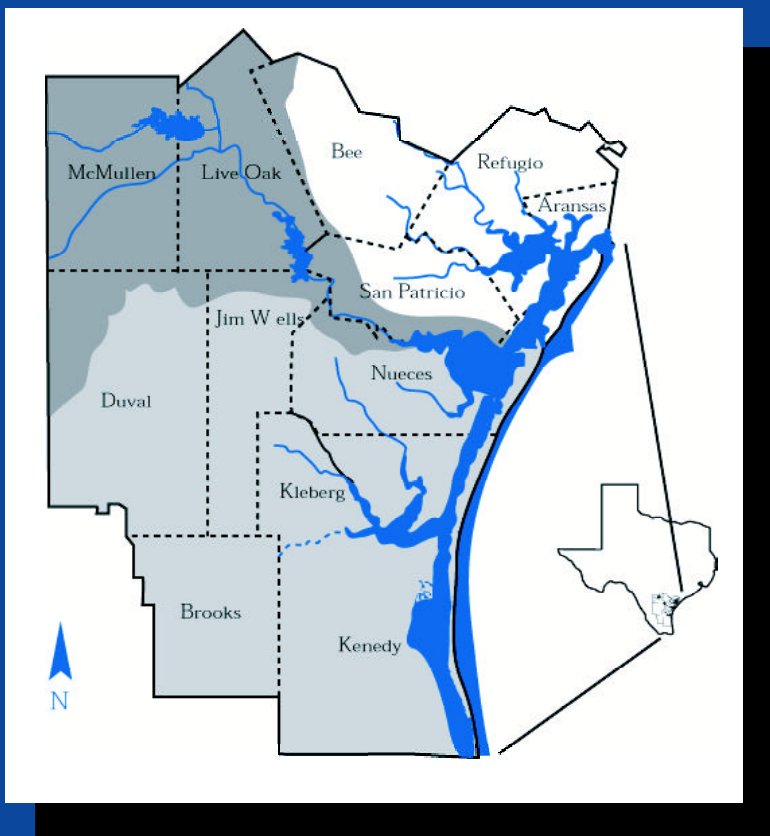
Identification of Tidal Flat Alterations and Determination of Effects on Biological Productivity of These Habitats Within the Coastal Bend



Corpus Christi Bay National Estuary Program

CCBNEP-26 • May 1998

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Identification of Tidal Flat Alterations and Determination of Effects on Biological Productivity of These Habitats Within the Coastal Bend

Principal Investigators:

Kim Withers, Ph.D.
John W. Tunnell, Jr., Ph.D.

Center for Coastal Studies
Texas A&M University-Corpus Christi
Corpus Christi, Texas

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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

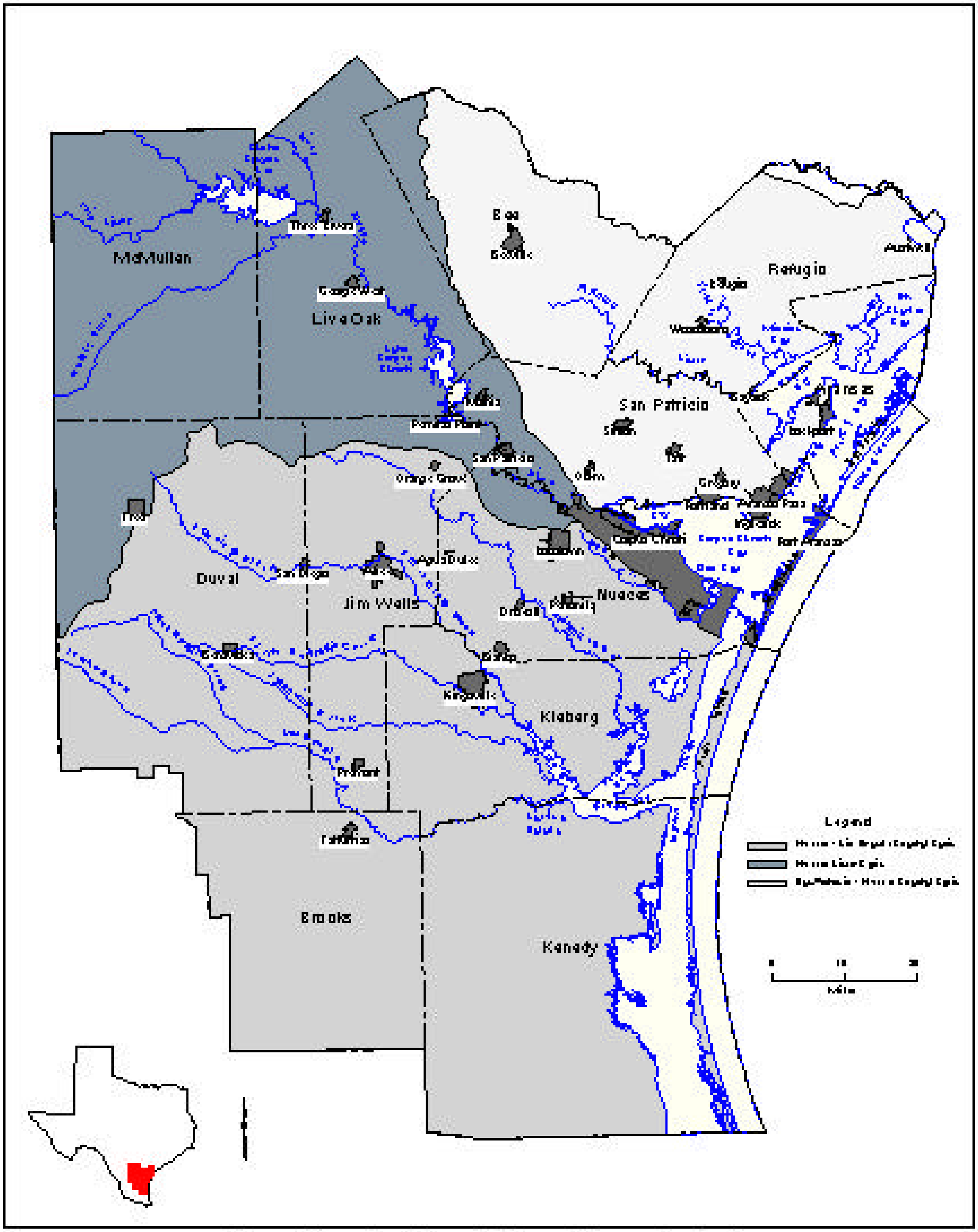
The CCBNEP study area includes three of the seven major estuary systems of the Texas Gulf Coast. These estuaries, the Aransas, Corpus Christi, and Upper Laguna Madre are shallow and biologically productive. Although connected, the estuaries are biogeographically distinct and increase in salinity from 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

EXECUTIVE SUMMARY

1. INTRODUCTION

Tidal flats within the Corpus Christi Bay National Estuary Program (CCBNEP) study area are unique because they are inundated and exposed mostly in response to winds rather than astronomical tides, hence “wind-tidal flat”. On bay sides of barrier islands wind-tidal flats replace salt marsh as the primary wetland type. Because tidal inundation is irregular and extreme temperatures occur when thin sheets of water are heated by the sun, macrophytic plant communities cannot develop and biologic activity is often restricted to felts or mats of blue-green algae which form over the surface of and bind the sand and/or mud substrate.

The public image of tidal flats as barren wastelands contributing nothing aesthetically, economically, or ecologically is the underlying cause of most human disturbances and alterations. However, their appearance belies their importance to overall productivity of estuaries within the CCBNEP study area. Worldwide, the most extensive wind-tidal flats are found around hypersaline lagoons like the Laguna Madre. There are nearly 62 square miles of wind-tidal flats within the study area, with almost 79% located on the bay sides of San Jose, Mustang and Padre islands. The remaining wind-tidal flats are found along mainland bay margins, around river deltas, and the mouths of creeks. Barrier island tidal flat sediments are mainly sands, whereas mainland sediments are mainly clays.

The objectives of the present study are: (1) to compile and synthesize all published and unpublished information concerning ecology, geology, and hydrology, of wind-tidal flats in the CCBNEP study area; (2) to determine locations of anthropogenic and natural disturbances and alterations to wind-tidal flats in the study area and rate their severity; and, (3) to formulate an evaluation strategy to determine wind-tidal flat productivity for both baseline and post-disturbance monitoring.

2. ECOLOGY

Blue-green algae (cyanobacteria), which may form felt-like or leathery mats on sediment surfaces, are the major primary producers found on tidal flats in the CCBNEP study area. Photosynthetic and chemosynthetic bacteria may contribute significantly to primary productivity. In addition, blue-green algae fix atmospheric nitrogen, and due to the characteristic “leakiness” (i.e. loss of materials across cell walls) of algae, flooded algal flats are a source of “new” inorganic nitrogen to adjacent wetland and open water systems.

Wetter flats (with more frequent inundation) are important biomass conversion sites, or areas where primary production is converted to animal biomass for use by higher-level consumers. Invertebrates which live in the blue-green algal mat, or sediments (benthos) provide the link between primary producers and higher consumers such as birds and fish. Macrofaunal communities of non-algal flats (e.g., Blind Oso) are dominated by polychaetes, whereas algal flats (e.g., most flats on baysides of barrier islands) are dominated by insect larvae (mainly fly maggots) in drier portions and polychaetes and/or tanaids (amphipod-like crustacean) in wetter areas. Twenty-five to 65 invertebrate taxa have been recovered from flats in the CCBNEP study area. Densities are typically highest in winter and early spring. There is no information available on meiofaunal or microfaunal communities of wind-tidal flats in the CCBNEP study area, and no information about invertebrate dispersal dynamics, colonization, or community succession.

Microbial decomposition of organic material is the primary link between primary and secondary production. Decomposer communities of tidal flats in the CCBNEP study area have not been studied extensively. On the Laguna Madre Flats south of the CCBNEP study area, anaerobic, non-photosynthetic bacteria thrived in the reducing zone found just below the algal mat. On flats around Redfish Bay, highest numbers of bacteria were found in sediments in spring reflecting increased decomposition.

When flats are flooded, vertebrate and invertebrate nekton may be present. The community present appears to be determined by water depth and salinity and no large fish (>30 mm) are usually found. The most common fish are sheepshead minnows; various shrimp species and blue crab are the most common invertebrates. Ten species of primarily juvenile fish were found in the Blind Oso. The temporary nekton of most other flats in the CCBNEP study area have not been described.

Wind-tidal flats within the CCBNEP study area are one of the most significant feeding areas for aquatic bird life on the entire Texas Gulf Coast. They are essential foraging habitats for wintering and migrating shorebirds and wading birds and are important to several state- or federally-listed endangered or threatened species or "species of concern": Piping and Snowy plovers (*Charadrius melodus*, *C. alexandrinus*), Reddish Egret (*Egretta rufescens*), White-tailed Hawk (*Buteo albicaudatus*), and Peregrine Falcon (*Falco peregrinus*). Benthic and epibenthic invertebrates form the prey base for shorebirds when flats are exposed and for crabs and demersal fish when they are inundated. Wading birds feed on nekton when flats are inundated, and raptors feed on shorebirds. Interruptions or alterations of these food web relationships due to either natural and/or human disturbances have the potential for catastrophic consequences to both threatened and non-threatened bird populations.

Shorebird populations on wind-tidal flats in the CCBNEP study area are dominated by sandpipers. Plovers, especially Piping and Snowy plovers, use algal flats extensively and long-legged shorebirds such as dowitchers and Dunlin are common in adjacent shallow waters, especially around non-algal flats. Over 20 species have been observed on flats in the study area. Shorebirds may be extremely abundant at times on tidal flats in the CCBNEP study area. Numbers are typically highest in late fall, winter and early spring. Wading birds use tidal flats when flooded and are also common in adjacent shallow waters. Seven species have been observed on flats in the study area. Great Egret, Great Blue Heron, and Reddish Egret are the most common species encountered; numbers are typically highest from late spring through fall.

Despite the absence of macrophytic vegetation, primary productivity on wind-tidal flats is comparable to seagrass meadows and about 20-40% of a typical cordgrass marsh. The often direct transfer of primary productivity to higher trophic levels on tidal flats results in energy flow which may be more efficient than the classical 10% efficiency of other food chains, possibly as high as 40%, which is similar to efficiency of decomposer food chains in marshes. Significant export of productivity from tidal flats caused by winter breakup of algal mats and wind may result in significant output to the estuary's detrital pool.

Estuarine food webs are commonly viewed as detritus-based, however, it is likely the grazing food chain is much more important than previously thought, particularly on tidal flats. Benthic invertebrates such as polychaetes and crustaceans, as well as larval insects are also important in the food chains of wetter algal flats in the study area. Presence of higher level consumers such as shorebirds and fish are dependent on inundation and exposure of the flat. Regardless of the basis of tidal flat food chains, these are major sites for conversion of plant biomass into animal biomass for use by larger estuarine predators.

Tidal flats appear to be nutrient sinks. Significant sources of nutrients include local runoff during periods of high rainfall and sediment nutrients that are brought to the surface by capillary action during dry periods and later redissolved. Nitrogen and phosphorus are major nutrients associated with primary production on tidal flats in the CCBNEP study area. Nitrogen is often considered a limiting nutrient. However, most nitrogen used by blue-green algal flats in the CCBNEP study area is fixed by the mat or anaerobic bacteria in sediments beneath the mat. In this area, phosphorus is probably more limiting than nitrogen.

Presence of tidal flats in the mosaic of the coastal environment is particularly important for shorebirds and wading birds. Flats provide an abundant source of food, and are near upland and transitional habitats for roosting and nesting. Alternate feeding sites on the beach are also nearby for wading birds when flats are exposed or for shorebirds when flats are completely flooded. Health of the bay ecosystem is one of the most critical aspects in survival of the tidal flat system because the bay supplies most of the water which nourishes flats. The next most critical component in long-term maintenance of tidal flats is runoff from adjacent upland areas. The primary threat to tidal flat systems is public perception they are barren wastelands. Tidal flats are often targeted for coastal development and frequently overlay oil and gas deposits. In the past, tidal flats were often chosen as sites for dredge material disposal and mitigation projects in which they were scraped down to attempt creation of coastal marsh or seagrass systems. Tidal flats act as flood basins which buffer or dampen wind-driven bay and lagoon waters, protecting adjacent vegetated habitats. Use of tidal flats as dredge material disposal areas leads to compartmentalization and alterations of natural water circulation patterns.

3. THE TIDAL (AND TITLE) BOUNDARY PROBLEM

Ownership determination of wind-tidal flats in south Texas has occupied court cases throughout the 20th Century (e.g. State v. Spohn in 1904, Humble v. Sun in 1951, and Kenedy Memorial Foundation v. Garry Mauro and State in 1995). During the previous century when much of the title was established, primarily via Spanish and Mexican Land Grants, few people cared about these seemingly barren and inhospitable flats. However, with the discovery of oil and gas reserves, specific ownership and mineral rights became important. The basic question is: are these coastal areas, the wind-tidal flats of the Laguna Madre, submerged, and therefore owned by the State, or are they not submerged and owned by the property owner of adjacent uplands. Under Texas law, if the land is "submerged", it belongs to Texas; royalties go into the Permanent School Fund. On the other hand, if the land is privately owned, royalties go to the land owner or mineral rights holder.

Legal boundaries of property that parallel the seacoast are typically determined by tidal datums and geomorphology of the shore. Most shorelines around the world exhibit sufficient elevation change where the sea meets the shore, to make shoreline determination fairly straightforward. However, shoreline determination along the very gently sloping shores, adjacent to much of the Laguna Madre, is an exacting process. Due to the unique environmental setting and special conditions, a multidisciplinary approach has been suggested and applied, in which scientific studies (geological, biological, meteorological, hydrological, etc.) are performed to support the location of a shoreline surveyed according to state laws. Historically, and ironically, courts have ruled in favor of a shoreline on both the landward side of the flats and the seaward side of the flats.

4. DISTURBANCES TO WIND-TIDAL FLATS AND PROBABLE CAUSES

Most disturbances to wind-tidal flats in the CCBNEP study area are anthropogenic. However, greatest losses have occurred due to inundation and conversion to shallow bay bottom because of eustatic sea-level rise. Table 1 summarizes both the natural and anthropogenic types and probable causes of impacts that have occurred or may occur in the future.

5. STATUS AND TRENDS OF WIND-TIDAL FLATS IN THE CCBNEP STUDY AREA

The Bureau of Economic Geology, UT-Austin provided the following information for this report. Tidal flat area in the CCBNEP study area decreased markedly between the 1950's and 1979. Over 11,000 ha was converted to other habitat classes with the most extensive losses (> 6,000 ha) occurring on barrier islands, especially Mustang and San Jose islands, Harbor Island, and in the upper Laguna Madre-Corpus Christi Bay estuarine complex. Most change (55%) was due to permanent inundation of flats and their replacement by either open water or seagrass beds. This change was likely due to accelerated sea-level rise between the mid-1960's to mid-1970's. Another 20% of the loss was due to conversion to marshes. As sea-level rises, vegetation, particularly cordgrass, colonizes upper fringes of tidal flats, because higher intertidal flats are more frequently flooded. About 20% of the loss was due to conversion to uplands. Some areas were lost due to dredge and fill activities associated with navigational channel development. Apparent net gains between 1979-1992 on Matagorda Island were attributed to photographs being taken at low tides during 1992; other gains were attributed primarily to differences in photographic interpretation.

Table 1. Wind-tidal flat impacts, probable causes, and scale of effects in the CCBNEP study area. S=species; C=communities; E=ecosystem; L=landscape; P=permanent; T=temporary; A=aesthetic.

Impact	Probable Causes	Scale of Effects
Natural		
Habitat loss	Sea-level increases; conversion	S, C, E, L; P
Elevation increases	Succession	S, C, E, L; P
Sea-level fall	Glaciation	S, C, E, L; P
Cold temperatures	Seasonal	S, C, E; T
Air & water temperature increases	Seasonal	S, C, E; T
Reduced freshwater inflow	Drought, seasonal	S, C, E; T
Tropical storms	Seasonal	S, C, E, L; T-P
Anthropogenic		
Habitat loss	Conversion, construction, dredging & disposal	S, C, E, L; P
Habitat &/or water quality degradation	Oil Spills, industrial effluents and runoff, petrochemical refining	S, C; P E, L; T-P
Organic enrichment	Domestic wastewater	S, C, E; T-P
Reduced freshwater inflows	Upstream damming and diking	S, C, E; P
Tracking	Vehicles, cattle	S, C; T
Trash	Recreational use, indiscriminate dumping	E, L; A

6. STRATEGY FOR EVALUATING TIDAL FLAT PRODUCTIVITY

Tidal flats in the CCBNEP study area are unique because the inundation regime is irregular and mainly governed by winds. In this environment, blue-green algal mats form on many flats. These two characteristics make it difficult, if not impossible, to compare most CCBNEP study area tidal flats to flats anywhere else in the world or to use data from outside this area to evaluate productivity. Parameters used to evaluate the relative value of a habitat must reflect value of the habitat to wildlife and fisheries species of management concern, but mobility of most wildlife and fisheries species makes it difficult to rely on presence or absence to indicate habitat productivity. In the CCBNEP study area, support of migrating and wintering shorebirds, particularly endangered and/or threatened Piping and Snowy plovers, is the primary management issue. In general, tidal flats have little or no obvious and readily identifiable physical structure or life, except when shorebirds are present, so parameters chosen to evaluate productivity must always be present on flats. Four tidal flats in the CCBNEP study area were sampled between November 1996 and March 1997. Because the Blind Oso study site exhibited characteristics of organic enrichment, it was not used to formulate this strategy. For this reason, the strategy is probably most appropriate for use in evaluating sandy, blue-green algal flats. The period was chosen because it is the time when area tidal flats are the most important to shorebirds.

Parameters measured were exposed area, benthic invertebrate abundance and biomass, bird density, sediment water content, sediment chlorophyll *a*, and sediment total organic carbon (TOC). These data were used to determine the range of values for various parameters of biologic interest. Value indices were derived from combinations of parameters (e.g., polychaete abundance vs polychaete biomass). Only two invertebrate taxa were frequently encountered, polychaetes and insect larvae. Total density and biomass were also used so that less frequently encountered, but often abundant taxa were taken into consideration,. Value indices were scaled on the range of parameters from zero to three, no (=0), low (=1), medium (=2) and high value (=3). Mean and standard deviation for each parameter were determined. The mean represented the upper limit of low with 1 SD above the mean representing the upper level of medium.

This strategy can be used in the following ways:

(1) as a foundation for a baseline assessment or monitoring program,
(2) as a baseline evaluation of different habitats and microhabitats within a project site,
(3) to compare alternative project sites,
(4) to predict whether proposed habitat modifications will be acceptable,
(5) as an evaluation to determine extent and severity of anthropogenic or natural disturbances (when baseline data are available),
(6) to determine mitigation effort,
(7) to determine restoration or equivalence of function, via either creation or enhancement for the purposes of mitigation or preservation (when baseline data are available),

Depending on the application of the methodology, the following inputs are needed:

(1) Specific Project Guidelines: includes engineering data on type and size of project, types of impacts expected, magnitude, area to be impacted, duration of activities, life of project, and projected secondary impacts.
(2) Site CharacterizationL includes number of different tidal flat habitats present in the project area, areal extent of each habitat or microhabitat type, and physical data from habitats and microhabitats

The following guidelines will help determine appropriate level of sampling intensity and approximate time frame:

(1) If time and resources are short, then a cursory examination of the site during a minimum of five days during at least two months between November and March will allow determination of the most critical aspects of the site. This approach is not recommended, as it is possible results will be misleading. All exposed areas must be sampled each day, and all adjacent habitats must be sampled at least twice. Sampling must be as intense as possible. Total shorebird density must be determined each sampling day. The USFWS Piping Plover Protocol must be followed.
(2) If time is short, but resources are not limiting, then the site must be evaluated at least once monthly between November and March. Adjacent habitats must be sampled at least three times in three different months. All habitats must be sampled and sampling must be as intense as possible. Total shorebird density must be determined each sampling day. The USFWS Piping Plover Protocol must be followed.

(3) If there is adequate time, but resources are limiting, then the site should be evaluated as in (2), but with the addition of sampling periods in October and April. Total shorebird density must be determined each sampling day. The USFWS Piping Plover Protocol must be followed.

(4) If neither time nor resources are limiting, then complete data sets should be collected from August through May. The USFWS Piping Plover Protocol must be followed. If possible, data collection should be over two years.

7. KNOWLEDGE GAPS

Moderate amounts of information exist on the physical aspects of wind-tidal flats in the CCBNEP study area, as well as taxonomic composition of most animal and plant communities. A moderate amount of information is also available on locations of impacts and alterations. Little information is available on energy flow, trophic levels and food web relationships, nutrient cycling, decomposer communities, linkages with other systems, and biological effects of impacts. Meiofaunal, microfaunal, and temporary zooplankton communities are virtually unknown. One of the most important knowledge gaps that needs attention is lack of knowledge of invertebrate dispersal dynamics, colonization, and community succession because these processes drive productivity of wind-tidal flats for shorebird consumers. Another very important gap is knowledge of long-term spatial and temporal fluctuations of biotic communities. Without this knowledge it is difficult to address important management issues of conservation and preservation of this vital habitat.

TABLE OF CONTENTS

LIST OF FIGURES

Figure		Page

Figure		Page

LIST OF TABLES

Table		Page

LIST OF ACRONYMS

BEG	Bureau of Economic Geology
CCNBEP	Corpus Christi Bay National Estuary Program
CCS	Center for Coastal Studies
NOAA	National Ocean and Atmospheric Administration
NPS	National Park Service
NWI	National Wetland Inventory
PI	Principal Investigator
PINS	Padre Island National Seashore
QA	Quality Assurance
TAMU-CC	Texas A&M University-Corpus Christi
GLO	Texas General Land Office
TXDOT	Texas Department of Transportation
TPWD	Texas Parks and Wildlife Department
US DOT	United States Department of Transportation
USFWS	United States Fish and Wildlife Service
YBP	Years Before Present

USEFUL CONVERSIONS

centimeter (cm) =
0.394 in
0.0328 ft

gram (g) =
0.353 oz
0.0022 lb

hectare (ha) =
2.471 acre
0.00385 mi^2

kilometer (km) =
0.621 mi

liter (l)=
0.264 gal

meter (m) =
39.37 in
3.281 ft

micrometer (ug) =
0.001 mm
0.000039 in

milligram (mg) =
0.001 g
0.00035 oz

millimeter (mm) =
0.1 cm
0.0394 in

square kilometer (km^2) =
247.1 acre
0.386 mi^2

square meter (m^2) =
10.764 ft^2
1.196 yd^2

ACKNOWLEDGEMENTS

This project was performed as contracted work for the Corpus Christi Bay National Estuary program. The authors would like to thank the following individuals: Tannika Engelhard (CCS) for assistance in the field and in the lab, Suzanne Dilworth (CCS) for assistance with impact maps and other figures in the text and Bill White and Tom Trembley (BEG) for providing maps and information on status and trends concerning wind-tidal flats. Larry McEachron, Chris Onuf, Sandra Alvarado and Laura Radde are gratefully acknowledged for their thorough review of and comments pertaining to the manuscript. We would also like to acknowledge Dr. Richard Watson, Bill Lothrop and Mark Knisely for their review of the tidal boundaries section of the manuscript.

Table of Contents

1. INTRODUCTION

1.1 Background

Tidal flats within the Corpus Christi Bay National Estuary Program (CCBNEP) study area are unique because they are inundated and exposed mostly in response to winds rather than astronomical tides, hence "wind-tidal flat". On bay sides of barrier islands wind-tidal flats replace salt marsh as the primary wetland type. Plant communities are generally restricted to mats of blue-green algae due to irregular inundation and extreme summer water temperatures. Despite absence of macrophytic vegetation, primary productivity on wind-tidal flats is comparable to seagrass meadows and is about 20-40% of a typical *Spartina* (cordgrass) marsh (Pulich and Rabalais, 1982, 1986; Pulich et al., 1982). In addition, blue-green algae fix atmospheric nitrogen, and due to characteristic "leakiness" (i.e. loss of materials across cell walls) of algae, flooded algal flats are a source of "new" inorganic nitrogen to adjacent wetland and open water systems (Gotto et al., 1981; Pulich and Rabalais, 1982, 1986). Wetter flats (with more frequent inundation) are important biomass conversion sites, or areas where primary production is converted to animal biomass for use by higher-level consumers (Withers, 1994).

Wind-tidal flats within the CCBNEP study area are one of the most significant feeding areas for aquatic bird life on the Texas Gulf Coast (Senner and Howe, 1984; Haig and Plissner, 1993; Withers and Chapman, 1993; Withers, 1994). They are essential foraging habitats for wintering and migrating shorebirds and wading birds and are important to several state- or federally-listed endangered or threatened species or "species of concern": Piping and Snowy plovers (*Charadrius melodus*, *C. alexandrinus*), Reddish Egret (*Egretta rufescens*), White-tailed Hawk (*Buteo albicaudatus*), and Peregrine Falcon (*Falco peregrinus*). Benthic and epibenthic invertebrates form the prey base for shorebirds when flats are exposed and for crabs and demersal fish when inundated. Wading birds feed on nekton when flats are inundated, and raptors feed on shorebirds. Interruptions or alterations of these food web relationships due to either natural and/or human disturbances have the potential for catastrophic consequences to both threatened and non-threatened bird populations. Distribution and abundance of food resources has been related to distribution and abundance of shorebirds (Wolff, 1969; Goss-Custard, 1970; Goss-Custard et al., 1977; Bryant, 1979; Goss-Custard, 1983; Hicklin and Smith, 1984; Meire and Kuyken, 1984; Wilson, 1990; Colwell and Landrum, 1993). Food shortages have been implicated in wintering shorebird mortality and even small increases in winter mortality due to habitat loss or degradation may have a large effect on shorebird numbers (Goss-Custard, 1979).

The public image of tidal flats as barren wastelands contributing nothing aesthetically, economically, or ecologically is the underlying cause of most human disturbances and alterations. However, their appearance belies their importance to overall productivity of estuaries within the CCBNEP study area. There are nearly 160 km^2 of wind-tidal flats within the study area north of South Bird Island (Fig. 1.1), with almost 79% on the bay sides of San Jose, Mustang and Padre islands. In the lower Laguna Madre over 90 $km^2$of tidal flats have been affected by federal projects including ship and barge canals (Brown et al., 1980; Farmer, 1991). There are no summaries of types or areal extent of disturbances or alterations of tidal flats in the CCBNEP study area.

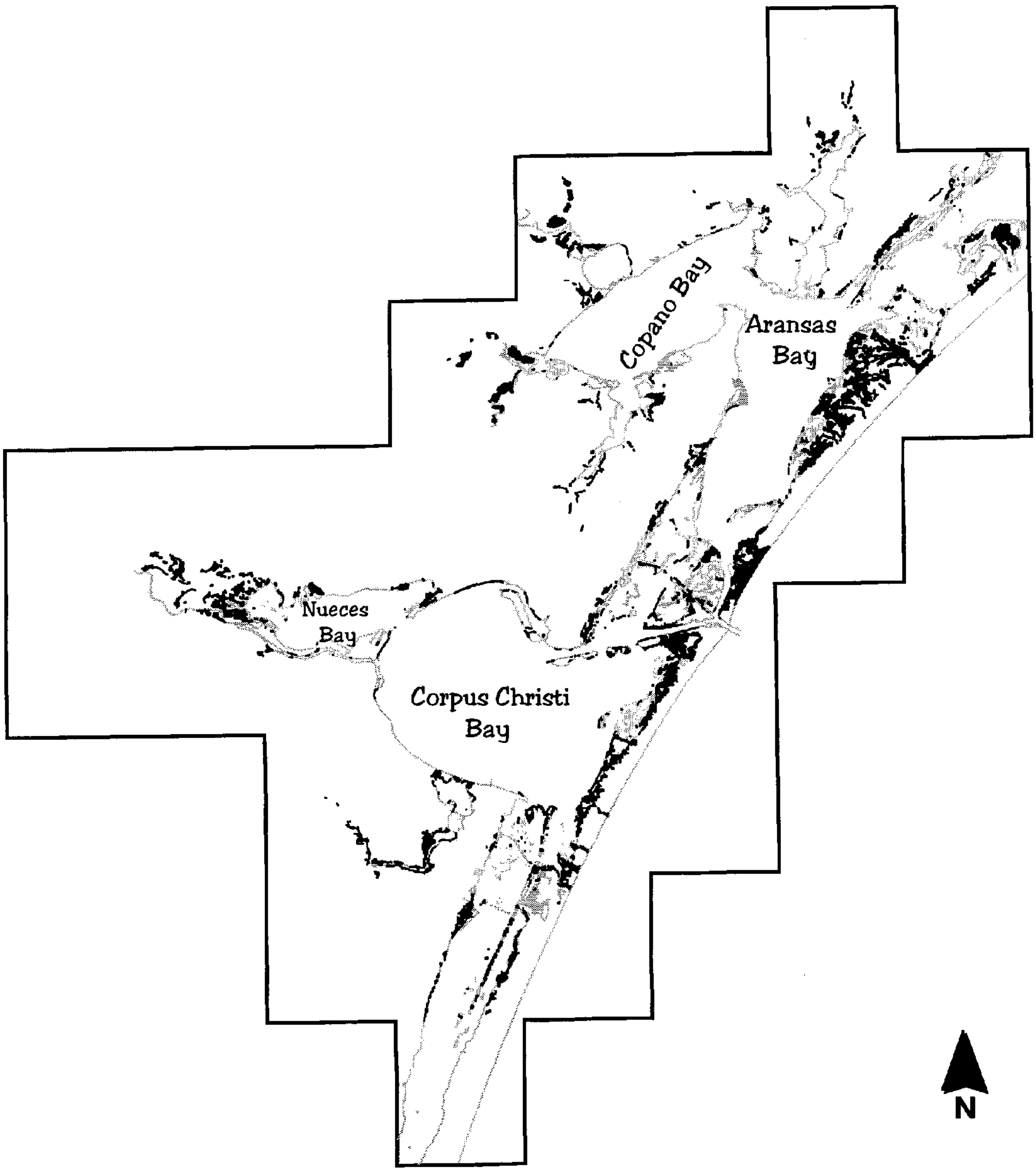


Fig. 1.1. Extent of wind-tidal flats in the CCBNEP study area north of South Bird Island. Map provided by BEG; based on 1991 NWI maps and data. Black areas are tidal flats.

Our inability to assess effects of impacts on productivity of wind-tidal flats for shorebirds has important management implications. US COE Section 10/404 permit applications for coastal projects require an assessment of the site for occurrence of Piping Plovers. Bird counts focusing on presence/absence of Piping and Snowy Plovers are the standard method for determining which sites may be developed. However, these studies ignore a site's potential for use which has important implications for shorebird conservation and management: (1) as shorebird populations grow, currently unused but suitable habitats are likely to be used; and (2) the need for marginal habitats if preferred habitats become unsuitable. Alternate habitats are necessary if traditional sites become unsuitable through crowding (Goss-Custard, 1980), naturally occurring long- or short-term alterations in inundation/exposure regimes which result in either prolonged exposure (invertebrate death) or inundation (habitat becomes unavailable for shorebird foraging), or prey depletion (Baker and Baker, 1973; Schneider, 1973; Bengtson et al., 1976; O'Conner and Brown, 1977; Evans et al., 1979; Schneider and Harrington, 1981; Quammen, 1984; Withers, 1994). Knowledge of distribution of food resources on tidal flats is vital for assessment of potential shorebird use but is not currently taken into consideration when assessing impacts or potential impacts to shorebird populations from either natural or anthropogenic disturbances.

Many wind-tidal flats within the CCBNEP study area have a high potential for alteration due to locations in areas experiencing increased beachfront and bayside development (e.g., Mustang Island). However, there is currently no standardized methodology in place to evaluate impacts of alterations/disturbances on wind tidal flat productivity in areas without regular inundation/exposure regimes. The main criteria in development of a tidal flat evaluation methodology for the US DOT for regularly inundated flats on the mid-Atlantic coast were: (1) that it is based on quantitative data; (2) accuracy in portraying the value of all tidal flat (including submerged) areas; (3) replicability such that different evaluators of the same area get equivalent results; (4) adaptable to amount of time and funds available; (5) understandable and applicable by environmental professionals of different backgrounds; and, (6) have site specific application (Diaz, 1982). Primary and secondary (support populations) producers were the only environmental variables evaluated. Because tidal flats on the east coast are inundated and exposed regularly in response to astronomical tides, hydrology was not evaluated. While presence of endangered species was taken into account, seasonal importance of tidal flats to Piping Plovers (not then listed as threatened) was not, leaving too much flexibility in the timing and duration of studies.

An evaluation strategy for tidal flats was developed for the US DOT in the late 1970's (Diaz et al., 1982a, 1982b; Diaz, 1982) using data collected from sites on the mid-Atlantic Coast. This evaluation strategy was intended for: (1) comparing habitats within a project site for baseline conditions; (2) comparing alternate project sites; (3) projecting habitat modifications from a project; and, (4) planning mitigation effort. A weakness of this strategy is that it was formulated prior to federal listing of the Piping Plover, so seasonal importance of flats as essential habitat is not recognized. In addition, because inundation and exposure of flats in this area are influenced primarily by winds, rather than astronomical tides, hydrologic regime and its effects on distribution and abundance of invertebrates was not taken into account. A strength of the scheme is that it provides a framework with which to quantitatively evaluate and compare sites. Parameters were graphed (e.g., annelid abundance vs biomass) to come up with "value index matrices" ranging from 0 to 3 for primary producers and support populations in each habitat (including subtidal areas up to 1 m deep). Consideration was given to percentage distribution or areal extent of habitats within the project site. This approach was intended to give an overall impression of relative site value, however there may be unique features of the habitat (e.g. essential habitat for Piping Plovers) that would be masked by this approach.

1.2 Objectives of Project

The objectives of the present study are: (1) to compile and synthesize all published and unpublished information concerning ecology, geology, and hydrology, of wind-tidal flats in the CCBNEP study area; (2) to determine locations of anthropogenic and natural disturbances and alterations to wind-tidal flats in the study area and rate their severity; and, (3) to formulate an evaluation strategy to determine wind-tidal flat productivity for both baseline and post-disturbance monitoring. The evaluation strategy formulated for this area used the framework established by Diaz (1982) and will allow standardization of baseline monitoring and evaluation of sites prior to impacts, as well as a way of determining success of creation, restoration, or enhancement projects. The inclusion of additional parameters (i.e., water levels, bird counts, total organic carbon, epibenthic insects, pore water salinity) allows better characterization of our unique tidal flats, as well as the creation of additional value index matrices for more accurate assessment of relative site value and unique habitat features.

2. METHODS

2.1 Literature Review - Data Acquisition, Compilation, and Analysis

Published and unpublished literature, as well as other sources of information (e.g. legal documents) from both within and outside the study area, particularly the upper and lower Texas coast, were reviewed by the Co-Principal Investigators to provide a comprehensive summary of the ecology, geology, and hydrology, and impacts/disturbances of tidal flats on the Texas gulf coast. Published data resources include peer-reviewed scientific journal articles and agency documents. Unpublished data resources included agency reports and permit reviews, dissertations, and theses. Quality of results and conclusions found in each document were assessed using the following criteria: (1) QA/QC measures imposed on data collection; (2) information of specific and consistent methodological procedures; (3) evaluation of concurrent research objectives, methods, and results of independent data sets for comparative purposes; and, (4) best professional judgement.

2.2 Impacts, Disturbances, and Alterations of Wind-Tidal Flat Habitat

2.2.1. Literature Review & Identification of Collateral Data Sources

Literature was reviewed and assessed in the same way as described in Section 2.1. Potential effects due to alterations on hydrology and ecology of wind-tidal flats in the study area were discussed in detail, emphasizing studies either inside or outside the study area which linked alterations with impacts to ecosystem function. In addition, other natural or human influences that may affect tidal flats but for which no information about presence or extent of such influences within the study area exists were discussed.

Collateral data sources, specifically map-based data and aerial photos, included: NOAA Navigation Charts; NPS-PINS maps/photos; CCBNEP Program Office maps/photos; USFWS maps/photos (including NWI maps/photos); GLO maps/photos; BEG, UT-Austin (Environmental Geologic Atlases, Submerged Lands of Texas); published county or regional maps.

2.2.2 Data Acquisition

Appropriate datasets, aerial photographs, reports, maps, etc. were examined to identify on maps and rate the severity of the following impacts and disturbances of tidal flats:

(1) gains, losses, conversions (e.g., natural transition to high marsh, change to saltmarsh via mitigation activities),
(2) channeling and dredge material disposal,
(3) increasing elevation or loss of inundation frequency,
(4) vehicle tracking,
(5) wastewater, stormwater, or produced water discharges.

Photographs from the 1930's (GLO, CCBNEP), 1970's (GLO), and 1980's (GLO), as well as NWI maps from 1956, 1979, and 1992, and the most recent navigational maps (NOAA) were the primary sources used to construct maps. Base maps for mapping were provided by the BEG and were based on 1992 NWI digitized data. The BEG also provided summaries of changes in total areal extent of wind-tidal flats (status and trends) from NWI digitized data in connection with their ongoing CCBNEP project "Status and Trends of Selected Estuarine Habitats in the CCBNEP Study Area".

2.2.3 Acceptance Criteria & Data Limitations

2.2.3.1 Photography

Acceptance criteria were not applicable to historical photography since they cannot be redone. Problems with inadequate photographic coverage, poor quality photographs, cloud cover, etc. were a data limitation.

2.2.3.2 Collateral Data Sources

Maps, charts, and regional reports are produced for many reasons unrelated to the present project. Each piece of collateral data was assessed for quality, completeness, and relevance using the previously stated criteria for literature reviews. References to data quality, scale, dates, and coverage were footnoted on all maps produced.

2.2.3.3 Photointerpretation and Cartographic Transfer

The scope of this project did not include determining exact sizes of impacts/alterations/disturbances. Tidal flat locations within the study area were mapped by BEG from 1994 NWI maps. Impacted flats were highlighted and impacts were qualitatively ranked (e.g., 1= minimal impact, 5 = extensive or severe impact) in the location of the impact/alteration/disturbance.

2.3 Evaluation Strategy for Assessing Tidal Flat Productivity - New Data Collection

The following sections deal with the methods and quality assurance/quality control measures used to ensure high quality biologic and abiotic data (new data) collected to formulate an evaluation strategy for assessing wind-tidal flat productivity in the CCBNEP study area.

2.3.1 Task Description

This project took place on wind-tidal flats located in the Corpus Christi Bay-upper Laguna Madre estuarine complex. To assess utility of various biologic and environmental measures in determining productivity of wind-tidal flats, sites were chosen that encompass variability of sediment types (sand to mud), inundation and exposure frequency, and algal coverage (0 to ≈100%). Since predicting potential shorebird use is an important aspect in formulating this monitoring strategy, the focus was on areas known as shorebird foraging habitats, but not necessarily used by high numbers of birds. Sites were located in the following areas (Fig 2.1): two sites on the bayside of Mustang Island (Newport Pass and Fish Pass), one site in Oso Bay adjacent to the TAMU-CC campus, and one site that was previously highly productive for both birds and benthos on north Padre Island (flat located at northern boundary of PINS, "Marker 83").

2.3.1.1 Methods and Approach

Twice monthly sampling occurred at all sites between November 1996 and March 1997 for the following parameters:

(1) exposed tidal flat area
(2) sediment water content
(3) bird density
(4) benthic invertebrate density
(5) sediment chlorophyll *a*
(6) total organic carbon (TOC)
(7) pore and surface water salinity

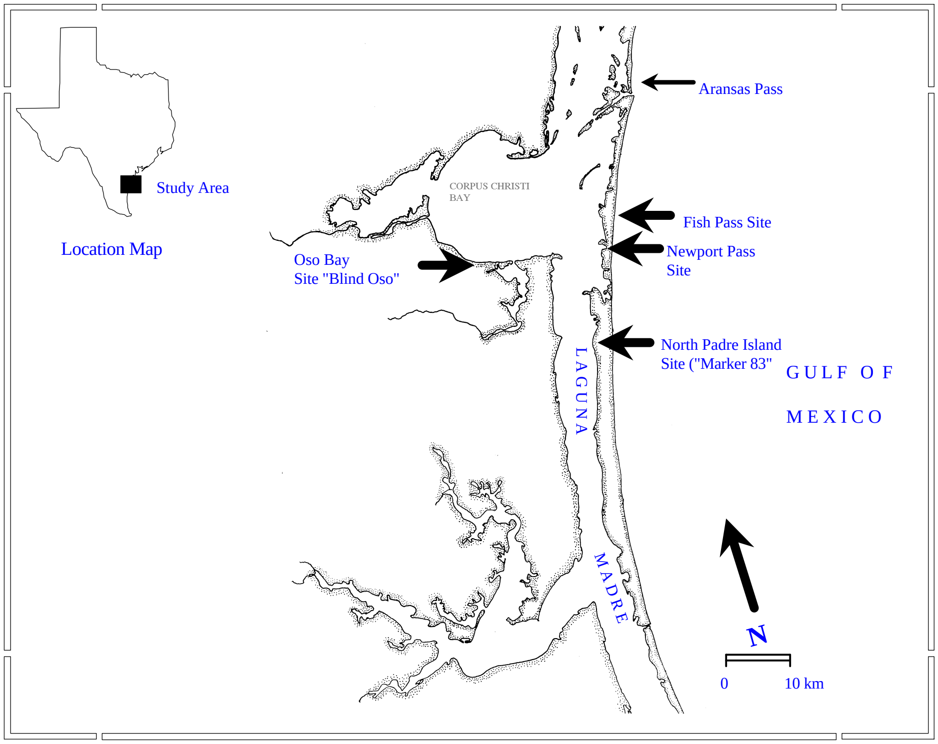


Fig. 2.1 Map of study area showing locations of sampling sites.

2.3.1.1.1 *Exposed Tidal Flat Area*

The purpose of this data collection was to (1) determine exposed area (ha) available to birds on any sampling day to determine bird density, and (2) collect data concerning frequency and extent of inundation/exposure on tidal flats so hydrologic regimes and their possible relationship to biologic parameters could be elucidated. Length of exposed flat area was measured from poles marking ends of the permanent transect (2 locations) located near or at the upland extent of the flat to the edge of the water using a range finder (≈95% accurate). Area of the polygon delimited by the permanent transect on the upland edge of the flat and the edge of the water was calculated.

2.3.1.1.2 *Sediment Water Content*

On CCBNEP study area tidal flats, sediment saturation is probably more important in determining algal productivity than amount and intensity of light available since inundation regimes are irregular and desiccation promotes dormancy and even death in the blue-green algae which dominate the flora. The purpose of this data collection was to determine sediment saturation in emergent areas of the flat for use in combination with other data (e.g., chlorophyll vs sediment saturation) to construct value index matrices as described previously. Sediment samples were collected using a 5.4 cm diameter PVC pipe core sampler and placed in ziplock bags. In the lab, 30-40 grams of sediment was placed into a pre-weighed aluminum pan, weighed to 0.0001 grams using an analytical balance, dried at 95° C to constant weight, and reweighed. Water content was expressed as a percentage of total wet weight.

2.3.1.1.3 *Pore and Surface Water Salinity*

The purpose of this data collection was to determine ranges of salinity during the study in both pore waters contained in sediments within emergent microhabitats (i.e., damp, wet, intertidal) and surface water in shallow, submerged areas of flats (<15 cm). A small amount of sediment was removed in each microhabitat to allow water to flow into the void from the surrounding sediment. A small amount of this water was removed using a pipette and analyzed with a temperature compensated refractometer. Surface water salinity was taken from the open water area adjacent to the tidal flat at a depth of less than 15 cm. Refractometers could be read accurately to the nearest part-per-thousand (ppt) , and were checked for accuracy with distilled water (0 ppt) and a standardized saline solution (40 ppt) prior to use.

2.3.1.1.4 *Benthic Invertebrate Abundance and Biomass*

The purpose of this data collection was to determine abundance and biomass of various taxa of macrobenthic invertebrates (>500µm). Population parameters of interest were numbers of individuals of each taxon per square meter per sampling period, and grams of dry weight biomass of each taxon per square meter per sampling period. These data were combined (e.g., polycheate numbers vs polychaete biomass) into "value index matrices" (Diaz 1982) to allow rating of productivity (e.g., 0 - no productivity to 3 - high productivity) associated with a taxon (e.g., polychaetes, insect larvae).

At each site a permanent transect 400-500 m long (depending on the size of the flat) was established near the transition from flat to upland and parallel to the shoreline (Fig. 2.2). On each sampling day, two sampling transects were established randomly and perpendicularly to the permanent transect. These sampling transects ran from the permanent transect into standing water to a depth of at least 5 cm, passing through all microhabitats present. Within each microhabitat (e.g. damp, wet, intertidal, submerged (5-15 cm depth), a 1 m x 5 m sampling area was established and five random 5.4 cm x 5 cm core samples were taken. Each sample was fixed in 10% formalin.

In the lab, samples were washed through a 500µ screen. Organisms retained on the screen were removed and stored in 45% isopropyl alcohol. Organisms were sorted into easily distinguishable taxonomic categories (e.g., annelids, amphipods, tanaids, molluscs, other crustaceans, insect larvae) and counted. Only live molluscs were included in analysis. Dry weight biomass was determined for each taxon by drying at 95° C for 72 hours and weighing on an analytical balance accurate to 0.0001 g. Aluminum pans for biomass determinations were pre-weighed after a period of storage in a desiccation chamber to remove any ambient moisture. Samples were cooled in a desiccation chamber prior to weighing to prevent uptake of moisture. Oven temperatures were monitored using an external thermometer. Analytical balances were calibrated and checked according to manufacturer' specifications.

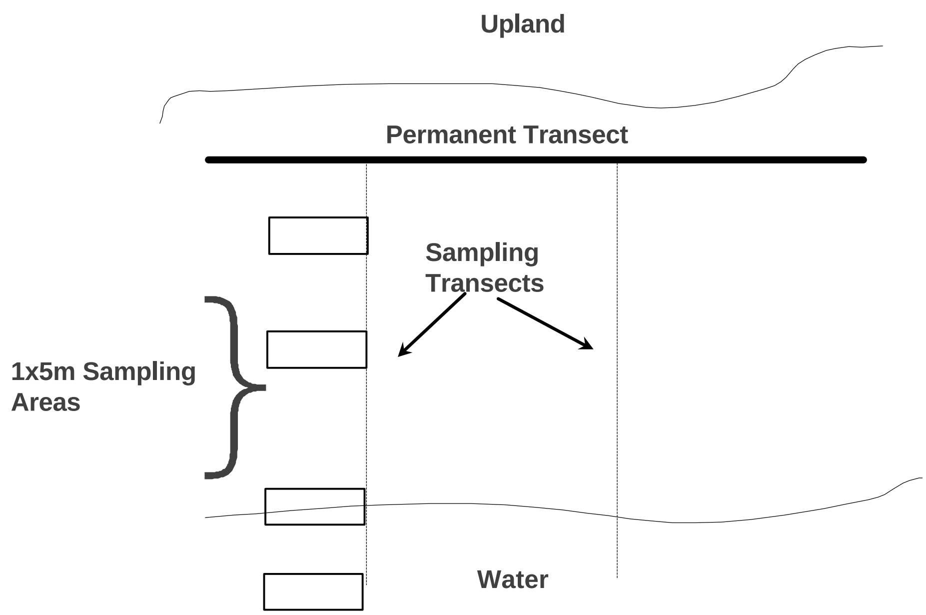


Fig. 2.2. Schematic of benthic field sampling.

2.3.1.1.5 *Bird Density*

The objective was to determine bird abundance and microhabitat use on wind-tidal flats for use in combination with other data (e.g. bird density vs benthic biomass) to construct value index matrices as previously described. Birds were counted prior to any other measurements or data collection to ensure accurate counts. Sampling days were chosen so environmental conditions were favorable for birds (e.g., winds less than 20 mph, no frontal passage within 24 hours). All birds were counted and identified by species and microhabitat use within the area. Density was expressed as number per hectare.

2.3.1.1.5 *Sediment Chlorophyll a*

The purpose was to determine amount of chlorophyll *a* in tidal flat sediments as an indirect measure of primary productivity for use in combination with other data (e.g. amount of chlorophyll vs % water) to construct value index matrices as described previously. One 5.4 cm x 5 cm core was taken from each benthic invertebrate sampling area (total 8-10 [depending on number of microhabitats]/site) for this purpose. The parameter of interest is milligrams chlorophyll *a* per square meter.

