Texas Coastal Bend

By Warren Pulich, Jr.[1]

Background

This vignette summarizes seagrass distribution data as of 1996 for the “Texas Coastal Bend” region near Corpus Christi (specifically the Nueces and Mission-Aransas estuaries). It also provides a review of trends in seagrass distribution over 40 yr for parts of the Nueces estuary and correlates these historical trends with natural and human-induced stressors that affect submerged vegetation.

Land use around the Texas Coastal Bend watershed (fig. 1) is dominated by southern Texas farmlands (row crops), pastures, and brushy rangeland. The population of the area (approximately 560,000 in 2000) is relatively sparse, despite having grown from 475,000 in 1980 (U.S. Census Bureau, *www.census.gov*). Urban development has been minor, with Corpus Christi the only city in the area with population above 20,000 (300,000 in 2000). The Port of Corpus Christi, which ranks sixth in the nation, and agriculture have been the mainstays of the local economy. Within the last 20 yr, however, accelerating resort, tourist, and retirement developments have been occurring along the barrier islands (Mustang and north Padre Islands), as well as in the Ingleside area and Blackjack Peninsula of the mainland north of Corpus Christi. This development pressure has put increasing stress on the submerged wetlands of the region (Coastal Bend Bays and Estuary Program, 1998).

Historically, waterborne shipping and hydrocarbon-extraction activities have been the major industries impacting the Texas Coastal Bend bays. More than any other feature, navigation channels that form extensive networks and are lined with dredged material have altered the Texas Coastal Bend bays, and these channels have locally affected seagrass habitats in the system. Approximately 110 km^2 (42.47 mi^2) of channels and dredged material were mapped in the early 1970s within the Corpus Christi area (Brown and others, 1976). Among the major channels are the Gulf Intracoastal Waterway (GIWW), Corpus Christi Pass and Aransas Pass ship channels, Lydia Ann Channel, La Quinta Channel, and Aransas Channel. Major boat harbors include the Inner Harbor and Turning Basin at the Port of Corpus Christi, Port Ingleside, and Conn Brown Harbor at Aransas Pass. Many small intrabay channels and canals were dredged across seagrass flats in Redfish Bay and Harbor Island, as well as the back side of Mustang Island, for access to shallow areas for oil and gas exploration. Dredged materials were dumped along the channels, forming upland mounds that locally blanketed seagrass habitats. Most of these channels were constructed before 1958, but dredging of the GIWW through the western Redfish Bay area along the mainland was only completed in 1959–60, and impacts from this project were documented in a trend analysis study by Pulich and others (1997). Numerous small industrial marinas and residential boat basins, built after 1960, occur along the shoreline along the GIWW.

Scope of Area

The Texas Coastal Bend area comprises two separate estuarine systems, the Nueces estuary system, formed by drainage from the Nueces River watershed, and the Mission-Aransas estuary system to the north, which receives inflow from the Mission and Aransas Rivers (fig. 1). These systems provide annual median freshwater inflows of 348,000 acre-ft (Nueces) and 318,000 acre-ft (Mission-Aransas) per year to the two estuaries. The area is a subtropical, semiarid region, with average annual rainfall of about 78 cm (30 inches) but with evaporation usually exceeding 180 cm (70 inches) per year for the Corpus Christi area.

The Nueces estuary system includes several distinct segments: north Corpus Christi Bay, Oso Bay, Nueces Bay, Redfish Bay, the Harbor Island complex, and the bay side of Mustang Island (fig. 2). The separate Mission-Aransas estuary system extends from near Rockport, along the bay side of San Jose Island, west to the Aransas and Mission River deltas, and north to the Aransas National Wildlife Refuge. This estuary includes Aransas Bay proper, Copano Bay, Port Bay, St. Charles Bay, and Mesquite Bay.

While current seagrass status was determined for both estuaries, only trends for the following separate segments of Nueces estuary were analyzed.

Redfish Bay

Redfish Bay lies north of Corpus Christi Bay proper and southwest of Aransas Bay and parallels the mainland

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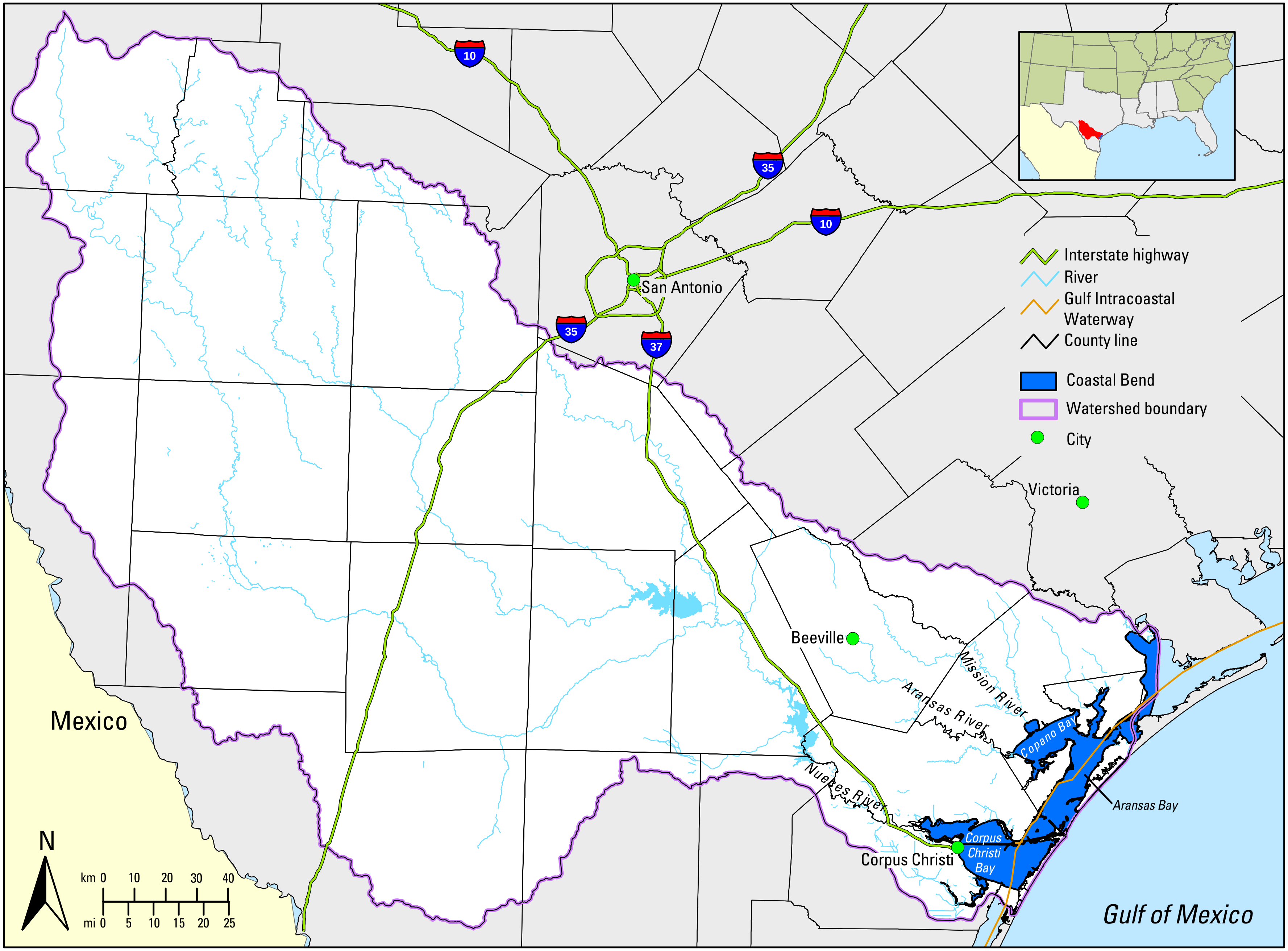


Figure 1. Watershed for Texas Coastal Bend region.

area between Ingleside and Rockport. The GIWW forms its western border, separating it from the mainland. This large, very shallow bay is protected from prevailing southeast winds by numerous saltmarsh islands, oyster reefs, and shoals and is well known for its extensive seagrass beds, particularly turtle grass (*Thalassia testudinum*) and manatee grass (*Syringodium filiforme*) beds. Salinities are typically polyhaline, and water clarity is moderately high.

Harbor Island

Harbor Island forms a flood-tidal delta complex that is large, triangular, and shallow and that is bordered and bisected by dredged channels and dredged-material disposal sites. It is bounded on the east by Lydia Ann Channel, which connects to the GIWW in Aransas Bay; on the west by Redfish Bay; on the north by Aransas Bay; and on the south by the Corpus Christi Channel, which separates it from Mustang Island. Bisecting this large bay-delta complex is the Aransas Channel. In addition, there are several smaller and tributary intrabay channels. This bay and tidal delta complex (approximately 4,047 ha, or 10,000 acres) represents the most extensive and northernmost estuarine tropical wetlands on the Texas coast and is composed of black mangrove (*Avicennia germinans*) and *Spartina* marsh, seagrass beds, and oyster reefs.

