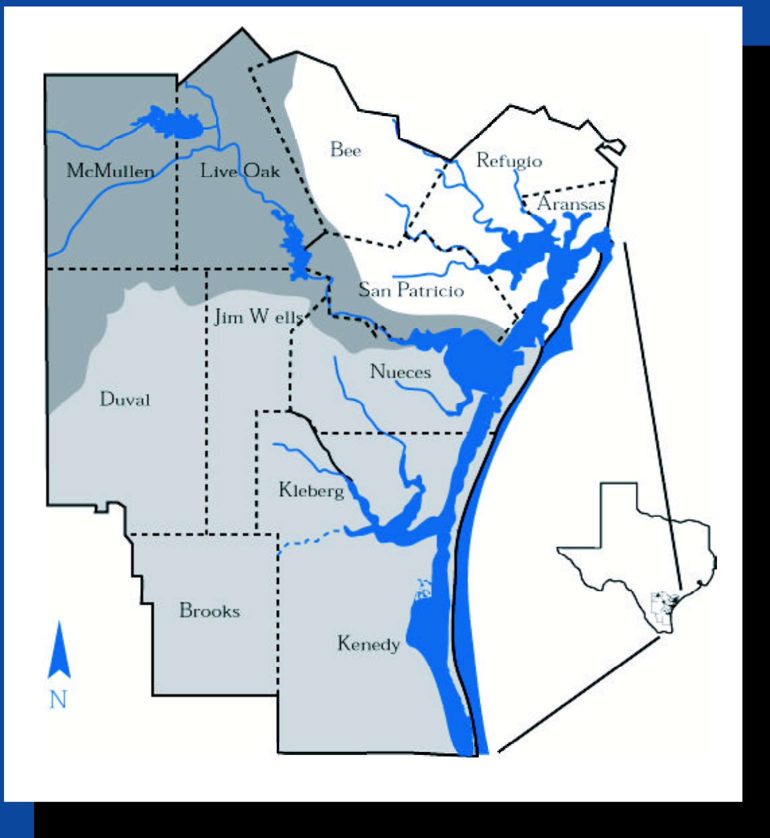
Current Status and Historical Trends of Seagrass in the Corpus Christi Bay National Estuary Program Study Area



Corpus Christi Bay National Estuary Program
CCBNEP-20 • October 1997

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Current Status and Historical Trends of Seagrasses in the Corpus Christi Bay National Estuary Program Study Area

Warren Pulich, Jr., Ph.D.
Catherine Blair

Coastal Studies Program
Texas Parks & Wildlife Department
3000 IH 35 South
Austin, Texas 78704

and

William A. White

The University of Texas at Austin
Bureau of Economic Geology
University Station Box X
Austin, Texas 78713

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CORPUS CHRISTI BAY NATIONAL ESTUARY PROGRAM

The Corpus Christi Bay National Estuary Program (CCBNEP) is a four-year, community based effort to identify the problems facing the bays and estuaries of the Coastal Bend, and to develop a long-range, Comprehensive Conservation and Management Plan. The Program's fundamental purpose is to protect, restore, or enhance the quality of water, sediments, and living resources found within the 600 square mile estuarine portion of the study area.

The Coastal Bend bay system is one of 28 estuaries that have been designated as an **Estuary of National Significance** under a program established by the United States Congress through the Water Quality Act of 1987. This bay system was so designated in 1992 because of its benefits to Texas and the nation. For example:

- Corpus Christi Bay is the gateway to the nation's sixth largest port, and home to the third largest refinery and petrochemical complex. The Port generates over $1 billion of revenue for related businesses, more than $60 million in state and local taxes, and more than 31,000 jobs for Coastal Bend residents.
- The bays and estuaries are famous for their recreational and commercial fisheries production. A study by Texas Agricultural Experiment Station in 1987 found that these industries, along with other recreational activities, contributed nearly $760 million to the local economy, with a statewide impact of $1.3 billion, that year.
- Of the approximately 100 estuaries around the nation, the Coastal Bend ranks fourth in agricultural acreage. Row crops -- cotton, sorghum, and corn -- and livestock generated $480 million in 1994 with a statewide economic impact of $1.6 billion.
- There are over 2600 documented species of plants and animals in the Coastal Bend, including several species that are classified as endangered or threatened. Over 400 bird species live in or pass through the region every year, making the Coastal Bend one of the premier bird watching spots in the world.

The CCBNEP is gathering new and historical data to understand environmental status and trends in the bay ecosystem, determine sources of pollution, causes of habitat declines and risks to human health, and to identify specific management actions to be implemented over the course of several years. The 'priority issues' under investigation include:

- altered freshwater inflow
- declines in living resources
- loss of wetlands and other habitats
- bay debris
- degradation of water quality
- altered estuarine circulation
- selected public health issues

The **COASTAL BEND BAYS PLAN** that will result from these efforts will be the beginning of a well-coordinated and goal-directed future for this regional resource.

STUDY AREA DESCRIPTION

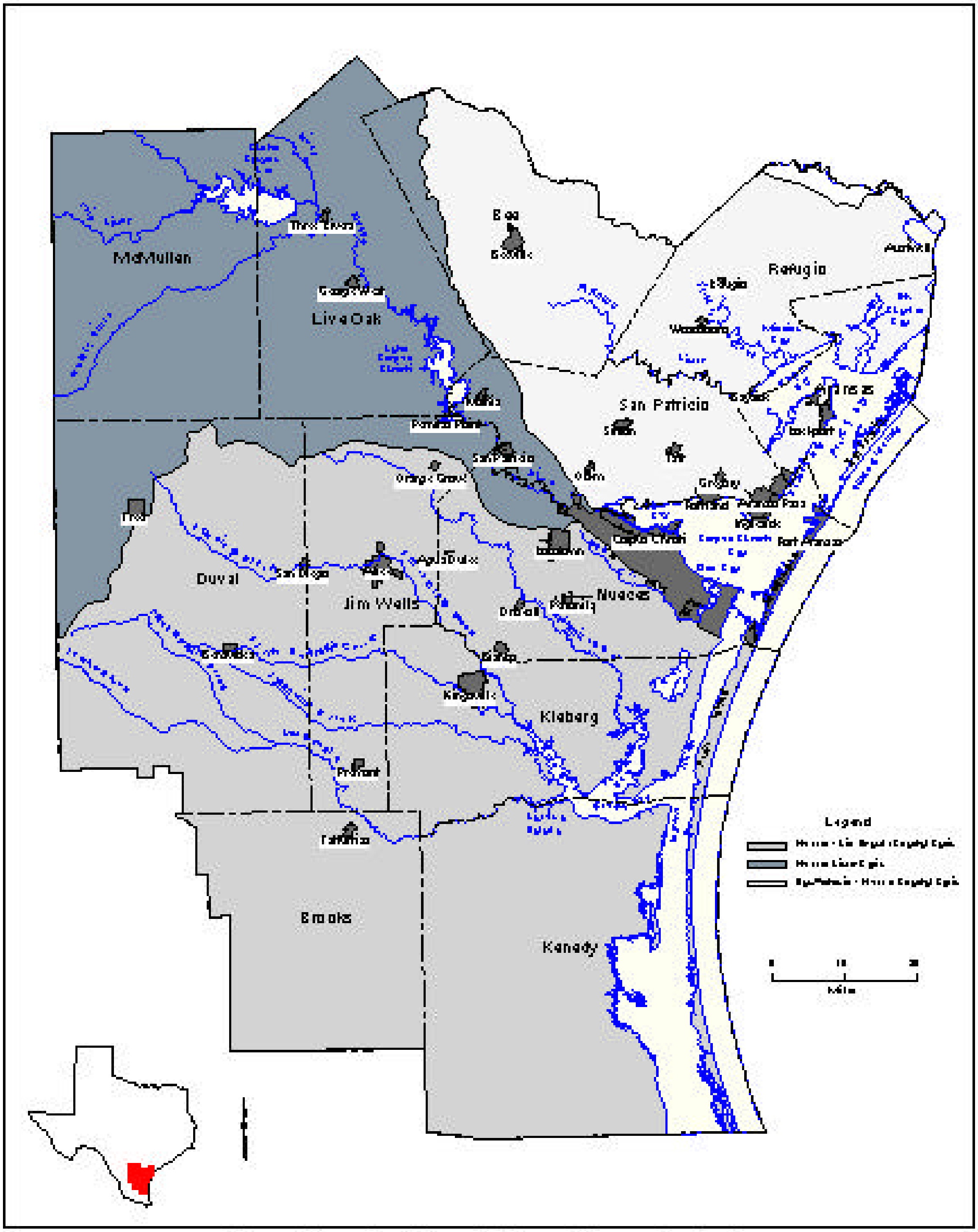
The CCBNEP study area includes three of the seven major estuary systems of the Texas Gulf Coast. These estuaries, the Aransas, Corpus Christi, and Upper Laguna Madre are shallow and biologically productive. Although connected, the estuaries are biogeographically distinct and increase in salinity from north to south. The Laguna Madre is unusual in being only one of three hypersaline lagoon systems in the world. The study area is bounded on its eastern edge by a series of barrier islands, including the world's longest -- Padre Island.

Recognizing that successful management of coastal waters requires an ecosystems approach and careful consideration of all sources of pollutants, the CCBNEP study area includes the 12 counties of the Coastal Bend: Refugio, Aransas, Nueces, San Patricio, Kleberg, Kenedy, Bee, Live Oak, McMullen, Duval, Jim Wells, and Brooks.

This region is part of the Gulf Coast and South Texas Plain, which are characterized by gently sloping plains. Soils are generally clay to sandy loams. There are three major rivers (Aransas, Mission, and Nueces), few natural lakes, and two reservoirs (Lake Corpus Christi and Choke Canyon Reservoir) in the region. The natural vegetation is a mixture of coastal prairie and mesquite chaparral savanna. Land use is largely devoted to rangeland (61%), with cropland and pastureland (27%) and other mixed uses (12%).

The region is semi-arid with a subtropical climate (average annual rainfall varies from 25 to 38 inches, and is highly variable from year to year). Summers are hot and humid, while winters are generally mild with occasional freezes. Hurricanes and tropical storms periodically affect the region.

On the following page is a regional map showing the three bay systems that comprise the CCBNEP study area.



Corpus Christi Bay National Estuary Program Study Area

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FIGURE CAPTIONS FOR REPORT

LIST OF ACRONYMS

CCBNEP - Corpus Christi Bay National Estuary Program

GIS - Geographic Information System

GPS - Global Positioning Satellite

GIWW - Gulf Intracoastal Waterway

NASA - National Aeronautics and Space Administration

NMFS - National Marine Fisheries Service

NOAA - National Oceanic and Atmospheric Administration

SAV - Submerged Aquatic Vegetation or Seagrass

TGLO - Texas General Land Office

TPWD - Texas Parks and Wildlife Department

TNRCC - Texas Natural Resource Conservation Commission

UT-BEG - University of Texas Bureau of Economic Geology

UTMSI - University of Texas Marine Science Institute

USACOE - US Army Corps of Engineers

USFWS - US Fish and Wildlife Service

USEPA - US Environmental Protection Agency

USGS - US Geological Survey

ACKNOWLEDGMENTS

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The authors wish to thank all the staff from the TPWD Coastal Studies Program, Resource Protection Division, who participated in field work and computer analyses on the project including Dr. Peter Eldridge, Melisa Minto, Janet Nelson, James Hinson, Leland Roberts, and Rich Gallacher. The GIS change analysis and contouring techniques were critically reviewed by James Hinson. We are especially grateful to Mr. Rusty Young from Coastal Fisheries Division, for his knowledgeable and skillful assistance with field logistics. The ground truthing phase of the project could not have been completed without his exciting airboat maneuvers! We also recognize Mr. Tom Heffernan and Mr. Ed Hegen, TPWD Coastal Fisheries Division, for their generous interdivisional support of the field work. Clerical assistance was provided by Bonnie Smith and Misty Goodson.

The interpretation of results benefitted from stimulating discussions with colleagues Drs. Peter Eldridge, Ken Dunton, and Chris Onuf; new ideas about Texas seagrass dynamics have emerged and evolved from this. The extra effort of Chris Onuf and Ken Dunton in reviewing an early draft of the report is also appreciated.

Current Status and Historical Trends of Seagrasses in the Corpus Christi Bay National Estuary Program Study Area

Executive Summary

Because of their high productivity and biodiversity, as well as limited extent, submerged seagrass habitats on the Texas coast are the focus of special conservation and management programs. A prerequisite to proper management is basic information on current status and historical trends in seagrass bed distribution and abundance. The CCBNEP, recognizing the importance of seagrasses to the Coastal Bend region and potential environmental factors impacting submerged vegetation locally, commissioned a special study to inventory seagrass beds and to determine historical trends in distribution changes. This report 1) presents results from data compilation and trend analysis studies on seagrass distributions in the northern CCBNEP region (inclusive of the Corpus Christi/Redfish/Nueces Bays System and the Aransas-Copano Bays System), 2) reviews trends in distribution for Laguna Madre seagrasses as published by previous researchers (Onuf and others), and 3) correlates historical trends in seagrass distribution over 40 years with probable causes.

Current status and distribution of seagrass beds for the northern CCBNEP region were based on field mapping surveys and photointerpretation of true color, aerial photography (1:24,000 scale) taken in November 1994. Beds were classified according to morphological type as either continuous or patchy, i.e. extensive, lush underwater meadows vs. fragmented ones, containing numerous open bare patches. Patchy beds are generally considered disturbed or stressed. Species composition of all grassbeds was determined by extensive ground truthing surveys during 1995/1996 using GPS to mark locations and verify the photography. Additional historical aerial photography at similar scale was analyzed for selected areas in order to quantitate historical changes and trends, both spatially (geographic locations) and numerically (net seagrass acreage lost or gained). Seagrass distributions for the entire Corpus Christi/Redfish/Nueces Bays system were thus compared from the 1956/58, 1975, and 1994 time periods using Geographic Information System techniques.

Seagrass landscape dynamics were correlated with physical and hydrographic factors known to influence submerged vegetation. Environmental factors included stressors and disturbances, both natural and anthropogenic, as well as enhancement conditons, mostly climatic. This is important since seagrass distribution can reflect environmental problems or merely typical responses to natural coastal cycles and processes. Probable causes were inferred from this correlation analysis. Four main categories of factors were considered: 1) Water Level Changes, 2) Physical, Mechanical Disturbances, 3) Water Quality Degradation, and 4) Episodic Events. Natural processes include mostly climatic effects from drought or freshwater inflow (hurricane) events. Disturbance effects associated with water quality degradation include: 1) Light attenuation from phytoplankton blooms, epiphyte growth, or macroalgae accumulation; 2) Suspended sediments from dredging and boat traffic. Physical/mechanical disturbances by far constitute the most direct impact to seagrasses,

including dredge material deposition, removal by channelization and construction activity, boat propeller scarring, and effects of other water-borne traffic.