Chlorophyll *a* was extracted from sediments using 90% aqueous acetone rendered basic by a drop of concentrated NaOH per liter. Cores were quartered and sediments ground using a an industrial blender, then combined with 100 ml of acetone for 2 hours. The eluate was centrifuged and aliquots used for spectrophotometric analysis. Optical density was read at 665 µm before and after acidification. Acidification was accomplished by adding 1-2 drops of 1 N

HCL directly to the cuvette. Acidification converts chlorophylls to phaeopigments so that amount of live chlorophyll can be distinguished from amount of dead chlorophyll and chlorophyll degradation products using a correction equation (Wetzel and Westlake 1969).

2.3.1.1.6 *Sediment Total Organic Carbon*

The objective was to determine total organic carbon (TOC) present in wind-tidal flat sediments as an indicator of the amount of material available to detrital food chains for use in combination with other data (e.g. total organic carbon vs numbers of benthic invertebrates) to construct value index matrices as described earlier. One 5.4 cm x 5 cm core was taken from each benthic invertebrate sampling area (total 8-10 [depending on number of microhabitats]/site) for this purpose.

Crucibles were cleaned, oven dried, cooled in a desiccation chamber and weighed. Sediment was added to the crucible, oven-dried for three days at 95° C to remove all moisture and weighed using an analytical balance accurate to 0.0001 g. Dried sediments were ashed in a muffle furnace at 560° C, for 3 hours, cooled in a desiccator to prevent moisture uptake and reweighed. Loss in weight, expressed as a percentage, represents amount of oxidizable organic matter present. This weight was corrected for accompanying decomposition of carbonates by adding ammonia carbonate, heated to 105° C to drive off excess solution, cooled in a desiccation chamber to prevent uptake of moisture and reweighed. Gain of weight indicates the amount of CO_2 lost by carbonates during ashing. This gain of weight is subtracted from the initial weight loss before percentage of organic matter is determined (Smith, 1980). Oven temperatures were monitored using an external thermometer and analytical balances were calibrated and checked according to manufacturer's recommendations

2.4 Identification of Probable Causes

The Co-Principal Investigators attempted to explain positive or negative trends by relating them to possible causative factors using best professional judgement. When probable causes were identified, a detailed discussion of the evidence, using supportive literature or the rationale used to determine the relationship was included.

2.5 Identification of Information Gaps

Synthesis of all available literature on the biotic and abiotic components of Texas tidal flat systems and alterations/disturbances that may affect them will provide users with a broad understanding of tidal flat structure and function, as well as the potentially deleterious impacts that may occur as a result of alterations/disturbances. Information gaps related to abiotic and biotic components and ecosystem function were highlighted. Information gaps, either in ability to identify alterations or disturbances from photos or on the ground, as well as effects of disturbances were emphasized. Specific information gaps are presented in tabular form and discussed thoroughly with a focus on future characterization and monitoring needs.

Table of Contents

3. ECOLOGY OF WIND-TIDAL FLATS

3.1 Physical Setting and Processes

3.1.1 Definition and Distribution within Study area

Tidal flats are seemingly barren, relatively featureless sand and/or mud environments bordering lagoons and bays. Within the CCBNEP study area, most tidal flats are "wind-tidal flats". These flats may be inundated by seasonal and astronomical tides, but are generally inundated and exposed only at irregular intervals by wind and stormtides, and/or by ponded rainwater. Inundation or exposure may occur rapidly (within a few hours) depending on the speed and direction of the wind (Fisk, 1959; Hayes and Scott, 1964; Hayes, 1965; Brown et al., 1977; White and Galloway, 1977; Weise and White, 1980). Because tidal inundation is irregular and extreme temperatures occur when thin sheets of water are heated by the sun, macrophytic plant communities cannot develop and biologic activity is often restricted to felts or mats of blue-green algae which form over the surface of and bind the sand and/or mud substrate (Pulich et al., 1982).

Worldwide, the most extensive wind-tidal flats are found around hypersaline lagoons like the Laguna Madre. In the CCBNEP study area, tidal flats occur primarily along bay sides of barrier islands, and to a lesser extent, along mainland bay margins, around river deltas, and the mouths of creeks. Moving southward, wind-tidal flats replace salt marsh vegetation, particularly on barrier islands. The shift from salt marsh to wind-tidal flat coincides with increased eolian erosion which accompanies decreasing barrier island vegetation (Brown et al., 1976). Wind-tidal flats reach their greatest development from Yarborough Pass (Padre Island) southward.

About 160 km^2 of wind-tidal flats occur within the CCBNEP study area (Table 3.1). Nearly 79% of the tidal flats in the study area are found on the bay sides of San Jose Island (Aransas County), Mustang Island (Nueces County) and north Padre Island (Nueces and Kleberg counties), and along bay margins of Baffin Bay and its secondary bays (Kleberg County). The remaining wind-tidal flats are found in deltas of the Mission, Aransas, and Nueces rivers, scattered along the bay margins of Nueces, Copano, and Redfish bays, and in the valleys along the lower reaches of Oso, Petronila, San Fernando, and Olmos creeks where the gradient decreases and the streams flow onto the wind-tidal flats of Oso Bay, Alazan Bay, Cayo del Grullo, and Laguna Salada, respectively (Brown et al., 1976, 1977; McGowen et al, 1976).

3.1.2 Historical Development

Tidal flats in the CCBNEP study area began developing after sea level reached its approximate present level 2,800 to 2,500 YBP. During that time, significant processes which contributed to formation of tidal flats were: (1) headward-eroding streams eroding the coastal plain; and (2) development of flood tidal deltas and washover fans associated with bay and lagoon margin environments (Brown et al., 1976).

Table 3.1. Areal extent of wind-tidal flats in the CCBNEP study area by county (Brown et al., 1976; McGowen et al., 1976; Brown et al., 1977). All values are in square kilometers.

	County (north to south)				
Type of Tidal Flat	Refugio	Aransas	San Patricio	Nueces	Kleberg
Fluvial-deltaic System					
Wind-tidal flat, sand and mud, firm, occurs locally in lower stream valley, transitional between bay and stream	7.0	11.4	9.6	0.0	3.1
Bay-Estuary-Lagoon System					
Wind-tidal flat, sand and mud, firm	0.0	0.0	0.0	37.0	69.9
Wind-tidal flat, sand and mud, extensive algal mats, alternatively emergent-submergent	0.0	0.0	0.0	0.0	2.6
Wind-tidal flat, mud and sand, algal-bound mud, gypsiferous, firm	0.0	2.6	0.0	3.1	0.0
Wind-tidal flat, sand and mud, barren to sparsely vegetated, subaerial, burrowed	0.1	13.7	0.0	0.0	0.0
Transitional zone, wind-tidal flat to eolian sand sheet, wind deflation, concentrated clay dunes, sand	0.1	0.0	0.0	0.0	0.0
Total wind-tidal flat by county	7.2	27.7	9.6	40.1	75.6
Percent of total	4.5	17.3	6.0	25.0	47.2

In estuarine deltaic environments, tidal flats develop upon crevasse splays, abandoned levees, relict meanderbelt sands, and slopewash-alluvial fans along valley walls (Fig. 3.1). Wind-tidal flats in lower reaches of streams such as Oso and Petronila creeks, develop on fluvial fan-delta sand deposits where gradients decrease and the erosional character of the stream diminishes (Fig. 3.1B). In Baffin Bay, these tidal flats develop on sandy valley-fill deposited in late Holocene and Modern times during brief periods of high discharge, usually associated with tropical storms or hurricanes. Between floods, long periods of eolian or wind-tidal modification and/or destruction of the fluvial deposits occurs (Brown et al., 1977). Since sea level reached its present level, the bayhead fan or lacustrine deltas at the mouths of rivers and ephemeral streams upon which tidal flats develop have been slowly filling the upper ends of the estuaries (Brown et al., 1976; Brown et al., 1977).

Wind-tidal flat development reaches its peak in bay and lagoon margin environments, particularly on Mustang and Padre islands (Fig. 3.2). Tidal flats form on the surface of sediments transported into the Laguna Madre from the islands by wind and storm-surge tides. During hurricanes when storm surges breach the islands, storm-generated currents carry sand to the bayside of the island where it is deposited as a washover fan behind the ridge. These low, unvegetated, sandy lobes are deposited at the point where the constricted hurricane channel opens onto submerged wind-tidal flats. Subsequent eolian modification of the fans has provided most sediment that has produced the extensive wind-tidal flats in the Laguna Madre (Fisk, 1959; Brown et al., 1977). A very large washover fan with wind-tidal flats occupies the northern end of San Jose Island in Aransas Bay (McGowen et al., 1976). Parts of the flood-tidal delta of Harbor Island (Redfish Bay) are also occupied by wind-tidal flats.

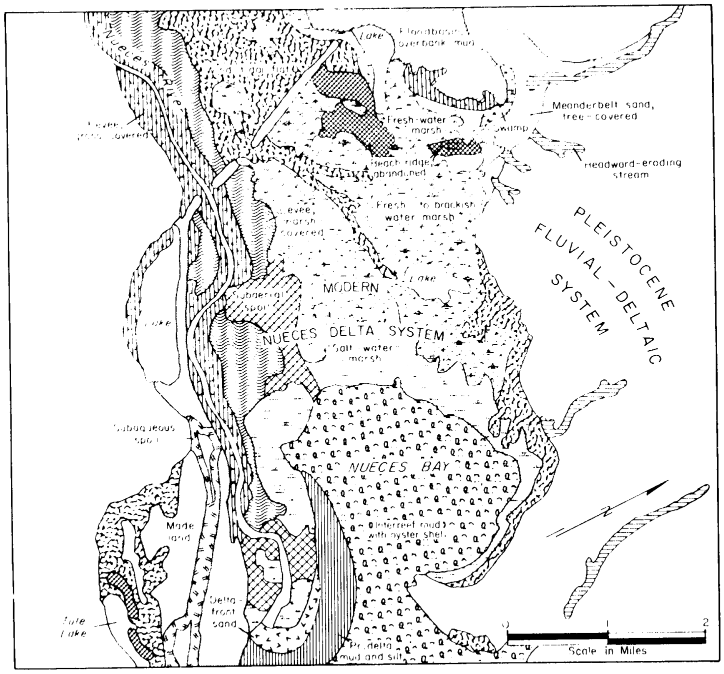
Tidal flats that occur on the mainland bay margin develop where southeasterly winds deflated older eolian deposits, Pleistocene barrier-strandplain deposits, and deltaic deposits. Unlike barrier island flats which are composed primarily of sand, mainland flats are primarily composed of clays. Mainland tidal-flats are generally small and are scattered throughout the study area. Greatest development occurs around Baffin Bay (Brown et al., 1976; McGowen et al., 1976; Brown et al., 1977).

The most extensive tidal flats on the entire Texas coast are located immediately south of the CCBNEP study area. The Landcut, consists of an area of the Laguna Madre filled with barrier island sand linking Padre Island with the mainland. The mainland in the Landcut is distinctly indented and deflated to form extensive wind-tidal flats as well (Fisk, 1959).

3.1.3 Physiography

Regardless of formation or location, tidal flats in the study area are found at elevations between mean sea level (MSL) and 1 m above MSL. They slope gently lagoonward ($\approx$ 10 cm/km) (Herber, 1981) and may occasionally be sparsely vegetated with *Salicornia biglowii* or other halophytic vegetation, particularly after extended rainy periods. Tidal flats in the study area range from high, sandy flats to low, depressed, muddy flats.

A



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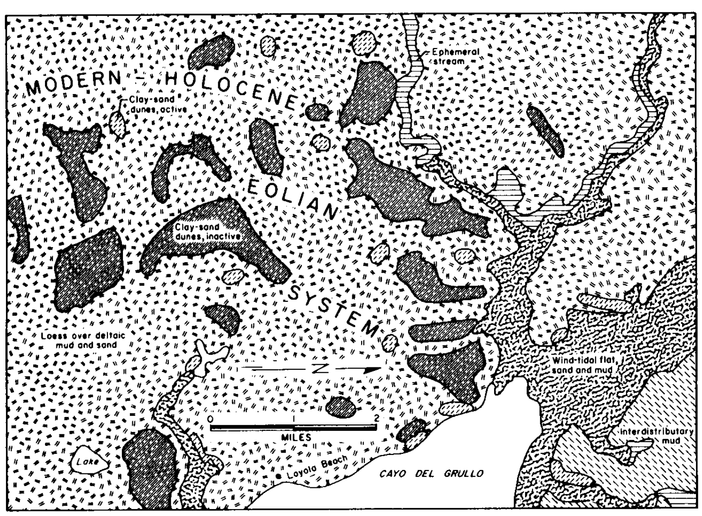
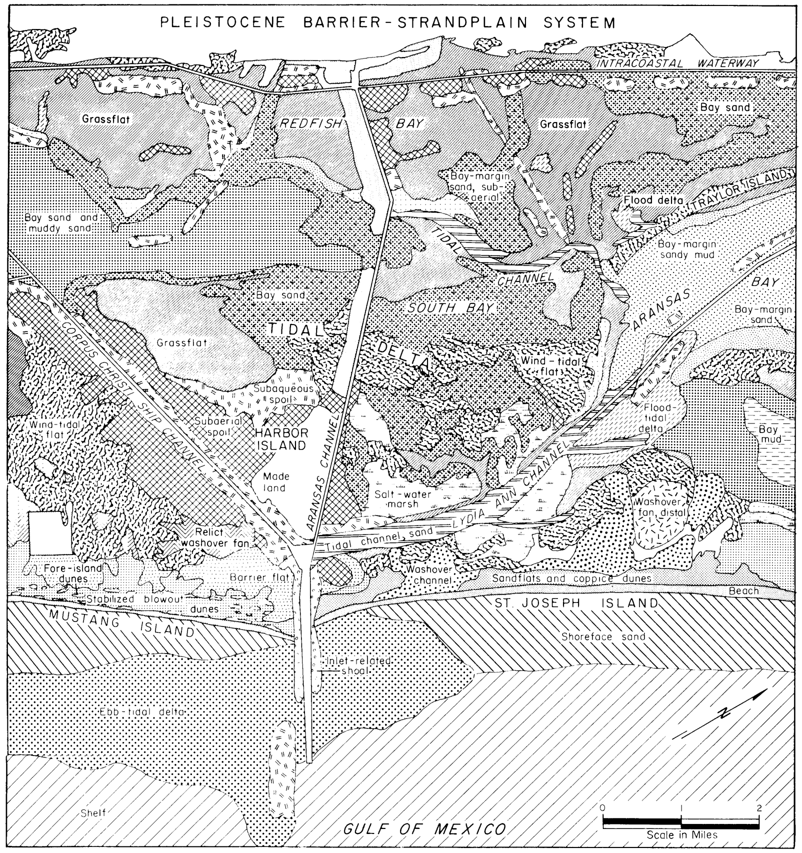


Fig. 3.1. Development of tidal flats in deltaic environments: (A) tidal flat development and extent in the Nueces River delta (from Brown et al., 1976); (B) tidal flat development in the stream courses of ephemeral streams flowing into Baffin Bay (from Brown et al., 1977).

A



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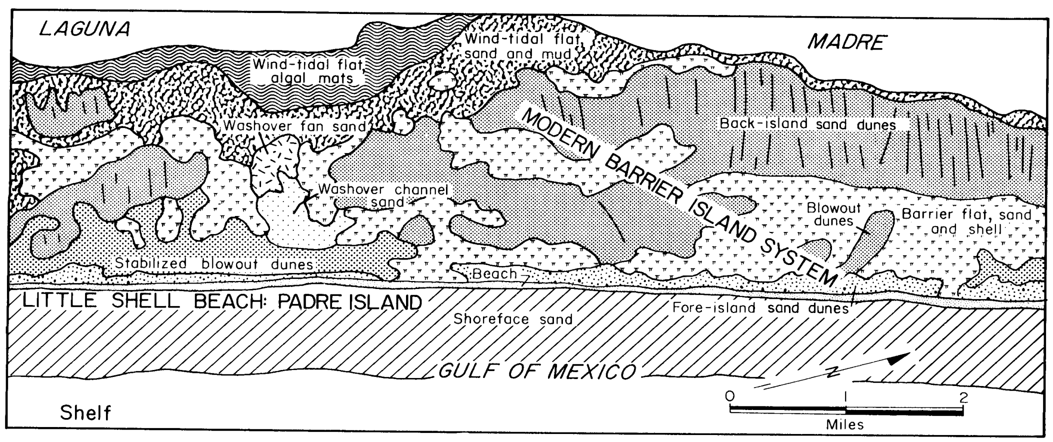


Fig. 3.2. Development of tidal flats in barrier island and tidal-delta environments. (A) Tidal flat development on Mustang and San Jose islands near Aransas Pass, including Harbor Island (from Brown et al., 1976); (B) tidal flat development on Padre Island (from Brown et al., 1977).

Herber (1981) stated the entire wind-tidal flat should be classified as intertidal, however, this may be inappropriate since only a small portion of the flat is affected by astronomical tides. He divided Padre Island wind-tidal flats into upper, middle, and lower intertidal flats. The lower intertidal flat was flooded nearly daily and was completely dry only during extreme low tide during summer. The upper intertidal flat was totally covered with water about 20 days annually (≈5%) during very strong winter storms or extreme high tides. The middle flat was flooded for some intermediate number of days, usually during winter storms and extreme high tides.

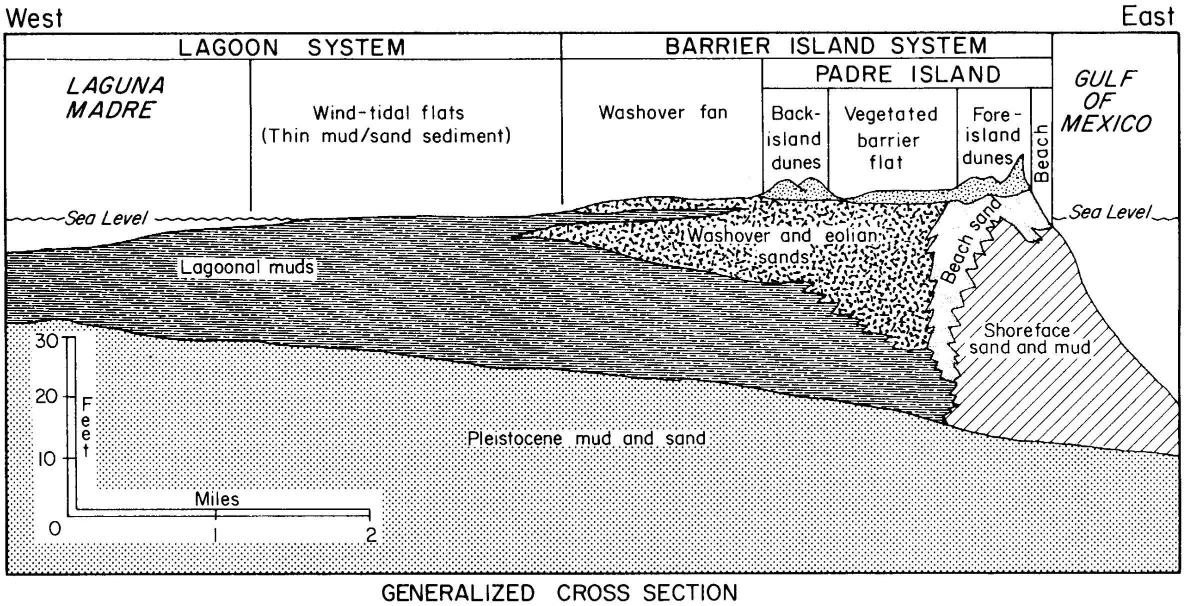
Although Herber's observations concerning timing and length of inundation are correct, Withers (1994) recognized that because the effect of astronomical tides on wind-tidal flats is negligible, a mosaic of microhabitats occurs rather than zoned habitats similar to sandy beaches. Three microhabitats were defined based on water depth and saturation of substrate: (1) Intertidal - areas at the edge of the water covered with 2-5 cm of water; (2) Wet - usually saturated but always wet areas, often covered with a film of water up to 2 cm deep; and (3) Damp - areas that may appear dry on the surface but are damp to wet below the surface, occasionally with standing water (up to 2 cm deep) in depressions. Areal coverage of microhabitats differs with water levels, and occasionally microhabitats are nonexistent. A typical back island flat is generally dry and sandy at the highest elevations near back island dunes, where inundation is rare. As elevations decrease, bare sand and/or mud grade into sand and/or mud covered with a blue-green algal mat, particularly at and just above MSL where inundation and exposure normally occur, if somewhat irregularly. There is a sharp textural boundary between the rarely exposed sandy or muddy areas below MSL and the blue-green algal flat, with a "step up" onto the algal bound areas (Herber, 1981, K. Withers, pers. obs.) (Fig. 3.3). Flats on Padre Island are unique because they are not crossed by tidal channels (Herber, 1981).

In deltaic environments (Fig. 3.4A), tidal flats replace salt and brackish water marsh vegetation locally. In lower reaches of ephemeral streams and along bay margins, wind-tidal flats may be backed by clay dunes such as along Oso Bay and Baffin Bay lower tributary drainages (Fig. 3.4B). San Jose Island is a unique case in which wind-tidal flats are interspersed with active washover fan components (Fig. 3.5).

3.1.4 Geology and Soils

Sedimentary processes are summarized in Table 3.2. The area became subaerial and deposition was complete about 200 years ago (Long and Gudramovics, 1983). Winds are the primary force which shape topographic and sedimentological features of tidal flats. Eolian transport of sands from barrier islands is the principal means by which flats increase in size. Previously estimated vertical accretion rates for Padre Island of about 6 mm/yr (Fisk, 1959, Lohse, 1958) have been discredited as too rapid. More recent work by Miller (1975) using ^{14}C dating of algal mat material revealed vertical accretion of sediments in the Landcut has been gradually decreasing during the past 2,500 years from 0.5 mm/yr to 0.25 mm/yr or less. However, rapid shoreline progradation and expansion of wind-tidal flats was noted for the Bird Island Basin area of north Padre Island between 1941 and 1969 (Prouty and Prouty, 1989). Shoreline progradation averaged 7.9 m between 1941-1950, 12.8 m between 1950-1964, 10.4 m

A



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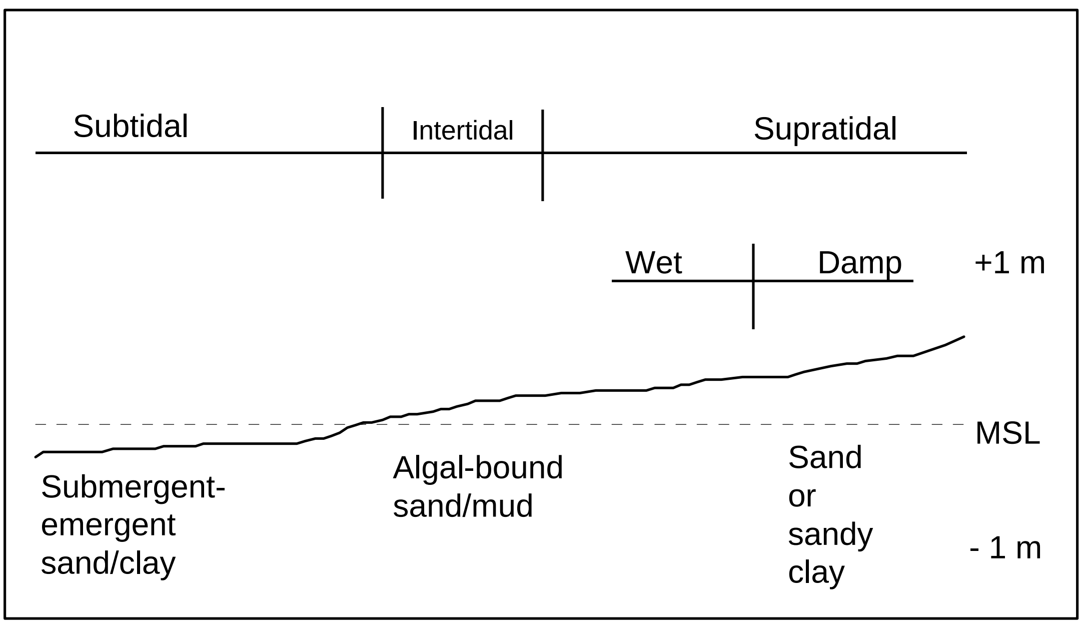


Fig. 3.3. (A) Profile of barrier island tidal flats showing relationships between flats and other topographic features (from Brown et al., 1977); (B) schematic of tidal flat showing physiographic zonation.

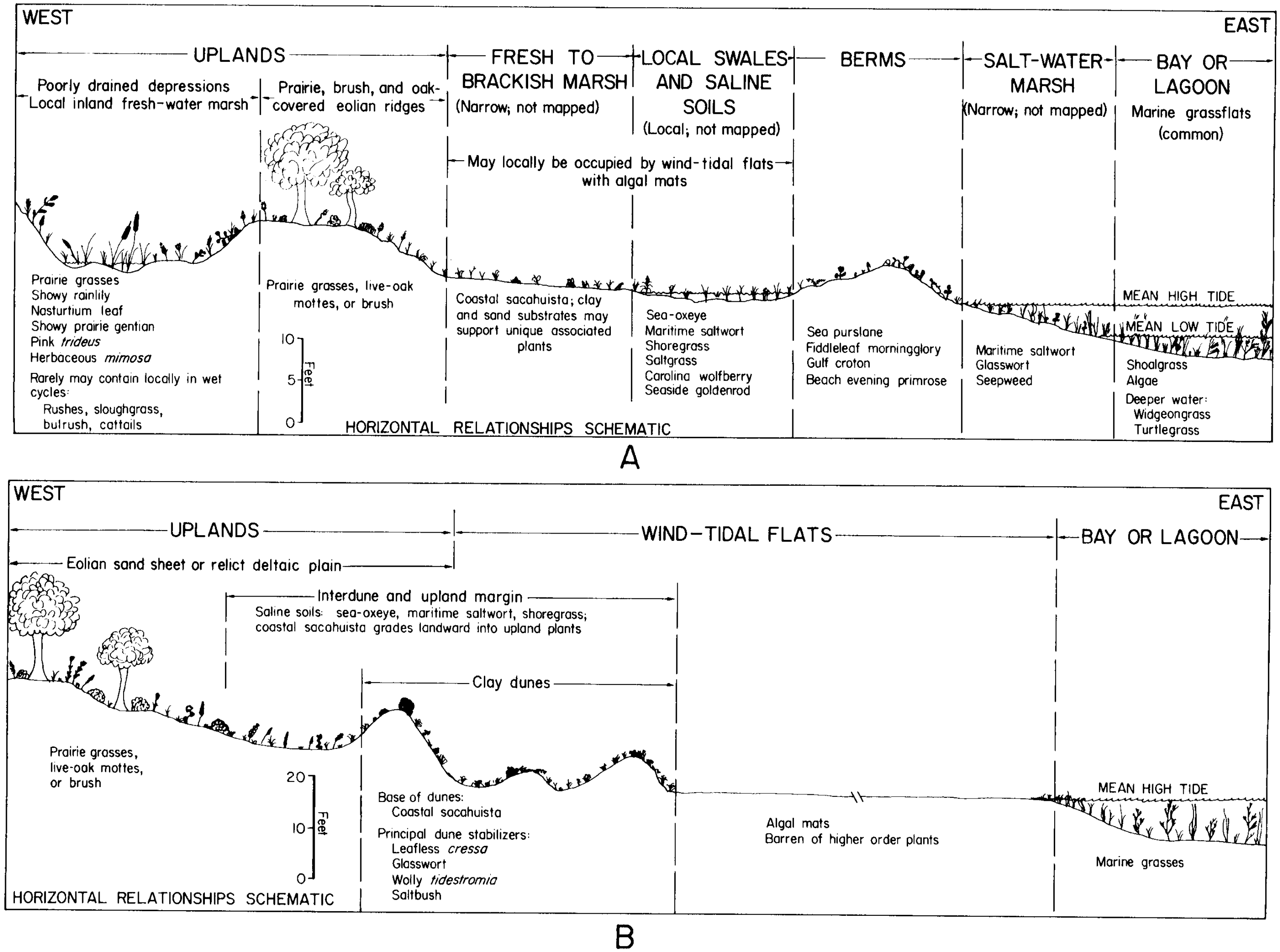
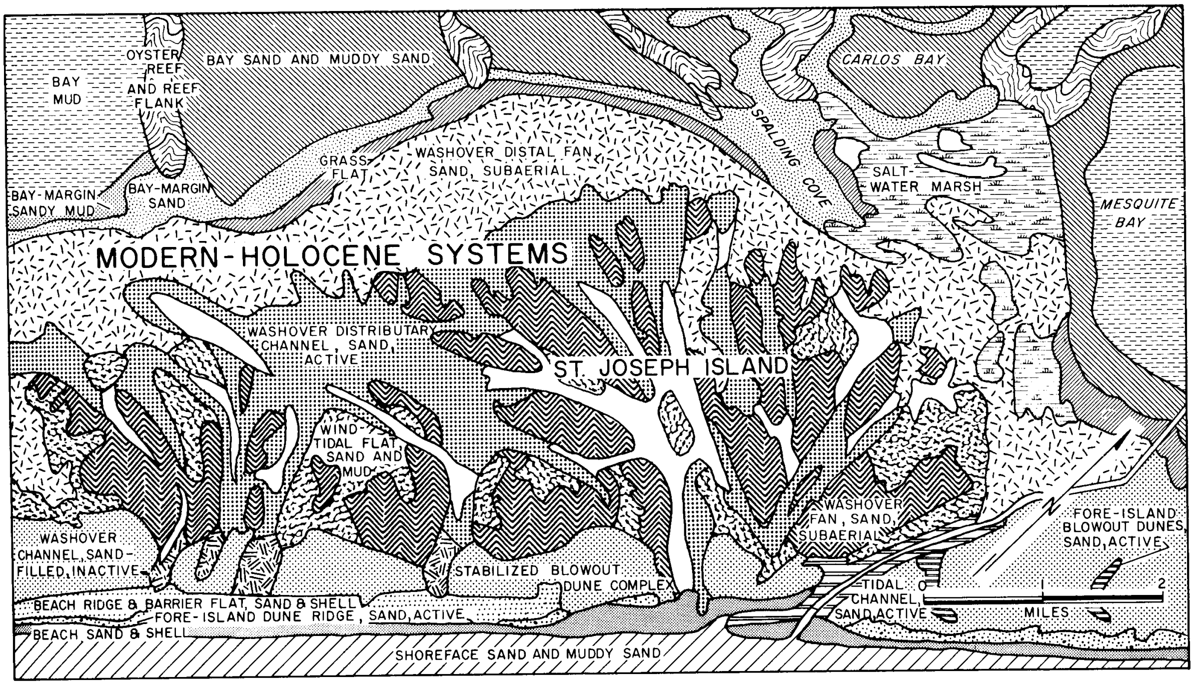


Fig. 3.4. Profiles of mainland tidal flats showing relationships between flats and other topographic features (from Brown et al., 1977). (A) Positioning of deltaic flats; (B) positioning of bay margin or lower stream course tidal flats.

A



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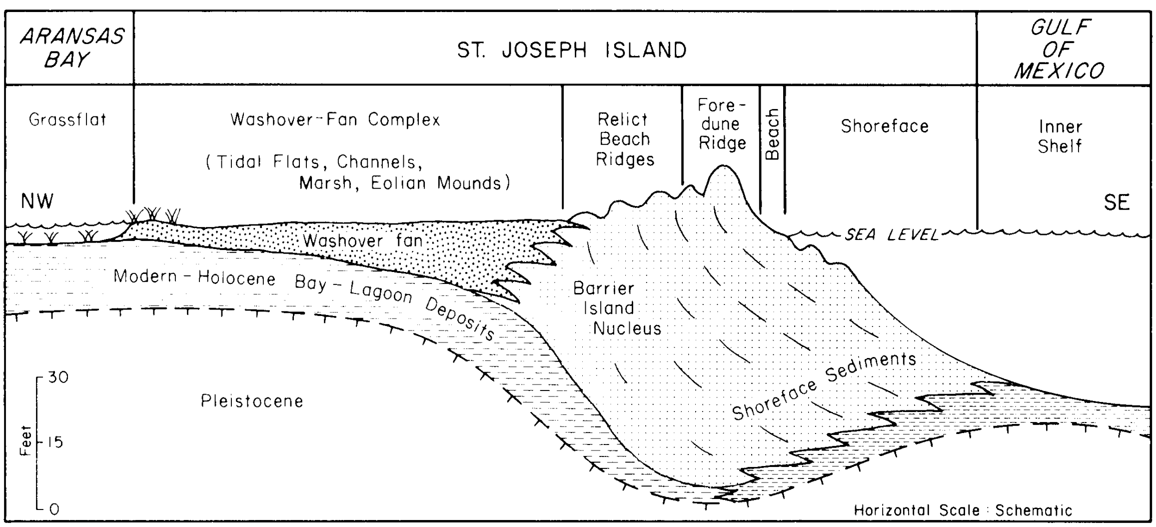


SCHEMATIC CROSS SECTION

Fig. 3.5. Tidal flats on San Jose Island. (A) Relationships of tidal flats to other washover fan components (from McGowen et al., 1976); (B) profile of flat showing relationships to other topographic features (from Brown et al., 1976).

Table 3.2. Summary of sedimentary processes affecting wind tidal flats (Herber 1981).

Type of Process	Process Description	Effect
Biologic	Disruption by plants	Minor
	Trapping or binding by blue-green algae	Major
	Addition of detritus by shell	Minor
	Addition of detritus by plants (seagrasses)	Major
Physical	Currents - wind tides	Major
	Currents - storms	Minor
	Eolian transport - sand	Minor
	Desiccation	Major
Chemical	Precipitation of carbonates	Major

between 1964-1969, and 1.5 m between 1969-1979. The shoreline has since been eroding, but not as rapidly as it prograded. Progradation was attributed to greater amounts of wind-blown sand caused by drought-induced devegetation of the dunes.

In addition to direct transport, winds shift lagoonal waters which carry suspended materials, create currents capable of transporting sand, and generate waves that locally erode mainland margins. The upper Laguna Madre is aligned northeast across the prevailing wind direction. Southeasterly winds force sediment-laden waters away from Padre Island into Baffin and Corpus Christi bays. Fisk (1959) stated that floodwaters over mainland flats were usually murky with suspended particles whereas island floodwaters were generally “crystal clear”. “Northers”, (winter storms with strong northerly winds) of long duration, or other storms push sediment-laden waters back onto the island flats and some mainland flats (e.g., Oso Bay). Advancing sheets of water carry clays to the western sections of the flats and nourish blue-green algal mats. Sedimentary events of this type are seasonal and infrequent on barrier island flats (Fisk, 1959; Herber, 1981).

Blue-green algal mats directly affect various sedimentation processes. When the mat is wet or wind velocity is too low to move sand, the mat acts a membrane keeping most transient sand separate until conditions are favorable for further transportation (Herber, 1981). When floodwaters lay over the mat for any length of time, the filamentous algae which compose it extend a few millimeters into the water. Clays settling from the water are intermixed with the algal carpet. When the mat is exposed for extended periods, a system of polygonal cracks forms and dry pieces of the mat are pulled up by the wind and blown across the flat. Curled laminae within the alternating laminated and massive gray clays attest to a long history of alternating wet and dry periods with concomitant algal growth and decay, resulting in diagenesis through bacterial action. Bacteria thrive in a reducing zone found directly beneath the mat surface and form massive gray clays by destroying organic portions of the algal mat (Fisk, 1959).

Although deflation is not a prominent process, when the algal mat becomes thoroughly desiccated, the resulting leathery crust cracks and peels away from the substrate. Clays exposed in cracks, 2-5 cm below the surface, aggregate into sand-sized granules which are blown across the flats (Fisk, 1959). These clay pellets provide the principal source of sediments for wind-accretion deposits such as clay dunes which fringe the landward edge of mainland wind-tidal flats (Brown et al., 1977). When the mat is flooded, bottom-feeding fish such as *Pogonias cromis* (black drum), *Sciaenops ocellata* (red drum), and *Mugil cephalus* (striped mullet) break the algal crust leaving small, circular pits that are readily scoured by wind when the mat is exposed (Fisk, 1959).

Wind-tidal flat sediments are composed of alternating layers of sand and mud. Flat sediments on barrier islands are texturally uniform and composed primarily of medium or fine sands (63-250 μm) (Withers, 1994). Bioturbation is virtually nonexistent as shown by distinctive alteration of sand and mud layers. Island flats are dominated by sand while mainland flats are dominated by mud. On all flats, thickness of sand layers decreases with depth while thickness of mud layers increases. Sand dominates on the eastward edge of a flat and decreases to the west, where mud becomes massive at the top and laminated at depth. Laminations are composed of organic rich layers alternating with authigenic mineral and mud. Shell is rare, limited to a few small shell berms on the islands and along the eastern margin of the mainland, and decreases westward (Herber, 1981).

Tidal flats in Baffin Bay and adjoining areas of the upper Laguna Madre contain abundant clay and sand lamina. Thick lamina composed of blue-green algae are also common. In areas where wind-tidal flow is restricted, algal-bound, gypsiferous clay and sand comprise the deposits. In locally depressed basins which retain water, thick clay lamina may be deposited interbedded with abundant algal mats (Brown et al., 1977). Clays in the northern lagoon area are probably transported by currents in Corpus Christi Bay, introducing material derived from both marine water entering Aransas Pass, and freshwater from the Nueces River. Smaller quantities of clay are derived from runoff from small streams which enter Baffin Bay and local runoff along the mainland margin (Fisk, 1959). Evaporite minerals (gypsum, halite, dolomite) are precipitated from thin sheets of water that advance across the flats. Shallow water is subject to high evaporation and salinity is greatly increased. Halite crystals which form on the tidal flat surface go into solution the next time the flat is inundated (Fisk, 1959; Brown et al., 1977).

3.1.5 Hydrology and Chemistry

3.1.5.1 Inundation and Exposure

Wind-tides are the primary cause of tidal flat flooding although astronomical tides may be important, particularly from Corpus Christi Bay northward. In deltaic and bay margin areas in the northern portion of the CCBNEP study area, astronomical tides may flood lower flats (approximately 0.25 m above MSL). Flats at elevations higher than 0.25 m above MSL are inundated mainly when winds are aligned to blow directly along the axis of the estuary. Bay waters are pumped through delta-plain marsh environments to flats via tidal creeks and small tidal passes during severe storms or long periods of persistent easterly or southeasterly winds (Brown et al., 1976).

In the upper Laguna Madre and Baffin Bay, effects of astronomical tides are virtually nonexistent, although once or twice a year they may temporarily meet or exceed wind tides (Brown et al., 1977). Mean annual tide range is about 10 cm, but the maximum range of water levels produced by wind tides is about 1 m (Fisk, 1959). Flooding of flats in upper Laguna Madre and upper reaches of Baffin Bay occurs at rates directly related to wind strength and persistence. Southeasterly winds of 13-17 km/hr forced water over flats in the Landcut 0.5 to 1.0 km/day. When wind speeds increased to 30-50 km/hr, the wind-tidal surge moved 4.2 to 6.1 km/day. Strong northerly winds pushed water completely across the Landcut in 36 hours at rates of 12 km/day (Fisk, 1959). During a 24 hour period with north winds of 8-20 km/hr, Amdurer (1978) noted a 6 cm rise in water level on a site on the Laguna Madre Flats (Kenedy County). When the wind direction changed, floodwater receded rapidly, with a drop of 3 cm in four hours. Complete inundation and exposure of a flat about 1 km wide in only a few hours has been observed on north Padre Island (K. Withers, pers. obs.). Areal exposure (mean number of hectares) of tidal flat study sites was generally as expected with greatest exposures during winter low tides (Fig. 3.6). Marker 83 (north Padre Island) and Fish Pass both experienced unexpected high tides during February, with virtually no exposure (≤0.05 ha) at Marker 83 during the two site visits that month.

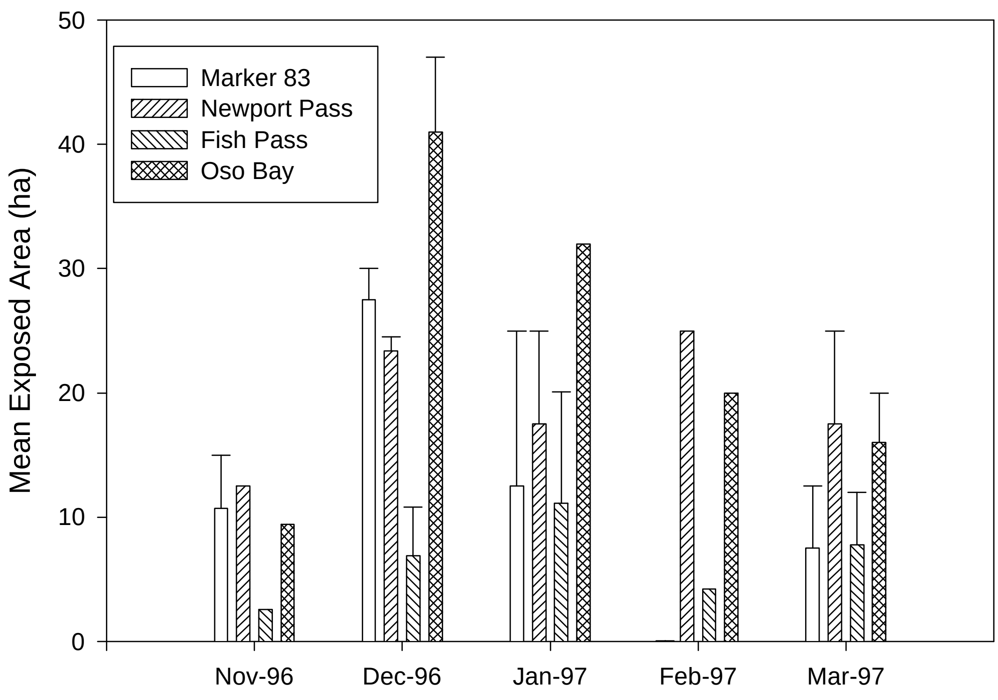


Fig. 3.6. Mean exposed area (ha) of tidal flats in the CCBNEP study area between November 1996 and March 1997.

3.1.5.2 Hydrologic Models

Hydrology of tidal flats in arid areas ("sabkhas") has been the subject of debate for many years. Four models have been proposed: seepage reflux (Adams and Rhodes, 1960), capillary fringe (Friedman and Sanders, 1967), evaporative pumping (Hsü and Siengenthaler, 1969), and flood-recharge (Butler, 1969; Masson, 1955). The reflux model proposes that because surface inflows of seawater are restricted, hypersaline brines formed in evaporating ponds on the surface of the sabkha percolate down through the sediment because it is denser than the underlying flood waters, and flows seaward at depth. This is a subaqueous process because reflux and evaporation takes place only while flood waters are present. The capillary fringe model is an extension of the normal flow regime for groundwater in coastal plains in which groundwater flows seaward through the sabkha. Interstitial water moves upward by capillary action where it evaporates, producing a caliche-like evaporite layer above the water table. In this model, dissolved solids and evaporite precipitates are derived from continental sources rather than seawater. The evaporative pumping model postulates that water moves upward in the sabkha to replace water lost near the surface by evaporation. With seawater recharge, the water table is level and slightly below high tide level. With continental recharge, the water table dips seaward and is located above the level of high tide (Amdurer, 1978; Long and Gudramovics, 1983). Flood-recharge is a subaerial process in which flood waters covering the sabkha are concentrated by evaporation and seep down into the sediment. Continued evaporation further concentrates subsurface water. Subsequent flooding by wind, tides, or rain results in more dilute waters near the surface. Movement of water in this model is caused by lowering the water table (Long and Gudramovics, 1983).

Amdurer (1978) stated the salient characteristic of hydrology in the Laguna Madre Flats (Kenedy County) was the extreme and rapid variability of surface conditions caused by sporadic and flashy distribution of precipitation combined with frequent episodes of wind-tidal flooding. In contrast, geochemistry of interstitial waters was relatively constant throughout the year. He found the dominant direction of water movement in the Sand Bulge was westward across the flats, away from the freshwater lens on Padre Island (Fig. 3.7). Infiltration of standing water, as proposed by the reflux hypothesis, was the most important source of interstitial water recharge. It did not occur at a uniform rate and each flooding episode did not necessarily lead to a substantial recharge. Laminated clays and sands and the impermeable algal mat isolate interstitial waters from surface conditions. Infiltration occurs in small areas where the algal mat has been eroded by wind during dry periods, but most recharge occurs through small brine ponds found after wind-tidal flooding. Reflux moves more concentrated surface brines to greater depths. Brine leaves the system either by reflux under Padre Island through entrenched Pleistocene stream valleys, mixing with the deeper, fresher regional groundwater, or by seepage into the Laguna Madre through the Gulf of Mexico.

Long and Gudromovics (1983) used bromide as a conservative indicator and found increased bromide concentrations at depth. Recharged waters moved down as salt fingers rather than a continuous salt sheet. They differentiated two water masses, one apparently derived from nonmarine parent water, possibly of continental origin, the other derived from the Laguna Madre.

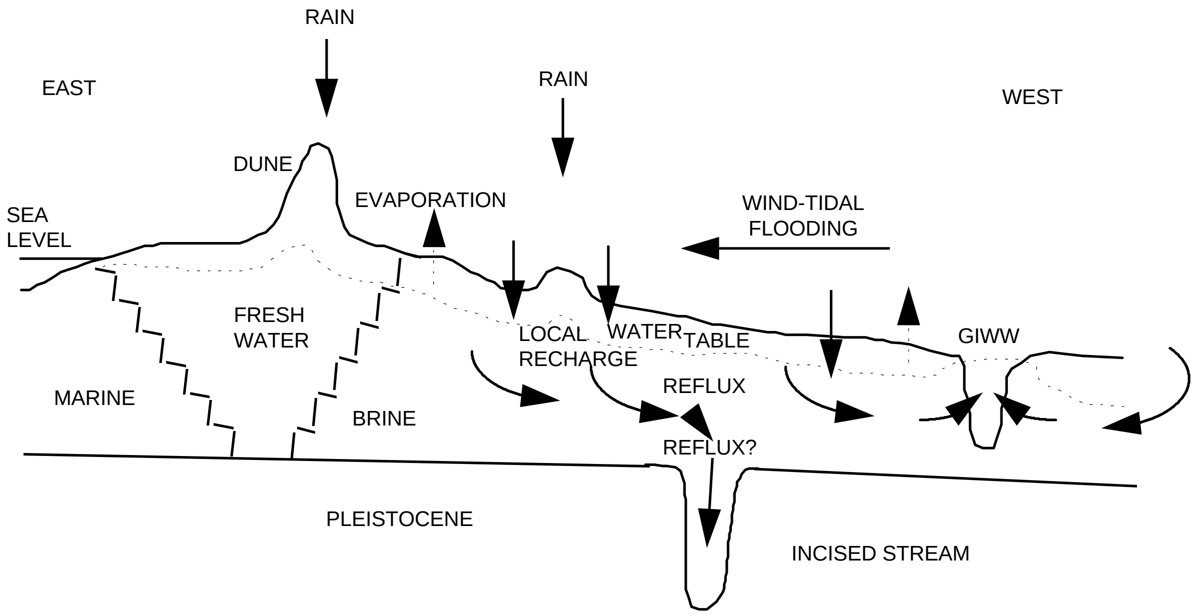


Fig. 3.7. Model of tidal flat hydrology in the Sand Bulge area of the Laguna Madre Flats (from Amdurer 1978).

They interpret their data as supporting the flood recharge model proposed by Fisk (1959) and Masson (1959) with reflux and evaporitic pumping of only minor importance.

Freshwater inflows to tidal flats in deltaic areas are greater than those along bay margins and inflows are greatest in areas with sources of permanent water such as the rivers and streams from the Nueces River north. Freshwater inputs to tidal flats in ephemeral stream valleys and along bay margins are unpredictable, and limited to rainfall. Prevalence of hypersaline conditions may account for the greater development of blue-green algal mats in these areas.

3.1.5.3 Salinity and Geochemistry

Salinities of bay and lagoon waters range from 10-15‰ in Copano Bay, 20-25‰ in Nueces Bay, to 30-40‰ or higher in the upper Laguna Madre and Baffin Bay (White et al., 1983; White et al., 1989). Salinities of water overlying tidal flats in the northern Laguna Madre ranged from 0-55‰. Pore water (10 cm deep) salinities in wet and damp microhabitats of blue-green algal flats in the upper Laguna Madre ranged from 0 - >160‰. Salinities were lowest following intense rainstorms, or protracted periods of rainfall (Withers, 1994).

South of the CCBNEP study area, geochemistry of tidal flat interstitial (pore) water in the area of the Laguna Madre Flats known as the Sand Bulge was determined (Amdurer, 1978). Chlorinity increased from east to west and with depth. Greatest change was at the fresh water - brine mixing zone where chlorinity increased from 5-8‰ to 79-94‰ at a depth of 1.5 m. The Na/Cl ratio and, to a lesser extent, the K/Cl ratio were generally slightly higher in interstitial waters than in seawater. Interstitial brines reached salinities up to 6.7 times (>200‰) that of the Gulf of

Mexico. Surprisingly, they were always undersaturated with respect to gypsum. Ca/Cl and HCO_3/Cl ratios in the brines dropped steadily with increasing salinities but sulfate concentrations were relatively conservative, increasing at about the same rate as chlorinity.

Chlorinity and Na/Cl and K/Cl ratios are generally considered to be conservative, that is, concentrations of ions are controlled by evaporation and/or dilution of source waters. Concentrations in the Sand Bulge area were consistent with the hydrologic model. However, behavior of Ca^{++} and SO_4^{--} was unexpected, with some reaction causing removal of calcium from interstitial brines or their source waters as they concentrate so that gypsum saturation does not occur in this area (Amdurer, 1978).

3.1.5.4 Blue-Green Algae and Precipitation of Carbonates

Several authors have suggested blue-green algae may be indirectly involved in precipitation of carbonates (Dalyrymple, 1965; Davies, 1970; Friedman et al., 1973; Logan, 1974; Monty, 1967). Algal micrites (cryptocrystalline aragonite intermeshed with mucilaginous organic material), have been found in close association with blue-green algal mats in Baffin Bay (Rusnak, 1960; Dalrymple, 1965), Middle Ground (Zupan, 1971), and the Sand Bulge (Amdurer, 1978). Grains of algal micrite occurred within the algal mats, between algal laminations, and in the sediment just below mats.

