/U	37	379	13	133	120
POW/U	1606	0	562	0	-562
POW, PFL	306	126	306	126	-180
Total EM + POW	**3715**	**2468**	**2647**	**2222**	**-425**
E2FL	214	272	214	272	58

1979-1992. There was a small net gain of less than 60 ha in estuarine flats between 1979 and 1992 (Table 29). Changes occurred primarily on the margins of Aransas and Redfish Bays.

Probable Causes of Changes. *1950's-1979-1992*. The trend or change in estuarine marsh (E2EM, E2EM/FL) and palustrine marsh (PEM) on Live Oak Peninsula and Ridge from the 1950's to 1979 was one of net gain of more than 500 ha. Gains of estuarine marsh occurred along the margins of the ridge and peninsula landward of the GIWW where emergent vegetation encroached on to intertidal flats, and into areas previously mapped as uplands. There were increases in estuarine marsh on the western margins of the peninsula near Port Bay, partly due to interpretation, but also possibly due to higher water levels in 1979. Apparent losses in estuarine marsh from 1979 to 1992 were due to drier conditions in 1992 compared to 1979, and to delineation of irregularly flooded areas consisting mostly of *S. spartinae* as E2EM in 1979 and upland in 1992. In addition, some areas on the west side of Live Oak Peninsula that were classified as E2EM in 1979 were classified as PEM in 1992. A few areas of E2EM/FL on the eastern side of the peninsula were developed and converted to uplands, but some apparent losses in E2EM/FL from 1979 to 1992 were interpretational, including changes in class and a more detailed subdivision of E2EM and E2FL in 1992. From the 1950's to 1992, there was a net loss in estuarine intertidal flats and a small net gain in palustrine wetlands (Table 30).

Table 30. Net change in marshes and intertidal flats from the 1950's-1992, Live Oak Ridge/Peninsula.

Habitat	1950's (ha)	1992 (ha)	1950's Adjusted	1992 Adjusted	Adjusted Net Change
E2EM	207	558	207	558	351
E2EM/FL	228	0	228	0	-228
PEM	995	1405	995	1405	410
PEM/U	1233	379	432	133	-299
POW/U	0	0	0	0	0
POW, PFL	243	126	243	126	-117
Total EM + POW	**2906**	**2468**	**2105**	**2222**	**117**
E2FL	1084	272	1084	272	-812

Wetter conditions in 1979 and its effect on palustine emergent wetlands is discussed previously. Although the overall trend from the 1950's to 1979 was a net gain, it should be noted that local losses of estuarine and palustrine emergent marsh occurred from land development on Live Oak Peninsula. For example, losses of about 50 ha of E2EM and E2EM/FL occurred east of Rockport, from development of Key Allegro (Fig. 31). An example of losses in palustrine marsh occurred from development of a trailer park west of Rockport, which displaced approximately 7 ha of marsh. Marsh habitat was excavated to form ponds and filled to create uplands (Fig. 32). More extensive losses in palustine emergent wetlands occurred from 1979 to 1992 and can be attributed in part to filling, draining, excavating, and quarrying potholes for residential, commercial, and recreational development, and for sand (Figs. 31-33).

Of the gross losses in estuarine intertidal flats from 1950's to 1979, about 40 percent was lost to uplands (more than half of which was to upland development), about 39 percent to permanent submergence, and 28 percent to the spread of emergent vegetation and conversion to E2EM and E2EM/FL habitats. Small gains in estuarine flats from 1979 to 1992 were not significant, and are attributed in part to the subdivision of 1979 E2EM/FL areas into marshes and flats in 1992.

Blackjack Peninsula

Marshes. *1950's-1979.* On Blackjack Peninsula, losses and gains in estuarine marsh (E2EM and E2EM/FL) resulted in a net gain of about 50 ha between 1950's to 1979 (Table 31). Most of the estuarine marsh is characterized as E2EM/FL on 1950's maps and E2EM on 1979 maps. This change reflects, in part, a spread of emergent vegetation over intertidal flats, principally along the eastern margins of Blackjack Peninsula (Figs. 20 and 21). Palustrine emergent wetlands (PEM and PEM/U) also underwent a net gain from the 1950's to 1979. Assuming that 35 percent of the PEM/U class (mapped only in 1979 in this area) consisted of emergent vegetation, the total net gain in PEM was about 1,500 ha (Table 31). Much of this gain is (1) interpretational, including the use of the PEM/U class in 1979, and (2) the result of wetter conditions in 1979 compared to the mid 1950's, which also affected interpretation.

1979-1992. There was a small gain in estuarine marsh of about 5 ha and a larger gain in palustrine marsh of almost 1,000 ha on Blackjack Peninsula from 1979 to 1992. Most of the gross gain in E2EM occurred in areas mapped in 1979 as E2EM/FL and E2FL, indicating some expansion of emergent vegetation over flats. Analysis of aerial photographs supported this expansion especially on the southern tip and eastern side of the peninsula. There were extensive gross losses and gains in the palustine emergent wetlands. As noted in the previous paragraph, PEM/U and U/PEM areas were assumed to consist of 35 percent PEM and were adjusted accordingly (Table 32). Extensive net gains in the PEM class occurred thoughout the peninsula but were more extensive on the eastern side inland from estuarine marshes fringing the bay-estuarine-lagoon system. Extensive PEM1A areas were mapped on 1992 photographs in areas previously (1979) mapped as uplands.

Estuarine Intertidal Flats. *1950's-1992*. There was a net gain of 152 ha in estuarine intertidal flat on Blackjack Peninsula from the 1950's to 1979. Gains were primarily in areas previously mapped as E2EM/FL.

1979-1992. There was little change in estuarine flats from 1970 to 1992. Although there were gross losses and gains of more the 100 ha, the net change was a loss of about 40 ha.

(a)

(b)

Figure 31. Examples of changes in intertidal flats, and estuarine and palustrine marshes on Live Oak Peninsula. Photographs were taken in (a) 1952 and (b) 1994.

QAc577c

Figure 32. Example of loss of palustrine marsh from trailer park development west of Rockport.

(a)

(b)

QAc574c

Figure 33. Quarrying of pot hole wetlands for sand resources on Live Oak Peninsula converts (a) palustrine marshes into (b) ponds or palustrine open water. Photographs taken in 1997.

Table 31. Net change in marshes and intertidal flats from the 1950's-1979, Blackjack Peninsula.

Habitat	1950's (ha)	1979 (ha)	1979 Adjusted	Adjusted Net Change
E2EM	76	1708	1708	1632
E2EM/FL	2344	764	764	-1580
PEM	727	1801	1801	1074
PEM/U	0	1205	422	422
Total EM	**3147**	**5478**	**4695**	**1548**
E2FL	152	306	304	152

Table 32. Net change in marshes and intertidal flats from 1979-1992, Blackjack Peninsula.

Habitat	1979 (ha)	1992 (ha)	1979 Adjusted	1992 Adjusted	Adjusted Net Change
E2EM	1708	2478	1708	2478	770
E2EM/FL	764	0	764	0	-764
PEM	1801	3061	1801	3061	1260
PEM/U, U/PEM	1205	489	422	171	-251
POW	25	2	25	2	-23
Total EM, OW	**5503**	**6030**	**4720**	**5712**	**992**
E2FL	306	263	306	263	-43

Probable Causes of Changes. *1950's-1979-1992*. Much of the change in marsh habitat on Blackjack Peninsula can be attributed to interpretation and classification differences of 1950's and 1979 aerial photographs. Overall, there was a marsh habitat gain of more than 1,500 ha, most of which was in the PEM and PEM/U classes. Considering the E2EM and E2EM/FL classes together, losses in E2EM/FL are virtually offset by gains in E2EM from 1950's to 1979, from 1979 to 1992, and from 1950's to 1992 (Tables 31-33). This is, in part, reflective of a real change toward a spread of emergent vegetation across intertidal flats. The cause, as on the barrier islands, is thought to be due to a rise in relative sea level (Fig. 24).

Table 33. Net change in marshes and intertidal flats from the 1950's-1992, Blackjack Peninsula.

Habitat	1950's (ha)	1992 (ha)	1992 Adjusted	Net Adjusted Change
E2EM	76	2478	2478	2402
E2EM/FL	2344	0	0	-2344
PEM	727	3061	3061	2334
PEM/U	0	489	171	171
Total EM	**3147**	**6028**	**5710**	**2563**
E2FL	152	263	263	111

Large gains in the palustrine classes (Tables 32 and 33) is largely interpretational due to the topographic complexity of this peninsula, and the use of the PEM/U class in 1979 and 1992 but not in the 1950's. The peninsula is part of the Pleistocene barrier-strandplain system composed almost entirely of fine grained, well-sorted sand. It has a complex geomorphology characterized by relict beach ridges and inter-ridge swales, as well as relict depressions and dunes caused by wind deflation and migrating sand. These features produce a complex topography of wet depressions in which marshes and ponds have formed, surrounded by upland, stabilized dunes and ridges covered with live oak trees. Most of this land is within the Aransas National Wildlife Refuge, and although there are some artificial ditches and levees that may have produced local changes, most changes are thought to be due to interpretation and to wetter conditions in 1979 compared to the mid 1950's. Wetter conditions and color infrared photographs in 1979 aided photointerpreters in delineating depressions that intermittently contain emergent vegetation. The gain in PEM between 1979 and 1992, although possibly in part real, is also due to photointerpretation and more liberal classification of topographically high marshes (PEM1A) in 1992.

Lamar Peninsula

Marshes. *1950's-1979*. On Lamar Peninsula, gains and losses in estuarine emergent wetlands resulted in a net gain of 756 ha. Much of the gain was offset by a loss in palustrine emergent wetlands of 506 ha (Table 34). Changes occurred primarily in the northern half of the peninsula in a topographically low area between the tip of Copano Bay and St. Charles Bay.

1979-1992. Between 1979 and 1992, estuarine marshes had an apparent loss of several hundred hectares, although this loss was partly offset by gains in palustrine marshes (Table 35). Much of the loss occurred in the northern part of the peninsula where gains were noted between 1950's and 1979.

Table 34. Net change in marshes and intertidal flats from the 1950's-1979, Lamar Peninsula.

Habitat	1950's (ha)	1979 (ha)	Net Change
E2EM	263	1214	951
E2EM/FL	346	151	-195
PEM	598	92	-506
Total EM	**1207**	**1457**	**250**
E2FL	285	150	-135

Table 35. Net change in marshes and intertidal flats from 1979-1992, Lamar Peninsula.

Habitat	1979 (ha)	1992 (ha)	Net Change
E2EM	1214	776	-438
E2EM/FL	151	0	-151
PEM	92	438	346
POW	40	10	-30
Total EM, OW	**1497**	**1224**	**-273**
E2FL, E2US	150	45	-105

Estuarine Intertidal Flat. *1950's-1979*. The general trend in tidal flats on Lamar Peninsula was one of net loss (-135 ha). Losses occurred primarily on the western side of the peninsula along the margins of Copano Bay.

1979-1992. The trend toward a loss in tidal flats established earlier, continued from 1979 to 1992 (Table 35). Net loss was slightly more than 100 ha.

Probable Causes of Changes. *1950's-1979-1992*. Most of the estuarine intertidal flat on Lamar Peninsula was converted to water (55 percent), marsh (28 percent) or uplands (15 percent) from 1950's to 1979. One area was the site of a housing development that altered the flats, converting some areas to uplands for houses and roads, and some to channels for boat access (Fig. 34). About 95 percent of the loss in estuarine intertidal flat from 1979 to 1992 was due to its replacement by estuarine marsh. Conversion of flats to open water, seagrass beds, and marshes is attributed primarily to a rise in relative sea level (Fig. 24), a common scenario throughout the study area.

Much of the estuarine and palustrine marsh change, resulting in a net gain of 250 ha from the 1950's to 1979, was due to photointerpretation. A large area on the northern half of the peninsula was mapped as PEM on the 1950's maps and E2EM on 1979 maps. This is an interpretative difference, because most of this area is characterized by *S. spartinae*. There is little evidence that vegetation composition and tidal communication in this area was different in the 1950's. Drainage ditches that cross the area were completed before the 1950's (Fig. 35a). Of the gross loss in PEM, about 60 percent was mapped as E2EM on 1979 maps, and about 35 percent was mapped as uplands. Some conversion to uplands was the result of residential/commercial development near State Highway 35. The net gain in marsh, however, is supported by actual expansion of emergent vegetation across estuarine flats on both the Copano Bay and St. Charles Bay sides of Lamar Peninsula.

Losses in estuarine marsh between 1979 and 1992 are in large part interpretational. Much of the area dominated by *S. spartinae* that extends between St. Charles and Copano Bays at the north end of Larmar Peninsula (mentioned in the preceding paragraph) was delineated as uplands and locally palustrine emergent wetlands in 1992. Recent field surveys revealed that the area is still dominated by *S. spartinae*, although shrubs such as *Iva frutescens* are more abundant than in the past (Fig. 35a). This area is very distinct on 1992 photographs, but the more abundant shrubs may have influenced the interpreters to map the area as uplands in 1992. The net change from the 1950's to 1992 in total emergent wetlands was a gain of less than 10 ha (Table 36).

Table 36. Net change in marshes and intertidal flats from the 1950's-1992, Lamar Peninsula.

Habitat	1956 (ha)	1992 (ha)	Net Change
E2EM	263	776	513
E2EM/FL	346	0	-346
PEM	598	438	-160
Total EM	**1207**	**1214**	**7**
E2FL	285	45	-240

(a)

(b)

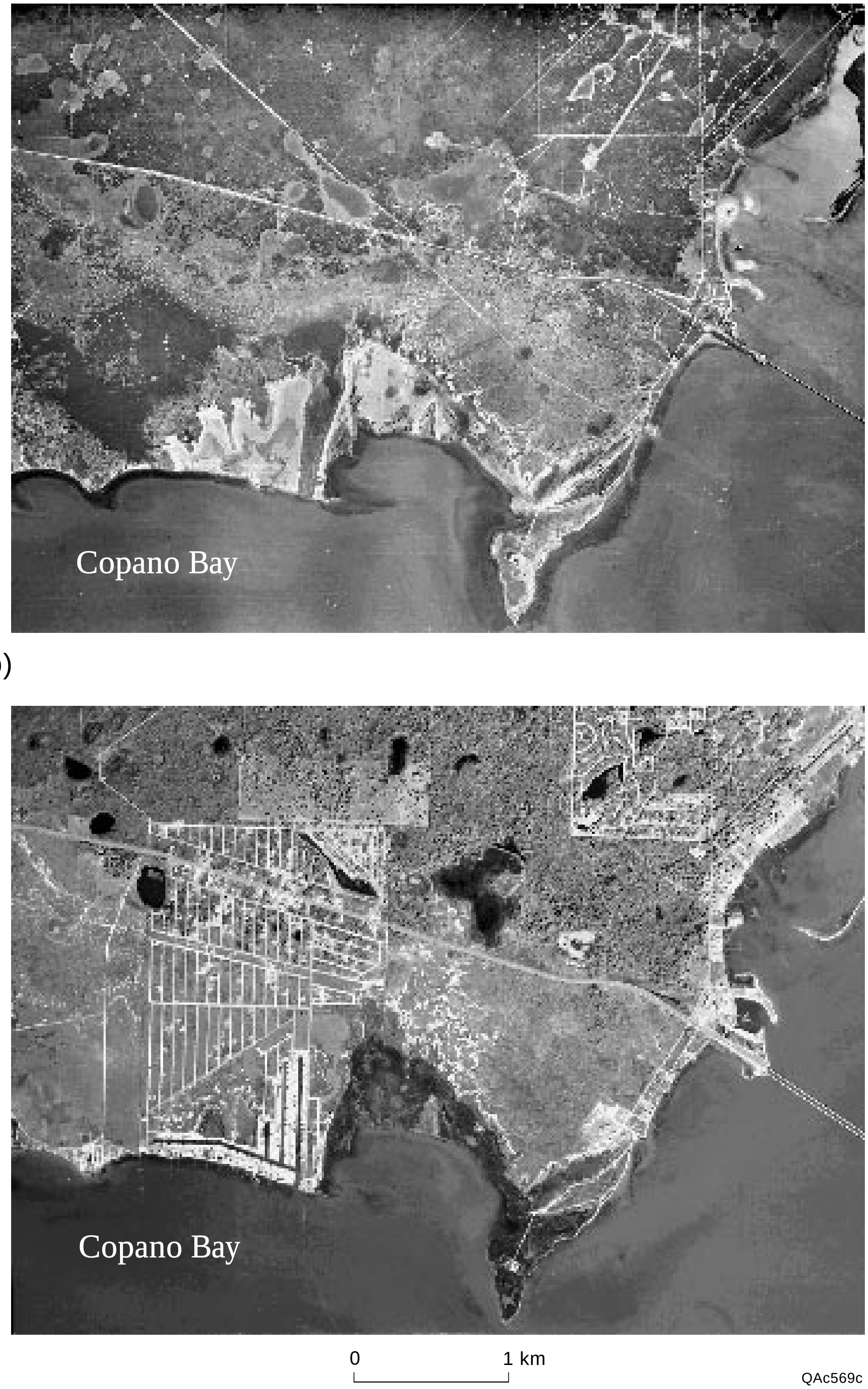


Figure 34. Changes in estuarine intertidal flats and marshes from community development on Lamar Peninsula along the margin of Copano Bay as shown on photographs taken in (a) 1952 and (b) 1979.

(a)

(b)

QAc573c

Figure 35. Examples of drainage ditches that cross *Spartina spartinae* marshes located (a) between State Highway 136 and St. Charles Bay and (b) south of Port Bay. The marsh at (b) was mapped in the 1950's and 1992 but not in 1979.

Encinal Peninsula

Marshes. *1950's-1979.* From the 1950's to 1979, there was a net loss of 80 ha of PEM and a net gain of 426 ha of L1OW (Table 37). These changes were due to construction of the Central Power and Lighting Barney M. Davis cooling reservoir (472 ha).

Table 37. Net change in marshes, intertidal flats, and lacustrine habitats from the 1950's-1979, Encinal Peninsula.

Habitat	1950's (ha)	1979 (ha)	1950's Adjusted	1979 Adjusted	Adjusted Net Change
E2EM	5	1	5	0	-5
PEM	598	562	548	468	-80
Total EM	**603**	**563**	**553**	**468**	**-85**
E2FL	15	11	15	16	1
L1OW/L2	0	451	9	436	426

1979 -1992. Lacustrine open water (L1OW) increased in area due to construction of a hatchery on the King Ranch (52 ha) (Table 38). PEM was greatly overdelineated in 1979; the 1992 delineation of PEM was more conservative despite overdelineation of the PEM1A category. The adjusted value for PEM showed an increase because of reclassification of uplands as PEM1A.

1950's-1992. Table 39 shows an adjusted net increase of 487 ha of L1OW, which replaced 400 ha of uplands and 84 ha of PEM. There was an adjusted net increase of about 90 ha of PEM.

Table 38. Net change in marshes, intertidal flats, and lacustrine habitats from 1979-1992, Encinal Peninsula.

Habitat	1979 (ha)	1992 (ha)	1979 Adjusted	1992 Adjusted	Adjusted Net Change
E2EM	1	1	0	0	0
PEM	562	638	468	638	170
Total EM	**563**	**639**	**468**	**638**	**170**
E2FL	11	18	16	18	1
L1OW/L2	451	496	436	496	61

Table 39. Net change in marshes, intertidal flats, and lacustrine habitats from 1950's-1992, Encinal Peninsula.

Habitat	1950's (ha)	1992 (ha)	1950's Adjusted	1992 Adjusted	Adjusted Net Change
E2EM	5	1	5	0	-5
PEM	598	638	548	638	90
Total EM	**603**	**639**	**553**	**638**	**85**
E2FL	15	18	15	18	3
L1OW/L2	0	496	9	496	487

Probable Causes of Changes. *1950's-1992.* The loss of uplands and conversion of PEM to L1OW was real. On the other hand, the dynamics of PEM-U changes are less certain. In 1992, the fact that 129 ha of PEM were reclassified as uplands and 318 ha of uplands reclassified as PEM reflects the difficulty of distinguishing PEM1A from upland grasslands or upland/wetland transitional areas.

Fluvial-Deltaic System

As in other natural systems, there were losses and gains in marshes and tidal flats in the three fluvial-deltaic systems analyzed: Nueces, Aransas-Chiltipin, and Mission Rivers (Figs. 3 and 22). The fluvial-deltaic systems lie within valleys entrenched during the most recent Pleistocene sea-level low stand (Brown et al. 1976). Riparian woodlands, which were analyzed in the fluvial-deltaic systems, consist of forested and scrub-shrub wetlands as well as other forested areas that are within entrenched river valleys.

Nueces River

Estuarine Intertidal Marshes and Flats. *1950's-1992.* In the Nueces River valley (Tables 40-42), there was a small net loss of E2EM (34 ha) to E1OW (30 ha) and PEM (4 ha) (Table 42). E2EM/FL decreased by about 300 ha with conversions to E1OW (150 ha), uplands (130 ha), and PEM (17 ha). PEM gained 291 ha, mostly from uplands (249 ha). E2FL showed a net loss of 18 ha due to conversion to E1OW.

Riparian Woodlands. *1950's-1992.* PFO showed a net gain of 35 ha mostly from uplands (32 ha). PSS showed a 23 ha net gain from uplands. These changes were likely due to differences in photointerpretation and classification. Since the 1950's, there has been relatively little net change in the amount of forested riparian habitat.

Table 40. Net change in marshes, intertidal flats, and other habitats from the 1950's to 1979, Nueces River valley.

Habitat	1950's (ha)	1979 (ha)	1950's Adjusted	1979 Adjusted	Adjusted Net Change
E2EM	1280	3461	2581	2677	96
E2EM/FL	2967	4	299	103	-196
PEM	2584	1050	3798	3741	-56
Total EM	**6831**	**4516**	**6677**	**6522**	**-156**
E2FL.	439	895	647	677	30
PSS	274	27	153	74	-78
PFO	599	156	617	569	-47
Riparian Woodlands	873	183	770	643	-125
L1OW/L2	6	58	5	46	41

Table 41. Net change in marshes, intertidal flats, and other habitats from 1979 to 1992, Nueces River valley.

Habitat	1979 (ha)	1992 (ha)	1979 Adjusted	1992 Adjusted	Adusted Net Change
E2EM	3461	2547	2677	2547	-130
E2EM/FL	4	0	103	0	-103
PEM	1050	4089	3741	4089	347
Total EM	**4516**	**6635**	**6522**	**6635**	**114**
E2FL	895	629	677	629	-48
PSS	27	176	74	176	101
PFO	156	652	569	652	83
Riparian Woodlands	183	828	643	828	184
L1OW/L2	58	121	46	121	75

Table 42. Net change in marshes, intertidal flats, and other habitats from the 1950's to 1992, Nueces River valley.

Habitat	1950's (ha)	1992 (ha)	1950's Adjusted	1992 Adjusted	Adusted Net Change
E2EM	1280	2547	2581	2547	-34
E2EM/FL	2967	0	299	0	-299
PEM	2584	4089	3798	4089	291
Total EM	**6831**	**6635**	**6677**	**6635**	**-42**
E2FL	439	629	647	629	-18
PSS	274	176	153	176	23
PFO	599	652	617	652	35
Riparian Woodlands	873	828	770	828	58
L1OW/L2	6	121	5	121	116

Probable Causes of Change. *1950's-1992.* Gains in PEM and L1OW were the result of dredging along the Viola Channel, and creation of spoil impoundments. These gains were at the expense of the E2EM/FL and upland categories. A salt-marsh creation project converted about 80 ha of E2EM to E1OW and E2FL (Nicolau and Adams, 1993, Nicolau 1995).

Aransas River-Chiltipin Creek

Marshes. *1950's-1979.* Direct analysis of GIS digital data of habitat distribution from the 1950's to 1979 shows a net gain of 227 ha of estuarine marsh (E2EM and E2EM/FL) and a loss of 547 ha of palustrine marsh (Table 43). Part of the apparent palustrine loss was due to an interpretative classification change from PEM to E2EM. Marshes as a whole had a net loss of 324 ha. Approximately 60 ha of loss could be verified from photographs, but most of the remaining apparent loss in PEM (265 ha) appears to be from inconsistences in photointerpretation and registration problems. Analysis of aerial photographs indicates an actual spread of estuarine emergent vegetation into areas of estuarine intertidal flats.

1979-1992. During this period, there was an apparent increase in marsh habitat, primarily palustrine emergent wetlands in which a net gain of 349 ha was recorded (Table 44). Estuarine emergent wetlands (E2EM and E2EM/FL) increased by about 90 ha. Of the gross gains in E2EM, about 50 percent occurred in areas mapped as E2EM/FL in 1979, and 40 percent in areas mapped as uplands. Of the gross gains in PEM, about 35 percent occurred in upland areas, 30 percent in lacustrine areas, and 30 percent in E2EM areas. Except for the lacustrine area, other changes are due primarily to interpretation.

Table 43. Net change in marshes, intertidal flats, and other habitats from the 1950's-1979, Aransas River-Chiltipin Creek fluvial-deltaic system.

Habitat	1950's (ha)	1979 (ha)	Net change
E2EM	242	1016	774
E2EM/FL	665	118	-547
PEM	917	366	-551
Total EM	**1824**	**1500**	**-324**
E2FL	432	546	114
PSS	20	48	28
PFO	0	34	34

Table 44. Net change in marshes, intertidal flats, and other habitats from 1979-1992, Aransas River and Chiltipin Creek fluvial-deltaic system.

Habitat	1979 (ha)	1992 (ha)	Net Change
E2EM	1016	1225	209
E2EM/FL	118	0	-118
PEM	366	715	349
Total EM	**1500**	**1940**	**440**
E2FL, E2US	546	368	-178
PSS	48	29	-19
PFO	34	8	-26
Riparian Woodlands	758	769	11
Lacustrine	178	51	-127

Estuarine Intertidal Flats. *1950's-1979*. There was a net loss of about 115 ha of estuarine intertidal flats in the Aransas River and associated fluvial deltaic area from the 1950's to 1979. About 75 percent of the gross losses in flats was due to replacement by subtidal habitats including open water and seagrass beds.