Mustang Island

This region of eastern Corpus Christi Bay, situated in the lee of Mustang Island, is well protected from prevailing southeasterly winds. In combination with the generally polyhaline to euhaline clear waters and sandy sediments, the habitat is conducive to supporting extensive seagrass beds and salt marsh.

Nueces Bay

Nueces Bay, a shallow, secondary bay in the upper estuary that receives direct inflow from the Nueces River, empties into the western portion of Corpus Christi Bay. Its salinity regime fluctuates from oligohaline to hypersaline levels, depending on inflows and evaporation. Along with its generally muddy waters, the salinity regime makes Nueces Bay a very dynamic habitat for seagrasses.

Methodology Employed To Determine and Document Current Status

A complete inventory of seagrass beds in the Texas Coastal Bend region, including for the first time the Mission-Aransas estuary, was performed for the Coastal Bend Bays and Estuaries Program (CBBEP, formerly the Corpus Christi Bay National Estuary Program) by Pulich and others (1997). Mapping was based on field surveys and photointerpretation of true color, aerial photography (1:24,000 scale) taken in November 1994. This inventory (Pulich and others, 1997) employed standard seagrass mapping protocols based on photointerpretation of 1:24,000-scale positive transparencies according to Ferguson and others (1993) and Dobson and others (1995). Seagrass distribution was determined from Kodak Aerocolor 2445 (color aerial film) photography flown on November 21, 1994, by aerial photography staff of the Texas Department of Transportation (TxDOT) in coordination with Texas Parks and Wildlife Department (TPWD), Coastal Studies Program. The mission was flown 2 days after a fall cold front when the weather was clear and winds calm. Tidal conditions were slightly higher than average annual water height. Large format (23 cm by 23 cm, or 9 inch by 9 inch) aerial film was exposed at an airplane altitude of 3,048 m (10,000 ft) to provide 1:24,000 scale.

Large format positive transparencies were photointerpreted for seagrass and other submerged features by using a backlit light table and 6-power magnifying lens onto 2 mil, transparent Mylar® sheets. The Mylar® overlays were scan digitized, and seagrass polygons were imported into ArcInfo geographic information system (GIS) software (ESRI, Redlands, Calif.). The digitized vector polygons were georeferenced to standard Universal Transverse Mercator map projection coordinate system by using Global Positioning System (GPS) based ground control points (at least eight control points per photo) and by using second-order rectification equations.

Classification Scheme

Mapping efforts resulted in discrimination of two seagrass bed types, continuous and patchy, based on morphology. Continuous beds represented extensive, homogeneous seagrass, with essentially 100% cover of plant shoots over 0.05-ha (0.12-acre) beds. Patchy beds were broken up into patches of plants interspersed with bare sediment patches. The size of these patches determined whether beds were mapped as patchy or continuous and in some cases whether an isolated patch of seagrass would be mapped at all. At 1:24,000 scale, the recognized standard for seagrass mapping, only features larger than about 0.05 ha (0.12 acre) in actual size can be accurately photointerpreted, and isolated patches smaller than 0.05 ha (0.12 acre) are omitted. Minimum mapping unit is also limited by water clarity in the aerial photography. Thus the definition of a patchy seagrass bed was a grouping of small patches of seagrass, between 0.05 and 0.1 ha (0.12–0.25 acre) in dimension, with equally small, open, bare sand areas separating them. Patchy beds often represented seagrass areas that are subject to impact from fetch, hydraulics, or mechanical disturbances such as dredged-material deposition, boating impacts, or shoreline development.

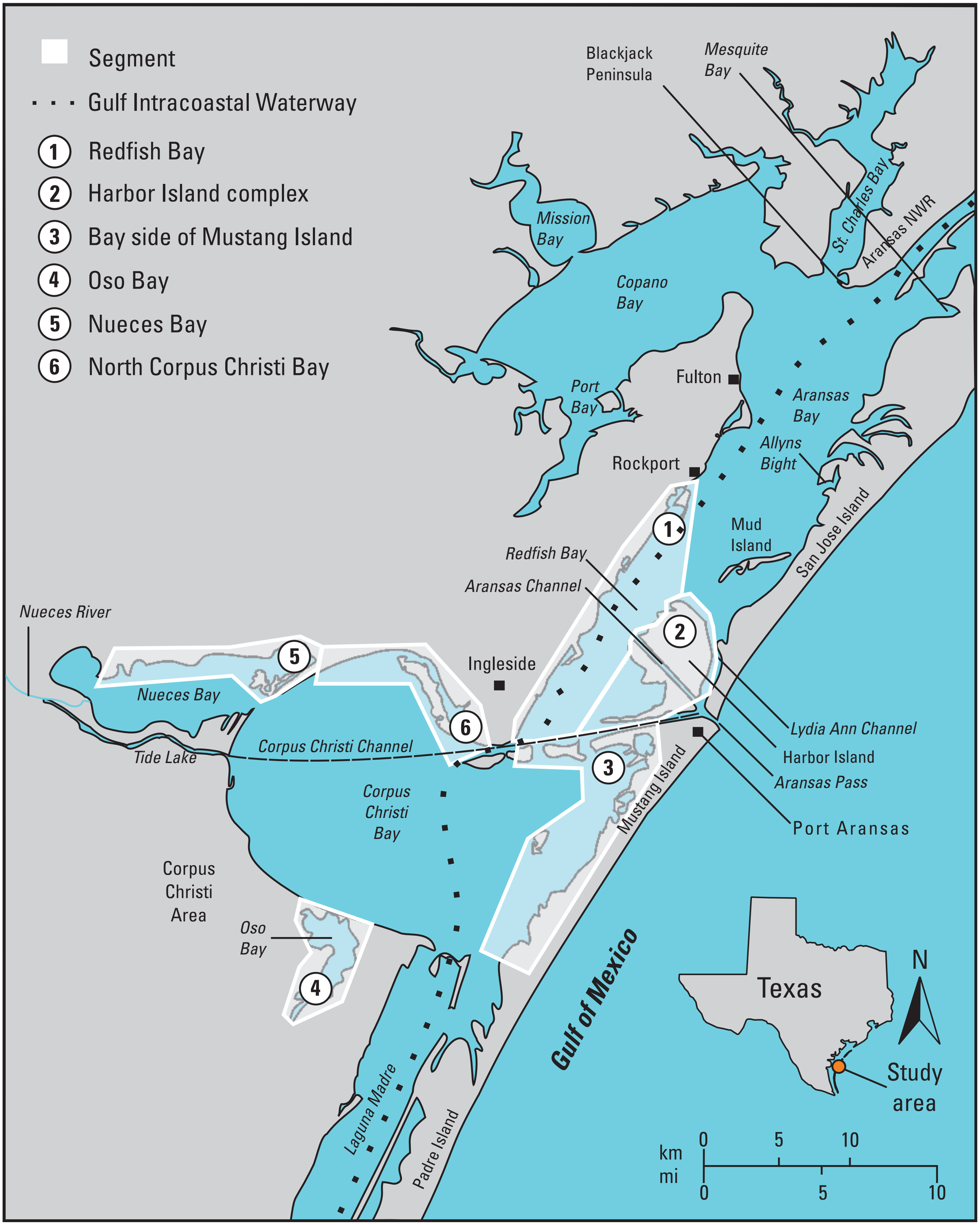


Figure 2. Scope of area for the Texas Coastal Bend seagrass vignette.

Attempts to separate seagrass beds into the density categories of sparse and dense produced variable results. Differences in water depth and clarity, as well as variable biomass between species, produced inaccuracies. Thus, although density categories were not used, ground surveys at extensive GPS stations allowed species distributions to be established. Percent frequency of species occurrence was calculated based on the total number of samples at GPS stations containing seagrass. From the spatial pattern of GPS points, the overall distribution of species was approximated from map coverages in each bay.

All groundtruthing surveys were conducted within 1.5 yr of acquiring the 1994 photography; thus, the trend analysis is considered accurate through the 1996 period. These surveys were often done from an airboat, which allowed access to very shallow grassflats. A GPS unit was used, which allowed real-time differential correction techniques to be applied. The seagrass distribution maps produced had a locational accuracy of ±3 m (10 ft).

Methodology Employed To Analyze Historical Trends

Seagrass trend analysis for the bay systems in the Texas Coastal Bend has received limited attention. Brown and others (1976) compiled the first quantitative wetland maps, including seagrass distribution, for this region from examination of 1950s black and white photography (scale 1:24,000) by Tobin Surveys, Inc. (San Antonio, Tex.). Biologists from TPWD also performed field surveys during the 1960s and 1970s of the San Antonio/Aransas/Corpus Christi/Laguna Madre areas, and McMahan (1965–67) and West (1971) produced a series of hand-drawn, small scale (>1:125,000) maps of these bays. Such mapping studies are very useful for general information on historical locations of seagrass although not reliable for quantitative evaluation of seagrass changes at 1:24,000 scale. A later mapping study by White and others (1978) at University of Texas-Bureau of Economic Geology provided data for the bay side of Mustang Island in the mid-1970s. Seagrass acreage was derived by quantitative photointerpretation of 1:24,000-scale color infrared photography acquired in 1974 by National Aeronautics and Space Administration (NASA) Johnson Space Center (JSC) (Houston, Tex.).