Several hypotheses have been advanced to explain formation of algal micrite grains, directly or indirectly involving organic activity associated with the mat. Removal of CO_2 from surface brine ponds by algal photosynthesis substantially alters carbonate equilibrium in ponds (Oppenheimer and Master, 1965). Monty (1967), Friedman et al. (1973), and Logan (1974) concluded this process promoted precipitation of either cryptocrystalline aragonite or magnesium calcite in a lagoon on Andros Island (Bahamas), an algal pool adjacent to the Gulf of Aqaba (Red Sea), and the supratidal facies at Shark Bay (Australia), respectively. Dalrymple (1965) found no evidence for this process in Baffin Bay, but both Masson (1955) and Fisk (1959) found carbonates on the surface of the Laguna Madre Flats. Carbonate was also found on the surface of the Sand Bulge, as well as in frothy, white scum found on the surface of brine ponds in the same area (Amdurer, 1978) indicating reduction of CO_2 by algal photosynthesis could not be ruled out. The second process for precipitation of algal micrite involves decomposition of organic matter in algal mats by sulfate-reducing or ammonifying bacteria (Purdy, 1963; Berner 1971). Bacteria causing these reactions are abundant in reducing environments just below the algal mat (Fisk, 1959; Sorenson and Conover, 1962). Dalrymple (1965) found evidence for this process in algal mats in Baffin Bay.

3.2 Producers and Decomposers

3.2.1 Primary Producers

Tidal flats are halophilic, semi-terrestrial ecosystems because variability in flooding frequency and duration of exposure between flooding causes in dry, hypersaline conditions which prevent establishment of macrophytic vegetation (Pulich et al., 1982). Benthic microalgae, which may form felt-like or leathery mats on sediment surfaces, are the major primary producers found on tidal flats in the CCBNEP study area. In low-energy, hypersaline areas, mats consisting mostly of filamentous blue-green algae are found. These mats range in thickness from 1-2 mm to nearly 3 cm (Withers, 1994). Classification of blue-green algae is problematical, and taxonomy follows Dr. Francis Drouet as summarized by Humm and Wicks (1980), except where noted. *Lyngbya confervoides* (classification of Bold and Wynne [1978]; Drouet classification *Microcoleus lyngbyaceus*), constitutes a minimum of 70% of the living community. *Microcoleus* spp., *Anabaena* spp., *Oscillatoria* spp., *Anacystis* spp., *Schizothrix arenaria*, *S. tenerrimus, S. salcicola*, *Spirulina subsala*, and *Johannesbaptistia pellucida* are found in small amounts (maximum 25% cover) (Fisk, 1959; Armstrong and Odum, 1964; Dykstra, 1966; Zupan, 1971; Herber, 1981; Pulich et al., 1982; Pulich and Rabalais, 1986). Pennate diatoms such as *Nitzschia*, *Navicula*, and *Pleurosigma* (<10% total algal biomass) may also be found interspersed among blue-green algae, particularly at moderate salinities (<60‰) (Simmons, 1957; Sorenson and Conover, 1962; Pulich et al., 1982; Pulich and Rabalais, 1986). Blue-green algal mats in the Laguna Madre do not usually contain green algae, unlike those in California and Mississippi (Pulich and Rabalais, 1986).

There has been no research on the benthic microflora of non-algal wind-tidal flats in the CCBNEP study area. In other areas benthic diatoms (Cadée and Hegeman, 1974), benthic dinoflagellates, filamentous green algae, and euglenoids are found on intertidal flats. Benthic diatoms may form films which color sediment surfaces brown, and green microalgae may tint sediments bright green. The most numerous diatoms are usually pennate forms such as *Nitzschia*, and *Navicula* (Peterson and Peterson, 1979; Whitlach, 1982). Benthic diatoms may form dense, multilayered sheets (Pamatmat, 1968).

Photosynthetic and chemosynthetic bacteria may contribute significantly to primary productivity (Lyons and Gaudette, 1979; Howarth and Teal, 1980). Photosynthetic purple sulfur bacteria such as *Chromatium* spp., *Desulfovibrio* spp. and *Beggiatoa* spp. (Sorenson and Conover, 1962; Armstrong and Odum, 1964; Pulich et al., 1982) and photosynthetic green and purple, nonsulfur bacteria (Horodyski, 1977) have been found with blue-green algal mats in the CCBNEP study area. They are undoubtedly found in sediments of non-algal flats as well, but their occurrence in the CCBNEP study area has not been documented.

When intertidal flats are flooded, phytoplankton are found in waters overlying flats. Little information is available concerning species composition of phytoplankton in these flood waters in the CCBNEP study area. On one occasion, water overlying a tidal flat in Oso Bay contained the diatoms *Nitschizia* (55.6%), *Navicula* (33.3%) and *Pleurosigma* (11.1%) (Hildebrand and King, 1978). Phytoplankton abundances were lowest during summer when temperatures and salinities rise in shallow waters, and highest during winter and early spring (Henley and Rauschuber, 1978). Phytoplankton abundance in tidal flat waters is influenced by nutrient concentrations, water temperature and circulation patterns, and grazing (Whitlach, 1982). In North Carolina tidal flats, various diatoms, especially *Skeletonema*, dominated the phytoplankton assemblage (Peterson and Peterson, 1979). In New England, diatoms were most abundant in cooler waters, whereas dinoflagellates predominated in warmer waters (Whitlach, 1982). The phytoplankton community in shallow estuaries was not diverse, usually consisting of large
concentrations of only one or two

species. This pattern was likely due to physically unstable inshore conditions favoring motile species that do not sink to the bottom in shallow water (Hurlburt, 1956; 1963).

Fleshy, benthic macroalgae are not found on tidal flats in the CCBNEP study area and vascular plants are rare to nonexistent. Scattered salt marsh vegetation may be found, particularly along tidal channels that drain and fill flats, or after extended rainfall. Common species are *Salicornia virginica, S. bigelovii*, and *Batis maritima*. Some tidal channels are fringed by *Spartina alterniflora*. *Avicennia germinans* may be found fringing tidal channels in the Aransas Pass area (Herber, 1981; White et al., 1983; Pulich and Scanlon, 1987; K. Withers, pers. obs.).

3.2.2 Secondary Producers

Invertebrates which live in the blue-green algal mat, or sediments (benthos) provide the link between primary producers and higher consumers such as birds and fish. On flats which stay wet or damp throughout most of the year (e.g., back sides of barrier islands), an abundant and diverse macroinvertebrate fauna consisting of deposit- or suspension-feeders or grazers develops (Withers, 1994). On drier flats, (e.g., Laguna Madre Flats and other flats south of the CCBNEP study area), invertebrates may be limited to saltwater-adapted insects living on the surface (Pulich et al., 1982).

3.2.2.1 <u>Macrofauna</u>

3.2.2.1.1 *Non-algal Flats (Blind Oso)*

Twenty-seven macroinvertebrate species (five phyla) were found between March 1991-March 1992 (T. Barrera unpubl. data) (Appendix 1). There was a diverse assemblage of arthropods (17 species in 11 families). Amphipods, primarily *Corophium louisianum*, were the most abundant organisms on the flat. Polychaetes were also common; eight polychaete species (five families) were recovered. Spionids, primarily *Polydora ligni*, dominated. Benthic organisms were most abundant during November and December, followed by January, February, March, and June.

In the present study (November 1996-March 1997), 24 invertebrate taxa were found (Appendix 1). Unlike the Barrera's study, the arthropod assemblage was not diverse. Only one species of amphipod, *Corophium louisianum* was found during this study. Polychaetes (six families, 13 species) were the most common and abundant organisms recovered. *Capitella capitata* (Family Capitellidae) and *Streblospio benedicti* (Family Spionidae) dominated. Numbers peaked in December (Fig. 3.8) then steadily declined until March when they increased slightly.

3.2.2.1.2 *Algal Flats (Padre Island, Mustang Island)*

Withers (1994) identified 51 invertebrate taxa were identified from a blue-green algal flat on north Padre Island (Marker 83) and 65 taxa were identified from a similar flat on Mustang Island (Corpus Christi Pass) between October 1991-October 1993 (Appendix 1). *Hargeria rapax*, a tanaid, was the most common and abundant organism found on both flats. Polychaetes and insect larvae, primarily dipterans, were also common. Sixteen polychaete species (nine families) were found on Padre Island, 28 species (16 families) were recorded on Mustang Island. Dominant polychaete families on Padre Island were, in order of abundance: Capitellidae, Orbiniidae, Sabellidae, Spionidae, and Syllidae. Dominant polychaete families on Mustang Island were, in order of abundance: Spionidae, Orbiniidae, Capitellidae, Maldanidae, and Phyllodocidae. Dominant insects on both sites were dipteran families Canaceidae and Dolichopodidae. Benthic organisms were generally most abundant during winter and spring (Fig. 3.9). Mean numbers on north Padre Island were much lower during winter-spring 1993 than during winter spring 1992; the opposite trend was seen on Mustang Island.

In the present study (November 1996-March 1997), far fewer taxa were recovered during 1991-1993. Only 11 invertebrate taxa were identified from the same north Padre Island site (Marker 83), only 22 taxa were recovered from Newport Pass and 21 taxa from Fish Pass on Mustang Island; these passes are located on either side of the 1991-1993 study area at Corpus Christi Pass. Insects, primarily larvae of the dipteran families Canaceidae and Dolichopodidae, dominated the assemblage at all three sites. Polychaetes were the next most abundant group on Padre Island and Newport Pass, but only five species (three families) were recovered from Padre Island, with 11 species (seven families) from Newport Pass and eight species (six families) from Fish Pass.

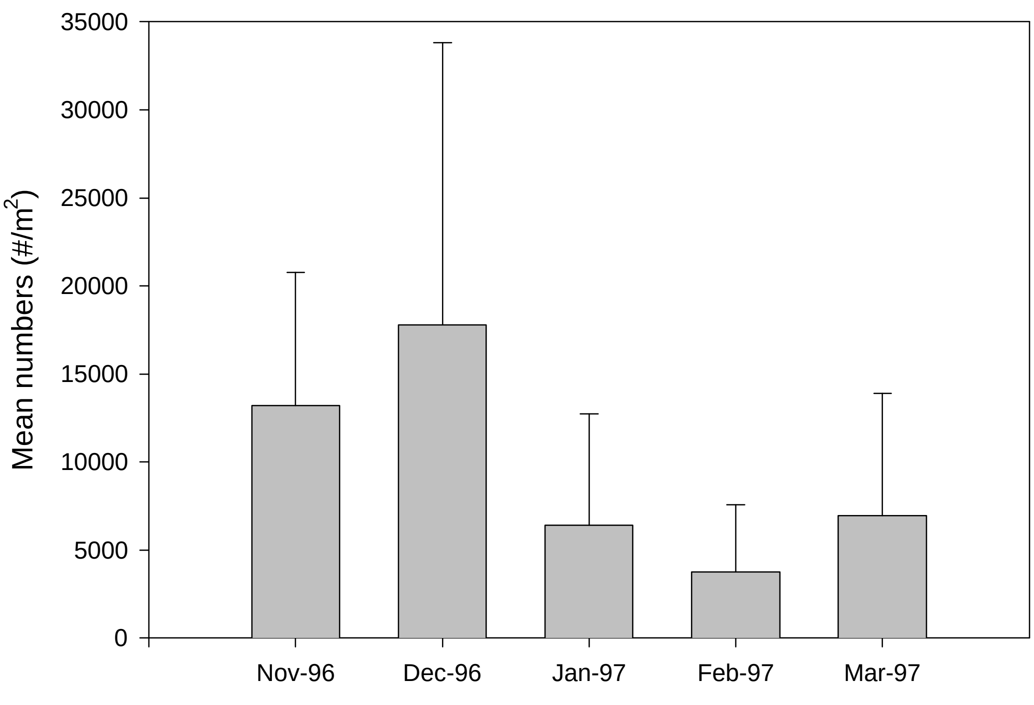


Fig. 3.8. Mean abundance (number/m^2; error bars = +1 standard error) of benthic invertebrates collected from the Blind Oso mudflat between November 1996 and March 1997.

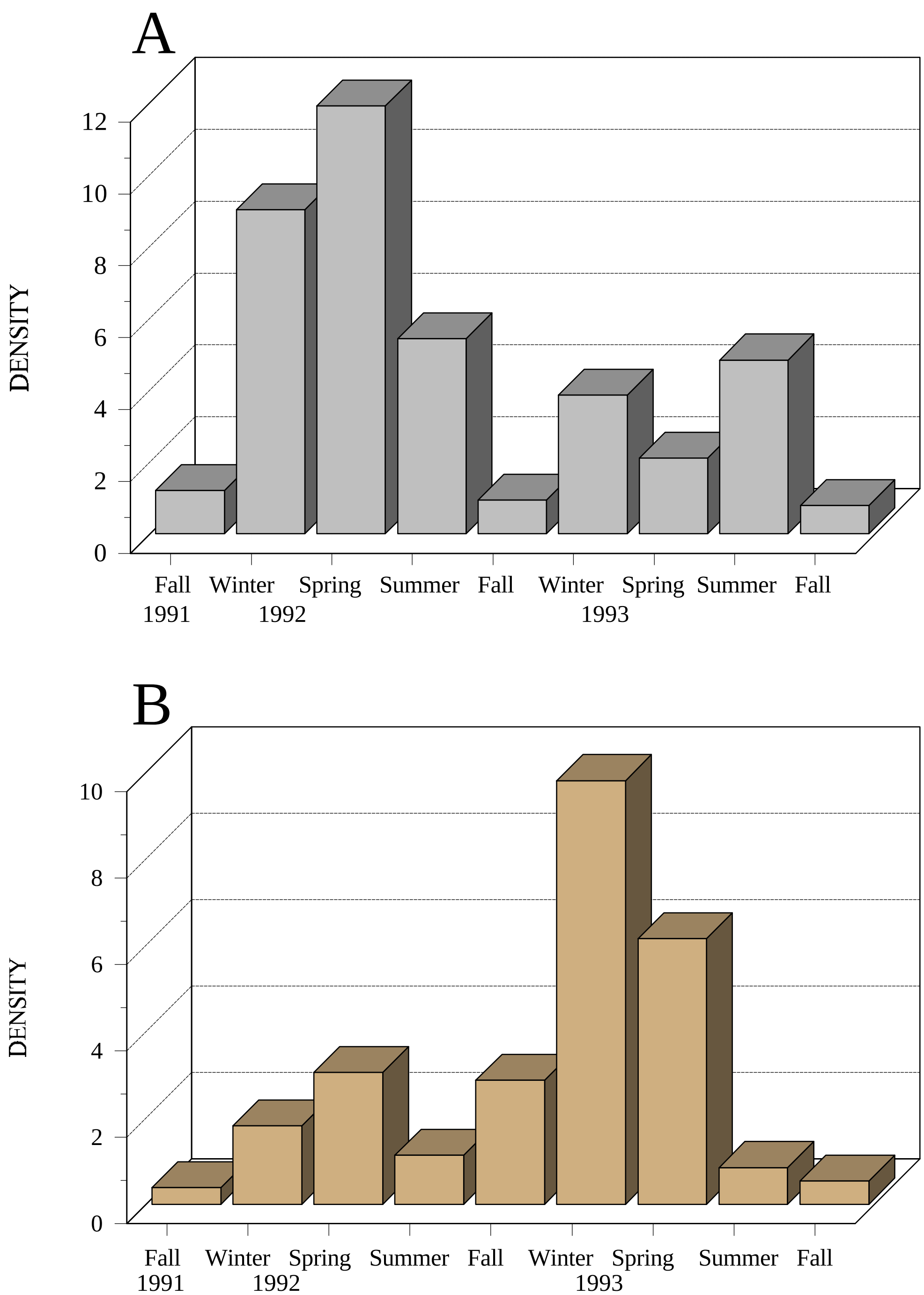


Fig. 3.9. Mean densities of organisms ($10^3/m^2$) in the top 10 cm of sediment by season from algal flats on northern Padre Island (A) and Mustang Island (B) (Withers, 1994).

Eteone heteropoda (Phyllodocidae) and *Haploscoloplos foliosus* (Orbiniidae) were recovered most frequently at all three sites. Amphipods (*Corophium* spp.) dominated with insects at Fish Pass. *Hargeria rapax*, which was the dominant organism found during 1991-1993, was only rarely recovered during this study, and was most commonly found at Newport Pass. Numbers were low throughout the study on Padre Island (Fig. 3.10); abundance peaked during March at both Newport and Fish passes.

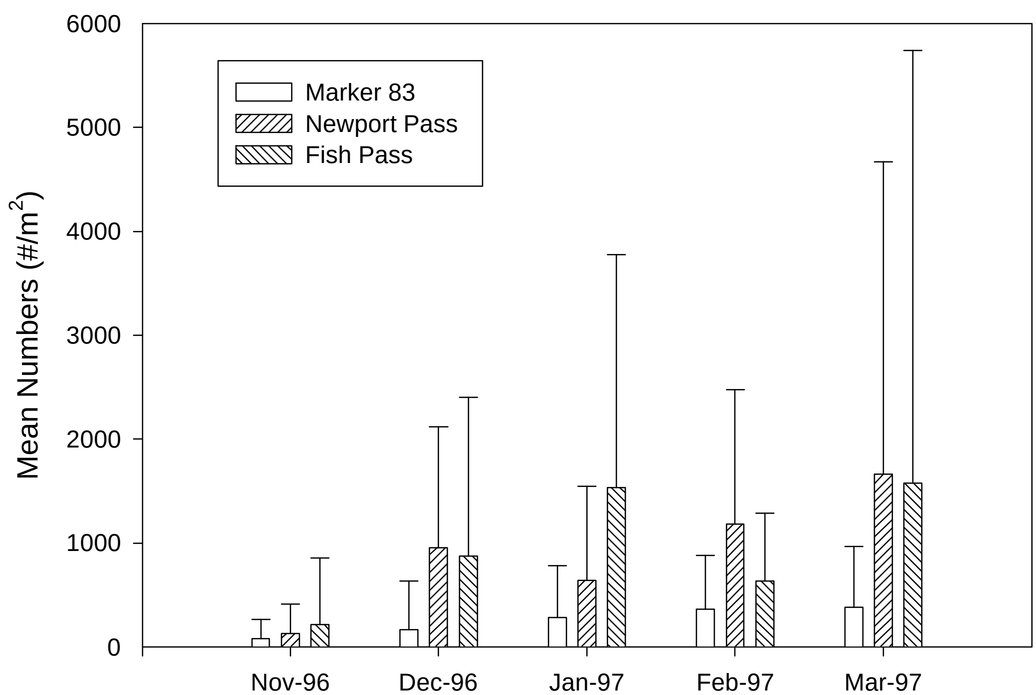


Fig 3.10. Mean numbers of macrofauna (number/m^2; error bars = +1 standard error) recovered from algal flats in the upper Laguna Madre from November 1996 - March 1997.

3.2.2.1.3 *Summary and Comparison of CCBNEP Tidal Flat Macrofauna*

Faunas described for the Blind Oso differ primarily in abundance and diversity of arthropods recovered. Between 1991-1992, 17 species were collected of which 13 were amphipod species. In the present study, only four arthropod species were collected, with only one amphipod species. These differences are likely due to different size and type of sampling gears employed in 1991-1992 (10 cm core sampler and marsh sled vs. 5.4 cm core sampler) as well as sampling of additional habitats near Hans Suter Park. Overall abundance patterns during winter and early spring were similar.

Some obvious differences existed between benthic faunas of the two upper Laguna Madre algal flats studied between 1991-1993. The polychaete fauna of the Corpus Christi Pass (Mustang

Island) flat was much more diverse than the north Padre Island flat, probably due to its proximity to seagrass beds and Corpus Christi Bay (Withers, 1994). During the present study the same pattern was noted, with greater numbers of polychaete species recovered from Mustang Island sites. The most notable difference between the present study and the 1991-1993 study was lack of dominance by tanaids at any site. In addition, numbers remain very low and show little fluctuation at Marker 83, and are much lower than reported for winter-spring 1993. This may be due to the brown tide which appeared to cause a reduction in both macrobenthic biomass and abundance (Buskey, 1996). Mean numbers on Mustang Island flats were also lower during the present study than during winter-spring 1993.

Differences between the non-algal Blind Oso flat and upper Laguna Madre algal flats are likely due to differences in sediment type (i.e., sand vs clay) and hydrology, which attests to the importance of these factors in determining species composition. In addition, the Blind Oso receives wastewater from the Oso Wastewater Treatment Plant and the assemblage of polychaetes recovered in the present study dominated by opportunistic species such as *Capitella capitata* and *Streblospio benedicti* is consistent with what would be expected if moderate organic enrichment was occurring. Differences in both species and abundances noted between the present study and previous studies underscore potential for extreme temporal variability in tidal flat invertebrate communities, and the need for multi-year studies to determine composition and abundance of "typical" invertebrate communities.

3.2.2.2 <u>Meiofauna</u>

Composition of the meiofaunal community of tidal flats in the CCBNEP study area is unknown. Some meiofaunal species (i.e., turbellarians, nematodes) were recovered incidentally when sampling for benthic macrofauna (Withers, 1994; T. Barrera, unpubl. data), but no systematic sampling for meiofauna has been attempted. Composition of meiofaunal communities in sandflats differs considerably from that of mudflats, primarily due to differences in interstitial spaces in sediments. Meiofauna inhabiting sandflats are generally interstitial organisms such as gastrotrichs and turbellarians, while those inhabiting mudflats are restricted to surface sediments. Mud meiofauna generally have large, stocky bodies, whereas sand meiofauna are smaller, vermiform animals (McIntyre, 1969). Meiofaunal communities in intertidal flats in North Carolina were dominated by nematodes, a pattern of abundance apparently typical of shallow marine sediments worldwide. Harpacticoid copepods were the second most abundant taxon. Others of importance were gastrotrichs, turbellarians, and gnathostomulids (Peterson and Peterson, 1979). Seasonal progressions of harpaticoids occurred regularly on mud flats in North Carolina, but in sandy habitats there was no predictable pattern of variation in abundance (Coull and Fleeger, 1977).

3.2.2.3 <u>Microfauna</u>

No information was found concerning microfauna of tidal flats in the CCBNEP study area; information is sparse in the literature as well. Microfauna includes all protozoans. Ciliates and foraminiferans can be extremely abundant on some intertidal flats. Their ecological role is poorly understood (Peterson and Peterson, 1979).

3.2.2.4 Temporary Zooplankton

Like microfauna, information concerning the temporary zooplankton communities of flooded tidal flats is lacking in both the CCBNEP study area and the literature. Zooplankton, particularly larval polychaetes, were most abundant in the upper Laguna Madre during September and October (Hildebrand and King, 1978). Increased numbers of polychaetes inside predator exclosures during November 1992 on north Padre Island, compared with initial densities when exclosures were erected during September 1992, indicated recruitment of benthic organisms to the flat had occurred. It is likely most recruitment was due to settling of larval polychaetes from the water column during seasonal high tides in September and October (Withers, 1994).

3.2.3 Decomposers

Microbial decomposition of organic material is the primary link between primary and secondary production (Odum and de la Cruz, 1967). A variety of fungi and bacteria are predominantly responsible for decomposition of detrital material on tidal flats (Peterson and Peterson, 1979; Whitlach, 1982). Dead plant matter often cannot be used directly by detritivores, but some polychaetes have the enzyme cellulase which aids in detrital breakdown (P. Montagna, UTMSI, pers. comm.). Both bacteria and fungi tend to be more abundant in sediments of mud flats because small-sized clay particles have greater surface areas than larger-sized, coarser sediments such as sands (Peterson and Peterson, 1979). However, in bay margin flats around Redfish Bay, coarse surface sediments generally had larger bacterial populations than clays (Volkmann and Oppenheimer, 1962). Bacteria are also associated with interstitial water (Whitlach, 1982). Most detritus produced in estuaries ultimately reaches intertidal flats because it floats on the water's surface, and is deposited by winds and tides in the intertidal zone. After deposition, detritus is fragmented and processed by organisms, and is gradually worked into sediments. Detrital content of intertidal flats can be substantial (Odum, 1970), especially on mud flats, providing abundant food for detritivores (Peterson and Peterson, 1979).

Decomposer communities of tidal flats in the CCBNEP study area have not been studied extensively. On the Laguna Madre Flats south of the CCBNEP study area, anaerobic, non-photosynthetic bacteria thrived in the reducing zone found just below the algal mat (Fisk, 1959; Herber, 1981). Bacterial counts of samples from an area where the reducing zone was 40 cm thick indicated densities decreased with depth. At the top of the zone, there were >40,000,000 bacteria/g, whereas at the base there were <6,000 bacteria/g (Fisk, 1959). However, on flat areas around the margin of Redfish Bay, bacterial numbers did not decrease consistently with sample depth unless sediment profiles had homogeneous textures (Volkmann and Oppenheimer, 1962). Bacterial abundance declined significantly with depth in an intertidal marsh, suggesting resources for detritivores were most abundant in surface sediments (Peterson and Peterson, 1979). Around Redfish Bay, highest numbers of bacteria were found in sediments in spring reflecting increased decomposition; there was also a distinct change from predominantly rod forms to several other types of microorganisms (Volkmann and Oppenheimer, 1962).

3.3 Consumers

3.3.1 Invertebrates

Benthic invertebrates discussed in section 3.2.2 Secondary Producers are primary consumers on flats as well, feeding on bacteria and/or meiofauna, detritus, each other, or grazing on blue-green algae (Table 3.3). Most polychaetes on upper Laguna Madre flats are deposit feeders, feeding on particulate organic matter (detritus) or gleaning protozoans, bacteria, and diatoms from sediment grains. Only one filter-feeding family (Sabellidae), was collected. Predatory families such as Phyllodocidae were not abundant. Molluscs were never abundant. Gastropods recovered were grazing herbivores, bivalves were deposit feeders, and most crustaceans were grazers or scavengers. Larval and adult insects were dominant predators among benthic invertebrates (Withers, 1994; the present study). Predatory beetles and hemipterans were the most common and abundant invertebrate consumers on the Laguna Madre Flats to the south of the CCBNEP study area. Spiders (Lycosidae [wolf spiders] and Clubionidae [sac spiders]), feed in cracks in algal mats, preying on small insects and other invertebrates (Pulich et al., 1982).

Crabs are the other invertebrate consumers frequently found on flats. *Callinectes sapidus* (blue crab) are common when flats are flooded, and are generally scavengers. *Uca* spp., primarily *Uca subcylindrica* (fiddler crab), are common in drier areas of flats and during the summer; they feed on a variety of foods including meiofauna and polychaetes.

3.3.2 Nekton

When flats are flooded, nektonic organisms may be present on the flats. The Blind Oso study (T. Barrera unpubl. data) addressed nekton using the flats in detail. *Penaeus aztecus* (brown shrimp) and amphipods, primarily *Corophium louisianum*, were the most abundant invertebrate nekton recovered (Table 3.4). Other common species encountered were *Palaemonetes* spp. (grass shrimp), *Mysidopsis almyra*, and *C. sapidus*. *Cyprinodon variegatus* (sheepshead minnow) was the most abundant fish found in the Blind Oso along with *Fundulus grandis* (Gulf killifish) and *Membras martinica* (rough silverside) (T. Barrera unpubl. data) (Table 3.4). Ten species of primarily juvenile individuals were recovered from the Blind Oso.

When Mustang Island flats were flooded, *C. variegatus*, *Fundulus* spp. (killifish), *Menidia beryllina* (tidewater silversides), *Palaemonetes* spp., *Penaeus* spp., *C. sapidus*, (blue crab) *Mugil* spp. (mullet), *Lagodon rhomboides* (pinfish), and a variety of unidentified juvenile fish were recorded (Brogden et al., 1977). *Cyprinodon variegatus* was also the most abundant fish on southerly Laguna Madre flats along with *Fundulus similis*, and *Menidia* spp. (silversides). Larval *Synodus foetens* (inshore lizard fish) were plentiful on one occasion during spring (Pulich et al., 1982). *Cyprinodon variegatus* was the only fish caught on upper Laguna Madre flats during 1991-1993. Adult *Paralichthys lethostigma* (southern flounder) were occasionally flushed from the sediments in shallow water just off the flats, with schools of small (“finger”) *Mugil cephalus* in ankle-deep water (K. Withers, unpubl. data). Both *C. variegatus*

Table 3.3. Consumer-types of major secondary producer taxa found on blue-green algal flats in the upper Laguna Madre. Categories after Merritt and Cummins (1984) and Uebelacker and Johnson (1984). S=shredders; DF=deposit feeder; FF=filter feeder; Sc=scraper; P=predator; Ps=parasitoid; Sv=scavenger. Shredders and deposit feeders are generally detritivores, scrapers are grazing herbivores.

Taxon	Consumer-Type
P. Annelida	
C. Polychaeta	
F. Phyllodocidae	P
F. Spionidae	DF, P
F. Capitellidae	DF
F. Maldanidae	DF
F. Arenicolidae	DF
F. Syllidae	P, DF
F. Sabellidae	FF
F. Ampharetidae	DF
F. Lumbrineridae	P, Sv
F. Eunicidae	Sc, DF
F. Orbiniidae	DF
F. Dorvilleidae	P
F. Terebellidae	DF
F. Paranoidae	DF
F. Nereidae	P, DF, Sv, Sc
P. Mollusca	
C. Gastropoda	
F. Bullidae	Sc
F. Acteocinidae	Sc
F. Cerithidae	Sc
C. Bivalvia	
F. Solenidae	FF
F. Mactridae	FF
F. Tellinidae	FF
F. Veneridae	FF
F. Mytilidae	FF
F. Corbiculidae	FF
SP. Crustacea	
C. Malacostraca	
O. Cumacea	
F. Diastylidae	FF, DF
O. Isopoda	
F. Sphaeromatidae	S

Table 3.3. Continued.

Taxon	Consumer-Type
O. Amphipoda	S, DF, Sv
O. Tanaidacea	Sc
SP. Insecta	
O. Diptera	
F. Canaceidae	Sc
F. Ceratopogonidae	P, DF
F. Simulidae	FF
F. Empididae	DF, S
F. Dolichopodidae	P
O. Coleoptera	
F. Carabidae	P
F. Curculionidae	S
F. Dysticidae	P
F. Hydrophilidae	Larvae=P, Adults=DF
F. Melyridae	P
F. Salpingidae	P, S
F. Staphylinidae	P
O. Collembola	
F. Entomybryidae	DF, Sv
O. Hemiptera	
F. Saldidae	P
F. Nabidae	P
F. Hebridae	P
O. Hymenoptera	
F. Eulophidae	Ps
F. Scelionidae	Ps
F. Pteromalidae	Ps
O. Odonata	
F. Aeshnidae	P
O. Plecoptera	
F. Leuctridae	S
SP. Chelicerata	P

and *Fundulus* spp. eat algae and detritus as juveniles. When they exceed 30 mm total length, they feed on crustaceans, small fish, and insects (Harrington and Harrington, 1972; Pfeiffer and Wiegert, 1981). As water recedes, they move into deeper water where they are prey for larger fish such as *Sciaenops ocellata* and *Cynoscion nebulosus* (spotted sea trout) (Pulich et al., 1982).

3.3.3 Reptiles and Amphibians

No information was found concerning reptile and amphibian occurrence on tidal flats. Because of the biologically harsh conditions, it is doubtful either group would occur on tidal flats except by chance.

3.3.4 Birds

Shorebirds (Charadriiformes) are the most conspicuous vertebrate consumers on flats. They feed on benthic invertebrate infauna and epifauna, and feed opportunistically on fiddler crabs, small fish and shrimp. Seasonal abundance of and habitat use by shorebirds was studied on blue-green algal flats in the upper Laguna Madre (Withers, 1994) and on a mudflat in Oso Bay (Withers and Chapman, 1993). Wading birds such as Great Blue Heron (*Ardea herodias*) and Reddish Egret (*Egretta rufescens*) are common in shallow waters adjacent to flats. Bay ducks such as scaup (*Aythya* spp.) and Redheads (*Aythya americana*) often feed in seagrass beds near flats.

Gulls and terns (Laridae) are often abundant, and use flats as “loafing” areas. Tidal flats are important foraging habitat for wintering Peregrine Falcon (*Falco peregrinus*), particularly south of the CCBNEP study area. Other birds such as Horned Lark (*Eremophila alpestris*), Barn Swallow (*Hirundo rustica*), Boat-tailed Grackle (*Quiscalus major*), Sandhill Crane (*Grus canadensis*), White Pelican (*Pelecanus erythrorhynchos*), Black Skimmer (*Rhynchops niger*), and Canada Goose (*Branta canadensis*) turn up occasionally on flats or in shallow adjacent waters (K. Withers, pers. obs.).

3.3.4.1 <u>Shorebirds</u>

3.3.4.1.1 *Non-algal Flats (Oso Bay)*

Twenty-six species of shorebirds used the Oso Bay mudflat (Table 3.5); 34,822 individuals were observed between January 1985-January 1986 (Withers and Chapman, 1993). Peeps (primarily Western Sandpiper [*Calidris mauri*] and Semipalmated Sandpiper [*C. semipalmatus*]) were the most common and abundant species, followed by dowitchers (*Limnodromous* spp.), Dunlin (*Calidris alpina*), and American Avocet (*Recurvirostra americana*). Densities were greatest during spring migration (February-April) and winter (November-January). The area did not appear to be an important stopover for high numbers of birds during fall (Fig. 3.11).

In the present study (November 1996-March 1997), only 12 species (n = 6,044)were observed in the Blind Oso mudflat (Table 3.5). Fewer species were observed than during 1985-1986 (Withers and Chapman, 1993) because this study did not encompass an entire year. The three most common species were the same as reported by Withers and Chapman (1993). Numbers

Table 3.4. Nektonic species recovered from the Blind Oso wind tidal flat. Flat was sampled when flooded with a marsh seine (T. Barrera unpubl. data). D=demersal; C=carnivore; H=herbivore; Dt=detritivore; O=omnivore; Sc=scavenger; Df=deposit feeder.

Taxon	Consumer-Type
P. Arthropoda	
SP. Crustacea	
C. Ostracoda	H, Sc, C, Dt
C. Malacostraca	
O. Mysidacea	
F. Mysidea	
Mysidopsis almyra	Dt
O. Tanaidacea	
F. Paratanaidae	
Hargeria rapax	H
O. Amphipoda	
F. Gammarida	C, Sc
Gammarus mucronatus	
F. Melitidae	Dt, Sc?
Melita dentata	
F. Hyalellidae	Dt, Sc?
Hyale frequens	
F. Corophiidae	Df
Corophium volutor	
Corophium louisianum	
Corophium asherusicum	
O. Decapoda	
F. Penaeidae	O
Penaeus aztecus	
P. setiferus	
P. duorarum	
F. Palaemonidae	H, Dt
Palaemonetes pugio	
P. intermedius	
P. vulgaris	
F. Portunidae	Sc
Callinectes sapidus	
SP. Insecta	
O. Hemiptera	
F. Corixidae	
Hesperocorixa	H
O. Diptera	
F. Ephydridae	DF, S, Sc

Table 3.4. Continued.

Taxon	Consumer-Type
P. Chordata	
SP. Vertebrata	
C. Osteichthys	
O. Elopiformes	
F. Elopidae	P
Elops saurus	
O. Clupeiformes	
F. Clupeidae	H
Brevoortia patronus	
O. Cyprinodontiformes	
F. Cyprinidontidae	
Cyprinodon variegatus	Juveniles=H; Adults=C
Fundulus grandis	Juveniles=H; Adults=C
O. Antheriformes	
F. Antherinidae	H
Membras martinica	
Menidia beryllina	
F. Sciaenidae	P
Leiostomus xanthurus	
F. Mugilidae	H
Mugil cephalus	
F. Gobiidae	H
Gobionellus boleosoma	
O. Pleuronectiformes	
F. Bothidae	D, C
Paralichthys lethostigma	

were greatest during November and March (Fig. 3.12). More birds may be using this area during fall because of apparent changes in hydrology which cause greater inundation of the Blind Oso area than were observed during 1985-1986 (K. Withers, pers. obs.)

3.3.4.1.2 *Algal Flats (Padre and Mustang Island)*

Twenty-four species of shorebirds were observed on the algal flats on Padre and Mustang islands (Table 3.5) between October 1991-October 1993 (Withers, 1994). Peeps, Dunlin, and Least Sandpipers (*C. minutilla*) were the most common and abundant species on both flats, followed by dowitchers and Piping Plovers (*Charadrius melodus*) on Padre Island and Piping Plovers and Snowy Plovers (*C. alexandrinus*) on Mustang Island. A total of 19,045 shorebirds

Table 3.5. Shorebird species observed on blue-green algal flats on Padre and Mustang islands, and on mudflats in Oso Bay ranked by total abundance during the study. Blank = none observed. Studies used: Padre Island - I = Withers (1994), II = the present study; Mustang - CC = Corpus Christi Pass, Withers (1994), New = Newport Pass, the present study, Fish = Fish Pass, the present study; Oso Bay - I = Withers and Chapman (1993), II = Blind Oso, the present study.

	Padre Island		Mustang Island			Oso Bay	
Species	I	II	CC	New	Fish	I	II
Peeps (*Calidris mauri, C. semipalmatus*)	1	1	1	1	1	1	1
Dunlin (*Calidris alpina*)	2	2	2	2	2	3	3
Least Sandpiper (*Calidris minutilla*)	3	3	3	4	3		9*
Dowitchers (*Limnodromous* spp.)	4		12	6		2	2
Piping Plover (*Charadrius melodus*)	5	4	4	5	5	21	10
Snowy Plover (*Charadrius alexandrinus*)	6	5	6	7	6	15	
Willet (*Cataptrophorus semipalmatus*)	7	6*	8	9	8	7	8
Sanderling (*Calidris alba*)	8	7	5	3	4	9	9*
Black-bellied Plover (*Pluvialis squatorola*)	9	6*	7	11	9	5	4
Long-billed Curlew (*Numenius americanus*)	10		14		7	12	
Ruddy Turnstone (*Arenaria interpres*)	11		15	8	12	17	11
Red Knot (*Calidris canutus*)	12		19				
Semipalmated Plover (*Charadrius semipalmatus*)	13		18	10		11	6
Marbled Godwit (*Limosa fedoa*)	14		11			6	7
American Avocet (*Recurvirostra americana*)	15					4	5
Lesser Yellowlegs (*Tringa flavipes*)	16	9	22	12	10	14	
Black-necked Stilt (*Himantopus mexicanus*)	17	8	21			8	
Greater Yellowlegs (*Tringa melanoleucus*)	18		16			19	
Wilson's Plover (*Charadrus wilsonia*)	19		10		11	10	
Baird's Sandpiper (*Calidris bairdii*)	20		15			22	
Wilson's Phalarope (*Phalaropus tricolor*)	21		20			18	
American Oystercatcher (*Haematopus palliatus*)	22		13				
Spotted Sandpiper (*Actitis macularia*)			17			23	
Stilt Sandpiper (*Calidris himantopus*)						13	
Killdeer (*Charadrius vociferus*)						16	
Whimbrel (*Numenius phaeopus*)						20	
Pectoral Sandpiper (*Calidris melanotus*)						24	

* tie

were observed on Padre Island, with 4,197 on Mustang Island. Shorebirds were most abundant on both flats between October and March or April (Fig. 3.11). Like the Oso Bay mudflat, these areas were not used by many birds during fall.

In the present study, 12 species of shorebirds were observed on algal flats on Mustang Island (Newport and Fish passes) and 10 species were observed on Padre Island (Marker 83). Fewer species were probably observed than during 1991-1993 because this study did not encompass the entire year. Peeps and Dunlin were the most common and abundant species on all three flats, followed by Least Sandpiper on both north Padre Island and Fish Pass and Sanderling (*Calidris alba*) on Newport Pass. Piping Plovers ranked either 4 or 5 on all three sites. A total of 1, 411 shorebirds were observed on north Padre Island, 4,330 on Newport Pass, and 1,861 on Fish Pass. Mean densities (# ha^{-1}) peaked in March on north Padre Island and Fish Pass (Fig 3.13), and in January on Newport Pass.

3.3.4.2 Wading Birds

Although wading birds use flats when flooded, and are common in surrounding shallow waters, little information was available concerning their use of flats in the CCBNEP study area. Five species were observed on algal flats on north Padre and Mustang islands (Pulich et al., 1982; K. Withers, unpubl. data), six were observed in the Blind Oso (T. Barrera, unpubl. data) and East Flats (Brogden et al., 1977) (Table 3.6). Tricolor Heron (*Egretta tricolor*) were often abundant on upper Laguna Madre flats (K. Withers, unpubl. data). Pulich et al. (1982) listed Reddish Egret as most common on flats of southern Padre Island. Twenty to 30 of these birds were occasionally observed actively foraging on their study sites using characteristic "canopy feeding" (i.e., wings outstretched to shade water) behavior. This behavior appeared to be particularly well-suited for use on algal flats because of the dark background. Great Egret (*Casmerodius albus*) and Roseate Spoonbill (*Ajaia ajaja*) were most common in the Blind Oso, particularly after flooding (T. Barrera, unpubl. data).

Total numbers of wading birds were nearly always higher on north Padre Island compared to Corpus Christi Pass (Mustang Island) (Fig 3.14A). Abundances were greatest in late spring and summer on both sites, peaking during July and August (K. Withers, unpubl. data). At East Flats (Mustang Island), numbers were highest in late fall, and late spring-early summer (Fig. 3.14B). An average 28 birds were counted per day (Brogden et al., 1977). In the Blind Oso, numbers of wading birds were counted in fixed, 100 m^2 plots (Fig. 3.15). A total of 213 wading birds were counted in that area between March 1991-March 1992. Numbers were highest in late spring and late fall within the plot. However, when flats were flooded, 3-4 times as many birds were found over the entire flat as were counted in the plot. Great Egret (22%), Roseate Spoonbill (21.5%), and Great Blue Heron (19.2%) were most common (T. Barrera, unpubl. data).

3.3.5 Mammals

Information concerning mammal use of tidal flats in the CCBNEP study area is anecdotal. *Urocyon cineroargentatus* (gray fox), *Procyon lotor* (raccoon), and *Canis latrans* (coyote) have been observed on flats. *Canis latrans* apparently forage for and eat fiddler crabs on north Padre

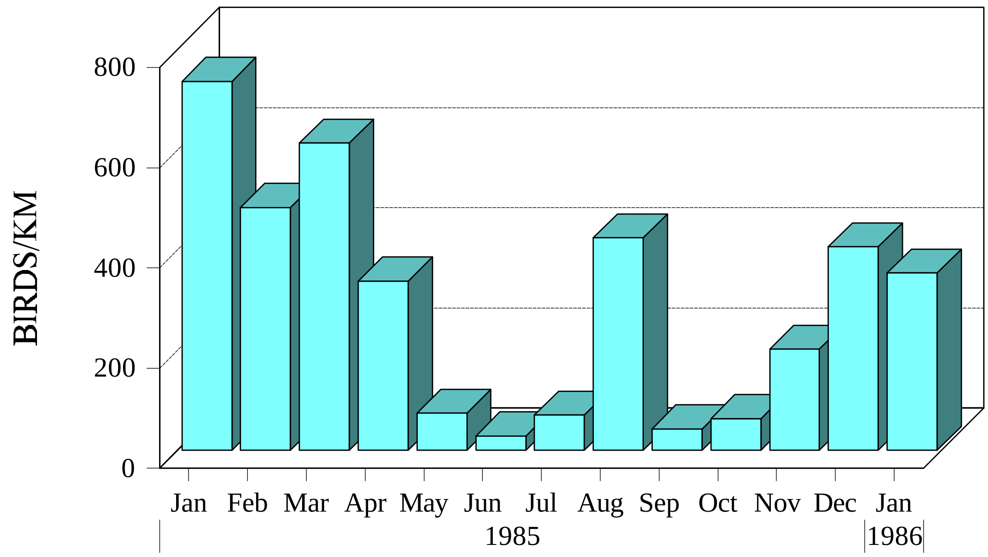
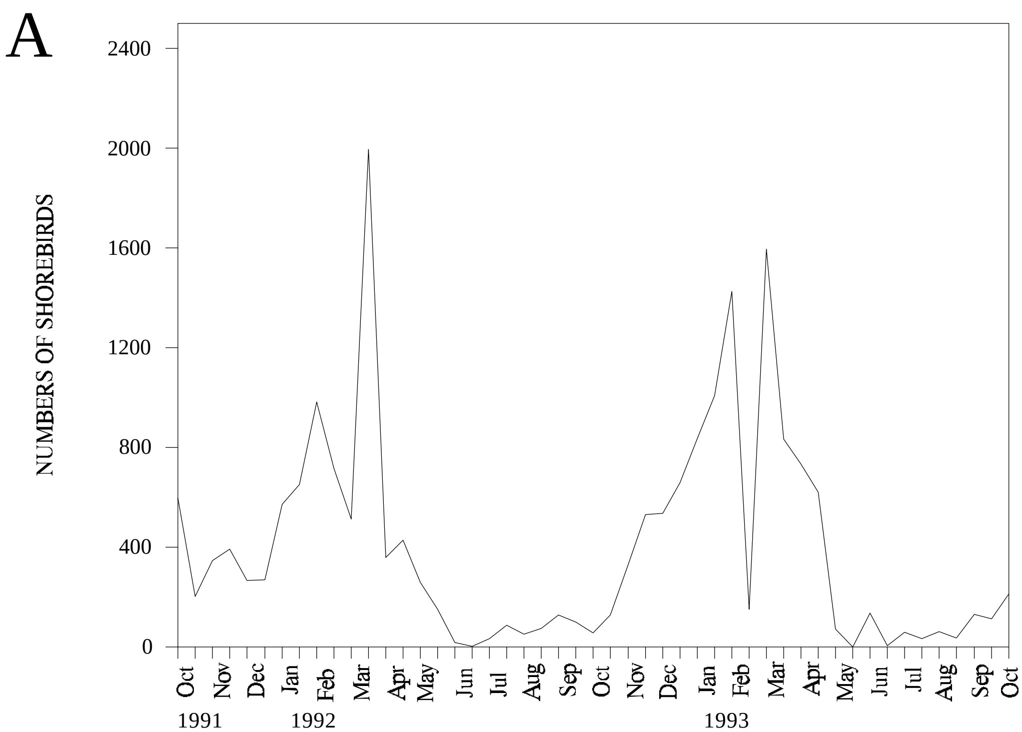


Fig. 3.11. Mean densities (numbers/km of shoreline) of shorebirds on an Oso Bay mudflat. A large flock of migrating peeps stopped over briefly during August 1985 (after Withers and Chapman, 1993).

Table 3.6. Wading bird species observed on dry or flooded blue-green algal flats on Padre Island (Pulich et al., 1982; K. Withers, unpubl. data), Mustang Island (Brogden et al., 1977; K. Withers, unpubl. data), and the non-algal mudflat in the Blind Oso (T. Barrera, unpubl. data), or in adjacent shallow waters.

Species	Padre Island	Mustang Island		Oso Bay
		CC Pass	East Flats	
Great Egret (*Casmerodius albus*)	X	X	X	X
Snowy Egret (*Egretta thula*)	X		X	X
Great Blue Heron (*Ardea herodias*)	X	X	X	X
Reddish Egret (*Egretta rufescens*)	X	X	X	X
Louisiana Heron (*Egretta tricolor*)	X	X	X	X
Little Blue Heron (*Egretta caerulea*)	X	X	X	
Roseate Spoonbill (*Phoenicopterus ruber*)				X

Island algal flats during hot summer months, as evidenced by abundant crab parts found in their droppings. *Canis latrans* have been observed cavorting on flats, and running across flats and throwing themselves into the water, possibly to cool off or remove fleas. *Odocoileus virginianus* (whitetail deer) and *Sylvilagus floridanus* (eastern cottontail rabbit) tracks have been observed on the flats; they probably use flats as a “salt lick” (K. Withers, pers. obs.).



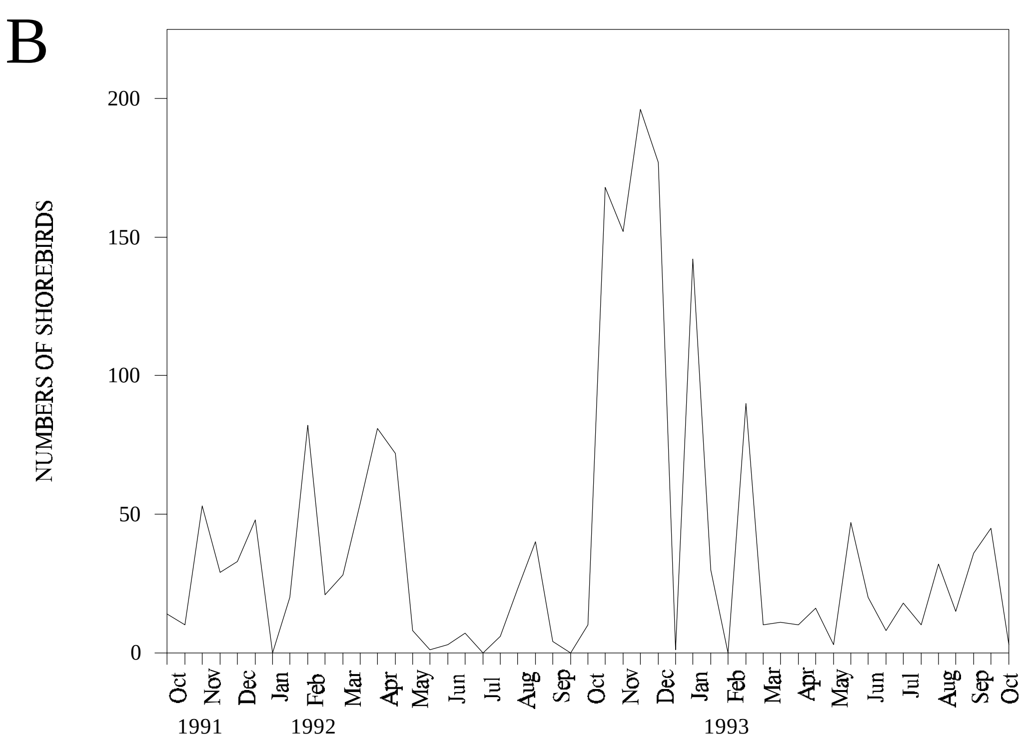


Fig. 3.12. Total numbers of shorebirds censused and seasonal distribution on north Padre Island (A) and Mustang Island (B) (Withers, 1994).