1979-1992. Estuarine flats continued to decline from 1979 to 1992. Approximately 75 percent of the gross loss in tidal flats was due to replacement by E2EM.

Riparian Woodlands. *1979-1992.* Riparian woodlands in the Aransas and Chiltipin fluvial-deltaic system increased slightly (11 ha) from 1979 to 1992 (Table 44). Apparent loss of PSS and PFO is due primarily to photointerpretation. Analysis of aerial photographs indicate that woodland areas, overall, had more gains than losses.

Probable Causes of Changes. *1950's-1979-1992*. From 1950's to 1979, gains and losses in marshes in fluvial-deltaic areas of Aransas River, Chiltipin Creek, and the drainage south of Chiltipin resulted in an apparent net loss of more than 300 ha of marsh habitat as a result of losses in PEM that exceeded gains in E2EM (Table 43). Changes were primarily due to photointerpretation and map registration problems. Overall, it appears that estuarine emergent vegetation had a limited expansion into flats. This is reflected in Table 43, which shows gains in E2EM and losses in E2EM/FL.

Losses in tidal flats were largely due to (1) conversion to subtidal areas, which accounted for 75 percent of the gross loss, and (2) replacement by estuarine intertidal marsh accounting for about 15 percent. There was an actual loss of about 60 ha of PEM north of the Aransas River as a result of inundation and formation of a lake (lacustrine system). This water feature is connected to the Aransas River and water levels dropped in 1992 allowing vegetation to become re-established. Almost 120 ha of the apparent 350 ha gain in PEM from 1979 to 1992 occurred in this area mapped as lacustrine in 1979. The net gain in E2EM and loss of E2FL from 1979 to 1992 and the 1950's to 1992 (Table 45) is believed in part related to rise in relative sea level.

Table 45. Net change in marshes, tidal flats, and other habitats from the 1950's-1992, Aransas River and Chiltipin Creek fluvial-deltaic system.

Habitat	1950's (ha)	1992 (ha)	Net Change
E2EM	242	1225	983
E2EM/FL	665	0	-665
PEM	917	715	-202
Total EM	**1824**	**1940**	**116**
E2FL	432	368	-64
PSS	20	29	9
PFO	0	8	8

Mission River

Marshes. *1950's-1979.* Aerial photographic analysis indicates few changes in this fluvial deltaic system except locally where emergent vegetation spread over wind-tidal flats. This change is reflected in part by expansion of E2EM and reduction in E2EM/FL (Table 46). Estuarine intertidal marshes were mapped farther up the river valley in 1979 than in the 1950's, indicating a conversion of PEM to E2EM in some areas. Analysis of changes before adjustments were made, indicates that marshes (E2EM, E2EM/FL, and PEM) decreased in area in the Mission River fluvial deltaic system between the 1950's and 1979. After adjustments for photointerpretation inconsistences, a net gain in emergent wetlands was realized. The apparent increase in flats, as shown in Table 46, is due to photointerpretation and is the result of a more concerted effort by interpreters to subdivide emergent vegetation and flats on the 1979 CIR aerial photographs. From the 1950's to 1979, a more realistic appraisal of the changes in flats would be to assume no change, and that E2EM/FL in the 1950's included areas that should have been mapped only as E2FL. To make adjustments, 278 ha (the difference between the 1950's and 1979 E2FL) was subtracted from the E2EM/FL resource in the 1950's and this amount was added to E2FL. This adjustment produced a net gain of 166 ha in emergent vegetation (E2EM, E2EM/FL, and PEM) (Table 46).

Table 46. Net change in marshes, intertidal flats, and other habitats from the 1950's-1979, Mission River.

Habitat	**1950's (ha)**	**1979 (ha)**	**1950's Adjusted**	**Adjusted net change**
E2EM	79	728	79	649
E2EM/FL	774	255	496	-241
PEM	594	352	594	-242
Total EM	**1447**	**1335**	**1169**	**166**
E2FL	22	300	300	0
PSS	196	31	196	-165
PFO	13	50	13	37

1979-1992. There was an apparent net gain of more than 200 ha in estuarine marshes (E2EM + E2EM/FL) in the Mission River fluvial-deltaic area from 1979 to 1992. A small net loss in palustrine emergent wetlands produced a total gain in emergent marshes of less than 200 ha (Table 47).

Estuarine Intertidal Flats. *1950's-1979*. Unadjusted data indicate that estuarine intertidal flats increased from the 1950's to 1979, but this is a reflection primarily of differences in aerial photointerpretation and inclusion of too many E2FL areas in E2EM/FL class in the 1950's. To make adjustments, we increased the area of E2FL for the 1950's so there was effectively no change from the 1950's to 1979.

1979-1992. Estuarine intertidal flats had a small net gain of less than 70 ha from 1979 to 1992. This was an apparent change due mostly to photointerpretation.

Table 47. Net change in marshes, intertidal flats, and other habitats from 1979-1992, Mission River.

Habitat	**1979 (ha)**	**1992 (ha)**	**Net change**
E2EM	728	1224	496
E2EM/FL	255	0	-255
PEM	352	305	-47
Total EM	**1335**	**1529**	**194**
E2FL	300	367	67
PSS	31	0	-31
PFO	50	2	-48
Riparian Woodlands	214	226	12

Riparian Woodlands. *1979-1992.* Riparian woodlands in the entrenched Mission River fluvial-deltaic area increased in area by about 12 ha (Table 47). Apparent loss in PSS and PFO is due to photointerpretation and inclusion of woodlands in the palustrine system in 1979 and the 1950's, and in the upland system in 1992. Much loss in the 1950's PSS was due to mapping of a mixed class, PSS/EM, that was classified only as PEM in 1979 and 1992. The area in question could have been mapped as PEM in the 1950's as well. Woodlands changed very little overall, with gains exceeding losses.

Probable Causes of Changes. *1950-1979-1992.* Changes were not extensive in the Mission River delta and were more reflective of photointerpretation differences on the 1950's and 1979 and 1992 aerial photographs. However, the increase in E2EM and decrease in E2EM/FL (Table 48) indicates an actual expansion of emergent vegetation into areas of intertidal flats. This was verified on aerial photographs. Increase in emergent vegetation may be due in part to sea-level rise contributing to more frequent inundation of flats and subsequent expansion of emergent vegetation.

Table 48. Net change in marshes, intertidal flats, and other habitats from the 1950's-1992, Mission River.

Habitat	1950's (ha)	1992 (ha)	1956 Adjusted	Adjusted Net Change
E2EM	79	1224	79	1145
E2EM/FL	774	0	496	-496
PEM	594	305	594	-289
Total EM	**1447**	**1529**	**1169**	**360**
E2FL	22	367	300	67
PSS	196	0	196	-196
PFO	13	2	13	-11

Selected Bays and Associated Topographically Low Mainland Areas

This system encompasses selected bays and associated adjacent lowlands. Included are Corpus Christi Bay-Upper Laguna Madre-Oso Bay, Redfish Bay, Port Bay, and Laguna Larga (Fig. 22). In Port Bay and Laguna Larga, wetland trends in the higher areas are among the most complex to decifer because of variable moisture levels and gently sloping landscapes characterized by topographically high marsh and transitional areas. Vegetation, in many areas is predominately *S. spartinae*, and delineation on aerial photographs was inconsistent from year to year.

Corpus Christi Bay – Upper Laguna Madre – Oso Bay

Marshes. *1950's –1992.* Tables 49-51 present habitat changes. This analysis was complicated by differential use of the E2EM/FL mixed category. This category was not used in 1992. There was an adjusted net gain of 358 ha of E2EM, coming mostly from E2FL (262 ha) and uplands (81 ha). About 285 ha of E2EM/FL was lost to E1OW (98 ha), uplands (107 ha), and L1OW (65 ha), independent of reclassification of the E2EM/FL category. There was a 68 ha gain of PEM coming mostly from uplands (28 ha) and E2FL (27 ha).

Table 49. Net change in marshes, intertidal flats, and other habitats from the 1950's-1979, Corpus Christi Bay–Upper Laguna Madre.

Habitat	1950's (ha)	1979 (ha)	1950's adjusted	1979 Adjusted	Adusted net Change
E2EM	271	461	418	537	120
E2EM/FL	636	232	285	60	-225
PEM	35	54	40	32	-7
Total EM	**943**	**747**	**742**	**629**	**-113**
E2FL	3151	1396	3058	1549	-1509

Table 50. Net change in marshes, intertidal flats, and other habitats from 1979-1992, Corpus Christi Bay–Upper Laguna Madre.

Habitat	1979 (ha)	1992 (ha)	1979 Adjusted	1992 Adjusted	Adusted net Change
E2EM	461	776	537	776	239
E2EM/FL	232	0	60	0	-60
PEM	54	107	32	107	75
Total EM	**747**	**883**	**629**	**883**	**254**
E2FL	1396	957	1549	957	-592

Table 51. Net change in marshes, intertidal flats, and other habitats from the 1950's-1992, Corpus Christi Bay–Upper Laguna Madre.

Habitat	1950's (ha)	1992 (ha)	1950's Adjusted	1992 Adjusted	Adusted net Change
E2EM	271	776	418	776	358
E2EM/FL	636	0	285	0	-285
PEM	35	107	40	107	68
Total EM	**943**	**883**	**742**	**883**	**141**
E2FL	3151	957	3058	957	-2101

Estuarine Intertidal Flats. *1950's-1992.* Table 51 shows an adjusted net loss of 2,100 ha of E2FL to E1OW (926 ha), E2EM (262 ha), L1OW (214 ha), uplands (563 ha), and POW (110 ha).

Probable Causes of Changes. *1950's-1992.* Many spoil containment areas were developed prior to 1979, and this was the main reason for losses of E2FL and E2EM/FL and gains in uplands, L1OW, and PEM. At the White's Point Oil Field, 135 ha of E2FL were converted to E1OW (63 ha) and E2EM (72 ha). Dredge and fill along the ship channel created upland, L1OW, and POW areas mostly at the expense of E2FL habitat.

Oso Bay Subunit. *1950's-1992.* In Oso Bay, there was a loss of E2FL (272 ha) and a gain of E2EM (117 ha) (Table 52), much of which occurred at a sewage plant outfall near Suter Park (Fig. 36). The input of fresh water and nutrients accounted for this expansion of E2EM.

Table 52. Net change in marshes, intertidal flats, and other habitats from the 1950's-1992, Oso Bay. Numbers presented are included in preceding Tables 49, 50, and 51.

Habitat	1950's (ha)	1992 (ha)	1950's Adjusted	1992 Adjusted	Adjusted Net Change
E2EM	33	261	144	261	117
E2EMFL	73	0	18	0	-18
PEM	17	34	23	34	11
Total EM	**123**	**295**	**184**	**295**	**111**
E2FL	773	444	716	444	-272

Redfish Bay

Marshes. *1950's-1979*. The Redfish Bay area consists almost entirely of estuarine habitats (Table 53). From the 1950's to 1979, there was an expansion of estuarine intertidal marsh (E2EM) of about 225 ha and a small decrease in estuarine intertidal marsh and flat, undifferentiated (E2EM/FL) (Table 53). The total change in emergent vegetation was a net gain of almost 200 ha, and including E2SS exceeded 200 ha.

Table 53. Net change in marshes and intertidal flats from the 1950's-1979, Redfish Bay.

Habitat	1950's (ha)	1979 (ha)	Net Change
E2EM	54	278	224
E2EM/FL	176	148	-28
E2SS	0	15	15
PEM	0	2	2
Total EM, SS	**230**	**443**	**213**
E2FL	708	111	-597

1979-1992. The trend toward a net increase in emergent vegetation that was begun in the preceding period in Redfish Bay continued from 1979 to 1992, although at a slower rate. There was a net gain of 7 ha of marsh and scrub-shrub (Table 54). Gain in PEM was a photointerpretation class change in the interior and higher portions of an island formerly (1979) mapped as E2EM.

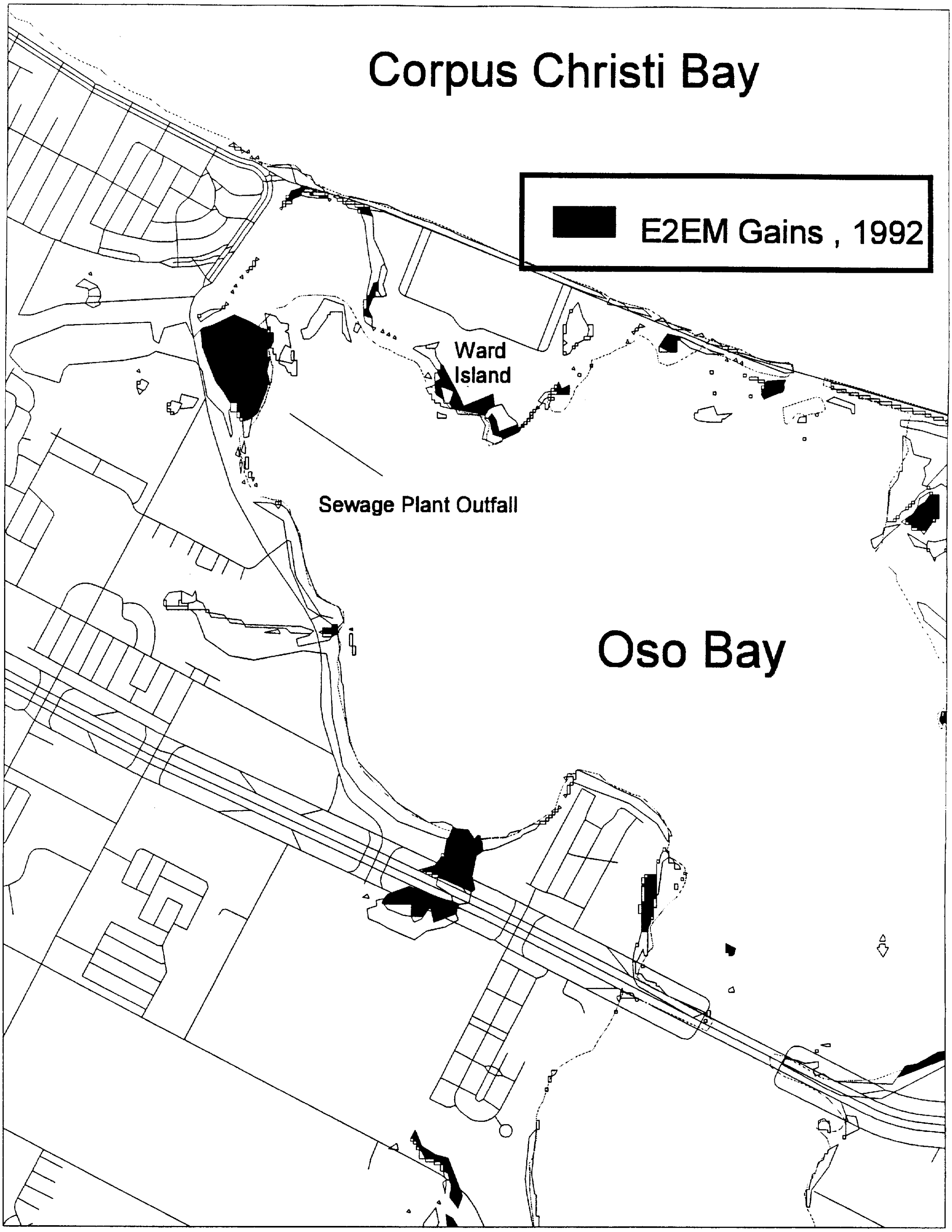


Figure 36. Increase of E2EM at sewage plant outfall on Oso Bay, 1950's-1992.

Table 54. Net change in marshes and intertidal flats from 1979-1992, Redfish Bay.

Habitat	1979 (ha)	1992 (ha)	Net Change
E2EM	278	414	136
E2EM/FL	148	0	-148
E2SS	15	6	-9
PEM	2	30	28
Total EM, SS	**443**	**450**	**7**
E2FL	111	87	-24

Estuarine Intertidal Flats. *1950's-1979*. The most extensive change in Redfish Bay was a net loss of almost 600 ha of intertidal flats. An area of approximately 700 ha in the 1950's was reduced to about 110 ha by 1979.

1979-1992. There was a continuing decline in estuarine intertidal flats of almost 25 ha from 1979 to 1992.

Probable Causes of Changes. *1950's-1979-1992*. Loss in tidal flat from the 1950's to 1979 occurred as approximately 65 percent was converted to subtidal environments and 30 percent to estuarine marsh. Much of this change was apparently a result of accelerated relative sea-level rise from the mid 1960's to 1975 (Fig. 24), which inundated some flats and increased the frequency of flooding of others. Some loss was a result of dredging of the GIWW in the late 1950's and disposing of dredged material on the flats. By 1979, however, inundation of the margins of the dredged material led to expansion of emergent vegetation in these areas; this expansion continued from 1979 to 1992. Expansion of marshes over flats is in part reflected by a conversion of E2EM/FL and E2FL to E2EM from 1950's and 1979 to 1992 (Tables 54-55). More than 50 percent of the gross gain in E2EM occurred in areas formerly mapped as E2EM/FL and E2FL.

Table 55. Net change in marshes and intertidal flats from the 1950's-1992, Redfish Bay.

Habitat	1950's (ha)	1992 (ha)	Net Change
E2EM	54	414	360
E2EM/FL	176	0	-176
E2SS	0	6	6
PEM	0	30	30
Total EM, SS	**230**	**450**	**220**
E2FL	708	87	-621

Port Bay Area

Marshes. *1950's-1979*. Major adjustments in marsh distribution had to be made in the Port Bay area. The major problem was caused by inconsistent delineations of a large *S. spartinae* marsh southwest of Port Bay that was mapped as PEM in the 1950's and 1992, but mapped as uplands in 1979. Analysis of aerial photographs indicates that this marsh, despite being crossed by drainage channels (Fig. 35b), did not change significantly from the 1950's to 1992 and should have been mapped as marsh on 1979 aerial photographs. This marsh encompassed about 470 ha on the 1950's map and 650 ha on the 1992 map. Accordingly, 560 ha was added to the total PEM habitat for 1979. In addition, a review of photographs taken in 1952 and 1958 of areas around Port Bay indicates more PEM could have been delineated on the 1950's photographs. In fact, about 75 percent of an apparent 530 ha PEM gain from 1950's to 1979 west of Port Bay can be eliminated because of this. These two adjustments reduced the net gain of PEM between the 1950's and 1979 (Table 56). In addition, a smaller error was made on the 1950's maps, in which an E2EM area of 45 ha was mistakenly mapped as E1AB. In the adjusted net changes shown in Table 56, this area was added to the 1950's E2EM habitat total. Considering these adjustments, there was a net loss of about 110 ha in the estuarine marsh (E2EM and E2EM/FL), and a larger net gain of 125 ha in palustrine marsh (PEM). The overall change in the marsh resource was a gain of 15 ha from the 1950's to 1979 (Table 56). Net gains occurred in areas both east and west of Port Bay.

Table 56. Net change in marshes and intertidal flats from the 1950's-1979, Port Bay area.

Habitat	1950's (ha)	1979 (ha)	1950 Adjusted	1979 Adjusted	Adjusted Net Change
E2EM	609	1389	654	1389	735
E2EM/FL	1140	295	1140	295	-845
PEM	978	940	1375	1500	125
Total EM	**2727**	**2624**	**3169**	**3184**	**15**
E2FL	437	320	437	320	-117

1979-1992. An apparent net loss of more than 300 ha in estuarine marsh occurred between 1979 and 1992, but the loss was more than offset by a larger net gain, > 400 ha, in palustrine marsh after adjustments were made for 1979 photointerpretation inconsistencies. Considering all areas of emergent vegetation, there was net gain of almost 140 ha (Table 57). Gains in PEM were in part due to reclassification of 1979 E2EM areas to PEM in 1992.

Table 57. Net change in marshes and intertidal flats from 1979-1992, Port Bay area.

Habitat	1979 (ha)	1992 (ha)	1979 Adjusted	Adjusted Net Change
E2EM	1389	1341	1389	-48
E2EM/FL	295	0	295	-295
PEM	940	1980	1500	480
Total EM	**2624**	**3321**	**3184**	**137**
E2FL	320	205	320	-115

Estuarine Intertidal Flats. *1950's-1979*. Intertidal flats in the Port Bay area decreased by more than 100 ha from the 1950's to 1979. About 80 percent of the gross losses in E2FL occurred from conversions to subtidal habitats, primarily, and to E2EM habitats, secondarily.

1979-1992. Estuarine intertidal flats continued their decline from 1979 to 1992, decreasing in net area by 115 ha. Most of the gross loss occurred as estuarine flats were replaced by estuarine marsh.

Probable Causes of Changes. *1950's-1979-1992.* As discussed previously, many changes in the Port Bay area, including some changes from E2EM to PEM, were due to differences in photointerpretation of the 1950's, 1979, and 1992 aerial photographs.

Eighty percent of the gross loss in E2EM/FL was to E2EM from 1979 to 1992. Although some change was due to photointerpretation, much was real indicating a spread of emergent vegetation into areas formerly characterized by estuarine flats. These changes were verified on aerial photographs, and were more apparent in intertidal flats near the head of Port Bay. From the 1950's to 1992, there were net gains in marshes and net losses in intertidal flats (Table 58).

Table 58. Net change in marshes and intertidal flats from the 1950's-1992, Port Bay area.

Habitat	1950's (ha)	1992 (ha)	1950's Adjusted	Adjusted Net Change
E2EM	609	1341	654	687
E2EM/FL	1140	0	1140	-1140
PEM	978	1980	1375	605
Total EM	**2727**	**3321**	**3169**	**152**
E2FL	437	205	437	-232

Many gains and losses in palustrine marshes are also due to interpretaton. Much of the PEM habitat is PEM1A, a topographically high, infrequently flooded marsh bordering on a classification of upland prairie. Therefore, interpreters had difficulty in defining the upland-wetland break consistently. Although there was a net gain in marsh habitat, losses did occur. One example is in the Bayside quadrangle east of Port Bay where between the 1950's and 1979, about 60 ha of estuarine marsh was flooded by a dam constructed across an entrenched drainage into Swan Lake on the edge of Copano Bay (Fresh Water Lake on Bayside quadrangle) (Fig. 37). The area behind the dam was mapped as estuarine in 1979 and lacustrine in 1992. From 1979 to 1992, there was an increase in marsh vegetation along the margins of the lake, offsetting some of the 1950's to 1979 marsh loss due to impoundment. Another example of marsh loss resulted from construction of tailing ponds east of Port Bay (Fig. 37); about 20 ha of estuarine marsh was displaced. Of the gross losses in estuarine marsh from 1979 to 1992, 50 percent was mapped as uplands, and 30 percent was changed to palustrine marsh (PEM). Much of the change to uplands was due to photointerpretation. Many areas, for example, west of Port Bay mapped as high palustrine marsh in 1979 (Fig. 21) could have been mapped as marsh in the 1950's and 1992. Almost all of the larger areas of high marsh have drainage ditches crossing them to reduce flooding and ponding of water (Fig. 38). Most ditches were dug before the 1950's, however, so they would have affected moisture levels for each period (1950's, 1979, and 1992). Variations in the extent to which high marshes were delineated is in part a reflection of the moisture levels at the time photographs were taken.

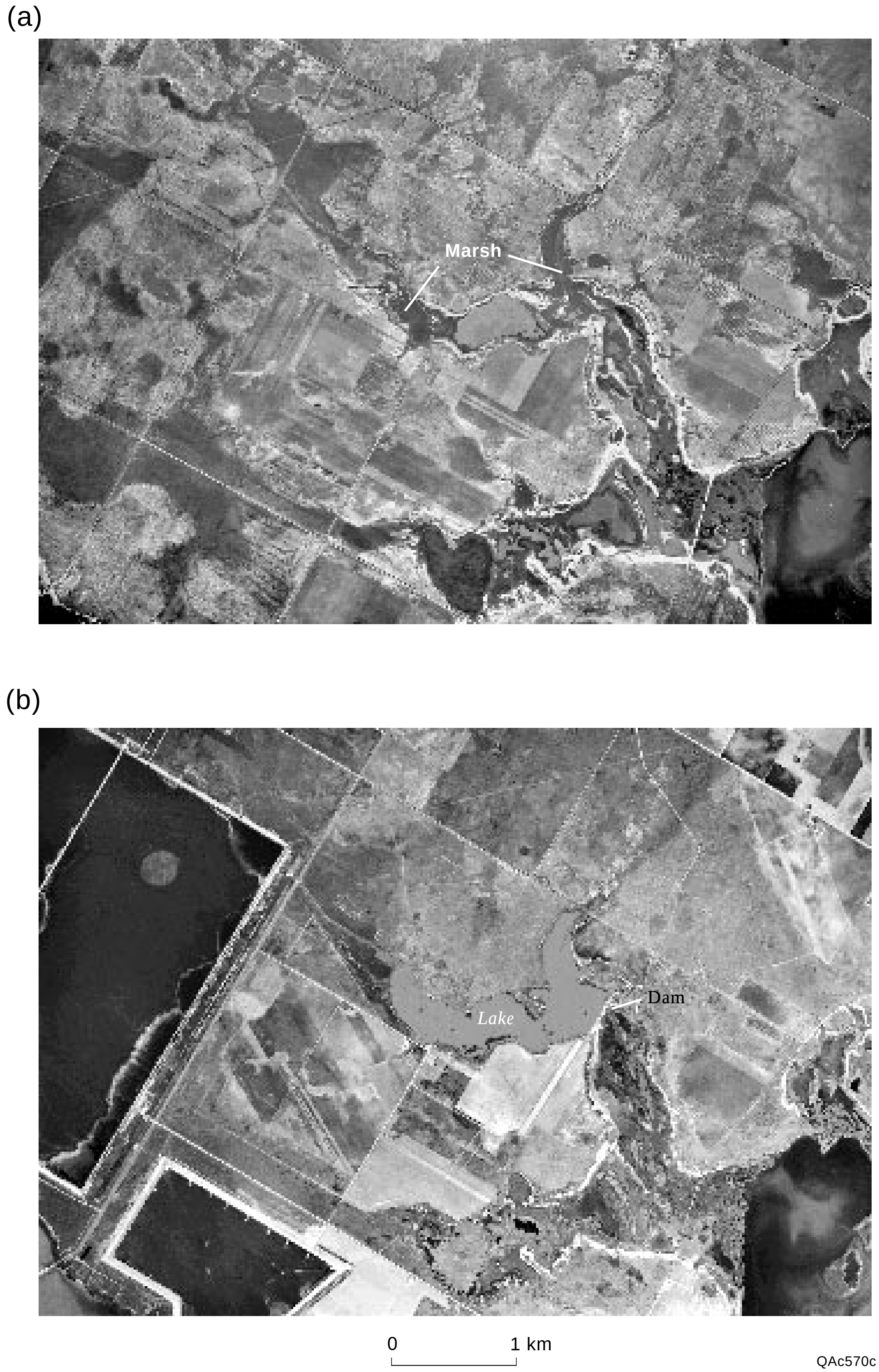


Figure 37. Example of marsh loss from a small impoundment west of Port Bay as illustrated by aerial photographs taken in (a) 1952 and (b) 1979.