Current acreages of seagrass beds determined for individual Bay systems in the northern CCBNEP area were: Corpus Christi/Redfish/Nueces Bays = 20,403 acres; Aransas/St. Charles Bays = 4,718 acres; and Copano/Port Bays = 2,958 acres. Total acreage for this northern region was 28,080 acres, which is 11.9 % of the seagrasses on the Texas coast. Of this total, 14,188 acres were in Redfish Bay/Harbor Island complex alone (6.0 % of all Texas seagrass). Quammen and Onuf (1993) reported that upper Laguna Madre contained 61,750 acres of seagrass in 1988, excluding Baffin Bay. The latter was estimated to contain an additional 5,000 acres in 1992 (Pulich, unpublished study). Thus, the upper Laguna plus Baffin Bay accounts for 28.5 % of Texas seagrasses.

Shoalgrass (*Halodule*) was found to be the dominant species in all northern Coastal Bend bays (73 to 90 % of all samples), while turtlegrass (*Thalassia*) was dominant in Redfish Bay (35 % of samples). Clovergrass (*Halophila*) and manateegrass (*Syringodium*) were minor species where found (1 to 6.0%) and were not recorded in the Copano Bay system. Widgeongrass (*Ruppia*) was found regularly in all bays, occurring most frequently in the spring and early summer (9 to 19 % of samples). Predominately *Halodule*, but no known *Thalassia*, occurs in the upper Laguna Madre. Mapping results show that seagrass distribution in the Coastal Bend parallels the extent of marine, shallow water less than 5 ft (1.5 m) deep and reflects the inflow and turbidity gradients in the bays. Seagrass establishment is also aided by protection from dredging impact, sediment erosion, and heavy wave action resulting from wind-induced fetch.

Results from trend analyses of landscape changes suggest that different coastal processes have contributed to seagrass trends at localized sites. In the entire Corpus Christi/Redfish/Nueces Bays system, total seagrass bed acreage appears fairly stable over a 40 year time frame, despite dynamic cycles and localized changes in seagrass bed distribution. Comparisons of 1958, 1975 and 1994 inventories for the Redfish Bay/Harbor Island complex revealed an increase of 819 ha (2023 acres) between 1958 and 1975, but a decrease of 488 ha (1205 acres) between 1975 and 1994, for a net increase of 330 ha (815 acres) in total acreage for this system between 1958 and 1994. Evidence of bed fragmentation or deterioration is reflected in the progressive increase in patchy grassbeds occurring as continuous beds apparently underwent conversion to patchy morphology. However, large increases in grassbeds (1838 ha [4540 acres] between 1958 and 1975; 519 ha [1282 acres] between 1975 and 1994) also occurred along Mustang Island over the same period. These results indicate that conditions overall are generally fairly stable for the entire Corpus Christi/Redfish Bays system.

Landscape analysis revealed “hot spots” of seagrass impact and loss in parts of the estuary. The north Redfish Bay and Harbor Island system may be at a stage where seagrass decline is escalating. Both progressive seagrass loss and fragmentation of beds were noted. Although not definitive, accumulations of wrack, drift macroalgae, and epiphytes observed there suggest possible water quality problems. Increase of shoreline development along the north Redfish Bay region may be contributing excess nutrients to this area. In addition, widespread evidence of impact to shallow water grassbeds was observed in the entire Redfish Bay/Harbor Island complex from mechanical damage and physical disturbances e.g. motorboat propeller scarring and navigation channel impacts.

The relatively stable Corpus Christi/Aransas Bays system is in contrast to the situation occurring in upper Laguna Madre. From the published studies by Onuf (1996) and Dunton (1996), it is apparent that the persistent brown tide is having a serious detrimental effect on seagrass beds in the lagoon. As of 1996, total seagrass acreage (predominantly *Halodule*) in the upper Laguna had decreased by 3.8 % to 59,430 acres, from a high of 61,750 acres in 1988. It remains to be seen whether conditions improve and seagrass loss is reversed or if Onuf's prediction of losses as great as 18 to 27% eventually come to pass. Regardless of the outcome, the important lesson would be that serious water clarity impacts on seagrass can occur, even in seemingly protected areas such as the Laguna Madre. Whether sound management and habitat monitoring can protect against such problems in the future remains to be seen.

These results indicate that resource managers must examine seagrass responses cautiously on a case by case basis to identify environmental stressors causing changes. Net quantitative change in acreage for an entire bay seldom gives an accurate clue as to causes of seagrass changes. Rather, spatial location of changes as determined by GIS analysis is necessary to determine real relationships to environmental factors. Generic stressors (e.g. water quality degradation, water level changes, and climatic conditions) can be suspected when effects are produced over wide bay areas. However, stressors such as mechanical or physical impacts generally produce localized, site-specific effects. So-called patch dynamics theory may be applicable to these situations where localized loss or increase of seagrass beds is occurring.
Monitoring programs for seagrasses must take into account the localized mechanisms by which stress responses are propagated. It is critical to continue seagrass status and trends monitoring at the landscape level (1:24000 scale) on a 2 to 3 year interval basis. Changing landscape patterns can indicate problems (e.g. fragmentation, change in species composition, patch disturbances, etc.) before complete loss of seagrass occurs. For monitoring at finer scales of resolution (> 1:12000), target sites should be established over the CCBNEP study area for conducting intensive, periodic field sampling of both seagrass parameters and related environmental, growth factors.

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STATUS AND TRENDS OF SEAGRASSES IN THE CCBNEP REGION

INTRODUCTION

Seagrass vegetation has long been recognized as valuable submerged marine habitat because of its basic ecological functions. It provides: nursery areas for estuarine fish and wildlife; direct food sources for various fauna including fishes, waterfowl, and sea turtles; major contributions of organic matter to coastal systems; key functions in nutrient cycling processes; and a stabilizing agent for coastal sedimentation and erosion control (McRoy and McMillan 1977). Seagrass-dominated communities, such as those located in the Coastal Bend area, support the highest biodiversity and production along the Texas coast. Because of the high quality and limited extent of seagrass systems (referred to as “beds”) in Texas (currently 235,000 total acres), any impact to this important shallow-water habitat raises concerns of resource managers, coastal scientists, conservationists and sportsmen groups.

Over the past 20 plus years, there has developed a growing awareness of major factors affecting seagrass productivity, species distribution, landscape dynamics, and susceptibility to human disturbance. Questions have been raised nationally and worldwide concerning the current status of seagrass distribution and abundance, historical trends in production dynamics and bed morphology, and probable causes of seagrass population changes. In recent years, seagrasses have received attention as environmental indicators of estuarine water quality and ecosystem health because of their sensitivity to nutrient enrichment and eutrophication processes (Dennison et al. 1993, NOAA-ORCA 1995). Various studies have documented significant impacts at regional scales due to dredging (Livingston 1987, Pulich and White 1991, Onuf 1994), boating traffic (Zieman 1976, Sargent 1995), nutrient loading (Orth and Moore 1983, Cambridge and McComb 1984, Tomasko and Lapointe 1991, Short and Burdick 1996), and altered freshwater inflow cycles (Eleuterius 1987).

In Texas, state and federal agencies (e.g. TPWD, TGLO, USFWS, NMFS, and USEPA) and university research scientists have recognized the need to address seagrass problems on a concerted basis. This applies to coastal zone planning, fisheries and waterfowl habitat management, and environmental impact assessment for such phenomena as brown tide blooms, channel dredging, dredge material disposal, or motorboat disturbance. National Estuary Programs (NEP’s) in other States (e.g. Virginia, Maryland, Florida) have served as focal points to identify and prioritize seagrass conservation issues, as well as facilitate research studies. Comprehensive, seagrass trend information has been synthesized and conservation planning initiated for those states under the sponsorship of the Chesapeake Bay Program (1995) and Florida Department of Environmental Protection (1996). In Texas, both the Galveston Bay and the Corpus Christi Bay National Estuary Programs (CCBNEP) have established similar working processes which direct attention to this unique coastal resource.

These NEP programs thus offer an excellent management framework to implement seagrass conservation measures for Texas.

Seagrass trends for two major Texas bay systems are well established. These cases illustrate the problems affecting seagrasses on a coastwide basis:

1. In ***Galveston Bay*** on the upper Texas coast, practically all seagrass beds have been gone from the main Galveston Bay system since the late 1970s. Only about 275 acres remain in the secondary bay region, Christmas Bay (Pulich and White 1991, Adair et al. 1994). Although 1956 is our earliest documented reference point, it is interesting to note that true seagrasses were actually more abundant in the Galveston Bay system (even in East Bay and upper Galveston) during the early part of 20th century based on anecdotal information. Turtlegrass *(Thalassia testudinum* Banks ex Koenig*)* formerly occurred in West Bay, where total seagrass acreage decreased from 1400 acres in 1956, to 500 acres in 1965, to 120 acres in 1975 and 0 in 1982 (Pulich and White 1991). In the Galveston Bay system, the complete disappearance of *Halodule wrightii* (Shoalgrass) and *Thalassia* from the main bay system has been attributed to direct effects of dredge-and-fill operations, adjacent shoreline development, and land subsidence, along with episodic climatic events (viz. hurricanes, freshwater inflow pulses). Indirect effects are suspected to involve nutrient/pollutant loading and spills or discharges from shoreline developments.

2. In the ***Laguna Madre*** along the lower coast, large changes in seagrasses have been documented since the 1950s. Locally different processes in the upper and lower Laguna Madre have produced contrasting results in seagrass dynamics of these two separate laguna regions. These dynamics will be reviewed in detail in the Literature Review.

For other parts of the coast, especially the Corpus Christi Bay region, trends in seagrass distribution have received little scrutiny despite the fact that this area comprises the second most extensive coverage of seagrasses on the Texas coast, exceeded only by the Laguna Madre. Some historical information is available from the University of Texas Bureau of Economic Geology (UT-BEG) reports of Brown et al. (1976) and White et al. (1983) on submerged grassbed changes between 1950s and 1979, but these data are now 15 years out-of-date and based on broad field surveys. Recent seagrass research investigations have been concentrated in three areas: Ecological studies of light and turbidity effects on seagrass productivity and growth; Physiological responses of seagrass plants to environmental factors; and Monitoring studies at seagrass restoration sites.

Based on recent events in the CCBNEP area and site-specific studies by Pulich (1980a, 1982, 1985), Onuf (1994, 1996a, 1996b), Dunton (1990, 1994, 1996), and Quammen and Onuf (1993), seagrass habitat distributions and trends are suspected of changing gradually under the influence of contemporary estuarine conditions including dredging, sediment factors, phytoplankton blooms or nutrient enrichment problems. Complete baywide inventories and rigorous trend analyses are needed to provide historical perspective for seagrass changes in the Coastal Bend over at least the last 40 years and to confirm probable causes of trends. Therefore, as part of the data synthesis program for developing its Comprehensive Conservation and Management Plan, the CCBNEP commissioned this study on seagrass status and trends for its study area, the Coastal Bend of Texas.

Objectives of Study

This report summarizes current seagrass distributions and inventories for the Coastal Bend area based on literature reports, intensive mapping studies and field monitoring surveys. Our study using 1994 aerial photography documents spatial distribution and acreage of especially pristine, sensitive seagrass locations outside the Laguna Madre. Complete distribution has been mapped for the first time for the Aransas/Copano Bay System. Species occurrence data demonstrate the clear separation between the more temperate, upper Coastal Bend and subtropical lower Coastal Bend regions. In the Nueces/Corpus Christi/Redfish Bay areas where sufficient historical data are available, we document trends in seagrass landscape dynamics over a 40+ period of record and analyze effects of suspected environmental stressors and their relationships to seagrass acreage changes. In these cases, the probable contribution of anthropogenic factors (ranging from dredging to water quality) to seagrass bed dynamics can be distinguished from natural coastal processes (e.g. bay water levels). This is significant since fluctuations in seagrass distribution and abundance may reflect environmental problems or merely response to natural coastal processes and cycles.

Study Area

Figure 1 indicates the overall boundary of the CCBNEP study region, which includes two major areas, the upper Laguna Madre and the northern Coastal Bend. The latter region constitutes the major area of analysis for our seagrass project. As shown in Figure 1, the northern Coastal Bend region includes the following bays: Nueces, Corpus Christi, Redfish, Aransas, Copano, Port, St. Charles, and Mesquite Bays, as well as extreme upper Laguna Madre north of the Kennedy Causeway. Altogether, we mapped seagrass distribution and evaluated trends for portions of 16 USGS 7.5 min quadrangles shown in Figure 1. This northern Coastal Bend region extends from the Mesquite Bay quadrangle southward to the Crane Islands NW and Oso Creek NE quads.

Recent work by Quammen and Onuf (1993), which is summarized in the Literature Review section, dealt with seagrass status and trends in the upper Laguna Madre (excluding Baffin Bay). This area comprises about 9 USGS quadrangles from Oso Creek NE southward to the Potrero Cortado quad in the Land Cut.

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LITERATURE REVIEW

Seagrass Distribution and Population Dynamics

An overall picture of distribution and species composition for CCBNEP grassbeds first emerged from various biological studies by the University of Texas, other local universities, and Texas Parks & Wildlife Department (TPWD) between the 1950s and early 1970s. Early reports in the Publications of the Institute of Marine Science (UTMSI) by Simmons (1957), Breuer (1962), Odum (1963), and others, provide background information, mostly in the form of field observations. Peter Edward s (1976) guide to the seaweeds and seagrasses around the Port Aransas area is one of the earliest reports to summarize general seagrass distribution for the Coastal Bend. From these works, the general distribution, relative abundance and species dominance for local bay areas is known. *Halodule wrightii* Aschers. (shoalgrass) is considered the most abundant species throughout the CCBNEP area, with the most expansive beds in upper Laguna Madre. The truly tropical species, *Thalassia testudinum* and *Syringodium filiforme* Kuntz.(manateegrass), are most abundant in the lower Laguna Madre and Redfish Bay area near Port Aransas.

Seagrass population dynamics of the CCBNEP area have been the subject of studies, dating back to early reports by Hoese (1960), Odum (1963), Conover (1964), McMahan (1968), McMillan and Moseley (1967), and the UT-BEG (Brown et al. 1976). Although field observations by Phillips (1960) were made in western Florida, his work appears applicable to Texas seagrasses because of the similarity in latitude between the Texas Coastal Bend and the area around Tampa Bay, Florida. It is probably not merely a coincidence that results reported in his classic paper (Phillips 1960), which involve the same five seagrass species as occur in Texas, seem remarkably similar to the dynamics observed in the Texas Coastal Bend. More recently, Phillips (1980), Pulich (1980a, 1982, 1985), and White et al. (1983) reported on population dynamics of *Halodule*, *Ruppia maritima* L. (widgeongrass), or *Thalassia* at field sites where active processes/impacts were occurring.