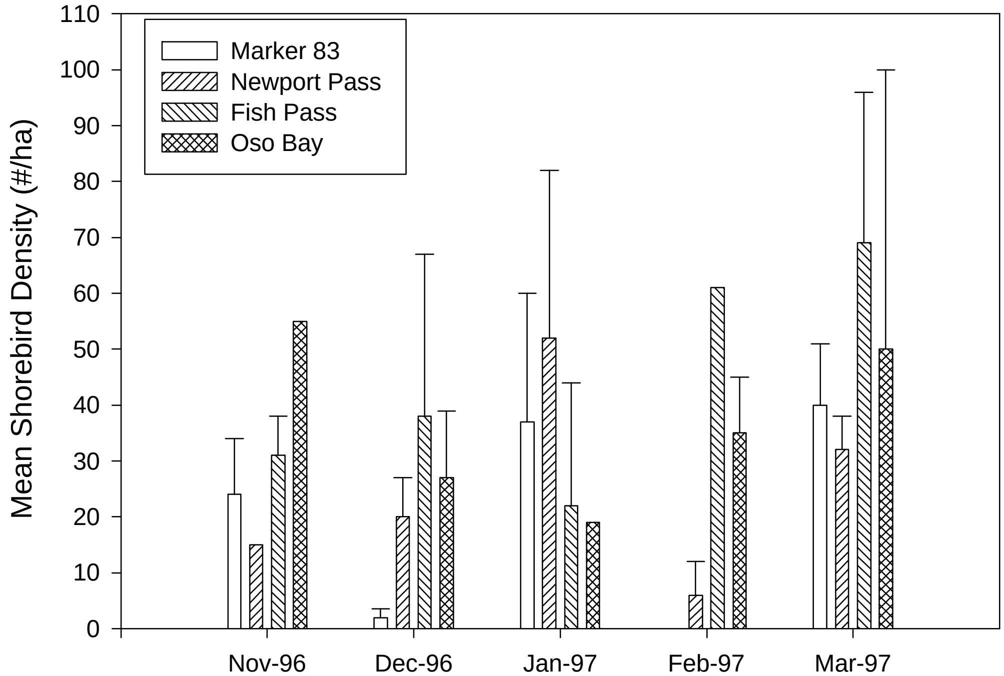


Fig. 3.13. Mean densities (numbers/hectare; error bars = +1 standard error) of shorebirds observed on wind-tidal flats between November 1996 and March 1997.

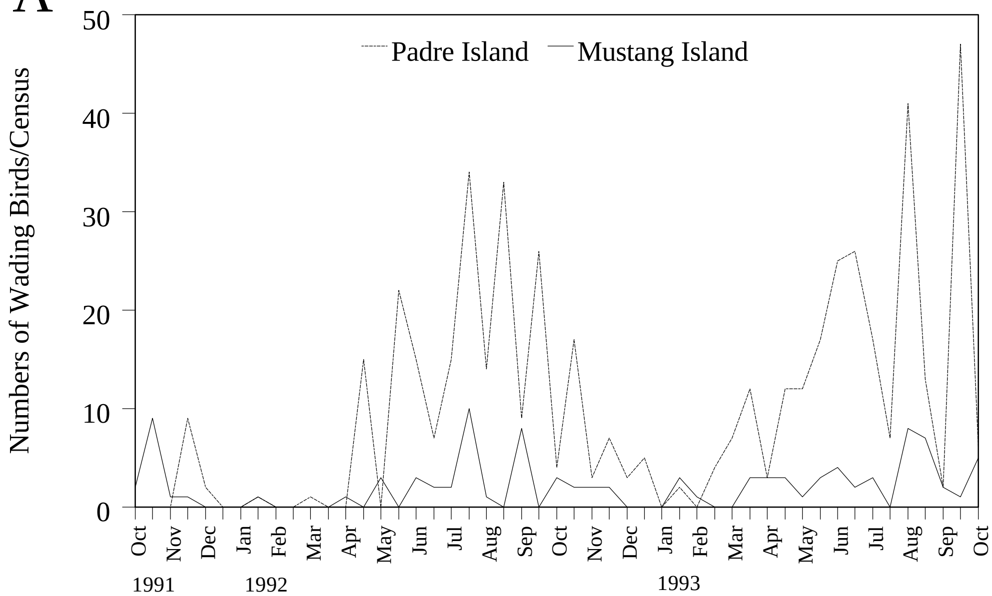
3.4 Community Structure

3.4.1 Plant Communities

Blue-green algal mats are zoned vertically by color, reflecting community interrelationships. Sorenson and Conover (1962) described five algal mat zones near Port Aransas: (1) darkly stained surface layer, (2) transitional zone which grades to, (3) lustrous blue-green, (4) yellow and pinkish-yellow, and (5) dirty yellow to black. Herber (1981) described four algal mat zones in the Laguna Madre Flats: (1) blackish to dark brown, (2) green, (3) salmon, and (4) black. Both designations are essentially the same except for differentiation of a transitional zone between the dark surface layer and the green layer. Color of surface zones range from light brown (diatoms) to grayish-tan (coccoid forms) depending on dominant biota (Herber, 1981).

The darkly stained surface layer may shield living sublayers from light and temperature extremes. Sheaths of *Lyngbya confervoides* contain a pigment, possibly a hydroxide of iron, that apparently darkens due to a photochemical reaction (Kylin, 1927, cited in Sorenson and Conover, 1962). Amount of pigment in mats increases as summer approaches and becomes an effective light shield, reducing penetration of incident light below the first millimeter by 95% (Sorenson and Conover, 1962). No additive growth of the mat community is contributed by the surface layer; there is actually a net loss of biomass (Fig. 3.16) due to shrinking and sloughing caused by

A



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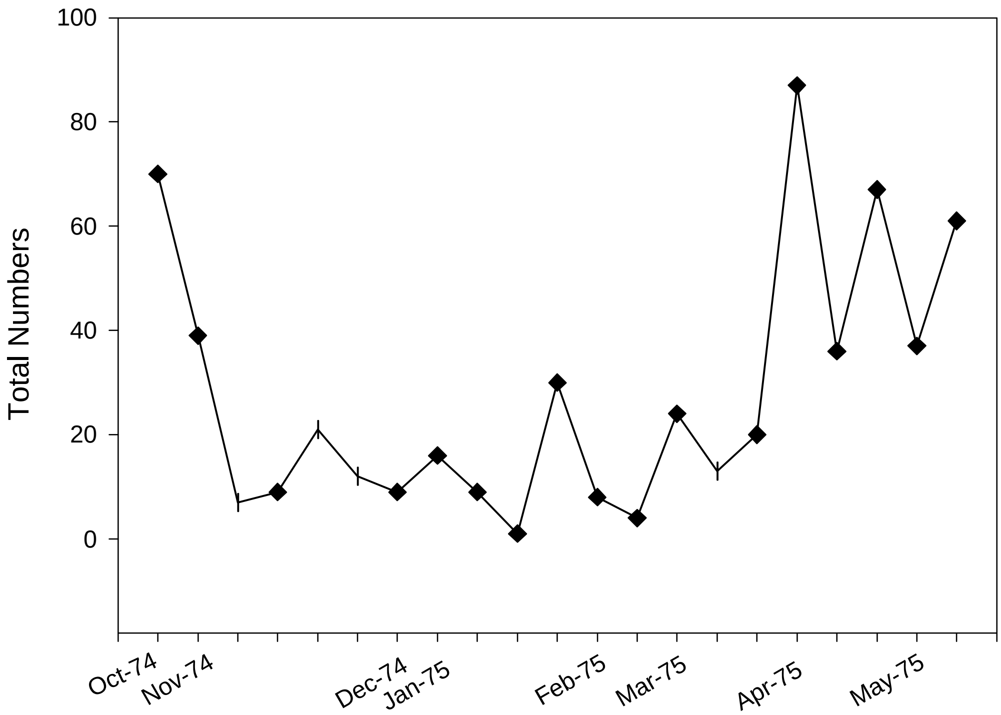


Fig. 3.14. Total numbers of wading birds on or in the adjacent shallow waters of the blue-green algal flats on (A) Padre Island and Corpus Christi Pass (Mustang Island) (K. Withers, unpubl. data) and (B) East Flats (Mustang Island) (Brogden et al., 1977)

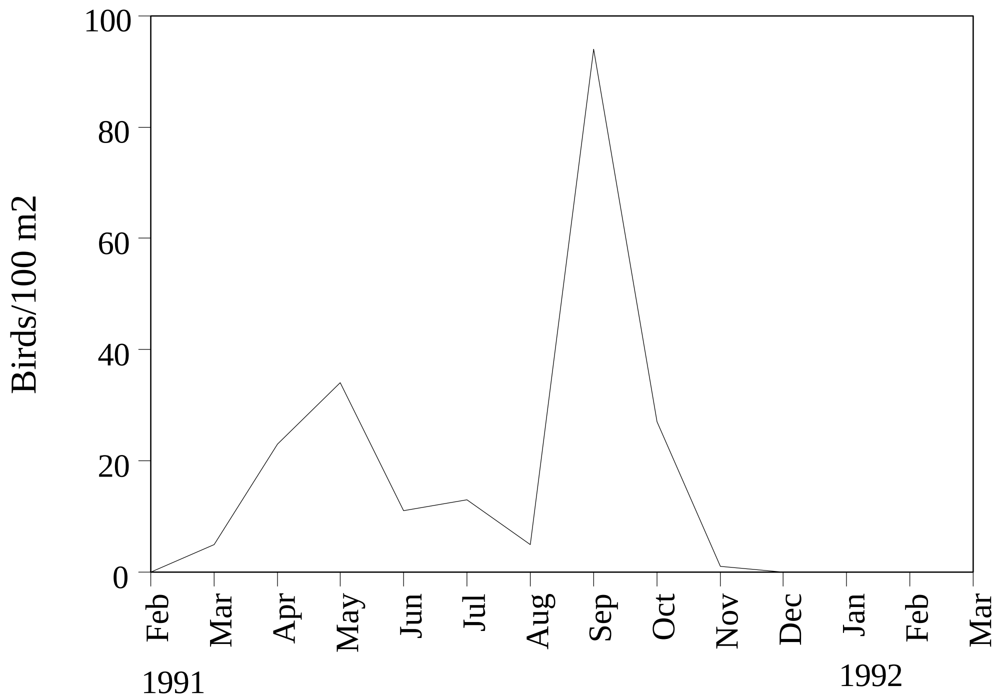


Fig. 3.15. Numbers of wading birds on the Blind Oso tidal flat or in adjacent shallow waters (Barrera, unpubl. data).

alternating wet and dry periods. The transitional zone beneath the surface layer probably contributes some additive growth to the community, but growth is greatest in the blue-green mid-layer. Most light is attenuated at this depth, but is enough to sustain photosynthesis. Chemosynthesis may provide some energy necessary to sustain plant life and may provide storage products (Sorenson and Conover, 1962).

Bacteria begin to increase in importance from the blue-green mid-layer downward. Some additive growth occurs in the salmon or yellowish-pink layer, but this is marginal habitat for algae and is primarily populated by autotrophic purple bacteria (Sorenson and Conover, 1962; Pulich and Rabalais, 1986). These bacteria modify or decompose primary organics, diatoms, and blue-green algae. The black zone is a decomposition zone, populated by non-photosynthetic, anaerobic bacteria (Herber, 1981). The algal mat is also horizontally zoned according to flooding frequency (Fig. 3.17). Because each blue-green algal species differs in ability to survive desiccation, elevation (=flooding frequency) determines composition of the mat community (Herber, 1981).

3.4.1.1 <u>Succession</u>

Succession from salt flat to algal flat to salt marsh may occur in the following sequence (Brogden et al., 1977): (1) salt flat is colonized by algae, and under the right conditions an algal mat develops; (2) if an algal mat develops, it stabilizes the surface promoting deposition, organic material accumulates, and the mat fixes atmospheric nitrogen; (3) *Salicornia* spp. seeds are washed from adjacent areas and if conditions are right (sufficient moisture and elevation), take

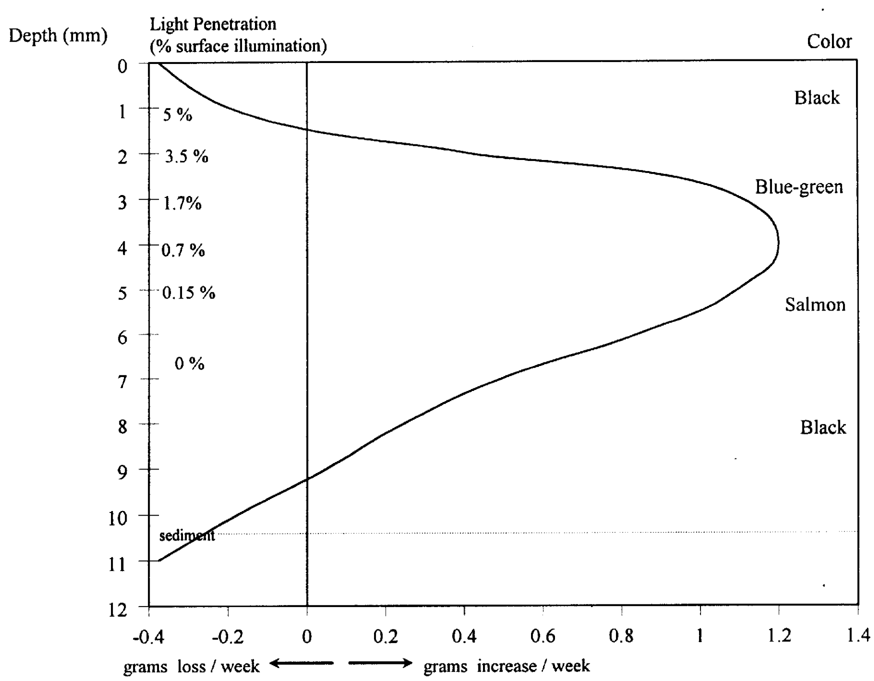


Fig. 3.16. Vertical zonation and estimated growth of blue-green algae within an algal mat near Port Aransas, Texas for May, based on laboratory experiments (modified from Sorenson and Conover, 1962).

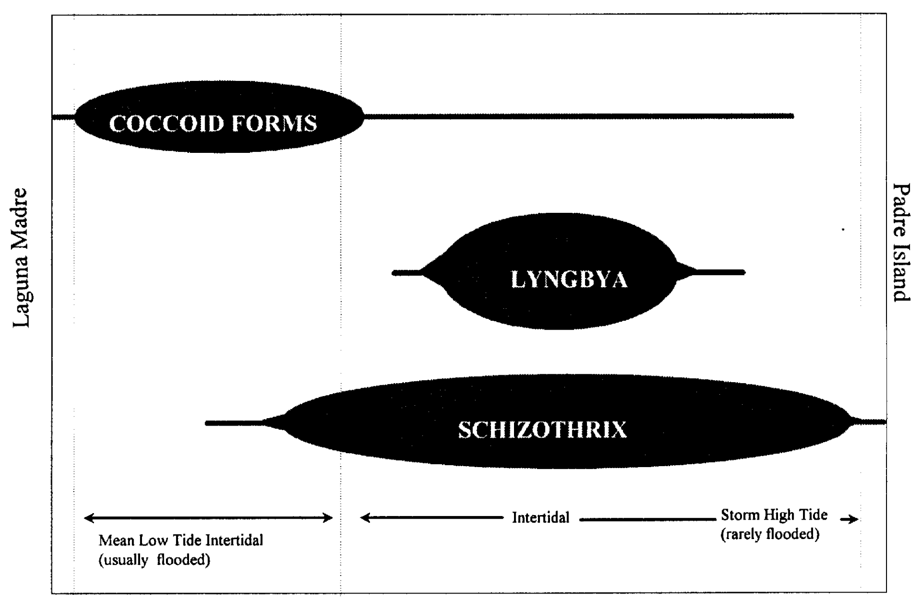


Fig. 3.17. Distribution of blue-green algae relative to the elevation of the tidal flat. Thickness of the bar roughly reflects abundance (after Herber 1981).

root and form relatively dense colonies; (4) *Uca* spp. (fiddler crab) feed on algae and burrow in the shelter of the *Salicornia*; their burrows ventilate the soil and make it easier for rainwater to soak in, ameliorating high soil salinities; and (5) as soil salinities are reduced, other salt marsh plants such as *Monanthochole littoralis* and *Distichlis spicata* are able to colonize. This sequence is dependent on adequate freshwater and may be halted or reversed by extended periods of drought or extremely high tides.

3.4.2 Invertebrate Community

3.4.2.1 Taxonomic Composition

Community composition of both blue-green algal flats in the upper Laguna Madre between October 1991-October 1993 was similar (Fig. 3.18). Crustaceans, primarily tanaids, dominated assemblages at both sites. Relative abundance of both insects and polychaetes was greater on the Mustang Island flat than on the north Padre Island flat. Influence of Corpus Christi Bay and nearby seagrass beds may explain greater dominance of polychaetes. It is possible the more irregular inundation/exposure regime of the Mustang Island flat explains greater insect dominance. Other taxa such as molluscs, oligochaetes, and turbellarians were uncommon at both sites (Withers, 1994).

Community composition of upper Laguna Madre blue-green algal flats (Marker 83 [Padre Island], Newport Pass and Fish Pass [Mustang Island]) in the present study (Fig. 3.19) was markedly different from that reported by Withers (1994). Dipteran larvae dominated, followed by polychaetes at all sites except Fish Pass. Crustaceans constituted less than 20% of the assemblage at all sites. Tanaids, which were the dominant crustacean between 1991-1993, were rare at all sites except Newport Pass, where they occurred in moderate numbers during the latter half of the present study (February-March 1997). The community of the non-algal flat in the Blind Oso was completely dominated by polychaetes.

3.4.2.2 Zonation

Elevational zonation of invertebrates is a prominent feature on rocky seashores and although it is not readily noticeable, it is also a common feature of tidal flat systems. Physical stress (e.g., osmotic imbalance, desiccation) and biological stress (e.g., inability to feed, aerobic respiration) associated with exposure at low tide sets upper limits of distribution for many rocky shore organisms and some soft sediment organisms (Peterson, 1991). Elevational zonation of organisms was seen in two blue-green algal flats studied by Withers (1994). Most organisms were concentrated in intertidal and wet microhabitats (Fig. 3.20). Analyses of variance revealed total density and biomass, polychaete density and biomass, and mollusc density increased from the damp microhabitat to low intertidal. Community similarity indices revealed damp microhabitats were less similar to both wet and intertidal microhabitats than wet and intertidal microhabitats were to each other. There appears to be at least two or three horizontal zones, characterized by increasing numbers of primarily aquatic-adapted organisms such as polychaetes, crustaceans, and molluscs in the wet areas nearest water (wet and intertidal microhabitats), and

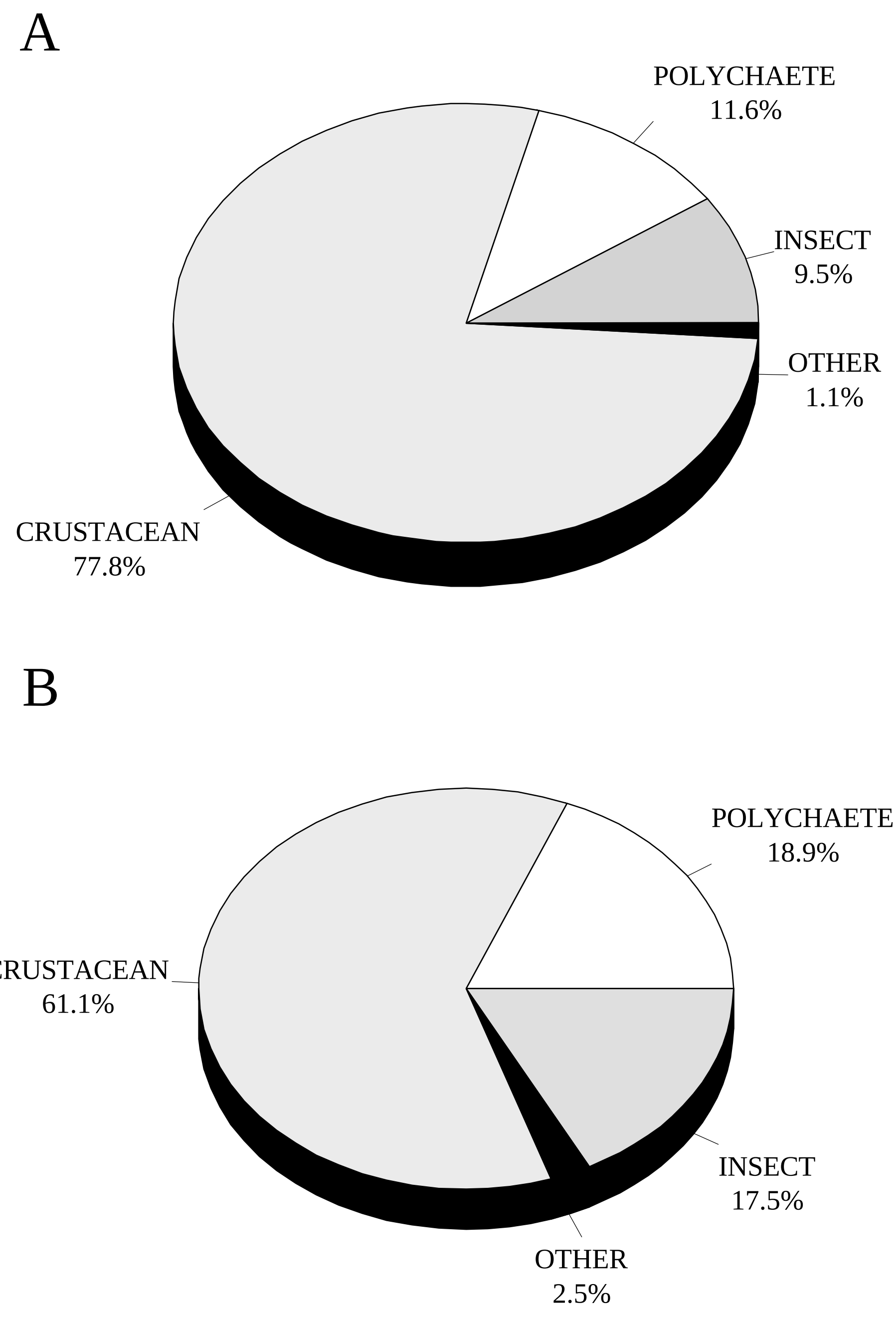


Fig. 3.18. Benthic invertebrate community composition on blue-green algal flats during 1991-1993 on (A) north Padre Island (Marker 83) and (B) Corpus Christi Pass (Mustang Island) (after Withers, 1994).

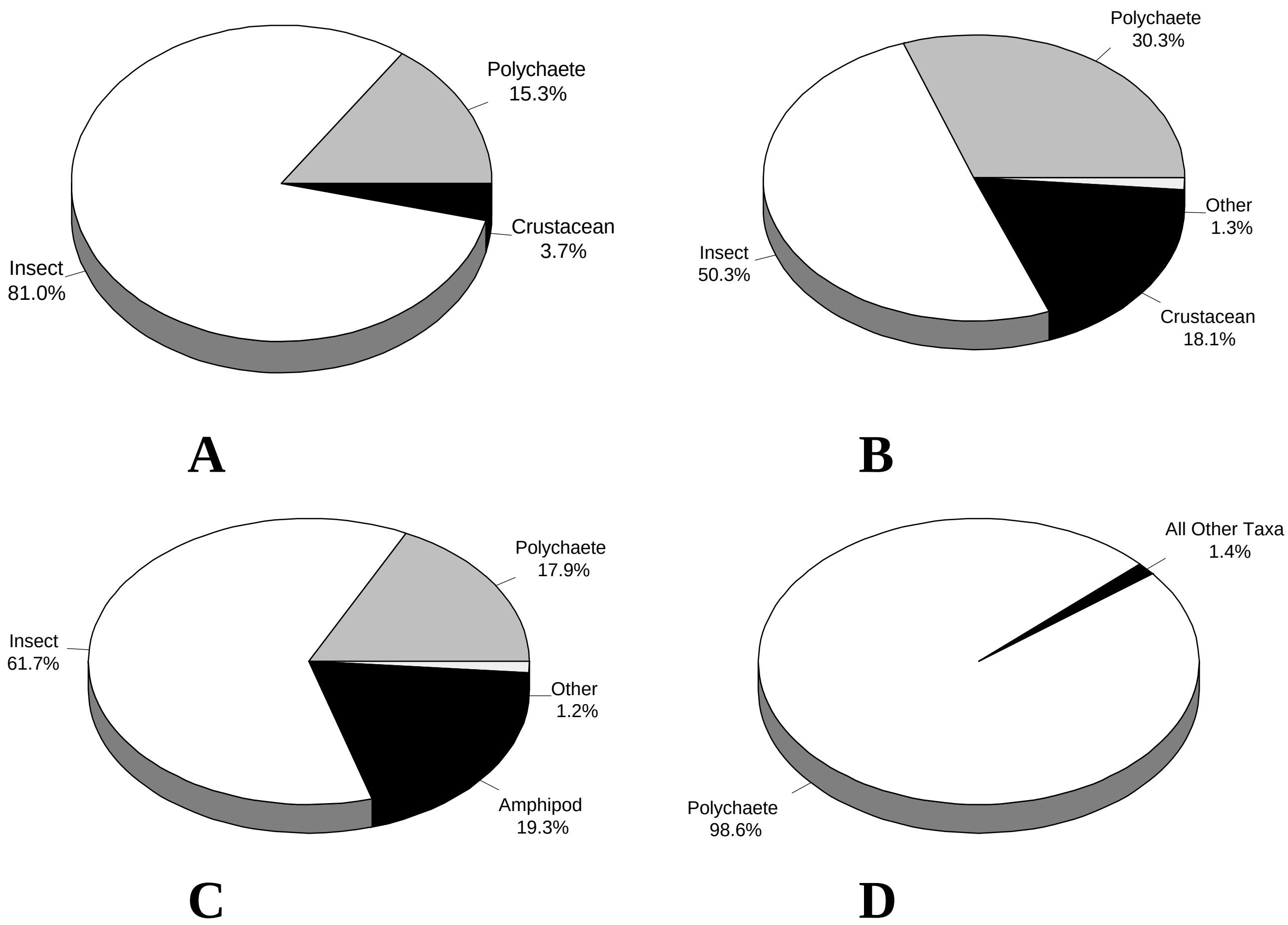


Fig. 3.19 Benthic invertebrate community composition on tidal flats during the present study on (A) north Padre Island (Marker 83) and (B) Newport Pass (Mustang Island), (C) Fish Pass (Mustang Island), and (D) Blind Oso.

increased representation of semi-terrestrial organisms such as insects in areas farther from the waters' edge (damp microhabitat) (Fig. 3.21).

In the present study, the invertebrate community of shallow submerged areas was also sampled. In general, all sites, whether algal or non-algal, exhibited a similar pattern of microhabitat distribution (Fig. 3.22). For algal flats, horizontal zones characterized by Withers (1994) were evident in the present study as well (Fig. 3.23A); however insects were much more important in all zones. Relative abundances of aquatic-adapted organisms still increased with increasing saturation of sediments. As expected, the submerged area was dominated by aquatic organisms. The non-algal flat (Blind Oso) exhibited no taxonomic zonation, with polychaetes dominating all microhabitats (Fig 3.23B)

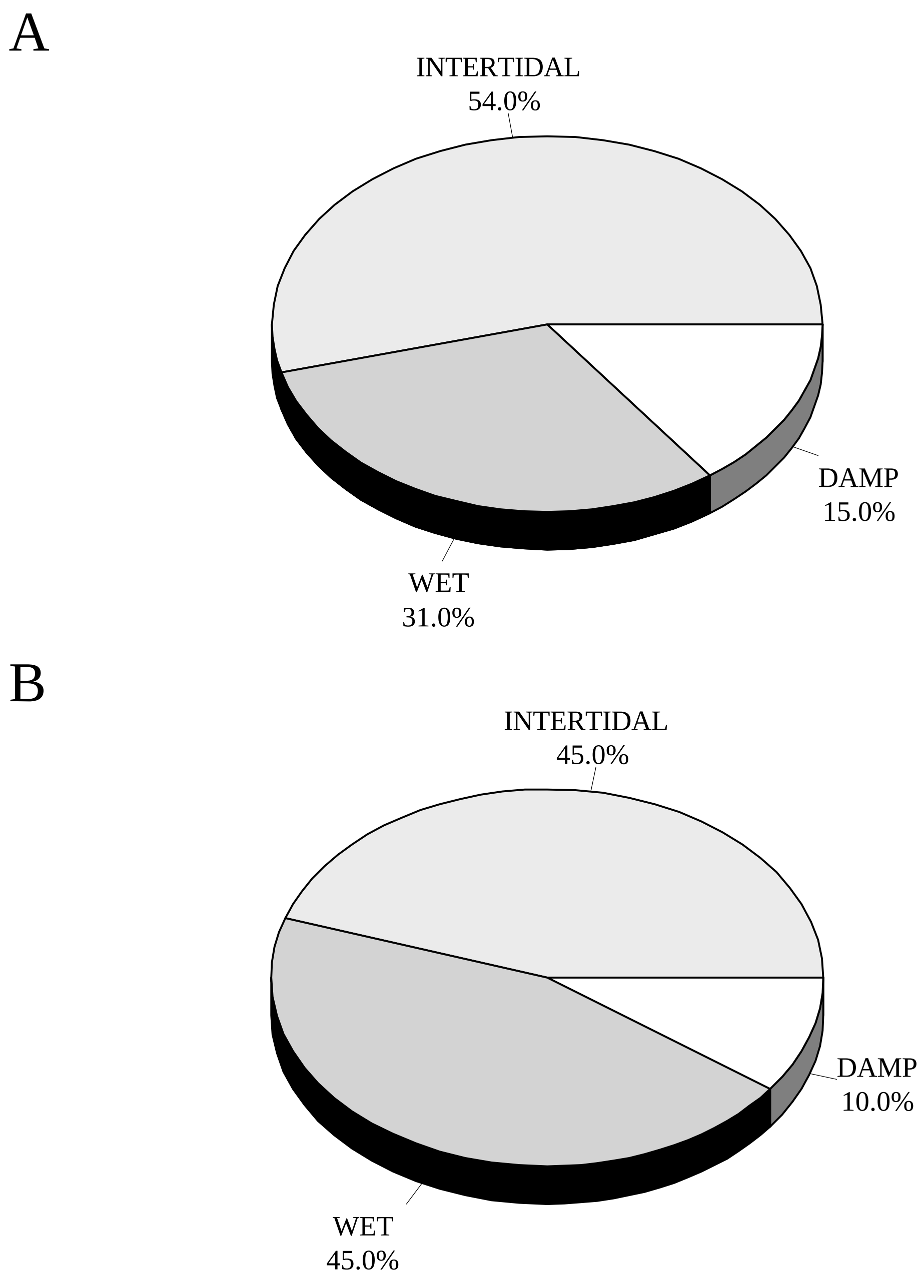


Fig. 3.20. Distribution of benthic organisms (density) recovered from blue-green algal flats on (A) north Padre Island (Marker 83) and (B) Corpus Christi Pass (Mustang Island) by microhabitat (after Withers, 1994).

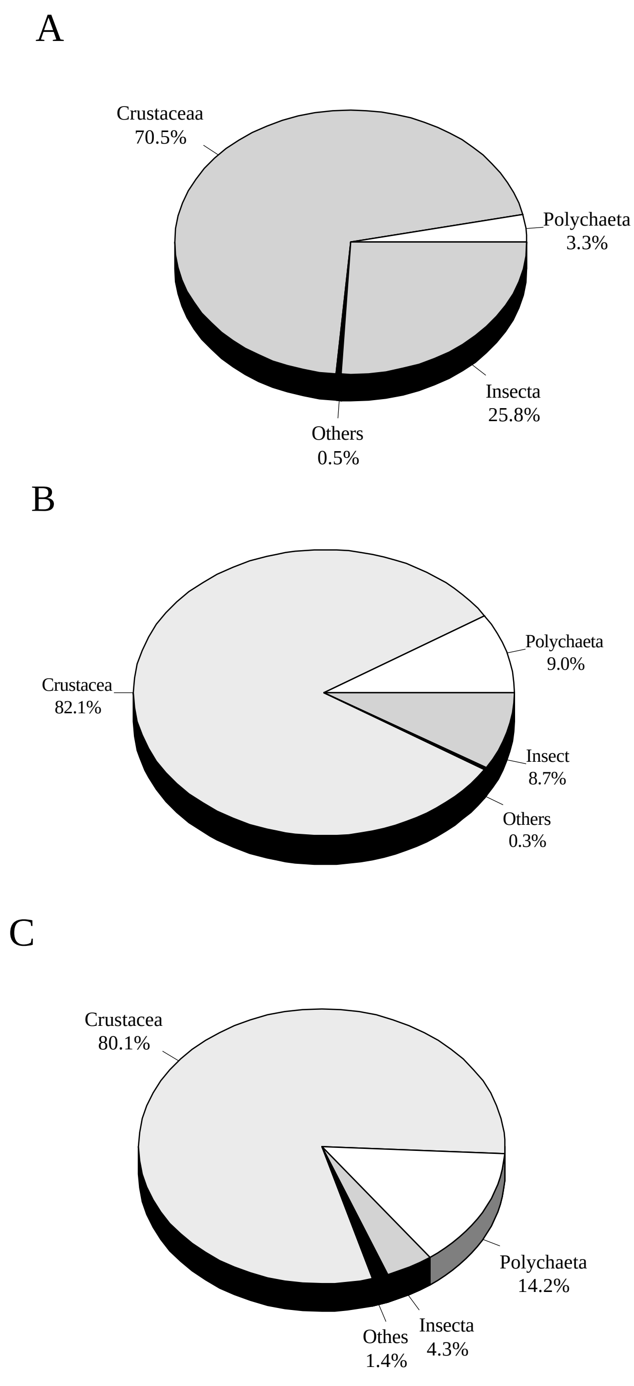
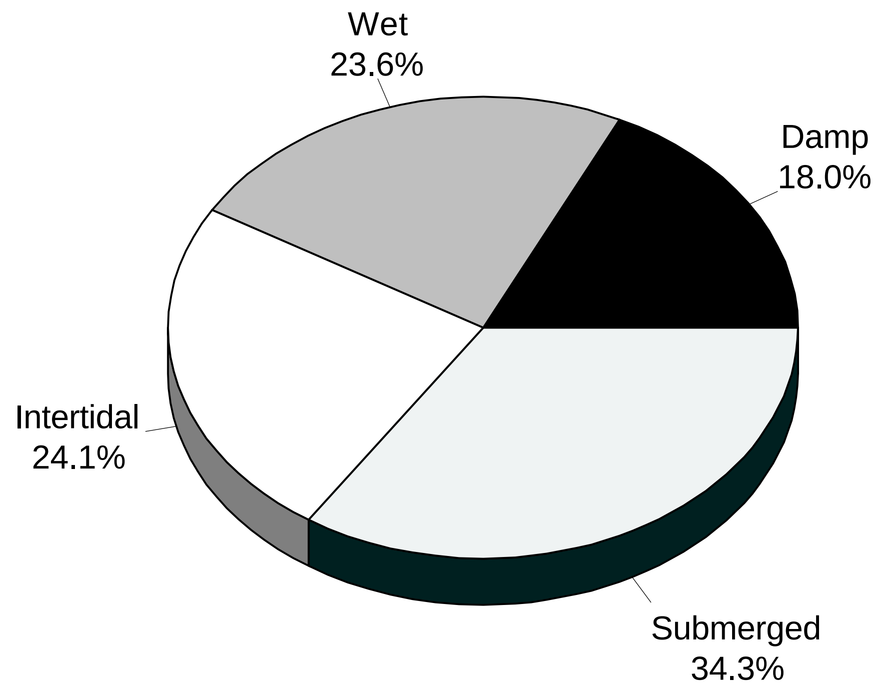


Fig. 3.21. Distribution of taxa in damp (A), wet (B) and intertidal (C) microhabitats of blue-green algal flats in the upper Laguna Madre (after Withers, 1994).

A



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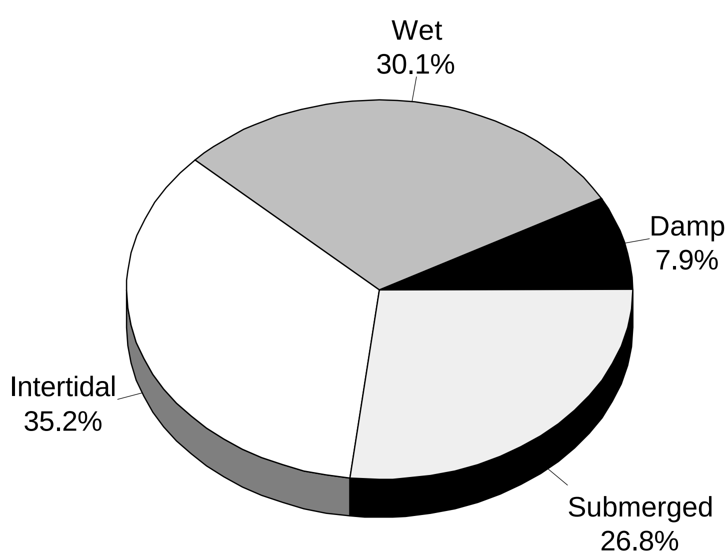

Fig 3.22. Distribution of benthic organisms (density) by microhabitat recovered during the present study from (A) blue-green algal flats on Padre and Mustang islands and (B) Blind Oso.

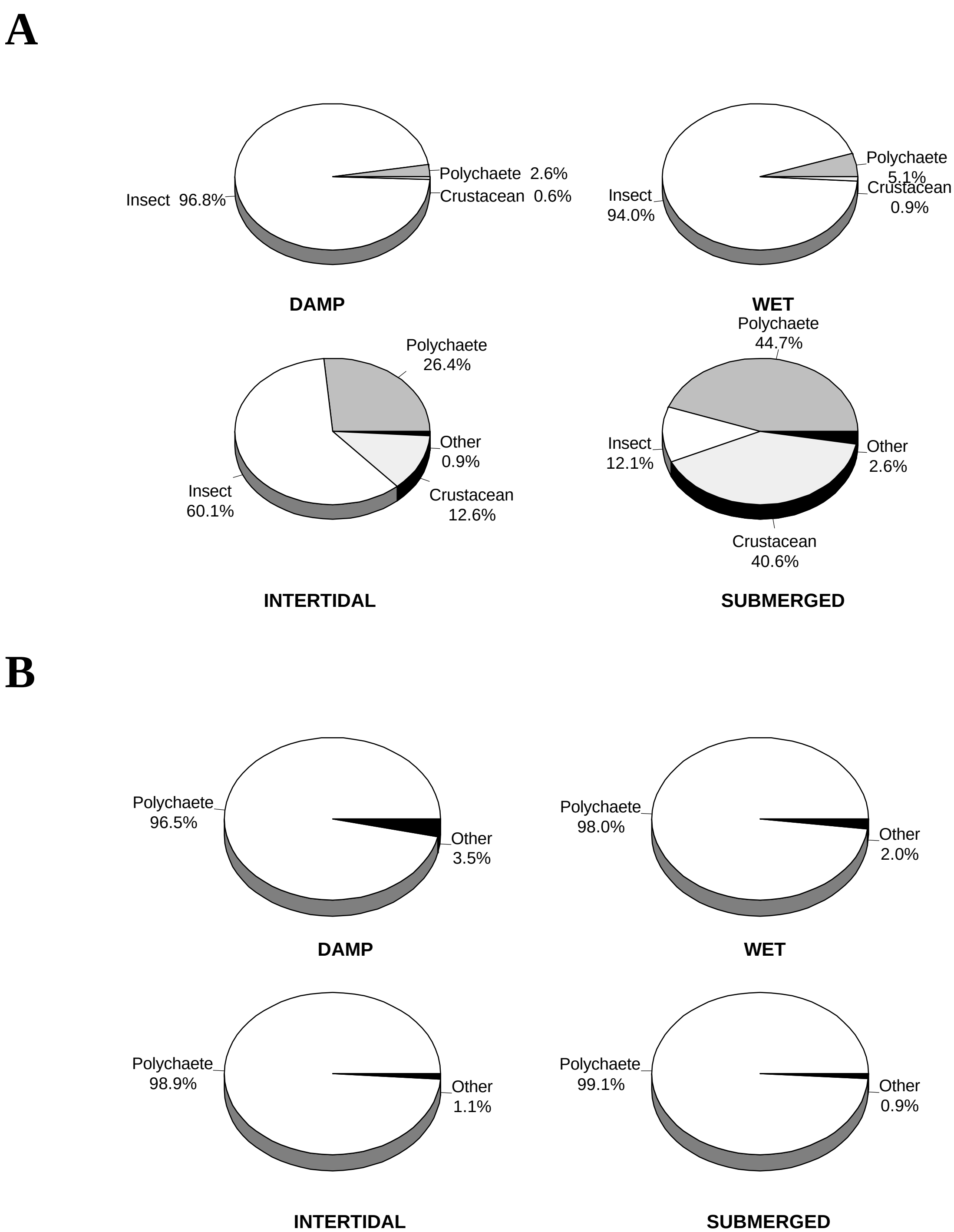

Fig. 3.23. Distribution of taxa in microhabitats during the present study: (A) blue-green algal flats in the upper Laguna Madre (Padre and Mustang islands); (B) non-algal flat, Blind Oso.

Algal flats in the upper Laguna Madre also exhibited vertical zonation within sediments. Low-oxygen, deep (>5 cm) sediments contained few organisms, with most concentrated in upper, oxygenated layers, either within the algal mat or at the algal mat-sediment interface (Fig. 3.24). The deep section was dominated by a few, large individuals, primarily *Arenicola cristata* and *Tellina tampaensis*, whereas the surface section was characterized by abundant polychaetes, crustaceans, and insects (Withers, 1994).

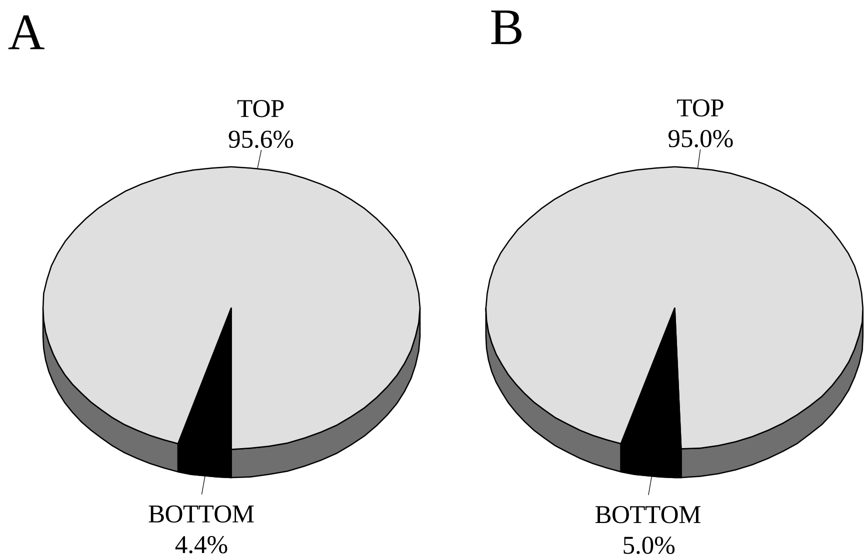

Fig. 3.24. Vertical distribution (density) of benthic organisms recovered in top five centimeters and bottom five centimeters of blue-green algal flat substrate from north Padre Island (A) and Mustang Island (B) (after Withers, 1994).

3.4.2.3 Dispersal Dynamics, Colonization, and Community Succession

No studies of invertebrate dispersal dynamics, colonization, or community succession on wind-tidal flats in the CCBNEP study area were found. Postlarval dispersal may be important in regulating both populations and communities of some soft-bottom habitats, including intertidal sandflats (Commito et al., 1995b). High rates of movement by postlarval organisms from areas of high density into low density patches created by small scale disturbance may affect local species distribution and/or abundance patterns (Commito et al., 1995a; Thrush et al., 1991). Three methods are used by dispersing postlarval meiofauna and macrofauna: (1) active crawling or burrowing on the bottom (Kukert and Smith, 1992); (2) passive transport in the bedload (Emerson, 1991; Commito et al., 1995a); and (3) active swimming and/or passive transport in the water column (Varon and Thistle, 1988; Cummings et al., 1993).

Dispersal dynamics in a wind-driven sandflat system in Manukau Harbour (Auckland, New Zealand) were studied (Commito et al., 1995b). Very strong positive relationships were found between wind condition (velocity x [fetch length/maximum possible fetch]), water velocity, sediment flux, and postlarval dispersal. Ambient infaunal density was not a good predictor of dispersal. In this system, bedload transport (passive) provided a mechanism for immediate postlarval dispersal into disturbed, defaunated patches. These results demonstrate postlarval dispersal may play a significant role in controlling community dynamics by smoothing out effects of small-scale disturbances. Experiments on an Oregon sandflat provided evidence that both active and passive modes of immigration occur into small, disturbed patches, but passive advection dominated (Savidge and Taghon, 1988).

On a tidal flat in the Wadden Sea, recolonization of disturbed patches by meiofauna was described (Reise, 1984a). Species composition in patches resembled composition in ambient sediment, differing primarily in abundances of dominant species. In contrast with Commito et al., 1995b, small scale disturbances were implicated in the frequently observed patchiness of sandflat fauna; if disturbances are frequent, patterns of relative abundances of the entire assemblage may be altered.

Species succession in soft-bottom communities in response to disturbance is not well-understood. Small scale disturbances occur constantly on intertidal flats through a variety of processes including: pit-digging by crabs, and rays or other fish (e.g., flounder, black drum, red drum, mullet); loss of algal covering and subsequent scouring by wind and/or waves; and tracking by large animals (cattle, deer) or humans (on foot or in vehicles). This results in a mosaic of states of recolonization (Thistle, 1981). Early immigrants that become unusually abundant appear to be responding to resource availability, but it is unclear whether competitive relaxation is important. Individual species' responses range from hours to months depending on strategies of exploitation. Whitlach (1980) suggests early colonists are resource specialists and their later disappearance results from resource exhaustion rather than displacement by later colonists. No clear model describing benthic succession has been formulated.

3.4.3 Vertebrate Communities

3.4.3.1 Shorebirds

Sandpipers (*Calidris* spp.) dominated shorebird communities of both blue-green algal flats in the upper Laguna Madre and non-algal flats in Oso Bay during the present study (Fig. 3.25) as well as in previous studies (Withers, 1994; Withers and Chapman, 1993). Relative abundance of plovers (Black-bellied Plover, *Pluvialis squatorola*, and banded plovers, *Charadrius* spp.) was greatest on the Corpus Christi Pass flat during 1991-1993. During this study, relative abundance of plovers were nearly equal at all sites. Black-bellied Plovers accounted for most plovers in Oso Bay, whereas banded plovers dominated in the upper Laguna Madre. Long-legged species including dowitchers (*Limnodromous* spp.) were not common in tidal flat communities of north Padre or Mustang islands in either study, but were an important part of the community in Oso Bay during all studies. These differences are probably due to species' abilities to forage in the presence of an algal mat. Plovers, (visual foragers) feed on organisms on or just below the surface of the substrate. Sandpipers are largely visual foragers also, but many, such as the

Western Sandpiper (*Calidris mauri*), include a tactile element in their foraging strategy (Pienkowski 1981) allowing them to use a variety of habitats. Dowitchers and other long-billed, probing, tactile-foraging shorebirds, are inhibited by the presence of algal mats on the substrate surface.

Most shorebirds exhibit preferences for certain microhabitats (Tables 3.7 and 3.8) this resulting in partitioning of the tidal flat by birds. In the upper Laguna Madre, most birds were found in wet microhabitats (Fig 3.26A) (Withers, 1994; this study). In Oso Bay, most were found in the shoreface (=intertidal) microhabitat during 1985-1986 (Fig. 3.26B) (Withers and Chapman, 1993) but during the present study most were found in the wet microhabitat. Because species exhibit preferences, the shorebird community within each microhabitat or zone is dominated by different species groups. On the Oso Bay mudflat during 1985-1986, shallow water areas were dominated by long-legged, long-billed shorebirds such as dowitchers, American Avocets (*Recurvirostra americana*) and Willets (*Cataptrophorus semipalmatus*) (Fig 3.27A). The assemblage in the shoreface microhabitat was dominated by sandpipers and plovers, whereas the flat microhabitat (= wet+damp) was dominated by plovers (Withers and Chapman, 1993). The pattern in the Blind Oso during the present study was similar (Fig. 3.27B), except sandpipers dominated in all habitats except submerged (=open water). The pattern was somewhat different on blue-green algal flats in the upper Laguna Madre (Fig. 3.28). Long-legged shorebirds were not abundant on either site, as indicated by dominance of the open water area by sandpipers, primarily Dunlin (*Calidris alpina*). Western Sandpipers were the primary sandpiper in the intertidal microhabitat, with Least Sandpipers (*Calidris minutilla*) increasing in abundance in wet microhabitats. Plovers, primarily Piping and Snowy plovers (*Charadrius melodus*, *C. alexandrinus*), increased in abundance in the wet community and dominated the assemblage found in the damp microhabitat during 1991-1993 (Withers, 1994), but were not as abundant during this study, possibly because of limited temporal coverage..

3.4.3.2 <u>Fish</u>

The community of fish present on flooded tidal flats appears to be determined by water depth and salinity. No large fish (>30 mm) are usually found (Pulich et al., 1982; T. Barrera, unpubl. data). *Cyprinodon variegatus* is tolerant of salinities of up to 138 ‰, and larval *Synodus foetens* were found at a salinity of 110 ‰ (Pulich et al., 1982). *C. variegatus* was considered to be the most stress-tolerant of all Laguna Madre fishes (Gunter, 1967). Greater diversity of fish species seen in the Blind Oso (refer to Table 3.4) was likely due to lower salinities and increased recruitment caused by water exchange with Corpus Christi Bay.