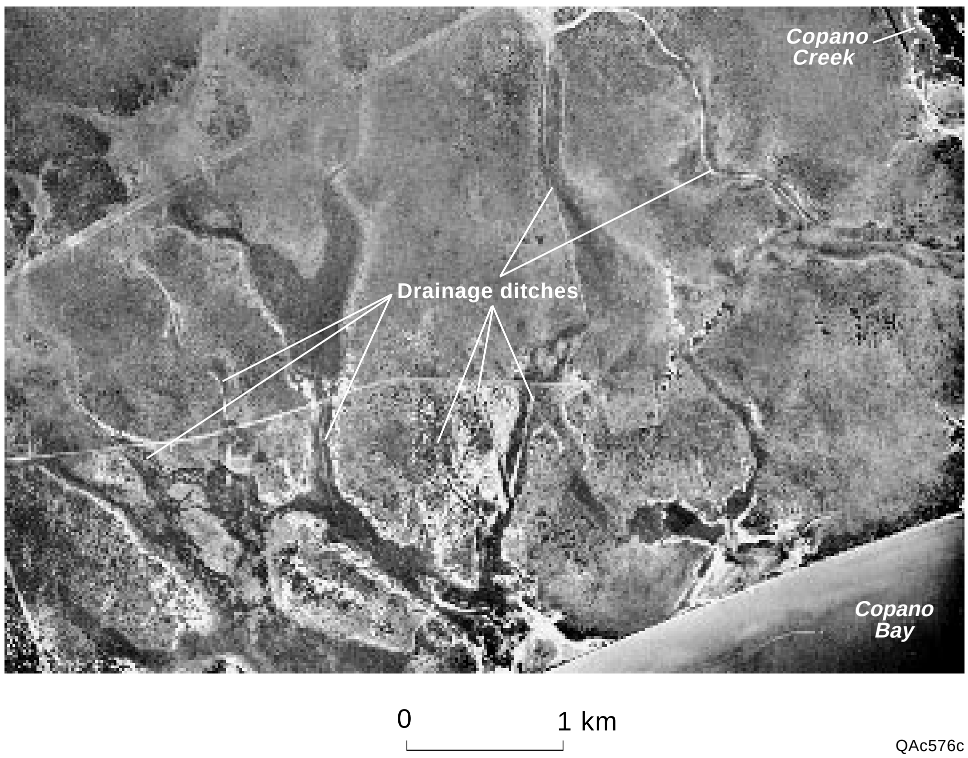


Figure 38. Example of drainage ditches in marshes north of Copano Bay and east of Copano Creek in the Lamar Quadrangle. Photograph was taken in October 1952.

Laguna Larga

Marshes. *1950's-1992.* Tables 59-61 show habitat changes for this region. From the 1950's to 1992, PEM gained 737 ha from uplands and lost 177 ha to uplands for a net increase of 560 ha. About 83 percent of the PEM gain was due to reclassification of uplands as PEM1A in 1992. Overall, PEM showed an adjusted net increase of about 122 ha (Table 61).

Lacustrine. *1950's-1992.* All L1OW changes were within the Laguna Larga depression. A gain of 606 ha and a loss of 90 ha gave a net gain of 516 ha of L1OW. About 89 percent of the gain (540 ha) came from the PEM category; mostly (98 percent) from PEM1C.

Table 59. Net change in marshes and lacustrine habitats from the 1950’s-1992, Laguna Larga.

Habitat	1950's	1979	1950's Adjusted	1979 Adjusted	Adjusted Net Change
PEM	2560	3432	3421	3648	227
L1OW/L2	1289	1361	1225	1326	101
POW/PFL	28	24	21	21	0
PSS/EM/OW	83	0	48	22	-26
U	8230	7373	7476	7174	-302

Table 60. Net change in marshes and lacustrine habitats from 1950's-1992, Laguna Larga.

Habitat	1979 (ha)	1992 (ha)	1979 Adjusted	1992 Adjusted	Adjusted NetChange
PEM	3432	3543	3648	3543	-105
L1OW/L2	1361	1741	1326	1741	415
POW/PFL	24	17	21	17	-4
PSS/EM/OW	0	50	22	50	29
U	7373	6839	7174	6839	-335

Table 61. Net change in marshes and lacustrine habitats from 1950's-1992, Laguna Larga.

Habitat	1950's (ha)	1992 (ha)	1950's Adjusted	1992 Adjusted	Adjusted Net Change
PEM	2560	3543	3421	3543	122
L1OW/L2	1289	1741	1225	1741	517
POW/PFL	28	17	21	17	-4
PSS/EM/OW	83	50	48	50	2
U	8230	6839	7476	6839	-637

Probable Causes of Change. *1950's-1992.* Spatially, most upland change occurred along drainageways and appeared to be wetland/upland transitional areas. Overdelineation of PEM1A in 1992 has been mentioned. It seems likely that the L1OW changes were the result of photointerpretation and classification differenes caused by fluctuating lake water levels. Eutrophication due to nonpoint source pollution and efforts to drain the basin may have also affected the distribution of PEM in Laguna Larga.

Coastal Plain System

The coastal plain system encompasses mainland areas inland from Corpus Christi and Copano Bays (Fig. 22). Most of the area is characterized by cropland and rangeland. In addition to broad flat coastal prairies, however, it includes small entrenched intertidal to supratidal valleys, creeks, and bayous along the northern and western shore of Copano Bay.

Corpus Christi Bay Coastal Prairie

Marshes and Ponds. *1950's-1979.* Depressional wetlands and ponds are scattered across the coastal plain. Many of these small prairie potholes (PEM = 135 ha) and ponds (POW = 67 ha) (Table 62) were lost to agriculture prior to 1979. About 1,400 PEM and POW habitats averaging about 0.2 ha were lost; about 90 percent of those losses were to upland agriculture.

1950's-1992. Gains (126 ha) and losses (171 ha) of PEM resulted in a net loss of 45 ha. There was a net loss of 78 ha of PSS; 95 ha of loss and 17 ha of gain. About 75 percent of PSS loss was to agriculture.

Impoundments. *1950's-1979.* An adjusted net increase of 179 ha of L1OW due to enlargement of tailing ponds occurred at an aluminum plant near Portland (Table 62). About 218 ha of uplands were converted to L1OW.

Table 62. Net change in marshes, lacustrine, and other habitats from the 1950's-1979, Corpus Christi Bay Coastal Plain.

Habitat	1950's (ha)	1979 (ha)	1950's adjusted	1979 Adjusted	Adjusted Net Change
E2EM	4	9	1	5	4
E2EM/FL	30	0	14	0	-14
PEM	328	85	326	192	-135
Total EM	**363**	**95**	**341**	**197**	**-144**
L1OW/L2	73	246	77	257	179
POW/PFL	260	218	212	144	-67
PFO/EM/SS	37	7	31	27	-5
PSS/EM/OW	207	36	131	46	-85

1979 -1992. Total emergent marsh showed a net increase (Table 63) due to an increase of PEM within large impoundments previously classified as upland areas. Uplands had an adjusted net decrease of about 170 ha.

1950's-1992. There was a net adjusted increase of 175 ha of L1OW for the region (Table 64).

Table 63. Net change in lacustrine and other habitats from 1979-1992, Corpus Christi Bay Coastal Plain.

Habitat	1979 (ha)	1992 (ha)	1979 Adjusted	1992 Adjusted	Adjusted Net Change
E2EM	9	1	5	1	-4
E2EM/FL	0	0	0	0	0
PEM	85	281	192	281	89
Total EM	**95**	**281**	**197**	**281**	**85**
L1OW/L2	246	253	257	253	-4
POW/PFL	218	206	144	206	61
PFO/EM/SS	7	53	27	53	26
PSS/EM/OW	36	52	46	52	6

Table 64. Net change in lacustrine and other habitats from the 1950's-1992, Corpus Christi Bay Coastal Plain.

Habitat	1950's (ha)	1992 (ha)	1950's Adjusted	1992 Adjusted	Adjusted Net Change
E2EM	4	1	1	1	0
E2EM/FL	30	0	14	0	-14
PEM	328	281	326	281	-46
Total EM	**363**	**281**	**341**	**281**	**-60**
L1OW/L2	73	253	77	253	175
POW/PFL	260	206	212	206	-6
PFO/EM/SS	37	53	31	53	21
PSS/EM/OW	207	52	131	52	-78

Probable Causes of Changes. *1950's -1992.* Loss of palustrine wetlands (PEM, POW, PSS) was due to agricultural development. Most of the PEM and POW losses were comprised of small, scattered depressional wetlands. About 50 percent of PEM gains (68 ha) resulted from reclassification of uplands within drainageways and may not be real gains but differences in photointerpretation.

Coastal Plain Inland from Copano and St. Charles Bays

Marshes. *1950's-1979.* There was a substantial apparent net gain in both estuarine and palustrine marshes inland (northwest) of Copano Bay from the 1950's to 1979 (Table 65). The largest gains occurred northeast of Mission Bay in the Lamar and Tivoli SW quadrangles. This map area includes Copano Creek, Mullens Bayou, Salt Creek, and Willow Creek and wetlands at the mouth of Mission Bay (Mission Bay and Bayside quadrangles). Losses in the E2EM/FL class were offset by gains in E2EM, yielding a net increase in estuarine marsh of approximately 400 ha. There was a similar gain in PEM of almost 400 ha (Table 65). Much of the change in marshes, however, is interpretational and largerly dependent on moisture levels at the time aerial photographs were taken. Among the real changes, however, was a spread of estuarine emergent vegetation into estuarine flats. This change is reflected in part by the loss of E2EM/FL and gain in E2EM.

Table 65. Net change in marshes and intertidal flats from the 1950's-1979, Copano Bay Coastal Plain.

Habitat	1950's (ha)	1979 (ha)	1950's Adjusted	Adjusted Net Change
E2EM	903	2352	903	1449
E2EM/FL	1285	244	1285	-1041
PEM	1650	2044	1637	394
Total EM	**3838**	**4640**	**3838**	**802**
E2FL	908	522	738	-216

1979-1992. There was an apparent net loss of more than 400 ha of estuarine marsh from 1979-1992 (Table 66). Most of the loss occurred in the 1979 E2EM/FL class, which was mapped primarily as E2EM in 1992. These changes occurred at the mouths of Mission Bay and other entrenched drainages on the northern margin of Copano Bay and St. Charles Bay. Some losses in estuarine marsh occurred in Burgentine Lake at the head of St. Charles Bay. About half of this lake is in the Blackjack Peninsula area of analysis. Almost 50 ha of estuarine marsh along the margins of the lake in 1979 were submerged in 1992 and replaced by lacustrine open water (L1UB). Primarily due to interpretation, more than 150 ha of E2EM extending landward from Copano Bay on the northeast side of Mission Bay was mapped as uplands in 1992; this accounts for much of the loss in E2EM. There was a small net change in PEM (Table 66), that resulted from relatively large gross losses offset by gains.

Table 66. Net change in marshes and intertidal flats from 1979-1992, Copano Bay Mainland Coastal Plain.

Habitat	1979 (ha)	1992 (ha)	Net Change
E2EM	2352	2158	-194
E2EM/FL	244	0	-244
PEM	2044	2004	-40
Total EM	**4640**	**4162**	**-478**
E2FL	522	331	-191

Estuarine Intertidal Flat. *1950's-1979.* Estuarine intertidal flats decreased in area from 1950's to 1979. Photo analysis shows a spread of emergent vegetation in some estuarine flats, but about 170 ha of the gross loss in flats was to subtidal habitats such as open water. Much of this loss is not real but misinterpretation on 1950's photographs; a strip of subtidal bay margin sand was interpreted as intertidal estuarine flats along the northern shore of Copano Bay. This misclassification may have been due in part to low tides. Substracting the 170 ha from the 1950's estuarine flat yields an adjusted net loss of 216 ha (Table 65).

1979-1992. Estuarine intertidal flats continued to decline in area from 1979 to 1992 (Table 66). Losses occurred along Copano Creek and in intertidal areas of other entrenched drainages into Copano Bay. Most tidal flats were replaced by estuarine marsh.

Probable Causes of Changes. *1950's-1979-1992.* The apparent net gain of more than 800 ha of marsh habitat from 1950's to 1979 and the net loss of more than 475 ha from 1979 to 1992 yielded a net gain of about 325 ha from 1950's to 1992 (Table 67). Net loss in emergent vegetation from 1979 to 1992 is in large part a result of photointerpretation. The mainland area of Copano Bay, especially between Mission Bay and St. Charles Bay, has numerous relict, subtle entrenchments that slope toward Copano Bay. Most have drainage ditches dug before the 1950's (Fig. 38). High marshes and prairie grasslands have developed in these areas, and distinction and classification depend on existing moisture levels. Many changes in higher marshes are thus interpretational. Changes include a reclassification of some 1950's/1979 interior E2EM areas to PEM in 1992.

Table 67. Net change in marshes and intertidal flats from 1950's-1992, Copano Bay Mainland Coastal Plain.

Habitat	1950's (ha)	1992 (ha)	1950's Adjusted	Adjusted Net Change
E2EM	903	2158	903	1255
E2EM/FL	1285	0	1285	-1285
PEM	1650	2004	1637	367
Total EM	**3838**	**4162**	**3838**	**324**
E2FL	908	331	738	-407

Among real trends was conversion of estuarine intertidal flats to estuarine marsh. From 1979 to 1992, more than 85 percent of the gross loss in intertidal flat and 95 percent of the loss in E2EM/FL was due to conversion to estuarine marsh (E2EM). Growth of emergent vegetation over flats occurred along Copano Creek and other creeks and bayous as well as at the mouth of Mission Bay and tidal inlets to the southwest toward the Aransas River. Some losses in estuarine marsh and flat occurred in Burgentine Lake at the head of St. Charles Bay from impounded water in 1992 that submerged 1979 fringing marshes and estuarine flats. Water levels in Burgentine Lake are managed using a water control structure.

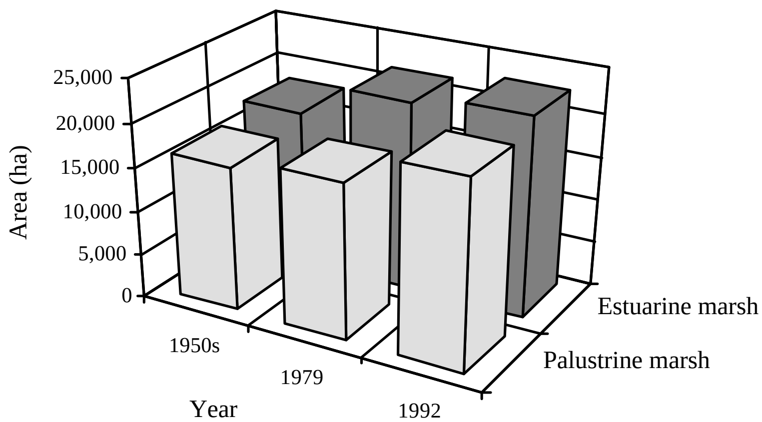
C. Summary of Trends

The general trend in wetland habitats in the CCBNEP study area from the 1950's to 1992 was one of marsh gains and tidal flat losses (Figs. 39-40). The largest increase in estuarine marshes occurred from the 1950's to 1979, the period that coincides with the largest decrease in intertidal flats (Fig. 40). From 1979 to 1992, estuarine marshes continued to increase and intertidal flats continued to decrease but at slower rates. Similar to estuarine marshes, palustrine marshes increased during both periods, with the largest increase occurring from 1979 to 1992 (Figs. 39–40). This trend of palustrine marsh increase does not hold for most of the Texas coast; Moulton et al. (1997) showed large decreases in palustrine marsh along the entire coast.

Because of inconsistencies in photointerpretation for different periods, emphasis is placed on the direction of trends rather than magnitude, even though adjustments were made to lessen photointerpretation effects. Nevertheless, subdivision of the study area into 18 areas (Fig. 22) for analysis revealed consistent trends: expansion of marshes and decline of intertidal flats. The most extensive losses in intertidal flats occurred on barrier islands. From the 1950's to 1992 there was a net loss in area of more than 6,000 ha, the largest loss (>2,300 ha) occurring on Mustang Island. Largest gains in estuarine marshes occurred on barrier islands, exceeding 3,900 ha from the 1950's to 1992; about 65 percent of the increase was on San José Island. Palustine marshes had greatest gains (>1,400 ha) on barrier islands, with Padre Island having the largest gain at more than 650 ha.

There is evidence that much of the decline in intertidal flats and expansion of estuarine marshes is related to relative sea-level rise. The large decline in tidal flats from the 1950's to 1979 coincides with an accelerated rise in relative sea level from the mid 1960's to mid 1970's. The average annual rate of rise during this period (1.7 cm/yr) was more than three times the rate from the mid 1970's to early 1990's (0.48 cm/yr). Tidal flats were permanently inundated in many areas, and replaced by seagrass beds or open water. On upper margins of the flats, salt marshes expanded. In the interior of barrier islands, palustrine marshes increased in total area. We believe that as relative sea level rises, the fresh-water lens, recharged by precipitation, also rises, creating wetter surface conditions and leading to more abundant and widespread hydrophytic vegetation. This scenario is supported by observations of environments on Padre Island National Seashore

(a)



(b)

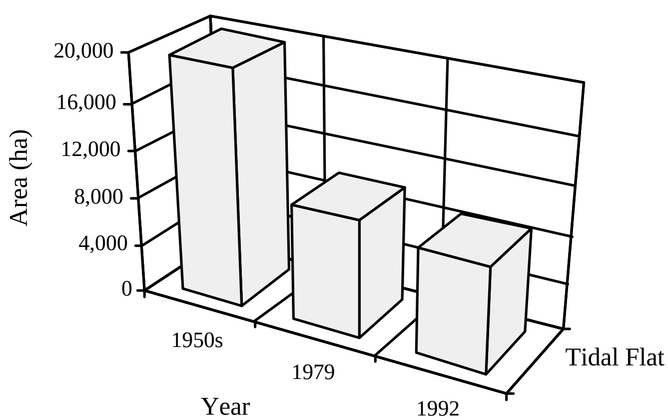


Figure 39. Area of (a) palustrine and estuarine marshes and (b) estuarine intertidal flats in the CCBNEP study area from the 1950's to 1992.

where active back island dunes have become stabilized by vegetation, and deflation areas and vegetated barrier flats have become wetter and marshes more extensive (Paul Eubanks, Padre Island National Seashore, personal communication, 1997). Furthermore, recent baseline studies of plant species on Mustang Island State Park indicate the presence of hydrophytic species not reported in previous plant surveys of Mustang and North Padre Island (Jenkins and Smith, 1997).

Although the general net trend was one of marsh gains, there were also marsh losses. Among the more prominent losses were pothole wetlands on the Pleistocene barrier strandplain (Live Oak Peninsula/Ridge) and the coastal plain. These depressional wetlands, though small (many <0.2 ha), are important natural resources (Collins, 1987) that generally have not been protected by regulation. On the coastal plain, many have been converted to uplands for agricultural purposes. On Live Oak Peninsula/Ridge, they have been quarried for sand resources, and filled and drained as the peninsula was developed.

Additional losses in marshes and tidal flats have occurred from dredging and filling activities for development of marinas, navigation channels, and residential and commercial development. Along high energy shores, marshes have been lost due to erosion (Paine and Morton, 1993; White and Calnan, 1990, Morton and Paine, 1990). Additional losses have been caused by human activities and natural processes (Table 68).

The areal distribution of riparian woodlands increased in all three fluvial-deltaic systems. The largest increase, from 1979 to 1992, was in the Nueces River valley and exceeded 180 ha. The Aransas-Chiltipin and Mission River valleys had small gains totaling slightly more than 20 ha.

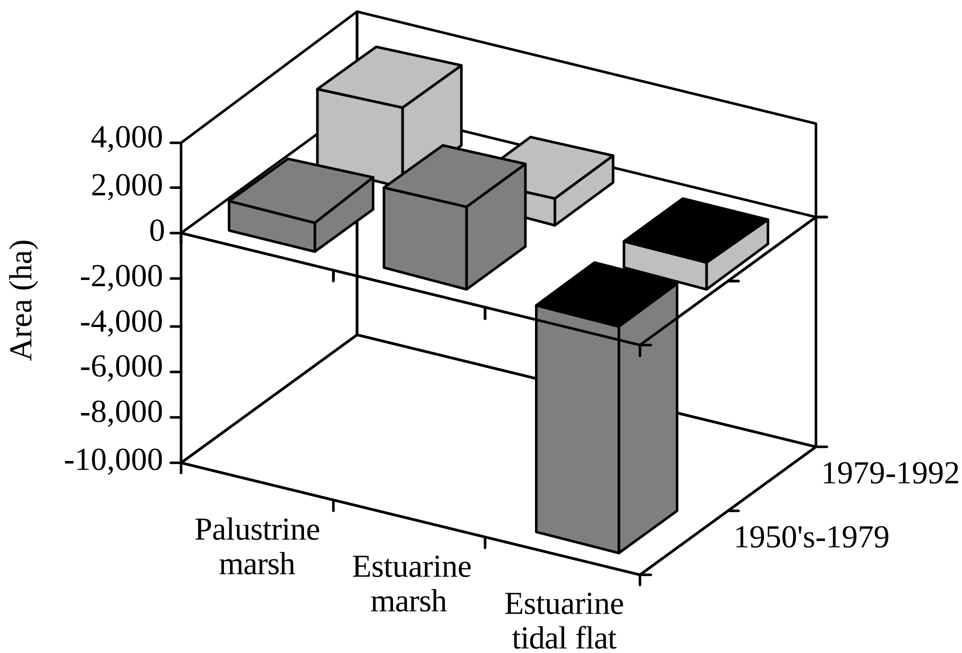


Figure 40. Changes in total area of marshes and intertidal flats in the CCBNEP study area for the periods 1950's-1979 and 1979-1992.

Table 68. Major causes of wetland loss and degradation. Modified from Tiner (1984) as compiled from Zinn and Copeland (1982) and Gosselink and Baumann (1980). Relative importance of causes in the CCBNEP area in parenthesis.

HUMAN THREATS

Direct:

1. Drainage for crop production and expansion of upland rangeland **(Moderate)**
2. Dredging and stream channelization for navigation channels, flood control, coastal housing developments, and reservoir maintenance **(Moderate)**
3. Filling for dredged spoil and other solid waste disposal, roads and highways, and commercial, residential and industrial development **(Moderate)**
4. Construction of dikes, dams, levees and seawalls for flood control, water supply, industrial purposes, irrigation and storm protection **(Minor to Moderate)**
5. Discharges of materials (e.g., pesticides, herbicides, other pollutants, nutrient loading from domestic sewage and agricultural runoff, and sediments from dredging and filling, agricultural and other land development) into waters and wetlands (Undetermined)
6. Mining of wetland soils for sand, gravel, peat, and other materials **(Moderate)**

Indirect:

1. Sediment diversion by dams, deep channels, and other structures (**Moderate**)
2. Hydrologic alterations by canals, spoil banks, roads and other structures (Undetermined)
3. Subsidence due to extraction of groundwater, oil, gas, sulphur, and other minerals **(Undetermined - possibly important locally)**
4. Salt-water intrusion resulting from indirect threats noted above (Undetermined)

NATURAL THREATS

1. Subsidence (including natural rise of sea level) (**Moderate, difficult to separate from humanly-induced subsidence**)
2. Erosion (**Moderate**)
3. Droughts (Undetermined)
4. Hurricanes and other storms (Undetermined)
5. Biotic effects (e.g., muskrat, nutria and goose “eat-outs”) (Undetermined)

VI. SHORELINE TYPES IN THE CCBNEP STUDY AREA

A. Mapping Procedures

The objective of shoreline mapping was to differentiate shores artificially hardened by riprap, bulkheads, seawalls, and other human structures, from natural or nonhardened shorelines consisting of sand and shell beaches, marshes, tidal flats, etc. Shorelines were mapped and classified using numeric or alpha-numeric codes that define shoreline types. Shoreline codes were derived from those developed for characterizing sensitivity of shores to oil impacts (Tables 69 and 70).

Mapping procedures consisted of identifying shoreline boundaries, marking boundaries on topographic base maps, and labeling each shoreline segment with the appropriate code. Shorelines were delineated on USGS 7.5 minute quadrangles using plots of the most up-to-date shorelines, which in the CCBNEP area are from USFWS NWI 1992 digital files compiled by the GLO.

Shorelines were mapped primarily using recent, vertical aerial photographs, and low altitude aerial videotape surveys of coastal Texas produced by the Center for Coastal, Energy and Environmental Resources at LSU, and recorded during cooperative helicopter flights by staff of LSU and the Bureau of Economic Geology in May of 1997. Videotapes are high quality and are accompanied by audio commentaries of shoreline types made by experienced coastal geologists.

Shoreline types were classified and mapped while viewing videotapes on a 68.5 cm, high-resolution color monitor and using a video cassette recorder with slow and fast advance and reverse features. In areas not covered by videography, shorelines were mapped using low and high altitude vertical stereographic aerial photographs taken during the 1990's. Where necessary, shorelines were analyzed using stereoscopes with a magnification of at least 6X.