Laguna Madre System

This system has undergone dramatic seagrass changes since the 1950s, primarily in response to salinity regime modification (Simmons 1957, Breuer 1962, Pulich 1980b). Since the 1970s, however, major divergence is evident between responses of Upper and Lower parts of the Laguna to historical events. These changes provide excellent examples of the dynamics of seagrass in response to both natural and human-induced factors and document the value of monitoring seagrass status and trends.

Seagrasses in **upper Laguna Madre** have been intensively studied as waterfowl and fisheries habitat, starting with surveys by Simmons (1957) and mapping work by McMahan (1965-1967).

Merkord (1978) followed this with more submerged vegetation mapping during 1975-76. Quammen and Onuf (1993) conducted a thorough review and remapping analysis in 1988. They compared historical distribution data from TPWD (McMahan 1965-67) and Merkord (1978) with recent data from surveys in 1988. Onuf (1996a) also reported new change data as part of a more recent study on brown tide effects. Figure 2 presents a map taken from Quammen and Onuf s paper showing the 1988 distribution of *Halodule*-dominated grassbeds (61,750 acres) in the upper Laguna Madre. A summary of seagrass changes from these studies reveals that:

i. From 1967 to 1976, *Halodule* area increased 66 %, to 49,200 acres total.

ii. From 1976 to 1988, *Halodule* area increased 29 %, to 250 km^2 (61,750 acres). While *Halodule* was by far the predominant species observed, minor species, *Ruppia* and *Halophila engelmannii* Aschers. (clovergrass), were reported as locally abundant at times (Pulich 1980b).

iii. From 1988 to 1994, *Halodule* area decreased 3.8 % (9.4 km^2 or 2322 acres lost). Patches of *Syringodium* also became established in the northern part.

iv. Between 1988 and 1993, Onuf (1996a) noted a 60 % decrease in *Halodule* biomass at depths >140 cm.This observation documents significant reduction in biomass 2 years before changes in *Halodule* cover were detected.

Salinity moderation of lagoonal waters and the Laguna s physiography can account for most of these successive increases in *Halodule* and *Syringodium*. The shallow depth, clear water, and warm climate of this lagoon are very conducive to seagrass production (Pulich 1980b). Since the 1950s, increased water exchange in the upper part, resulting from the Gulf Intracoastal Waterway (GIWW) construction and higher periods of rainfall, have moderated the extreme high salinities of this hypersaline lagoon. This has promoted rapid colonization and expansion by *Halodule, Ruppia* and *Halophila*. Seagrass decreases since 1990 in the upper Laguna are attributable to the well-known brown tide phytoplankton bloom which has caused light attenuation and seagrass losses in water > 1.5 m depth (Onuf 1996a). Onuf also predicted that 18% to 27% of upper Laguna *Halodule* could disappear if underwater light regimes stay indefinitely reduced from brown tide and the seagrass plants reach a steady state at these light levels. Losses would be confined to the deeper waters.

The **lower Laguna Madre** showed major decreases in seagrass acreage between 1965 to 1988 (Quammen and Onuf 1993). *Halodule* decreased 60% (to 220 km^2 or 54,340 acres) over this period. *Syringodium* (primarily) and some *Thalassia* increased 270% in acreage (to 260 km^2 or 64,200 acres total). Overall, bare area has increased 280% (to 190 km^2 or 46,930 acres total). Maintenance dredging on the GIWW has been implicated (Onuf 1994) as a major causative factor in the decline of *Halodule* and the increase in unvegetated substrate. The chief mechanism appears to be resuspension of dredged sediments after discharge into the open Laguna and the resulting light attenuation. Changes in species composition, especially increases in *Syringodium*, were attributed to competitive differences in salinity tolerance and colonizing abilities of the various species (Onuf 1996b).

Corpus Christi Bay and Aransas/Copano Bay Systems

Seagrass status elsewhere in the Corpus Christi or Aransas Bay systems has received limited study. The UT-Bureau of Economic Geology first compiled a wetland atlas for this region in the 1970s (Brown et al. 1976). This work contained wetland maps produced from examination of mid 1950s black and white photography. TPWD biologists also surveyed the Aransas/Corpus Christi/Laguna Madre systems, and McMahan (1965-67) produced a series of small scale (> 1:125,000) maps. Such mapping studies are useful for information on general locations of seagrass, but are not reliable for quantitative evaluation of seagrass changes at less than 1:100,000 scale. This means only approximate bay locations of grassbeds are known. In addition, there have been no published reports documenting seagrass occurrence in the upper parts of bay systems such as Nueces and Copano where seagrass cover is sparse and where episodic changes are frequent.

Recent mapping by White et al. (1983) at UT-BEG established that significant seagrass changes have occurred in the main Corpus Christi/Redfish Bay system, i.e. the lower part of the Estuary. This study was based on aerial photointerpretation from 1:63,000 NASA JSC color infrared photography from November 1979. This photography was taken towards the end of a rather long period, the mid 1960s to mid 1970s, that was characterized by a high rate of relative sea level rise. White et al. concluded that the higher baywater (sea) levels had greatly promoted the spread of seagrass onto bare tidal flats in the Harbor Island complex and on backside of Mustang Island. This will be further examined in the present study.

Various studies have examined population dynamics and stress responses at specific seagrass sites in the Corpus Christi Bay or Aransas Bay Systems. Hoese (1960) reported on seagrass changes in Mesquite Bay after the 1950s drought was broken. His study demonstrated that *Ruppia maritima* (a low-salinity tolerant species) almost entirely replaced *Halodule* five months after freshwater inflows from heavy rainfall in early 1957 lowered the salinity in Mesquite Bay. Phillips (1980) described negative impacts of sedimentation from dredging on seagrass transplant sites near Ransom Island in Redfish Bay. This work documented direct, short-term effects of suspended sediments on *Halodule* and *Thalassia* beds over five miles from dredging activity in the Corpus Christi ship channel. Pulich (1980a) correlated trace metal concentrations in *Halodule* plants with sediment metal levels for sites in Corpus Christi and Redfish Bays. Pulich (1982) further examined sediment conditions (edaphic factors) in relationship to *Halodule* colonization dynamics at disturbed sediment sites in Redfish Bay and Laguna Madre. In another study, the dynamic seasonal growth cycles of *Halodule* and *Ruppia* populations in Redfish Bay and upper Laguna Madre were documented (Pulich 1985).

McMillan from UT-Austin conducted considerable research on the environmental tolerances of the southern Texas seagrasses. This included ecological studies on salinity limits (McMillan and Moseley 1967), flowering and reproduction (McMillan 1976), and chlorophyll responses to light intensity (Wiginton and McMillan 1979). He also made observations on variations in seed production and germination between local seagrass populations (McMillan 1984). Much of this work however, was performed under laboratory conditions and applications to actual field situations may be limited. Results have been corroborated by field observations of workers elsewhere in the eastern Gulf of Mexico, particularly regarding salinity responses and seasonality of occurrence (i.e. temperature requirements). This applies to seagrass work by Phillips (1960) and Dawes (1987) from western Florida, and Eleuterius (1987) from Mississippi.

Field and laboratory studies by Dunton and colleagues at UTMSI have recently extended and quantified many of these earlier results. Dunton (1990) compared production ecology of *Ruppia* and *Halodule* between Corpus Christi and San Antonio Bay populations. Dunton (1994) confirmed definitive, minimum light requirements for photosynthesis in *Halodule*, while Dunton and Tomasko (1995) examined the *in situ* photosynthetic performance and growth dynamics of Laguna Madre populations of *Halodule*. Dunton (1996) provided results of long-term field monitoring and production dynamics of *Halodule* in response to abiotic factors in three Coastal Bend estuaries (e.g. natural phytoplankton bloom [brown tide] in Laguna Madre, salinity variations, and ambient dissolved nitrogen).

Physical Processes and Environmental Factors

Climatic Events and Associated Stream Discharge

Climatic events such as droughts, hurricanes, and periods of higher than normal rainfall, the latter often associated with hurricanes and tropical storms, can influence bay water levels and turbidities, which in turn will affect the distribution of seagrass. The extent of submerged vegetation in 1956 along the Texas coast appears partly related to such climatic factors (Pulich and White 1991). The most extreme drought in recorded history occurred in Texas in the 1950's and climaxed in 1956 (Riggio et al. 1987). Tide gauge records, as illustrated by data from the Galveston and Port Isabel tide gauges (Figure 3), reflect the effects of this drought, which produced lower average sea-levels along the entire Texas coast.

Following the 1950s drought was a period of abnormally high rainfall that was punctuated by aftermath rains associated with Hurricanes Beulah in 1967 and Fern in 1971. Streamflow in the Nueces, Aransas, and Mission Rivers reflected these events (Figs. 4- 6). Hurricane Carla (1961) also affected the Corpus Christi Bay system, but it was characterized more by storm surge flooding than aftermath rains.

The period from 1968 to 1975 was much wetter than normal in south central Texas (Figure 7). Other parts of the Gulf Coast also experienced wetter than normal conditions during this time. For example, Eleuterius and Miller (1976) in a study of the Mississippi coast noted that 1971, 1972, 1973, and 1974 were four consecutive years of heavy rainfall that were unprecedented in the 24-year period of thier analysis. Bay and Gulf water levels rose at an accelerated rate, Gulf Coast wide from the 1960s to 1975, as exemplified by tide gauges at Galveston, Rockport, and Port Isabel, Texas (see

Figs. 3 and 8), as well as in Louisiana, Mississippi, Alabama, and Florida (Burdin 1990, Ramsey and Penland 1989). Average annual water levels recorded at the Rockport gauge rose approximately 20 cm between 1964 and 1975 (Fig. 8). Although much of the relative rise in sea level along the Texas Gulf Coast (and at Rockport) is attributed to subsidence as noted in the next section, the reason for this accelerated rise is not fully understood. However, climatic variations, which affect precipitation and riverine/groundwater discharges, can also have short-term influence over coastal water levels (Emery and Aubrey 1991) and probably contributed to this observed rise.

The higher streamflow along the Nueces River during this time resulted in higher suspended sediment loads discharging into the bay system. The increased river discharge and suspended sediment can be correlated with higher rates of sedimentation in fluvial-deltaic areas in the Nueces River valley (White and Morton 1996). Much of the sediment delivered by the Nueces River is apparently deposited in shallow Nueces Bay (Shideler 1980). There is evidence that dams constructed in the Nueces River drainage basin, however, have greatly reduced sediment input to the bay system (Liebbrand 1987), and in fact may have contributed to changes in sediment textures on the bay floor (Mannino and Montagna 1996).

Conner et al. (1989) emphasized that hurricanes are normal episodic events in the climatic regime of the Gulf Coast and generally contribute to the development and maintenance of coastal ecosystems. Nevertheless, these storms can have long-term adverse impacts in areas altered by man (Eleuterius 1987, Conner et al. 1989). Hurricanes can also cause physical damage to seagrass beds, as well as longer term effects. Eleuterius and Miller (1976) reported a 33 percent reduction in seagrass beds in Mississippi Sound as a result of erosion and sedimentation during Hurricane Camille and subsequent reductions in salinities due to aftermath flooding. Pulich and White (1991) reported losses in seagrass in the Galveston Bay system from Hurricane Carla. In the Redfish Bay area, Hurricane Carla apparently did not measurably affect seagrasses (Oppenheimer 1963, cited by Nessmith 1980). However, the main effect on the southern Texas coast from this storm was high tides, and not erosion, wind or fetch damage, unlike its impact on the upper Texas coast.

Relative Sea-Level Rise /Bathymetry Changes

Relative sea-level rise as described here is the relative vertical rise in water level with respect to a datum at the land surface, whether it is caused by a rise in mean-water level or subsidence of the land surface. Along the Texas coast both processes, eustatic sea-level rise and subsidence, are part of the relative sea-level rise equation. However, subsidence, especially associated with pumpage of ground water and oil and gas, is the overriding component. Secular variations in sea level, or time dependent fluctuations (Hicks and Crosby 1975), can be caused by climatic factors, such as droughts and periods of higher than normal precipitation and riverine discharge. These short-term sea-level variations produce temporary adjustments in the longer term trends related to eustatic sea level rise and subsidence.

Relative sea level rise and changing baywater depths can affect the distribution of seagrass, causing gains or losses. For example, rising sea level can lead to the permanent submergence of wind-tidal flats and the subsequent encroachment of seagrass species such as *Halodule* and *Ruppia* over the resulting shallow subaqueous flats (White et al. 1978 and 1983). It is also possible that seagrass located in deeper water may be adversely affected by increasing water depths (Pulich and White 1991), which would reduce light penetration and thereby decrease photosynthesis.

Over the past century, sea level has been rising on a worldwide (eustatic) basis at a rate of about 1.2 mm/yr, with a rate in the Gulf of Mexico and Caribbean region of 2.4 mm/yr (Gornitz et al. 1982, Gornitz and Lebedeff 1987). Adding subsidence to these rates yields a relative sea-level rise that at some locations along the Texas coast, including Port Aransas, exceeds 10 mm/yr (Swanson and Thurlow 1973, Penland et al. 1988). But these rates are locally dwarfed by human-induced subsidence. For example, in the Houston area, subsidence rates near the heart of the subsidence bowl exceed 75 mm/yr (Gabrysch and Coplin 1990); and over the Saxet Oil and Gas field in the Corpus Christi area, subsidence rates have been as high as 70 mm/yr (Kreitler 1977). The major cause of human-induced subsidence is the withdrawal of underground fluids, principally ground water, oil, and gas (Pratt and Johnson 1926, Winslow and Doyel 1954, Gabrysch 1969, Kreitler 1977, Verbeek and Clanton 1981, and Hillenbrand 1985).

Shoreline Erosion, Redfish Bay - Harbor Island Complex

Shoreline changes in the Corpus Christi Bay system and bays to the north have been studied by Paine and Morton (1993), Morton and Paine (1984), and White et al. (1978). Figure 9 presents locations of previous established monitoring sites on the Redfish Bay/Harbor Island complex where Paine and Morton (1993) measured shoreline erosion. Table 1 lists shoreline change data at the stations shown in Figure 9. The areas of highest erosion occurred in the vicinity of Lydia Ann Channel and edge of Aransas Bay, while the back-bay mainland part of Redfish Bay had lowest activity.