3.5 Ecosystem Processes

3.5.1 Productivity and Energy Flow

Productivity on tidal flats is often assumed to be insignificant due to lack of macrophytic vegetation, particularly by the public. However, large numbers of shorebirds use flats, and there are often well-developed benthic communities on wetter flats. Rather than being barren and

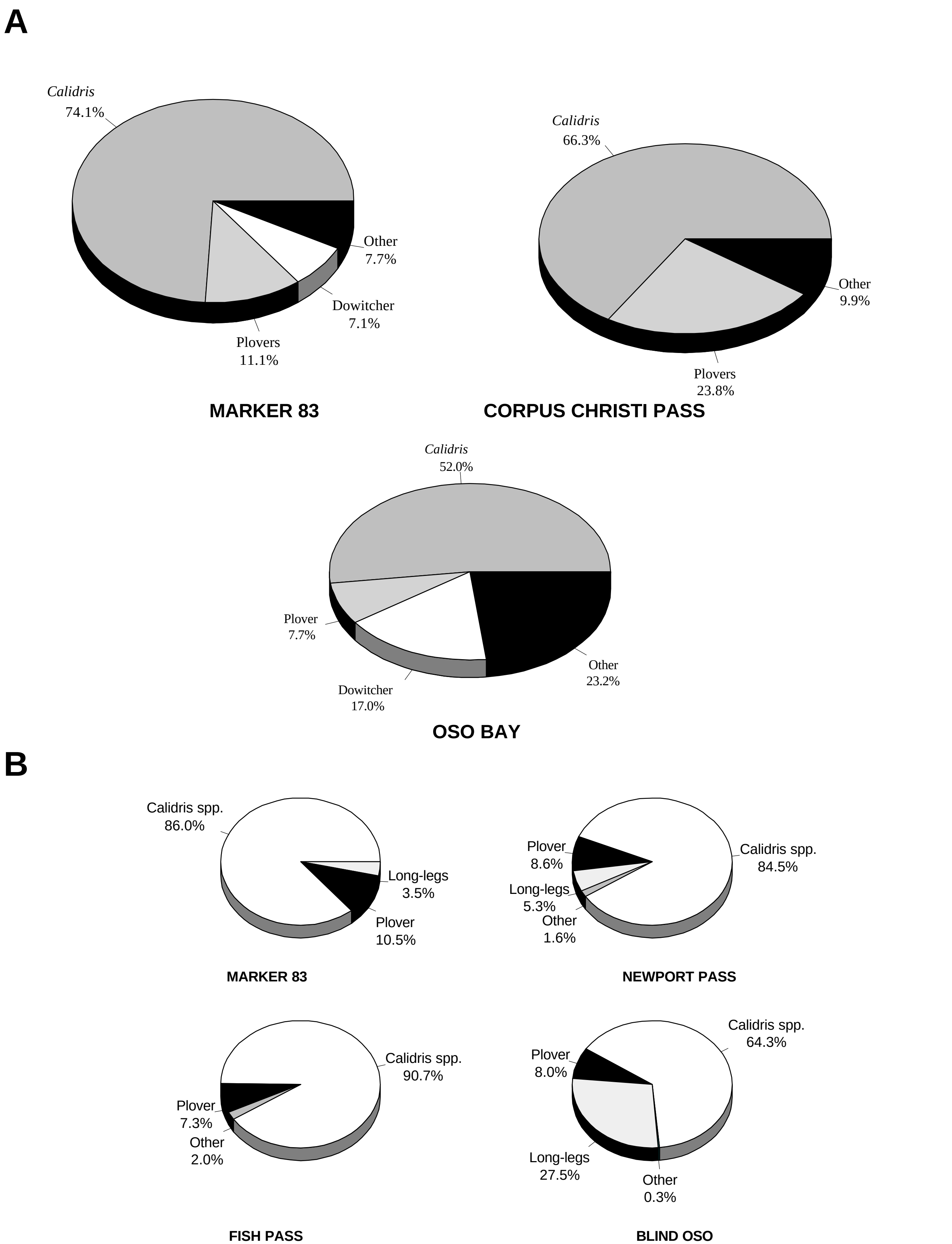

Fig. 3.25. Shorebird community composition on algal and non-algal flats during: (A) previous studies (Withers, 1994; Withers and Chapman, 1993) and (B) the present study

Table 3.7. Overall microhabitat preferences (frequency %) for all shorebird species observed on the Oso Bay mudflat (modified from Withers and Chapman, 1993).

Species	Open Water	Shoreface	Flat
American Avocet	74	20	6
Baird's Sandpiper	50	50	0
Black-bellied Plover	25	48	27
Black-necked Stilt	75	19	3
Dowitchers	60	37	4
Dunlin	51	37	12
Greater Yellowlegs	53	34	13
Killdeer	5	29	66
Lesser Yellowlegs	76	18	6
Long-billed Curlew	25	20	55
Marbled Godwit	69	22	9
Pectoral Sandpiper	0	100	0
Peeps	29	54	17
Piping Plover	0	64	36
Ruddy Turnstone	25	42	33
Sanderling	28	57	18
Semipalmated Plover	13	63	25
Snowy Plover	4	50	46
Spotted Sandpiper	0	50	50
Stilt Sandpiper	71	29	0
Whimbrel	6	31	63
Willet	44	22	34
Wilson's Phalarope	25	75	0
Wilson's Plover	10	34	56

unproductive, they are important biomass conversion sites, or areas where primary production is converted to animal biomass for use by higher-level consumers.

High productivity (388 g C/m^2/yr) and an algal turnover rate of 10.8 times/yr was estimated for the Yarborough Pass tidal flat on Padre Island (Pulich and Rabalais, 1982; 1986). Productivity on this flat was higher than in most other similar habitats (Table 3.9) and conforms to the latitudinal gradient in productivity (higher latitudes = lower productivity) in salt marsh vegetation and mudflat microalgae suggested by other workers (Peterson, 1981; Whitlach, 1982). Odum and Wilson (1962) measured very high rates of productivity, but found net production of carbon was negligible because respiration rates were nearly equal to photosynthetic rates. These rates may not be typical; Pamatmat (1968) measured respiration at about 23% of production.

Table 3.8. Pooled totals and proportions ± 95% confidence intervals of shorebird species in each microhabitat on blue-green algal flats in the upper Laguna Madre (modified from Withers, 1994). Microhabitats were significantly (*P* <0.05) preferred (*) if the confidence interval on the observed proportion(s) was greater than the expected proportion of 0.25 (Haney and Solow, 1992).

Species	Open Water	Intertidal	Wet	Damp
American Avocet	68	16	0	0
n = 84	0.81±0.08 *	0.19±0.08		
American Oystercatcher	6	16	5	2
n = 29	0.21±0.15	0.55±0.18 *	0.17±0.14	
Black-bellied Plover	181	219	272	94
n = 766	0.24±0.03	0.29±0.03	0.36±0.03 *	0.12±0.02
Black-necked Stilt	47	0	0	0
n = 47	1.00 *			
Dowitchers	806	175	71	2
n = 1,054	0.77±0.03 *	0.17±0.02	0.07±0.02	
Dunlin	2,631	1,145	1,181	14
n = 4,971	0.53±0.01*	0.23±0.01	0.24±0.01	<0.01
Greater Yellowlegs	25	6	1	1
n = 33	0.76±0.15 *	0.18±0.13		
Least Sandpiper	10	352	1,567	255
n = 2,184	<0.01	0.16±0.02	0.69±0.02 *	0.11±0.01
Lesser Yellowlegs	69	9	2	0
n = 80	0.86±0.08 *	0.11±0.07		
Long-billed Curlew	17	19	5	13
n = 54	0.32±0.10	0.35±0.13	0.09±0.08	0.24±0.11

Table 3.8. Continued.

Species	Open Water	Intertidal	Wet	Damp
Marbled Godwit	75	9	7	0
n = 91	0.82±0.08 *	0.10±0.07	0.08±0.04	
Peep	381	579	2274	100
n = 3,334	0.11±0.01	0.17±0.01	0.68±0.02 *	0.03±0.01
Piping Plover	0	29	531	582
n = 1,142		0.03±0.01	0.47±0.03 *	0.51±0.03 *
Red Knot	69	38	40	0
n = 147	0.47±0.08 *	0.26±0.07	0.27±0.07	
Ruddy Turnstone	10	30	261	83
n = 384	0.03±0.02	0.08±0.03	0.68±0.05 *	0.22±0.04
Sanderling	111	290	370	223
n = 994	0.11±0.02	0.29±0.03	0.37±0.03 *	0.22±0.03
Semipalmated Plover	0	2	57	61
n = 120			0.48±0.09 *	0.51±0.09 *
Snowy Plover	2	96	495	422
n = 1,015		0.10±0.19	0.49±0.03 *	0.42±0.03 *
Western Sandpiper	195	1778	2923	239
n = 5,139	0.04±0.01	0.35±0.01 *	0.57±0.01 *	0.05±0.01
Willet	550	335	308	68
n = 78	0.44±0.03 *	0.27±0.02	0.24±0.02	0.05±0.01
Wilson's Plover	2	11	16	49
n = 78		0.16±0.09	0.24±0.10	0.72±0.11 *

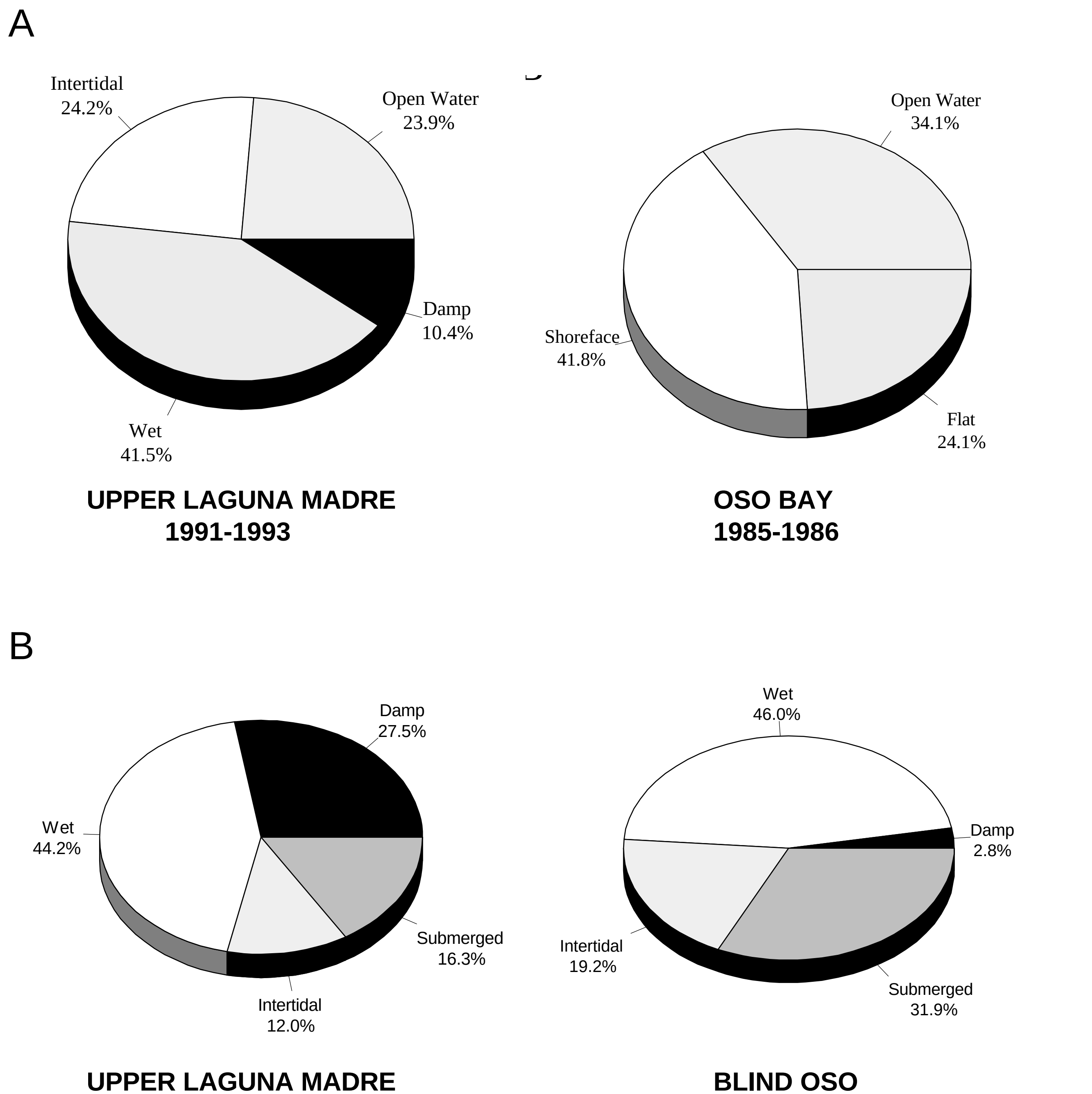

Fig. 3.26. Relative abundance of shorebirds in tidal flat microhabitats during: (A) previous studies, upper Laguna Madre algal flats (Withers, 1994) and Oso Bay (Withers and Chapman, 1993); and (B) the present study.

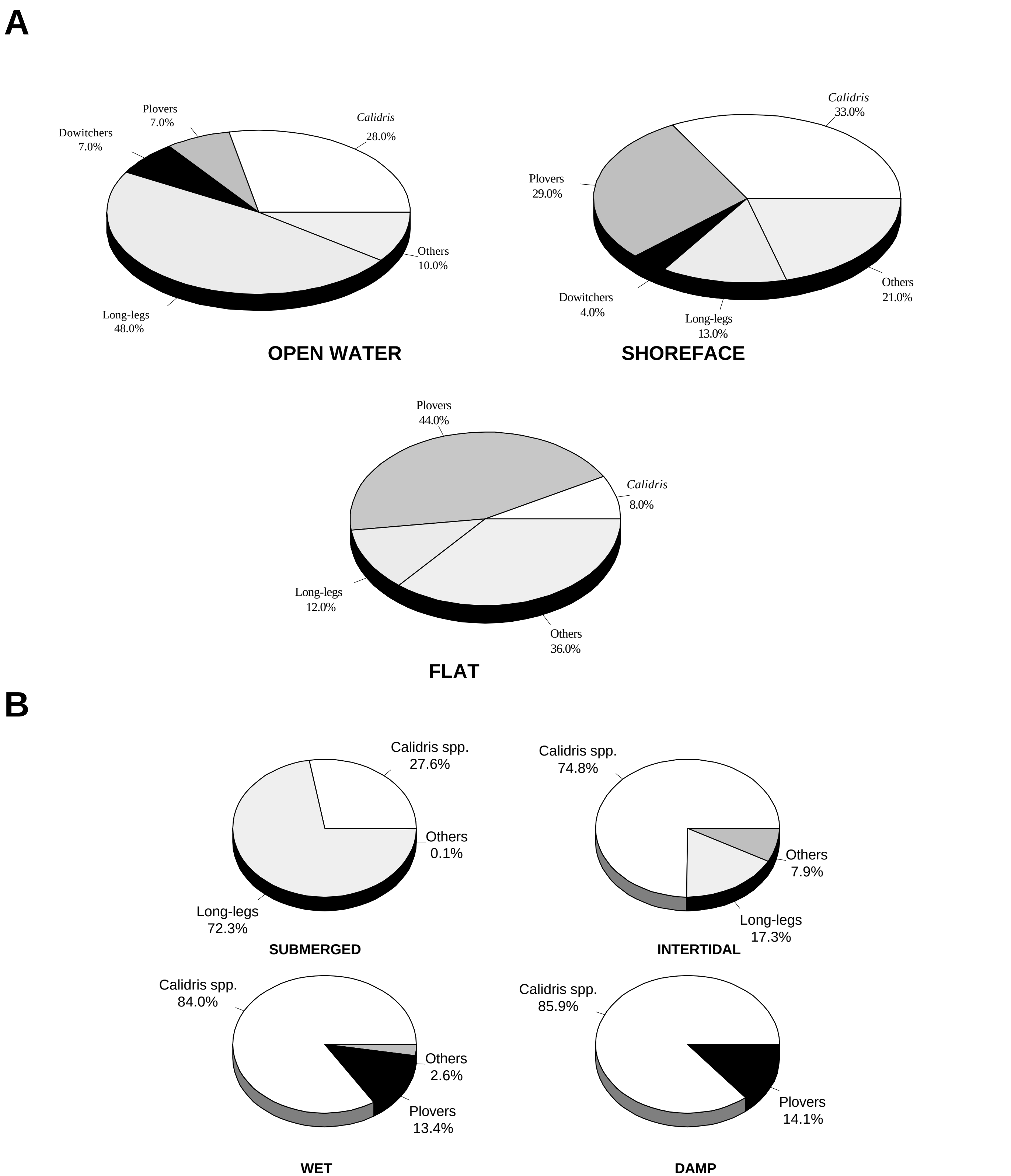

Fig. 3.27. Relative abundance of shorebirds by species in the Oso Bay mudflats: (A) January 1985-January 1986 (from Withers and Chapman, 1993); (B) Blind Oso, the present study.

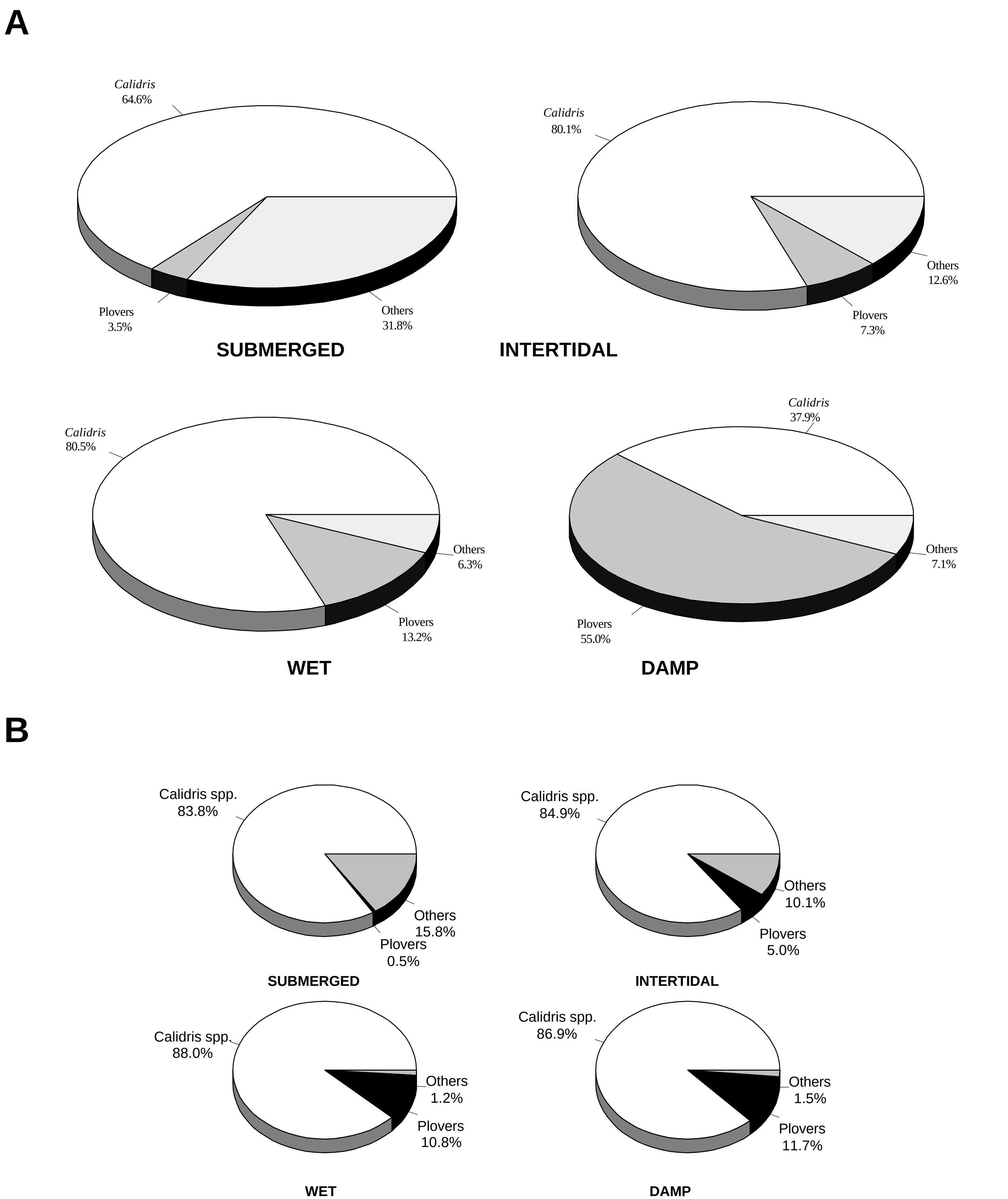

Fig. 3.28. Relative abundance of shorebirds by species on blue-green algal flats in the upper Laguna Madre: (A) 1991-1993 (after Withers, 1994); (B) the present study.

Table 3.9. Primary productivity by benthic microalgae in the CCBNEP study area and in other temperate intertidal flats and shallow subtidal areas.

Area	Production ($g\ C/m^2/yr$)	Reference
North Padre Island algal mat	388 [a]	Pulich and Rabalais, 1982, 1986
Brownsville Ship Channel algal mat	222 [a]	Pulich and Rabalais, 1982, 1986
Texas algal mat	562 [bc]	Odum and Wilson ,1962
Texas sand flat	300 [d]	Brogden et al., 1977
Georgia	200	Pomeroy. 1959
Southern California	200	Onuf et al., 1980
North Carolina (Newport River Estuary)	40 [e]	Bigelow, 1977
Western Wadden Sea (Balgzand)	29-188	Cadée and Hegeman, 1977
Western Wadden Sea	101±38.5	Cadée and Hegeman ,1974
Danish fjords	116	Grøntved, 1960
Danish Wadden Sea	115-178 [b]	Grøntved, 1962
Eastern Wadden Sea	80	van den Hoek, 1976 (cited in Cadée and Hegeman, 1977)
Eastern Wadden Sea (Dollard)	100	van den Hoek, 1976 (cited in Cadée and Hegeman, 1977)
False Bay, Washington	143-226 [b]	Pamatmat, 1968
Ythan Estuary, Scotland	31	Leach, 1970
Long Island Sound	84	Burkholder, 1965
Southern New England Shoals	81	Marshall et al., 1971
Laboratory (North Carolina)	75 [bc]	Sollins, 1969

[a] Extrapolated from 3 hr rates and 300 days of effective productivity/yr.
[b] Estimated using the oxygen method.
[c] Converted from $g\ O_2/m^2/d$ using $1g\ O_2 = 0.375\ g\ C$ (Lind 1974) x 300 days.
[d] Values for inundated flat, estimated at 300 days of effective productivity/year.
[e] Probably not representative (Peterson and Peterson 1979).

Cadée and Hegeman (1977) explored relationships (using correlation) between primary productivity and suspendible matter (<50 μm) in sediment, organic carbon content of sediment, tidal level, and functional chlorophyll *a* content of sediment. All variables were significantly correlated to primary productivity, but correlations with tidal level and functional chlorophyll α were strongest. Highest primary productivity was found in high areas of the tidal flat (=lower tidal levels) which received more solar energy than low areas of the flats, where turbid waters attenuate light levels. Close correlation between annual average chlorophyll α content and annual production ($r = 0.7982$, $p = <0.0005$[calculated $r^2 = 0.64$]) was thought to indicate a rough estimate of annual benthic primary production could be obtained from only six to 12 chlorophyll samples distributed regularly over the year. Few sediment chlorophyll *a* values have been reported for blue-green algal flats in the CCBNEP study area or elsewhere prior to this study (Table 3.10). Mean values reported in the present study were higher than those reported by Pulich and Buskey (unpubl. data) at all sites except Newport Pass; maximum values exceeded 1 g/m^2 in Newport Pass and Oso Bay. Mean chlorophyll *a* values did not vary much among sites or months (Fig. 3.29). This was unexpected since Oso Bay does not have a prominent algal mat, however, there appeared to be extensive diatom films present on several occasions. Highest mean values were recorded during January at Marker 83 and Oso Bay, during December at Fish Pass, and during February for Newport Pass.

Table 3.10. Chlorophyll *a* values for tidal flats and/or blue-green algal mats. When mean values were reported, ranges are given in parentheses.

Area	Chlorophyll *a* (mg/m^2)	Reference
Blue-green algal flat, variable water depths (mostly emergent), Marker 83 flat (North Padre Island), Laguna Madre, Texas (n=52)	161.2 (8.6-694.3)	the present study
Blue-green algal flat, variable water depths (mostly emergent), Newport Pass, Laguna Madre, Texas (n=77)	119.4 (4.3-1095.4)	the present study
Blue-green algal flat, variable water depths (mostly emergent), Fish Pass, Laguna Madre, Texas (n=74)	157.0 (4.3-370.9)	the present study
Mudflat sediments, variable water depths (<15 cm), Oso Bay, Texas (n=46)	183.1 (0-1052.3)	the present study
Blue-green algal mats, variable water content, Land-Cut, Laguna Madre, Kenedy County, Texas (n=13)	141.9 (4.8-475.8)	Pulich and Buskey, unpublished data
Blue-green algal mat, water depth 10 cm, Laguna Madre, Texas	28-38	Odum et al., 1958
Blue-green algal mat, water depth 10 cm, Portland, Texas	55 (38-75)	Odum et al., 1958
Blue-green algal mat in flowing microcosm UTMSI, Port Aransas, Texas	0.3-38	Odum and Hoskins, 1957
Blue-green algal mat, polluted stream, Mission River, Refugio, Texas	250	Odum et al., 1958
Algal ooze on sand, Laguna Madre	32-60	Odum et al., 1958
Blue-green algal mat, 2 cm deep, artesian water trough, Beaufort, N.C.	66	Odum et al., 1958

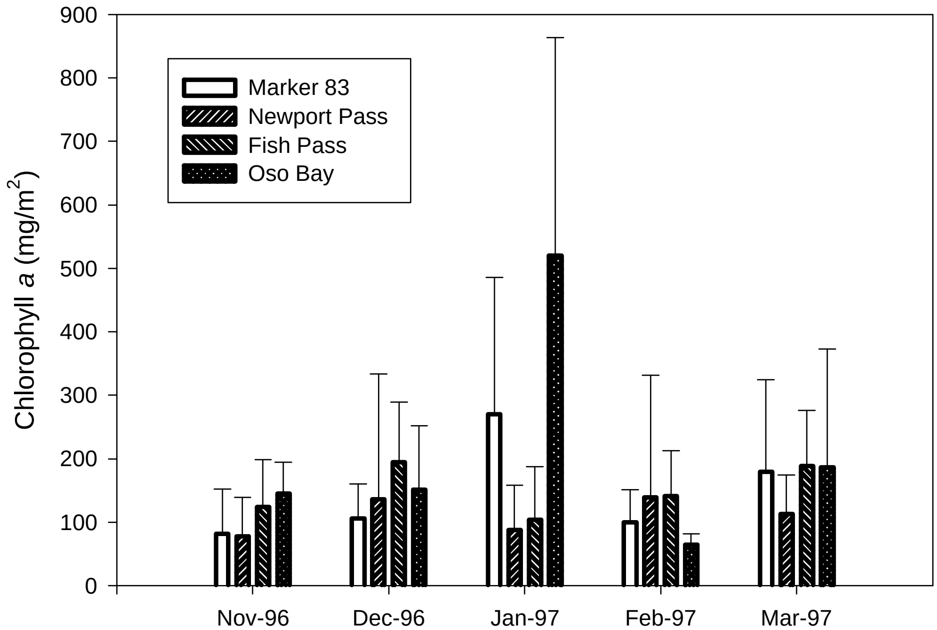

Fig. 3.29. Mean chlorophyll *a* values with standard errors for tidal flat sites sampled in the CCBNEP study area.

Tidal flat productivity in the CCBNEP study area is comparable to seagrass beds, and about 20-40% of a typical *Spartina* spp. (cordgrass) marsh (Pulich et al., 1982). Although less than half the productivity of a salt marsh, the value is substantial and cannot be ignored when tidal flats occupy a significant proportion of the total acreage in an estuary (Peterson, 1981). Benthic algae contributed as much as one third of total estuarine primary productivity in Georgia (Pomeroy, 1959). Benthic microalgae do not accumulate biomass *in situ* like marsh plants and many seagrasses, but some groups, like diatoms, are nutritious and highly edible, and consequently are of immediate use to consumers. Blue-green algae are also nutritious, but vary widely in edibility. The often direct transfer of primary productivity to higher trophic levels on tidal flats results in energy flow which may be more efficient than the classical 10% efficiency of other food chains, possibly as high as 40%, which is similar to efficiency of decomposer food chains in marshes. A substantial amount of energy contained in marsh and seagrass detritus never appears in bacterial biomass, the edible form of that energy. It may take about 2.5 kg of marsh grass production to provide the same amount of food to consumers as only 1 kg of benthic microalgae (Fig. 3.30). This makes productivity of benthic microalgae appear to be even more significant (Peterson, 1981). Photosynthetic efficiency of benthic microflora in northerly regions has been estimated at about 0.2% of total solar energy (Pamatmat, 1968 [Washington]; Cadée and Hegeman, 1974 [western Wadden Sea]); efficiency of blue-green algal mats in the CCBNEP study area with respect to visible light has been estimated at 0.5-1.62% (Odum and Wilson, 1962; Armstrong and Odum, 1964).

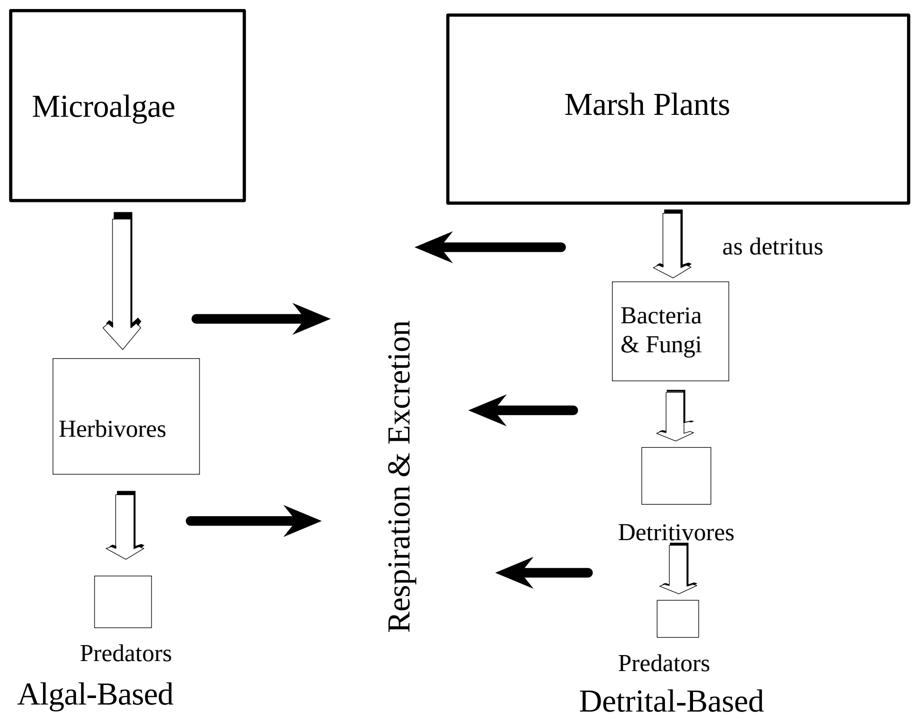

Fig. 3.30. The fate of primary productivity in algal-based (tidal flat) and detrital-based (salt marsh) food chains (redrawn from Peterson 1981). Boxes are sized to convey relative amounts of primary productivity at each level.

Organic matter enters tidal flat sediments as a result of alteration of sediment and old algal layers beneath the active mat and from breakdown of marsh and seagrass detritus carried to the mat by wind tides and currents (Peterson, 1979). Organic content of tidal flat sediments is highly variable. Few data are available on origin or amount of organic matter present in tidal flat sediments. Sollins (1969) found 270-640 g/m^2 organic matter in the top layers on North Carolina tidal flats, and 970-1350 g/m^2 for the entire core. In the western Wadden Sea, most organic matter in tidal flats was attributed to allochthonous sources (e.g., dead phytoplankton); amounts decreased with depth in sediments due to mineralization by bacteria. Organic content of tidal flat sediments ranged from 3.4-4.8% on the surface to 0.8-1.7 % at ≥ 48 cm deep; annual burial of carbon was estimated at 34 g C/m^2/yr (Cadée and Hegeman, 1977). In the CCBNEP study area, percent total organic carbon in tidal flat sediments ranges to as high as 4.8% (Table 3.11). Organic carbon did not consistently increase or decrease with depth, but mineralization by bacteria was recorded (Volkmann and Oppenheimer, 1962). Seasonal trends in amounts of organic carbon were noted by Volkmann and Oppenheimer (1962), with highest values recorded in October. However, in the present study, carbon values were relatively stable throughout the study (Fig. 3.31).

The question of energy transfer efficiency is complicated by dissolved (DOC) and particulate organic matter (POC) found in the water column and sediments. This organic matter is used by both bacteria and deposit-feeding organisms. DOC values of 5-11 mg C/l were recorded

Table 3.11. Total organic carbon values (% sediment dry weight) for tidal flat areas in the CCBNEP study area. When mean values were reported, ranges are given in parentheses.

Area	TOC (%)	Reference
Blue-green algal flat, variable water depths (mostly emergent), Marker 83 flat (North Padre Island), Laguna Madre, Texas (n=56)	2.5 (0.6-4.8)	the present study
Blue-green algal flat, variable water depths (mostly emergent), Newport Pass, Laguna Madre, Texas (n=73)	1.6 (0.5-3.7)	the present study
Blue-green algal flat, variable water depths (mostly emergent), Fish Pass, Laguna Madre, Texas (n=64)	2.0 (0.4-4.2)	the present study
Mudflat sediments, variable water depths (<15 cm), Oso Bay, Texas (n=53)	1.7 (1.1-2.9)	the present study
Clay sediments, Redfish Bay shore	<0.5-3.7	Volkmann and Oppenheimer, 1962[1]
Coarse sand and shell sediments, Redfish Bay shore	<0.5-3.0	Volkmann and Oppenheimer, 1962
Clay surface sediments with coarser fraction below surface, Redfish Bay shore	0.5-2.4	Volkmann and Oppenheimer, 1962

[1] These values are estimated from graphs.

by Maurer (1971) for upper Laguna Madre waters. There may be high concentrations of organic matter in water over algal flats due to algal productivity (Longley et al., 1989) and the characteristic "leakiness" of algae. Haines (1977) found the detrital pool of particles available for breakdown in a Georgia estuary was largely derived from algal sources. Significant export of productivity from tidal flats caused by winter breakup of algal mats and wind may result in significant output to the estuary's detrital pool (Brock, 1983; Brogden et al., 1977).

No estimates were found concerning contribution of phytoplankton to primary productivity of the CCBNEP tidal flat system when it is flooded. Although the prevailing view is phytoplankton contribute an insignificant fraction of carbon to estuaries, Sellner and Zingmark (1976) found phytoplankton production as high as 350 g C/m^2/yr in shallow tidal creeks and estuaries of South Carolina. The brown tide in the Laguna Madre probably contributed a substantial amount of carbon to the system, since the organism was not grazed (Buskey, 1996). Peterson and Peterson (1979) suggest that because summer turbidity in shallow water of North Carolina sounds and estuaries is low, phytoplankton production could often be significant. Phytoplankton productivity above tidal flats in New England was generally low because they were only flooded part of the day and water was turbid (Whitlach, 1982). In the western Wadden Sea, production depended on submergence time and water height during submergence (Cadée and Hegeman,

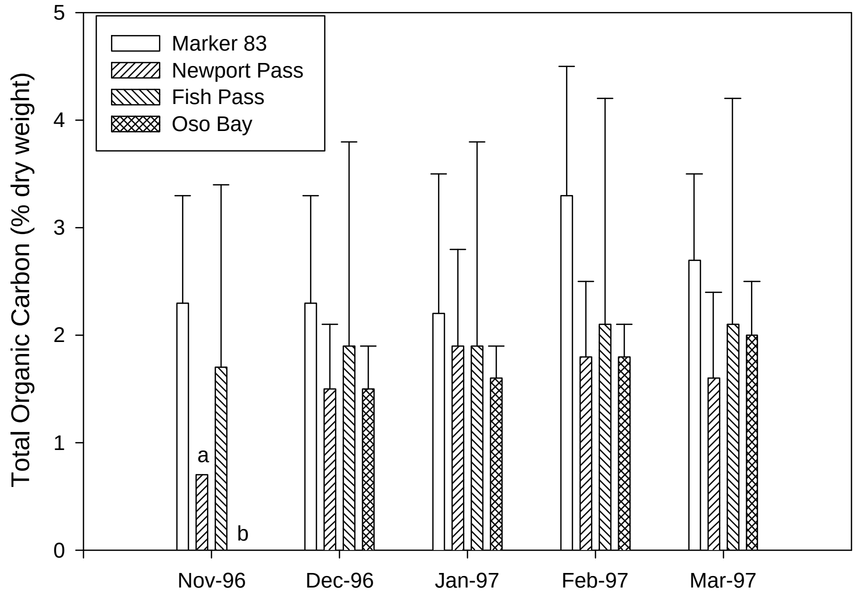

Fig. 3.31. Mean total organic carbon (TOC) values with standard errors for tidal flat sites sampled in the CCBNEP study area.

1974). Production by phytoplankton over submerged tidal flats in the western Wadden Sea averaged 20 g C/m^2/yr (10-40 g C/m^2/yr) (Cadée and Hegeman, 1974; 1977).

3.5.2 Trophic Levels and Food Web Relationships

Estuarine food webs are commonly viewed as detritus-based. Whitlach (1982) asserts detrital material is conspicuous in guts of tidal flat organisms and the grazing food web contributes less than the detrital food web to tidal flat energy. However, Peterson and Peterson (1979) note gut contents are not especially useful for determining diets of detritivores and other low-level consumers. Gut contents of these organisms are nearly always in an advanced stage of decomposition; the basic distinction of marsh plant and diatom or seagrass detritus is usually impossible. In addition, gut contents do not necessarily reflect what is being digested and assimilated since many detritivores use bacteria and fungi that colonize the detritus rather than the detritus itself. Results of δ^{13}C analyses of detritivores in a Georgia salt marsh tend to contradict previous assumptions of the importance of vascular plant detritus in the food webs of estuarine systems (Haines and Montague, 1979). These data indicate algae are far more important than expected in nutrition of primary consumers in estuarine systems. Benthic microalgae are highly nutritious and often palatable (Peterson, 1981); it is likely the grazing food chain is much more important than previously thought, particularly on tidal flats. Carbon isotope studies (δ^{13} C) on insects collected from the algal flat at Yarborough Pass (Padre Island) indicated that in open flat habitats, blue-green algae from the algal mat was the source of organic carbon (Pulich and Scanlon, 1987); this is strong evidence for the importance of grazing food chains on tidal flats in the CCBNEP study area.

On southerly Laguna Madre algal flats an abbreviated food chain based on microalgae and mature saltwater-adapted insects has been suggested (Pulich and Rabalais, 1982; Pulich and Scanlan, 1987). Benthic invertebrates such as polychaetes and crustaceans, as well as larval insects are also important in the food chains of wetter algal flats in the study area (Withers, 1994; T. Barrera, unpubl. data). A generalized food chain for tidal flats is depicted in Figure 3.32. Presence of higher level consumers such as shorebirds and fish are dependent on inundation and exposure of the flat. Because of shallow water, large fish such as *Sciaenops ocellata* only rarely use the flats. The grazing food chain may be more important on algal flats than non-algal flats, although most benthic organisms recovered from flats in the upper Laguna Madre were either deposit-feeders or predators (refer to Table 3.3). Detritus may be more important during some times of the year than others. Large amounts of seagrass detritus are often found along the high tide line after high tides, particularly in fall and winter, and after storms (K. Withers, pers. obs.). Regardless of the basis of tidal flat food chains, these are major sites for conversion of plant biomass into animal biomass for use by larger estuarine predators.

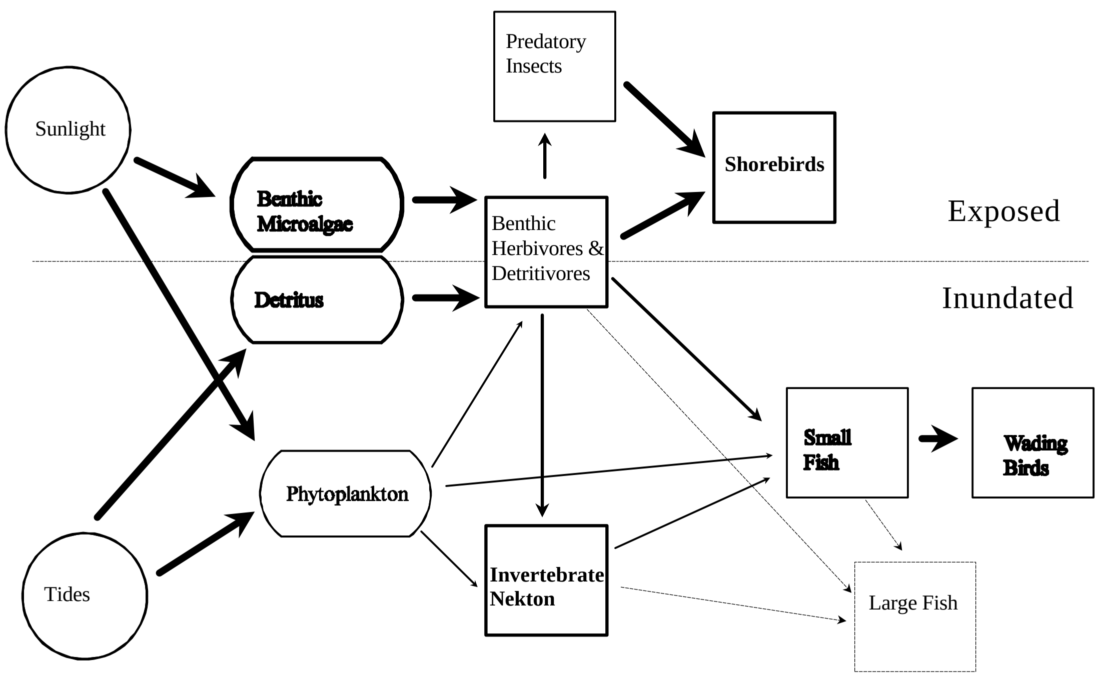

Fig. 3.32. Generalized food web for tidal flats. The weight of the arrows and boxes reflect the relative importance of each compartment and pathway.

3.5.3 Nutrient Cycling

Tidal flats appear to be nutrient sinks. Mudflat sediments in western Connecticut adsorbed nutrients derived from an adjacent saltmarsh and tidal creek. They were so effective in trapping nutrients that very little was transported into the open estuary (Welsh, 1980). Other significant sources of nutrients include local runoff during periods of high rainfall and sediment nutrients that are brought to the surface by capillary action during dry periods and later redissolved (Oppenheimer and Ward, 1963). Nitrogen and phosphorus are major nutrients associated with primary production on tidal flats in the CCBNEP study area.

Nitrogen is often considered a limiting nutrient. However, most nitrogen used by blue-green algal flats in the CCBNEP study area is fixed by the mat or anaerobic bacteria in sediments beneath the mat. About 26 kg N/ha/yr was fixed by an algal mat in a salt marsh (Van Raalte et al., 1974) while Jones (1974) measured fixation on an English algal flat over mud substrate at about 200 kg N/ha/yr. Since algal flats in the CCBNEP study area are frequently dry for extended periods of time, nitrogen fixation is not as high as in areas more frequently flooded. However, even for mats flooded only 30% of the time nitrogen fixation is probably a major source of nitrogen to the ecosystem (Brogden et al., 1977). Gotto et al. (1981) estimated an average annual input of nitrogen in an algal mat in the Port Aransas area at 40.6 kg N/ha. This conservative estimate represents a considerable contribution to the nitrogen economy of the shallow coastal environment. Pulich and Rabalais (1982; 1986) measured nitrogen fixation in algal mats near Yarborough Pass on north Padre Island and the Brownsville Ship Channel. They estimated average nitrogen inputs between 4-16 kg N/ha/yr and 19-89 kg N/ha/yr, respectively. Moisture content of the mat was correlated to nitrogen fixation activity; darkness and dim light supported better activity than full sun.

Substantial amounts of dissolved ammonia were always detected leaching out of algal mats at Yarborough Pass and the Brownsville Ship Channel. There was little pattern in the process, and the ammonia pools probably reflected local variation in decomposition occurring within or beneath the mat. The same measurements revealed a fairly consistent pattern of phosphate flux. Accumulated phosphate was readily washed out of a non-growing, desiccated mat when it was reflooded. Phosphate also appears to be lost by downward percolation. When the mat was wet or flooded, net uptake phosphate by the mat was observed. High nitrogen fixation combined with high ammonia leaching results suggest fixed nitrogen is generally available, if not abundant, for algal production. Conversely, the phosphate leaching pattern demonstrates potential for phosphate as a limiting nutrient (Pulich and Rabalais, 1982).

3.5.4 Linkages with Other Systems

Because tidal flats can be considered semi-terrestrial, they interact with both aquatic and terrestrial environments. Runoff from upland areas contributes freshwater, detritus, nutrients and sediment and may be a source for pollutants such as agricultural chemicals, industrial wastes, and chemical spills, particularly on the mainland. In urban areas, direct discharges of domestic and industrial wastes can constitute significant nutrient inputs into tidal flat systems. About 57 million liters of treated municipal wastewater are discharged daily into Oso Bay adjacent to wind-tidal flats. Some nutrients brought to wind-tidal flat systems via streams actually originate as waste discharges and agricultural runoff. Oso Creek receives municipal wastewater from Corpus Christi's westside and Robstown, and over 1.9 billion liters of hypersaline water each day pumped out of the Laguna Madre from the Central Power and Light Barney Davis Power Plant. The power plant discharges significantly affect hydrology of lower Oso Creek and Oso Bay. In addition, Petronila Creek and many other ephemeral or intermittent streams flowing into Baffin Bay receive much agricultural runoff from intensively cultivated areas along their banks.

Deflation of barrier island dunes contributes most sediment to island flats. Coastal marshes contribute nutrients and detritus to tidal flats in deltaic and bay margin environments, particularly from Corpus Christi Bay northward. Benthic invertebrates may be recruited from coastal marshes onto tidal flats. These invertebrates also provide a source for consumers such as fish, shrimp, and crabs. Seagrass meadows also provide detritus and a source of invertebrates and nektonic consumers. Tidal flats interact with the open bay primarily as a water, nutrient, and invertebrate source and transport system.

Presence of tidal flats in the mosaic of the coastal environment is particularly important for shorebirds and wading birds. The flats provide an abundant source of food, and are near upland and transitional habitats for roosting and nesting. Alternate feeding sites on the beach are also nearby for wading birds when flats are exposed or for shorebirds when flats are completely flooded. Health of the bay ecosystem is one of the most critical aspects in survival of the tidal flat system because the bay supplies most of the water which nourishes the flats. The next most critical component in long-term maintenance of tidal flats is runoff from adjacent upland areas (Longley et al., 1989). The primary threat to tidal flat systems is public perception they are barren wastelands. Tidal flats are often targeted for coastal development and frequently overlay oil and gas deposits. In the past, tidal flats were often chosen as sites for dredge material disposal and mitigation projects in which they were scraped down in order to attempt creation of coastal marsh or seagrass systems. Tidal flats act as flood basins which buffer or dampen wind-driven bay and lagoon waters, protecting adjacent vegetated habitats (White and Brogden, 1977). Use of tidal flats as dredge material disposal areas leads to compartmentalization and alterations of natural water circulation patterns.

Table of Contents

4. THE TIDAL (AND TITLE) BOUNDARY PROBLEM

4.1 What is the Problem?

Ownership determination of wind-tidal flats in south Texas has occupied court cases throughout the 20th Century (e.g. State v. Spohn in 1904, Humble v. Sun in 1951, and Kenedy Memorial Foundation v. Garry Mauro and State in 1995). During the previous century when much of the title was established, primarily via Spanish and Mexican Land Grants, few people cared about these seemingly barren and inhospitable flats. However, with the discovery of oil and gas reserves under, specific ownership and mineral rights became important. Under Texas law, if the land is "submerged", it belongs to Texas; royalties go into the Permanent School Fund. On the other hand, if the land is privately owned, royalties go to the land owner or mineral rights holder.

The basic question is: are these coastal areas, the wind-tidal flats of the Laguna Madre, submerged, and therefore owned by the State, or are they not submerged and owned by the property owner of adjacent uplands (Fig. 4.1). Legal boundaries of property that parallel the seacoast are typically determined by tidal datums and the geomorphology of the shore (Gutstadt, 1990). Most shorelines around the world exhibit sufficient elevation change where the sea meets the shore, to make shoreline determination fairly straightforward. However, shoreline determination along the very gently sloping shores, adjacent to much of the Laguna Madre, is an exacting process. Due to the unique environmental setting and special conditions, a multidisciplinary approach has been suggested and applied, in which scientific studies (geological, biological, meteorological, hydrological, etc.) are performed to support the location of a shoreline surveyed according to state laws (Watson et al., 1990). Historically, and ironically, courts have ruled in favor of a shoreline on both the landward side of the flats (Humble v. Sun) and the seaward side of the flats (Luttes v. State). Since hundreds of millions of dollars are generated in royalties of oil and gas revenues beneath the more than 932 km^2 of wind-tidal flats adjacent to the Laguna Madre, this is no insignificant matter; many issues must be considered when evaluating the problem. Significant wind-tidal flats within the CCBNEP study area are found in Nueces, Kleberg, and Kenedy counties.

4.2 What are The Issues?

The principles of Texas law governing tidal boundaries (the legal boundary of a property subject to the ebb and flow of tidal forces) are based upon English Common Law and Spanish and Mexican Civil Law. One must understand and apply these and other property boundary laws along with a knowledge of tides and tidal datums to determine a tidal boundary.

Tidal waters are reduced in tidal range (difference between high and low tides) within the Laguna Madre when compared to the adjacent Gulf of México (Smith, 1978; NOAA, 1994). Within the Laguna Madre, normal, astronomical tidal ranges are typically less than 2 cm, and most commonly less that 1 cm.