Along some shoreline segments, more than one shoreline type was present. For example, shells may have been concentrated in beaches that front a clay scarp. Such a shoreline was assigned two codes, given in the order in which they occur going from the most landward to the most seaward position. Accordingly, a shell beach seaward of a clay scarp was designated as 2/6 on maps. The first numeric code, 2, refers to the landward most feature, or clay scarp, and the succeeding code refers to the seaward most feature, the shell beach. Locally, as many as three shoreline types were recognized in an alpha-numeric sequence, such as 2/10A/3, which details a shoreline that progresses from a clay scarp to a salt/brackish marsh to a sand beach.

Shoreline types were digitized from the 7.5 minute quadrangles on which shorelines were mapped. These digital data were entered into the GIS ArcInfo from which hard copy maps were plotted for verification.

Where possible, questionable sites were field checked to ensure completeness and accuracy of shoreline designations. Digitized shorelines were compared with mapped shorelines for accuracy and completeness. Areas needing correction were marked on work maps, and corrections were made in digital files.

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Table 69. Standardized Environmental Sensitivity Index (ESI) rankings for Texas. From Morton and White (1995) as modified from Hayes et al. (1980).

ESI No.	**Shoreline Type**
1	Exposed walls and other structures made of concrete, wood, or metal
2A	Scarps and steep slopes in clay
2B	Wave-cut clay platform
3A	Fine-grained sand beaches
3B	Scarps and steep slopes in sand
4	Coarse-grained sand beaches
5	Mixed sand and gravel (shell) beaches
6A	Gravel (Shell) beaches
6B	Exposed riprap structures
7	Exposed tidal flats
8A	Sheltered solid man-made structures, such as bulkheads and docks
8B	Sheltered riprap structures
8C	Sheltered scarps
9	Sheltered tidal flats
10A	Salt- and brackish-water marshes
10B	Fresh-water marshes (herbaceous vegetation)
10C	Fresh-water swamps (woody vegetation)
10D	Mangroves

Table 70. Codes used in shoreline type mapping for this project. Modified from Table 69.

Code	**Shoreline Type**
1	Solid man-made structures such as bulkheads and other structures made of concrete, wood, or metal, and riprap
2	Clay scarps
3	Sand beaches and shores
5	Sand and shell
6	Shell beaches and berms
7	Tidal flats
8C	Sheltered scarps and slopes
10A	Salt and brackish water marshes
10D	Mangroves

B. Shoreline Types

Shores along the Gulf coast including the CCBNEP area (Fig. 41) are dynamic features that influence flora and fauna as well as economic and recreational value. Many shorelines are erosional (Morton and Paine, 1984, Paine and Morton, 1993) and have been armored with rip rap, bulk heads, groins and other structures to slow or prevent shoreline retreat (Figs. 42 and 43). Non-armored shorelines include those along natural and dredged material shores, and may be characterized by salt marshes (Fig. 44), tidal flats, sand and shell beaches, or sand and clay scarps and slopes. In some areas, natural resources such as salt marshes have been lined with armor, including bulkheads, articulated concrete mats, and grout bags to prevent erosion. Most marsh shoreline along the GIWW in the Aransas National Wildlife Refuge has been protected in this manner. The most extensive hardened shoreline occurs along the south shore of Corpus Christi Bay (Figs. 41, 42 and 43). Some shorelines have been artificially nourished to create or restore eroded sand beaches for recreational purposes (Fig. 43a).

Shoreline types listed in Table 71 are those along the waters edge and do not include the upper shore that may be of a different type. For example, a sand beach shoreward of a marsh or tidal flat is listed as sand. Hardened shorelines include all shorelines that have bulkheads, rip rap, groins or other structures even though some may have a fringing marsh or sand and shell beach seaward of the structure. Beaches that have been artificially nourished are included in the sand or sand and shell types. The most extensive artificially nourished beach is about 2 km in length at North Beach in the Corpus Christi quadrangle.

Cumulatively, marshes are the most common shoreline type, making up 45 percent of the total length of shorelines (Table 71). Marsh shorelines in Table 71 include narrow fringing marshes as well as more extensive marshes that extend landward of the shore. Mangroves (included with the marsh shorelines) are abundant along some shores especially on Harbor Island, but cumulatively have a length of less than 0.2 km. Shell berms and beaches (6 percent) are common along shores with high wave energy and are often erosional. Many of the shorelines characterized by sheltered scarps and steep slopes (11 percent of total) occur along unarmored dredged and natural channels or in protected embayments. Hardened or armored shorelines represent more than 16 percent of the total length. Major concentrations of hardened shorelines include bulk-headed navigation channels in recreational-community developments such as on north Padre Island and along erosional shores such as the south and west sides of Corpus Christi Bay (Fig. 42).

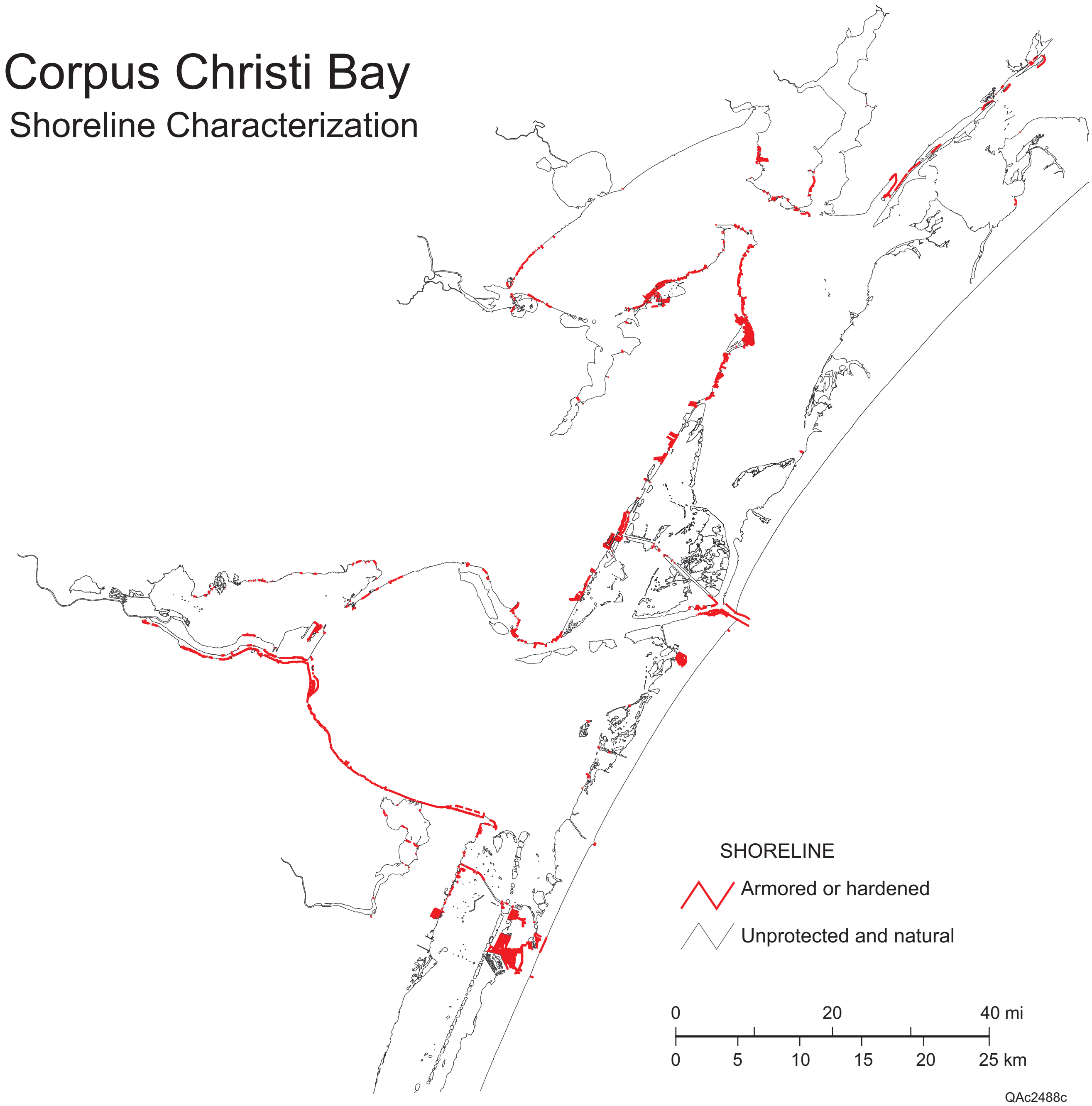


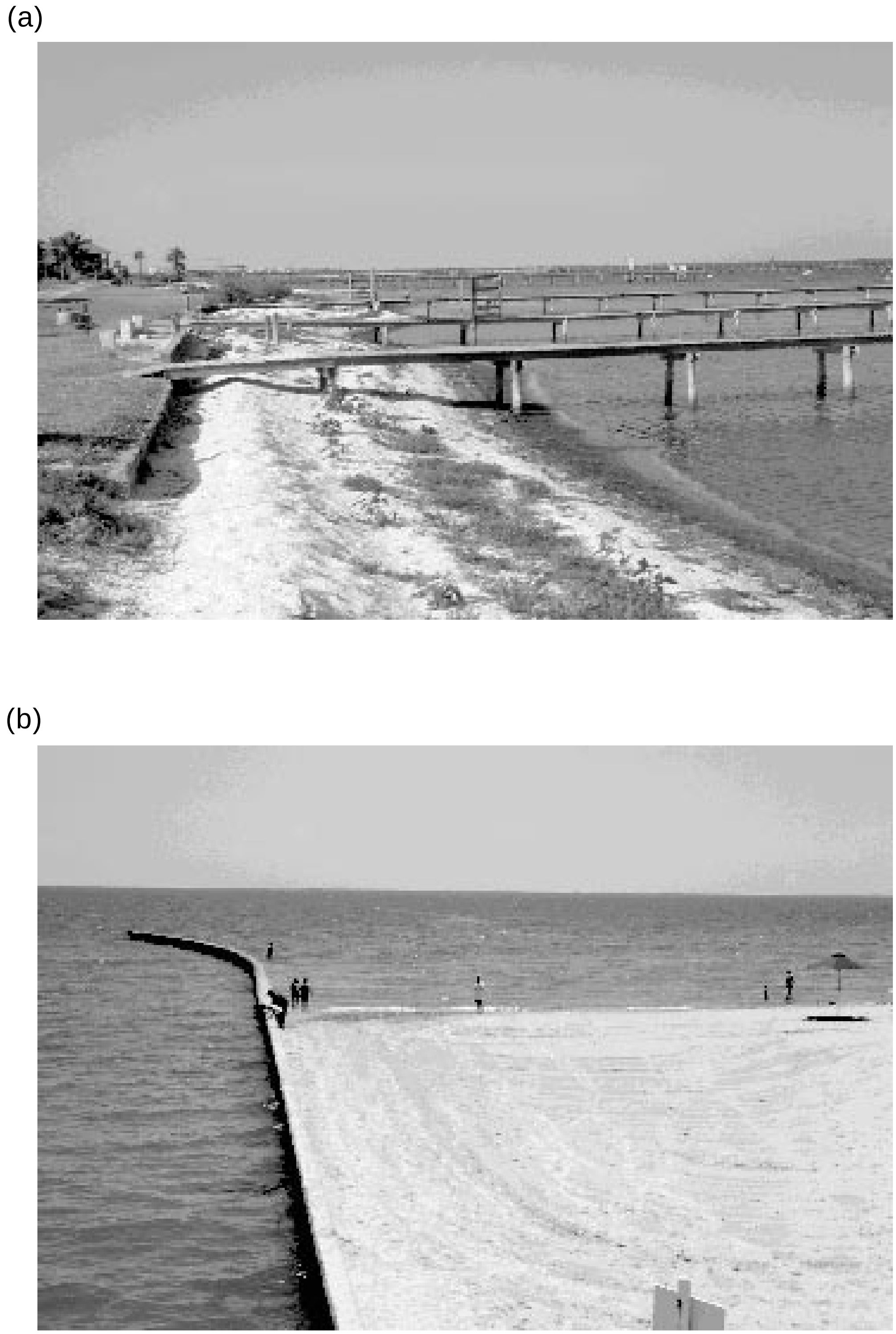
Figure 41. Location of hardened and nonhardened shorelines in the CCBNEP study area.

(a)

(b)

QAc571c

Figure 42. Example of (a) riprap shoreline on the south side of Corpus Christi Bay east of the mouth of Oso Bay and (b) concrete bulkhead "backed" by stone riprap and concrete apron at a park on the west side of Corpus Christi Bay.



QAc572c

Figure 43. Example of (a) shell beach, low bulkhead, and piers along the shore of Live Oak Peninsula on Aransas Bay and (b) artificially constructed beach and concrete groin on the west side of Corpus Christi Bay.

QAc575c

Figure 44. Shoreline fringed by marsh and scattered shrubs of black mangrove along the navigation channel to Aransas Pass.

Table 71. Type and length of shorelines in the CCBNEP study area. Does not include Pita and South Bird Island quadrangles. Lengths of natural or non-hardened shores based on type of shoreline along waters edge.

Shoreline Type	Length (km)	Percent of Total Shoreline
Natural and Non-Hardened		
Marsh	899	45
Sand	161	8
Shell	122	6
Sand and Shell	65	3
Clay	87	4.3
Tidal flats	128	6.3
Sheltered scarps/slopes	222	11
Subtotal	1,684	83.6
Hardened or Armored	330	16.4
Total	2,014	100

VII. A SUMMARY OF THE STATUS AND TRENDS OF ROOKERY ISLANDS IN THE CCBNEP AREA

A. Introduction

The CCBNEP area encompasses an extensive, biologically productive, estuarine and lagoonal system composed of numerous diverse and essential habitats and vast array of associated organisms. One such habitat type is natural and dredged material islands that are crucial to colonial nesting waterbirds. Evaluating rookery islands through time is critical in developing a comprehensive management plan for the Texas Coastal Bend. Chaney et al. (1996) overviewed habitats utilized by avian species within the CCBNEP area surrounding the bay systems. They emphasized the importance of natural and dredged material islands as nesting habitat for many species of gulls, terns, herons, egrets, pelicans, spoonbills, ducks, and ibises. Their assessment grouped all data for each species from all colonies surveyed and evaluated trends for 22 species during 1973-1990.

In a recent report (Smith and Cox, 1998), data were summarized by colony through time to qualitatively assess changes in nesting habitat types on islands for both common and selected rare species. This approach allowed a more detailed overview of ecological dynamics of selected colonies located in the CCBNEP area in relation to natural and human-induced events serving as probable causes for observed nesting dynamics. Suggestions were also included evaluating current surveys, continued monitoring programs, data gaps, research needs, and conservation efforts useful in developing a rookery island management plan for the CCBNEP area. Examples of the approach taken are summarized in this chapter.

Background

Natural and dredge material islands located within the bay systems of the CCBNEP area support high numbers of colonial nesting waterbirds (Texas Colonial Waterbird Society 1982). Changes in island area and vegetative diversity through time may affect use as rookeries. Five natural bay islands, five natural rookeries, 13 natural islands with dredged material deposits, and 27 dredged material islands occur within the study area delineated previously in this report.

Colonial waterbirds are dependent upon estuarine habitats for both foraging and reproduction. These species typically feed on fish and crustaceans in shallow and open water areas. Natural and created bay islands away from disturbance for nesting are critical for continued survival. Therefore, colonial waterbirds are excellent indicators of ecosystem health (Soots and Landin, 1978). Islands in Texas are used in varying degrees depending upon one or more of the following factors: 1) accessibility of islands to predators; 2) human disturbance and activities; 3) size of islands; and, 4) presence of vegetation, topography, or elevation suitable to support one or more nesting species (Chaney et al. 1978). Islands may also be important to non-breeding birds (e.g., resident and migratory waterbirds, shorebirds, songbirds, and raptors) for resting, roosting, and feeding (Soots and Landin, 1978).

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Objectives

Objectives of the rookery island study were to (1) evaluate vegetation succession and spatial configuration of selected rookery islands throughout a 20-year period, (2) overview potential relationships between vegetation structure and colonial waterbird nesting success, and (3) propose probable causes for changes in nesting dynamics as related to habitat availability and/or human activities.

B. Methods

Rookery Island Nesting Habitat Evaluation

Rookery and natural areas used as bird nesting sites were delineated for the CCBNEP study area from historical data (Chaney et al. 1978, Texas Colonial Waterbird Society 1982). Five natural bay islands, five natural rookeries, 13 natural islands with dredged material depositions, and 27 dredged material islands were variously used to accomplish tasks in Smith and Cox (1998). The following rookery islands were selected in that report to evaluate current vegetation patterns based on availability of historic vegetation analyses: Pelican Island Spoil, Shamrock Island, Marker 17 Island in Marker 2-17 Spoil Islands (New Markers 13-35), North Bird Island, South Bird Island, South of South Bird Island (Marker 55, 57, 57a islands), Marker 63-65 Spoil Island (New Marker 127-131), and Marker 81 (New Marker 163) rookeries. In this summary, Marker 17 Island in Marker 2-17 Spoil Islands (New Markers 13-35), South of South Bird Island (Marker 55, 57, 57a islands), and Marker 81 (New Marker 163) rookeries will be overviewed.

Number of transects were determined individually on each island in relation to vegetative complexity and to assist in verification of photointerpretation work. Field work was conducted during October - December 1996, as islands are inaccessible during the January-September nesting season. Transects were aligned perpendicular to the elevational gradient that encompassed the maximum number of vegetation associations and, when appropriate, along a similar direction as historic transects (Chaney et al. 1978). Vegetation type was recorded as: dominant grass, dominant herb (perennial), dominant forb, or dominant shrub. Unvegetated areas were recorded as unvegetated shell or unvegetated sand. Using a hand level and staff, elevations were recorded at each dominant floral change, unvegetated or pond area to evaluate changes in horizontal distance and the change in elevation between each habitat type in relation to relative sea level. Both field data in this study and historic data were grouped according to the following categories: bare, sparse herbaceous, herbaceous, herbaceous/shrub, shrub, shrub/tree, and tree.

Initially, habitat types were to be used to describe wetland and upland habitats from the National Wetland Inventory (NWI) data for 1992; however, important habitat characteristics were documented in the field surveys were not mapped on NWI draft maps due to scale limitations. In addition, upland designations on the islands were not differentiated into vegetation types critical to nesting use evaluation. Therefore, 1995 aerial photographs (CCBNEP files) were scanned using Adobe Photoshop and imported into Microsoft Powerpoint V.7. Habitat types were determined by unique color signatures and field transect data, and polygons were constructed for each type. Due to scaling problems, no attempt to quantitatively compare habitat changes was undertaken. These habitat maps were visually compared to historic data from the 1970s (Chaney et al. 1978) to determine major changes in habitat on each rookery island.

Colonial Waterbird Nesting Dynamics

Bird atlas and census information during 1973-1994 formed the basis of determining nesting use changes for the CCBNEP area (north of Baffin Bay) and selected rookery sites (Smith and Cox, 1998). Species pair data from Texas Colonial Waterbird censuses were summarized in relation to preferred nesting substrate (ground, shrub/tree) for the entire study area and for selected rookery islands with sufficient data throughout the survey. Graphics were organized similarly by rookery to facilitate visual comparisons and missing data were not graphed. Rookeries located in upper Laguna Madre are described within this summary to determine if population shifts were occurring among rookeries. Brown and American White Pelicans are included here to postulate nesting population movements within the CCBNEP area. Other species having significant population changes (Chaney et al. 1996) were examined in relation to habitat requirements to identify probable causes of change.

C. Results

Status and Trends of Rookery Islands Use in CCBNEP Area

Selected Island Vegetation Dynamics

All islands evaluated for vegetation dynamics in Smith and Cox (1998) are depicted in Fig. 45. Marker 17 (New Marker 35) dredged material island is the southernmost island of the Marker 2-17 Spoil Island (New Marker 13-35) Colony in upper Laguna Madre (TCWS, 1982) and most active rookery within the colony area (Coste and Skoruppa, 1989). The island was about 6.8 hectares in the 1970s, and encompassed several nesting habitats of trees, prickly pear, shrubs, subshrubs, grasses and forbs, annuals, and shell, sand and mud beaches (Chaney et al. 1978, TCWS, 1982). Historically, this island represents one of the oldest dredged material islands as defined by timing of the dredged material deposition and vegetation establishment. The island changed relatively little from 1975 to 1995 in physical configuration (Fig. 46). However, more herbaceous/shrub habitat covers the island, replacing herbaceous species documented in 1975. Small areas of *Paspalum monostachyum* (gulfdune paspalum) and *Sporobolus virginicus* (seashore dropseed) are still dominant along the north and east portions of the island. The bare area located in the southeast quadrant of the island ponded, holding tidal waters following high tide events. In addition, tree habitat covers the high ridge of the island, surrounded by an impenetrable ring of prickly pear cactus and tall (>1 m) *Baccharis neglecta* (Roosevelt weed). Available habitat types appear to have increased in complexity through the last 20 years, although less bare substrate may be available for ground-nesting species requiring sand or shell substrate. The TGLO owns this and other dredged material islands along the GIWW (TCWS, 1982).

LM 55, 57, and 57A dredged material islands are located in upper Laguna Madre immediately north of the junction of Bird Island Basin Channel and GIWW and are included in the South of South Bird Island Colony (see Fig. 45). Four islands are broadly connected by intertidal infrequently exposed flats and encompass a broad range of nesting habitats of trees, prickly pear, shrubs, subshrubs, grasses and forbs, annuals, and bare beaches of sand and clay. Chaney et. al (1978) described three islands. LM 57a was chosen as a representative island in this rookery and encompasses diverse habitat types (Fig. 47). The island eroded along the north, east, and south

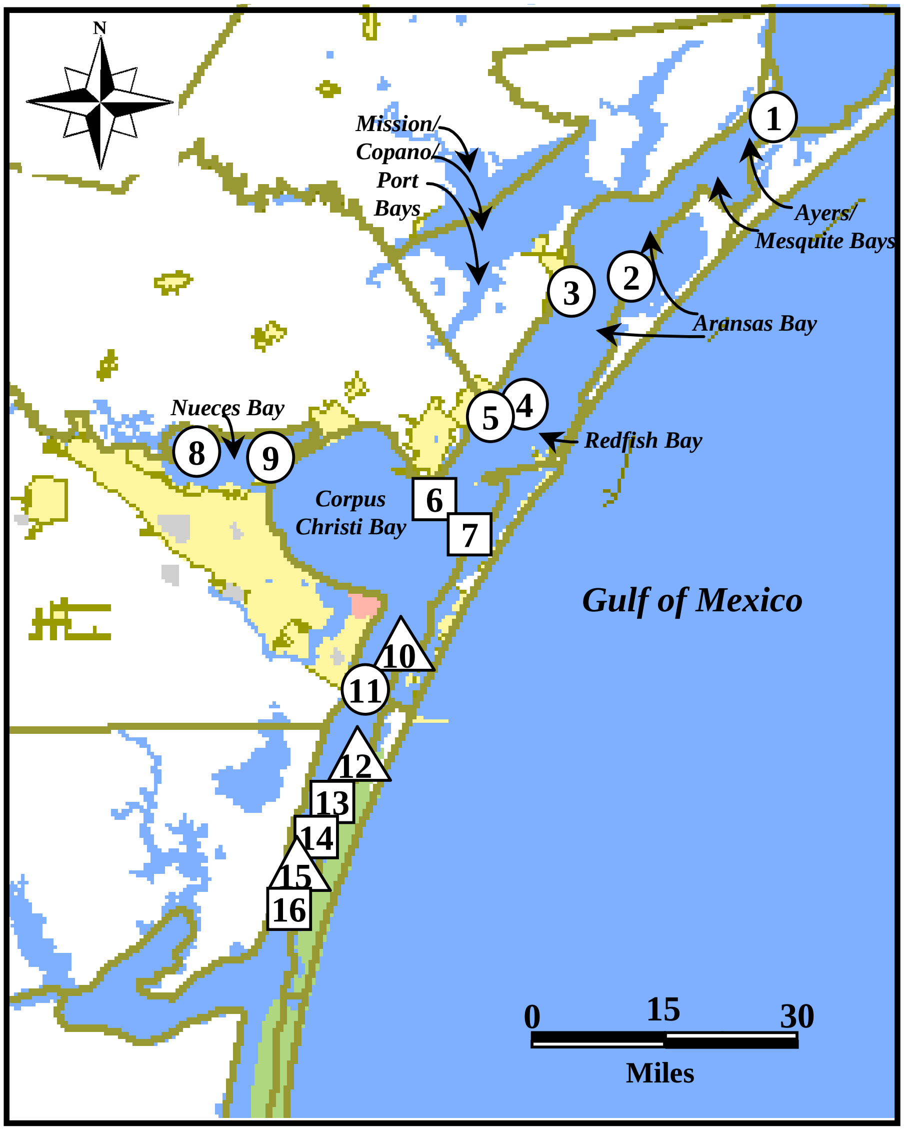


Figure 45. Locations of rookery islands evaluated in Smith and Cox (1998) for status and trend assessments. Circles denote rookeries where Colonial Waterbird (CWB) census were used, squares denote both CWB and habitat descriptions, and triangles denote habitat descriptions only.