Dredging/Channel Construction

Losses in seagrass as a result of dredging activities can be both direct and indirect. Direct losses occur by physical destruction from excavation during dredging and from burial by discharged dredged material. Indirect losses may follow as dredged material is redistributed by waves and currents, from resuspension of sediments during maintenance dredging, and from changes in water circulation patterns due to newly formed islands and shoals. Dredging

Table 1. Shoreline changes in the Redfish Bay—Harbor Island complex from 1958 to 1994. Shorelines at stations 1 to 4 and 13 to 16 were modified by dredging and disposal. Data for 1958 to 1982 from Paine and Morton (1993).

Redfish Bay station number	Distance (ft) (Dec 58 - Jul 82)	Rate (ft/yr) (Dec 58 -Jul 82) (23.6 yrs)		Distance (ft) (Jul 82 - Nov 94)	Rate (ft/yr) (Jul 82 to Nov 94) (12.3 yrs)	
1	20	0.8	Disposal site	-31	-2.5	Disposal site
2	0	0.0	Disposal site	37	3.0	Disposal site
3	-210	-8.9	Dredged site	18	1.5	Dredged site
4	-34	-1.4	Dredged site	21	1.7	Dredged site
5	0	0.0		0	0.0	
6	-0.96	-4.1		-18	-1.5	
7	0	0.0		11	0.9	
8	0	0.0		0	0.0	
9	0	0.0		0	0.0	
10	-54	-2.3		-15	-1.2	
11	-62	-2.6		-9	-0.7	
12	40	1.7		0	0.0	
13	384	16.3	Disposal site	-16	-1.3	Disposal site
14	76	3.2	Disposal site	-21	-1.7	Disposal site
15	126	5.3	Disposal site	-58	-4.7	Disposal site
16	-380	-16.1	Dredged site	0	0.0	Dredged site
17	130	5.5		-60	-4.9	
18	0	0.0		-7	-0.6	
19	-16	-0.7		0	0.0	
20	22	0.9		0	0.0	
21	-38	-1.6		-25	-2.0	
22	-16	-0.7		-21	-1.7	
23	40	1.7		-29	-2.4	
24	56	2.4		-28	-2.2	
25	0	0.0		-41	-3.3	
26	0	0.0		46	3.7	
27	0	0.0		-112	-9.1	
28	54	2.3		0	0.0	
29	0	0.0			0.0	
30	-56	-2.4		0	0.0	
31	-58	-2.5		0	0.0	
32	380	16.1		0	0.0	
33	0	0.0		47	3.8	
34	-2388	-101.2		0	0.0	
35	0	0.0		0	0.0	
36	0	0.0		0	0.0	
37	-36	-1.5		0	0.0	
38	-236	-10.0		0	0.0	
39	-138	-5.8		0	0.0	
40	-440	-18.6		0	0.0	
41	1080	45.8		0	0.0	
42	118	5.0		-93	-7.6	
43	0	0.0		0	0.0	
44	-50	-2.1		-13	-1.1	
45	0	0.0		-52	-4.2	
46	-88	-3.7		0	0.0	
47	14	0.6		35	2.9	
48	0	0.0		-24	-1.9	
49	-62	-2.6		29	2.4	
50	-316	-13.4		15	1.2	
51	0	0.0		-109	-8.8	

Table 1 continued..

Aransas Bay station number	Distance (ft) (Dec 58 - Jul 82)	Rate (ft/yr) (Dec 58 - Jul 82) (23.6 yrs)	Distance (ft) (Jul 82- Nov 94)	Rate (ft/yr) (Jul 82 - Nov 94) (12.3 yrs)
60	50	2.1	-122	-9.9
61	52	2.2	-68	-5.5
62	-166	-7	-153	-12.4
63	-154	-6.5	-43	-3.5
64	-228	-9.7	0	0.0
65	-84	-3.6	-10	-0.8
66	60	2.5	0	0.0
67	0	0	36	2.9
68	-26	-1.1	-43	-3.5

Lydia Ann Channel station number	Distance (ft) (Dec 58 - Jul 82)	Rate (ft/yr) (Dec 58 - Jul 82) (23.6 yrs)	Distance (ft) (Jul 82- Nov 94)	Rate (ft/yr) (Jul 82 - Nov 94) (12.3 yrs)
9	-60	-2.5	0	0.0
10	-140	-5.9	0	0.0
11	98	4.2	-213	-17.3
12	-174	-7.4	-80	-6.5
13	90	7.3	-85	-6.9

operations and erosion and reworking of dredged materials can increase the quantity of suspended sediment in the water column, thereby increasing local rates of sedimentation (Hellier and Kornicker 1962), and reducing light penetration and inhibiting photosynthesis (Odum 1963, Onuf 1994). Also, potentially detrimental contaminants existing in the sediments or interstitial waters may be released into the water affecting seagrass beds. Where conditions are favorable and dredging operations are discontinued, however, moderate recovery of seagrass beds may occur as submerged vegetation spreads over shallow subaqueous flats on to the margins of dredged material. Losses of seagrass may be partially offset by these gains.

An extensive network of navigation channels, lined with discharged dredged material, has altered natural environments and locally impacted seagrass habitats in the Corpus Christi Bay System (Fig. 10). Approximately 110 km^2 of channels and dredged material were mapped in early 1970s within the Corpus Christi area (Brown et al. 1976). Among the major channels are the Gulf Intracoastal Waterway (GIWW), Corpus Christi and Aransas Pass ship channels, Lydia Ann Channel, La Quinta Channel, Aransas Channel, and associated smaller intrabay channels and canals (Fig. 10). Harbors include the Inner Harbor and Turning Basin at Corpus Christi, Port Ingleside, and Conn Brown Harbor at Aransas Pass. Numerous smaller marinas and small boat basins line the shoreline near the GIWW.

Redfish Bay Area

Redfish Bay and adjacent Harbor Island form a large triangular shallow bay-flood-tidal delta complex that is bordered and bisected by dredged channels and dredge material disposal sites (Fig. 10). Along the western shore is the GIWW, to the east is Lydia Ann Channel that connects to the GIWW in Aransas Bay, and to the south is the Corpus Christi Ship Channel. Bisecting this large triangular complex is Aransas Channel. In addition, there are several smaller tributary intrabay channels.

Prior to 1958, several channels were dredged across seagrass areas in Redfish Bay and Harbor Island, primarily for navigation purposes and to gain access to shallow areas for oil and gas exploration (Fig. 11). Dredged materials were dumped along the channels forming upland mounds flanked by reworked sediments that locally blanketed seagrass habitats.

Gulf Intracoastal Waterway. In the Redfish Bay area, the GIWW , which has a project depth of approximately 3.7 m (12 ft) and width of about 38 m (125 ft), was dredged between 2/2/59 to 3/4/60 across the northwestern edge of Redfish Bay from Rockport to Port Ingleside (USACOE unpublished dredging records). More than 6 million cu yds of sediment was dredged (Fig. 12) and disposed of primarily in 16 open bay disposal areas that line the eastern margin of the waterway (Fig. 10). Since the original construction of the GIWW through Redfish Bay, the channel has been maintained through periodic dredgings (Fig. 12; Table 2) with the dredged material added to the previously created islands.

Table 2. Dredging activities for the GIWW between Aransas Bay and Corpus Christi Bay. Data from USACOE, Galveston District (Unpublished).

Dates	Downstream station (ft)	Up stream station (ft)	Distance (ft)	Total Cu Yds
2-2-59 to 3-4-60	901,000	911,000	10,000	890,545
	911,000	922,000	11,000	978,715
	922,000	933,000	11,000	862,506
	933,000	944,000	11,000	1,062,529
	950,000	956,000	6,000	485,767
	956,000	963,000	7,000	648,508
	963,000	970,000	7,000	573,688
	970,000	978,450	8,450	759,775
				6,262,033
3-1-60 to 10-30-60	944,570	944,750	180	359,336
8-13-61 to 9-29-61	929,000	935,000	6,000	77,056
	938,200	944,500	6,300	103,283
	977,000	978,000	1,000	16,765
				197,104
3-4-63 to 7-11-63	906,000	929,000	23,000	215,467
	947,500	960,000	12,500	143,989
				359,456
5-28-64 to 10-25-64	960,000	976,000	16,000	192,611
	976,600	978,215	1,615	40,716
				233,327
1-18-67 to 4-5-67	976,000	977,100	1,100	11,371
1-20-70 to 3-03-70	976,900	977,100	200	6,788
7-2-73 to 8-23-73	940,500	946,000	5,500	63,697
	946,000	950,000	4,000	66,852
	950,000	955,000	5,000	84,150
	955,000	960,000	5,000	72,408
	960,000	965,000	5,000	73,904
	965,000	969,000	4,000	44,756
	975,000	976,900	1,900	28,080
				433,847
10-3-83 to 5-10-84	937,000	945,000	8,000	101,874
	945,000	950,000	5,000	59,807
	950,000	955,000	5,000	71,166
	955,000	960,000	5,000	87,089
	960,000	965,000	5,000	82,240
	965,000	970,000	5,000	59,954
	970,000	975,000	5,000	61,801
	975,000	978,450	3,450	33,399
	979,000	985,000	6,000	100,917
				658,247

Lydia Ann Channel. In Aransas Bay, southeast of Rockport, the channel splits and connects to Lydia Ann Channel east of Harbor Island. Open bay disposal sites line the western side of the channel, and flank a north-south oriented chain of islands that mark the eastern margin of Redfish Bay. The islands from north to south are Talley, Traylor, Shellbank, and Harbor Island (Figs. 9 - 10). The disposal areas nearest to Redfish Bay are just east of Talley and Traylor Islands. Southeast of Shellbank Island, open bay disposal is on the east side of the channel toward San Jose Island. Periods and locations of dredging are shown in Table 3, with volume of dredged material in Figure 13.

Aransas Channel. The channel to Aransas Pass bisects Harbor Island and Redfish Bay, extending along the northeastern side of State Highway 361 from Aransas Pass to Port Aransas. Since its initial construction in 1940, maintenance dredging has occurred approximately each decade (Fig. 14, Table 4). Six disposal areas occur along Aransas Channel. Total area of the disposal sites is 480 ac, and at least three of the disposal areas are unconfined and adjoining marshland (Espey Huston, & Associates, Inc., 1976). The average volume of dredged material disposed per year from Aransas Channel ranges from 2,174 cu-yd to almost 10,000 cu-yd.

Corpus Christi Ship Channel. The Corpus Christi Ship Channel, a deep-draft channel that cuts between Mustang Island and Harbor Island (Fig. 10), was initially dredged in the 1920s. Disposal sites are located on both sides (east and west) of the channel, some on land and some in open water in the Gulf and Corpus Christi Bay. Dates, locations, and volumes of maintenance dredged material are listed for this channel in Table 5.

Water Quality Conditions

Very few Texas studies have correlated water quality components *per se* (e.g. dissolved nutrients, suspended sediments, and pollutant levels) to seagrass distribution and population dynamics. These studies require continuous measurements of parameters usually by a rigorous survey or monitoring program. One of the few datasets available was produced in a long-term study by Dunton (1996). This work examined production of *Halodule* along an estuarine gradient in three Coastal Bend estuaries, including Laguna Madre, Corpus Christi Bay, and San Antonio Bay. He found no clear correlation (positive or negative) between *Halodule* productivity, biomass, and chlorophyll content and various abiotic factors including dissolved inorganic nitrogen and porewater ammonia.

In other states, such as Florida or Maryland, such programs have been recommended as part of National Estuary or EPA environmental programs (Chesapeake Bay Program 1995). Dennison et al. (1993) presented relationships between seagrass productivity and growth and water quality which were developed for the Chesapeake Bay region. The primary basis was hypothesized to be underwater light attenuation caused by nutrient enrichment which

Table 3. Dredging activities for Lydia Ann Channel. Data from USACOE, Galveston District (Unpublished).

Dates	Downstream Station (ft)	Up Stream Station (ft)	Distance (ft)	Volume (Cu Yds)	Section Number
12-3-47 to 7-15-48	903,200	916,800	13,600	389,100	1
7-18-54 to 10-17-54	917,000	927,800	10,800	219,859	2
1-23-68 to 4-1-68	949,300	951,300	2,000	29,900	3
10-3-83 to 5-10-84	904,000	910,000	6,000	123,066	1

Table 4. Dredging activities for Channel to Aransas Pass. Data from USACOE, Galveston District (Unpublished).

Dates	Downstream Station (ft)	Up Stream Station (ft)	Distance (ft)	Volume (Cu Yds)
7-6-40 to 11-05-40	450	32,300	31,850	384,389
5-13-50	0	10,000	10,000	248,000
	10,000	20,000	10,000	160,000
	20,000	32,352	12,352	470,000
	0	2,200	2,200	382,000
				1,260,000
1-23-57 to 2-20-57	17,900	25,000	7,100	74,672
	25,000	32,100	7,100	97,186
				171,858
3-04-63 to 6-1-63	18,900	30,900	12,000	301,645
	12	5,000	4,988	293,080
1-23-68 to 4-1-68	1,400	9,000	7,600	109,666
12-21-71 to 2-29-72	4,500	8,500	4,000	57,975
	18,500	20,000	1,500	28,592
	20,000	25,000	5,000	66,763
	25,000	30,000	5,000	72,066
	30,000	32,442	2,442	122,816
				348,212
2-10-79 to 4-19-79	1,000	5,000	4,000	86,781
	5,000	10,000	5,000	129,717
	10,000	15,000	5,000	107,137
	15,000	20,000	5,000	146,558
	20,000	24,000	4,000	184,235
	24,000	27,000	3,000	83,190
	27,000	32,442	5,442	140,182
	26	5,000	4,974	246,556
				1,124,356
1-11-95	2,000	7,000	5,000	106,545
	7,000	12,000	5,000	50,152
	18,000	23,000	5,000	155,052
	23,000	28,000	5,000	114,469
	28,000	32,442	4,442	105,289
	26	1,800	1,774	72,999
				604,506

Table 5. Dredging activities for Corpus Christi Ship Channel in the Harbor Island—Redfish Bay complex. Data from USACOE, Galveston District (Unpublished).