A complete study of seagrass bed trends for Corpus Christi and Redfish Bays, as well as for Harbor Island, in the Nueces estuary was performed for the CBBEP by Pulich and others (1997). Historical aerial photography at similar scales (at least 1:24,000 scale) was analyzed and compared for the late 1950s, 1975, and 1994 time periods. Historical changes and trends were established at 1:24,000 scale, including both spatial (geographic) locations and quantitative seagrass acreages lost or gained.

For the CBBEP study (Pulich and others, 1997), seagrass distribution maps from the three different time periods were produced by photointerpretation as described earlier. Historical photographic missions included 1956 and 1958 series black and white Tobin surveys (San Antonio, Tex.), scale 1:24,000; early October 1975 NASA-JSC (Houston) color-infrared series, scale 1:24,000; and early November 1989 NASA-Ames Research Center, California, color-infrared series, scale 1:63,000. Data for the recent (1994–96) time period and classification of seagrass features were previously described. For 1975 photos, a Bausch & Lomb stereo zoom transfer scope was used to transfer and register seagrass features to the appropriate 7.5 min U.S. Geological Survey (USGS) planimetric base map. For the 1950s photointerpretation, features were traced directly off of the rectified black and white prints which had been mosaicked, producing a USGS quadrangle-size sheet (50 by 58 cm (19.75 by 22.75 inches), similar to the 7.5 min planimetric base maps produced in 1975). Except for trend analysis in Nueces Bay, 1989 photography was used only as visual reference material.

After digitization, all digital map coverages for the 1950s, 1975, and 1994 time periods were entered into an ArcInfo GIS database, where trend analysis was performed by using GIS change analysis. Change maps were determined by postclassification change detection from the seagrass distribution maps representing the different time periods (Dobson and others, 1995). Digitized seagrass coverages were spatially correlated with a variety of ancillary spatial data on such parameters as channel dredging, spoil disposal areas, bathymetry, and locations of shoreline developments. Simple GIS overlay and buffer analysis techniques were used to correlate environmental features with seagrass distributions.

Trend analysis for the bayside area of Mustang Island (eastern shoreline of Corpus Christi Bay) was conducted by using different data sources from those used for Redfish Bay and Harbor Island. Numerical acreage values for the 1950s (as derived from 1956/58 Tobin photography) were taken from the study report by Brown and others (1976). Map data for 1974 were digitized and calculated from the printed georeferenced maps in White and others (1978), and the 1994 map data were from the study by Pulich and others (1997).

Trend analysis for Nueces Bay seagrass was conducted over different time periods. The only historical photography that could be located in which seagrass was visible was from the 1961 and 1989 periods. The 1961 photography was 1:20,000-scale black and white photographs taken by the U.S. Department of Agriculture Soil Conservation Service, and the 1989 photographs were high-altitude color-infrared from NASA-Ames (see previous paragraph). Seagrass coverage was photointerpreted from both sets of photographs and transferred to 1:24,000-scale USGS quadrangle maps of the Nueces Bay area by using zoom transfer techniques.

No historical trends were analyzed for the Mission-Aransas estuary.

Status and Trends

System Summary

Nueces Estuary System

In 1994, distribution of seagrass beds in the Nueces estuary system was as follows: Nueces Bay, 294 ha (726 acres); Oso Bay, 483 ha (1,193 acres); northshore Corpus Christi Bay, 290 ha (717 acres); bay side of Mustang Island, 1,503 ha (3,714 acres); Redfish Bay, 3,644 ha (9,004 acres); and the Harbor Island complex, 2,064 ha (5,100 acres) (fig. 3). The Nueces estuary system does not include the Laguna Madre north of John F. Kennedy Causeway. Total seagrass area, 8,278 ha (20,455 acres), was 9.3% of all Texas seagrasses. Continuous seagrass amounted to 4,194 ha (10,363 acres), while patchy beds made up 4,084 ha (10,092 acres).

Mission-Aransas Estuary

The 1994 distribution of seagrass beds for the Mission-Aransas estuary system (3,107 ha, or 7,677 acres total) was as follows: Mission/Copano Bays, 473 ha (1,169 acres); Port Bay, 724 ha (1,789 acres); St. Charles Bay, 348 ha (860 acres); Mesquite Bay, 236 ha (583 acres); and Aransas Bay proper comprising mostly Mud Island and bay side of San Jose Island, 1,326 ha (3,277 acres) (fig. 4). Continuous seagrass amounted to 1,691 ha (4,178 acres), while patchy beds made up 1,416 ha (3,499 acres).

Status Summary

In 1994, the Nueces and Mission-Aransas estuary systems of the Texas Coastal Bend contained a combined 11,385 ha (28,132 acres) of seagrass, of which 5,885 ha (14,542 acres) were continuous seagrass beds, while 5,500 ha (13,590 acres) were patchy (fragmented) seagrass beds. Both systems accounted for 12.8% of all Texas seagrass beds, by far the largest amount of seagrasses found in Texas bay systems outside of the Laguna Madre. Seagrass species found in the Texas Coastal Bend study area are turtle grass, shoal grass (*Halodule wrightii*), wigeon grass (*Ruppia maritima*), manatee grass, and star grass (*Halophila engelmannii*).

Primarily, seagrass distribution in the Texas Coastal Bend parallels the extent of mesohaline, shallow-water depth zones of less than 1.5 m (5 ft). Secondarily, it tends to follow the inflow and turbidity gradients in the bays. Seagrass is scarce in upper bays, where direct inflows are high and salinities are usually below 15 ppt, compared to areas in the lower estuary, where inflows are low, salinities are above 20 ppt, and depth is uniformly shallow. Not only must salinity be at appropriate levels for seagrass, but there must also be protection from physical disturbance factors, dredging, shoreline erosion, and the heavy wave action resulting from wind-induced fetch. This requirement for protection is critical in various parts of the Texas Coastal Bend. Seagrass beds on the lee side of the barrier islands (Mustang, Harbor, and San Jose Islands) show considerable expansion from this protective effect, whereas beds in open parts of Corpus Christi, Copano, and Aransas Bays tend to develop as fringe bands because of exposure stress. Beds in more developed areas (e.g., Redfish Bay) show a combination of stress from this impact, as well as from channelization and dredging.

Trends Summary

Redfish Bay

As mentioned previously, the Redfish Bay segment of Nueces estuary contains the most extensive, pristine seagrass beds on the Texas coast outside the Laguna Madre, with 1994 acreage of about 3,644 ha (9,000 acres) (fig. 3). Redfish Bay also contains the largest abundance of all five seagrass species outside the lower Laguna Madre. Historical distributions in this region for the 1950s and 1975 are presented in figures 5 and 6, respectively. Numerical results for Redfish Bay are presented in table 1. Figure 5 shows the 1950s coverage,

Table 1. Summary of total seagrass change for Mustang Island, Redfish Bay, and Harbor Island segments from the late 1950s to the mid-1970s and then to 1994.

Time period	Mustang Island	Redfish Bay	Harbor Island
Late 1950s	1,030 ha (2,545 acres)	4,180 ha (10,328 acres)	1,199 ha (2,962 acres)
Mid-1970s	1,128 ha (2,786 acres)	3,985 ha (9,847 acres)	2,211 ha (5,463 acres)
1950s–1970s net	+98 ha (+241 acres)	-195 ha (-482 acres)	+1,012 ha (+2,500 acres)
Percent change	+9.5%	-4.7%	+84.4%
Time period			
Mid-1970s	1,128 ha (2,786 acres)	3,985 ha (9,847 acres)	2,211 ha (5,463 acres)
1994	1,503 ha (3,713 acres)	3,644 ha (9,004 acres)	2,064 ha (5,100 acres)
1970s–1994 net	+375 ha (+927 acres)	-341 ha (-843 acres)	-147 ha (-363 acres)
Percent change	+33.3%	-8.6%	-6.7%

which represents seagrass distribution prior to dredging the GIWW along the mainland side of Redfish Bay. Between 1958 and 1975, total seagrass showed a slight decrease (4.7%) for the area. Between 1975 and 1994, seagrass coverage in Redfish Bay then decreased significantly (by 8.6%). Overall results indicate that a net loss of 536 ha (1,324 acres) (13%) of seagrass occurred between the 1950s and 1994 in Redfish Bay. Table 2 shows that this change was accompanied by substantial loss (48%) of continuous beds and a progressive increase (88%) in patchy (i.e., fragmented) seagrass beds.

Harbor Island

Historical seagrass distributions in the Harbor Island segment of the Nueces estuary system were determined for 1958 (fig. 5) and 1975 (fig. 6) (also see table 1). For the Harbor Island complex (north and south parts combined), there was a large increase in seagrass from the 1950s to 1975, especially of continuous seagrass beds (all shoal grass or wigeon grass). There followed a measurable decrease of about 6% (147 ha, or 363 acres) between 1975 and 1994 (fig. 6 and table 1). Overall results indicate that there was a net gain of 77% (866 ha, or 2,140 acres) seagrasses in the Harbor Island area that occurred between 1958 and 1994. This increase was mostly patchy beds (562 ha, or 1,389 acres) and lesser amounts of continuous beds (304 ha, or 751 acres) (table 2).