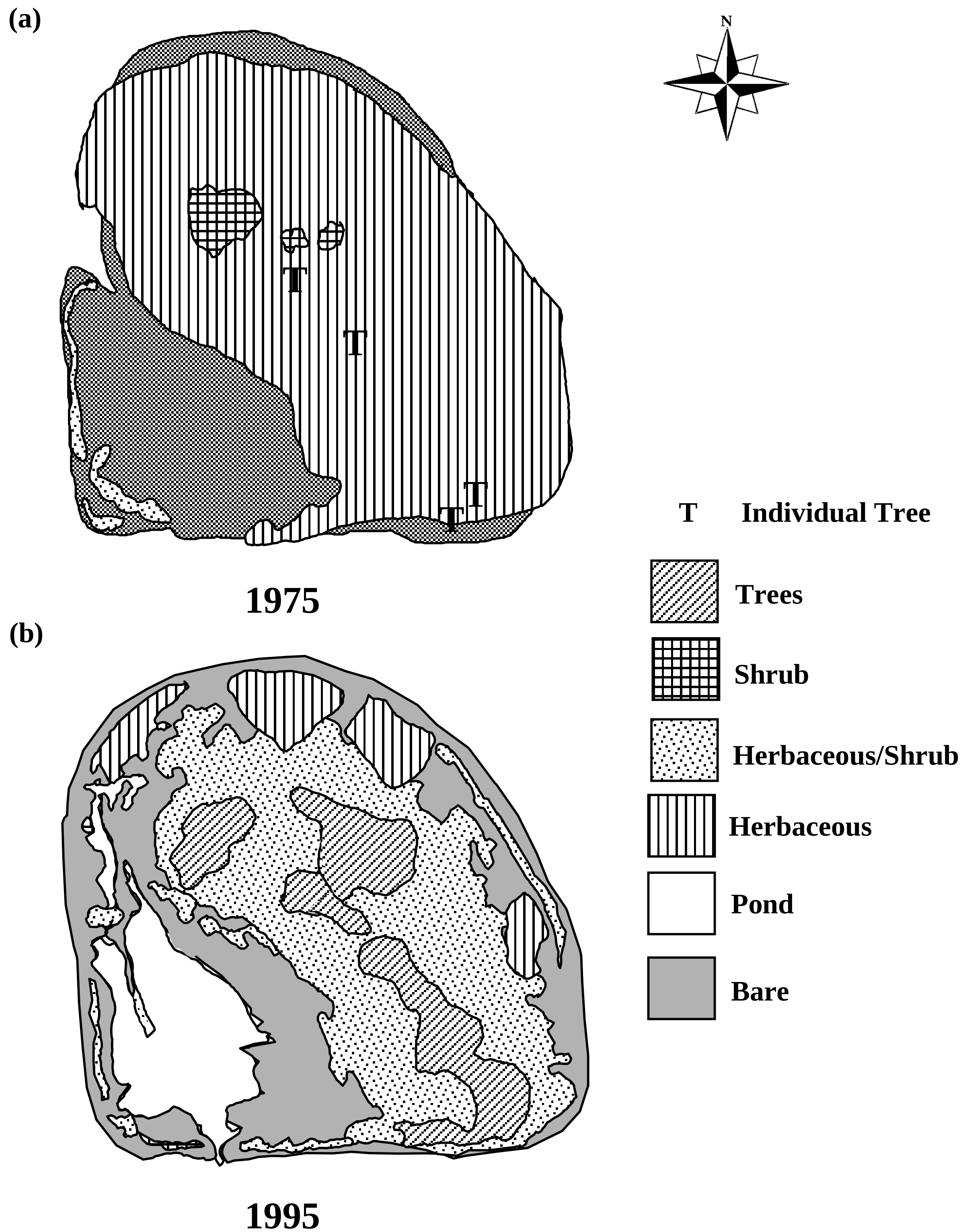


Figure 46. Nesting habitat for Marker 17 (New Marker 35) in Marker 2-17 (New Marker 13-35) from (a) 1975 (modified from Chaney et al. 1978) and (b) 1995.

shorelines since 1978, resulting in loss of some herbaceous, salt-tolerant species on the east, and several grass/shrub (herbaceous/shrub) associations along the southern shoreline. Increase in shrub and shrub/tree habitats occurred in the middle of the island, as well as development of shrub habitat in the southeastern quadrant. The islands are within the boundary of PINS (Chaney et al. 1978, TCWS, 1982).

Marker 81 (New Marker 163) Spoil Island is located in upper Laguna Madre adjacent to the GIWW within the boundary of PINS (see Fig. 45). The dredged material island encompassed about 1.7 hectares in the 1970's (TCWS, 1982) but had decreased to about 1.11 hectares in 1986 (Coste and Skoruppa 1989); nesting habitats include shrubs, subshrubs, and bare sand (TCWS, 1982). The entire island continued to decrease in areal extent from erosion (Fig. 48). Bare habitat suitable for ground-nesters in the 1970s became intertidal flats along the southern portions, and the northern perimeter exhibits an abrupt terrace from herb/shrub habitat to a narrow bare beach, intertidal habitat. A narrow herbaceous area is located downslope from the higher, herbaceous/shrub habitat primarily composed of *Paspalum vaginatum* (seashore paspalum). The herb/shrub habitat included *Aster tenuifolius* (saline aster), *Ambrosia psilostachya*, overlying *Cynodon dactylon* (bermudagrass).

Selected Rookery Island Nesting Population Trends

Twenty colonies were variously surveyed between 1973-1990 in upper Laguna Madre (TCWS, 1998). Many colonies encompass several dredged material islands in proximity to each other and adjacent to other colony designations. Two islands have sufficient data during the survey to assess within-colony population trends; however, since numerous colonies are located in a limited spatial area, no evaluation can be attempted for among-colony dynamics.

The South of South Bird Island rookery appeared to exhibit two cycles of nesting populations (Fig. 49a). Most years ranged about 4000 nesting pairs of colonial waterbirds, although the 1978 survey documented >15,000 pairs, a peak year for Laughing Gulls (Fig. 49e), Sandwich Terns (Fig. 49a), and Cattle Egrets (Fig. 49f). The rookery is important to many shrub/tree nesting species, such as White-faced Ibises, Tricolored Herons, and Reddish Egrets (Fig. 49b). Rookery use increased through time for Great Egrets, whereas peak usage for Great Blue Herons occurred in the 1980's (Fig. 49c). Roseate Spoonbills also increased in the rookery beginning in the 1980's (Fig. 49e). Snowy Egrets exhibited variable pair values throughout the survey, and during the 1980's exceeded 100 pairs (Fig. 49d). Numbers of Black-crowned Night-Herons and White Ibises were sporadic with low pair values throughout the survey (Fig. 49d,e). Cattle Egrets were documented most years with about 500 pairs each year, with peaks in 1976, 1978, 1979, and 1984. Sandwich Tern numbers typically were less than Royal Tern numbers when both were present, however, an extremely high pair value for Sandwich Terns was recorded in 1978 (Fig. 50a). Black Skimmers were not numerous in the 1970's and early 1980's, and were not recorded in the rookery after 1982 . Although 1978 was a peak year for Gull-billed Terns, this species and Caspian Terns were virtually nonexistent in the following years (Fig. 50c). Least Terns were only documented in 1979 and 1984, and two pairs of Forster's Tern were recorded in 1975 (Fig. 50d). Laughing Gulls were variable in pair values throughout the survey, but appeared to maintain a nesting population of 2000-3500 pairs (Fig. 50e). This rookery was utilized by American White Pelicans as they moved off South Bird Island in the mid-1970's and peak use occurred in the early 1980s (Fig. 50f). The nesting population moved to Marker 81 (New Marker 163) rookery, where they remained throughout the 1990's.

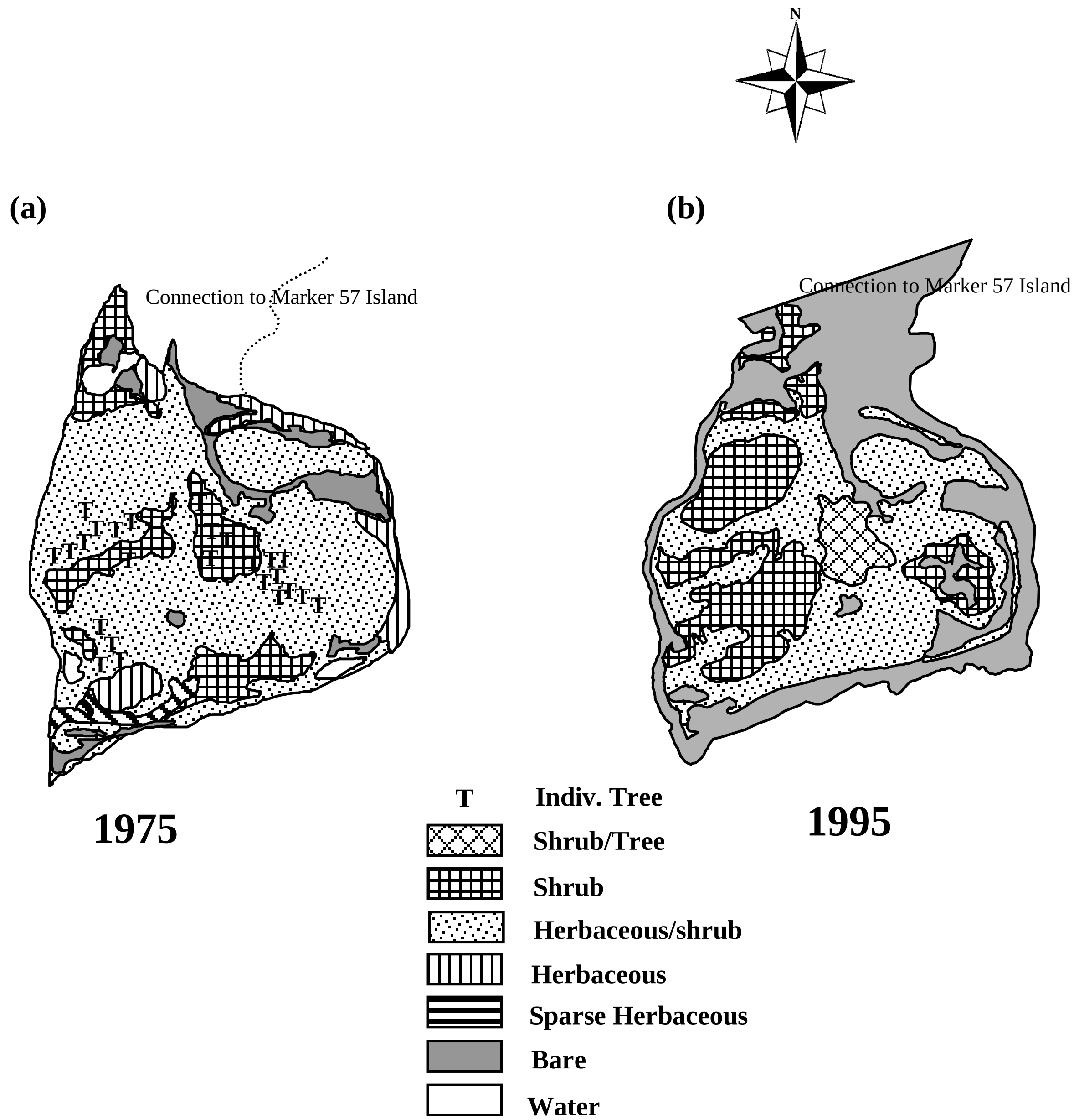


Figure 47. Nesting habitat for Marker 57A island (part of South of South Bird Island rookery) from (a) 1975 (modified from Chaney et al. 1978) and (b) 1995.

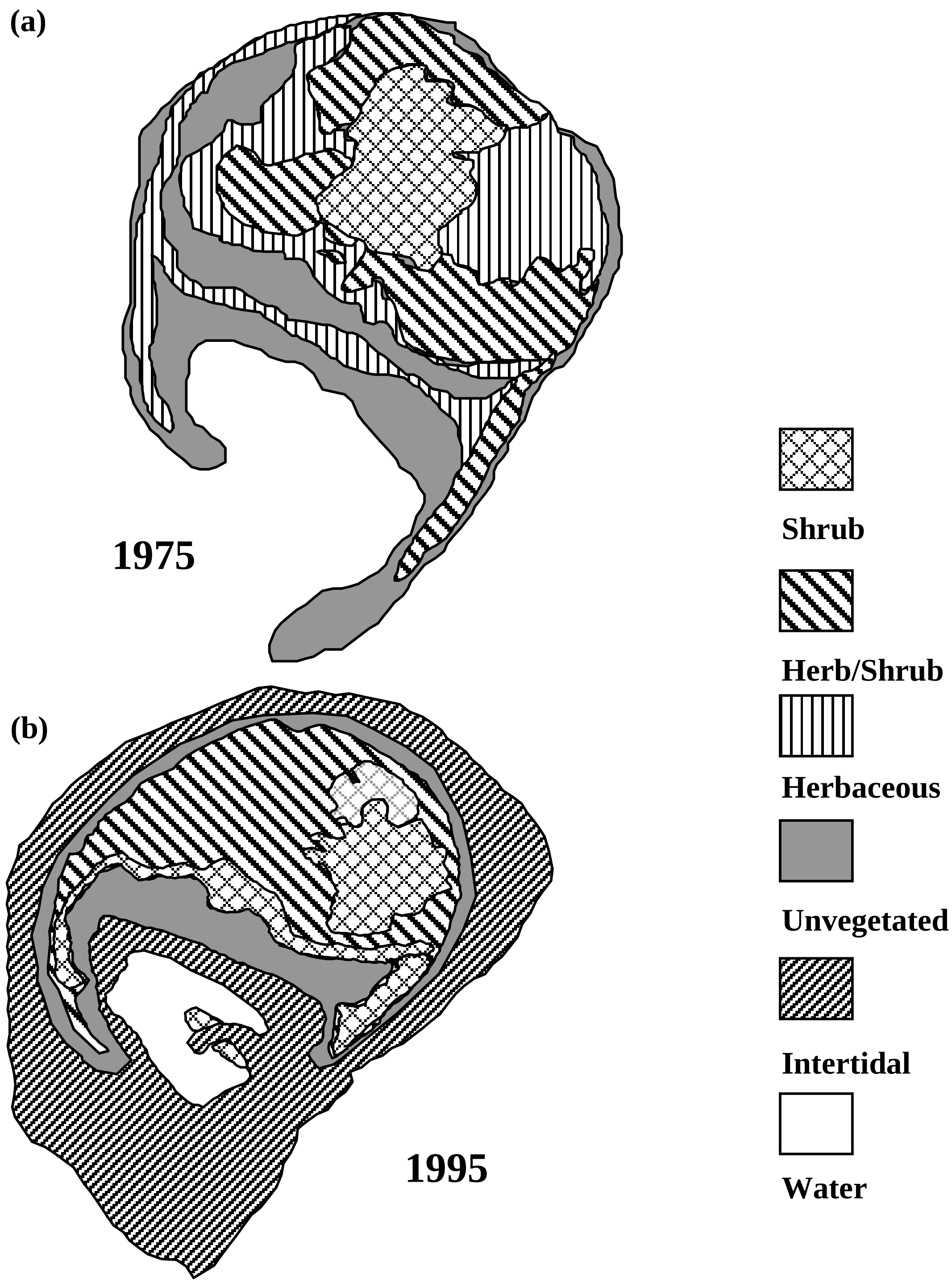
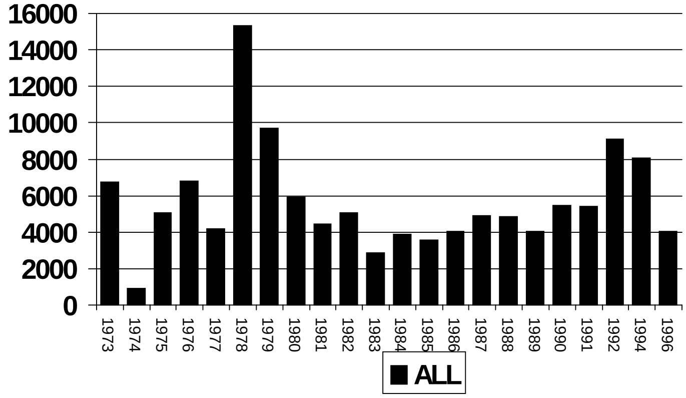
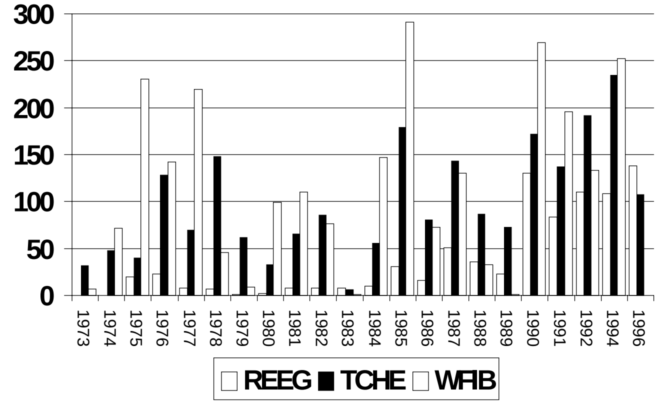


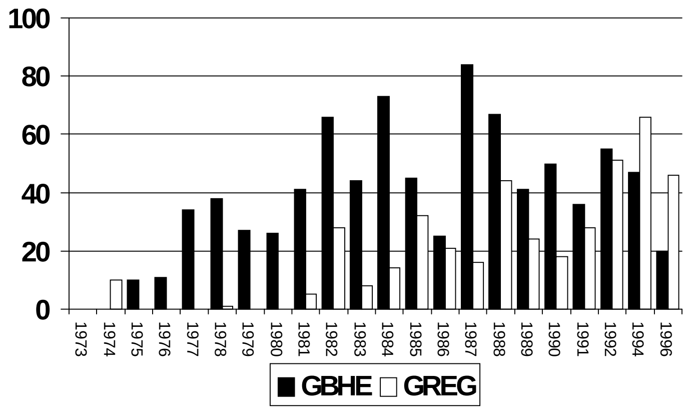
Figure 48. Nesting habitat for Marker 81 (New Marker 163) rookery from (a) 1975 (modified from Chaney et al. 1978) and (b) 1995.



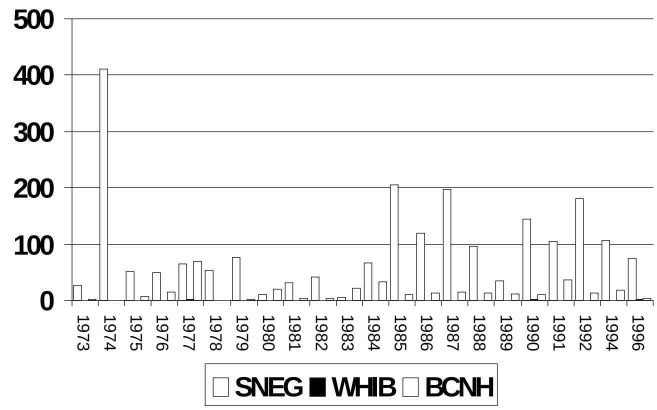
(a) all pairs



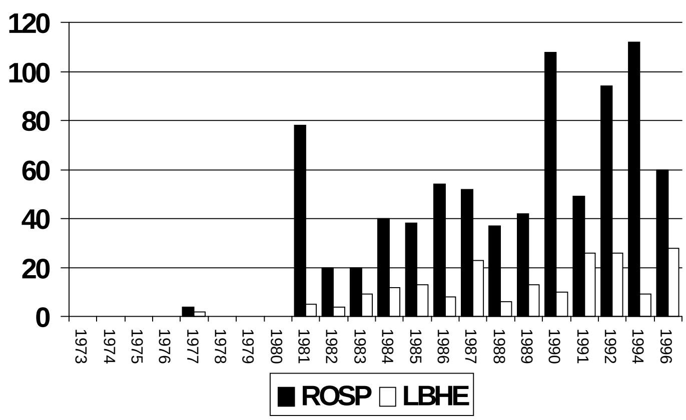
(b) Reddish Egret, Tricolored Heron, White-faced Ibis



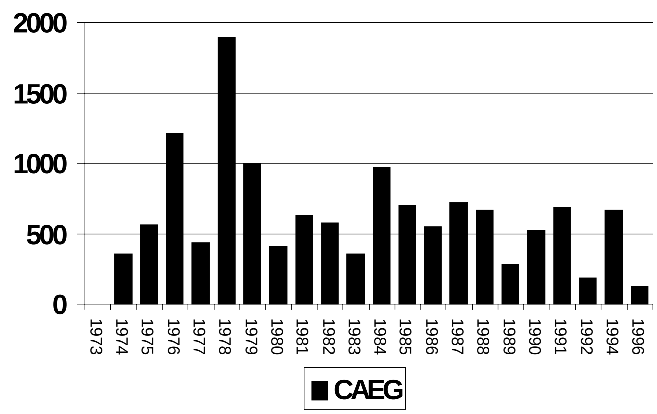
(c) Great Blue Heron, Great Egret



(d) Snowy Egret, White Ibis, Black-crowned Night-Heron



(e) Roseate Spoonbill, Little Blue Heron



(f) Cattle Egret

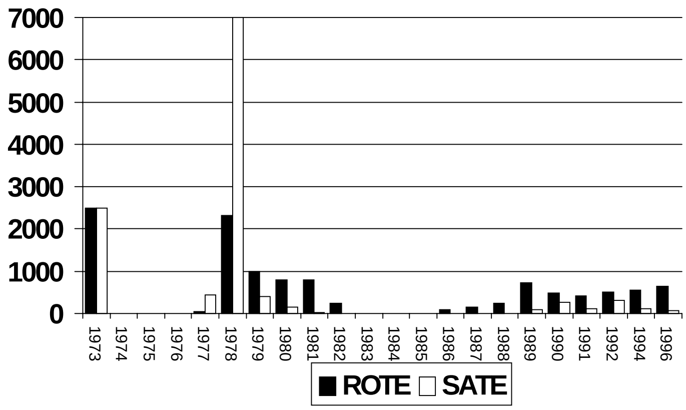
Figure 49. Year pair totals of (a) all colonial waterbird species that have utilized South of South Bird Island rookery, and (b-f) species that prefer shrub/tree habitat from 1973-1996.

Marker 81 (New Marker 163) rookery generally supported between 500 and 1000 pairs of nesting colonial waterbirds during 1973-1994, with values decreasing in 1992 and 1994 (Fig. 51a). The rookery originally supported abundant nesting populations of Reddish Egrets, Tricolored Herons, and White-faced Ibises in 1970's, but all populations decreased through time (Fig. 51b). Snowy Egrets generally maintained a nesting population at about 40 pairs each year, although some years the rookery supported higher pairs (1974, 1976, 1979, 1985) and other years much lower (1978, 1983, 1989, 1994) (Fig. 51d). Great Egrets were not predominant shrub/tree nesters; White Ibises, Black-crowned Night-Herons, and Little Blue Herons nested intermittently (Fig. 51c,d,e). Roseate Spoonbill numbers peaked in 1978 at 120 pairs, decreased for several years, then were not present after 1986 (Fig. 51e). Cattle Egret numbers increased during 1976-1980, then decreased to low pair values (Fig. 51f). Several ground-nesting species were predominant in the first year of the survey including Black Skimmers, Gull-billed Terns, and Forster's Terns; these species were not abundant in following years (Figs. 52b,c). Laughing Gull pair values decreased throughout the survey (Fig. 52e), whereas royal and Sandwich Terns were first recorded in 1986 (Fig. 52a). The American White Pelican colony began shifting to Marker 81 (New Marker 163) rookery in 1982, supporting the main nesting population along the Texas Coast (Fig. 52f).

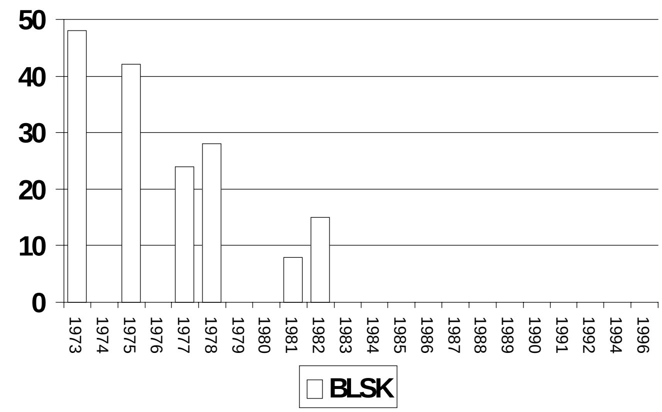
Selected Species of Concern Overview

Brown Pelicans made a dramatic recovery in the CCBNEP area since the early 1970s, pirmarily establishing a rookery on Pelican Island Spoil in northern Corpus Christi Bay (Fig. 53). However, pelicans also nested in other rookeries during the survey. Brown Pelicans were recorded in the Second Chain of Islands rookery in Ayres Bay at the northern edge of the CCBNEP area. Few pairs (<10) were documented in the 1970's, but between 12-22 pairs nested in the rookery in the early 1980s. Then, no nesting birds were observed until 1989, when ten pairs were documented. Long Reef/Deadman Island Rookery recorded ten pairs in 1977 and 17 pairs in 1979. No definitive data exists explaining if these pairs were expanding their nesting range from Pelican Island, or if they were migrating into the area from the north (upper Texas coast and Louisiana) or the south (Laguna Madre Tamaulipas and other populations along the Mexican coast) (Elliott, 1995). However, populations did not persist in either rookery. Several potential factors were identified that may determine where rookeries may be established: proximity to passes for increased water clarity and prey availability, vegetated areas that would support a nest on or near the ground, and limited human disturbance (Elliott, 1995). Importance of Pelican Island Spoil rookery to this Brown Pelican nesting population necessitates close supervision and protection for continued recovery.