Dates	Downstream station (ft)	Up Stream Station (ft)	Distance (ft)	Volume (cu-yds)
11-2-45 to 9-29-46	27,300	55,000	27,700	8,780,951
	55,000	82,700		
	82,700	110,300		
				8,780,951
6-14-49 to 10-24-49	46,000	60,000	14,000	1,923,811
	102,000	110,400		
	2D			
	110,700	114,000		
				1,923,811
1-1-50 to 5-13-50	700	1,500	800	1,254,705
Channel to Aransas Pass	0	10,000		
	10,000	20,000		
	20,000	32,352		
	0	2,200		
				1,254,705
6-10-51 to 8-28-51	26,000	42,600	16,600	1,839,631
5-2-52 to 10-2-52	800	1,600	800	143,544
3-31-55 to 5-20-55	27,100	41,000	13,900	1,039,359
4-18-56 to 9-18-56	50,000	69,000	19,000	2,845,892
11-29-57 to 2-05-58	29,500	41,000	11,500	2,036,355
	41,000	52,400	11,400	
3-26-58 to 12-01-58	3,950	11,000	7,050	2,818,324
	11,000	18,000	7,000	
	18,000	25,000	7,000	
	25,000	29,500	4,500	
3-07-60 to 1-29-61	29,500	39,000	9,500	1,689,817
	39,000	46,000	7,000	1,237,574
	46,000	52,400	6,400	1,249,133
	52,400	59,300	6,900	1,304,127
				5,480,651
3-06-62 to 5-14-62	27,000	42,000	15,000	983,023
	50,000	58,800	8,800	653,537
				1,636,560
12-25-63 to 2-26-65	700	1,540	840	102,019
	25,000	34,000	9,000	847,986
	34,000	43,000	9,000	793,896
	43,000	50,000	7,000	629,830
	50,000	58,000	8,000	945,793
				3,319,524
3-07-66 to 8-06-66	-1,540	-800	740	112,733
	52,000	63,000	11,000	654,182
				766,915

Table 5 continued..

Dates	Downstream station (ft)	Up Stream Station (ft)	Distance (ft)	Volume (cu-yds)
7-9-68 to 2-7-69	23,000	36,000	13,000	835,967
	36,000	49,000	13,000	521,950
	49,000	62,000	13,000	934,729
				2,292,646
4-28-71 to 9-25-71	52,000	55,000	3,000	214,373
	55,000	60,000	5,000	429,941
				644,314
7-9-73 to 5-30-74	-3,803	-500	3,303	562,734
	1,255	4,000	2,745	641,122
	4,000	8,000	4,000	537,033
	8,000	13,000	5,000	853,064
	13,000	17,000	4,000	698,267
	17,000	22,000	5,000	943,797
	22,000	27,000	5,000	977,088
	27,000	31,000	4,000	1,188,407
	31,000	35,000	4,000	1,432,745
				7,834,257
6-17-74 to 12-17-75	35,000	40,000	5,000	1,554,461
	40,000	43,700	3,700	955,041
	43,700	49,000	5,300	2,238,778
	49,000	52,400	3,400	791,316
	52,400	54,000	1,600	629,937
				6,169,533
10-11-75 to 10-27-76				
5-30-78 to 8-11-78	-380	0	380	323,622
	1,255	6,000	4,745	237,853
				561,475
10-23-81 to 4-30-82	-3,803	-2,136	1,667	310,784
	27,000	35,000	8,000	1,110,041
	35,000	40,000	5,000	384,580
	40,000	45,000	5,000	256,908
	45,000	50,000	5,000	509,670
	50,000	54,000	4,000	367,759
				2,939,742
4-3-89 to 4-12-89	-3,803	-2,136	1,667	201,671
4-13-91 to 7-15-91	43,700	49,000	5,300	263,012
12-6-91 to 1-27-92	27,000	32,000	5,000	245,140
	32,000	36,000	4,000	310,582
	35,539	35,539		41,213
	36,000	41,000	5,000	254,016
				850,951

stimulates phytoplankton blooms or epiphyte overgrowth. Studies in Florida (Tomasko and Lapointe 1991) have attempted to confirm and extend this mechanism. They also suggested that other responses could include effects from macroalgal biomass increases and from pre-dawn hypoxia on seagrass. Recently, Tomasko et al. (1996) observed that *Thalassia* biomass and productivity were negatively correlated with watershed N loadings, but that water column nutrient levels did not clearly reflect these watershed loadings.

The designated Texas water monitoring agency, Texas Natural Resource Conservation Commission (TNRCC), collects four water quality samples per year (one each season, every three months) for a few widely-scattered bay stations as part of its Coastal Water Monitoring Program. Since dissolved nutrients are rapidly taken up into microbial biomass, defineable nutrient patterns in Coastal Bend bay waters cannot usually be established or detected from such erratic sampling. Moreover, the effect of bay circulation on mixing/dilution of nutrients would make it difficult to detect nutrient plumes except under very limited conditions. Even in the Laguna Madre where the brown tide bloom has now been present for 7 years, routinely low, but measurable, concentrations of dissolved N were generally observed (see Dunton 1996). Thus, nutrient levels in the water column may be poor indicators of incipient water quality problems for seagrass beds.

TNRCC approves and issues wastewater discharge permits for sewage treatment plants and industrial operations. These so-called NPDES permits potentially represent the most direct source of nutrient-rich effluents added to bay waters. Such materials have been implicated in eutrophication impacts to seagrass beds in other parts of the country, although not in Texas (NOAA-ORCA 1995). Figure 15 shows the point source locations of approximately 80 wastewater discharge sites around the Corpus Christi/ Nueces/Redfish Bays system. Most of these sites are industrial effluents near Corpus Christi, as well as eight to ten along the mainland between Ingleside and Rockport. The four sites on Mustang Island, three sites in Oso Bay, and two sites near Portland, are for wastewater sewage discharges. Non-point source runoff represents another likely source of nutrients because of the density of both urban area and cropland/farmlands in the Coastal Bend. This source has been implicated in nutrient loading problems in the Chesapeake Bay region (Dennison et al. 1993).

Generally, water quality impacts are mediated through phytoplankton (microalgal) blooms and drift macroalgae accumulations. In other cases, poor water quality causes fouling by epiphyte algae which grow attached to seagrass leaves (Sand-Jensen and Borum 1991). Since nutrient zones may be hard to detect directly in the water column, workers have recommended using the presence of epiphytes and macroalgae as indicators of reduced water quality (NOAA-ORCA 1995). Growth of these nuisance plants is stimulated by the high dissolved nutrient levels, and they tend to shade out and overgrow bottom- rooted seagrasses. The red and brown drift algae (seaweeds) reach large biomass often during summer and early fall (Cowper 1978, Edwards 1976). Although macroalgae are common inhabitants of the local bays, their presence in such large abundance was reported by

Cowper (1978) to pose a potential stress to seagrasses in Redfish Bay. Epiphytes have also been reported by Pulich (1980b) to reach potentially noxious levels to seagrass.

Underwater Light Conditions

Since nutrient effects on seagrass are ultimately mediated through light shading and underwater light attenuation, some studies have focused on monitoring underwater light levels directly. Dunton (1994) has measured underwater irradiance continuously for several years at several grassbed sites, including East Flats in Corpus Christi Bay as well as upper Laguna Madre (Fig. 16). These long-term measurements of light conditions from 1989 to current time provide a baseline of the photic regimes to which seagrass are exposed for the Coastal Bend bay systems. When compared to such data from other areas, the low irradiance conditions over these years in Laguna Madre due to the ongoing brown tide provides a standard for assessing analogous water quality impacts in other places.

In addition to the actual light energy regimes, it is important to remember that different types and amounts of suspended particulate material contribute to light attenuation. The sources of major components of suspended particulate materials may differ greatly. This is illustrated by two factors causing attenuation of underwater light reaching seagrasses which represent two different components of the suspended solids found in bay waters. Although the two factors, suspended sediments and water column phytoplankton, are potentially serious light shading materials for seagrasses (Kenworthy and Haunert 1991, Dunton et al. 1994), both are produced by different processes. Nutrient enrichment from point or non-point source discharges, as explained above, fuels phytoplankton blooms or epiphyte/macroalgae growth. Alternatively, dredging and boating activities, along with wind-generated waves, can contribute to suspended sediment impacts (Schubel et al. 1979, Onuf 1996a). Thus, the source and composition of light-attenuating materials is critical in assessing light reduction impacts on seagrasses.

METHODS AND MATERIALS

Aerial Photography

Seagrass mapping procedures for this study followed the general protocol according to Ferguson et al. (1993) and Dobson et al. (1995), based on photointerpretation of high resolution aerial photography. Seagrass distribution was determined from 1:24,000 scale, true color aerial photography flown on November 21, 1994 by the Texas Department of Transportation (TXDOT). The photomission coverage was planned under the supervision of TPWD staff, but all airplane operations and actual photography were conducted by the Aerial Photography staff of TXDOT. Flight lines were laid out with 25 % sidelap and 30% endlap. The mission was flown two days after a fall coldfront when the weather was clear and winds calm. Tidal conditions were slightly higher than average annual water height. Large format (9 in. x 9 in.) aerial film (Aerocolor 2445 film) was exposed at an airplane altitude of 10,000 ft. to provide 1:24,000 scale.

Inventory and Ground Truthing

During spring and summer 1995, groundtruthing surveys were conducted throughout Corpus Christi, Redfish, and Nueces Bays and extreme upper Laguna Madre to verify seagrass signatures from the 1994 fall photography. Most of these surveys utilized an airboat allowing access to very shallow grassflats. Global positioning satellite system (GPS) was used allowing real-time differential correction techniques to be applied. The 1994 seagrass distribution maps produced from this technique had a locational accuracy of 10 ft (3 m) for land features. During late spring of 1996, similar groundtruthing was conducted in the Copano, Port, and Mission Bays region. St. Charles, Mesquite, and Aransas Bays, including backside of San Jose Island, were surveyed in late summer 1996.

Mapping Analysis

Seagrass distribution maps from current and various historical time periods were constructed by photointerpreting positive copies of the aerial photography. The dates and source of earlier photographs analyzed were: 1956-58 series black & white Tobin surveys, scale 1:24,000; early October 1975 NASA JSC color infrared series, scale 1:24,000; and early November 1987-89 NASA Ames series, scale 1:63,000. In most cases, large format (9x9 in) positive transparencies were photointerpreted for seagrass and other features onto 2 mil, transparent Mylar sheets. Seagrass and other features were classified according to the land cover scheme of Klemas et al. (1993). Features were traced using a backlit light table and 6 power magnifying lens. For the 1975 photos, a Bausch & Lomb stereo zoom transfer scope was used to transfer and register seagrass features to the appropriate 7.5 min USGS planimetric base map. For the 1950s photointerpretation, features were traced directly off the rectified black and white prints which had been mosaicked together, producing a USGS quadrangle size sheet.

Classification Scheme

Because fragmentation of seagrass beds can be considered an initial stage in the decline of seagrasses, mapping focused on discriminating between two morphological bed types, *continuous* vs. *patchy*. Continuous beds represent typical extensive, undisturbed seagrass areas, with homogeneous lawns of plant shoots. Patchy beds are often broken up into patches of plants interspersed with bare sediment. The size of these patches determines whether beds are mapped as patchy or continuous, but also, in some cases, whether an isolated patch of seagrass will be mapped. Patchy beds generally represent seagrass areas that are subject to impact from fetch, hydraulics, or mechanical disturbance. In the latter case, impact from dredge spoil deposition, boats, or shoreline development can cause this pattern. Kaldy (UTMSI, personal communication) has recently reported that seagrass patches may also arise from colonization events such as propagule or seed establishment.

Mapping scale is very important, since at 1:24,000 scale, the recognized standard for most mapping, only features larger than ca 0.12 acre in actual size can be accurately mapped. Minimum mapping unit was limited in our case by clarity in the aerial photography and the patchy distribution patterns of seagrass. Underwater features in the 1:24,000 scale photography were not clearly discriminated below 0.05 ha (0.12 ac) in size. Thus the definition of a patchy seagrass bed was a grouping of small patches of seagrass, between 0.12- 0.25 acre in dimensions, with equally small, open bare sand areas separating them.

Initial attempts were made to separate density of seagrass beds into two categories, sparse and dense. However it was soon evident that differences in water depth and clarity in local areas, as well as variable biomass between species, made this attribute equivocal. In addition, species identification was not feasible on a widespread basis. The signatures of the various species were not distinctive enough to reliably separate them in the photography. However the sampling design for ground assessment with extensive GPS points allowed for an extensive network to establish species distributions. This sampling design consisted of line transects approximately 0.5 mile (0.8 km) apart perpendicular to shore with GPS stations at least every 0.2 mile (0.3 km). From the spatial pattern of such points, the overall distribution of species can be visually approximated from map coverages. A percent frequency of species occurrence was also calculated based on the total number of samples recorded.

Digitization and Registration (Geocoding) of Seagrass Polygons

Traced seagrass boundaries on the mylar overlays were converted to digitized images by scanning the mylar sheets using an Ideal Contex optical scanner. This produced a 400 dpi raster (tiff) image file which was converted into a vector polyline file using PixelTrak software (Cadix Research Corp., Ontario, Canada). The vector polyline file was then imported into Arc/Info GIS software (ESRI Inc., Redlands, CA) using ArcEdit routine and converted to an Arc/Info line or polygon coverage. All subsequent Arc/Info processing was done on a SUN workstation running under UNIX.

The digitized vector polygons were georeferenced using GPS-based ground control points (GCP's) to perform registration and rectification calculations. Least squares transformations were performed in the Arc/Info software package. Normally a second-order polynomial calculation was employed based on at least 8 GCP's evenly distributed as "tic" marks across the 9 in. x 9 in. photo area. All root mean square errors for transformation coefficients were less than 0.002. Seagrass habitat polygons were thus transformed and mapped into a standard UTM map projection coordinate system. This technique, described in Tudor and Sugarbaker (1993), represents a modified form of orthographic digitizing directly from aerial photography. Because all land surface features are basically at sea level and no relief displacement occurs, it is not necessary to correct for distortion from relief displacement using a digital terrain model.

Geographic Information System Analysis

All digital map coverages were entered into the Arc/Info GIS database. Trend Analysis was performed using GIS change maps derived from the land cover map data in the Arc/Info database. Change maps were determined by postclassification change detection from the seagrass distribution maps representing different time periods (Dobson et al. 1995). All procedures were performed with Arc/Info. The 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.

Sources of Environmental Data Sets

1. Historical dredging data for the GIWW, Corpus Christi and Aransas Pass ship channels, and Lydia Ann channel were obtained from original unpublished records at the USACOE, Galveston District. This includes project records of times and locations of all COE channel dredging activities and quantities of dredged material in the Redfish Bay area. The map of authorized COE dredge material disposal areas (Fig. 10) was obtained from the GLO, Coastal Division. Map data had been compiled and digitized from original USACOE project maps on file at Galveston.

2. Bathymetry for the 3-ft and 6-ft depth contours was obtained from NOAA nautical charts of Redfish Bay area. Water depths less than 3 ft (0.9 m) were determined from depth measurements made during 1995 mapping surveys. These depths were converted to corrected MLLW values by

analyzing the 1995 tide records for the Rockport and Ingleside tide gauges. Daily water level records were based on tide gauge data from Rockport gauge, a long-term NOAA certified gauge with a 50 + period of record. All tide gauge data were obtained from the TCOON Network (GLO) through the Blucher Institute at TAMU-Corpus Christi.

3. Data on NPDES wastewater discharge locations were obtained from the TNRCC Coastal Monitoring Database, Information Resources Division, Austin.