Mustang Island

On the bay side of Mustang Island, seagrass increased by 98 ha (241 acres) between 1958 and 1974, as reported by White and others (1978). That study concluded that, after the 1950s drought ended, higher bay water (sea level) greatly promoted the spread of seagrass onto bare tidal flats in the Harbor Island complex and on the bay side of Mustang Island. In the Pulich and others (1997) study, an additional 33% (375 ha, or 927 acres) increase in seagrass area was measured between 1974 and 1994, as shown in figures 3 and 6 and table 1. Gains in seagrass occurred not only along the upland margins of the wind-tidal flats in some areas but also along the bayward margins of the flats in deeper areas (fig. 3). In 1994, there were 917 ha (2,266 acres) of continuous seagrass beds and 586 ha (1,448 acres) of patchy seagrass beds in the Mustang Island segment.

Nueces Bay

Figure 3 shows the 1994 mapped seagrass distribution for Nueces Bay; numerical data for other time periods are reported here in the text. From 1961 photography, only 79 ha (195 acres) of seagrass (reported to be shoal grass by McMahan, TPWD, oral commun.) were mapped for Nueces Bay. After 1961, there was essentially a 100% loss of seagrass

Table 2. Changes in continuous and patchy seagrass beds in Redfish Bay and Harbor Island segments between late 1950s to mid-1970, and mid-1970s to 1994.

Time period	**Redfish Bay**		**Harbor Island**	
	Continuous	Patchy	Continuous	Patchy
Late 1950s	3,100 ha (7,660 acres)	1,080 ha (2,669 acres)	1,016 ha (2,511 acres)	182 ha (450 acres)
Mid-1970s	2,969 ha (7,337 acres)	1,016 ha (2,511 acres)	1,776 ha (4,389 acres)	436 ha (1,077 acres)
1950s–1970s net	-131 ha (-324 acres)	-64 ha (-158 acres)	+760 ha (+1,878 acres)	+254 ha (+628 acres)
Percent change	-4.2%	-5.9%	+74.8%	+139.6%
Mid-1970s	2,969 ha (7,337 acres)	1,016 ha (2,511 acres)	1,776 ha (4,389 acres)	436 ha (1,077 acres)
1994	1,669 ha (4,124 acres)	1,976 ha (4,883 acres)	1,320 ha (3,262 acres)	744 ha (1,838 acres)
1970s–1994 net	-1,300 ha (-3,212 acres)	+960 ha (+2,372 acres)	-456 ha (-1,127 acres)	+308 ha (+761 acres)
Percent change	-43.8%	+94.5%	-25.7%	+70.6%

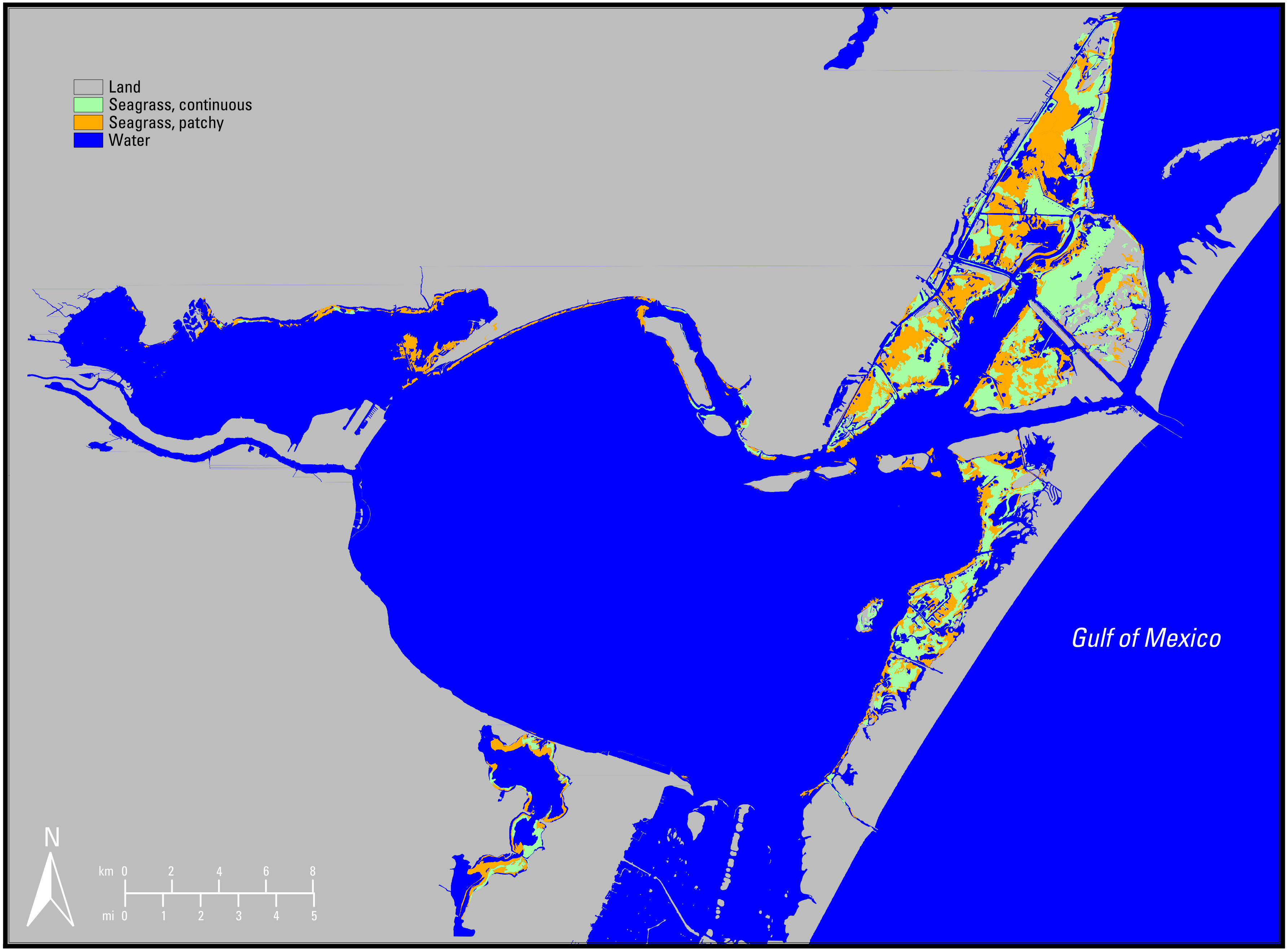


Figure 3. Distribution of seagrass in the Nueces estuary system, 1994.