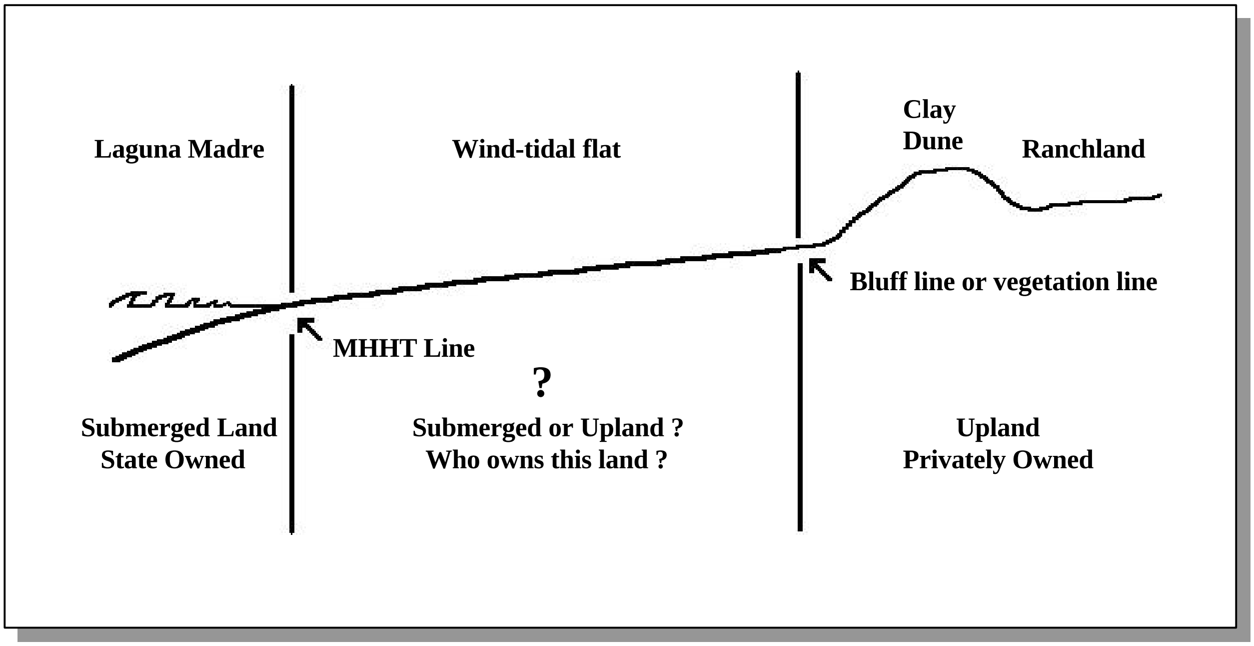

Fig. 4.1 Schematic profile along the Laguna Madre shoreline depicting the century old question "Who owns the wind-tidal flats?" the state of Texas, as owner of submerged lands, or the private owner of adjacent uplands!

Tidal datums of use in the Laguna Madre include high water, which is maximum height reached by rising tide, and low water, which is minimum height reached by the falling tide. Mean High Water (MHW) and Mean Low Water (MLW) are average water heights observed over a 19-year period, the National Tidal Datum Epoch. This period (precisely, 18.6 years) covers all possible variations of astronomical effects on tides. Mean High Water Line (MHWL) and Mean Low Water Line (MLWL) are lines on a chart or map which represent the intersection of the land with the water surface at the elevation of MHW or MLW (Fig. 4.2). (Note: the term "Tide" is sometimes used interchangeably with the word "Water" in these definitions/acronyms; e.g. MHT, for Mean High Tide, is equal to MHW. In Texas, the word "Tide" is most commonly used with these terms). Determination of MHW and MLW is made NOAA based on a network of tide gauges (Gutstadt, 1990). It has not been shown, however, that such a determination by NOAA of MHW or other datums, dictated the location of a tidal boundary, since the datum can easily be computed by others.

Geomorphology of the shore. Figure 4.2 depicts a schematic profile of a coast showing tidal datums and the usual legal and geomorphic terminology. The legal term upland (or fast land) begins at the lower limit of the backshore and extends inland. The tideland, or sometimes synonymous word "beach", is equivalent to the foreshore or between MHWL and MLWL. Lastly, submerged land is the general legal term for all the sea floor below MLWL (Gutstadt, 1990).

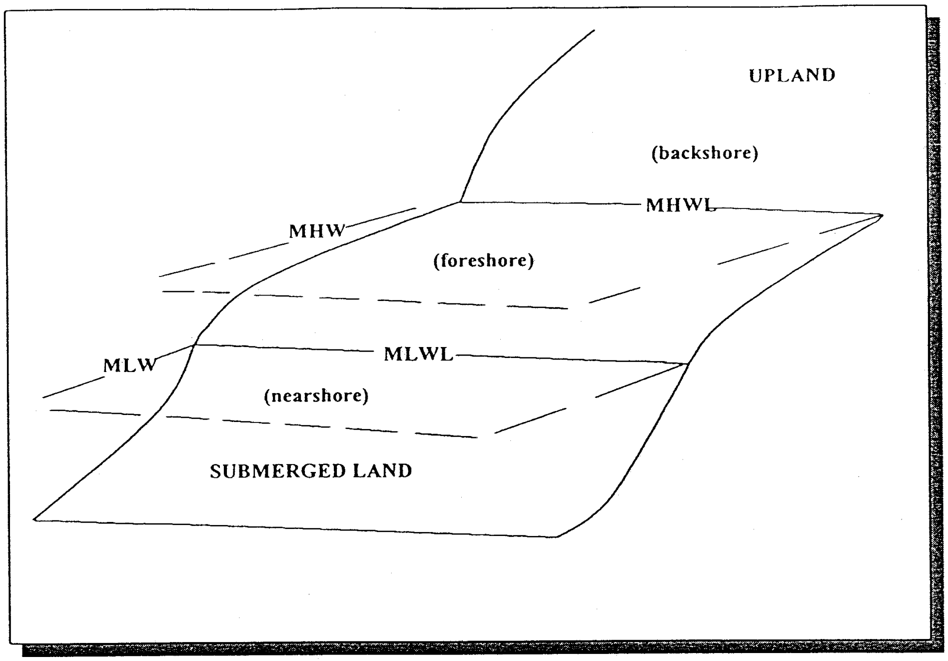

Fig. 4.2. Schematic profile of the shoreline showing tidal datums and the usual legal and geomorphic (in parenthesis) terminology. MHW = Mean High Water, MLW = Mean Low Water, MHWL = Mean High Water Line, MLWL = Mean Low Water Line. No scale. Slopes greatly exaggerated (Adapted from Gudstadt, 1990).

Boundary call for tidal waters. To qualify as a tidal or littoral boundary, the original grant, as well as subsequent conveyances, must contain a primary call for the adjacent body of water as the boundary (e.g. " … and bounded on the east by the Laguna Madre …"). Therefore, the true legal boundary of a tidal or littoral boundary is the intersection of the vertical elevation of MHW or MHHW with the land, rather than a metes and bounds description (normal surveying description). This was upheld in Luttes v. State in 1958. However, this stance was challenged in Texas courts after NOAA (1994) made a "determination" that some of the waters of the Laguna Madre were "non-tidal", according to their criteria. Contrary to NOAA's "finding", tide gauges operated by the Conrad Blucher Institute for Surveying and Science throughout the Laguna Madre do record consistent, although small, tidal signals.

Littoral or riparian nature of tidal boundary. One of the most important aspects of a boundary is its propensity for change. As coastal morphologic features slowly evolve over time, sea level and tidal datums fluctuate and property lines running parallel with the coast migrate seaward and/or landward. Such moveable boundaries are referred to as ambulatory in legal terms. One owner may gain land while the other loses land (Gutstadt, 1990). A littoral owner can properly claim title to new land added by accretion, legally defined as the slow, imperceptible, and natural addition of fast land. Alternatively, the littoral owner loses title to land removed by erosion, the slow, imperceptible, and natural removal of fast land. Relection is the receding of water, which results in the exposure of new fast land that becomes the property of the littoral owner. Avulsion is the sudden, perceptible, and natural removal or addition of fast land, which does not result in a change of title.

Rights of riparian owner. The primary benefit derived from a tidal boundary is the enjoyment and use of the water. For this reason the boundary thus must be ambulatory to allow an owner continued right of access to water.

Determination of the tidal boundary by a surveyor on the ground varies with Civil Law grants (pre-1840) and Common Law grants (post-1840). For grants made before adoption of the Common Law in Texas in 1840, the boundary is defined as Mean Higher High Tide (MHHT), and for grants after 1840 subject to Common Law, the boundary is defined as Mean High Tide (MHT). The difference in these two measurements, which involves averaging the higher of the two semidiurnal (two highs and two lows per day) high tides versus the single diurnal (one high and one low per day) high tide, is miniscule in the microtidal Laguna Madre.

4.3 Laguna Madre Environmental Setting and Special Conditions

About 936 km^2 of wind-tidal flats are found adjacent to the shoreline of the hypersaline Laguna Madre (Table 4.1 and Fig. 4.3) (Brown et al., 1976; 1977; 1980). A wind-tidal flat is defined as a broad, barren flat partially inundated at irregular intervals by lagoonal or bay waters under the influence of wind-generated tides (Fisk, 1959; Hayes and Scott, 1964; Hayes, 1965; White and Galloway, 1977; Morton and McGowen, 1980; Weise and White, 1980; Watson et al., 1990). These expansive flats, sometimes reaching 8-13 km in width, have slopes on the order of 0.2 m/km (Brown et al., 1977). Astronomical tidal ranges in the adjacent Laguna Madre are usually less than 0.5 ft. and therefore, cause only minimal flooding of the flats. However, flats are occasionally wetted or flooded by multi-directional wind-tides and storm waters (Watson et al., 1993). Consequently, along these gently sloping shorelines, there is typically no obvious shoreline or vegetation line in most areas.

Wind-tides are pivotal in understanding, uniqueness and determination of tidal boundaries within the Laguna Madre. These wind-tides, although little known or understood to the non-scientific community or even the scientific community unfamiliar with the phenomenon, are well known to scientists studying dynamics of the Laguna Madre. Copeland et al. (1968) noted wind-driven tides will cover “normally dry land” within the Laguna Madre. Brown et al. (1977) state “wind-driven tides may flood as much as 200 mi^2 of low-lying lagoonal margin” within the Kingsville Geologic Atlas Area; “wind-tidal flats are flooded rapidly, generally by northers or the prevailing southeasterly wind regime”; and, flooding from wind tides can be localized on flats and is a “function of the duration, intensity, and direction of the wind”. Strong winds, accompanied by spring tides and a barometric low can create tides up to 1 m higher than those produced solely by astronomical conditions (McGowen et al., 1977). Weise and White (1980) define a wind-tide as a rise in water level on the downwind side of a body of water, such as a lagoon, caused by the force of wind on the water surface. They also note wind-tides are more influential on tidal amplitude than astronomical tides in the Padre Island area, and that they are produced when

Table 4.1. - Areal extent of wind-tidal flats in the Laguna Madre area of south Texas, including Baffin Bay and South Bay, (compiled from Brown et al. 1976, 1977, 1980); all values are in square kilometers. Nueces, Kleberg, and northern Kenedy counties are within the CCBNEP study area.

	County (north to south)					
Type of Tidal Flat	Nueces[1]	Kleberg	Kennedy	Willacy	Cameron	Total
Wind-tidal flat, sand, loose, rarely flooded	0.0	0.0	59.8	0.0	0.0	59.8
Wind-tidal flat, sand and mud, firm	37.2	70.2	162.5	12.5	150.3	432.7
Wind-tidal flat, sand and mud, extensive algal mats, alternatively emergent-submergent	0.0	2.6	93.6	51.5	78	225.7
Wind-tidal flat, mud and sand, algal-bound mud, gypsiferous, firm	3.1	0	104.0	11.7	0.0	118.8
Wind-tidal flat, mud and sand, extensive algal mats, depressed relief, wet and soft	0.0	0.0	33.8	9.9	2.1	45.8
Total wind-tidal flat by county	40.3	72.8	419.9	85.6	230.4	849.0
Percent of total	4.7	8.6	49.5	10.1	27.1	100
Transitional zone, wind-tidal flat to eolian sand sheet, wind deflation, concentrated clay dunes, sand	0.0	1.3	172.1	19	0.0	192.4

[1]Nueces County figures also include wind-tidal flats outside of Laguna Madre. Square kilometers not separable by bay system in publication.

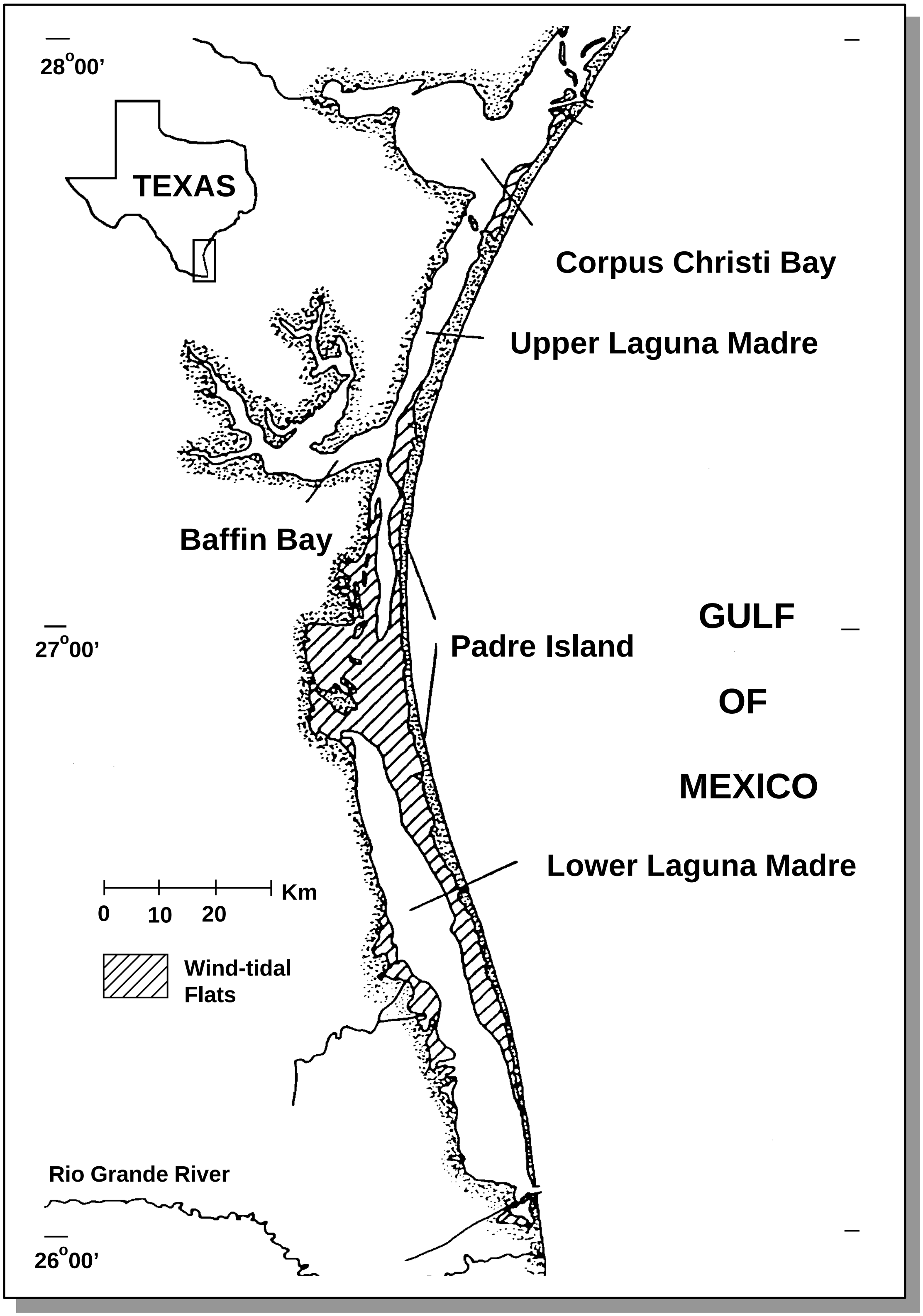

Fig. 4.3. Map of wind-tidal flats adjacent to the Texas Laguna Madre (modified from Pulich and Rabalais, 1986).

strong and steady winds elevate the water surface, flooding areas of low elevation. Finally, Morton and McGowen (1980) note "that wind-tides inundate areas not normally affected by astronomical tides".

Some argue wind-tides are not true tides, and in the astronomical sense, they are not. Others conclude that wind-tidal flats are intertidal, since wind-tides periodically push water across or over them, making them "between" the tides (intertidal). However, most scientists cited herein conclude flats are supratidal or above the highest astronomical tides. Ground surveying, using tidal datums, likewise show the flats as supratidal. It should also be noted the MHHW datum computed for trial (Kenedy v. Mauro and State) on tide stations adjacent to the Land-Cut flats include in the datum high waters generated by "wind tides", and were only insignificantly different from "preliminary" MHHW datums computed by NOAA.

Several detailed land surveys of wide geographical expanses on wind-tidal flats in the Laguna Madre using tidal datums have placed the tidal boundary adjacent to the normal location of the water body (Settles and Claunch, 1967; Claunch and Associates, 1971; Claunch and Lothrop, 1986). State land surveys have, conversely, placed the boundary on the upland (or high) side of the flats, generally along the elevated clay dunes of the mainland in the Land-Cut area, for example (Shine, 1995). A summary of these tidal boundary surveys is presented in Table 4.2 along with several others.

These surveys embody the essence of the long-term controversy of wind-tidal flat ownership within the Laguna Madre. Matt Claunch and his colleague Bill Lothrop together have over 50 years of experience surveying in the microtidal Laguna Madre. They are the only ones to use tidal datums, according to Civil and Common Law and the ruling in Luttes v. State, to actually put a tidal boundary line on the ground. Claunch's extensive research and discussions of former surveys and quantitative analysis of tidal datums and meteorological conditions in the lower Laguna Madre, where he filters out wind-tides, are very persuasive that a MHT or MHHT line can be placed on the ground and should be used (Settles and Claunch, 1967; Claunch and Associates, 1971).

On the other hand, the State has argued that wind-tidal flats are submerged lands, even if not regularly inundated on a daily basis, as evidenced by surveys which follow a geomorphic (bluff line) or vegetative line on the landward side of the flats at elevations of 2 to 4 feet above mean sea level. Their lines generally follow along the base of mainland clay dunes (e.g., Cocke 1879; Maddox, 1907; Shine, 1995). State arguments for using such surveys have been based on various themes: the land was submerged at the time of the original grant; previous old maps and old letters indicating submerged land with islands; that tidal flats represent a broad shoreline or tideland as indicated in Roman Law, "the seashore extends as far as the greatest winter flood runs up"; and, the Laguna Madre is "non-tidal" and therefore subject to these other considerations, rather than a typical tidal datum boundary determination. The Roman Law issue in a broad interpretation, is what allows public use or access of the seashore or beaches in Texas and therefore also seems plausible.

Table 4.2. Selected tidal boundary and topographic surveys along the South Texas coast.

Who	Where	When
Boundary Survey		
F. von Blucher	El Peñascal Grant, Kenedy County	1861
F. von Blucher	Los Mirasoles Grant, Kenedy County	1869[1]
J. J. Cocke	"Little Barreta" Grant, Kenedy County	1879
State v. Spohn (F. M. Maddox)	Land Cut, Kenedy County	1904
F. M. Maddox	"Big Barreta" Grant, Kenedy County	1907[1]
J. S. Boyles	Padre Island	1941
Humble Oil & Refining Co. & H. N. Fisk	Land Cut, Kenedy County	1949
Sun Oil Co.	Land Cut, Kenedy County	1949
Luttes v. State	Luttes Ranch, Lower Laguna Madre	1958
Settles and Claunch	South Padre Island	1967
Claunch and Associates	El Sauz Ranch, Lower Laguna Madre	1978
Claunch and Lothrop	Land Cut, Kenedy County	1986
D. D. Shine	Land Cut, Kenedy County	1995
Topographic Survey		
H. N. Fisk	Land Cut, Kenedy County	1959
Claunch and Associates	South Padre Island	1971
D. Pyle (City of Corpus Christi)	Blind Oso, Oso Bay	1991

[1] Patented

The previous discussion is a condensed overview of the complicated issue of private versus public ownership adjacent to the shoreline of the Laguna Madre in South Texas. The most recent case, Kenedy v. Mauro and State, which began in 1987 and went to trial in 1995, is still under appeal. The Kenedy Foundation lost in court in what seemed to be a confusing, "split" decision. Of four questions posed to the jury, they answered "No" to three and "Yes" to one, which seemed to counteract or negate the entire process. The judge, however, threw out the "Yes" and used the other rulings in the State's favor to declare that the disputed Land-Cut tidal-flats (14,200 ha) belonged to the State. He, likewise, discredited the Texas Supreme Court ruling in the Luttes v. State case, which has been the ruling case controlling tidal boundaries since 1958, that the Mean Higher High Tide line should represent the tidal boundary and should be located at the water's edge of the flats. So, after a century of dispute, it seems the age old question of tidal flats ownership is still in question.

4.4 Alternative Shoreline Determination Methods

Land ownership disputes in the Laguna Madre have not only generated interesting and intriguing legal cases, they have generated considerable scientific knowledge about the unique environmental setting of wind-tidal flats. The Humble v. Sun case generated several years of study on the Land-Cut tidal flats by Fisk (1959), which still forms the foundational knowledge of their geologic history, as well as functional processes. The more recent case, Kenedy v. Mauro and State, likewise generated extensive geological and biological studies of the flats. Although most of these studies were used for the case, and therefore were not published, one published report provides insight to alternative methods that can be used in shoreline determination along these gently sloping shores (Watson et al., 1990). These methods are only supportive and used in a multidisciplinary approach in conjunction with the traditional legal and land surveying boundary determination criteria.

Geologists use studies of sedimentology, topography, hydrography, and climate to provide a qualitative aid in helping locate the present boundary position, and to determine and explain processes which have operated to change the position of the historical boundary to the present boundary, if it has changed. They assist the attorney in understanding the complex physical processes affecting present and historical boundary positions (Watson et al., 1990).

Biologists provide qualitative assistance in supporting the location of the modern boundary position based on the presence or absence of inundation-sensitive plants and animals. They assist the geologist in faunal interpretation of surface and subsurface environments of deposition and explain the significance of biological indicators of shoreline position to the attorney (Watson et al., 1990).

Due to the complexity of law, surveying, and science associated with the legal boundary of the wind-tidal flats in South Texas and the high value of oil and gas under these flats, it is likely that tidal-flat land disputes will continue. Although the boundary law concerning location of shoreline boundaries in Texas is clear-cut and precise, and has been upheld in court (Luttes v. State 1958), it appears the State would like to change boundary law to deal with the special conditions of wind-tidal flats in the Laguna Madre.

Table of Contents

5. DISTURBANCES TO WIND-TIDAL FLATS

5.1 Natural Disturbances

5.1.1 Subsidence and Sea-Level Rise

5.1.1.1 Physical Effects

Sea level has been rising since the last glacial period ended (ca. 12,000 YBP). The process is accelerating because of global warming (Titus, 1990; Raffielli and Hawkins, 1996) and may be exacerbated in some areas due to subsidence. Estimates of future global sea level rise range from 50-200 cm by 2100 (Titus, 1990). Global sea-level rise is currently estimated at 0.12 cm/yr while mean sea-level rise in the Gulf of Mexico is estimated at 0.23 cm/yr (Gornitz et al., 1982). Rising sea levels will affect coasts in different ways, depending on regional geological movements. In coastal areas actively and rapidly subsiding like the Mediterranean, Pacific Rim, southern United Kingdom, northeastern Texas, and Louisiana (Raffielli and Hawkins, 1996; Dolan and Goodell, 1986; Pulich and White, 1991; Salinas et al., 1986), effects will be more severe than in areas that are being actively uplifted like Scandinavia and northern United Kingdom (Raffielli and Hawkins, 1996) or where subsidence is less severe, like the CCBNEP study area. Estimated rates of relative sea level rise along the Texas coast range from 1.32 cm/yr at Sabine Pass to 0.31 cm/yr at Port Isabel (Lyles et al., 1988). In Rockport, local rate of relative sea-level rise is ~0.4 cm/yr, nearly twice the current rate of Gulf of Mexico sea-level rise. Relative rates of sea-level rise are determined by interaction of eustasy (global sea-level changes), subsidence (Ramsey and Penland, 1989), and/or emergence (Titus, 1990).

In the Gulf of Mexico, subsidence rates increase from south to north along Texas, Mississippi, Alabama, and Florida shorelines, converging in Louisiana with the highest rates in the Mississippi River deltaic plain. Subsidence accounts for 63% of water-level rise in Galveston and 29% of water-level rise at Port Isabel. Causes of subsidence include downwarping of the geosyncline, compaction of Holocene, Pleistocene and Tertiary sediments, local consolidation, tectonic activity, and subsurface fluid withdrawal (Ramsey and Penland, 1989). Subsidence in the CCBNEP study area has occurred inland and in areas where shallow (<1,525 m) gas production has occurred (e.g., Saxet Oil Field), encompassing a 390 km^2 area between Corpus Christi across the Nueces River and into San Patricio County including some low-lying lands along the Nueces River (Brown et al., 1976). Unlike the upper Texas coast, groundwater withdrawal will probably not contribute to land subsidence in the CCBNEP study area, primarily because aquifers are much deeper and contain a larger proportion of sand to mud, and surface water provides most water for the area. However, future production of geothermal waters could initiate some land-surface subsidence or faulting. White et al. (1983) implicate compactional subsidence complemented by eustatic sea-level rise in spread of marsh vegetation, particularly on San Jose and Mustang islands, and grassflats into areas previously mapped as wind-tidal and shallow subaqueous flats.

Most information regarding effects of sea-level rise on tidal flats comes from Europe, where tidal flats are mainly located on seaward edges of coasts and islands, and are often found seaward of protective walls or dikes, rather than on backsides of islands or bayshores and/or river deltas of mainland as in the CCBNEP study area. In Europe, tidal flat accretion mostly occurs as a result of settling of suspended sediments. In areas without seawalls or other barriers, a rise in sea-level should lead to classic “sea-level transgression” over land in which erosion of the existing coast provides sediments that can be pushed inshore and redeposited (Goss-Custard et al., 1990). In this case, as long as the slope of the shore remains unchanged, no coastline would be lost and the shore would retain its existing width; however, it would take many years for marshes to be eroded and new mudflats to develop. In low-lying areas protected by dikes or seawalls, transgression would be prevented and overall width of the intertidal zone would decrease. Erosion would probably increase at all levels of the shore but derived sediments would not be redeposited because of seawalls. On the German North Sea Coast, where tidal flats are found below protective dikes, mean sea level has risen about 15 cm in the last 35 years, with concomitant increases in mean high water by at least 20 cm and mean storm surge level by twice that amount (Siefert, 1990). Significant increases in tidal flat elevations have not occurred, and there is no evidence that tidal flat accretion will keep pace if sea level continues to rise or rates accelerate.

In the CCBNEP study area, tidal flat accretion mainly occurs as a result of eolian processes and is generally incredibly slow, gradually decreasing during the last 2,500 years from 0.5 mm/yr to 0.25 mm/yr or less (Miller, 1975). It seems unlikely this rate of tidal flat accretion could keep pace with even slowly rising sea-level. However, on the bayshore of north Padre Island rapid shoreline progradation and expansion of wind-tidal flats was noted between 1941-1969 (Prouty and Prouty, 1989). Progradation was attributed to greater amounts of wind-blown sand due to devegetation of dunes caused by drought and concomitant devegetation. Global warming is likely to cause precipitation to become more variable (e.g., drier droughts, wetter rainstorms) (Titus, 1990) so during drought, shoreline progradation might also occur and ameliorate some effects of sea-level rise. In addition, presence of a relict tidal flat and associated inactive clay-dune complexes on the south shores of Copano Bay (Swan Lake) that were active between ca. 5300-2600 YBP (based on corrected and calibrated radiocarbon dates) suggest that (1) relative sea level was between 60-90 cm higher then than at present (Ricklis, 1995; Ricklis and Blum, 1997), and (2) tidal flats did form and were active at higher elevations and under higher sea level regimes at least along some bayshores. This may also suggest that mechanisms other than accretion (e.g., increases in soil salinities caused by irregular, periodic inundation) may contribute to tidal flat formation in this area, possibly mitigating some effects of sea-level rise, and resulting in shores that would retain their original width. However, like the scenario presented for unprotected European shores previously, it would likely take many years for uplands and/or marshes to erode and new tidal flats to form.

Other effects of rising sea-levels on tidal flats in the CCBNEP study area may be caused by ways barrier island communities choose to protect themselves. There are four responses possible (Titus, 1990): (1) no protection, which will result in loss of some homes and businesses to rising water; (2) engineered retreat, or building new land in areas behind the dune line onto which homes and businesses may be moved; (3) island raising, in which sand is pumped onto the beach, elevating the island in place; and (4) encircling the island with levees to hold back rising waters. Each of these approaches would result in immediate impacts to tidal flat if they had not already been inundated, but levee building would not allow tidal flats to rebuild over time.

5.1.1.2 Biologic Effects

The following discussion is based on a review by Goss-Custard et al. (1990) of possible consequences for birds using tidal flats in northwestern Europe, and a sea level rise of 100 cm over the next 100 years.

Sediment instability would increase with higher sea-levels causing increased turbidity and possibly decreased primary productivity. If unprotected shorelines of seaward tidal flats retained their existing width, but moved farther inland and if the rate of change were slow in relation to the life cycles of most invertebrates, faunas might not show abnormal changes. However, eroding sediments are often characterized by depauperate faunas, probably because larvae have difficulties settling. If shorelines became narrower, then total area would be reduced resulting in reduction in total abundance of invertebrates.

In areas protected by narrow entrances (more analogous to the position of tidal flats in the CCBNEP study area), low-level flats would become always submerged and low-level flats would translate landward. Changes in area of zones would result if the slope at the shore was not constant. Often there is an abrupt change in slope at the landward margin of flats. In this case, rising sea-level would result in a compression of wind-tidal flats. This would result in changes in species composition. Salt marsh (or upland) vegetation might colonize high flat areas, resulting in decreased area of suitable tidal flats for invertebrate prey of shorebirds. If sea-level rose over protective bars at the mouth of an estuary (e.g., closed barrier island passes in the CCBNEP study area), erosion would begin and changes noted for unprotected, seaward tidal flats would take place.

There is increasing evidence that food supply is critical in determining numbers of many carnivorous shorebirds. As bird density increases, interference that occurs between birds as they forage becomes more intense and prey depletion rates increase. This competition may already limit the numbers of birds using tidal flats; there is some evidence that birds may be limited in this way in the CCBNEP study area (Withers, 1994). Birds mostly feed on exposed flats at low water, so exposure times affect length of time they are able to forage. When feeding time is reduced by removal of upper levels of flats by reclamation for industrial purposes, numbers of some species decrease sharply. In addition, some shorebirds seem to actively avoid narrow shores.

Changes previously discussed in the nature of sediments and invertebrates likely to result from rising sea-levels would be disadvantageous for most shorebirds for the following reasons:

(1) Abundance of many food organisms would be reduced (especially short-term) because of unfavorable changes in the nature and stability of the sediments. Greater turbidity would also reduce primary productivity,
(2) Reduced width (=area) of the shore would force birds to feed at higher densities and would increase both interference and depletion competition,
(3) Reduced exposure time would reduce available feeding time,
(4) Narrow shores might increase rates of predation and disturbance of vulnerable species.

Goss-Custard et al. (1990) also note that areas with small tidal ranges will experience the earliest and largest effects of sea-level rise. Mudflats found along shores of the Wadden Sea are the most important staging areas for migrating shorebirds in northwestern Europe. It is also the area with the smallest tidal range. If carrying capacity were reduced, pressure on other intertidal areas would increase, and the decrease in food supplies would make it difficult for many birds to complete migrations. The upper Laguna Madre and most bays within the CCBNEP study area are generally considered microtidal, with most changes in water level or water movements related to wind speed and direction or seasonal effects rather than astronomical effects. Tidal flats of the upper Laguna Madre-Corpus Christi Bay estuarine complex are also one of the most significant staging and wintering areas for shorebirds on the Texas coast (e.g., Senner and Howe, 1984; Withers and Chapman, 1993; Withers 1994). Blue-green algal flats adjacent to the Laguna Madre are particularly important to threatened Piping and Snowy plovers. Effects in the CCBNEP study area, particularly the upper Laguna Madre, would likely be similar to those expected for the Wadden Sea because of small tidal range and importance to shorebirds. Like mudflats of the Wadden Sea, reduction in carrying capacities of tidal flats in the CCBNEP study area due to changes caused by rising sea-levels could be catastrophic for many species of aquatic birds that depend on flats for foraging habitat.

5.1.2 Sea-Level Fall

Sea-level fall is generally associated with return to glacial conditions, and with global warming, is unlikely this will occur within the next 100 years. No information was found about effects of decreases in sea-level on tidal flats, but benthic mortalities caused by abnormally low tides have been noted on tidal flats in Minas Basin, Bay of Fundy, Canada (Bleakney, 1972). Extinction of benthic faunas from tidal flats during summer low tides has been noted in the CCBNEP study area (Withers, 1994). It seems likely that if sea-levels fell at a rate greater than the local rate of subsidence, tidal flats in the CCBNEP study area would be impacted. Most current tidal flats would probably become relicts, at elevations higher than would be inundated with sufficient frequency to maintain benthic invertebrate communities, similar to the relict tidal flat on the south shore of Copano Bay (Ricklis,1995; Ricklis and Blum, 1997). These losses might be mitigated by conversion of shallow, subaqueous areas into tidal flats. Unlike conversion of marsh or terrestrial habitat into tidal flat habitat as mentioned previously (Section 5.1.1.2), conversion of subaqueous areas to tidal flats would probably be nearly immediate. There would be some changes in composition of benthic fauna, and it would likely take some years for algal mats to form in suitable areas, but it is unlikely shorebirds would be impacted by sea-level decreases alone. Rather, additional shorebird habitat might become available if sea-level fell significantly.

5.1.3 Cold Temperatures

Although very cold or freezing weather is rarely severe or prolonged in the CCBNEP study area, there may be some effects to tidal flat flora and fauna. In years of normal winter weather shorebirds using tidal flats as foraging habitat may experience at least temporary difficulties in finding food, since benthic invertebrates tend to burrow deeper in sediments and become less active during cold weather. However, periods of extreme cold may result in mortality to benthic invertebrates, and if the cold spell is prolonged, could result in direct and indirect effects to shorebirds as well. On a tidal flat in the North Sea during a winter characterized by temperatures ranging from 0.1 to 4.3° C below normal, the extent of changes in numbers of species and individuals ranged from none to complete extinction (Reichert and Dörjes, 1980). Only a few species showed no effects, and a few increased. However, all crabs, nearly all polychaetes, and most molluscs decreased from 27-100% over a previous "normal" year. Damages were attributed to low temperatures, as well as lack of oxygen, insufficient coverage by water, and mechanical effects of ice floes. In the CCBNEP study area, winters with severe, prolonged cold spells, such as were experienced in the winters of 1983 and 1989, may cause some of the same effects as were seen in the North Sea. In addition, there is some evidence that the mass mortality of fish and benthic invertebrates after the 1989 freeze provided sufficient nutrients for the initiation of the brown tide bloom in the Laguna Madre in January 1990 (Buskey, 1996). This bloom, which continued for more than six years, resulted in decreased bay bottom macrobenthic abundance and biomass; and may explain the dramatically decreased numbers of invertebrates collected at the wind-tidal flat on north Padre Island during the present study when compared with numbers from 1991-1992 (Withers, 1994). Since cold weather in this area may be sudden and preceded by very warm temperatures, flora and fauna may not have time to properly acclimate, and effects may be more severe than might be expected in areas where temperatures fall gradually.

5.1.4 Air and Water Temperature Increases

During periods of inundation, tidal flats are covered by relatively shallow water (usually less than 20 cm). Water temperatures in shallow waters increase rapidly compared with deep waters. Detrimental effects to benthic invertebrates are possible from high temperatures of water and/or substrate (temperatures up to 40° C have been measured on flats in Laguna Madre [Withers, 1994]), as well as deoxygenation of both water and substrates that may accompany temperature increases. On algal flats in the upper Laguna Madre, a brief flush of benthic invertebrates following spring high tides and increases in ambient temperature was noted (May and June), however, very hot summer temperatures combined with summer low tides resulted in complete extinction of the benthic community from late July until after fall high tides in October (Withers, 1994). Goss-Custard et al. (1990) note increases in ambient temperatures associated with sea-level rise may decrease ice coverage of flats during winter, increase activity of invertebrates making them more accessible to shorebirds, and increase growth rates of some invertebrates making them better prey for larger bodied shorebirds. Conversely, warmer oceanic water temperatures could increase the frequency and severity of hurricanes by as much as 50% (Emmanuel, 1988) increasing the possibility of both erosion and storm damage. It seems likely that as long as air and water temperature increases were limited to those "normal" seasonal effects expected, benthic invertebrate communities would suffer no long-term impacts.

5.1.5 Storms

Hurricane Beulah (*sic*) (28-29 July 1975; actually Hurricane Blanche) with wind speeds of 120 km/h and a major storm (19-21 August 1975) with wind speeds averaging 35 km/h (gusts to 80 km/h) both caused significant erosion of flats and catastrophic mortalities of intertidal benthos in the Minas Basin, Bay of Fundy, Canada (Yeo and Risk, 1979). Wind direction during both storms was parallel to the maximum fetch of Minas Basin, resulting in very strong wave activity. The area was characterized by a high density, low diversity benthic assemblage dominated by the amphipod *Corophium volutator* and the bivalve *Macoma balthica*. The hurricane caused reductions in numbers of both species, particularly in the lower intertidal zone where densities were greatest. Shallow burrowing organisms (*Corophium* and smallest *Macoma*) were affected most. Densities were reduced by over 90% in the lower intertidal and in some areas densities were still less than 20% of pre-storm values one year later. Areas hardest hit by these storms had not recovered to prestorm densities by 1977, and it was estimated that it might require 10 or more years for recovery to be complete.

In the CCBNEP study area, hurricanes and tropical storms have potential for causing damage to wind-tidal flats. Erosion of flats is possible and would decrease flat area by decreasing elevation, converting flats to shallow subaqueous habitats. However, the more likely cause of damage, particularly to flat biota, is burial caused by increased sand transport and creation of washover fans when storm surges breach barrier islands forming passes. Hurricane Beulah (20 September 1967) deposited as much as 0.3 m of sand immediately behind washover passes on Padre Island, although amounts deposited beyond washover fan boundaries (=tidal flats) were not usually thick enough to obliterate tire tracks of seismic crew marsh buggies (Behrens, 1969). In the long term, if these events do not increase flat elevations enough to prevent fairly frequent inundation and cause their conversion to terrestrial habitat, the eventual result may be increased tidal flat area. However, in the short term, burial will cause death of algal mats, and may cause death of invertebrates, particularly if storms occur during either June or October-November, when invertebrates are fairly abundant. Erosion or burial also have potential for affecting shorebirds, at least during the season following the storm, by reducing availability of invertebrate prey in traditional foraging areas.

5.2 Anthropogenic Disturbances

5.2.1 Oil Spills

5.2.1.1 Physical Effects

Infiltration of oil into sediments appears to be controlled by water content of sediments and how oil gets onto the sediments. In experiments where high concentrations of pure oil and an oil/dispersant mixture were sprayed on an exposed tidal flat during an ebbing tide, chemically dispersed oil penetrated deeper into sediments than untreated oil (Dörjes, 1984). However, in experiments where low concentrations of both chemically and ultrasonically dispersed Arabian light crude oil (Farke et al., 1985) and a chemical dispersant premixed with Murban crude oil

(Page et al., 1985) were added to the water during high tide, there was little infiltration of oil into mudflat sediments. Spraying of Nigerian crude oil, oil followed by a dispersant, and an oil/dispersant mixture (to simulate stranding of a treated oil slick arriving on the shore) on a waterlogged muddy sand flat also did not result in long-term contamination of tidal flat sediments but when the same treatments were applied to a relatively well-drained sandflat, oil sank into sediments to a greater extent (Rowland et al., 1981). However, in both cases and for all treatments, less than 10% of spilled oil was incorporated into sediments. Although there may have been some lateral diffusion of oil out of the study area, most oil was probably removed by tidal action. Rowland et al. (1981) concluded: (1) treatment with dispersants does affect fate of oil in sediments; (2) tidal action removed both treated and untreated oil from waterlogged intertidal sediments; (3) dispersant treated oil was retained in greater concentrations than untreated oil in sandy, well-drained sediments; and (4) factors affecting the fate of dispersed oil in sediments include sediment water content, time of dispersant treatment in relation to tidal cycle, and whether dispersants were applied to oil before or after stranding. In experiments on a muddy sandflat where dispersants were applied to stranded, lightly weathered crude oil and emulsified medium fuel oil (mousse), researchers concluded that use of dispersants did not dramatically alter the fate of most oil, and suggested that relatively high energy sandflats (those receiving regular inundation by astronomical tides) would eventually self-clean (Little and Scales, 1987).

5.2.1.2 Biologic Effects

Biologic effects of oil contamination on organisms and habitats are grouped into the following categories (Moore and Dwyer, 1974): (1) immediate death due to direct lethal toxicity; (2) disruption of behavior (e.g., feeding, reproduction) or physiological processes which may eventually cause death; (3) smothering, mechanical interference with activities (e.g. movement, feeding) or loss of insulative properties of feathers or fur caused by direct coating with oil; (4) incorporation of hydrocarbons into tissues that may cause tainting or biomagnification of hydrocarbons in food chains; and (5) alteration of physical (i.e., substrate characteristics) or chemical (i.e., water quality) environments which result in shifts in species composition and distribution. Most biological effects are caused by hydrocarbons, with most toxic effects caused by lower boiling (higher solubility) aromatics. Estimated concentrations (ppm) of soluble aromatics needed to cause toxicity for tidal flat organisms are: plants - 10-100; all species of larvae - 0.1-1.0; gastropods - 1-100; bivalves - 5-50; benthic crustaceans and other invertebrates - 1-10. Concentrations lower than 0.1-1.0 ppm may cause sub-lethal effects. Dispersed oil that loses enough buoyancy to diffuse downward in relatively shallow water has lost most lower boiling petroleum fractions usually associated with toxic effects (Page et al., 1985).

Effects on mudflat flora and fauna are mixed. Chemically dispersed oil at a concentration of 4 ppm doubled gross photosynthetic rate of microbenthic algae, whereas oil concentrations of 10 ppm reduced photosysthesis (Farke et al., 1985). In both cases algal biomass was not affected and algae appeared to react physiologically; it was concluded that this was one reason algae recovered quickly. Farke et al. (1985) reported no changes in species composition or abundance when oil/dispersant concentrations in shallow, overlying waters ranged from 2-4 ppm over three days while slightly higher concentrations and more prolonged contamination clearly affected abundances of some species (e.g., *Macoma balthica*, *Pygospio elegans*, *Eteone longa*, oligochaetes) for several months but had no effect on species richness. Experiments in Long Cove, Maine, indicated dispersed oil treatments had no effect on infaunal communities, whereas undispersed oil treatments caused mortality of some species and shifted community structure toward dominance by opportunistic polychaetes such as *Capitella capitata* and *Streblospio benedicti* (Gilfillan et al, 1983). Untreated oil caused extinction of *Corophium* (amphipod)and dose-dependent mortality of *Macoma* and *Ceratoderma* (bivalves)in experiments using model tidal flat ecosystems (Dekker and Van Moorsel, 1987). Dispersed oil treatments caused high mortalities of *Corophium*, *Cerastoderma*, and *Arenicola* (polychaete), and moderate mortality of *Macoma*. Dispersion of oil appeared to aggravate effects of oil addition, and after ten months, effects on remaining fauna were similar to effects in oil only treatments. Macrobenthic biomass was similar in all treatments after ten months, but both dispersed oil and oil only treatments exhibited differently structured communities compared with controls.

5.2.1.3 Effects of Oil Removing Vehicles

Dörjes (1982) assessed impact of oil removing vehicles on tidal flat infauna. Although use of vehicles resulted in severe immediate effects on macrofauna, rapid recolonization due to strong population pressure followed. He concluded vehicles should be used for cleanup only if damage caused by vehicles was less than damage caused by the oil itself. In the CCBNEP study area, the decision to use vehicles must involve a determination of saturation of sediments. If vehicles are likely to sink more than a few centimeters into the sediment, and must be driven perpendicularly to the shoreline, long-term alterations in rates of exposure may occur, since tracks tend to work as channels and may cause water to drain off flats more quickly. This could effect recruitment and persistence of infaunal invertebrates, and ultimately, shorebird use of flats.

5.2.1.4 Sensitivity of Wind-Tidal Flats in the CCBNEP Study Area

Tidal flat sediments in the CCBNEP study area range from muddy sand (e.g., Blind Oso) to sand (areas near washover passes) to algal-bound sand (most flats in upper Laguna Madre). The main difference between flats in this area and those where experiments concerning oil infiltration occurred is lack of regular tidal inundation and a great deal of variability in water content of sediments. This would probably result in oils being left stranded on tidal flats that might be fairly dry, and without regular inundation, no mechanism for self-cleaning as was suggested by both Rowland et al. (1981) and Little and Scales (1987). It is likely that on non-algal flats, oil infiltration of sediments would be greater than the 10% or less reported by Rowland et al. (1981) whether left untreated or treated with dispersants. Algal mats might prevent infiltration to some extent.

Many tidal flats in the CCBNEP study area, particularly those in the upper Laguna Madre, are at risk for oil spills because of proximity to channels used to transport petrochemicals. Despite lack of a clear pattern in the experimental evidence, it seems likely invertebrate abundances and community structure would be affected. These impacts might be more severe and long-lasting, particularly on algal flats, because invertebrate communities are generally less diverse and most organisms are not abundant. Conversely, since tidal flat communities in the CCBNEP study area are not dominated by bivalves like experimental communities, and polychaete assemblages are generally characterized by opportunistic species, effects may not be severe. In addition, insect larvae are important components of tidal flat communities, and effects of oil on these organisms has not been established. However, if an oil spill occurred while shorebirds were migrating or wintering (August-April), direct impacts (e.g., oiling, ingestion) to birds, and especially to those endangered and threatened species associated with flats, would be severe.

An environmental sensitivity index for south Texas coastal environments was prepared after the *Ixtoc I* oil spill in 1979 (Hayes et al., 1980). Tidal flats were divided into three categories: exposed tidal flats with low biomass; exposed tidal flats with moderate biomass; and sheltered tidal flats with high biomass. Exposed tidal flats were given sensitivities of 5 and 7, respectively, on a scale from 1-10, with 10 (mangrove and salt marsh habitats) being the highest sensitivity. Sheltered tidal flats were given a sensitivity of 9. Much of the upper Laguna Madre shoreline (Padre and Mustang islands) was designated as exposed tidal flats, although some areas near East Flats and in the Shamrock Cove area were designated as salt marsh habitat but are mostly tidal flats. Additional areas of exposed tidal flats were found along bayshores. Most sheltered tidal flats were located on the mainland shoreline around and south of Baffin Bay and Oso Bay. Some flat areas in Oso Bay were designated as salt marsh habitat, and the Blind Oso received no sensitivity index. Much of the area designated as exposed tidal flat probably should have received higher sensitivity ratings since it is used extensively by Piping Plovers and they could be seriously affected if oil spills impacted these sites. In exposed sites, biological damage was predicted to be slight to severe, and recommended cleanup activities were focused on removing oil from high-tide swash areas. Heavy equipment use was not recommended due to soft sediments. In sheltered areas, it was predicted that oil would persist and be incorporated into sediments due to lack of tidal action; biological damage would be severe. Mechanical or manual cleanup was recommended where sediments were well-compacted. It was suggested mechanical operations be minimized or restricted.

5.2.2 Effluents and Runoff

5.2.2.1 Organic Enrichment

Organic enrichment occurs in response to discharge of treated and untreated wastewater. Tidal flats may be impacted and experience effects of organic enrichment when wastewater is discharged directly onto the flat or in tidal channels adjacent to flats that flood when wind and tide conditions are right. Organic wastes affect aquatic environments primarily by disrupting oxygen balance and by eventually affecting levels of inorganic nutrients (Essink, 1984). Changes in basic patterns of infaunal community composition and abundance can be summarized as follows (Pearson and Rosenberg, 1978): (1) Sediments nearest discharge point are devoid of fauna; (2) first species encountered are small and few; and (3) as distance from the most organically enriched area increases, number of species increases, at first slowly, but after passing the “ecotone point”, increase rapidly to values consistent with non-polluted areas

This pattern is illustrated in Fig. 5.1. The community on the most heavily polluted side of the ecotone point is characterized by a few pollution-tolerant species, but abundances may be extremely high. A small peak in biomass corresponds to maximum abundances of small, opportunistic species On the less polluted side of the ecotone point a series of transitory communities gradually approach abundance and community composition of unpolluted environments. Biomass increases to a second higher maximum as species richness peaks and a greater variety of larger species are encountered, finally stabilizing at a lower level as communities characteristic of non-polluted areas develop. This secondary biomass maximum probably occurs where organic enrichment is enough to provide a rich food source but too low to cause serious oxygen depletion (biostimulation). The ecotone point community is poor in species, abundance and biomass and consists of species from both adjacent communities. Changes in species assemblages along a gradient of increasing organic enrichment are not a series of distinct groupings, but take the form of a continuos successional sequence.

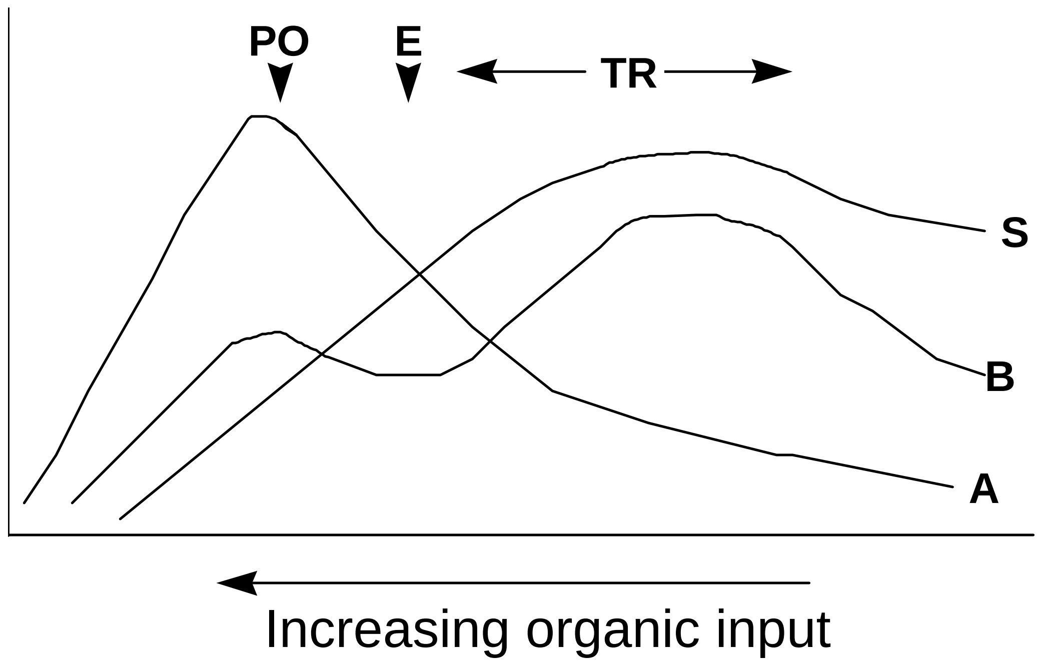

Fig. 5.1. Generalized species-abundance-biomass diagram showing changes along a gradient of increasing organic enrichment (from Pearson and Rosenberg, 1978). S = species richness; A = total abundance; B = total biomass; PO = peak of opportunistic species; E = ecotone point; TR = transition zone.