4. Physical disturbance features (e.g. shoreline construction, boat propeller scars, wrack and drift algae accumulation) were identified from aerial photointerpretation and corroborated by field surveys. Recent shoreline erosion data between 1982 - 1994 was calculated from measurements on the 1994 1:24,000 scale color aerial photography according to procedures described in Paine and Morton (1993). The same shoreline stations (transects) established by Paine and Morton (1993) in the Redfish Bay/Harbor Island complex were used (Fig. 9).

5. Other physical factors data were derived from published references or agency databases as indicated.

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SEAGRASS STATUS AND TRENDS RESULTS

Current Seagrass Inventories for Coastal Bend Area

In 1994, total coastwide seagrass acreage for Texas was approximately 95,142 ha (235,000 acres) (Pulich, unpublished data and this study; Quammen and Onuf 1993). This includes permanently established beds of the four perennial seagrass species and associated *Ruppia* beds. Inventories for individual bay systems reveal that the vast majority of seagrass (79.1 %) occurs in Laguna Madre (Upper/Baffin Bay = 28.6 % and Lower = 50.5 %). Figure 2 shows the 1988 seagrass coverage from Quammen and Onuf (1993) for the upper Laguna.

Figure 17 presents the 1994 distribution of seagrass beds in the Corpus Christi/Nueces/Redfish Bays System (including the Laguna Madre north of Kennedy Causeway). This area contains a total of 10,693 ha (26,412 acres), by far the largest amount (11.2 %) of Texas seagrasses found in one bay system outside the Laguna Madre. Figure 18 indicates the 1994 distribution of seagrass beds for the Aransas Bay/San Jose Island part of the Coastal Bend (1,910 ha total), while Figure 19 likewise shows seagrass distribution for the Copano/Port Bays region (1,197 ha total). Combined, the entire bays of the northern part of the Coastal Bend contain 13,800 ha of seagrass, of which 7,596 ha are continuous (fairly dense) grassbeds, while 6,204 ha are patchy (fragmented) grassbeds. This amounts to 14.5 % of all Texas seagrass beds.

Species Distributions for Northern Coastal Bend Area

Figures 20 - 22 present seagrass species distributions determined from 1995 - 1996 field surveys for the Redfish Bay/Harbor Island complex, San Jose Island area, and backside of Mustang Island, respectively. *Halodule wrightii* (shoalgrass) is the dominant species in upper Laguna Madre and from Aransas Bay northward to San Antonio Bay and in Copano Bay. Small amounts of the minor species, *Halophila engelmannii* (clovergrass), are found in all bay systems except Nueces, Copano, Port and St. Charles Bays. The low-salinity tolerant species *Ruppia maritima* (widgeongrass) is found frequently in all *Halodule* beds within the Coastal Bend area. *Ruppia*, being primarily an annual, is very seasonal, occurring most abundantly in spring and fall. However, in some back-bay and upper bay areas, *Ruppia* is also frequent in summer (Port, Mission and Nueces Bays; San Jose and Harbor Islands areas).

Thalassia testudinum (turtlegrass) and *Syringodium filiforme* (manateegrass) were found only in the Redfish Bay/Harbor Island complex, east Corpus Christi Bay ("East Flats" area), and around Mud Island and Allyn's Bight in Aransas Bay. They are locally dominant species of the submerged vegetation community in entire beds, and frequently occur together. Except for a relict population of *Thalassia* still located in Christmas Bay (near West Galveston Bay), no other populations of either species are presently known to occur further north than this on the Texas coast.

Based on groundtruthing surveys, frequency of species occurrence was calculated (Table 6) for these individual bay regions. The relative percent occurrence reveals the dominance of *Halodule* (73-90% of all samples) in the system, and the scarcity of *Syringodium* (2-3%) and *Halophila* (1.7-6%). *Thalassia*, interestingly, appeared much more frequent in Redfish Bay/Harbor Island area (34.6% of samples) than in either East Corpus Christi or Aransas Bays (15.5% average).

Table 6. Frequency of occurrence (% of samples) for five seagrass species in the Coastal Bend. Total percentage in each bay area is more than 100% because of mixed assemblages of species in many samples.

Bay Area	Halodule	Ruppia	Thalassia	Syringo-dium	Halophila
Redfish Bay/ Harbor Island	73.2	19.1	34.6	3.2	1.7
East Corpus Christi Bay	86.0	15.0	15.8	1.9	0.4
Aransas Bay	90.0	9.2	15.3	2.8	6.0

Seagrass Trends in Redfish Bay/Harbor Island Complex

Seagrass distribution and inventories in the Redfish Bay/Harbor Island complex are displayed in Figures 23 - 33 for 1958, 1975, and 1994 periods, respectively. This region as explained earlier, contains the most extensive, pristine seagrass beds on the Texas coast outside the Laguna Madre, with a current acreage of about 14,000 acres (57 km^2). Moreover it is the main area containing an abundance of all five seagrass species outside the lower Laguna. Figure 23, which shows the 1958 coverage, represents seagrass distribution prior to dredging the GIWW along the mainland side of Redfish Bay. It also reflects the effect on seagrass of low baywater levels due to the mid-50's drought. Figure 24, the 1975 coverage, shows a substantial increase in seagrass distribution for Harbor Island area, but a significant decrease for the Redfish Bay area. By 1994, seagrass coverage had decreased more in Redfish Bay, and some loss has occurred in Harbor Island as shown in Figure 25.

GIS Change Maps for the Redfish Bay/ Harbor Island complex show the spatial locations of seagrass changes that occurred between 1958, 1975, and 1994 periods. Each part of this complex was examined separately. **Redfish Bay maps** are shown in Figures 26 - 28 for three time period increments: 1958 to 1994 (Fig. 26), 1958 to 1975 (Fig. 27), and 1975 to 1994 (Fig. 28). Figure 29 summarizes the acreage changes for Redfish Bay seagrass in graphic format. The north and south parts of Redfish Bay (separated by the causeway to Port Aransas) are treated separately. For both parts, there was progressive loss of continuous beds and increase in patchy beds. Overall results indicate that a net loss of 536 ha (13%) seagrass occurred between 1958 to 1994 in Redfish Bay, with substantial increase in fragmented grassbeds (52%).

Harbor Island maps are shown in Figures 30 - 32: 1958 to 1994 (Fig. 30), 1958 to 1975 (Fig. 31), and 1975 to 1994 (Fig. 32). Figure 33 summarizes acreage changes graphically for the north and south seagrass beds of Harbor Island. For both north and south parts, there was a large progressive increase from 1958 to 1975, especially of continuous grassbeds (all *Halodule/Ruppia*). For both parts, there followed a measurable decrease (ca 6%) between 1975 and 1994. This loss includes some *Halodule,* but mostly *Thalassia*. Overall results indicate there has been a net gain of 72% (866 ha) seagrass acreage in Harbor Island area which occurred between 1958 to 1994.

The *net result* for the entire Redfish Bay/Harbor Island region has been a gain of 330 ha (815 acres) over the 38 year period. This however represents the quantitative result and does not reflect spatial patterns of change. Another indication of changing patterns is evident from species distribution within the areas of seagrass change, as presented in Figure 34. Table 7 presents quantitative statistics derived from this spatial analysis of species. Based on the survey samples from Redfish Bay and Harbor Island (considered separately), *Thalassia* appears to occur most frequently in areas that have either remained stable or lost grass cover over the years. *Halodule* occurs more frequently in the areas that have changed (whether gain or loss) in seagrass cover, although the pattern is different between Harbor Island and Redfish Bay. In Harbor Island, *Halodule* was found most frequently (51 %) in the areas that gained seagrass, while in Redfish Bay, it occurred most frequently (43.4 %) in the areas that lost seagrass.

Seagrass Trends in Corpus Christi Bay

On the backside of Mustang Island, seagrass increased dramatically (by 1,319 acres) between 1958 and 1974, as reported by White et al. (1978). In the present study, an additional 20.6 % increase (519 ha) in seagrass acreage was measured between 1974 and 1994, as shown in Figure 35. Gains in seagrass occurred both 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. 35). The increase in shallow waters was due to *Halodule/Ruppia* expansion.

Table 7. Percent species occurrence related to net change in seagrass coverage of Harbor Island or Redfish Bay Areas between 1956 and 1994. Values indicate number and % of total samples observed.

Type of Change	**Harbor Island**		**Redfish Bay**	
	Halodule	**Thalassia**	**Halodule**	**Thalassia**
w/in Loss Area	34 (18.8%)	23 (43.4%)	96 (43.4%)	98 (42.4%)
w/in Gain Area	93 (51.4%)	9 (17.0%)	61 (27.6%)	22 (9.5 %)
in Unchanged Area	54 (29.8%)	21 (39.6%)	64 (28.9%)	111 (48.0%)
Total Samples	181 (100%)	53 (100%)	221 (100%)	231 (100%)

Seagrass Trends in Nueces Bay

Figure 36 compares seagrass distribution for Nueces Bay between 1961 and 1989, while Figure 37 shows the additional increase of 94 ha between 1989 and 1994. In 1961, only 79 ha of seagrass (*Halodule*) was mapped in the bay. After 1961, there was essentially a 100% loss of grassbeds by late 1960s, apparently coinciding with Hurricane Beulah in 1967. During the 1970s, only fringe shoreline patches of mostly *Ruppia* were observed and reported by TPWD biologists on sampling trips to Nueces Bay (R. Harrington, TPWD, Corpus Christi, personal communication). By mid-1980s, major *Halodule* beds had reappeared, reaching 200 ha by 1989 and 294 ha by 1994. Percent changes in seagrass acreage were: 1961 to about 1970 (essentially 100% loss); 1970 to early 1980s (no grassbeds); 1980 to 1989 (112 % gain compared to 1961); and 1989 to 1994 (47 % gain over 1989). These trend data indicate that upper Nueces Bay is unusually dynamic.

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PROBABLE CAUSES: EFFECTS OF ENVIRONMENTAL FACTORS ON SEAGRASS TRENDS

Natural Process Changes

Climatic Events and Associated Streamflow Discharge

The major drought in the mid 1950s followed by periods of higher than normal rainfall in the late 1960s and into the mid-1970s (see Literature Review) form the setting for seagrass changes. Reduced streamflow (Fig. 3) and runoff from coastal upland areas during the drought probably produced lower turbidities. These conditions would have allowed submerged vegetation to reach maximum distribution in deeper water areas in the mid 1950s. Shallower areas became emergent, however, which inhibited the spread of submerged vegetation, for example, on portions of the flood-tidal delta, Harbor Island. Rising water levels at the end of the drought in 1957, plus temporary increases in turbidity, phytoplankton, and/or epiphytes associated with increasing streamflow and runoff, may have stressed submerged vegetation in deeper areas of the bay (Pulich and White 1991).

Hurricanes Beulah and Fern in 1967 and 1971, respectively, affected bay waters primarily by torrential rains that fell within the drainage basin, causing high inflows into the bays. Undoubtedly, the groundwater in large sand bodies like the modern barrier islands and Ingleside barrier-strandplain (Brown et al. 1976) that border the bays and lagoons was recharged during these high rainfall events, and was a source of discharging water into the bay system for extended periods. These discharging waters would partially contribute to the elevated bay waters recorded by the tide gauges. A different, but related, hurricane effect seems to explain the loss of *Halodule* grassbeds from Nueces Bay during the late 1960s. This episode appears most related to torrential runoff/sediment deposition from adjacent farmlands caused by Hurricane Beulah in 1967 (McGowen 1971).

Relative Sea-Level Rise/ Bathymetry Changes

Shallow Flats

Harbor Island. The most dramatic changes in seagrass distribution relate to bathymetric changes that occurred on shallow flats of the flood-tidal delta, Harbor Island. Between 1958 and 1975 there was a net increase of more than 1,000 ha in seagrass beds as *Halodule* and *Ruppia* expanded into areas previously mapped as wind-tidal flats (Brown et al. 1976, White et al. 1983). This expansion is attributed to an increase in water depth over the flats following the severe drought of the mid 1950s and an accelerated rate of relative sea-level rise (Fig. 8). The Rockport tide gauge recorded a mean annual water level that was approximately 20 cm higher in 1975 than in 1964 (Fig.

8). This seagrass expansion was complete by 1975. Between 1975 and 1994, we actually measured a slight decrease in seagrass acreage (ca 100 ha) from Harbor Island north and south sides combined (see Fig. 33).

Mustang Island. The trend of expansion of seagrass beds over wind-tidal flats as a result of rising relative sea-level also occurred on Mustang Island. Seagrasses expanded over broad flats on the bayward side of Mustang and North Padre Islands increasing in areal distribution from approximately 1,030 ha in 1956 to 2,700 ha in 1974 (White et al. 1978). The trend that was set during this period from the mid 1950s to 1974 , continued from 1974 to 1994 although at a reduced rate (Figs. 38). In the area investigated in this study, which included Mustang Island and a smaller section of North Padre Island than mapped by White et al. (1978), seagrass areas increased 20.6% from approximately 2,375 ha in 1974 to approximately 2,870 ha in 1994. Again, these increases in seagrass area from the mid 1950s to mid 1970s correlate positively with the increase in water levels for this time period as recorded by the Rockport tide gauge (Fig. 38). Much of the increase can be attributed to rising water levels during the 1970s and the protected physiography along this leeward side of Mustang Island. In addition there is a noticeable lack of residential and marina development along this protected shoreline which would eliminate a source of impact to grassbeds. One area in the upper Laguna Madre shows noticeable recent seagrass loss which may be related to the brown tide algal bloom.

Deeper Seagrass Areas

Losses and gains of seagrass in deeper areas of Redfish Bay and Nueces Bay are more difficult to assess and relate to changes in bathymetry. Losses can occur in seagrass beds due to increasing depth and reduction in light reaching seagrass. The increase in relative sea-level rise from the mid 1960s to 1975 (Fig. 38) which caused submergence of wind-tidal flats, also affected deeper areas. However, there is a lack of good bathymetric data to define trends in these shallow bay areas for the period of our study, 1958-1996, and although sea level was rising, water depths may not have increased. This is because sediments contributed to the bays and estuaries tend to settle out in deeper, protected areas of the bay floor. It is possible that resulting sediment accumulation rates kept pace or exceeded rates of relative sea-level rise.

There is evidence that seagrass beds alter the sedimentation process by increasing sedimentation rates, by concentrating preferentially the finer particles sizes, and by stabilizing the deposited sediments (Burrell and Schubel 1977). Studies by Ward et al. (1984) and Almasi et al. (1987) indicate that sedimentation rates are substantially higher in seagrass communities than in unvegetated areas. The reduction in resuspension of the sediments is a direct function of plant biomass (Kemp et al. 1984). If the rates of sedimentation are equal to the rate of relative sea-level rise, essentially, there will be no change in water depth. In fact, Shepard (1953) using unpublished bathymetric data from the mid 1800s to mid 1930s detected in Texas bays and estuaries an overall trend toward shoaling at an average rate of 3.8 mm/yr. Shepard's measurements do not include Nueces and Redfish Bays, so we are unable to verify this.