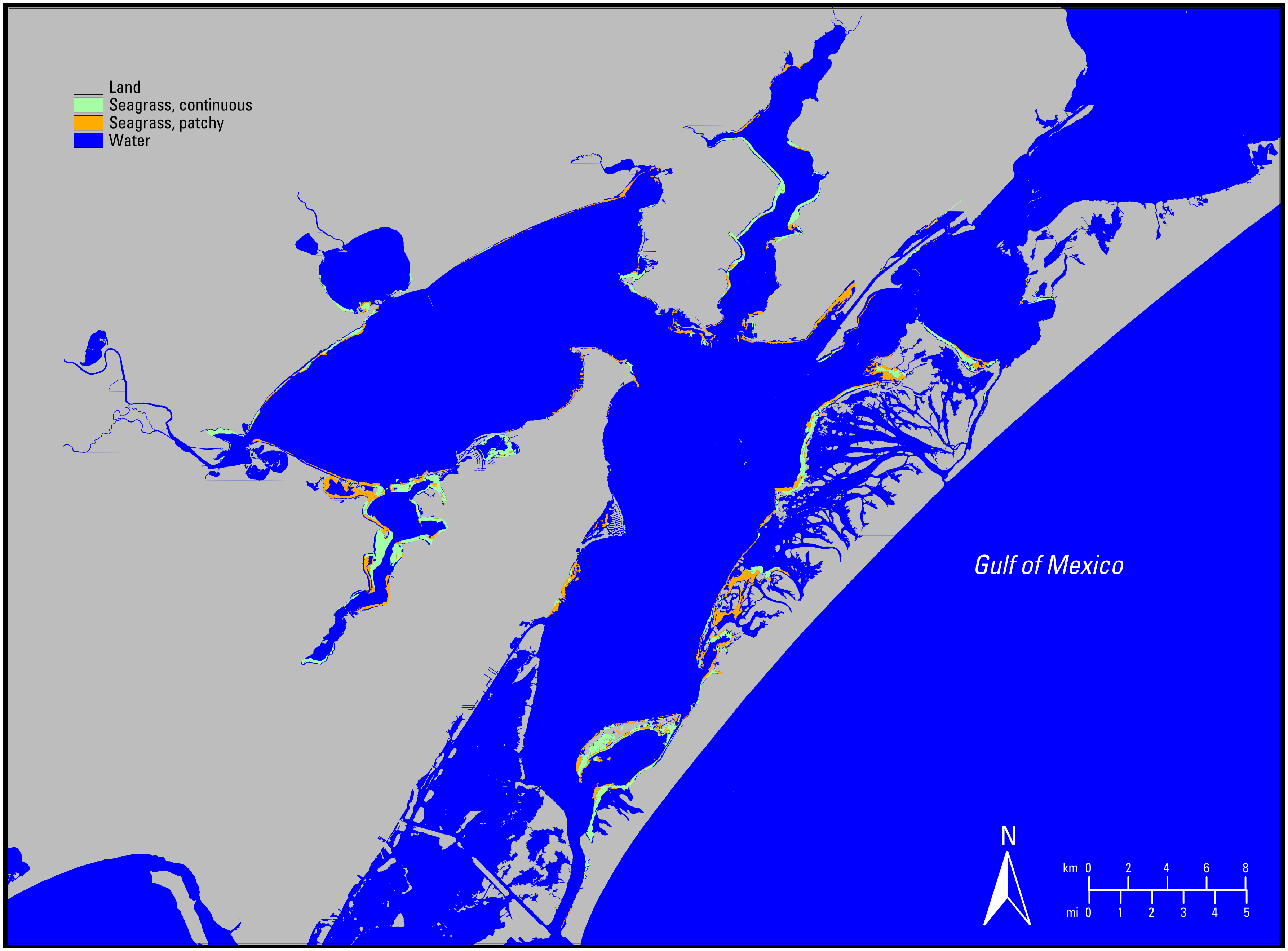


Figure 4. Distribution of seagrass in the Mission-Aransas estuary system, 1994.

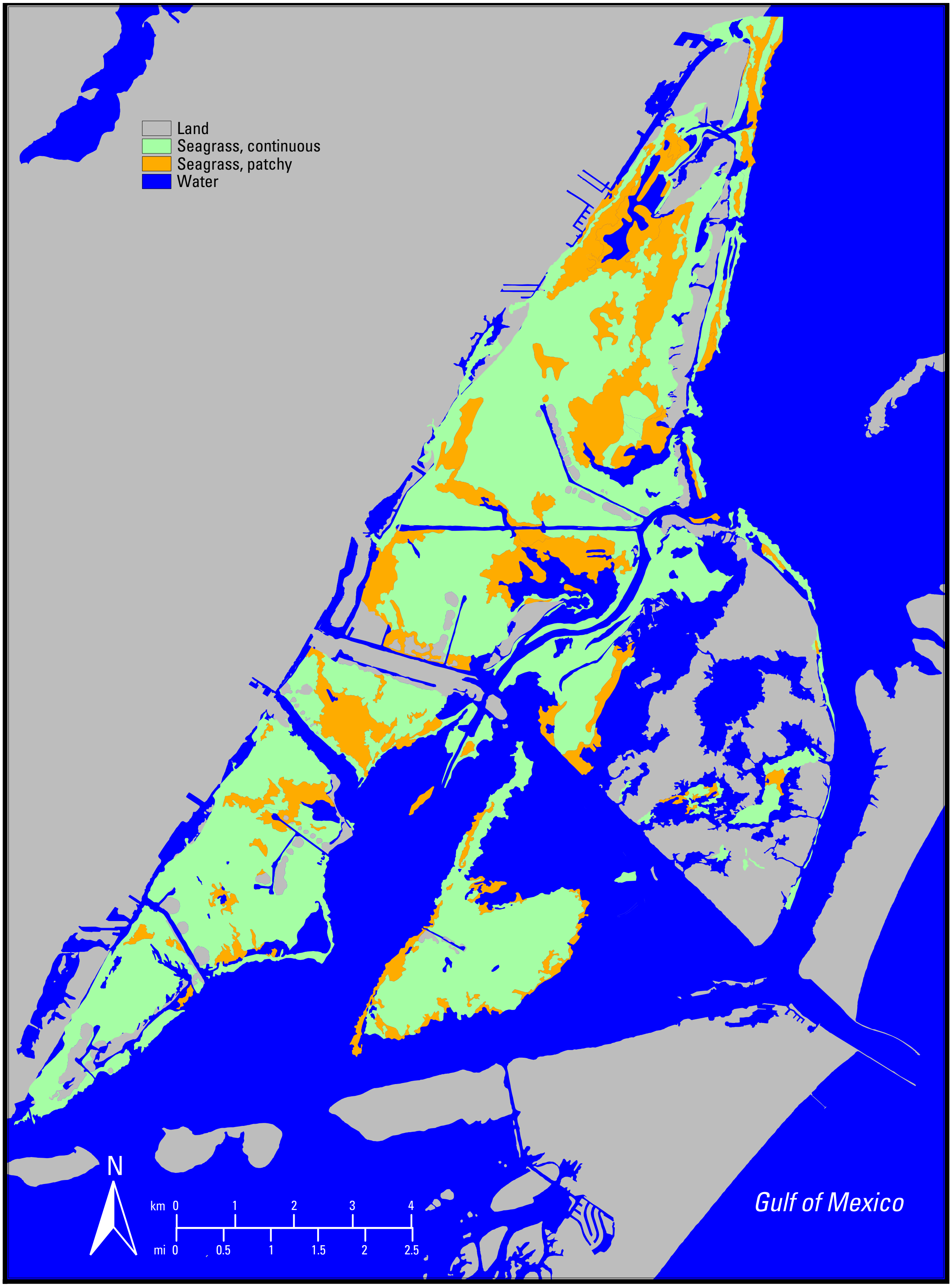


Figure 5. Distribution of seagrass in Redfish Bay and Harbor Island, late 1950s.

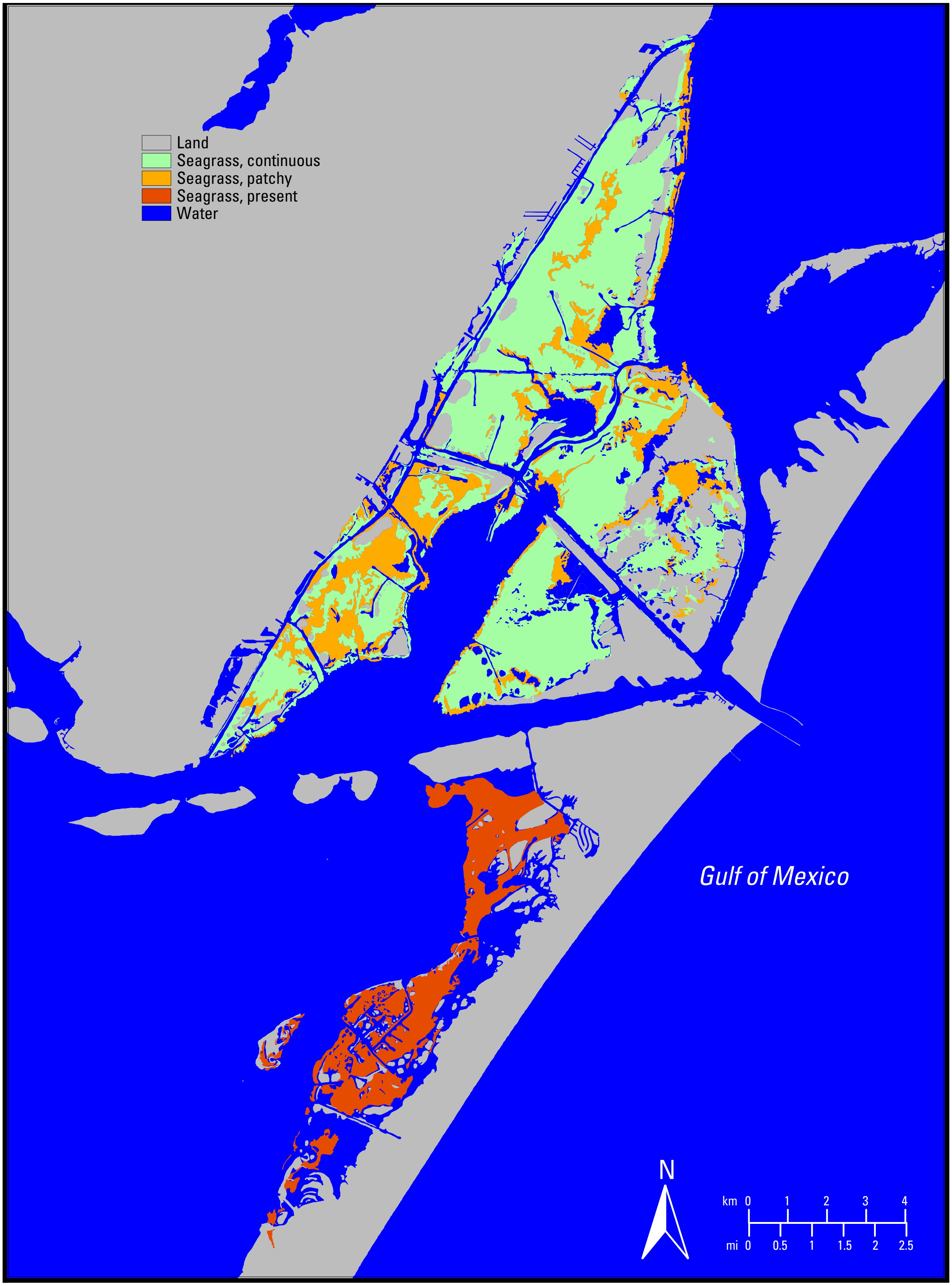
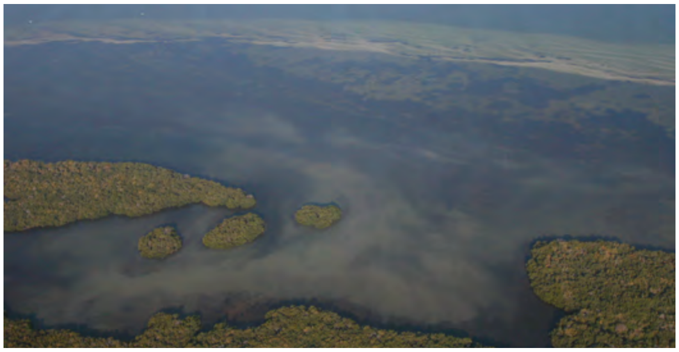