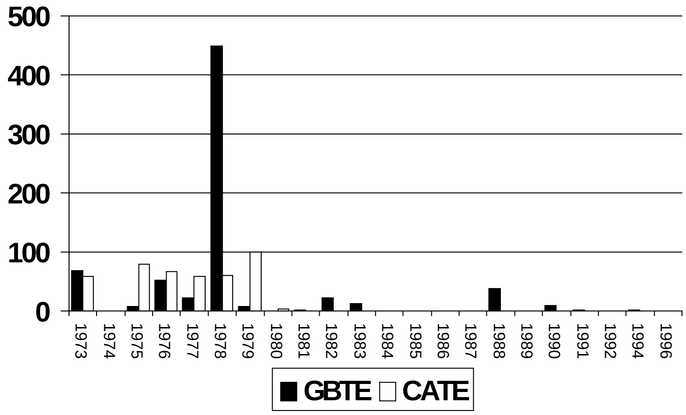
American White Pelicans sustained a nesting population in upper Laguna Madre for many years, although they moved from island to island in the past 20+ years (Fig. 54). The nesting population was documented on South Bird Island rookery during 1973-1975. In 1976 and 1977, some pairs had established nests at nearby South of South Bird Island Rookery. No birds nested in the latter rookery in 1978 and few were recorded in 1979. On South Bird Island, total pair numbers were lower during these years, and 100 pairs nested in South of South Bird Island in 1980. In 1981, the only nesting population occurred in this rookery. The birds appeared to begin migrating southward to Marker 81 (New Marker 163) Island rookery in 1982, then the entire nesting population began nesting in this rookery during 1983-present; one nesting pair was documented in South of South Bird Island rookery in 1986. Several explanations were postulated to understand this species' migration among these islands: elevated ectoparasite levels in established rookeries, storms, predator disturbance, and brood reduction (Chapman, 1988). Since the islands are located within the PINS, the rookeries experience limited human disturbance. Alternately, the island's location in proximity of the bay shoreline of Padre Island and the shallow lagoon between the rookeries and island could be a corridor for predators (e.g., coyotes,



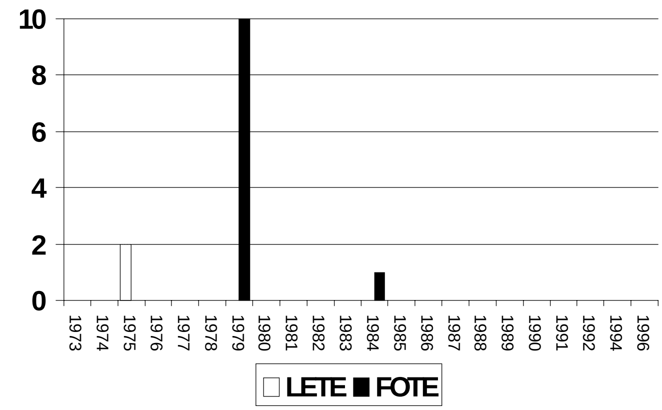
(a) Royal Tern, Sandwich Tern



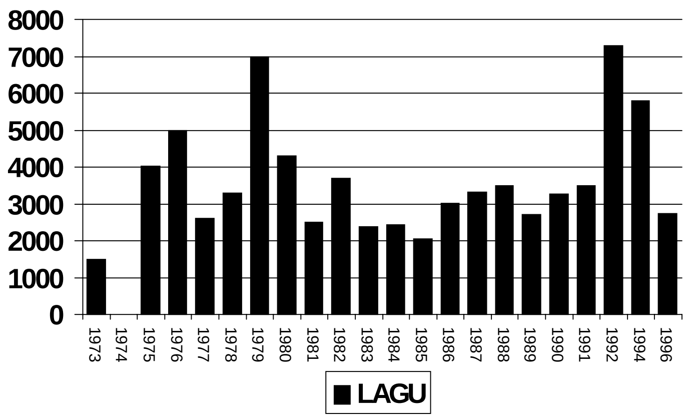
(b) Black Skimmer



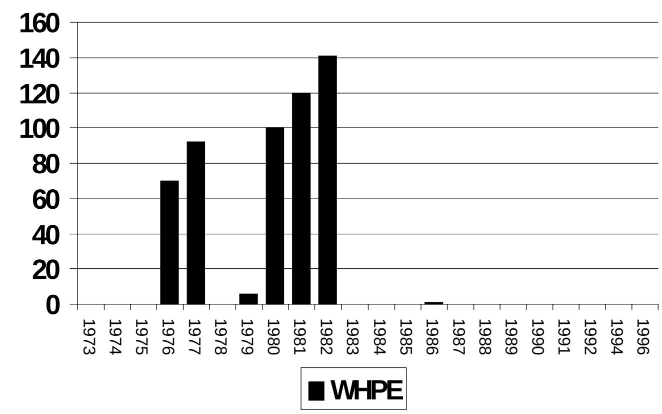
(c) Gull-billed Tern, Caspian Tern



(d) Least Tern, Forster's Tern

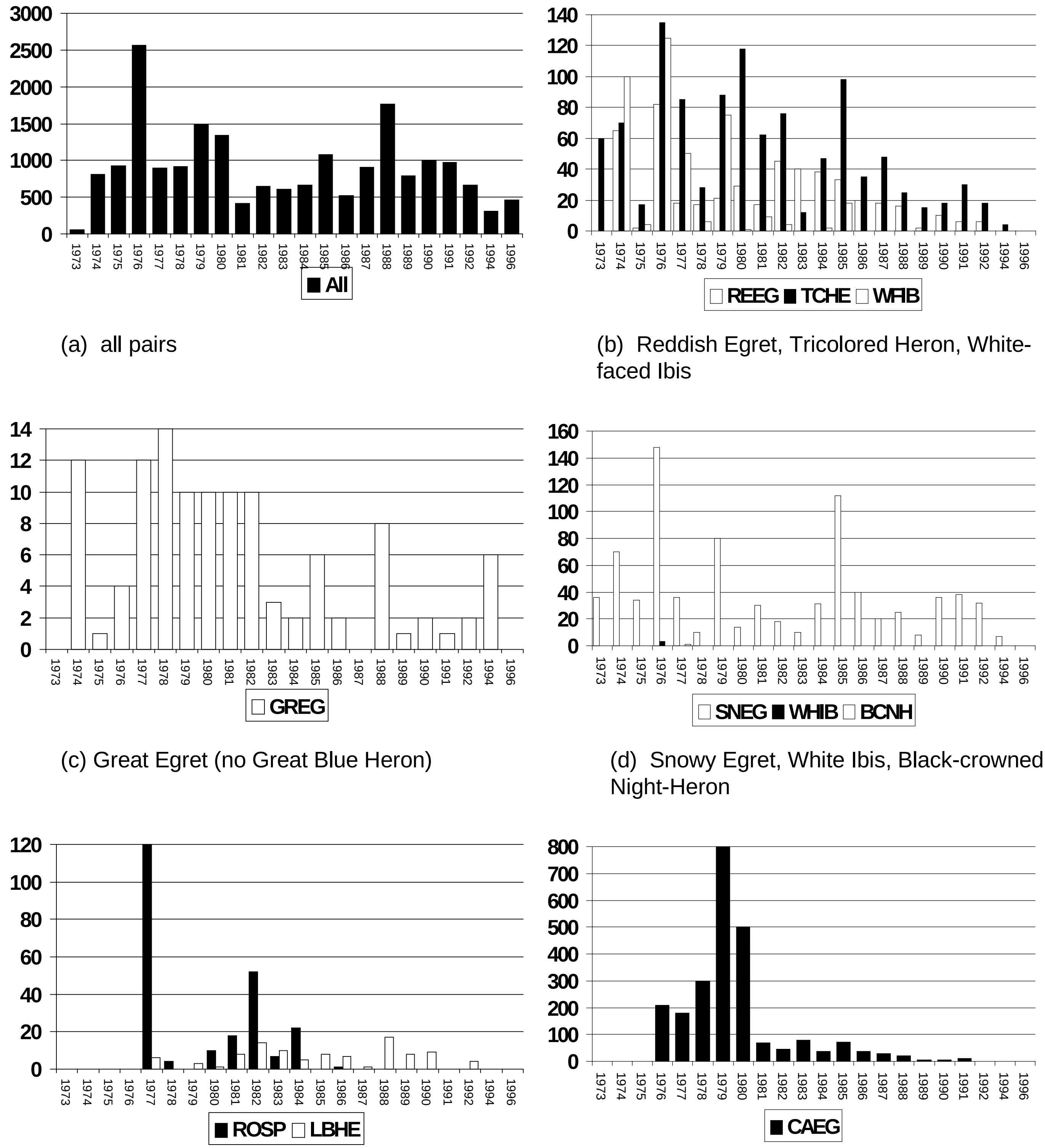


(e) Laughing Gull



(f) American White Pelican

Fig. 50. Year pair totals of (a-f) ground-nesting colonial waterbird species that have utilized South of South Bird Island rookery from 1973-1996.



(a) all pairs

(b) Reddish Egret, Tricolored Heron, White-faced Ibis

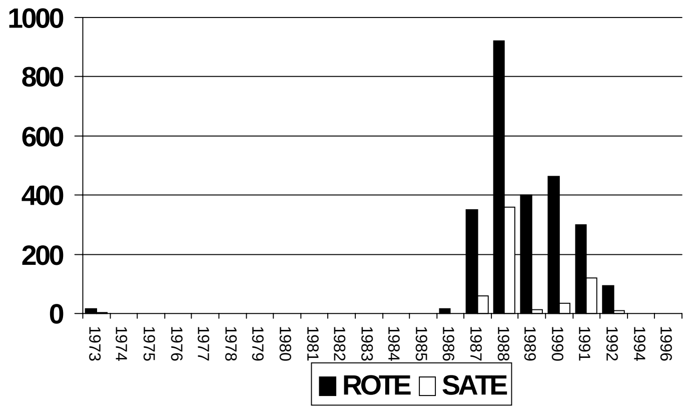
(c) Great Egret (no Great Blue Heron)

(d) Snowy Egret, White Ibis, Black-crowned Night-Heron

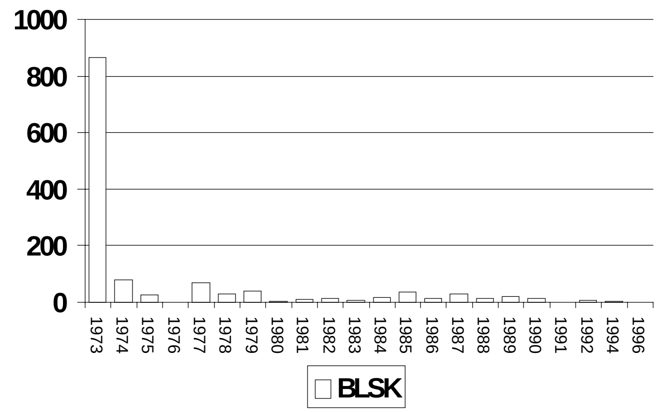
(e) Roseate Spoonbill, Little Blue Heron

(f) Cattle Egret

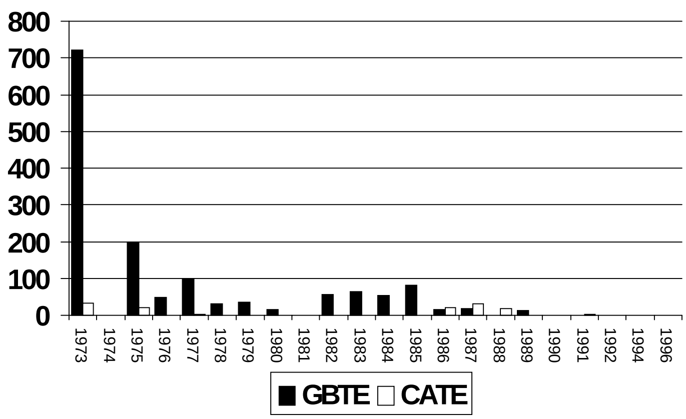
Figure 51. Year pair totals of (a) all colonial waterbird species that have utilized Marker 81 Dredged Material Island Rookery, and (b-f) species that prefer shrub/tree habitat from 1973-1996.



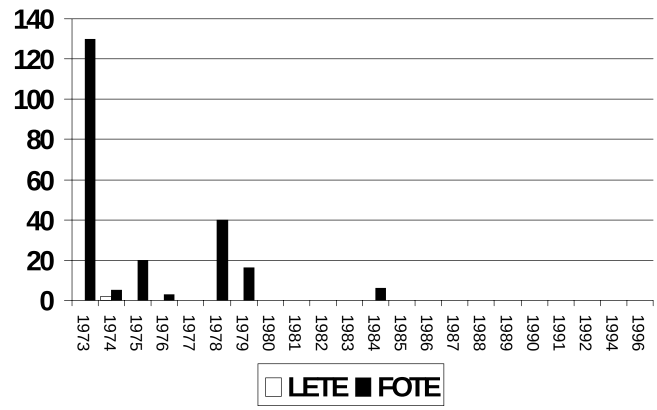
(a) Royal Tern, Sandwich Tern



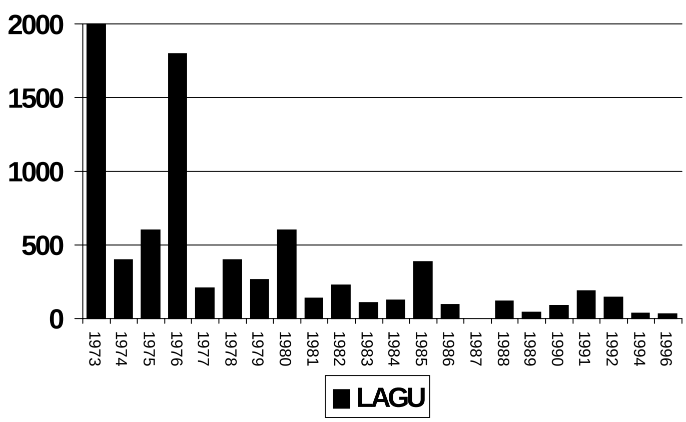
(b) Black Skimmer



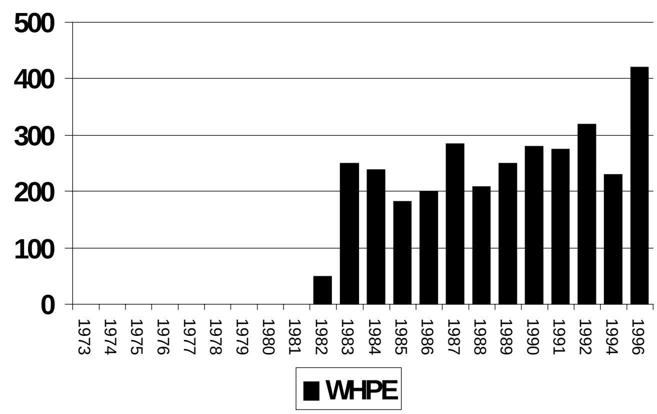
(c) Gull-billed Tern, Caspian Tern



(d) Least Tern, Forster's Tern



(e) Laughing Gull



(f) White Pelican

Figure 52. Year pair totals of (a-f) ground-nesting colonial waterbird species that have utilized Marker 81 Dredged Material Island Rookery from 1973-1996.

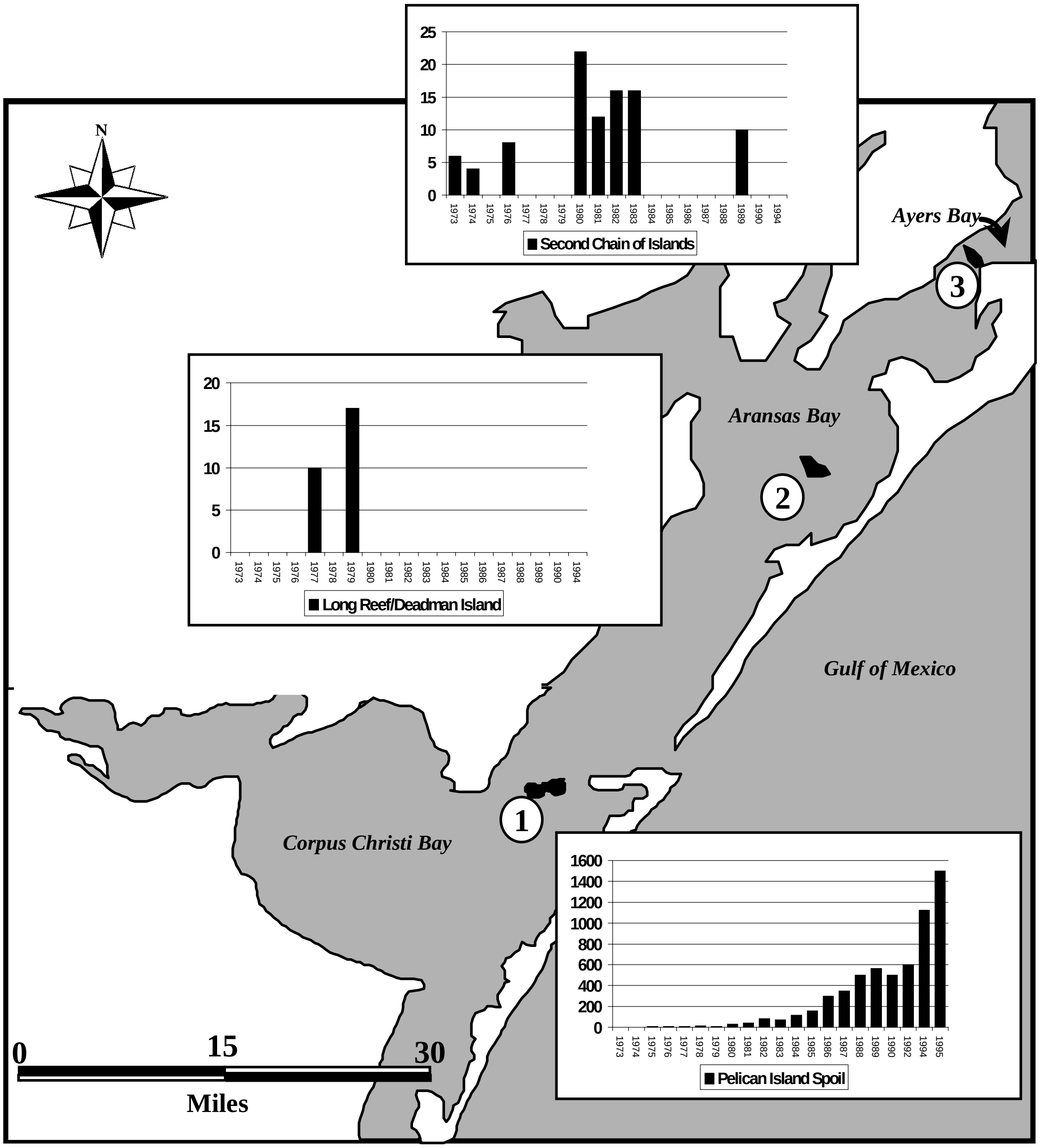


Figure 53. Summary of nesting population dynamics for the Brown Pelican in CCBNEP area documented from (1) Pelican Island Spoil, (2) Long Reef/Deadman Island, and (3) Second Chain of Islands rookeries.

raccoons, feral hogs) in years of extremely low spring tides. Although no documentation exists of storm tides decimating the nests and young, it is possible the birds moved following repeated nest failures. Additionally, it was noted that although nesting pairs are an indirect indicator of nest success, years were documented (1930, 1978, 1981) where pairs produced eggs or young later abandoned prior to fledging.

Probable Causes of Changes in Rookery Island Dynamics and Recommendations

Habitat Loss and/or Habitat Degradation

Natural and dredged material island loss has not been quantified in the CCBNEP area, although some islands became inactive as rookeries through time. Because a rookery often encompasses several islands, nesting populations may shift among islands within a colony, making distinct evaluations of an island's importance difficult. Erosion was cited as a primary factor as well as changes in vegetation types (i.e., from bare to vegetated) (Chaney et al. 1996). Factors driving erosion in south Texas include predominant southeast winds in summer and high-velocity winds from northers during winter. Wave action from watercraft may accelerate rate of erosion.

Several rookeries were identified as exhibiting erosion problems (Table 72). Islands composed of finer clays and silt often exhibit steep shelf shorelines, eliminating potential habitat for ground nesters around the island perimeter. Dredged material islands, such as Marker 81 Spoil Island (New Marker 163) rookery, exhibited low, sloping elevation gradients to the south and abrupt shoreline terrace along the northern shorelines. Even natural islands, such as North Bird Island, eroded to where most habitat is comprised of vegetated areas, with little to no beach habitat for ground-nesters requiring bare substrates above the high tide level.

Reworking of shoreline sediments is difficult to evaluate without aerial photographs of sufficient resolution throughout successive years. Shamrock Island changed considerably through time, losing unvegetated shell berms on the north end, yet increasing the areal extent of this habitat on the southern end. Other natural islands eroded such that frequent tidal inundation occurs during the nesting season, resulting in nest failure for that year. Some rookeries were renourished through beneficial uses of dredged material to reestablish unvegetated nesting habitats. Through a cooperative effort of the National Audubon Society and US Army Corps of Engineers, renourishment programs were implemented in Long Reef/Deadman Island and Pelican Island Spoil rookeries. Renourishment activities should be designed to increase habitat area for nesting colonial waterbird, yet maintain structural diversity of other important habitats within the rookery. Renourishment should not "link" independent islands together, as a corridor for predators may be established [e.g., Marker 103-117 (New Marker 207-221) Spoil Island rookery in Baffin Bay area] (Coste and Skoruppa, 1989). Sediment size is an important consideration when evaluating renourishment options, as finer sediments settle in existing channels and are difficult to place in a selected areas. Some rookeries adjacent to maintained channels will not result in substrate enhancement because of this type of dredged material available (e.g., False Live Oak Point) (Coste and Skoruppa, 1989). Source of dredged material is critical to evaluate potential of pollutants in the sediments (heavy metals, petroleum hydrocarbons, polychlorinated biphenyls, and organochlorines) (L. Gamble, pers. comm., in Coste and Skoruppa, 1989). Final elevations of the renourished site are very important as well, as sediments at low elevations will wash away during high tides and sediments at high elevations are subject to wind erosion (Chaney et al. 1978). Often islands are not adjacent to dredged material sources, either because of natural locations or they were created with material from a channel no longer maintained. The

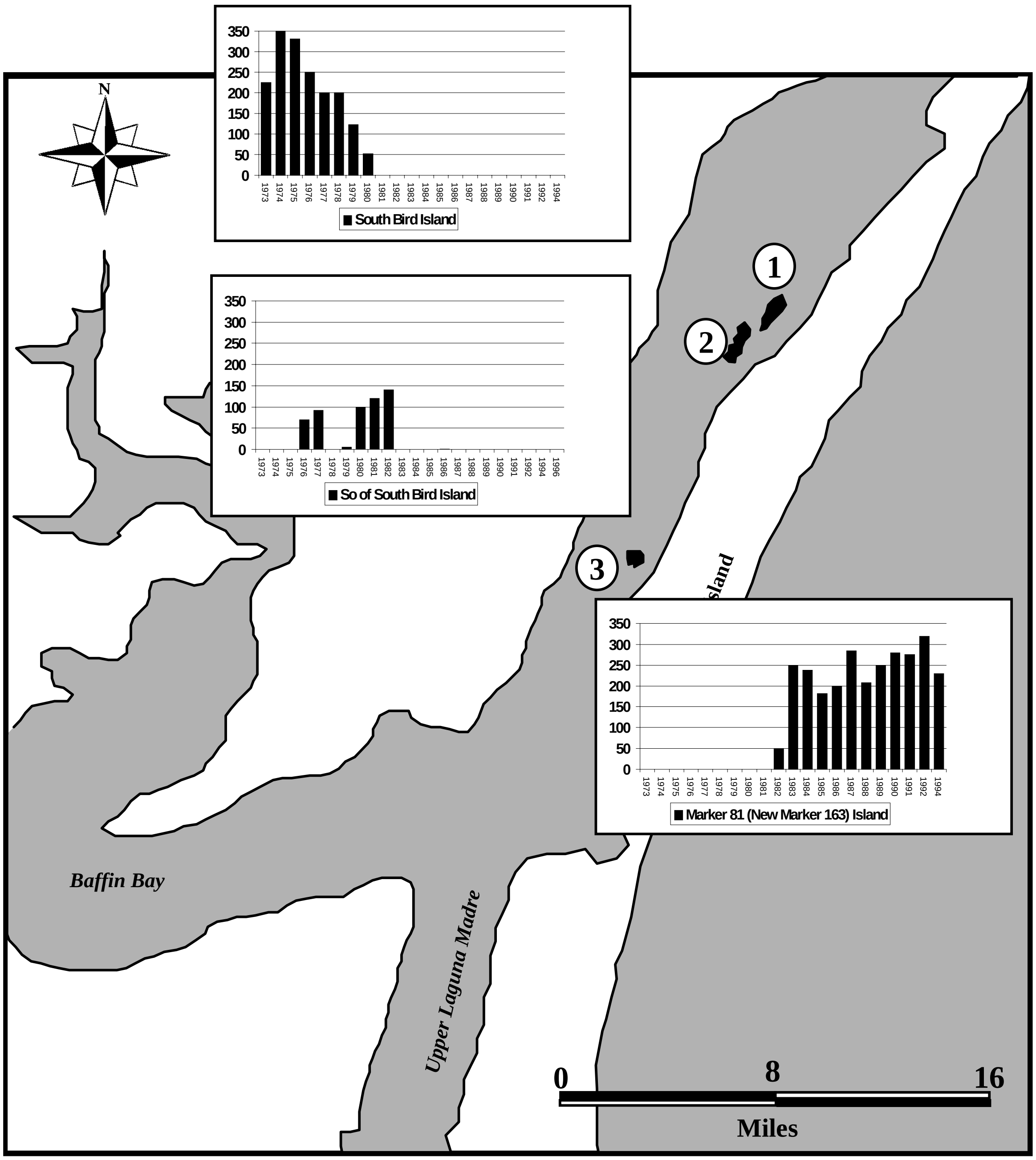


Figure 54. Summary of nesting population dynamics for the American White Pelican in CCBNEP area documented from (1) South Bird Island, (2) South of South Bird Island, and (3) Marker 81 (New Marker 163) spoil island rookeries.

Table 72. Potential causes of nesting colonial waterbird population shifts, declines or abandonment in rookeries within the CCBNEP area (north of Baffin Bay) (adapted from Coste and Skoruppa, 1989).