Most effects of organic wastewater discharges on tidal flat infauna in the Wadden Sea were attributed to oxygen deficits in water overlying flats caused by bacterial decomposition of organic materials (Essink, 1984; Van Es et al., 1980). In the Dollard, severe effects were only found in the vicinity of outfalls, although the extent of local effects was dependent on the topography of the area and the location where wastewater was introduced. Severity of oxygen deficits was dependent on dilution of wastewater by estuarine waters. Oxygen deficits were severe in the vicinity of outfalls discharging directly onto flats or into shallow tidal channels, but were restricted to upper water layers when discharges were made into deeper water. Numbers of sulphur cycle bacteria increased in the vicinity of outfalls. Diversities of meio- and macrofauna were very low in the vicinity of the wastewater outfall, with macrofauna completely disappearing in areas nearest the outfall. In contrast, meiofaunal numbers (primarily diatom feeding nematodes) significantly increased over values found in unpolluted areas of the estuary. Other studies noted increased diatom production in the vicinity of outfalls due to increased concentration of ammonium in sediments; this evidence suggests that at high loads of enrichment the meiofaunal community would be dominated by nematodes (Raffaelli and Mason, 1981; Warwick, 1981) Other factors which modify effects of discharges include total amount of waste and time of year when discharge volumes are greatest. If volumes are greatest during months with low water temperatures, bacterial decomposition slows and oxygen deficits may be ameliorated (Essink, 1984).

Although rising numbers of shorebirds on tidal flats are often cited as evidence for improved or restored environments, they can also be associated with deterioration (Van Impe, 1985). After WWII, intertidal areas of the Western Scheldt estuary (Netherlands) began to be severely polluted by heavy inputs of organic matter with incomplete mineralization as well as increasing amounts of heavy metals, polycyclic aromatic hydrocarbons (PAH), and organochlorine pesticides. Waters overlying sediments exhibited oxygen deficits typical of areas polluted with organic wastes, particularly during spring and autumn. Macrofaunal communities exhibited typical responses of reduced species richness (usually down to one or two species) with high abundances and a rise in biomass over pre-polluted conditions. During the same period numbers of important intertidal bird species increased 1.2-8.9 times. Causes other than pollution for increases in bird numbers, including decreased hunting pressure and closure of other estuaries, were discounted; evidence from other studies in similar areas indicated increased numbers of ducks feeding on worms and seeds associated with domestic and industrial effluents.

Development of macroalgal mats composed primarily of *Enteromorpha* and *Ulva* is another consequence of organic enrichment impacting faunas of tidal flats in many parts of the world (Hull, 1987; Nicholls et al., 1981; Perkins and Abbott, 1972; Raffielli et al., 1989; Reise, 1984b; Soulsby et al., 1982; 1985). Interactions of infauna, macroalgal mats, and higher predators are exceedingly complex. In some areas, *Arenicola* burrows facilitated anchorage of green algae when large thalli grew into the burrows; their increased ability to resist dislocation by tidal currents allowed the mat to become more coherent (Reise, 1984b). In general, widespread, persistent macroalgal mats cause sediments to become anaerobic, which in turn causes reductions of both species richness and biomass, but abundances of organisms present (notably *Capitella capitata*) are often extremely high. In addition, some epifaunal herbivores such as *Hydrobia ulvae* (Gastropoda) may increase dramatically. While increased numbers of epifauna may benefit some birds, and the mats themselves may provide food for herbivorous ducks and geese, foraging by shorebirds may be inhibited by the mats; increases in some birds may put others at a competitive disadvantage.

5.2.1.1.1 *Effects in the Blind Oso*

About 57 million l/day$^-$ of treated municipal wastewater is discharged into Oso Bay adjacent to wind-tidal flats of Blind Oso. Additional inputs into Oso Bay come from municipal wastewater discharges into Oso Creek from Corpus Christi's westside and Robstown along with 1.9 billion l/day of potentially hypersaline water pumped out of the upper Laguna Madre from Central Power and Light Company Barney Davis Power Plant. Water and sediment chemistry for an area near the Oso Wastewater Treatment Plant outfall are summarized in Tables 5.1 and 5.2 (Bowman and Jennings, 1992) and all values are within acceptable ranges except fecal coliforms. Currently there is no evidence for widespread occurrence of macroalgae, however, abundant clumps of *Enteromorpha* were noted several times during the present study. We made no attempt to determine zonation associated with the discharge near the flats, however, abundance and species richness of the benthic infauna located about 1 km east of the discharge was characterized (See Sections 3.2.2.1 and 3.4.2 for details). While species richness in the area cannot be characterized as low (10 polychaete, 2 mollusc, 2 crustacean, 2 insect), most organisms were either *Capitella capitata* or *Streblospio benedicti*, polychaetes which are associated with organic enrichment (Pearson and Rosenberg, 1978). *Capitella capitata* is nearly always dominant in impoverished areas just beyond the abiotic zone nearest an outfall. *Streblospio benedicti* is variously described as a co-dominant with *Capitella* in stations just beyond the impoverished zone or as a pioneer species of denuded areas following pollution abatement. In addition, shorebird numbers can be very high in this area. These results are consistent with moderate organic enrichment, with a transitional faunal assemblage characterized by fairly high species richness with species from either side of the ecotone point, and fairly high abundance and biomass.

Table 5.1. Water chemistry for the area of Oso Bay located west of Ward Island and adjacent to the Oso Wastewater Treatment Plant outfall (from Bowman and Jennings, 1992).

Date	Temp (°C)	DO (mg/l)	Cond (μhom/cm)	pH	NH_4^+ (mg/l)	NO_3 (mg/l)	Total PO_4 (mg/l)	Chloro *a* (μg/l)	Cl^- (mg/l)	SO_4 (mg/l)	Fecal Coli (col/100 ml)
10/87	27.2	10.5	43.6	8.5	0.03	0.01	0.69	3	16,348	2,313	27
12/87	21.8	7.1	43.0	8.1	0.69	0.87	0.79	5	15,671	2,140	833
4/88	19	11.2	48.6	8.4	0.06	0.03	0.34	11	17,510	2,534	3
8/88	29	5.4	66.5	8.1	1.3	0.48	0.91	2	23,475	3,684	520

Table 5.2. Sediment contaminants for the area of Oso Bay located west of Ward Island and adjacent to the Oso Wastewater Treatment Plant outfall (from Bowman and Jennings, 1992)

Contaminant	Concentration
Metals (mg/kg)	
Arsenic	1.9
Barium	130
Cadmium	<0.4
Copper	4.8
Lead	6.4
Maganese	71
Mercury	0.034
Nickel	2.1
Selenium	<0.4
Silver	<0.4
Zinc	22
Pesticides, Herbicides, and PCB (μg/kg)	
Total DDT	9.6
ALDRIN	<1.0
DIELDRIN	<3.0
ENDRIN	<3.0
Total CHLORDANE	<6.0
MALATHION	<5.0
PARATHION	<3.0
METHYLPARATHION	<30
DIAZINON	<5.0
SILVEX	<10
2, 4, -D	<50
2, 4, 5, -T	<10
PCB	<20
Miscellaneous Constituents (mg/kg)	
Volatile Solids	25,300
Kjeldahl Nitrogen	700
Total Phosphorus	390
Oil and Grease	280

5.2.2.2 Industrial Effluents and Runoff

Industrial effluents and runoff may contain a variety of contaminants including hydrocarbons and metals. On the west coast of Korea, industrial effluents discharged directly onto mudflats resulted in high concentrations of heavy metals in sediments (Ahn et al., 1995). Decreases in both species richness and abundance were found. *Heteromastus filiformis* (Capitellidae), a small, opportunistic polychaete, replaced the previously dominant fauna at the site with the least organic matter. However, *Perinereis aibuhitensis* (Nereidae) remained dominant, although in reduced numbers, at the most contaminated site where organic matter was also high. Organic matter appeared to reduce the bioavailability of metals to infauna ameliorating effects. In Manukua Harbor, New Zealand, runoff caused significant sediment contamination with hydrocarbons and metals (Roper et al., 1988). Faunas were dominated by a combination of small opportunistic species (polychaetes and tubificid oligochaetes) and large, long-lived, hardy species such as crabs and pulmonate gastropods. Changes at the most heavily contaminated site could be attributed to runoff, but changes at less contaminated sites may or may not have been caused by pollution. The inherent variability between sites made detection of anything other than gross pollution difficult.

McClusky (1982) and McClusky and McCrory (1989) examined effects of petrochemical effluents on tidal flat faunas in the Firth of Forth, Scotland. Invertebrate communities exhibited low species richness, dominated by oligochaetes and the opportunistic polychaete *Manayunkia aestuarina*. High abundances and biomasses were recorded. Zones of pollution with associated faunas were found and were similar to those described for organic enrichment. Faunas recovered rapidly and dramatically to near nonpolluted states when discharges were stopped. Long-term changes in community structure were attributed to man-induced changes in the quality and quantity of effluents over time.

At this time, no tidal flats in the CCBNEP study area are impacted by petrochemical effluents although some tidal flats in northwestern Nueces Bay have been seriously impacted locally by brine discharges (J. W. Tunnell, pers. obs). However, Phase II of the Allison Wastewater Treatment Plant demonstration project will contain 11 million l/day of effluent from Koch Refinery which may contain low concentrations of hydrocarbons (B. Nicolau, per. comm.). This effluent will be piped through the Nueces Delta Mitigation area and has the potential to find its way to the scattered tidal flats in the Nueces River delta. Since no data exists on faunas from tidal flats in that area, it will be impossible to determine if there are any deleterious effects in the future.

5.2.3 Dredging and Dredge Material Disposal

There have been no studies on effects of dredge material disposal on tidal flats even though they are often used as disposal areas. However, most effects are obvious. Dredging channels through flats destroys benthic faunas, reduces area for birds, and changes hydrology by both preventing floodwaters from blowing up onto flats, as well as causing remaining flats to drain more quickly. Dredge material disposal causes destruction of benthic fauna through burial, reduces foraging area for birds, although additional roosting areas may be obtained, and changes hydrology by blocking wind-tides and isolating remaining flats from inundation. This may cause elevational changes through increased accretion and cause conversion of flats to terrestrial habitats. At a minimum, by blocking inundation, most function ceases. Rapid and more extensive flooding and erosion of vegetated barrier flats, subaerial spoil, and made-land may be caused by proliferation of navigation channels and marinas and associated dredge disposal on tidal flats (Morton et al., 1977; White and Brogden, 1977).

5.2.4 Tracking by Vehicles

Tracking by vehicles represents a serious impact to tidal flats in the CCBNEP study area, especially if driven on when wet. Evidence of tracking can persist for decades. Off-road vehicle traffic on open flats in Cape Cod National Seashore affected survival of marine infauna (Wheeler, 1978). Counts of animals in driven areas showed marked reductions, especially of amphipods, over non-driven areas. In experimental low-level impacts (50 passes per day for 20 days), polychaete and clam populations were totally decimated (Leatherman and Godfrey, 1979). They concluded only a few passes of a vehicle on a tidal flat was sufficient to cause maximum damage and that the environment could not tolerate even light use by vehicles. They recommended a complete ban on vehicles in tidal flat areas.

The benthic infauna of old tracked areas was characterized on two wind-tidal flats on PINS (Withers, 1996). The only significant differences between tracked areas and control area were increased numbers of tanaids and insect larvae in the tracked areas during some months. In the present study, the tire tracks appeared to act as refugia for benthic organisms since they retained water after surrounding areas began to dry. They may also act as recolonization pools. Although initial tracking is detrimental to organisms (Leatherman and Godfrey, 1979), in this case organisms were able to recolonize these areas and appeared to thrive when impacts ceased.

In the Wadden Sea, an impact similar to vehicle tracking occurs from lugworm (*Arenicola marina*) harvesting dredges (Beukema, 1995). These dredges come up onto the flats during high water and dig gullies about 1 m wide by 0.4 m deep, sieve the material to remove the lugworms, and dump the sieved sediment in and along the gullies. Immediate effects include large reductions in abundance of several species and total biomass. However, densities generally recovered within a few days to a few months, particularly of small sized fauna, but not of total biomass or of long-lived, non-migratory species.

5.2.5 Power Plant Construction

Since tidal ranges are very small in the CCBNEP study area, it is unlikely tidal power will ever be used to generate electricity as has been proposed in the Bay of Fundy (van Walsum, 1987). Central Power and Light Company Barney Davis Power Plant has impacted areas in Oso Creek and Oso Bay that fit the description of tidal flats through the pumping of water out of the upper Laguna Madre into Oso Bay (Hildebrand and King, 1978). However, alterations caused by hydrologic changes in Oso Bay cannot be described as negative. The greatest change was increased flooding of areas that received little or no flooding previously; this resulted in establishment of fairly persistent benthic infaunas at several sites.

5.2.6 Construction

There have been no studies of the effects of construction on tidal flats, however, the detrimental impact is obvious. Any covering of tidal flat habitat, by platforms, buildings, or other structures will result in loss of habitat for all organisms, extinction of benthic faunas, and changes in inundation and exposure regimes. Table 5.3 lists flats that have been impacted by construction.

5.2.7 Upstream Damming and Diking

There have been no studies of the effects of upstream damming and diking on tidal flats. It is likely that the alterations of hydrology caused by this activity would lead to changes in sedimentation regime and invertebrate communities and it is likely that both detrimental and positive effects could occur, depending on ambient conditions and the project plan. There could be either gains or losses of both shorebird and invertebrate habitat.

5.2.8 Mitigation and Restoration Projects

Because of their perceived barrenness, tidal flats have been targeted for conversion to other wetland types, particularly cordgrass marsh, or seagrass beds as mitigation for other wetland destruction of degradation. Table 5.3 lists tidal flat habitats that have been impacted by this activity. It is interesting to note that in only one case (Island Construction, Inc., Permit # 16533) was mudflat enhancement part of the proposed mitigation.

Table 5.3. List of mitigation projects impacting tidal flats in south Texas (from Cobb, 1987)

COE Permit Number	Applicant	Project Location	Mitigation Location	Resource Impacted	Proposed Mitigation
13625	R. E. Jenkins	Port Aransas Municipal Boat Harbor, Nueces County	On site	Shallow sand and mudflat, smooth cordgrass and high marsh	Enhancement of existing shore by planting smooth cordgrass, black mangroves, and marshhay cordgrass
14454	Mustang Beach Development Corp	Corpus Christi Bay wetlands, west side of Mustang Island, Nueces County	Tidal flats adjacent to project site	smooth cordgrass marsh	Enhancement of 400 ft^2 of unvegetated shoreline by transplanting smooth cordgrass from the adjacent project site
15365	E. Manson	Port Isabel Small Boat Harbor, Cameron County	On site	tidal glasswort marsh and algal mudflat	Creation of black mangrove habitat
15832	Settlement II	Lower Laguna Madre, Cameron County	On site	high marsh and sandflat	Creation of smooth cordgrass and black mangrove marsh around perimeter of a dredged basin
16075	Island Moorings subdivision	Corpus Christi Bay wetlands, Nueces County	Tidal flats adjacent to project site	smooth cordgrass marsh	Enhancement of 0.4 ha unvegetated shoreline by transplanting smooth cordgrass from adjacent project site
16564	J. M Inhofe	Lower Laguna Madre, Cameron County	On site	seagrasses with scattered oysters, intertidal algal flats with saltwort	Enhancement of existing unvegetated intertidal habitat by planting smooth cordgrass

Table 5.3. Continued.

COE Permit Number	Applicant	Project Location	Mitigation Location	Resource Impacted	Proposed Mitigation
16533	Island Construction, Inc.	Corpus Christi Bay wetlands, Nueces County	Partial on site and off site - Corpus Christi Bay wetlands	unvegetated algal flats and marsh	Removal of 0.07 ha of fill from mudflat. Creation of 0.39 ha of intertidal habitat for marsh development from uplands
16867	H. Tucker	Oso Creek, Nueces County	On site	high mudflats	Creation of 12.6 ha of submergent shallow water habitat from high mudflats

Table of Contents

6. STATUS AND TRENDS OF WIND-TIDAL FLATS IN THE CCBNEP STUDY AREA

6.1 Trends: Mustang Island and North Padre Island 1938-1974

Changes in areal coverage of tidal flat habitats was determined for Mustang and north Padre islands (to Nueces County line) using near vertical aerial photographs and mosaics flown in 1938, 1956, and 1974 (Table 6.1) (White et al., 1978). Areal extent of tidal flats changed significantly between 1938 and 1974 with changes in the relative importance of natural processes and intensity of human activity. Eolian processes dominated in 1938, with 19% of total area in eolian landforms, including wind-tidal flats. Decreased importance of wind-tides between 1938-1974 are reflected in the 37% overall decrease of tidal flat area, and decreases from 16% of total area in 1938 to 11% of total area in 1974. The most important human activity affecting all habitats during this time period was the increase of dredge spoil and made-land from 4% of total area in 1938 to 14% in 1974.

Most changes in wind-tidal flat coverage occurred in the north Mustang Island area. Changes in wind-tidal flat coverage between 1938 and 1956 were largely the result of progradation of subaerial dredge material deposited along the south side of the Corpus Christi Ship Channel. Wind-tidal flats were partially reestablished by 1974 into areas that had been previously covered with dredge material, however, overall extent was decreased by tremendous expansion of seagrass meadows into former tidal flat areas. Reduction in wind-tidal flats between 1938-1956 was caused by increased human activity, primarily dredge material disposal. Large decreases due to expansion of seagrass meadows between 1956-1974 was attributed to an unprecedented relative sea-level rise (including subsidence and actual water-level rise) that converted many flats to grass beds or open water (Fig. 6.1). Changes on south Mustang Island were attributed to extension of wind-tidal flats into areas occupied by stabilized vegetated dunes and barrier flats in both 1938 and 1974 (White et al., 1978).

Table 6.1. Areal extent (ha) of wind-tidal and tidal flats on north Mustang Island (Aransas Pass to Wilson's Cut), south Mustang Island (Wilson's Cut to Corpus Christi Pass), and north Padre Island (Corpus Christi Pass to Nueces County line). Areas given in hectares and determined by planimeter.

Date	North Mustang	% Change	South Mustang	% Change	North Padre	% Change	Total	% Change
1938	1,942.5		443		0		2,385.5	
1956	1,719.8	-11.5	20.7	-95.3	0		1,740.5	-27.0
1974	997.2	-42.0	481.7	+95.7	31.1	+100	1,510.0	-13.0
Total		-49.0		+8.0		+100		-37.0

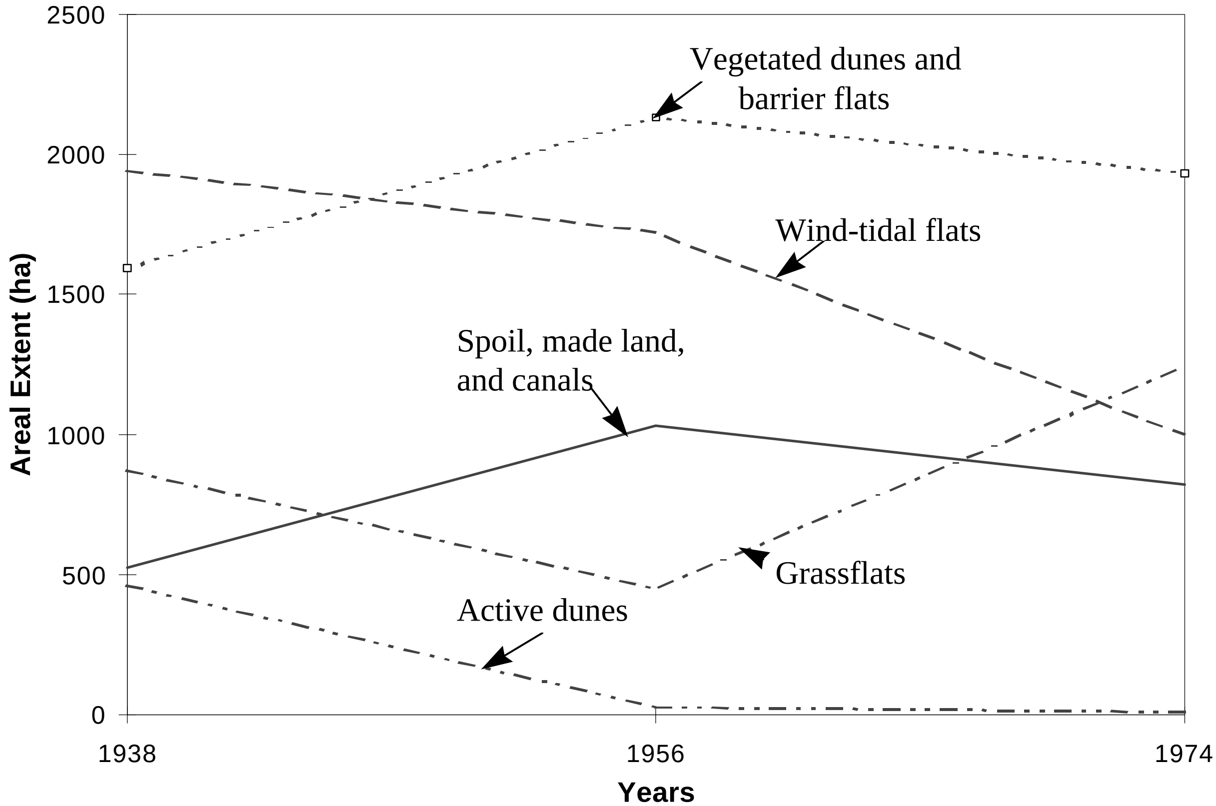

Fig. 6.1 Changes in areal extent of habitats on north Mustang Island (from White et al., 1978).

6.2 Trends: 1950's, 1970's, 1990's from NWI Maps and Data

The following discussion is based on results from "Current Status and Historical Trends of Selected Estuarine and Coastal Habitats in the Corpus Christi Bay National Estuary Program Study Area" (White et. al., in review). Emphasis was placed on the direction of trends rather than magnitude because of inconsistencies in wetland delineation for the three time periods

In the 1950's and 1979, NWI mapped tidal flats under the code E2FL which includes all barren intertidal flats. In 1992, NWI mapped tidal flats under two codes: E2US - Estuarine intertidal unconsolidated shore, which encompasses tidal flats, storm washover channels and flats, beaches and berms; in other words, generally all "barren" estuarine flats and shores that are regularly or irregularly flooded; and E2AB - Estuarine intertidal aquatic beds, which are usually algal flats. Estuarine flats comprised about 8,700 ha (2%) of the CCBNEP study area north of South Bird Island based on 1992 NWI maps.

Tidal flat area in the CCBNEP study area decreased markedly between the 1950's and 1979. Over 11,000 ha was converted to other habitat classes with the most extensive losses (> 6,000 ha) occurring on barrier islands, especially Mustang and San Jose islands, Harbor Island, and in the

Table. 6.2. Areal extent (ha) of tidal flats in the CCBNEP study area between 1950's and 1992 based on NWI maps and data (White et. al., in review). Data presented represent adjusted estimates based on the best professional judgement of the investigators since data required considerable adjustment due to cartographic errors, photointerpretation errors, and inconsistent classification categories.

	1950's	1979	1992	Net Change	% Change
Mustang Island	3,708	1,348	1,343	-2,365	-64
San Jose Island	4,837	2,977	2,724	-2,113	-56
Matagorda Island	86	109	557	+471	+85
Harbor Island	2,365	357	295	-2,070	-88
North Padre Island[1]	669	300	197	-473	-71
Live Oak Ridge/Peninsula	1,084	214	272	-812	-75
Blackjack Peninsula	152	304	263	+111	+42
Lamar Peninsula	285	150	45	-240	-84
Encinal Peninsula	15	16	18	+3	+20
Nueces River	647	677	629	-18	-3
Aransas River/Chiltipin Creek	432	546	368	-64	-15
Mission River	300	300	367	+67	+18
Corpus Christi Bay-Upper Laguna Madre[2]	3,058	1,549	957	-2,101	-69
Redfish Bay	708	111	87	-621	-12
Port Bay	437	320	205	-232	-53
Copano Bay	738	522	331	-407	-55
Total	19,521	9,800	8,676	-11,117	-57

[1]Area north of South Bird Island only

[2]Including Oso Bay

upper Laguna Madre-Corpus Christi Bay estuarine complex. Most change (55%) was due to permanent inundation of flats and their replacement by either open water or seagrass beds. This change was likely due to accelerated sea-level rise between the mid-1960's to mid-1970's (White et al., 1983; Pulich et al., 1997). Another 20% of the loss was due to conversion to marshes. As sea-level rises, vegetation, particularly *Spartina alterniflora*, colonizes upper fringes of tidal flats, because higher intertidal flats became more frequently flooded. About 20% of the loss was due to conversion to uplands. Some areas were lost due to dredge and fill activities associated with navigational channel development. Apparent net gains between 1979-1992 on Matagorda Island were attributed to photographs being taken at low tides during 1992; other gains were attributed primarily to differences in photographic interpretation.

6.2.1 Trends on Mustang Island: 1938-1992

To determine trends on Mustang Island between 1938-1992, some areas mapped separately by White et al. (1978) must be combined to come up with analogous map units and associated areal coverages (Table 6.2). The E2FL designation used by NWI in 1950's and 1979 includes areas mapped by White et al. (1978) as "active dunes and blowout areas" and "subareal sand" (washover areas). As always, differences must be viewed within the context of the available information; some changes can probably be attributed to different photos and problems of photointerpretation, tidal levels, and different methods for calculating areas (e.g., planimeter vs computer program). For instance, 1979 NWI aerial photographs "captured" a high tide along most of the coast, so actual losses may be overestimated between 1950's-1979, and underestimated from 1979-1992 (W. White, pers. comm.).

At least 58% of tidal flat habitats were lost between 1938 and 1992, with the largest losses between 1956-1979. Most loss is attributed to rise in relative sea levels and conversion to seagrass beds or open bay habitats as noted earlier. Relative sea level rise between the mid-1970's and 1992 slowed (W. White, pers. comm.); tidal flat loss was also reduced and may have been mostly due to human impacts during that time.

Table 6.3. Areal extent (ha) tidal flat habitats on Mustang Island, 1938-1992. Areas were determined from near vertical or mosaic aerial photographs and planimeter 1938, 1956, and 1974. Areas for 1979 (E2FL) and 1992 (E2US and E2AB) were calculated from NWI maps and digitized data using GIS technology (W. White, pers. comm.). Ranges represent minimum and maximum areas and percentages because of difficulty in comparing non-NWI map units with NWI map units.

Date	Hectares[1]	Loss or Gain	% Change
1938	3,220-4,665		
1956	2,340-3,395	-880 to -1270	-27
1974	1,750-1,755	-590 to -1640	-25 to -52
1979	1,350	-400 to -405	-27
1992	1,340	-10	-1
Total		-1880 to -3335	-58 to -71

[1]minimum does not include active dune unit; maximum includes active dune unit between Wilson's Cut and Corpus Christi Pass

6.3 Location and Relative Severity of Impacts to Tidal Flats in the CCBNEP Study Area

Using 1992 NWI maps showing locations of tidal flats and closely related habitats (e.g. washover passes), the following impacts were mapped and severity was rated on a scale of 1 (minimal) to 5 (severe):

(1) Channels and dredge material disposal,
(2) Vehicle tracking and propwash,
(3) Oil spills,
(4) Apparent elevation increases,
(5) Trash

Most tidal flats in the CCBNEP study area have been impacted in some way (Figs. 6.1-6.4). Lack of indication of impacts on maps does not mean areas have not been impacted, only that either photographs were not available or ground surveys were not done. Tracking (probably by cattle) was noted in 1930's aerial photographs on Mustang Island; today tracking by vehicles is the most widespread impact. Tidal flat areas within PINS and south of mapped areas may be the most heavily impacted by vehicle tracking. Some tracks within PINS were made in the 1950's and evidence persists until today (P. Eubanks, pers. comm.). Trash is a problem on and around tidal flats near popular fishing areas, especially in the Egery Flats area of Copano Bay and the Mud Bridge area of Oso Bay. Channeling and dredge material disposal have affected flats mostly in the Harbor Island area and near Shamrock Cove; there may be some effects in the Nueces River delta since many dredged channels for servicing oil and gas platforms are in that area. The most obvious effects of dredging and channelization is destruction; less obvious is the rapid dewatering of flats that channels facilitate. Only one area, Corpus Christi Pass clearly showed elevational increases (or sea-level rise), evidenced by large amounts of *Salicornia* spp. over the surface of the flat and scattered areas of *Spartina alterniflora* and *Avicennia germinans* along the edges.

Only one oil spill is known to have affected tidal flat habitats, Gum Hollow in 1994. Only the upland fringes of the tidal flat was oiled with crude oil. Primary and severest impacts were to marsh vegetation. Minimal cleanup was done. Oil did not appear to persist in tidal flat habitats, as evidenced by only small patches of weathered oil remaining 2-3 months after the spill (B. Hardegree, pers. comm.).

Tidal flats in Oso Bay (primarily Blind Oso) and Port Aransas have been impacted by municipal point-source discharges from wastewater treatment plants. In both areas, some portions of tidal flats have been converted to marshes due to influx of water (Barrera et al., 1992; J. W. Tunnell, pers. comm.). Bird usage is also high at both sites. In the Blind Oso, the effects of organic enrichment ("biostimulation") of the area are reflected in the dominance of *Capitella capitata* and *Streblospio benedicti* in the benthic community and overall abundance of benthic invertebrates (See Section 5.2.2.1). The rich resource base provides an abundant food supply for migrating and wintering shorebirds. While changes in invertebrate community composition have

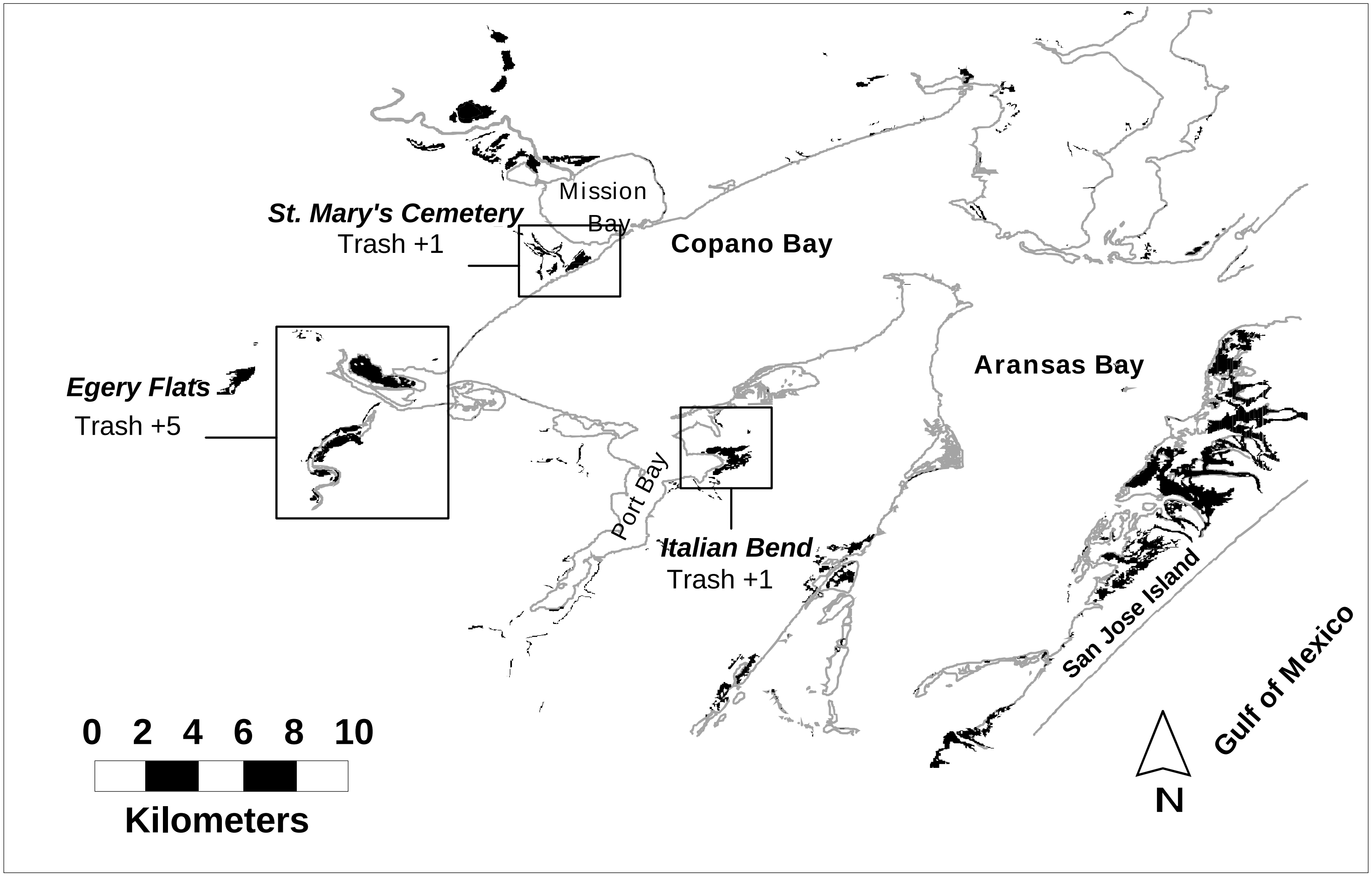

Fig. 6.2. Known impacts to tidal flats in Aransas-Copano Bays area. 1 = minimal; 2 = light; 3 = moderate; 4 = moderately severe; 5 = severe. Map provided by BEG; based on 1991 NWI maps and data. Black areas are tidal flats.

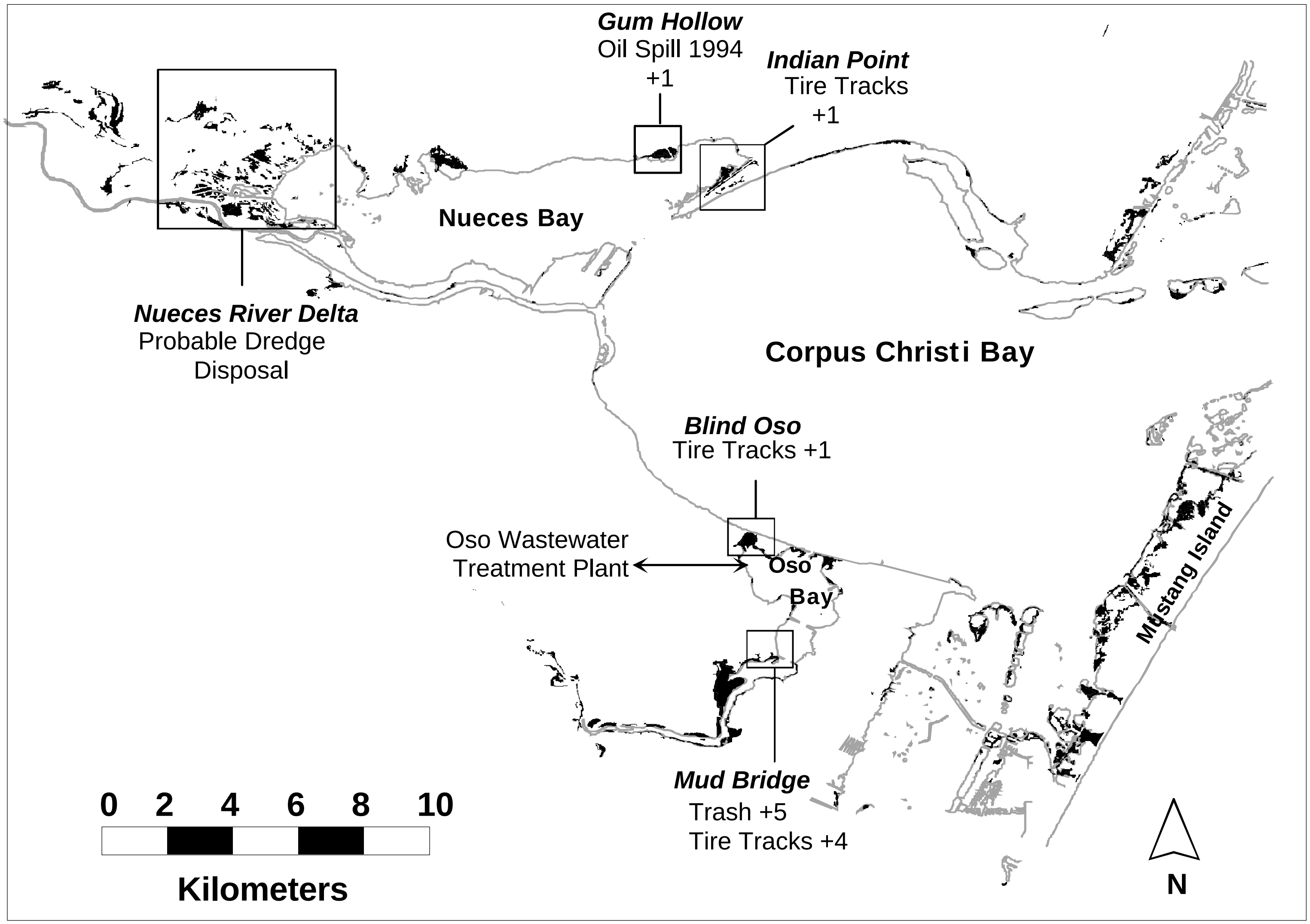

Fig 6.3. Known impacts to tidal flats in Corpus Christi Bay area. 1 = minimal; 2 = light; 3 = moderate; 4 = moderately severe; 5 = severe. Maps provided by BEG; based on 1992 NWI maps and data. Black areas are tidal flats.

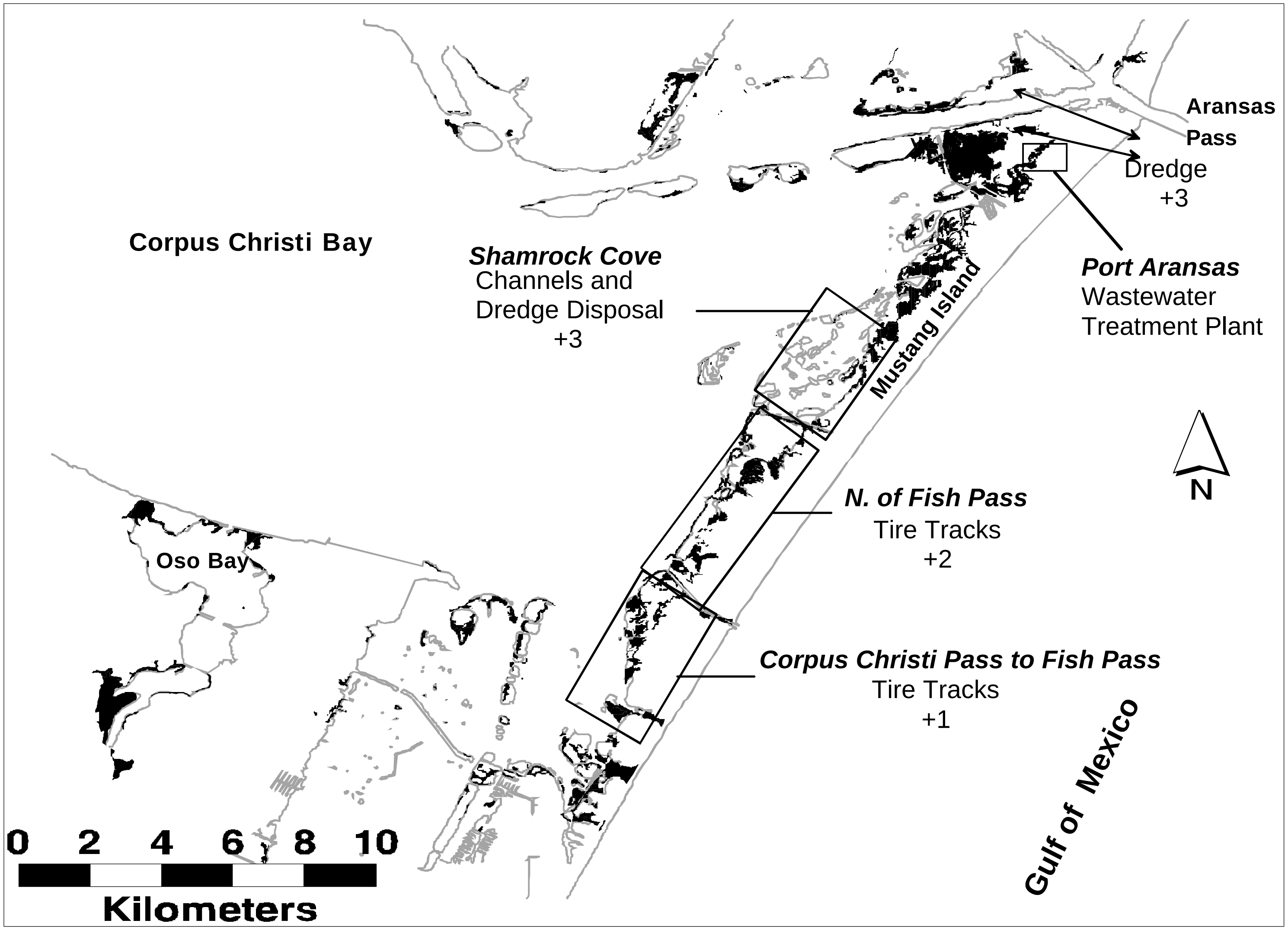

Fig 6.4. Known impacts to tidal flats in Mustang Island area. 1 = minimal; 2 = light ; 3 = moderate; 4 = moderately severe; 5 = severe. Maps provided by BEG; based on 1992 NWI maps and data. Black areas are tidal flats.

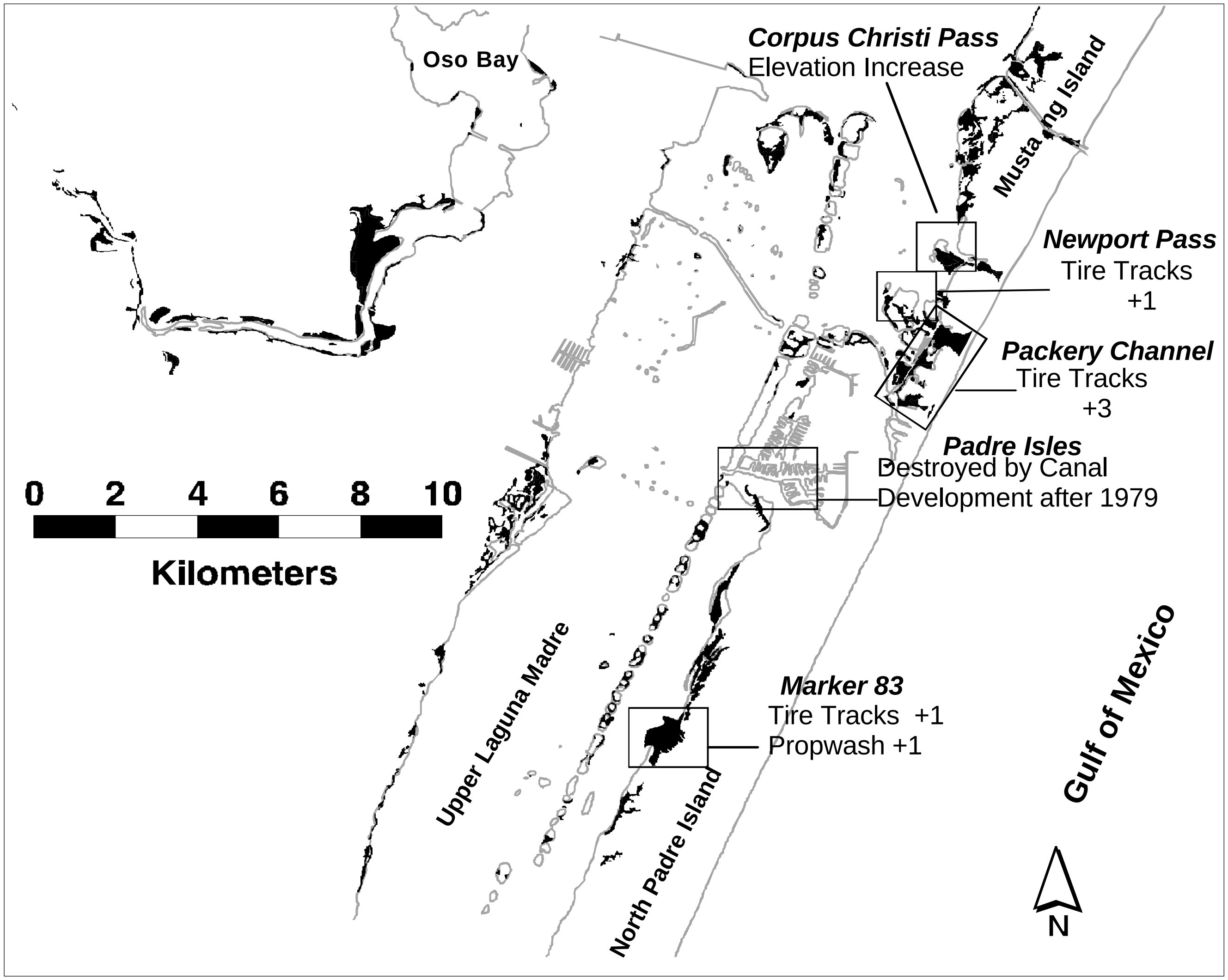

Fig 6.5. Known impacts to tidal flats in North Padre Island area. 1 = minimal; 2 = light; 3 = moderate; 4 = moderately severe; 5 = severe. Maps provided by BEG; based on 1992 NWI maps and data. Black areas are tidal flats.

undoubtedly occurred, it is difficult to classify them as deleterious since the overall effect is to provide greater resources to shorebirds than would probably be available otherwise.

6.4 Conservation Efforts in the CCBNEP Study Area

Far from being barren and unproductive, tidal flats represent one of the most important and productive habitats in the CCBNEP study area, and are essential wintering foraging habitat for several endangered or threatened species, with Piping Plover the most notable. Even though most tidal flat losses over the last 60 years can be attributed to natural causes (e.g., sea level rise, decreased predominance of eolian processes), this means that losses attributable to human activities must be minimized if adequate amounts of tidal flat habitat are to be maintained for wildlife. Table 6.4 lists wetland areas containing wind-tidal flats that have been identified as potential sites for restoration, enhancement or creation (Smith et al., 1997).

Two recent preservation efforts deserve mention. The Mollie Beattie Coastal Habitat Community was established in 1996 under the Adopt-A-Habitat program begun by GLO and USFWS. Located in the Newport Pass area (and one of the sampling areas for the present study), it encompasses approximately 405 ha of mudflats and salt marshes. It was protected from development for five years, after which it will be reevaluated to determine if it will remain a preserve or be made available for development. This area is a very productive site for shorebirds in general, and Piping and Snowy plovers in particular. Plans for the habitat include restricting vehicle access to the flats and marshes, providing parking and access for wadefishing, and education programs. In late 1997, about 3 ha of tidal flat habitat was set aside in the Corpus Christi Pass area as mitigation for the development known as "The Village" that will impact tidal flats around the JFK Causeway.

Table 6.4. Potential sites for tidal flat restoration or enhancement from Smith et al., 1997.

Site #	Name	Ownership or Management	Habitat
16	Nueces Bay East Shoreline	Private, State	Irregularly flooded, vegetated and unvegetated flats
19	Oso Golf Course Drainage Creek & Hans Suter Park	City of Corpus Christi	Regularly flooded, vegetated flats
20	Mud Bridge	Private, State	Regularly and irregularly flooded unvegetated flats
33	Mustang Island State Park - Water Exchange Pass	TPWD	Irregularly flooded, unvegetated flats

Table 6.4. Continued.

Site #	Name	Ownership or Management	Habitat
34	Corpus Christi/Newport Pass	Private, State, County	Irregularly flooded, unvegetated flats
37	Snoopy's Flats	Private, State	Irregularly flooded, vegetated and unvegetated flats
38	City of Port Aransas Intertidal Flat	City of Port Aransas, TXDOT, TPWD	Irregularly flooded, unvegetated flats
39	Piper Channel	Private, State	Irregularly flooded, unvegetated flats

Table of Contents

7. STRATEGY FOR EVALUATING TIDAL FLAT PRODUCTIVITY

7.1 Structure of Methodology

7.1.1 Approach, Parameter Selection, and Value Index Determination

Tidal flats in the CCBNEP study area are unique because the inundation regime is irregular and mainly governed by winds. In this environment, blue-green algal mats form on many flats. These two characteristics make it difficult, if not impossible, to compare most CCBNEP study area tidal flats to flats anywhere else in the world or to use data from outside this area to evaluate productivity. Parameters used to evaluate the relative value of a habitat must reflect value of the habitat to wildlife and fisheries species of management concern (Diaz, 1982) but mobility of most wildlife and fisheries species makes it difficult to rely on presence or absence to indicate habitat productivity. In the CCBNEP study area, support of migrating and wintering shorebirds, particularly endangered and/or threatened Piping and Snowy plovers, is the primary management issue. In general, tidal flats have little or no obvious and readily identifiable physical structure or life, except when shorebirds are present, so parameters chosen to evaluate productivity must always be present on flats. Four tidal flats in the CCBNEP study area were sampled between November 1996 and March 1997. While all were used by shorebirds to some extent, and some were used extensively, they were chosen with the idea they would reflect as much variability in all parameters as possible, not because they were used extensively by shorebirds. Because the Blind Oso study site exhibited characteristics of organic enrichment, it was not used to formulate this strategy. For this reason, the strategy is probably most appropriate for use in evaluating sandy, blue-green algal flats. The period was chosen because it is the time when area tidal flats are most important to shorebirds.

Parameters measured were exposed area, benthic invertebrate abundance and biomass, bird density, sediment water content, sediment chlorophyll *a*, and sediment total organic carbon (TOC). These data were used to determine the range of values for various parameters of biologic interest. Value indices were derived from combinations of parameters (e.g., polychaete abundance vs polychaete biomass). Only two invertebrate taxa were frequently encountered, polychaetes and insect larvae. So that less frequently encountered, but often abundant taxa were taken into consideration, total density and biomass were also used. Value indices were scaled on the range of parameters from zero to three, no (=0), low (=1), medium (=2) and high value (=3). Mean and standard deviation for each parameter were determined. The mean represented the upper limit of low productivity with 1 SD above the mean representing the upper level of medium productivity.