Figure 6. Distribution of seagrass in Redfish Bay and Harbor Island, mid-1970s.

beds by the late 1960s, coinciding with Hurricane Beulah in 1967 (McGowen, 1971). During the 1970s, only fringe shoreline patches of mostly wigeon grass were observed by TPWD biologists during sampling trips to Nueces Bay (Richard Harrington, TPWD, Corpus Christi, oral commun.). By the mid-1980s, major shoal grass beds had reappeared (Harrington, TPWD, oral commun.), reaching 200 ha (494 acres) by 1989 and 294 ha (726 acres) by 1994, as determined by this mapping study and representing an increase of 94 ha (232 acres) between 1989 and 1994. Percent changes in seagrass acreage were as follows: 1961 to about 1970, essentially 100% loss of shoal grass; 1970 to the early 1980s, small amounts of wigeon grass and no shoal grass observed; 1961 to 1989, 112% gain in seagrass compared to 1961; and 1989 to 1994, a 47% gain of shoal grass over 1989. These trend data indicate that Nueces Bay is an unusually dynamic seagrass area.

Texas Coastal Bend as a Whole

For the combined Redfish Bay, Harbor Island, and Mustang Island segments of the Nueces estuary system, net seagrass bed area may appear fairly stable over 40 yr, but this conclusion ignores the dynamic cycles in localized seagrass bed changes. Spatial analysis reveals that seagrass losses and gains occur simultaneously. Overall, a net increase occurred in total area for the system between 1958 and 1994 (net gain 802 ha, or 1,981 acres) (table 1). This gain was due primarily to the large expansion of seagrass into the Harbor Island complex between the late 1950s and 1975 (84% or 1,012 ha) and along Mustang Island (375 ha, or 926 acres) between 1974 and 1994. The simultaneous 13.3% decrease (536 ha, or 1,324 acres) and accompanying bed fragmentation in seagrass beds noted for Redfish Bay over the period from the late 1950s to 1994, however, suggested that seagrass conditions should be interpreted with caution for the entire system.



Causes of Change

Redfish Bay

Changes Related to Dredging and Channel Construction

Extensive, direct seagrass losses associated with dredged-material deposition occurred between 1958 and 1975 as shown by the network of dredged channels and disposal sites created in Redfish Bay. The majority of the losses were caused by seagrass burial principally related to construction of the GIWW through Redfish Bay and the resulting disposal of dredged material directly into seagrass areas; however, at some distance from disposal sites, seagrass beds were often converted to sparsely vegetated (patchy) beds. Odum (1963) reported a decrease in seagrass productivity and an imbalance of respiration over photosynthesis in Redfish Bay in summer 1959 that he attributed to dredging of the GIWW. Recovery was noted the following year when growth was exceptional, and he suggested that released nutrients may have stimulated growth (Odum, 1963).

Many smaller, intrabay channels had been dredged across seagrass areas in Redfish Bay prior to 1958. The initial impacts on seagrass beds from these channels and disposed dredged material have not been determined. Of interest is that between 1958 and 1975 there were gains in seagrass along the channels as seagrasses spread over the margins of these reworked, submerged dredged materials. Between 1975 and 1994, however, there were additional losses along some of these intrabay channels, apparently from maintenance dredging or boat traffic using the channels.

From GIS analysis (Pulich and others, 1997), 795 ha (1,964 acres) of seagrass were lost between 1958 and 1994 because of dredged-material deposition and channel impact zones. Concomitantly, 407 ha (1,006 acres) were gained, for a net loss of 388 ha (959 acres). Since most of this loss occurred in the Redfish Bay portion of the regional complex, it is interesting to compare this number to the total seagrass lost in Redfish Bay alone, which was 536 ha (1,324 acres). Thus it is evident that the 388 ha (959 acres) lost from channel dredging accounts for approximately three-fourths (72%) of the Redfish Bay total, which is a substantial impact.

Changes Related to Bathymetry

In the Redfish Bay area, Hurricane Carla (1961) apparently did not measurably affect seagrasses (see Pulich and others, 1997), substantiating that the main effect on the middle Texas coast from this storm was high tides and not erosion, wind, or fetch damage. This tidal effect is a great contrast to the destructive effect of Hurricane Carla on the seagrasses in Galveston Bay (Pulich and White, 1991).

Changes Related to Boat Propeller Scarring

Damage from boat traffic (i.e., propeller scarring) was noted extensively in a number of areas, especially where seagrass losses occurred. Most of the 1994–95 data came from groundtruthing and field surveys since propeller scars are features beyond the normal limit of resolution (0.05 ha or 0.12 acre) of 1:24,000-scale photographs. It was obvious that certain shallow areas (water depth less than 0.6 m, or 2 ft) were greatly affected by propeller disturbance. The affected areas tended to be the large, expansive areas in north Redfish Bay (near Hog Island and Estes Cove) and near Harbor Island (south side) where boaters attempted to take “short cuts” between favorite fishing areas in grassflats and residential developments or dredged channels. Comparison of 1994 and 1975 photography revealed obvious physical scarring of seagrass beds in this area of Redfish Bay over the 20-yr period. Since the dominant species in these seagrass beds is turtle grass, a sensitive, slow-growing climax species, this scarring may be more severe and long lasting than at other sites in the bay. Dunton and Schonberg (2002) quantitatively determined that scarring of seagrass beds within the boundaries of the CBBEP region ranged from 14.5% to 97.6%. The most severe scarring was found within north Redfish Bay in Nueces and Aransas Counties (91%–97.6%). Severe winter storms (cold fronts) and hurricanes in the Gulf of Mexico also exacerbate propeller scar damage to some seagrass beds as a result of high wave energy scouring the bottom.

Changes Related to Shoreline Development and Construction

The mainland (western) side of Redfish Bay is highly developed along the GIWW, whereas the Harbor Island (eastern) shoreline is essentially undisturbed. As has been observed in Australia (Cambridge and McComb, 1984), there is a high probability that impacts to seagrass may occur along the western margin from both industrial and residential activities. It is difficult, however, to directly quantify effects of this shorefront stress apart from GIWW dredging and channel impacts in the Redfish Bay area. Significant motorboat activity originating from these developments does in fact occur in this area and has contributed to large amounts of seagrass decline.

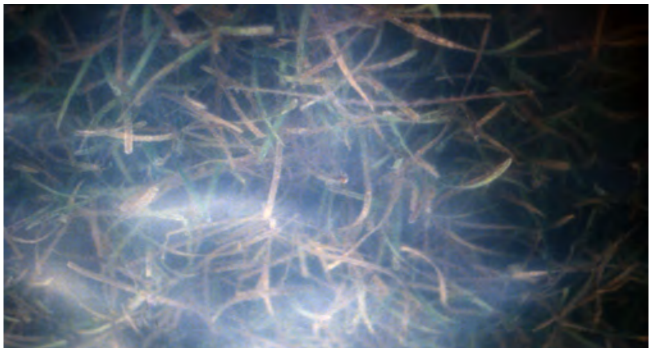
Changes Related to Light-attenuation Effects

From examination of 1996 National Pollutant Discharge Elimination System (NPDES) permit records from Texas Natural Resource Conservation Commission (TNRCC), it does not appear that direct wastewater discharges into seagrass beds regularly occur; however, nonpoint discharges from sites along the Ingleside-Aransas Pass-Rockport shoreline have the potential for contributing to higher nutrient loadings in that area. With the increase in shoreline marina developments along the GIWW from Aransas Pass to Rockport (about 517 ha, or 1,278 acres between 1975 and 1994), increased nonpoint-source runoff was predicted for this part of the bay (Pulich and others, 1997).

Because nutrient loadings may be hard to detect directly in the water column (see Dunton, 1996; Tomasko and others, 1996), nutrient concentrations in the water column may be poor indicators of incipient water-quality problems. Conversely, phytoplankton blooms, epiphytes, and macroalgae accumulations are considered good indicators of reduced water quality (National Oceanic and Atmospheric Administration, Office of Ocean Resources Conservation Assessment, 1995). Growth of these nuisance plants is stimulated by high dissolved nutrient levels, and the algae tend to shade and overgrow bottom-rooted seagrasses (Dennison and others, 1993). Recent reports from New England (Short and Burdick, 1996) and Florida (Tomasko and others, 1996) document the loss of seagrasses caused by dissolved nutrients leached from residential septic systems and carried into surrounding bay waters.