Rookery	Erosion	Vegetation succession	Predation	Human disturbance
Ayres/Mesquite Bays				
False Live Oak Point	X			
Aransas Refuge Spoil		X	Raccoons	Limited
Second Chain of Islands	X			Moderate
Cape Carlos Dugout			Raccoons	
Cedar Bayou			Coyotes, Raccoons	Minimal
Aransas Bay				
Panther Reef			Raccoons	Limited
Ballou Island			Raccoons	Moderate
Long Reef/Deadman Island	X		Fire Ants	Limited
San Jose Reef/Platforms			Raccoons	Limited
Balckjack Point Reef		X	Raccoons	
Redfish Bay				
Danger Island			Coyotes, Raccoons	Minimal
Aransas Channel Spoil			Coyotes, Raccoons	Limited
Ransom Island/Spoil		X	Coyotes, Raccoons	Moderate
Causeway Islands/Platforms	X			Moderate
Big Bayou Spoil			Coyotes, Raccoons	Heavy
Hog Island Complex			Coyotes, Raccoons	Heavy
Harbor Island			Raccoons	Moderate
Stedman Island			Raccoons	Heavy
Emilie Island			Raccoons	Moderate
Hwy 361 Spoil			Raccoons	
East Shore Spoil			Coyotes, Raccoons	
Nueces Bay				
West Nueces Bay	X		Fire Ants	Moderate
East Nueces Bay	X		Fire Ants	Heavy
Sunset Lake			Domestic dogs	Heavy
Corpus Christi Bay				
LaQuinta Spoil Islands			Raccoons	
Sun Oil Channel Spoil			Raccoons	Heavy
Castor's Cut			Coyotes	
Upper Laguna Madre				
GIWW Marker 51 Spoil			Raccoons	Moderate
NAS Islands			Coyotes, Raccoons	Limited
Marker 13-35 Spoil			Coyotes	Moderate
Marker 65-74				Moderate-Heavy
Marker 72-75			Coyotes, Raccoons	Heavy
North of Bird Island (Marker 87-91)			Coyotes, Raccoons	
North Bird Island	X		Coyotes, Raccoons	
West Side Spoil Islands			Coyotes, Feral Cats	
South Bird Island			Coyotes	
South of South Bird Island			Coyotes, Badger	Limited
Marker 72 Spoil Island				Moderate-Heavy
Marker 81 (New Marker 163)	X			Minimal

Causeway Islands/Platforms rookery in Redfish Bay is adjacent to a channel no longer in use, so renourishment is unlikely (Coste and Skoruppa, 1989). In many cases, the rookery may be surrounded by other sensitive estuarine habitats; for example, Second Chain of Islands in Ayres Bay is adjacent to prime oyster reef and seagrass meadow habitat. Renourishment activities around this rookery would probably result in degradation of other essential habitats, a strategy strongly discouraged (Coste and Skoruppa, 1989).

Other rookeries experiencing continued erosion may benefit from placement of sandbags, riprap, or offshore reefs. One of the islands in the East Nueces Bay rookery had protective measures employed along portions of the shoreline to reduce erosion (Coste and Skoruppa, 1989). Riprap placed on the northern shoreline of Pelican Island Spoil rookery resulted in erosion rate reduction and perches for Brown Pelican (E. Payne, pers. comm. in Coste and Skoruppa, 1989). The Causeway Islands/Platforms and Marker 81 (New Marker 163) rookeries in Redfish Bay and upper Laguna Madre, respectively, were suggested as potential sites for shoreline protection on the north side and protecting existing vegetated habitats and south-facing unvegetated shorelines from further erosion (Coste and Skoruppa 1989). Shamrock Island in Corpus Christi Bay is under consideration for extensive shoreline protection measures to minimize further erosion to the islands north and interior habitats (J. Bergan, pers. comm.).

Vegetation succession on dredged material islands along the south Texas coast proceed at a slower rate in south Texas than was documented in the upper coast of Texas and other East Coast areas due to lower rainfall and higher evaporation rates (Chaney et al. 1978). Existing island vegetation communities appeared to be maintaining similar patterns on islands evaluated in this study, although the density of prickly pear and mesquite increased at the apex of many islands since 1978. Several rookeries were listed as becoming inactive due to loss of ground-nesting habitat for skimmers, gulls, and terns (see Table 5). Some species may tolerate changes in vegetation in their nest site if they selected the site under optimum conditions. Eventually, if succession continues, the species will abandon the site in search of an alternate area (Parnell et al. 1988). Therefore, sites in various stages of succession will support a diversity of colonial waterbirds in an area. Some vegetation communities may be maintained naturally at a particular stage as a result of limited nutrients, water, or space; other methods were employed to mechanically set back successional stages (e.g., burning, mowing, use of herbicides, placement of dredged material) (Parnell et al. 1988). All methods may change the vegetation composition structure for a period of time; however, some methods may actually enhance vegetation growth (Soots and Landin, 1978). Placement of new material should be designed to minimally change the site elevation (Chaney et al. 1978).

Predation

Many rookeries became inactive or exhibit decreased numbers in the CCBNEP area due to increased predation pressure by raccoons, coyotes, fire ants, feral hogs, and other species of colonial waterbirds. Rookeries having mainland connections or shallow waters between the mainland and the rookery increase probability of mammalian predation. Several rookeries were listed as inactive due to predation in the CCBNEP area (see Table 72). Implementation of predator removal/control is dependent upon probability of reestablishment and effects of other impacts on the rookery recovery (human disturbance, appropriate habitat). Active removal of predators on Harbor Island by Animal Damage Control was undertaken in the past, however, continued removal is necessary through annual or semi-annual trapping. The islands within the Naval Air Station rookery in upper Laguna Madre are isolated from both the mainland and each other. This rookery is stable, therefore, an active predator removal program on a semi-annual or annual basis would be beneficial. Other rookeries with stable populations were recommended as well: Marker 35 dredged material island (part of Marker 2-17 Spoil Islands (New Marker 13-35), Marker 72 Spoil Island) New Marker 152), North of Bird Island Marker 43 (New Marker 87-91), South Bird Island, and South of South Bird Island (Coste and Skoruppa, 1989). Fire ant control was suggested for Long Reef/Deadman Island, West Nueces and East Nueces Bay rookeries (Coste and Skoruppa, 1989). A project was initiated in Second Chain of Islands rookery following 100% mortality of colonial waterbird chicks on some islands in 1991 (A. Strand and S. Robertson, pers. comm. in Roper, 1992). An insecticide (Logic) was applied in 1991 and 1992, however, the birds did not recolonize the site. Therefore, quantitative assessments of the treatment were not obtainable. Treatments using the same insecticide was employed during the fall in a rookery at Rollover Pass in east Galveston Bay, where suppression of fire ant populations was achieved. This method of treatment may be cost prohibitive and insecticide effects on other organisms is not well understood (Roper 1992).

The introduction of domestic and/or feral animals within or adjacent to a rookery may have devastating effects on colonial waterbird nesting success. Rookeries in proximity to urban areas may be preyed on by domestic dogs (Sunset Lake rookery) feral cats (West Side Spoil Islands rookery) (Coste and Skoruppa, 1989), or feral hogs (South of South Bird Island rookery) (Smith and Cox pers. observ.). Other studies identified similar introduced predators, including domestic cats and rats (Anderson et al. 1989). The introduction of rabbits on some dredged material islands in upper Laguna Madre may support predators year-round, increasing their potential of being present when the colonial waterbirds begin the nesting phase.

Predation by other species within the colony also occurs; Black-crowned Night-Herons were associated as predators by Common Terns at night in a rookery in New Jersey. Nocturnal predation by the night herons also caused an increase in predation by gulls and ants when the parents deserted the nest (Shealer and Kress, 1991). Nocturnal predation by owls on adult gulls was documented in several studies, and indicate avian predators may maximize prey availability in colonial waterbird colonies. The adults may be the prime prey target, but the young are also negatively impacted by environmental stresses or surplus taking by the owls. Newly hatched chicks are particularly susceptible to low temperatures or rain when left unprotected (Southern et al. 1982).

Effects of continued predation may be directed toward a particular suite of colonial waterbird species. During a three-year study of dredged material island rookery in South Carolina, White Ibises were continually predated upon by fish crows and large mammals to local extinction. Other wading bird species’ survival rates were lower one year, but returned to previous values the following year. Factors attributing to the ultimate decline of White Ibises included the significant interspecific differences of nest height and nest stability (Post 1990).

Human Disturbance

Nesting success of colonial waterbirds is differentially affected by human disturbance. Each species appears to exhibit a different tolerance level to the presence of humans, that may also change during the breeding cycle. Whereas wading birds often leave the nest and retreat to nearby shallow water habitats, gulls and terns often fly overhead until the disturbance is abated (Vos et al. 1985, Erwin, 1989). The additional impact of prolonged disturbance occurs when the young are unprotected from environmental conditions (e.g., intense heat during day, cold temperatures at night), when young chicks retreat to the water and are blown offshore, or from predation on the eggs and young from other colonial waterbirds (primarily Laughing Gulls) (Chaney et al. 1978). Additional mortality may occur as the result of hatching failure, lower feeding rates, injury, lower growth rates (as a result of less food or regurgitation of food), premature fledging, and colony abandonment (Burger, 1981, Rodgers and Burger, 1981).

Disturbance by humans may occur by physically walking on the islands, wading around the islands, or passing by in a boat; and, unintentional and intentional disturbance have the same negative effect. Additional impacts occur when colonial waterbirds establish nests on dredged material islands where cabins are still permitted or where houseboats are anchored nearby (Coste and Skoruppa, 1989). Whereas humans are not allowed in rookery areas in CCBNEP area during January-September, enforcement is difficult. Public education may be the most important deterrent to continued human disturbance. Monitoring and research activities during the breeding cycle should also be designed carefully. The presence of a human in the rookery may modify the behavior of the colony, thus biasing the observation, or may cause the colony to abandon the site. The timing and frequency of the visits should be carefully assessed (Tremblay and Ellison, 1979, Rodgers and Burger, 1981).

Black Skimmers appear to be extremely sensitive to disturbance, although the degree of impact changes throughout the reproductive cycle. They seem most sensitive to disturbance early in the prelaying phase, where they would abandon the disturbed site and select an alternate, less-disturbed site nearby. Because of these early movements to alternate sites, these sites may result in higher nesting densities. Intraspecific aggression may increase in the colony, and lowering nesting success. The early incubation phase was also a sensitive period in response to disturbance, and the skimmers would abandon their nests if disturbed. As incubation progressed, the skimmers were less likely to abandon or leave the nest for long periods. Hatching success was lower when disturbance occurred more frequently. Survivability during the chick phase was dependent upon amount of stresses experienced by the young. Gulls may predate on unprotected chicks, but other skimmer parents may also kill a chick wandering too close to their nest site (Burger, 1983).

Disturbance may be reduced by establishing “barriers” between the colony and human activities. Heronries isolated from adjacent human use areas by fencing or water-filled moats had a higher fledgling rate, than those surrounded by adjacent buffers of land or water. These two methods were most likely successful due to the degree of structure permanence; foot traffic through the rookery was effectively eliminated (Carlson and McLean 1996). Fencing was assessed for terns and skimmers, when low direct mortality by Black Skimmer chicks was observed, whereas Roseate Terns were injured more often (Safina and Burger, 1983). In a study assessing disturbance effects of several species after nest territories had been established, most birds did not flush when disturbance was >150 m away. Because birds are more easily disturbed when establishing nests, 200 m was suggested for Black Skimmers and Common Terns and 100 m for least and Royal Terns. Signs should be erected at least three weeks before nest establishment and should be spaced at 50 m intervals around the colony perimeter (Erwin, 1989).

Oil well activities during the breeding season may have negatively affected colony establishment and/or fledgling success in a Galveston Bay rookery. Breeding bird use in the rookery may have been affected early in the season when the pairs were establishing nesting territories. Many pairs did not use the previous year’s site, but were still located within the rookery. Some species, such as Roseate Spoonbill, did not establish nests at all that year, whereas White-faced Ibis established their nests after drilling activities had ceased (Mueller and Glass, 1988).

D. Management Recommendations

All avian nesting information used for this report focused on the Colonial Waterbird Census data. This database was maintained by the volunteer efforts of several individuals, and most data in the CCBNEP area was collected by a handful of individuals during the 20+ year period. This invaluable information is the only long-term database available to assess status and trends of colonial waterbirds and the habitats they require for nesting success. All efforts should be made to continue the collection of this information combining financial, logistical, and volunteer support levels. Continued partnerships among agencies, research and academic institutions, nonprofit conservation groups, and interest groups should be encouraged.

At present, quantitative data are not available to evaluate successional changes in vegetation or spatial changes of island configuration. Detailed studies of key rookeries should be conducted, particularly those essential to species of concern. This information would be useful to identify those islands that would benefit from dredged material deposits. In addition, personal observations and recommendations of colonial waterbird census participants are not documented. A workshop should be organized with the goal to synthesize all available information and comments. Through such an approach, recommendations could be made concerning how to protect sensitive rookery habitat, which areas are in need of restoration or enhancement, and methodologies necessary for future quantitative status and trends assessments.

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VIII. CONCLUSIONS

A. Wetland Status (1992)

- Wetlands and aquatic habitats in the CCBNEP study area are dominated by an estuarine system that encompasses about 161,000 ha and represents 83 percent of the wetland and deep-water habitats. The palustrine system is second at 14 percent (26,578 ha), followed by lacustrine (2.5 percent), marine (0.37 percent, excluding open water), and riverine (0.13 percent).

- Vegetated wetlands (marshes, scrub-shrub, and forested wetlands) have a total area of about 48,375 ha; 97 percent are marshes (estuarine and palustrine emergent wetlands).

- Salt and brackish marshes (estuarine intertidal emergent wetlands) constitute about 48 percent (22,855 ha) of the marsh system; fresh or inland marshes (palustrine emergent wetlands) make up the remaining 52 percent (24,250 ha). These numbers are unadjusted.

- Forested (740 ha) and scrub-shrub (530 ha) wetlands have a total area of about 1,270 acres, representing about 3 percent of all vegetated wetland habitats.

- Riparian woodlands in the three major fluvial-deltaic systems (Nueces, Aransas–Chiltipin, and Mission Rivers) have an area of about 1,820 ha.

- Approximately 8,900 ha of sand and mud flats and bay beaches (estuarine intertidal unconsolidated shores and estuarine intertidal aquatic bed) were mapped on the 1992 photographs.

B. Wetland Trends

- The trend in vegetated wetlands is one of net gain as revealed by total marsh areas of 34,550 ha in the 1950’s, 39,460 ha in 1979, and 43,970 ha in 1992. Numbers were adjusted to offset some photointerpretation inconsistencies. The rate of gain, increased over time from about 200 ha per year between the 1950's and 1979, to more than 300 ha per year between 1979 and 1992. The total gain in marshes was about 14 percent from the 1950's to 1979, and 11 percent from 1979 to 1992.

- Marshes (emergent wetlands) experienced losses in some areas. Among notable losses were pothole wetlands, on the coastal prairie and on the Pleistocene barrier-strandplain ridge, Live Oak Peninsula/Ridge.

- Estuarine intertidal flats underwent major losses. From the 1950's to 1979 more than 50 percent of this habitat was converted to other habitat types, primarily subtidal classes such as seagrass beds and open water.

- Riparian woodlands expanded in total area from 1979 to 1992 by about 200 ha.

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C. Causes of Trends

Marshes (Emergent Wetlands)

- Much of the gain in estuarine marshes occurred on intertidal flats as vegetation spread in areas that became more frequently flooded. Largest gains in estuarine marshes occurred from the 1950's to 1979, coinciding with an accelerated rise in relative sea level of 1.7 cm/yr from the mid 1960's to 1975. This annual rate of rise is substantially higher than the subsequent rate of 0.5 cm/yr from 1976 to 1993.

- Marsh expansion on intertidal flats was aided by sewage treatment discharges in some areas such as near Port Aransas and along the margins of Oso Bay.

- Palustrine marshes had largest gains on barrier islands and the Pleistocene barrier-strandplain, Blackjack Peninsula. Although some gain is due to photointerpretation and more inclusive delineations in 1992, there is evidence that island environments have become wetter, possibly from a combination of higher amounts of precipitation and rising sea level since the 1950's.

- Marsh losses in some areas were associated with human activities. From the 1950's to 1992, many pothole wetlands were converted to agricultural land on the coastal prairie. Pothole wetlands on Live Oak Peninsula/Ridge were also affected by human activities including quarrying to develop sand resources.

- Marshes in some areas were lost by draining, impounding, filling, and dredging.

- Marshes were eroded along high energy shorelines.

Estuarine Intertidal Flats

- Major conversions of wind-tidal flats to subtidal habitats correlate spatially and temporally with a relative sea-level rise. Most loss in flats occurred during the 1950's-1979, coinciding with an accelerated rise in relative sea level from the 1960's to 1975.

- Modest losses in tidal flats occurred as a result of dredging and filling activities.

Riparian Woodlands

- There were modest gains in riparian woodlands in the major fluvial-deltaic systems of the Nueces, Aransas-Chiltipin, and Mission Rivers. Clearing of woodlands occurred primarily before the 1950's, which preceded the period of analysis for this study. Since the 1950's, woodlands in the various valleys have generally been maintained.

D. Shoreline Types

- Total cumulative length of mapped shorelines in the study area is 2,014 km.
- About 330 km, or 16.4 percent, of shorelines are hardened.
- Marshes (about 900 km in cumulative length) are the most common shoreline type, composing 45 percent of the total shoreline length.

E. Rookery Islands

- Rookery islands in the CCBNEP area are critical to the long-term survival of colonial waterbirds (gulls, terns, herons, egrets, pelicans, spoonbills, and ibises).
- Changes in island size, configuration, and available habitat types variously affected the success of certain species. Decreases in nesting pairs of bare-ground, nesting species (e.g., terns and skimmers) may be due primarily to loss of unvegetated beaches and flats to vegetated grasses, forbs, and shrubs. Some rookery islands were abandoned from extensive erosion.
- American White Pelicans nested on three different islands in upper Laguna Madre since 1973. This population is the only coastal nesting population in the United States.
- Brown Pelicans made a dramatic recovery in the CCBNEP area since the mid-1970s, with consistently increasing nesting populations on Pelican Island Spoil rookery in Corpus Christi Bay.
- Factors that may negatively effect nesting trends of colonial waterbirds include: habitat loss and/or habitat degradation, predation, and human disturbance.
- Monitoring of colonial waterbird nesting success should be continued, as the Colonial Waterbird Census is the only long-term dataset available to assess status and trends. Continued partnerships among agencies, research and academic institutions, nonprofit conservation groups, and interest groups should be encouraged and supported financially.
- No quantitative data are presently available to evaluate successional changes in vegetation or spatial changes of island configuration and areal extent. Detailed studies of key rookeries should be conducted, particularly those essential to species of concern.

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IX. REFERENCES

(Includes relevant references not cited in report)

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.

Armstrong, W., Wright, E. J., Lythe, S., and Gaynard, T. J., 1985, Plant zonation and the effects of the spring-neap cycle on soil aeration in a Humber salt marsh: Journal of Ecology 73:323-339.

Baccus, J. T., and Horton, J. K., 1979, An ecological and sedimentary study of Padre Island National Seashore: Southwest Texas State University, Department of Biology, for Office of Natural Resources, Southwest Region, National Park Service, Santa Fe, New Mexico, 272 p.

Benton, A. R., Jr., Hatch, S. L., Kirk, W. L., Newnam, R. M., Snell, W. W., and Williams, J. G., 1977, Monitoring of Texas coastal wetlands: College Station, Texas A&M University, Remote Sensing Center, Technical Report RSC-88, 124 p.

Bertness, M. D, 1991, Interspecific interactions among high marsh perennials in a New England salt marsh: Ecology 72:125-137.

Bertness, M. D., Gough, L., and Shumway, S. W., 1992, Salt tolerances and the distribution of fugitive salt marsh plants: Ecology 73:1842-1851.

Bleakney, J. S, 1972, Ecological implications of annual variation in tidal extremes: Ecology 53:933-938.

Britton, J. D., and Morton, B., 1989, Shore ecology of the Gulf of Mexico: University of Texas Press, Austin, Texas, USA.

Brown, L. F. Jr., Morton, R. A., McGowen, J. H., Kreitler, C. W., and Fisher, W. L., 1974, Natural hazards of the Texas Coastal Zone: The University of Texas at Austin, Bureau of Economic Geology, 13 p., 7 maps.

Brown, L. F., Jr., Brewton, J. L., McGowen, J. H., Evans, T. J., Fisher, W. L., and Groat, C. G., 1976, Environmental geologic atlas of the Texas Coastal Zone—Corpus Christi area: The University of Texas at Austin, Bureau of Economic Geology, 123 p., 9 maps.

Brown, L. R., Jr., McGowen, J. H., Evans, T. J., Groat, C. G., and Fisher, W. L., 1977, Environmental geologic atlas of the Texas Coastal Zone—Kingsville area: The University of Texas at Austin, Bureau of Economic Geology, 131 p., 9 maps.

Burger, J., 1981, Effects of human disturbance on colonial species, particularly gull: Colonial Waterbirds 4:28-36.

Carlson, B. A., and McLean, E. B., 1996, Buffer zones and disturbance types as predictors of fledging success in Great Blue Herons, *Ardea herodias*: Colonial Waterbirds 19:124-127.

Chabreck, R. H., 1972, Vegetation, water and soil characteristics of the Louisiana coastal region: Louisiana Agricultural Experiment Station Bulletin 664, Baton Rouge, Louisiana, USA.

Chabreck, R. H., and Palmisano, A. W., 1973, The effects of Hurricane Camille on the marshes of the Mississippi River delta: Ecology 54:1118-1125.

Chaney, A. H., Blacklock, G. W., and Bartels, S. G., 1996, Current status and historical trends of avian resources in the Corpus Christi Bay National Estuary Program study area, Vol. 2 in J. W. Tunnell, Q. R. Dokken, E. H. Smith, and K. Withers, Current status and historical trends of the estuarine living resources within the Corpus Christi Bay National Estuary Program study area: CCBNEP-06B, Texas Natural Resource Conservation Commission, Austin, Texas.

Chaney, A. H., Chapman, B. R., Karges, J. P., Nelson, D. A., Schmidt, R. R., and Thebeau, L. C, 1978, Use of dredged material islands by colonial seabirds and wading birds in Texas, Technical Report D-78-8: U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Cobb, R. A., 1987, Mitigation evaluation study for the South Texas Coast, 1975 - 1986: Corpus Christi State University, Center for Coastal Studies, Report prepared for U. S. Fish and Wildlife Service Ecological Services, Corpus Christi, Texas, under Cooperative Agreement No. 14-16-0002-86-919, 88 p.

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

Correll, D. S., and Johnston, M. C., 1970, Manual of the vascular plants of Texas: Texas Research Foundation, Renner, Texas, USA.

Coste, R. L., and Skoruppa, M. K., 1989, Colonial waterbird rookery island management plan for the South Texas Coast: Center for Coastal Studies, Corpus Christi State University, Corpus Christi, Texas.

Cowardin, L. M., Carter, V., Golet, F. C. and LaRoe, E. T., 1979, Classification of wetlands and deepwater habitats of the United States: United States Department of Interior, Fish and Wildlife Service, Washington, D.C., USA, 103 p.

Darnell, T. M., Smith, E. H., Tunnell, J. W., Withers, K., and Jones, E. R., 1997, The influence of landscape features on bird use of marsh habitat created for Whooping Cranes (*Grus americanus*) through beneficial use of dredged material: Final Report: Center for Coastal Studies, TAMU-CC-9704-CCS. Texas A&M University-Corpus Christi, Corpus Christi, Texas, USA.

Davis, R. A., and Fox, W. T., 1972, Coastal dynamics along Mustang Island, Texas: Western Michigan University Technical Report No. 9, ONR Contract No. 388-092, 68 p.

Deegan, L. A., Day, J. W., Jr., Gosselink, J. G., Yanez-Arancibia, A., Chavez, G. S., and Sanchez-Gil, P., 1986, Relationships among physical characteristics, vegetation distribution and fisheries yield in Gulf of Mexico estuaries, in Wolfe, D. A., ed., Estuarine variability: Academic Press, Inc., Orlando, p. 83-100.

Diener, R. A., 1975, Cooperative Gulf of Mexico estuarine inventory and study-Texas: area description: National Oceanic and Atmospheric Administration, Technical Report, National Marine Fisheries Service Circular 393, 129 p.

Drawe, D. L., Chamrad, A. D., and Box, T. W., 1978, Plant communities of the Welder Wildlife Refuge: Welder Wildlife Foundation, Sinton, Texas, Contribution No. 5, Series B, revised, 2 maps, 40 p.

Duxbury, A. C., 1971, The earth and its oceans: Reading, Massachusetts, Addison-Wesley Publishing Company, 381 p.

Elliott, L. F., 1995, Reddish Egret/Brown Pelican colony monitoring: Final report to Texas Parks and Wildlife Department, Project No. 9.4.

Erwin, R. M., 1989, Responses to human intruders by birds nesting in colonies: Experimental results and management guidelines: Colonial Waterbirds 12:104-108.

Espey, Huston and Associates, Inc., 1977, Marsh plant production and potential detritus in Lavaca, San Antonio, and Nueces Bays: report prepared for Texas Department of Water Resources, Document No. 7688, variable pages, 3 maps.

Federal Intergency Committee for Wetland Delineation, 1989, Federal manual for identifying and delineating jurisdictional wetlands: U.S. Army Corps 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. plus appendices.

Franki, G. E., Garcia, R. N., Hajek, B. F, Arriaga, D., and Roberts, J. C., 1965, Soil Survey Nueces County, Texas: U. S. Department of Agriculture, Soil Conservation Service, 65 p. 79 maps.

Funicelli, N. A., and Benson, N. G., 1983, Choke Canyon Reservoir: Estuarine impacts and management, in, Magoon, O. T., and Converse, Hugh, Coastal Zone '83, Volume III: American Society of Civil Engineers, New York, p. 2866-2876.

Gabrysch, R. K., 1969, Land-surface subsidence in the Houston–Galveston region, Texas: United Nations Educational, Scientific and Cultural Organization (UNESCO), Studies and Reports in Hydrology, Land Subsidence Symposium, v. 1, p. 43–54.

Gabrysch, R. K., 1984, Ground-water withdrawals and land-surface subsidence in the Houston–Galveston region, Texas, 1906–1980: Texas Department of Water Resources Report 287, 64 p.

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

Gabrysch, R. K., and Coplin, L. S., 1990, Land-surface subsidence resulting from ground-water withdrawals in the Houston–Galveston region, Texas, through 1987: U.S. Geological Survey Report of Investigations No. 90-01, 53 p.

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

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

Gosselink, J. G, 1984, The ecology of delta marshes of coastal Louisiana: a community profile: U.S. Fish and Wildlife Service. FWS/OBS-84/09.

Gosselink, J. G., and Bauman, R. H., 1980, Wetland inventories: Wetland loss along the United States Coast: Journal of Geomorphology Supp. v. 34, p. 173-187.

Gould, F. W., 1978, Common Texas grasses: an illustrated guide: Texas A&M University Press, College Station, Texas, USA.

Gould, F. W., and Box, T. W, .1965, Grasses of the Texas Coastal Bend (Calhoun, Refugio, Aransas, San Patricio and northern Kleberg counties): Texas A&M Press, College Station, Texas, USA.