Still, accelerated rises in sea level over the short term may exceed sedimentation rates. The declines in seagrass in Nueces Bay after the early 1960s were possibly due to a combination of higher water levels caused by the abnormally high rainfall in the late 1960s to mid 1970s (Fig. 4) and higher turbidities associated with increased stream discharge, suspended load, and runoff from adjacent lands. These factors, coupled with the observation that dredged material was discharged into Nueces Bay from Corpus Christi Ship Channel turning basin and inner harbor, and the fact that between the years 1959 and 1974, more than 13 million yd^3 of oyster shell was dredged from Nueces Bay (Brown et al. 1976), may have maintained turbidities at levels that caused the decline in seagrass. It should be noted, however, that shell production in this area began many years before 1959, but records for individual bays were not kept before that time.

Shoreline Changes, Redfish Bay - Harbor Island System

A retreating shoreline is not necessarily defined by a relatively steep subaerial scarp or berm that is being attacked and eroded by intense wave and current activity. A shoreline can also advance landward (retreat) along a more protected embayment where relative sea-level rise, through time, permanently inundates a gently sloping wind-tidal flat.

Changes in the distribution of seagrass as a result of shorelines advancing (accretion) or retreating (erosion), were examined in the Redfish Bay/Harbor Island complex. The distances and rates of shoreline change for two periods (1958-1982 and 1982-1994) at 65 stations are presented in Table 1 . Although rates were calculated at stations along artificially modified shores, e.g., those affected by dredging and filling, these average rates are somewhat misleading because the changes probably occurred incrementally over a short time span due to human activities.

In general, the "average" shoreline in the Copano-Aransas-Redfish Bay systems retreated at 2.5 ft/yr between 1958 and 1982 (Paine and Morton 1993). During this period average land loss in Redfish Bay was 13 ac/yr. The highest rates of erosion in Redfish Bay between 1958 to 1982 occurred along the western margin of Harbor Island at stations R-34 to R-40 (Fig. 9). Rates of erosion were also relatively high along Lydia Ann Channel and at various stations along the islands bordering Aransas Bay (Fig. 9). From 1982 to 1994, in general, shoreline positions either remained unchanged or retreated (Table 1). Among the highest retreating rates were those along Lydia Ann Channel, and at some stations on the eastern shore of Harbor Island and adjacent islands bordering Redfish Bay.

A relationship between shoreline movement and seagrass distribution was most apparent on Harbor Island. As mentioned previously, stations on the western shoreline of Harbor Island were among those having the highest rates of retreat during the period from 1958 to 1974 (Fig. 9). This landward migrating shoreline coincides with the submergence or permanent inundation of wind-tidal flats as a result of relative sea-level rise, and correlates with the spread of seagrass into areas previously mapped as wind-tidal flats (Brown et al. 1976). Less clear is the relationship between actual shoreline erosion and loss of seagrass, although losses in seagrass between 1975 and 1994 in the southwest corner of Harbor Island along the Corpus Christi Ship Channel (Fig. 30) appear to be related to erosion and perhaps redistribution of dredged material along the Corpus Christi Ship Channel. There is no shoreline monitoring station at this location along the ship channel, but examination of 1970s aerial photographs indicates erosion is occurring and dredged material may have been reworked and deposited in seagrass areas. Shoreline monitoring station R-41, located on north shore of this corner of Harbor Island, shows extensive accretion at this site between 1958 and 1982 (Fig. 9). The accretion may be the result of erosion from the channel side and overwash and deposition of sediment on the north shore where the accretion was documented.

Physical Disturbances

Dredging Activities

An example of direct losses associated with discharged sediment deposits is shown in Figure 11, in Redfish Bay to the south of Ransom Island along oil well channels. In the discussion of seagrass trends in the following paragraphs, we focus primarily on direct spatial and temporal changes in seagrass distribution that can be documented through aerial photo analysis. Figure 39 illustrates the network of dredged channels and dredge material disposal sites created in the Redfish Bay-Harbor Island complex, as determined from aerial photoanalysis during our study.

Redfish Bay/Harbor Island Complex

The most extensive dredging-related losses in seagrass occurred between 1958 and 1975 (Figs. 27 & 31). The losses were principally related to construction of the GIWW through Redfish Bay and the resulting discharge of dredged material directly into seagrass areas (Fig. 40. The majority of the losses were due to seagrass burial at the disposal sites (Fig. 39). However at some distance from disposal sites, seagrass beds were often converted to sparsely vegetated beds (patchy). Odum (1963) reported a decrease in productivity and imbalance of respiration over photosynthesis in seagrasses in Redfish Bay in the summer of 1959 that he attributed to dredging of the GIWW. However recovery was noted the following year when growth was exceptional, and he suggested that nutrients released may have stimulated growth.

On Harbor Island, the most extensive losses due to dredging activities also occurred between 1958 and 1975 (Fig. 31). 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 (Fig. 31). Overall, these losses were relatively small compared to those along the GIWW. Losses of seagrass along the eastern, Aransas Bay, side of Talley and Traylor Islands 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 near shore areas that were previously more densely vegetated in 1975 may have been buried by discharged or reworked dredged material by 1994.

Many smaller intrabay channels were dredged across seagrass areas in Redfish Bay prior to 1958 (Fig. 39). The initial impacts on seagrass beds from these channels and disposed dredged material were not determined because our analysis is post 1958. Of interest, is that between 1958 to 1975, there were gains in seagrass along the channels as marine grasses spread over the margins of reworked and submerged dredged material (Fig. 40). 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 (Fig. 40).

As indicated in Figure 40, a total of 795 ha of seagrass was lost due to dredge material deposition and channel impact zones. Concomitantly, 407 ha was gained during the same time period, for a *net loss* of 388 ha. Since most of this loss occurred in the Redfish Bay portion of the regional complex, it is interesting to compare this to the total seagrass lost in Redfish Bay alone which was 536 ha. Thus it is evident that the 388 ha lost related to channel dredging accounts for approximately 2/3 (72%) of this total. This represents a substantial impact.

Mustang Island

Direct changes in seagrass due to dredging operations on Mustang Island have been minimal since the mid-1950s. More extensive changes occurred between 1938 and 1956 when several channels related to oil and gas exploration were dredged across seagrass beds and wind-tidal flats east of Shamrock Island (White et al. 1978). Between 1956 and 1975, seagrass beds encroached onto the margins of reworked and submerged dredged material as part of broader trend characterized by the spread of marine grasses over submerging wind-tidal flats (White et al. 1978).

Nueces Bay

Direct losses in seagrass as a result of channel dredging and discharge of dredged materials could not be documented in Nueces Bay because seagrass areas are located along the north shore of Nueces Bay, and sediment dredged from the Corpus Christi Ship Channel and Turning Basin are discharged along the southern shore of the Bay. Thus, any effects of dredging and disposal operations on seagrass beds are indirect and related to suspended sediments and increased turbidities rather than direct discharge and burial by dredged sediments.

Boat Propeller Scarring

Damage from boat traffic (i.e. propeller scarring) was noted extensively in a number of areas, especially where seagrass loss occurred. Figure 41 presents a typical low altitude aerial view in 1994 from the north Redfish Bay area adjacent to Hog Island showing the network pattern created by boat propellers cutting through grassbeds. Since the dominant species in these grassbeds is *Thalassia*, a sensitive, slow-growing climax species (Fig. 34), this scarring may be more severe and long-lasting than other sites in the bay. Such excavation of seagrass plants and bottom sediments in Florida is known to cause bed fragmentation and patchy morphology to develop (Sargent et al. 1995).

In general, propeller scars are features often beyond the normal limit of resolution (0.05 ha) of 1:24,000 scale photographs. Our study could not quantitatively determine the extent of this damage. Most of our observations came from ground truthing and field surveys. It was obvious that certain shallow areas (< 2 ft. MSL) were greatly affected by propeller disturbance. These tended to be the large expansive areas in north Redfish Bay and 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 (Figs. 41 and 42, respectively) revealed an obvious increase in physical scarring of grassbeds in this area of Redfish Bay over the 20-year period. This impact suggests a likely factor related to the pronounced loss of seagrass measured in Redfish Bay.

Seismic Exploration Craters

Presently, there is little documentation on the extent of impact from this oil and gas exploration activity to seagrass beds. However, the potential for damage has been suggested to be significant from discussions with various resource managers (C. Onuf, USGS, Corpus Christi, personal communication). We did not observe extensive impacts to seagrass beds from this disturbance in the 1994 photography or during our 1995/1996 field surveys. However, very limited seismic surveys were in fact conducted in the Redfish/Corpus Christi/Aransas Bays areas that we surveyed during the 1994 to 1996 period (Bill Grimes, TGLO, Austin, personal communication). Thus, additional investigations are needed and data should be collected to determine any effects of seismic exploration impacts on seagrasses.

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 (data not shown). Thus there is a high probability that impacts to seagrass could occur along the GIWW margin from both industrial and residential activities. Recent reports from New England (Short and Burdick 1996) and Florida

(Tomasko et al. 1996) document the loss of seagrasses from dissolved nutrients leached from residential septic systems and carried by groundwater into surrounding bay waters. However it is difficult to directly quantify this process separate from dredging and channel impacts in the Redfish Bay area.

Water Quality Impacts

Nutrient Loading Effects

From examination of the NPDES permit locations in Figure 15, it does not appear that widespread direct discharges into seagrass beds regularly occur. This applies mainly to sites on Mustang Island, in the Oso Bay area, and within the Corpus Christi Harbor area. However, any discharge (point or non-point) from sites along the Ingleside-Aransas Pass shoreline would have the potential for contributing to higher nutrient loadings there. With the abundance of residential marina developments along the GIWW from Aransas Pass to Rockport, increased non-point source runoff could be expected in this part of the bay. Moreover, localized circulation and hydrology patterns in the western Redfish Bay area may contribute to nutrient buildup. If the entire western part of Redfish Bay were essentially out of the main circulation and tidal flow through the Corpus Christi or Aransas Bays System, longer residence time would result for bay waters in that part. Materials discharged into waters on this western side of Redfish Bay, including dissolved nutrients, would tend to accumulate there.

Macroalgae and Wrack Accumulations

Evidence that the north portion of Redfish Bay acts as a sink to trap material is in fact provided by the extensive wrack deposits (seagrass detritus and macroalgae) observed there in the fall 1994 photography. As shown in Figure 25, large accumulations of wrack were identified and mapped mainly from this part of the bay system. It seems unlikely that such floating particulate material would have been washed selectively into this area and no other areas. Rather, it seems more reasonable that the material was indigenous there, but not transported out of the area by the high fall tides preceding the photography.

Large amounts of drift macroalgae (live and dead) were observed in the Redfish Bay/Harbor Island system during the 1995 spring and summer field surveys, which occurred 6 to 9 months after the 1994 photography was taken. The most significant accumulations were noted in the western Redfish Bay area, again on the north side of the causeway. In some cases, extensive rafts of Red Algae (mostly *Gracilaria, Laurencia, Digenia*) or filamentous Green Algae (*Chaetomorpha, Enteromorpha)* literally blanketed square meters of grassbeds to depths of 1-2 ft (30 to 60 cm). Often these rafts appeared to be depositing in topographic depressions within the grassbeds. Although algal rafts were noted on survey dates, little quantitative information on their seasonal or geographic fluctuation can be provided.

It is interesting to note that large quantities of drift macroalgae are not unusual in the Coastal Bend bays. Cowper (1978) reported similar occurrences as far back as 1974 around Ransom Island in Redfish Bay. She commented that the "knee-deep" accumulations posed a potentially light limiting stress for seagrasses. However, another effect we noted was the noxious, stagnant conditions produced over grassbeds from dead, decomposing algae. The anoxia, accompanied by H_2S, would be toxic to seagrass, in addition to light limitation by shading from algae plants. A similar "smothering" effect of macroalgal mats has been noted by Kaldy (UTMSI, personal communication) on seagrass beds in lower Laguna Madre. Preliminary work there indicates that large accumulations of primarily *Laurencia* and *Digenia* can cause bare areas or "pot-holes" to develop in the grassbeds.

In addition to drift algae, epiphytic growth on seagrass was also commonly observed throughout the Redfish Bay area. The pattern of distribution appeared to generally parallel that of drift algae.

Light Attenuation Problems

In an attempt to determine if water column light attenuation was related to seagrass changes, we examined seagrass changes in relation to depth of water. We hypothesized that if reduced light was a problem, then seagrass changes (i.e. loss) should be more pronounced in deeper water depths. A detailed bathymetry map was constructed and then seagrass changes for the Redfish Bay/Harbor Island complex were analyzed according to depth zones in the bay (Fig. 43). Depths were contoured into zones at 1.5 ft (0.5 m) increments below MSL (Fig. 43) and overlaid with seagrass change maps for the 1958 to 1975 period, the 1975 to1994 period, or the combined 1958 to 1994 periods (see Figs. 26 - 28 and Figs. 30 -32). The amount of change occurring in each depth zone was calculated and graphic results for the 1958 to 1975 and the 1975 to 1994 time period changes are shown as seagrass gain or loss for each depth increment (Figs. 44- 47). Distribution of seagrass change was examined separately for Redfish Bay (north and south sides), and Harbor Island (north and south sides). Tabular results of net seagrass change acreage were also computed, but the time periods presented in Tables 8 - 11 are for 1958 to 1994 combined or the more recent period of 1975 to 1994.

Redfish Bay. Most seagrass (> 85 % total) occurs in the shallow submerged zone of 0 to 3 ft (1 m) depth below MSL on both north and south sides (Figs. 44 & 45). Between 1958 and 1994, both sides showed a major difference in seagrass change for this depth zone (Tables 8 & 9). The south side had very small losses of only 1.3-1.7 % (net total area of 19.2 ha), while the north side lost fairly large amounts (9.6 - 23.5 % or net total area of 363.7 ha) in this zone (Tables 8 & 9). Most of the loss on the north side (247 ha) was in water deeper than 1.5 ft. Moreover, the remainder of the seagrass loss for the north side was at deeper depths; the total loss for the 3 ft to > 6 ft zones was another 112.5 ha. The south side even showed some gain over the 36 yr period for the depths > 3 ft (49.5 ha). Table 8 indicates that most changes in the 0 to 3 ft zone for the north side actually occurred during the period between 1975 and 1994 (north side net loss = 356.2 ha). The south side shows a net gain (7.9 ha) for this later time period.