Changes Related to Macroalgae and Wrack Accumulation

Macroalgae mats (especially red and brown algae) in Redfish Bay were reported by Cowper (1978) to pose a potential light-shading stress to seagrasses. Epiphytes were also postulated by Pulich (1980) to reach potentially noxious levels for seagrass. Large accumulations of wrack and drift macroalgae were identified and mapped mainly from the western Redfish Bay system during the 1995 and 1996 field surveys. Often, rafts of red and green macroalgae appeared to be depositing in topographic depressions within the seagrass beds. Noxious, stagnant conditions produced over seagrass beds from dead, decomposing algae were also noted. The anoxia, accompanied by hydrogen sulfide, would be toxic to seagrass, in addition to the light limitation caused by shading from the algae plants. These conditions could also cause bacterial or fungal diseases to develop in the seagrass (Dennison and others, 1993; Short and Wyllie-Echeverria, 1996).



Localized hydrodynamics and circulation patterns in the western Redfish Bay area may contribute to nutrient and subsequent organic matter buildup. Extensive wrack and macroalgae deposits observed in the 1994 photography provide evidence that the north portion of Redfish Bay acts as a sink to trap material. Much of the western part of Redfish Bay may lie essentially out of the main circulation and tidal flow through the Corpus Christi or Aransas Bay system. Because of longer residence time for bay waters in that region, materials discharged into Redfish Bay waters, including dissolved nutrients, would tend to accumulate there. Studies by Tomasko and Lapointe (1991) in Florida suggest that this mechanism would lead to increased growth of macroalgae from the nutrients.

Harbor Island

Changes Related to Dredging and Channel Construction

On Harbor Island, the most extensive losses caused by dredging activities also occurred between 1958 and 1975 (Pulich and others, 1997). Losses occurred in the southwest corner of the island complex as a result of channels dredged for hydrocarbon exploration and from disposal of dredged material excavated from the Corpus Christi Ship Channel. Overall, these losses were relatively small compared to those along the GIWW. Losses of seagrass along the eastern side of Talley and Traylor Islands (Aransas Bay) may have been in part the result of open water discharge of dredged material on the western side of the GIWW to Lydia Ann Channel or in association with local intrabay channels. Barren nearshore areas that were more densely vegetated in 1975 may have been buried by discharged or reworked dredged material by 1994. Between 1975 and 1994, a slight decrease in seagrass area (approximately 148 ha, or 366 acres) was measured; the decrease was attributed to loss of mostly turtle grass beds along channels.

Changes Related to Bathymetry

Between 1958 and 1975, there was a net increase of more than 1,000 ha (2,471 acres) in shoal grass and wigeon grass beds from expansion onto shallow wind-tidal delta flats of north Harbor Island (Brown and others, 1976; White and others, 1983). This seagrass bed expansion is attributed by Pulich and others (1997) to an increase in water depth over the flats because of an accelerated rate of relative sea-level rise that followed the severe drought of the mid-1950s (Swanson and Thurlow, 1973; Ramsey and Penland, 1989). This seagrass expansion was complete by 1975.

Mustang Island

Changes Related to Dredging and Channel Construction

Direct changes in seagrass because of dredging operations on the bay side of Mustang Island have been minimal since the mid-1950s. Extensive changes occurred between 1938 and 1956, however, when several channels related to oil and gas exploration were dredged across seagrass beds and wind-tidal flats east of Shamrock Island (White and others, 1978).

Changes Related to Bathymetry

Seagrass beds also expanded over wind-tidal flats on Mustang Island as a result of rising relative sea level after the 1950s drought. Seagrasses expanded over the broad flats on the bay side of Mustang and North Padre Islands, increasing from approximately 1,030 ha (2,545 acres) in 1958 to 2,700 ha (6,672 acres) in 1974 (White and others, 1978). The trend set during this period from the late 1950s to 1974 continued from 1974 to 1994, with seagrass cover increasing 20.6% from 2,375 ha (5,868 acres) in 1974 to 2,870 ha (7,092 acres) in 1994. These increases in seagrass area from the late 1950s to the mid-1970s correlate positively with the increase in water levels for this time period as recorded at the Rockport tide gage (Swanson and Thurlow, 1973; Ramsey and Penland, 1989). Thus, seagrass expansion can be attributed to rising water levels during the 1970s, the protected physiography along the leeward side of Mustang Island, and the noticeable lack of residential and waterfront development along this protected bayside shoreline.

Nueces Bay

Changes Related to Dredging and Channel Construction

Direct losses in Nueces Bay seagrass are not documented as being a result of channel dredging or dredged-material disposal; however, oyster shell dredging, which actively occurred in the open bay prior to 1970 but was stopped in 1972, probably impacted the seagrass beds in the 1950s and 1960s.

Changes Related to Sedimentation

A major hurricane effect seems to explain the disappearance of shoal grass beds from Nueces Bay after Hurricane Beulah during the late 1960s. Seagrass dynamics appear most related to heavy runoff/sediment deposition from Gum Hollow Creek caused by Beulah's torrential, and record-level, rainfall in 1967 (McGowen, 1971). Most of the runoff from the extensive adjacent farmlands on the north side of Nueces Bay flows through this creek drainage into Nueces Bay. The extreme sediment deposition from this hurricane event created a large fan delta of fine clay and silt sediments in the bay (McGowen, 1971), which buried the existing seagrass beds and prevented reestablishment of shoal grass for about 15 yr.

Species Information

Generally, turbid, low-salinity water regimes appear to be responsible for stressing seagrasses in upper estuary bays (e.g., Nueces, Copano, and San Antonio Bays). The cyclical occurrence of shoal grass and wigeon grass in Nueces Bay (this vignette) seems to reflect these salinity and turbidity fluctuations. The resurgence of seagrass in Oso Bay over the last 20 yr also correlates with the growth requirements of shoal grass for clear, polyhaline (>18 ppt) marine waters which are discharged from the cooling pond system at the Central Power and Light Company powerplant in south Corpus Christi.

Seagrass species distributions were determined from the 1995–96 field surveys for the Redfish Bay area, Harbor Island complex, Aransas Bay/Copano Bay area, and Mustang Island area (Pulich and others, 1997). Based on the groundtruthing surveys, frequency of species occurrence was calculated (table 3) for these individual bay regions. The relative percent occurrence reveals the dominance of shoal grass (63%–90% of all samples) in the system and the scarcity of manatee grass (2.0%–7.6%) and star grass (0.4%–6.0%). Turtle grass appeared much more frequently in Redfish Bay (61%) and the Harbor Island area (24% of samples) than in either Mustang Island or Aransas Bay (15.5% average). The low-salinity-tolerant wigeon grass is found frequently in all shoal grass beds within the Texas Coastal Bend area. Wigeon grass, being primarily an annual species, is very seasonal, occurring most abundantly in spring and fall; however, in some backbay and upper bay areas, wigeon grass is also frequent in summer (Port, Mission, and Nueces Bays; San Jose Island and Harbor Island areas), when salinities are low.

Shoal grass is the most abundant species throughout the Texas Coastal Bend area, with extensive beds even in mesohaline, upper bay segments. Shoal grass is the dominant species in all bay segments except Redfish Bay. Along with wigeon grass, these two are the only species found in Nueces, Copano, Port, and St. Charles Bays. Small amounts of star grass are found in all bay systems except Nueces, Copano, Port, and St. Charles Bays.

Turtle grass and manatee grass were locally dominant only in the Redfish Bay area, in the Harbor Island complex, along Mustang Island in the "East Flats" area, and around Mud Island and Allyns Bight in Aransas Bay proper. These two tropical species frequently occur together and appear most abundant in polyhaline areas, primarily the lower bay outlets to the gulf at Port Aransas. Except for the relict population of turtle grass still located in Christmas Bay (near West Galveston Bay), no other populations of turtle grass or manatee grass are presently known to occur farther north on the Texas coast than this southeastern shore of Aransas Bay.

Monitoring for Seagrass Health

Seagrass monitoring work should be conducted while seagrasses are actually disappearing. Consequently, monitoring is a primary objective of the proposed coastwide Texas Seagrass Monitoring Program (Pulich and others, 2003), which is currently under development by State resource agencies (see Statewide Summary for Texas, this report). As indicated previously, studies in Texas Coastal Bend bays since 1990 have been conducted after seagrass declines. These results demonstrate the need for a proactive, regular

Table 3. Frequency of occurrence (percent of samples) for five seagrass species in the Texas Coastal Bend, 1995–96. Total percentage in each segment is more than 100% because of mixed species assemblages in samples.

Segments	Shoal grass[1]	Wigeon grass[2]	Turtle grass[3]	Manatee grass[4]	Star grass[5]
Redfish Bay	62.7	7.1	61.2	7.6	4.6
Harbor Island	84.6	24.9	24.2	3.0	0.5
Mustang Island	86.0	15.0	15.8	1.9	0.4
Aransas/Copano Bay system	90.0	9.2	15.3	2.8	6.0

[1] *Halodule wrightii*. [2] *Ruppia maritima*. [3] *Thalassia testudinum*. [4] *Syringodium filiforme*. [5] *Halophila engelmannii*.

monitoring program to assess seagrass health and to detect impacts prior to fragmentation or loss of seagrass habitat. In addition, monitoring would be important in documenting the success of restoration efforts.