Guckian, W. J., and Garcia, R. N., 1979, Soil survey of San Patricio and Aransas Counties, Texas: U. S. Department of Agriculture, Soil Conservation Service, 122 p., 96 maps.

Gustavson, T. C., and Kreitler, C. W., 1976, Geothermal resources of the Texas Gulf coast—environmental concerns arising from the production and disposal of geothermal waters: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 76-7, 35 p.

Haigh, S. L., 1984, Habitat selection and production of nesting birds on two lakes in South Texas: Master's thesis. Texas A&I University, Kingsville, Texas, USA.

Hayes, M. O., 1974, Hurricanes as geological agents: case studies of Hurricanes Carla, 1961, and Cindy, 1963: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 61, 56 p.

Hayes, M. O., Gundlach, E. R., and Getter, C. D., 1980, Sensitivity ranking of energy port shorelines, in Proc. Specialty Conference, American Society of Civil Engineers, New York, N.Y., p. 697-709.

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

Hillenbrand, C. J., 1985, Subsidence and fault activation related to fluid extraction Saxet Field, Nueces County, Texas: University of Houston, Master's thesis, 144 p.

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

Holmes, C. W., and Martin, E. A., 1976, Rates of sedimentation, *in* Holmes, C. W., and others, Environmental studies, South Texas Outer Continental Shelf, 1976, Geology report for the Bureau of Land Management prepared by the U.S. Geological Survey, 626 p.

Hopkinson, C. S., Gosselink, J. G., and Parrondo, R. T., 1978, Aboveground production of seven marsh plant species in coastal Louisiana: Ecology 59:760-769.

Hunter, R. E., Watson, R. L., Hill, G. W., and Dickinson, K. A., 1972, Modern depositional environments and processes, northern and central Padre Island, Texas, in Padre Island National Seashore field guide: Gulf Coast Association of Geological Societies, convention field trip, p. 1-17.

Jenkins, K.V., and Smith, E.H., 1997, Baseline evaluation of the natural resources of Mustang Island State Park, Nueces County, Texas: Center for Coastal Studies Technical Report (draft).

Johnston, J. B., and Ader, R. A., 1983, The use of a GIS for Gulf of Mexico wetland change: in Magoon, O. T., and Converse, H., eds., Coastal Zone '83, Volume I: American Society of Civil Engineers, New York, p. 362-371.

Jones, F. B, 1982, Flora of the Texas Coastal Bend: Welder Wildlife Foundation, Sinton, Texas, USA, 262 p.

Kaplan, E. H, 1988, Southeastern and Carribean seashores: Cape Hatteras to the Gulf coast, Florida, and the Caribbean: The Easton Press, Norwalk, Connecticut, USA.

Kier, R. S., and White, W. A., 1978, Land and water resources of the Corpus Christi Area, Texas: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 95, 22 p., 1 map.

Kreitler, C. W., 1977, Faulting and land subsidence from ground-water and hydrocarbon production, Houston–Galveston, Texas: The University of Texas at Austin, Bureau of Economic Geology Research Note 8, 22 p.

Kreitler, C. W., White, W. A., and Akhter, M. S., 1988, Land subsidence associated with hydrocarbon production, Texas Gulf Coast (abs.): American Association of Petroleum Geologists Bulletin, v. 72, no. 2, p. 208.

LBJ School of Public Affairs, 1978, Preserving Texas' natural heritage. Research project report No. 31: The University of Texas at Austin, Austin, Texas, USA.

LeBlanc, R. J., and Hodgson, W. D., 1959, Origin and development of the Texas shoreline: Gulf Coast Association of Geological Societies Transactions 9:197-220.

Liebbrand, N. F., 1987, Estimated sediment deposition in Lake Corpus Christi, Texas, 1972–1985: U.S. Geological Survey Open-File Report 87-239, 26 p.

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

McGowen, J. H., 1971, Gum Hollow fan delta, Nueces Bay, Texas: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 69, 91 p.

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

Miller, W. R., and Egler, F. E., 1950, Vegetation of the Wequetequock-awcatuck tidal marshes, Connecticut: Ecological Monographs 20:147-170.

Mitsch, W. J., and Gosselink, J. G., 1993, Wetlands, 2nd edition: Van Nostrand Reinhold, New York, USA.

Morton, R. A., 1977, Historical shoreline changes and their causes, Texas Gulf Coast: Gulf Coast Association of Geological Societies Transactions, v. 27, p. 352-364.

Morton, R. A., and McGowen, J. H., 1980, Modern depositional environments of the Texas coast: The University of Texas at Austin, Bureau of Economic Geology Guidebook 20, 167 p.

Morton, R. A., and Paine, J. G., 1984, Historical shoreline changes in Corpus Christi, Oso, and Nueces Bays, Texas Gulf Coast: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 84-6, 66 p.

Morton, R. A., and Paine, J. G., 1990, Coastal land loss in Texas–an overview: Gulf Coast Association of Geological Societies Transactions, v. 40, p. 625-643.

Morton, R. A., and White, W. A., 1995, Shoreline Types of the Upper Texas Coast: Sabine-Galveston-Freeport-Sargent Areas, Final report prepared for the Texas Natural Resources Invertory Program, Texas General Land Office, Texas Natural Resources Conservation Commission, Texas Parks and Wildlife Department, and Minerals Management Service: The University of Texas at Austin, Bureau of Economic Geology, 42 p.

Morton, R. A., and Pieper, M. J., 1976, Shoreline changes on Matagorda Island and San Jose Island (Pass Cavallo to Aransas Pass), An analysis of historical changes of the Texs Gulf shoreline: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 76-4, 42 p.

Moulton, D. W., Dahl, T. E., and Dall, D. M., 1997, Texas coastal wetlands; status and trends, mid-1950s to early 1990s: U. S. Department of the Interior, Fish and Wildlife Service, Albuquerque, New Mexico, 32 p.

Mueller, A. J., and Glass, P. O., 1988, Disturbance tolerance in a Texas waterbird colony: Colonial Waterbirds 11:119-122.

Nicolau, B. A., 1995, Estuarine faunal use in a mitigation project, Nueces River delta, Texas: year five: Texas A&M University–Corpus Christi, Center for Coastal Studies, 107 p.

Nicolau, B. A., and Adams, J. S., 1993, Estuarine faunal use in a mitigation project, Nueces River delta, Texas: years two and three: Texas A&M University–Corpus Christi, Center for Coastal Studies, 114 p.

Nittrouer, C. A., Sternberg, R. W., Carpenter, R., and Bennett, J. T., 1979, The use of Pb-210 geochronology as a sedimentological tool: application to the Washington continental shelf: Marine Geology, v. 31, p. 297–316.

Oldfield, F., and Appleby, P. G., 1984, Empirical testing of ^{210}Pb-dating models for lake sediments, *in* Haworth, E. Y., and Lund, J. W. G., eds., Lake sediments and environmental history: Minneapolis, Minnesota, University of Minnesota Press, p. 93–124.

Otvos, E. G., 1970b, Development and migration of barrier islands, northern Gulf of Mexico: Geological Society of America Bulletin 81:3783-3788.

Otvos, E. G., 1970a, Development and migration of barrier islands, northern Gulf of Mexico: Geological Society of America Bulletin 81:241-246.

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

Paine, J. G., and Morton, R. A., 1993, Historical shoreline changes in Copano, Aransas, and Redfish Bays, Texas Gulf Coast: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 93-1, 66 p.

Paine, J. G., 1993, Subsidence in the Texas coast: inferences from historical and late Pleistocene sea levels: Tectonophysics, v. 222, p. 445–458.

Parnell, J. F., Ainley, D. G., Blokpoel, H., Cain, B., Custer, T. W., Dusi, J. L., Kress,S., Kushlan, J. A., Southern, W. E., Stenzel, L. E., and Thompson, B. C., 1988, Colonial waterbird management in North America: Colonial Waterbirds 11:129-169.

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 Terrebone Parish region: Baton Rouge, Louisiana Geological Survey, Coastal Geology Technical Report No. 4, 121 p.

Pethick, J. S, 1974, The distribution of salt pans on tidal salt marshes: Journal of Biogeography 1:57-62.

Post, W., 1990, Nest survival in a large ibis-heron colony during a three-year decline to extinction: Colonial Waterbirds 13:50-61.

Pratt, W. E., and Johnson, D. W., 1926, Local subsidence of the Goose Creek oil field: Journal of Geology, v. 34, p. 577–590.

Price, W. A., and Gunter, Gordon, 1943, Certain recent geological and biological changes in South Texas, with consideration of probable causes: The Texas Academy of Science Proceedings and Transactions, v. 26, p. 138-156.

Prouty, J. S. and Prouty, D B., 1989, Historical back barrier shoreline changes, Padre Island National Seashore, Texas: Transactions--Gulf Coast Association of Geological Societies, v. 39, p. 481-490.

Pulich, W., Jr., Blair, C, and White, W. A., 1997, Current status and historical trends of seagrasses in the Corpus Christi Bay National Estuary Region: Corpus Christi Bay National Estuary Program, CCBNEP report.

Pulich, W., Jr., Rabalais, S., and Wellso, S., 1982, Food chain components on Laguna Madre tidal flats, Contribution No. 572: The University of Texas, Marine Science Institute, Port Aransas, Texas, USA.

Ratzlaff, K W., 1980, Land-surface subsidence in the Texas coastal region: U. S. Geological Survey Open-File Report 80-969, 18 p.

Rechenthin, C. A., and Passey, H., 1967, The vegetation of Padre Island National Seashore: Soil Conservation Service, Temple, Texas, USA.

Reed, P. B, 1988, National list of plant species that occur in wetlands: 1988 Texas: USFWS, NERC-88/18.43, St. Petersburg, Florida, USA.

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 pp.

Rodgers, J. A., and Burger, J., 1981, Concluding remark: Symposium on human disturbance and colonial waterbirds: Colonial Waterbirds 4:69-70.

Roper, J. C., 1992, Effects of fire ant predation on colonial waterbirds on the Texas coast: A literature review, CCSU-9202-CCS: Center for Coastal Studies, Corpus Christi State University, Corpus Christi, Texas.

Ruth, B. F., 1990, Establishment of estuarine faunal use in a salt marsh creation project, Nueces River delta, Texas: Texas A&M University-Corpus Christi, Center for Coastal Studies, 51 p.

Scott, A. J., Hoover, R. A., and McGowen, J. H., 1969, Effects of Hurricane Beulah, 1967, on Texas coastal lagoons and barriers, in Castanares, A. A., and Phleger, F. B., eds., Lagunas costeras, un simposio: Mexico, D. F., UNAM-UNESCO, Memoir Simposio International Lagunas Costeras, Nov. 28-30, 1967, p. 221-236.

Shealer, D. A., and Kress, S. W., 1991, Nocturnal abandonment response to black-crowned night-heron disturbance in a Common Tern colony: Colonial Waterbirds 14:51-56.

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.

Shiflet, T. N, 1963, Major ecological factors controlling plant communities in Louisiana marshes: Journal of Range Management 16:231-235.

Smith, E. H., and Cox, S., 1998, Status and trends of rookery islands in the Corpus Christi Bay National Estuary Program Area.

Southern, L. K., Patton, S. R., and Southern, W. E., 1982, Nocturnal predation on *Larus* gulls: Colonial Waterbirds 5:169-172.

Starkey, H. C., Blackmon, P. D., and Hauff, P. L., 1984, The routine mineralogical analysis of clay-bearing samples: U.S. Geological Survey Bulletin 1563, 32 p.

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

Texas Colonial Waterbird Society, 1982, An atlas and census of Texas waterbird colonies 1973-1980: Kingsville, Texas, Caesar Kleberg Wildlife Research Institute.

Texas Department of Water Resources, 1981, Nueces and Mission-Aransas estuaries: a study of the influence of freshwater inflows: Texas Department of Water Resources, LP-108, 308p.

Texas Department of Water Resources, 1983, Laguna Madre estuary: a study of the influence of freshwater inflows: Texas Department of Water Resources, LP-182, 250p.

Texas Department of Water Resources, 1984, Mathematical simulation capabilities in water resources systems analysis: estuarine hydrodynamics, salinity, and water quality simulation: LP-16.

Tiner, R. W., 1993, Field guide to coastal wetland plants of the southeastern United States: The University of Massachusetts Press, Amherst, Massachusetts, USA.

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

TPWD, 1990, Mustang Island State Park: summary of representative plant communities: Unpublished report, Texas Parks and Wildlife Department, Austin, Texas, USA.

Tremblay, J., and Ellison, L. N., 1979, Effects of human disturbance on breeding of Black-crowned Night-Herons: Auk 96:364-369.

Tunnell, J. W., Jr., Withers, K., and Hardegree, B., 1997, Environmental impact and recovery of the Exxon Pipeline oil spill and burn site, Upper Copano Bay Texas: Final report: Center for Coastal Studies, TAMU-CC-9703-CCS, Corpus Christi, Texas, USA.

Turner, R. E., 1991, Tide gauge records, water level rise, and subsidence in the Northern Gulf of Mexico: Estuaries 14:139-147.

Verbeek, E. R., and Clanton, U. S., 1981, Historically active faults in the Houston metropolitan area, Texas, *in* Etter, E. M., ed., Houston area environmental geology: surface faulting, ground subsidence, hazard liability: Houston Geological Society, p. 28–68.

Vos, D. K., Ryder, R. A., and Graul, W. D., 1985, Response of breeding Great Blue Herons to human disturbance in northcentral Colorado: Colonial Waterbirds 8:13-22.

Ward, G. H., Jr., Armstrong, N. E., and the Matagorda Bay Project Teams, 1980, Matagorda Bay, Texas: its hydrography, ecology, and fishery resources: U.S. Fish and Wildlife Service, Washington, D.C. FWS/OBS-81/52.

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

Weise, B. R., and White, W. A., 1980, Padre Island National Seashore, a guide to the geology, natural environments, and history of a Texas Barrier Island: The University of Texas at Austin, Bureau of Economic Geology Guidebook 17, 94 p., 1 map.

White, W. A., and Calnan, T. C., 1990, Sedimentation and historical changes in fluvial-deltaic wetlands along the Texas Gulf Coast with emphasis on the Colorado and Trinity River deltas: The University of Texas at Austin, Bureau of Economic Geology, report prepared for the Texas Parks and Wildlife Department and Texas Water Development Board under interagency contract (88-89) 1423, 124 p., 6 appendices.

White, W. A., and Calnan, T. C., 1991, Submergence of vegetated wetlands in fluvial-deltaic areas, Texas Gulf Coast, *in* Coastal depositional systems in the Gulf of Mexico: Quaternary framework and environmental issues: 12th Annual Research Conference, Society of Economic Paleontologists and Mineralogists, Gulf Coast Section, Houston, Texas, p. 278–279.

White, W. A., and Morton, R. A., 1993, Determining recent sedimentation rates of the Nueces River System, Texas: The University of Texas at Austin, Bureau of Economic Geology, report prepared for the Texas Water Development Board under interagency contract no. 95-483-075, 123 p.

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

White, W. A., Morton, R. A., Kerr, R. S., Kuenzi, W. D., and Brogden, W. B., 1978, Land and water resources, historical changes, and dune criticality: Mustang and North Padre Islands, Texas: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 92, 46 p., 1 map.

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

Williams, H. F. L., 1997, Shoreline erosion at Shamrock Island Preserve, Nueces County, Texas: University of North Texas, Denton, Department of Geography, 30 p., 1 Appendix.

Winslow, A. G., and Doyel, W. W., 1954, Land-surface subsidence and its relation to the withdrawal of ground water in the Houston–Galveston region, Texas: Economic Geology, v. 49, no. 4, p. 413–422.

Withers, K., and Tunnell, J. W., Jr., In Press, Wind-tidal flat ecology in the Corpus Christi Bay National Estuary Program study area: Effects of natural and anthropogenic disturbance on biological productivity and function: Corpus Christi Bay National Estuary Program, CCBNEP Report.

Wood, F. J., 1986, Tidal dynamics: Coastal flooding, and cycles of gravitational force: D. Reidel Publishing Co., Dordrect, The Netherlands.

Wood, T., T. Engelhard, and Kelly, K., 1995, Baseline survey of Black Point wetland, Refugio County, Texas: Unpublished report, Texas A&M University-Corpus Christi, Corpus Christi, Texas, USA.

Wright, S. S., 1980, Seismic stratigraphy and depositonal history of Holocene sediments on the central Texas Gulf coast: The University of Texas at Austin, Master's thesis, 123 p.

Zinn, J. A., and Copeland, C., 1982, Wetland management: Environment and Natural Resources Policy Division, Congressional Research Service, Library of Congress Serial No. 97-11, 149 p.

Appendix. Total habitat areas determined from seamless data sets of 29 quad area.

1950’s and 1979 data include South Bird Island quadrangle but not Tivoli SW

1992 data include Tivoli SW quadrangle but not South Bird Island

1992 Habitats	Hectares	1979 Habitats	Hectares	1950’s Habitats	Hectares
E1AB1L	224	E1AB2L	68	E1AB.	15,005
E1AB3L	18,404	E1AB2L.	21,796	E1ABOW.	616
E1AB3Lx	41	E1AB2L/E1OWL.	1,049		
E1AB5L	58	E1AB6L	68	E1OW.	113,625
		E1AB6L.	894	E1OW/RF.	78
E1RF2M	31	E1AB6L/E1OWL.	8		
E1UBL	108,177	E1AB7L.	3	E1RF.	277
E1UBLx	2,375			E2BB.	59
		E1OWL	1,208	E2EM.	6,213
E2AB1N	32	E1OWL.	110,888	E2EM/FL.	2,338
E2AB1P	107	E1OWLH.	88	E2EMFL.	11,759
E2AB3L	1	E1OWLX.	364		
E2AB3N	20			E2FL.	19,416
		E1RF2M.	19	E2RF.	94
E2EM1N	12,009	E2AB2L.	58	E2RS.	1
E2EM1Ns	54	E2AB2M.	20	E2SB.	3
E2EM1Nx	3	E2AB6M.	4	E2SS.	17
E2EM1P	10,576			E2SSEM.	5
E2EM1Ps	114	E2BBP.	2		
E2EM1Px	2	E2EM1P	38	L1OW.	159
		E2EM1P.	8,115	L2AB.	7
E2FO2P	2	E2EM1PH.	14	L2FL.	61
E2SS1P	10	E2EM1N	114	L2OW.	1,361
E2SS3N	42	E2EM1N.	5,578	M1OW.	77,138
E2SS3P	46	E2FM1P.	3	M2BB.	780
				M2BB2.	339
E2USM	53	E2EM1P/E2FLP.	1,410		
E2USN	5,917	E2EM1M/E2FLM.	4	PAB.	0
E2USNs	185	E2EM1N.E2FLN.	2	PABOW.	2
E2USNx	62	E2EM1N/E23FLN.	1		
E2USP	2,422	E2EM1N/E2FLM.	1	PEM	4
E2USPs	92	E2EM1N/E2FLN	57	PEM.	13,539
E2USPx	10	E2EM1N/E2FLN.	5,884	PEM/FL.	36
				PEM/OW.	0
L1AB3Hh	22	E2FL.	1	PEMFL.	85
L1UBH	12	E2FL6N.	156	PEMOW.	197
L1UBHh	199	E2FL6Y.	12	PEMOW..	2
L1UBHx	89	E2FLM	53	PEMU.	1,840
L1UBKh	78	E2FLM.	533		
L1UBKhs	384	E2FLMH.	12	PFL.	275
L1UBKx	795	E2FLN	129	PFO.	559
		E2FLN.	5,796	PFOEM.	112
L2AB3H	1,785	E2FLP	91	PFOSS.	8
L2AB4Hx	9	E2FLP.	3,157		
		E2FLPH.	32	POW.	721
L2UBFx	8	E2FLUH.	26	POWFL.	1

Table of Contents

1992 Habitats	Hectares	1979 Habitats	Hectares	1950's Habitats	Hectares
L2USCh	11			POWU.	15
L2USCx	19				
L2USKh	514	E2RF2M.	20	PSS.	499
L2USKhs	787	E2SS3N.	569	PSS/EM.	305
L2USKx	28	E2SS3N/E2FLN.	125	PSSEM.	147
				PSSFL.	3
M1UBL	55,787	L1AB2H/L1OWH.	21	PSSOW.	5
M1UBL.	17,031	L1AB6G/L1OWG.	13		
				R1FL.	8
M2USN	376	L1OWG.	16	R1OW.	170
M2USN.	4	L1OWH	13	R1SB.	14
M2USP	331	L1OWH.	132	R2OW.	221
M2USP.	4	L1OWHH.	30	R2SB.	19
		L1OWHHX.	1,338	R4OW.	1
PAB3F	0	L1OWHx.	59	R4SB.	9
PAB3Fx	0	L1OWV.	83	U.	243,412
PAB3Kh	4				
PAB4F	4	L2AB6F.	35		511,558
PAB4Fx	12	L2AB6F/L2OW6F.	2		
PAB4Hx	10	L2AB6F/L2OWF.	20		
		L2AB6FHX/L2OWFHX	7		
PEM1A	18,361	L2AB6H/L2OWH.	147		
PEM1A.	16	L2AB7G/L2OWG.	33		
PEM1A/U	494	L2AB7H.	34		
PEM1Ad	133	L2AB7T.	13		
PEM1Ah	96				
PEM1As	3	L2FLC.	10		
PEM1Ax	8	L2FLH.	54		
PEM1B	1	L2FLR.	45		
PEM1C	3,207	L2FLU.	27		
PEM1C.	1				
PEM1C/U	43	L2OWF.	1,426		
PEM1Cd	11	L2OWGh.	11		
PEM1Ch	116				
PEM1Chs	4	M1OWL	30,189		
PEM1Cx	68	M1OWL.	48,017		
PEM1F	745				
PEM1Fh	61	M2BBP	119		
PEM1Fhs	3	M2BBP.	734		
PEM1Fx	92				
PEM1Kh	78				
PEM1Khs	120	PAB5HH.	16		
PEM1Kx	68	PAB6FHX.	1		
PEM1R	79	PAB7F.	11		
PEM1S	22	PAB7F/POWF.	1		
		PAB7FD.	1		
PFO1A	687	PAB7T.	9		
PFO1Ah	5				
PFO1Ax	17	PEM1A	2		
PFO1C	18	PEM1A.	511		
PFO1Ch	3	PEM1AD.	3		

1992 Habitats	Hectares	1979 Habitats	Hectares	1950's Habitats	Hectares
PFO1Cx	12	PEM1AHX.	217		
PFO1S	0	PEM1C	39		
PFO2A	0	PEM1C.	4,359		
		PEM1C/UA.	111		
PSS1A	433	PEM1CD.	13		
PSS1Ah	0	PEM1CH.	3		
PSS1C	80	PEM1CHX.	1		
PSS1Ch	2	PEM1CU.	985		
PSS1Cx	4	PEM1CX.	1		
PSS1Fx	1	PEM1Cd.	30		
PSS2A	1	PEM1Ch.	5		
PSS3A	5	PEM1F	38		
		PEM1F.	1,314		
PUBF	78	PEM1F/POWF.	760		
PUBFh	33	PEM1F/U.	8		
PUBFx	276	PEM1F/UA.	1,462		
PUBFx.	0	PEM1FD.	3		
PUBH	34	PEM1FH.	2		
PUBHh	41	PEM1FHX.	1		
PUBHx	202	PEM1FU.	24		
PUBHx.	1	PEM1FUF6.	16		
PUBKh	17	PEM1FX.	3		
PUBKhs	27	PEM1Fx.	9		
PUBKx	86	PEM1H/POWH.	2		
		PEM1O.	1		
PUSA	12	PEM1P/POWP.	3		
PUSAh	3	PEM1R.	1,005		
PUSAx	17	PEM1S.	22		
PUSC	36	PEM1T.	115		
PUSCh	10	PEM1Y	59		
PUSChs	0	PEM1Y.	4,278		
PUSCx	54	PEM1Y/POWY.	1		
PUSKhs	110	PEM1YHX.	0		
PUSKx	21	PEMR/PFLR.	9		
R1UBV	4	PFL2C.	0		
R2UBH	229	PFLC.	2		
R2UBHx	6	PFLCH	0		
		PFLJ.	10		
R4SBAx	0	PFLR.	39		
R4SBCx	16	PFLY.	22		
		PFLYX.	7		
U	245,141				
U.	21	PFO1R.	4		
		PFO6.	1		
U/PEM1A	232	PFO65.	1		
U/PEM1C	161	PFO6A.	66		
		PFO6C.	13		
	511,337	PFO6F.	1		
		PFO6R.	18		
		PFO6S.	47		
		PFO6Y.	170		

1992 Habitats	Hectares	1979 Habitats	Hectares	1950's Habitats	Hectares
		PFOGY.	3		
		POW.	0		
		POWF	6		
		POWF.	612		
		POWF/AU.	68		
		POWF/UA.	285		
		POWF/UF6.	45		
		POWFH.	10		
		POWFHX.	30		
		POWFU.	33		
		POWFUA.	1,097		
		POWFUF6.	84		
		POWFX	0		
		POWFX.	243		
		POWFh.	10		
		POWFhx	1		
		POWFhx.	13		
		POWFx.	104		
		POWG.	15		
		POWGH.	6		
		POWGHX.	8		
		POWGX.	9		
		POWGhx.	3		
		POWGx.	2		
		POWH	4		
		POWH.	87		
		POWHH	2		
		POWHH.	32		
		POWHHX.	4		
		POWHX.	103		
		POWHx.	7		
		POWT.	21		
		PSS6A.	636		
		PSS6C.	286		
		PSS6CD.	10		
		PSS6R.	97		
		PSS6S.	6		
		PSS6Y/PEM1Y.	8		
		R1FLR.	17		
		R1OWV.	142		
		R2OWH.	193		
		U.	2		
		UA	1,672		
		UA.	193,734		
		UAR.	96		
		UB.	58		
		UBD	5		
		UBD.	784		
		UBS.	589		
		UF6.	10,536		

1992 Habitats	Hectares	1979 Habitats	Hectares	1950's Habitats	Hectares
		UF7.	1		
		UR.	123		
		UU	17		
		UU.	28,584		
		UUO.	1,982		
		UUO/A.	563		
		UUO/F6.	140		
		UUOA.	51		
		UUo.	14		
		UUo/A.	1,262		
			511,501		

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