Table 8. Seagrass changes in depth zones of Redfish Bay, north and south sides, between 1958 - 1994. Net areal change (in hectares) and percent change (%) occurring.

	DEPTH ZONES (in feet below MSL)						
	>MSL	**0 - 1.5**	**1.5-3.0**	**3.0-4.5**	**4.5-6.0**	**>-6.0**	**unknwn**
North Side							
Net Change (ha)	-4.9	-116.2	-247.5	-47.7	-36.2	-28.6	-56.9
Net %	-4.5	-9.6	-23.5	-28.9	-62.7	-97.5	-79.0
South Side							
Net Change (ha)	-37.7	-10.5	-8.7	30.2	15.5	3.8	-0.3
Net %	-49.7	-1.7	-1.3	32.2	172.1	47.3	-3.4

Table 9. Seagrass changes in depth zones of Redfish Bay, north and south sides, between 1975 - 1994. Net areal change (in hectares) and percent change (%) occurring.

	DEPTH ZONES (in feet below MSL)						
	>MSL	**0 - 1.5**	**1.5-3.0**	**3.0-4.5**	**4.5-6.0**	**>-6.0**	**unknwn**
North Side							
Net Change (ha)	16.8	-129.8	-226.4	-42.6	-16.8	-4.8	-2.6
Net %	17.1	-10.6	-21.9	-26.7	-43.8	-86.7	-14.5
South Side							
Net Change (ha)	-1.2	-13.9	20.8	31.7	21.8	2.5	3.5
Net %	-3.2	-2.2	3.4	34.3	816.8	26.6	55.4

Harbor Island. More than 95 % of the seagrass occurs in the intertidal zone (above 0 ft) and the 0 to 1.5 ft below MSL depth zone (Figs. 46 & 47). This reflects the extremely shallow nature of this complex and the seasonal *Ruppia/Halodule* beds which can grow there over the course of one year. Changes here between 1958 and 1994 reflect the dramatic increases that occurred on both sides (Tables 10 & 11). The north side showed a net gain of 690 ha total, 6 ft zones), net losses occurred (north side = 46.4 ha; south side = 42.8 ha), although this while the south side had a gain of 290 ha in this shallow zone. For deeper waters (1.5 ft to represents less than 5 % of the grass in either side. Tables 10 & 11 also indicate that since 1975, shallow water zones of both sides are generally experiencing some loss of seagrass. In addition, both sides show different patterns of seagrass loss in deeper zones (> 1.5 ft to 6 ft). Since 1975, the north side has continued to lose 54.4 ha of deeper water seagrass, while south side showed only a slight net loss of 1.8 ha.

These data provide evidence that seagrass impacts are occurring primarily to the north portion of Redfish Bay in contrast to the south portion. Consideration of the depth differences suggests that light attenuation may be a significant factor affecting deep water seagrass. An associated problem could still involve excessive nutrient loading and retention, with subsequent overgrowth and accumulation of drift macroalgae and epiphytes, as previously noted. Shallow water seagrasses in this portion of Redfish Bay appear more disturbed from mechanical damage, mostly motorboat propeller scarring. Both mechanisms ultimately cause fragmentation and lead to patchy beds or complete loss of grassbeds. In the Harbor Island

Table 10. Seagrass changes in depth zones of Harbor Island, north and south sides, between 1958 - 1994. Net areal change (in hectares) and percent change (%) occurring.

	DEPTH ZONES (in feet below MSL)						
	>MSL	**0 - 1.5**	**1.5-3.0**	**3.0-4.5**	**4.5-6.0**	**>-6.0**	**unknwn**
North Side							
Net Change (ha)	127.6	562.4	-25.6	-17.5	-3.3	8.8	0.0
Net %	620.0	169.7	-26.6	-40.1	-16.5	237.0	0.0
South Side							
Net Change (ha)	13.8	276.6	-18.2	-20.9	-3.7	-4.1	0.0
Net %	48.9	53.1	-20.3	-61.3	-98.1	-100.0	0.0

area, there is evidence that north side grassbeds, in both deep and shallow water, are experiencing impact and stress. This may in fact reflect influence of the same factor(s) affecting the north portion of Redfish Bay. The south side of Harbor Island shows recent fragmentation patterns mostly in shallow beds, probably from mechanical disturbance.

Table 11. Seagrass changes in depth zones of Harbor Island, north and south sides, between 1975 - 1994. Net areal change (in hectares) and percent change (%) occurring.

	DEPTH ZONES (in feet below MSL)						
	>MSL	**0 - 1.5**	**1.5-3.0**	**3.0-4.5**	**4.5-6.0**	**>-6.0**	**unknwn**
North Side							
Net Change (ha)	24.6	-47.8	-33.6	-6.2	-14.6	8.8	0.0
Net %	19.9	-5.1	-31.1	-19.1	-46.4	237.0	0.0
South Side							
Net Change (ha)	-13.3	-32.4	-5.8	4.0	0.1	0.0	0.0
Net %	-24.0	-3.9	-7.5	42.9	100.0	0.0	0.0

DISCUSSION

Historical Trend Analysis

Availability of good photography and reliable field data limit historical seagrass trend analysis to only about the last 40-50 years. This perspective is important to recognize since long-term cycles may require more time to detect. However, because seagrass plants in this area are mostly perennial species (*Halophila* and *Ruppia* being the exceptions), the population dynamics of established grassbeds are very stable compared to annual plants which must reestablish from seeds every year. Consequently, seagrass distributions can be reliably detected from clear, large scale historical photography. Using such techniques in this study, seagrass trends were sufficiently documented in the Coastal Bend bay systems over two, approximately 20-year, intervals.

Results from this study demonstrate that normal coastal processes contribute to seagrass establishment at localized sites. To a large extent, overall seagrass distribution in the Coastal Bend parallels the spatial extent of marine, shallow-water depth zones less than 5 ft (1.5m). Moreover it tends to follow the inflow and turbidity gradients in the bays. Seagrass is scarce in upper bay areas where direct inflows are high and salinities are usually low to moderate, compared to seagrass-dominated areas in the lower estuary reaches where inflows are low, salinities high, and depth uniformly shallow. The generally turbid water regimes are probably most responsible for restricting growth in the upper parts of Nueces or Copano Bays. The cyclical occurrence of *Halodule* and *Ruppia* in Nueces Bay seems to dramatically reflect this response to the turbidity factor. The resurgence of seagrass in Oso Bay over the last 20 years also seems to correlate with the growth requirements of *Halodule* for clear, polyhaline (> 18 ppt) marine waters being discharged from the CPL power plant.

Not only must the water depth be appropriate for seagrass, but so too there must be protection from physical disturbance factors, dredging, shoreline erosion, and the heavy wave action resulting from long, wind-induced fetch. This requirement is seen as critical in various parts of the Coastal Bend. Seagrass beds on the leeside of the barrier islands (Mustang, Harbor and San Jose Islands), historically have showed considerable expansion due to this protective effect and to natural water (sea) level cycles. This was especially noticeable between the 1950s and 1970s. Beds in open parts of Corpus Christi, Copano and Aransas Bays tend to develop as fringe bands due to this exposure stress. Other beds in more developed areas (e.g. Redfish Bay) show a combination of stress from this impact and channelization and dredging.

Mapping and landscape analysis reveals that trends are dynamic. Table 12 summarizes the net seagrass acreage changes and trends within the Redfish Bay/Harbor Island complex and for Mustang

Island. It is remarkable that numerical seagrass losses and gains occur simultaneously. For example, in the combined ***Corpus Christi/Redfish Bays system***, total seagrass bed acreage appears fairly stable over a 40 year time frame, despite the dynamic cycles and localized changes in seagrass bed distribution. Comparisons of 1958, 1975 and 1994 inventories revealed evidence of progressive bed fragmentation in places, but overall a net increase in total acreage for the system between 1958 and 1994 (net gain 2168 ha or 5355 acres) (Table 12). Admittedly, this is due primarily to the large expansion of seagrass into the Harbor Island complex (84 % or 1,014 ha) or along Mustang Island (1,319 ha) between 1958 and 1975. Coupled with the simultaneous increase of 519 ha (1282 acres) in grassbeds noted for Mustang Island over the 1975-1994 period, the data indicate that conditions are fairly pristine for this entire system.

Table 12. Summary of seagrass acreage changes for Mustang Island, Redfish Bay, and Harbor Island areas between 1958, 1974/5, and 1994. Values in hectares or %.

Time Period	**Mustang Island**	**Redfish Bay**	**Harbor Island**
1958	1030.0	4184.3	1200.1
1974 or 1975	2348.8	3989.3	2213.8
58 - 75 Net	+1318.8	-195.0	+1013.7
% Change	128.0%	-4.7%	+84.5%
Time Period			
1974 or 1975	2348.8	3989.3	2213.8
1994	2867.7	3648.2	2066.5
75 - 94 Net	+518.9	-341.1	-147.3
% Change	+18.1%	-8.6%	-6.7%

The power of GIS landscape analysis, however, is that it can show where changes are occurring. Table 13 lists the probable causes of changes determined from the GIS analysis that was performed. This analysis revealed “hot spots” of seagrass disturbance and concentrated loss in places. Part of the Redfish Bay system now seems to be at a stage in time where seagrass decline may be escalating. Results of the correlation analysis between depth zones and seagrass change point to deteriorating conditions generally in the north sides of Redfish Bay and Harbor Island. Both seagrass loss andfragmentation of beds were noted. Fragmentation in this study was considered to be a stage in seagrass bed decline, leading to

Table 13. Summary of probable causes of seagrass dynamics for Corpus Christi Bay/Redfish Bay areas.

Impacts between 1958 to 1975	Impacts between 1975 to 1994
Redfish Bay Area	
•Dredge Material Deposits	
Loss of 202 ha, Gain of 112 ha, Net = - 90 ha SAV	
•100 m Channel Impact Zone	
Loss of 490 ha, Gain of 223 ha, Net = - 267 ha SAV	
•Shoreline Developments	
1958 = 185.2 ha	1994 = 700.7 ha
•Altered Bay Circulation	•Wrack (799 ha in 94)
	•Macroalgae & Epiphyte Accumulation
	•Motorboat Prop Scarring
	•Bed Fragmentation
Harbor Island Area	
•Dredge Material Deposits	
Loss of 30 ha, Gain of 10 ha, Net = - 20 ha SAV	
•100 m Channel Impact Zone	
Loss of 74 ha, Gain of 62 ha, Net = - 12 ha SAV	
•Shoreline Developments	
1958 = 201.9 ha	1994 = 355.2 ha
•Increasing Water Depth	•Fetch Protection
	•Motorboat Prop Scarring
Mustang Island Shoreline	
•Minimal Shoreline Developments	•Minimal Shoreline Developments
•Increasing Water Depth	•Increasing Water Depth
•Fetch Protection	•Fetch Protection

loss. Although it is difficult to draw definitive conclusions, the accumulation of wrack, drift macroalgae, and epiphytes suggests possible water quality problems. The increase in numbers of shoreline developments along the north Redfish Bay region (*ca* 515 ha between 1975 - 1994 from Table 13) could present a source of excess nutrients to the system in a manner analogous to that documented by Tomasko et al. (1996) and Short and Burdick (1996) on the U.S. east coast. This could account for major losses in deeper waters of Redfish Bay, especially since 1975. However, there is also evidence for considerable impact to shallow water grassbeds in the entire Redfish Bay/Harbor Island complex from mechanical damage and hydrologic alterations e.g. motorboat propeller scarring, navigation channel impacts and potential wrack buildup from altered bay circulation.

The relatively stable Corpus Christi/Redfish Bays system contrasts with the situation occurring in ***upper Laguna Madre***. From the published studies by Onuf (1996a) and Dunton (1996), it is apparent that the persistent brown tide has had a serious detrimental effect on seagrass beds in the lagoon. It remains to be seen whether conditions improve and seagrass loss is reversed, or if Onuf's prediction of losses as great as 18 to 27% eventually come to pass. Regardless of the outcome, the important lesson would be that serious water clarity impacts on seagrass can occur, even in relatively protected areas such as the Laguna Madre.

CONCLUSIONS

The overall conclusion from this study is that seagrass dynamics for the CCBNEP area were highly variable between individual bay sites. The pattern for seagrass impacts can best be termed as reflecting "hot spots". This demonstrates that resource managers need to examine seagrass responses on case by case bases to identify environmental stressors causing changes. Generic stressors (e.g. water quality degradation, water level changes, and climatic conditions) can be suspected when effects are produced over wide regions e.g. entire bay systems. However, stressors such as the mechanical or physical impacts documented herein, will generally produce localized, site-specific effects. This same rationale applies to spread or increase of seagrass beds. Any monitoring program for seagrasses should take into account these localized mechanisms for propagating stress responses.

Data Limitations and Future Needs

These map data provide a reference baseline for comparing future inventory results. It is critical to continue this type of status and trends monitoring at the landscape level to detect effects of environmental stress on seagrass distributions. Mapping at 2 to 3 year intervals represents the best strategy for routine monitoring of such seagrass landscape dynamics. Landscape patterns can indicate problems before complete loss of seagrass occurs by allowing observations of changes in bed morphology. Fragmentation patterns within grassbeds can be correlated with incipient stages of stress response (Robbins and Bell 1994). By understanding at least partially the causes for these landscape bed dynamics, we may be able to predict future seagrass changes from potential impacts.

Species composition of grassbeds is another key parameter for monitoring incipient stress effects. While replacement of a colonizing species, e.g. *Halodule*, with the climax species, *Thalassia*, may represent normal succession in a grassbed over time, the opposite direction of succession, from *Thalassia* to *Halodule*, is more likely to indicate some disturbance or stress to the grassbed. As a stage in the grassbed fragmentation process, this response could be expected to occur prior to complete loss of seagrass. Monitoring of such species succession would require more detailed ground surveys than the landscape monitoring described herein.

Species composition and plant biomass measurements (as well as other standard field parameters) are critical to enhancing the scale of resolution of landscape dynamic patterns. As earlier stated, these measurements are at a much finer scale than the landscape data we have compiled. Such field studies provide a measure of variability over very small ground distances. In order to increase the resolution of the landscape (i.e. spatial) data, process data should be collected at a 1:12,000 or larger scale. Patch coalescence and spreading rates, or denudation rates of fragmenting grassbeds, are needed at target monitoring sites to understand the landscape changes at this scale. This would be especially important around sites or foci where change is actively occurring, or expected to occur.

Patch dynamics, including either colonization into bare areas or expansion of bare patch size, should be monitored at selected sites to adequately interpret landscape scale trends. Selection of target monitoring sites should be performed using GIS landscape patterns to guide their placement and establishment. Spatial statistical sampling methods should be used to provide representative coverage of the landscape. When appropriate, aerial photography can be obtained at larger scale and more frequently on a seasonal basis to extend field observations of patch dynamics.

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