Mapping and Monitoring Needs

For the proposed Texas Seagrass Monitoring Program (see Pulich and others, 2003), it is critical to develop good indicators of seagrass community health and then to establish a statistically robust sampling scheme to measure these indicators. The Texas monitoring program plans to use a two-part approach of intensive, probabilistic-based field sampling combined with landscape sampling from aerial photography. Intensive field sampling will be focused on detecting water-quality degradation and establishing water-quality criteria (standards) for these seagrass systems. Aerial photography will be flown at 1:24,000 scale every 5–10 yr for status and trends assessment of seagrass distribution in an entire bay system, and annual photographs at 1:9,600 or larger scale will be taken at targeted sites where impacts are suspected from specific stressors. The high-resolution photography will be especially important for monitoring seagrass patch dynamics at these "target sites" or documenting restoration of former seagass areas.

Restoration and Enhancement Opportunities

Propeller Scar Restoration

Because of the serious fragmentation of seagrass beds noted from monitoring studies (Pulich and others, 1997; Dunton and Schonberg, 2002), TPWD recently started an active program to prevent and restore motorboat damage to turtle grass beds. This program has primarily targeted turtle grass beds because of their scarcity as climax habitat and their slow recovery from such damage. While restoration and recovery of propeller scar areas in turtle grass have been studied at some length in Florida seagrass beds (Dawes and others, 1997; Kenworthy and others, 2000), no studies had been previously undertaken in Texas waters. Since conditions between Florida and Texas seagrass beds are expected to be different, TPWD sought to document the applicability of such restoration techniques for Texas turtle grass beds.

With funding available from the National Oceanic and Atmospheric Administration (NOAA) Gulf of Mexico Sustainable Fisheries Program, a 1999–2001 propeller scar restoration project was conducted to test restoration techniques (see McEachron and others, 2001). Initial work was undertaken in the Redfish Bay area because of its proximity to urban areas and heavy use by boaters. Restoration techniques included filling propeller scar trenches with sediment (clean sand), removal of seaweed and seagrass wrack/litter, and injection of nutrients (fertilizer) and growth hormone mixtures into bare sediments of propeller scars or bare, "blowout" areas. A limited amount of work was performed to enhance recovery by manipulated transplanting of bare-root seagrass sprigs into representative propeller scars or bare areas. Regular monitoring of treated and untreated scars over a 2-yr period was designed to determine effects of underwater light attenuation, water-column conditions, wrack accumulation, and sediment chemistry on plant production. Seagrass recovery in scars was compared to adjacent undisturbed native seagrass beds.

Shoal grass transplantings and nutrient/growth hormone additions were performed by using a special pontoon boat and injector wheel system developed by ASIS Inc. (Aquatic Subsurface Injection Systems) of Ruskin, Fla. (McEachron and others, 2001). Turtle grass propagules with meristems were also hand planted. Results indicated problems with using the special ASIS boat and injector wheel to transplant shoal grass sprigs. Problems were related to sediment type (too soft a substrate), the wheel sprigging mechanism itself, and the method of bundling the donor sprigs into planting units. Other results indicated that the addition of nutrients, growth hormone, or root stimulator solutions used in this restoration effort did not aid in recolonization of hand planted turtle grass in Redfish Bay. Until these methods are improved for Texas sites, hand planting of shoal grass plugs would be recommended (McEachron and others, 2001).

Other restoration efforts demonstrated that the addition of sand into propeller scars contained in a geotube ("sand sock") may promote seagrass expansion, but this technique needs further investigation (McEachron and others, 2001). The geotube technique stabilizes the added sand, but sediment grain size within the geotube appears to be critical. If fine grain sediments are used, recolonization and lateral expansion of native seagrasses across the scar may be enhanced.

Texas Parks and Wildlife Department continues to recommend that techniques to restore turtle grass beds be developed. While the collection of turtle grass propagules is destructive to donor beds, whose survival is then impaired, work with seedlings and nurseries may hold promise. The use of seedlings and nursery propagation could make turtle grass replanting feasible. Shoal grass appears to often recover extensively by recolonization, and this species also acts as a natural colonizer to stabilize propeller scars in turtle grass beds.

Designation of State Scientific Areas

As explained in "Statewide Summary for Texas" (this report), TPWD, Texas General Land Office (TGLO), and TNRCC developed the Seagrass Conservation Plan for Texas (SCPT), which identified research issues, management and policy issues, and education/public outreach needed to conserve Texas seagrass beds (Pulich, 1999). Because research thus far indicates that efforts to restore turtle grass propeller scars are unpredictable, inefficient, and expensive on a large scale, TPWD has concluded that an effective, practical solution in some cases is protective management of seagrass beds. Using its management authority to protect coastal fisheries habitat, TPWD therefore designated Redfish Bay in 2000 as an official State Scientific Area (Texas Parks and Wildlife Department, 2001). Under this jurisdiction, the establishment of no-motor zones was proposed in shallow turtle grass beds to protect them from propeller scarring and allow natural recovery over a sufficient time period (3–5 yr).

Public participation and outreach activities were also identified as critical in the process of conserving seagrasses. A citizens advisory group (Seagrass Task Force) was organized to help develop strategies to protect seagrasses in the "Redfish Bay Scientific Area." The Seagrass Task Force included stakeholders and bay user groups including local governments, private citizens, business owners, and organized boater/fishing groups. They recognized the need for educating boaters about the ecological importance of seagrass beds and for providing navigation aids in shallow seagrass waters. This task force determined that propeller scarring was occurring primarily for two reasons: (1) boat operators were unfamiliar with the bay and did not know the limitations of their boats, and (2) boaters familiar with the area were using shallow grass flats as shortcuts to travel across the bay instead of using deeper channels. The result in both cases was unintended propeller scarring.

Signage and Boater Education Activities

To aid in boater navigation around seagrass beds, the Seagrass Task Force recommended that signage be developed to mark and restrict boating channels in severely scarred seagrass areas. With volunteer help and support from the task force, three popular but sensitive seagrass areas of Redfish Bay were marked as voluntary no-motor zones, and signs were erected in the water to warn boaters and to allow natural recovery of damaged grass beds. They also recommended that large displays be developed and placed at bay area boat ramps/marinas to provide information to boaters about seagrasses, the effects of propeller scarring, and ways to prevent it. These marina displays contained a photomap of Redfish Bay that indicated the location of the voluntary no-motor zones. In an effort to protect scarred turtle grass beds, 135 navigation signs were placed in the waters, and 11 displays were posted at marinas. As a result of this volunteer outreach project, sign postings now help protect approximately 1,385 ha (3,422 acres) of seagrass beds in Redfish Bay in the form of voluntary no-motor zones.

Seagrass Restoration Through Beneficial Use Projects

In the Corpus Christi area, beneficial use and disposal of dredged material from ship channel and GIWW dredging have been proposed as a method of creating and restoring seagrass beds, along with marshlands, bird islands, oyster reefs, and other bay habitats. The Port of Corpus Christi Authority and the U.S. Army Corps of Engineers established the Regulatory Agency Coordination Team in 2000 which also included U.S. Fish and Wildlife Service, U.S. Environmental Protection Agency, NOAA's National Marine Fisheries Service, TPWD, and TGLO. This group will evaluate such possible beneficial uses of dredged material and incorporate them into a dredged materials placement plan for the Corpus Christi Ship Channel-Channel Improvement Project (CCSC-CIP). This project will generate 114.7 million m^3 (150 million yd^3) of new sediment requiring disposal in Corpus Christi Bay proper, and substantial amounts would be available for open-water, beneficial uses, if disposal problems can be adequately solved by planning and engineering techniques.

The beneficial uses approach is committed to having a net positive environmental effect over the 50-yr life of such projects. Thus, the dredged materials management plan must address environmental issues and problems up front. Protection of existing seagrass in the Redfish Bay area, the selection of candidate disposal sites, and the creation of habitat sites are particularly critical issues. Other potential disadvantages include the type of sediment being dredged and turbidity from the fine particles. Sandy sediments, with minimal amounts of clays, would allow for controlled disposal and subsequent establishment of seagrasses. Seagrass protection would also require construction of breakwaters or underwater berms to reduce wave energy. Some dredged material would be used to fill geotextile tubes for breakwaters to reduce shoreline or underwater erosion.

Coastal Bend Bays and Estuaries Program Outreach Strategies

The CBBEP, since its inception as a National Estuary Program in 1992, has worked to develop education plans and outreach projects focused on seagrass habitats. The publication and distribution of Bay Fishing and Bay User Guide Maps (2002) are two CBBEP outreach projects that provide locational information to the public for protecting seagrass areas. Currently CBBEP is planning to participate in the Texas Seagrass Monitoring Program by funding seagrass monitoring projects in the Texas Coastal Bend, and this work will complement other existing coastwide management programs.

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