7.1.2 Overall Evaluation Strategy

This strategy emphasizes measured parameters of productivity over six months during late fall through spring, but also offers options that may allow timespans to be reduced. In all cases at least some measurements must be made between November and March. A flowchart (Fig. 7.1) shows how the strategy fits into the overall planning scheme. Before attempting any evaluations,

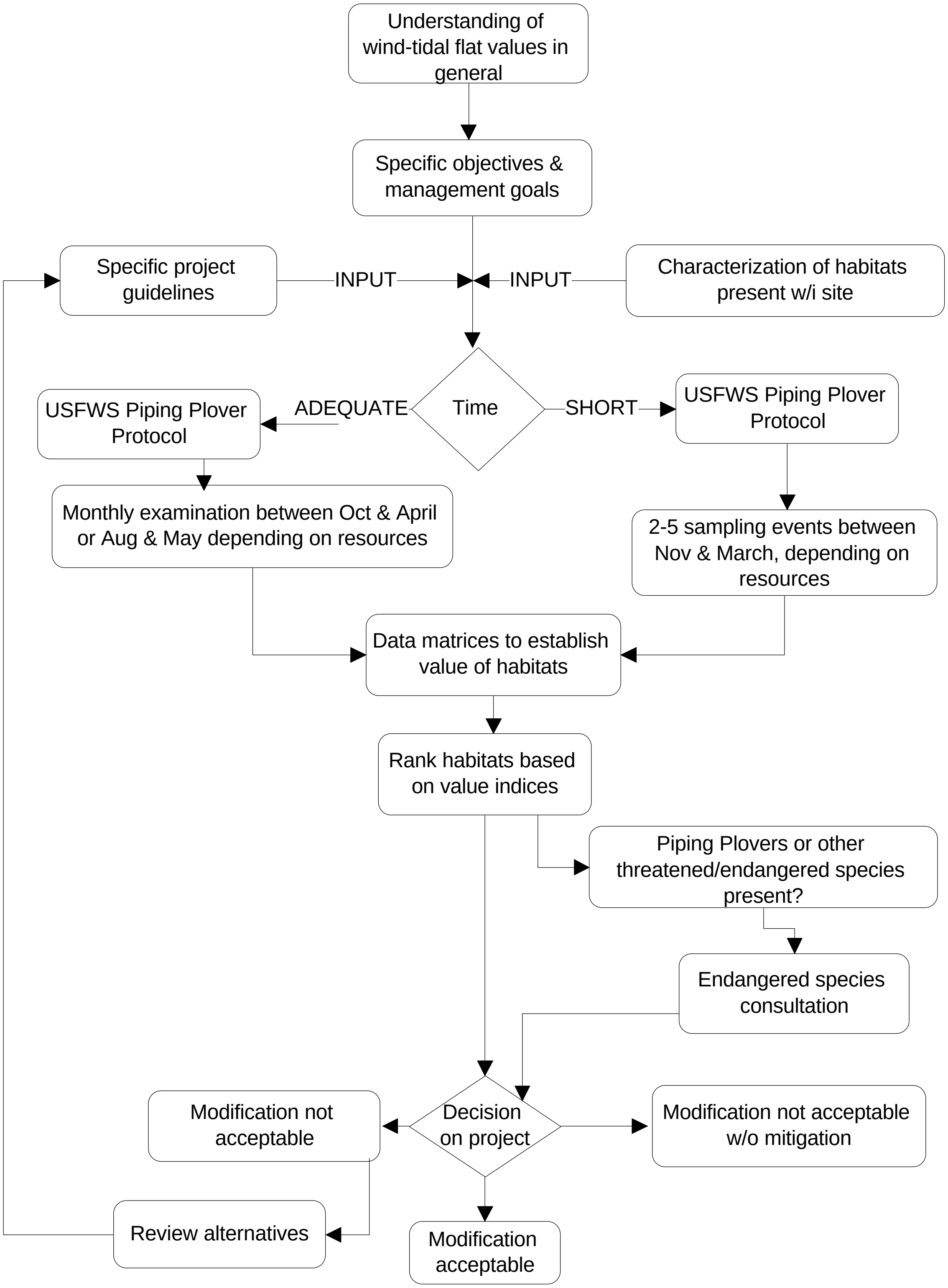

Fig. 7.1. Flow chart showing where evaluation strategy fits into overall scheme of project planning (modified from Diaz, 1982).

users must become familiar with tidal flat values and are encouraged to read Section 3 "Ecology of Wind Tidal Flats" in this volume before proceeding. This strategy can be used in the following ways:

(1) as a foundation for a baseline assessment or monitoring program,
(2) as a baseline evaluation of different habitats and microhabitats within a project site,
(3) to compare alternative project sites,
(4) to predict whether proposed habitat modifications will be acceptable,
(5) as a evaluation to determine extent and severity of anthropogenic or natural disturbances (when baseline data are available),
(6) to determine mitigation effort,
(7) to determine restoration or equivalence of function, via either creation or enhancement for the purposes of mitigation or preservation (when baseline data are available).

Depending on the application of the methodology, the following inputs are needed:

(1) Specific Project Guidelines: includes engineering data on type and size of project, types of impacts expected, magnitude, and area to be impacted, duration of activities, life of project, and projected secondary impacts.
(2) Site Characterization: this includes number of different tidal flat habitats present in the project area, areal extent of each habitat or microhabitat type, and physical data from habitats and microhabitats

7.1.3 Endangered Species Considerations

In the CCBNEP study area, tidal flats are essential migrating and foraging habitat, particularly between August and May, for a number of endangered or threatened species: Piping Plover (*Charadrius melodus*), Snowy Plover (*Charadrius alexandrinus*), Peregrine Falcon (*Falco peregrinus*), Reddish Egret (*Egretta rufescens*), and White-tailed Hawks (*Buteo albicaudatus*). Least Terns (*Sterna antillarum*), also threatened, often nest on or just adjacent to tidal flats in the area. In addition, since many shorebirds have shown population declines (Howe et al., 1989), these species are also of concern. Presence of endangered or threatened species on or near tidal flats results in the need for consultation with USFWS Service biologists to determine if the project or even the evaluation itself will result in "jeopardy" to the species of concern.

7.1.4 Time Frame

Project guidelines and site characterization must be understood before recommending the time frame under which the evaluation should proceed. One difficulty with evaluating tidal flats in the CCBNEP study area is the extreme temporal variability that sites can exhibit with regard to a measured parameter. For example, tanaids were incredibly abundant on tidal flats sampled in the CCBNEP study area during 1991-1993, but were only rarely caught during November 1996-March 1997. In addition, shorebirds, including plovers, were very abundant on one site during 1991-1993; few birds, and virtually no plovers were observed on that same site during the present study. Another difficulty is identifying microhabitats which are more important in this milieu than adjacent habitats; microhabitats based on degree of sediment saturation must be identified and sampled to adequately characterize productivity on sites. Parties interested in developing tidal flat sites must understand that evaluations cannot be completed within a few days or generally even within a few weeks; all evaluations must be performed during late fall through early spring. While manpower and monetary resources must be taken into consideration, few wind-tidal flats in the CCBNEP study area can be adequately evaluated with only a cursory examination. The following guidelines will help determine the appropriate level of sampling intensity and approximate time frame:

(1) If time and resources are short, then a cursory examination of the site during a minimum of five days during at least two months between November and March will allow determination of the most critical aspects of the site. All exposed areas must be sampled each day, and all adjacent habitats must be sampled at least twice. Sampling must be as intense as possible. Total shorebird density must be determined each sampling day. The USFWS Piping Plover Protocol (Appendix 3) must be followed. This approach is not recommended, as it is possible results will be misleading.
(2) If time is short, but resources are not limiting, then the site must be evaluated at least once monthly between November and March. Adjacent habitats must be sampled at least three times in three different months. All habitats must be sampled and sampling must be as intense as possible. Total shorebird density must be determined each sampling day. The USFWS Piping Plover Protocol must be followed.
(3) If there is adequate time, but resources are limiting, then the site should be evaluated as in (2), but with the addition of sampling periods in October and April. Total shorebird density must be determined each sampling day. The USFWS Piping Plover Protocol must be followed.
(4) If neither time nor resources are limiting then complete data sets should be collected from August through May. The USFWS Piping Plover Protocol must be followed. If possible, data collection should be over two years.

7.2 Data Matrices for Evaluation Parameters

7.2.1 Parameters

The evaluation strategy described is only applicable to blue-green algal flats within the CCBNEP study area. The following data are necessary for the evaluation:

(1) Engineering and descriptive data on the project and various habitats and microhabitats within the project area
(2) Data on biological resources for use in value indices

Data are divided into three categories with the following measurements:

(1) Primary Production: sediment chlorophyll *a* (mg/m^2), total organic carbon (% dry weight), water content (%),

(2) Secondary Production: Polychaete abundance (#/m^2) and biomass (g dry weight/m^2), insect larvae abundance(#/m^2) and biomass (g dry weight/m^2), mean invertebrate (all taxa) abundance (#/m^2) and biomass (g dry weight/m^2),

(3) Consumers - bird density (#/ha).

7.2.2 Primary Production

Although chlorophyll *a* and light intensity were used by Diaz (1982) to characterize primary production, sediment water content was felt to be more limiting than light intensity since most primary areas of interest in the CCBNEP study area are not inundated, except by very shallow (usually <20 cm) water. In addition, we measured sediment total organic carbon (TOC) as an measurement of carbon availability for decomposers. Methods for obtaining field data are in Sections 2.3.1.1.2, 2.3.1.1.5, and 2.3.1.1.6. These three parameters were converted to value indices using Figure 7.2 A and B. For example, if chlorophyll *a* concentration was 160 mg/m^2, TOC was 2.5% and water content was 30% you would obtain value indices for both measures of primary productivity of 2. Indices would be determined for each set of samples and each habitat or microhabitat and recorded on a habitat evaluation form.

7.2.3 Secondary Production

Coarse groupings were used to construct value index matrices for secondary production since fine taxonomic grouping would increase analysis time and effort substantially, but would shed little, if any, additional light on secondary production. Two primary groupings were polychaete and insect larvae abundance and biomass, but because many organisms are patchily distributed in both space and time, an additional matrix of mean total abundance and density was also constructed (Fig. 7.3A-C). Methods for obtaining field data are in Section 2.3.1.1.4. Indices are determined in the same manner as described for primary production.

7.2.4 Consumers

A value index matrix was also constructed using mean shorebird density and mean benthic abundance because of importance of CCBNEP tidal flats to shorebirds, and the probable relationship between shorebirds abundance and resource abundance (Fig. 7.4). An additional matrix was constructed using mean shorebird density and mean exposed area, however, on small (<10 ha) sites this matrix may not accurately reflect productivity of the site. Alternative measures such as percentage of exposed flat or number of days more than 50% of the site is exposed would probably be more suitable on small sites. Methods for obtaining field data are in Section 2.3.1.1.5. These indices are determined in the same manner as described for primary production.

7.2 4 Additional Parameters

Because tidal flats in the CCBNEP study area are inundated and exposed mostly in response to winds rather than tides, changes in exposed area are needed to adequately describe function of the study area. A crude method for obtaining these data is described in Section 2.3.1.1.1,

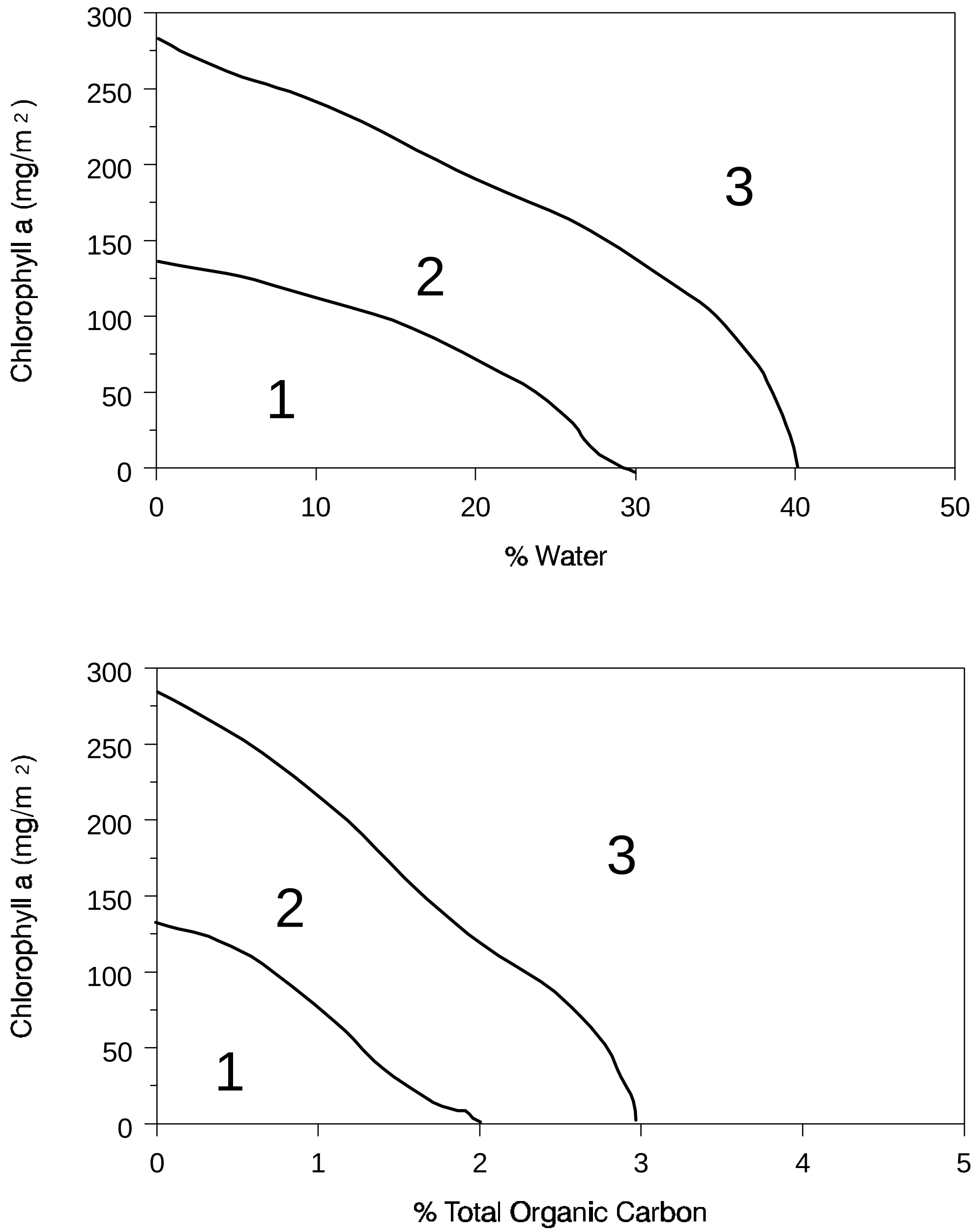

Fig. 7.2 Primary productivity value index matrices.

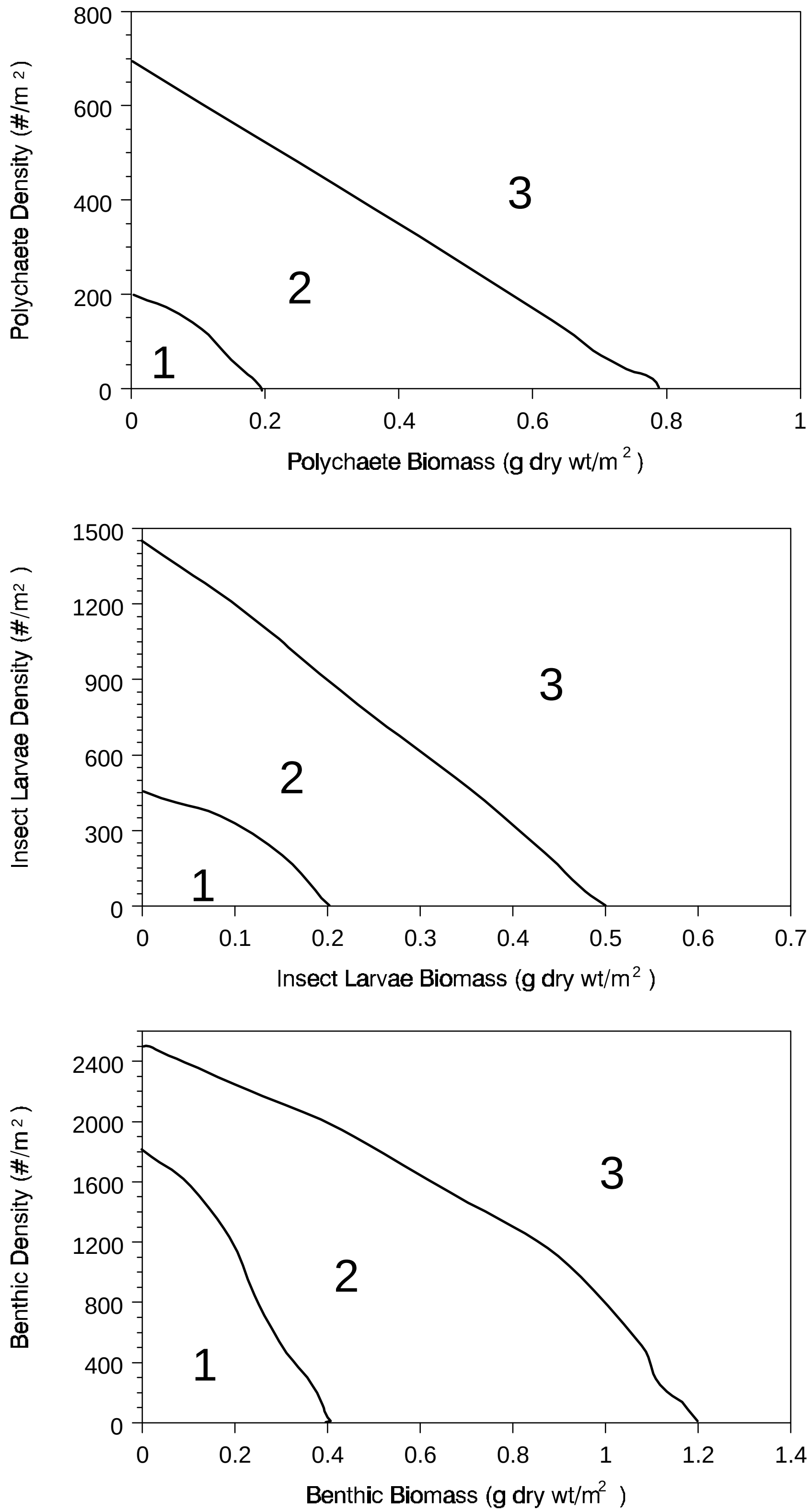

Fig. 7.3. Value index matrices for secondary producer populations.

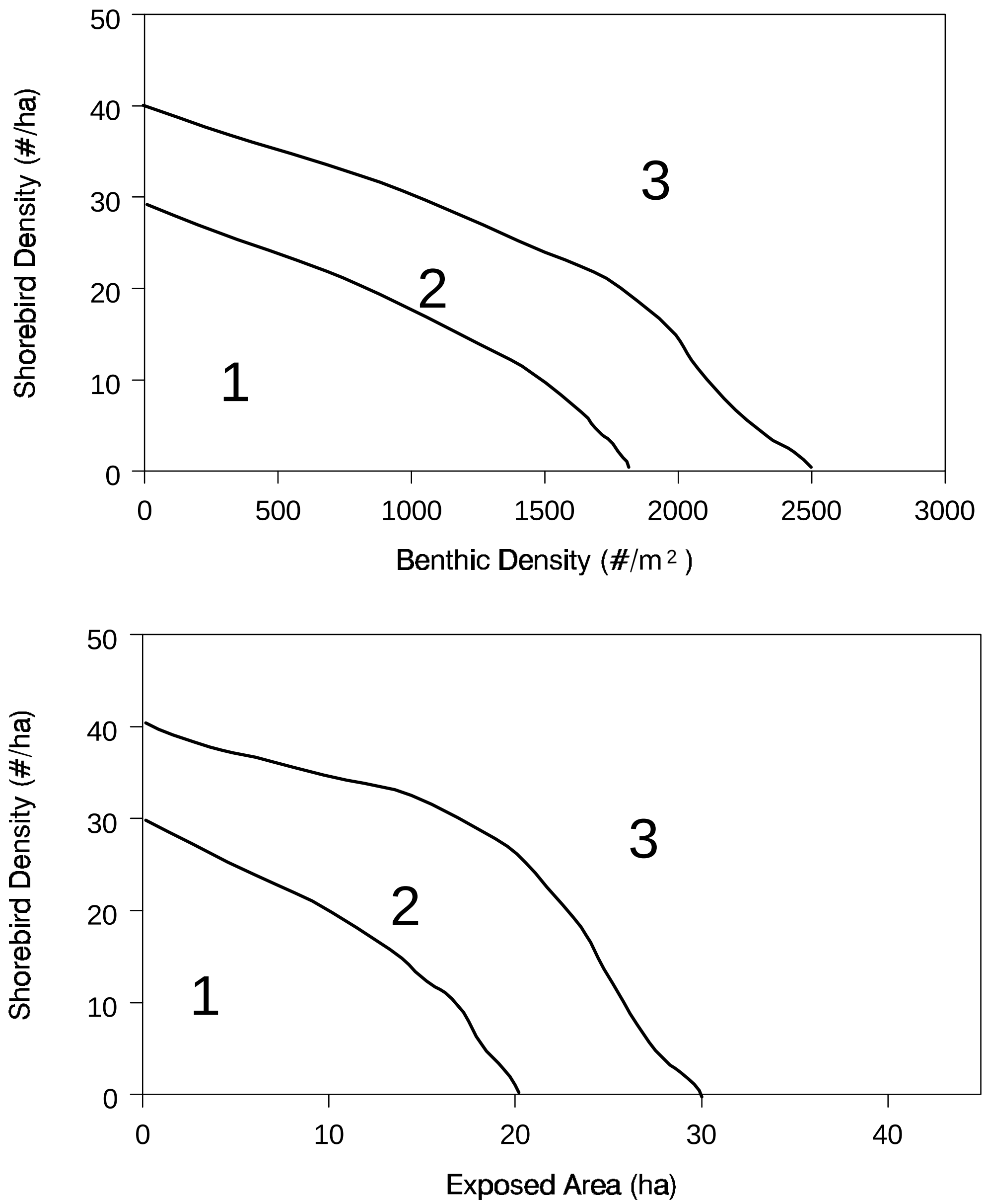

Fig. 7.4. Value index matrices for consumer (shorebird) populations.

however, more sophisticated methods would be preferable and result in higher quality data.

7.3 Evaluating Results

When the evaluation period has ended, data should be compiled and the average and range of value indices should be determined for each microhabitat, as well as any adjacent habitats sampled. Interpretation will be discussed under each of the management objectives described earlier.

7.3.1 Foundation for a Baseline Assessment or Monitoring Program

Baseline data are collected to understand the existing value of various habitats and microhabitats and how it changes through time. The data must be collected over a period of years, ideally three or more consecutive years. All habitats and microhabitats must receive the same amount of sampling effort to eliminate bias. Areal extent of habitats should be determined when possible; areas of small islands of vegetation in the middle of flats or fringing vegetation can be determined, however, it may not be possible to determine areas of microhabitats based on sediment saturation with any certainty, because they are present as a mosaic rather than as zones. In addition, areas vary over time depending on inundation and exposure regimes. Although value indices can be weighted based on the relative area of various habitats or microhabitats it is not necessary in this application. Value indices allow easy comparisons of tidal flats to one another and to themselves over time, especially by non-scientists and managers.

7.3.2 Baseline Evaluation Of Different Habitats And Microhabitats Within A Project Site

This application does not differ from 7.3.1 except that time frames may be compressed and value indices are generally weighted based on the relative areas of various habitats in the project area. When possible, data collection over a period of years is preferable. Determining percent distributions of habitats (when possible) allows value indices to be weighted to determine which habitats contribute most to productivity of the entire study area. In this area, since microhabitats based on sediment saturation are very important, but areas may be extremely difficult to determine, general habitat groupings will most likely include exposed flat, inundated flat or submerged area, and vegetated islands or fringe. Other habitat types might include tidal creeks (vegetated or unvegetated) and adjacent grass beds. Interpretation of the baseline evaluation should include a discussion of the following (Diaz, 1982): habitats of uniformly low relative value; habitats of uniformly high relative value; juxtaposition and distribution of habitats, areal extent of habitats (and microhabitats if possible); and habitats identified as critical to the ecological character of the area.

7.3.3 Compare Alternative Project Sites

When alternative project sites are proposed, this evaluation method can be used to compare alternative sites and determine where loss would be most acceptable. Each alternative site must be assessed in exactly the same manner, within a few days of all other sites, and using the same effort to eliminate bias.

7.3.4 Predict Whether Proposed Habitat Modifications Will Be Acceptable

In any project there will be short- and long-term impacts of the activities associated with the project. By understanding the percentages of habitats that will be affected, and the timing and length of the disturbance, predictions of changes in value indices may be made. To make these predictions the following must be understood (Diaz, 1982): general magnitude of habitat modification; patterns of habitat modification; extent to which habitat is modified; severity of habitat modification; duration of modification; recovery from acute impacts; disturbance of critical habitat.

7.3.5 Determine Extent and Severity of Anthropogenic or Natural Disturbances

Often disturbances occur that are unexpected and beyond our control. When baseline data are available, sites can be evaluated after disturbance and compared with predisturbance values to determine extent and severity of the disturbance. Even if baseline data are not available, post-disturbance evaluation can be useful in determining recovery of habitat, as evidenced by increases in value indices.

7.3.6 Determine Mitigation Effort

Unfortunately, mitigation for construction activities on tidal flats has not often been practiced and no guidelines currently exist. In marshes and emergent wetlands, mitigation is always greater than 1:1 and types and amounts are determined by the Interagency Coordinating Teams composed of federal, state, and local officials. Determination of pre-project values, and identification of sites with equivalent or better values to be set aside and preserved can be accomplished using this evaluation strategy. In planning a mitigation effort it is necessary to consider the following (Diaz, 1982): relative value of habitat lost; relative value of habitat preserved or developed; and relative value of habitat displaced by development of new habitat.

7.3.7 Determine Restoration or Equivalence of Function

Because tidal flats have only recently been recognized as valuable habitat, it may be some time before mitigation is routine and our abilities to create or enhance habitat are fully developed. However, this evaluation strategy can be used to determine the success in these endeavors.

Table of Contents

8. PROBABLE CAUSES

Most disturbances to wind-tidal flats in the CCBNEP study area are anthropogenic. However, greatest losses have occurred due to inundation and conversion to shallow bay bottom because of eustatic sea-level rise. Table 8.1 summarizes both the natural and anthropogenic types and probable causes of impacts that have occurred or may occur in the future.

9. KNOWLEDGE GAPS

Moderate amounts of information exist on the physical aspects of wind-tidal flats in the CCBNEP study area, as well as taxonomic composition of most animal and plant communities (Table 9.1). A moderate amount of information is also available on the locations of impacts and alterations (Table 9.2). Little information is available on energy flow, trophic levels and food web relationships, nutrient cycling, decomposer communities, linkages with other systems, and biological effects of impacts. Meiofaunal, microfaunal, and temporary zooplankton communities are virtually unknown. One of the most important knowledge gaps that needs attention is the lack of knowledge of invertebrate dispersal dynamics, colonization, and community succession, because these processes drive productivity of wind-tidal flats for shorebird consumers. Another very important gap is knowledge of long-term spatial and temporal fluctuations of biotic communities. Without this knowledge it is difficult to address important management issues of conservation and preservation of this vital habitat.

Table 8.1. Impact matrix for wind-tidal flats in the CCBNEP study area showing probable effects at several levels of scale. T= Temporary; P = Permanent; A = Aesthetic.

Impact	Probable Causes	Individuals/ Species	Communities	Ecosystem	Landscape
Natural					
Habitat loss	Sea-level increases; conversion	**** P	**** P	**** P	**** P
Elevation increases	Succession	*** P	**** P	**** P	**** P
Sea-level fall	Glaciation	** P	** P	*** P	**** P
Cold Temperatures	Seasonal	*** T	*** T	** T	
Air & Water Temperature Increases	Seasonal	*** T	*** T	** T	
Reduced Freshwater Inflow	Drought, seasonal	*** T	*** T	** T	
Tropical storms	Seasonal	*** T-P	*** T-P	*** T-P	*** T-P
Anthropogenic					
Habitat Loss	Conversion via mitigation; development and construction; dredging and disposal	**** P	**** P	**** P	**** P
Habitat and/or water quality degradation	Oil spills, industrial effluents and runoff; dredging and disposal	**** P	**** P	*** T-P	*** T-P
Organic Enrichment	Domestic and industrial wastewater	**** T-P	**** T-P	** T-P	?
Reduced Freshwater Inflows	Upstream damming and diking	*** P	*** P	*** P	?
Tracking	Vehicles, cattle	*** T	***T	?	
Trash	Recreational use, indiscriminant dumping practices			* A	* A

blank = no influence
* = slight influence
** = moderate influence
*** = significant influence
**** = major influence
? = unknown influence

Table 9.1. Knowledge gap matrix for ecology of wind-tidal flats in the CCBNEP study area. For topics with no knowledge for CCBNEP study area, availability and amount of information from outside the area is presented

	CCBNEP	Outside
3.1 Physical Setting & Process		
3.1.1 Distribution	**	
3.1.2 Historical Development	**	
3.1.3 Physiography	**	
3.1.4 Geology & Soils	**	
3.1.5 Hydrology & Chemistry		
3.1.5.1 Inundation & Exposure	**	
3.1.5.2 Hydrologic Models	*	
3.1.5.3 Salinity & Geochemistry	**	
3.1.5.4 Blue-Green Algae Precipitation of Carbonates	*	
3.2 Producers & Decomposers		
3.2.1 Primary Producers	**	
3.2.2 Secondary Producers		
3.2.2.1 Macrofauna	**	
3.2.2.2 Meiofauna		*
3.2.2.3 Microfauna		*
3.2.2.4 Temporary Zooplankton	*	
3.2.3 Decomposers	*	
3.3 Consumers		
3.3.1 Invertebrates	**	
3.3.2 Nekton (Vertebrate & Invertebrate)	*	
3.3.3 Reptiles & Amphibians		
3.3.4 Birds		
3.3.4.1 Shorebirds	**	
3.3.4.2 Wading Birds	**	
3.3.5 Mammals	*	
3.4 Community Structure & Zonation		
3.4.1 Plant Communities	**	
3.4.3.1 Succession		*
3.4.2 Invertebrate Community		
3.4.2.1 Taxonomic Composition	**	
3.4.2.2 Zonation	**	
3.4.2.3 Dispersal Dynamics, Colonization, & Community Succession		**

Table 9.1. Continued.

	CCBNEP	Outside
3.4.3 Vertebrate Communities		
3.4.3.1 Shorebirds	**	
3.4.3.2 Fish	**	
3.5 Ecosystem Processes		
3.5.1 Productivity & Energy Flow	*	
3.5.2 Trophic Levels & Food Web Relationships	*	
3.5.3 Nutrient Cycling	*	
3.5.4 Linkages With Other Systems	*	

blank = no information is listed in the literature for the CCBNEP study area
* = little information is available
** = moderate amount of information is available

Table 9.2. Knowledge gap matrix for natural and anthropogenic disturbances to wind-tidal flats in the CCBNEP study area and general knowledge from outside the area.

	CCBNEP	Outside
5.1 Natural Disturbances		
5.1.1 Subsidence & Sea-Level Rise		
5.1.1.1 Physical Effects	**	**
5.1.1.2 Biologic Effects		**
5.1.2 Sea-Level Fall		
5.1.3 Cold Temperatures	*	*
5.1.4 Air & Water Temperature Increases	*	*
5.1.5 Storms	*	*
5.2 Anthropogenic Disturbances		
5.2.1 Oil Spills		
5.2.1.1 Physical Effects		**
5.2.1.2 Biologic Effects		**
5.2.1.3 Effects of Oil Removing Vehicles		*
5.2.1.4 Sensitivity of Wind-Tidal Flats in the CCBNEP Study Area	*	
5.2.2 Effluents & Runoff		
5.2.2.1 Organic Enrichment	*	***
5.2.2.2 Industrial Effluents & Runoff		**
5.2.3 Dredging & Dredge Material Disposal	*	
5.3.4 Tracking by Vehicles	*	*
5.3.5 Power Plant Construction	*	
5.3.6 Construction	*	
5.3.7 Upstream Damming & Diking		
5.3.8 Mitigation & Restoration Projects	*	

blank = no information is listed in the literature for the CCBNEP study area
* = little information is available
** = moderate amount of information is available
*** = an extensive amount of information is available

Table of Contents

10. LITERATURE CITED

Adams, J. E. and M. L. Rhodes. 1960. Dolomitization by seepage refluxion. Amer. Assoc. Petrol. Geol. Bull. 44: 1912-1920.

Ahn, I. Y, Y.C. Kang and J. W. Choi. 1995. The influence of industrial effluents on intertidal benthic communities in Panweol, Kyeonggi Bay (Yellow Sea) on the west coast of Korea. Mar. Poll. Bull. 30: 200-206.

Amdurer, M. 1978. Geochemistry, hydrology, and mineralogy of the Laguna Madre flats, south Texas. M.A. Thesis, Univ. Texas. Austin, Texas. 172 pages.

Armstrong, N. E. and H. T. Odum. 1964. Photoelectric system. Science 143: 256-258.

Baker, M. C. and A. E. M. Baker. 1973. Niche relationships among six species of shorebirds on their wintering and breeding range. Ecol. Monogr. 43: 193-212.

Barrera, T. A. unpublished. Historical changes and ecological characterization of the "Blind Oso" of Cayo del Oso Bay, Corpus Christi, Texas. unfinished M.S. Thesis, Texas A&M Univ. -Corpus Christi. Corpus Christi, Texas.

Barrera, T. A., D. Waechter, G. Jeffress, and J. W. Tunnell. 1992. A temporal salt marsh vegetation study: implementation of a GIS. Pages 251-260 *in* Freund, D. M. (ed.) URISA '92. Urban and Regional Information Systems Assoc. Ann. Proc. Vol. 1. Washington, D.C.

Behrens, E. W. 1969. Hurricane effects on a hypersaline bay. Pages 301-312 *in* Lagunas Costeras, un Simposio. Mem. Simp. Intern. Lagunas Costeras. UNAM-UNESCO, Nov. 28-30, 1967. México, D.F.

Bengtson, S. A., A. Nilson, S. Nordstrom, and S. Rundgren. 1976. Effect of bird predation on lumbricid populations. Oikos 27: 9-12.

Berner, R. A. 1971. Principles of chemical sedimentology. McGraw Hill. New York, New York. 240 pages.

Bergstrom, P. W. 1986. Daylight incubation sex roles in Wilson's plover. Condor. 88:113-115.

Beukema, J. J. 1995. Long-term effects of mechanical harvesting of lugworms *Arenicola marina* on the zoobenthic community of a tidal flat in the Wadden Sea. Neth. J. Sea Res. 33: 219-227.

Bigelow, G. W. 1977. Primary productivity of benthic microalgae in the Newport River estuary. M.S. Thesis, North Carolina State Univ. Raleigh, North Carolina. 44 pages.

Birke, L. 1974. Marine blue-green algal mats. Pages 331-345 *in* Odum, H. T. B. J. Copeland and E. A. McMahon (eds.). Coastal ecological systems of the United States, vol. I. The Conservation Foundation. Washington, D.C.

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

Bold, H. C. and M. J. Wynne. 1978. Introduction to the algae: structure and reproduction. Prentice-Hall. New Jersey. 706 pages.

Bowman, J. W. and P. Jennings. 1992. Oso Bay: an assessment of a south Texas bay system. Draft Rept., Texas Water Commission. Austin, Texas.

Boyles, J. S. 1941. Field notes incorporated in Final Judgement Balli v State: Cause No. 20707-B, The State of Texas v. Alberto Balli, et al. Judgement Vol. 13, Page 112 et sez., in the 117th District Court, Nueces County, Texas. On file in archives of TGLO.

Brock, D. 1983. Primary and secondary bay production. Chap. VII *in* Laguna Madre estuary: a study of the influence of freshwater inflows. TDWR LP-182.

Brogden, W. B., C. H. Oppenheimer, D. Bowman. 1977. Selected biological data, Mustang and north Padre islands. Chap IV *in* Kier, R. S. and E. G. Fruh (eds.) Environmental and economic impacts of recreational community development, Mustang Island and north Padre Island, vol. 2. Univ. Texas. Austin, Texas.

Brown, L. F., Jr., J. L. Brewton, J. H. McGowen, T. J. Evans, W. L. Fisher, and C. G. Groat. 1976. Environmental geologic atlas of the Texas coastal zone: Corpus Christi area. Bur. Econ. Geol., Univ. Texas. Austin, Texas. 123 pages., 9 maps.

Brown, L. F., Jr., J. L. Brewton, T. J. Evans, J. H. McGowen, W. A. White, C. G. Groat, and W. L. Fisher. 1980. Environmental geologic atlas of the Texas coastal zone: Brownsville-Harlingen area. Bur. Econ. Geol., Univ. Texas. Austin, Texas. 140 pages., 9 maps.

Brown, L. F., Jr., J. H. McGowen, T. J. Evans, C. G. Groat, and W. L. Fisher. 1977. Environmental geologic atlas of the Texas coastal zone: Kingsville area. Bur. Econ. Geol., Univ. Texas. Austin, Texas. 131 pages., 9 maps.

Bryant, D. M. 1979. Effects of prey density and site character on estuary usage by overwintering waders (Charadrii). Est. Coast. Mar. Sci. 9: 369-384.

Buskey, E. J. 1996. Current status and historical trends of brown tide and red tide phytoplankton blooms in the Corpus Christ Bay national Estuary Program study area. CCBNEP-07. TNRCC, Austin, Texas. 174 pages.

Butler, G. D. 1969. Modern evaporite deposition and geochemistry of coexisting brines, the sabkha, Trucial Coast, Arabian Gulf. J. Sed. Petrol. 39: 70-89.

Cadée, G. G. and J. Hegeman. 1974. Primary production of the benthic microflora living on tidal flats in the Dutch Wadden Sea. Neth. J. Sea Res. 8: 240-259.

Cadée, G. G. and J. Hegeman. 1977. Distribution of primary production of the benthic microflora and accumulation of organic matter on a tidal flat area, Balgzand, Dutch Wadden Sea. Neth. J. Sea Res. 11: 24-41.

Claunch and Associates. 1971. Report on survey, 18,386 acres, Padre Island, Cameron County, Texas. Surveyed for South Padre Island Investment Corp., Claunch and Assoc., Brownsville, Texas. Private survey files of Mr. Tom Stovall, Weslaco, Texas 12 pages, 8 exhibits.

Claunch and Associates. 1978. El Sauz. Private survey files of Mr. Tom Stovall, Weslaco, Texas.

Claunch and Lothrop. 1986. “Map showing 35,039.83 acres in 3 tracts in the eastern portion of the Las Motas de la Barreta (Little Barreta) Grant and the La Barreta (Big Barreta) Grant, Kenedy County, Texas”. Portions surveyed (shoreline boundary) 1985-1986, map compiled July 1986. Drawing KMF No. 18 in archives of J. G. and M. S. Kenedy Memorial Foundation, Corpus Christi, Texas.

Cobb, R. A. 1987. Mitigation evaluation study for the south Texas coast, 1975-1986. Corpus Christi State Univ., Center for Coastal Studies Tech. Report, Coop. Agree. No. 14-16-0002-86-919. Corpus Christi, Texas. 88 pages.

Cocke, J. J. 1879. “Little Barreta” Grant, Kenedy County, map and field notes of confirmation. Survey recorded in Vol. 1, Pages 49-50, Surveyor’s Records of Kenedy County and archives of TGLO.

Colwell, M. A. and S. L. Landrum. 1993. Nonrandom shorebird distribution and fine-scale variation in prey abundance. Condor 95: 94-103.

Commito, J. A., C. A.Currier, L. R. Kane, K. A. Reinsel, and I. M. Ulm. 1995a. Dispersal dynamics of the bivalve *Gemma gemma* in a patchy environment. Ecol. Monogr. 65: 1-20.

Commito, J. A., S. F. Thrush, R. D. Pridmore, J. E. Hewitt, and V. J. Cummings. 1995b. Dispersal dynamics in a wind-driven benthic system. Limnol. Oceanogr. 40: 1513-1518.

Copeland, B. J., J. H. Thompson, Jr., and W. Ogletree. 1968. Effects of wind on water levels in the Texas Laguna Madre. Tex. J. Sci. 20: 196-199.

Coull, B. C. and J. W. Fleeger. 1977. Long-term temporal variation and community dynamics of meiobenthic copepods. Ecology 58: 1136-1143.

Cummings, V. J., R. J. Pridmore, S. F. Thrush, and J. E. Hewitt. 1993. Emergence and floating behaviours of post-settlement juveniles of *Macomona liliana* (Bivalvia: Tellinacea). Mar. Behav. Physiol. 24: 25-32.

Dalrymple, D. W. 1965. Calcium carbonate deposition associated with blue-green algal mats, Baffin Bay, Texas. Inst. Mar. Sci. Publ., Univ. Tex. 10: 187-200.

Davies, G. R. 1970. Algal-laminated sediments, Gladstone Embayment, Shark Bay, Western Australia. Pages 169-205 *in* Amer. Assoc. Petrol. Geol. Mem. 13. 223 pp.

Dekker, R. and G. W. N. M. Van Moorsel. 1987. Effects of different oil doses, dispersant and dispersed oil on macrofauna in model tidal flat ecosystems. Pages 117-131 *in* Kuiper, J. and W. J. Van den Brink (eds.) Fate and effects of oil in marine ecosystems. Martinus Nijhoff Publ. Dordrecht, Netherlands.

Diaz, R. J. 1982. Examination of tidal flats: vol. 3, evaluation methodology. US Dept. Transportation, FHWA/RD-80/183. Washington, D. C. 48 pages.

Diaz, R. J., G. Markwith, R. J. Orth, W. Rizzo, and R. Wetzel. 1982. Examination of tidal flats: vol. 1, research report. US Dept. Transportation, FHWA/RD-80/181. Washington, D. C. 82 pages.

Diaz, R. J., R. J. Orth, G. Markwith, W. Rizzo, R. Wetzel, and K. Storey. 1982. Examination of tidal flats: vol. 2, a review of identified values. US Dept. Transportation, FHWA/RD-80/182. Washington, D. C. 47 pages.

Dolan, R. and H. G. Goodell. 1986. Sinking cities. Amer. Sci. 74: 38-46.

Dörjes, J. 1982. Der einsatz von ölbeseitigungsfahrzeugen im watt und seine auswirkung auf das makrozoobenthos. Senckenbergiana mariti. 14: 175-181. (English abstract)

Dörjes, J. 1984. Auswirkungen von röhol und röhol/dispergator gemischen auf die fauna und flora der watten: einfürung und zusammenfassung. Senckenbergiana marit. 16: . (English abstract)

Dykstra, R. F. 1966. Investigation of some algae of the Texas Gulf Coast. M.S. Thesis, Univ. Texas. Austin, Texas. 100 pages.

Ecoservices. 1993. Laguna Madre bird project from Yarborough Pass to Mansfield channel during July 1992 through April 1993. Rept. to Padre Island National Seashore. Contract No. 1443PX7000092582. Corpus Christi, Texas. 852 pages.

Emerson, C. W. 1991. A method for the measurement of bedload sediment and passive faunal transport on intertidal sandflats. Estuaries 14: 361-371.

Emmanuel, K. A. 1988. The dependence of hurricane intensity on climate. Nature 326: 483-485.

Essink, K. 1984. The discharge of organic waste into the Wadden Sea - local effects. Pages 165-177 *in* Laane, R. W. P. M. and W. J. Wolff (eds.) The role of organic matter in the Wadden Sea. Neth. Inst. Sea Res. Publ. Ser. 10.

Evans, P. R., D. M. Herdson, P. J. Knights, and M. W. Pienkowski. 1979. Short-term effects of reclamation of part of Seal Sands, Teesmouth, on wintering waders and shelduck. Oecologia 41: 83-206.

Farke, H. D. Blome, N. Theobald and K. Wonneberger. 1985. Fiedl experiments with diespersed oil and a dispersant in an intertidal ecosystem: fate and biological effects. Pages 515-520 *in* Proc. 1985 Oil Spill Conf. Amer. Petrol. Inst. Publ. 4385. Washington, D. C.

Farmer, M. 1991. Reddish Egrets of the lower Laguna Madre, Texas. Rept. to USFWS, Lower Rio Grande Natl. Wild. Ref., Alamo, Texas. 50 pages.

Felder, D. L. 1973. An annotated key to crabs and lobsters (Decapoda, Reptantia) from coastal waters of the northwestern Gulf of Mexico. LSU-SG-73-02, Louisiana State Univ. Baton Rouge, Louisiana. 103 pages.

Felder, D. L. and S. A. Rodrigues. 1993. Reexamination of the ghost shrimp *Lepidophthalmus louisianensis* (Schmitt, 1935) from the northern Gulf of Mexico and comparison to *L. siriboia*, new species, from Brazil (Decapoda: Thalassinidea: Callianassidae). J. Crust. Biol. 13:357-376.

Fisk, H. N. 1959. Padre Island and the Laguna Madre flats: coastal south Texas. Second Coastal Geography Conference, Louisiana State Univ. Baton Rouge, Louisiana.

Friedman, G. M. and J. E. Sanders. 1967. Origin and occurrence of dolostones. Pages 267-348 *in* Chilingar, G. V., H. J. Bissell, and R. W. Fairbridge (eds.), Carbonate rocks: origin, occurrence, and classification. Developments in Sedimentology vol. 9A. Elsevier. Amsterdam, The Netherlands.

Friedman, G. M., A. J. Amiel, M. Braun, and D. S. Miller. 1973. Generation of carbonate particles and laminates in algal mats: example from sea-marginal hypersaline pool, Gulf of Aqaba, Red Sea. Amer. Assoc. Petrol. Geol. Bull. 57: 541-557.

Gilfillan, E. S., S. A. Hanson, D. Vallas, R. Gerber, D. S Page, J. Foster, J. Hotham, and S. D. Pratt. 1983. Effect of spills of dispersed and non-dispersed oil on intertidal infaunal community structure. Pages 457-463 *in* Proc. 1983 Oil Spill Conf. Amer. Petrol. Inst. Publ. 4356. Washington, D.C.

Gornitz, V., S. Legedeff, and J. Hansen. 1982. Global sea level trend in the past century. Science 215: 1611-1614.

Goss-Custard, J. D. 1970. The responses of Redshank (*Tringa totanus* (L.)) to spatial variations in the density of their prey. J. Anim. Ecol. 39: 1-13.

Goss-Custard, J. D. 1979. Role of winter food supplies in the population ecology of common British wading birds. Verh. orn. Ges. Bayern 23: 125-146.

Goss-Custard, J. D. 1980. Competition for food and interference among waders. Ardea 68: 31-52.

Goss-Custard, J. D. 1983. Spatial and seasonal variations in the food supply of waders Charadrii wintering in the British Isles. Proc. 3rd Nordic Cong. Orn.: 85-96.

Goss-Custard, J. D. 1985. Foraging behaviour of wading birds and the carrying capacity of estuaries. Pages 169-188 *in* Sibly, R. M. and R. H. Smith (eds.), Behavioural ecology. Blackwell Scientific Publ. Oxford, England.

Goss-Custard, J. D., D. G. Kay, and R. M. Blindell. 1977. The density of migratory and overwintering Redshank *Tringa totanus* (L.) and Curlew *Numenius arquata* (L.) in relation to the density of their prey in south-east England. Est. Coast. Mar. Sci. 15: 491-510.

Goss-Custard, J. D., S. McGrorty, and R. Kirby. 1990. Inshore birds of the soft coasts and sea-level rise. Pages 189-193 *in* Beukema, J. J., W. J. Wolff, and J. J. W. M. Brouns (eds.) Expected effects of climatic change on marine coastal ecosystems. Kluwer Academic Publ. Dordrecht, Netherlands.

Gotto, J. W., F. R. Tabita, and C. Van Baalen. 1981. Nitrogen fixation in intertidal environments of the Texas Gulf coast. Est. Coast. Shelf Sci. 12: 231-235.

Grøntved, J. 1960. On the productivity of microbenthos and phytoplankton in some Danish fjords. Meddr. kommn. Danm. Fisk.-og Havunders (N.S.) 3(3): 55-92.

Grøntved, J. 1962. Preliminary report on the productivity of microbenthos and phytoplankton in the Danish Wadden Sea. Meddr. kommn. Danm. Fisk.-og Havunders (N.S.) 3(12): 347-378.

Gunter, G. 1967. Vertebrates in hypersaline waters. Contrib. Mar. Sci. 12: 230-241.

Gutstadt, A.M. 1990. Coastal processes and legal boundaries. J. Geol. Educ. 38:94-100.

Haig, S. M., and J. H. Plissner. 1993. Distribution and abundance of Piping Plovers: results and implications of the 1991 international census. Condor 95: 145-156.

Haines, E. B. 1977. The origins of detritus in Georgia salt marsh estuaries. Oikos 29: 254-260.

Haines, E. B. and C. L. Montague. 1979. Food sources of estuarine invertebrates analyzed using $^{13}C/^{12}C$ ratios. Ecology 60: 48-56.

Haney, J. C. and A. R. Solow. 1992. Testing for resource use and selection by marine birds. J. Field Ornithol. 63: 43-52.

Harrington, R. W. and E. S. Harrington. 1972. Food of female marsh killifish, *Fundulus confluentus* Goode and Bean, in Florida. Amer. Midl. Nat. 87: 492-502.

Hayes, M. O. 1965. Sedimentation on a semi-arid, wave dominated coast (south Texas) with emphasis on hurricane effects. Ph.D. Dissertation, Univ. of Texas. Austin, Texas. 350 pages.

Hayes, M. O., D. D. Domeracki, C. D. Getter, T. W. Kana, and G. I. Scott. 1980. Sensitivity of coastal environments to spilled oil, south Texas coast. Research Planning Institute, Inc. Rept. No. RPI/R/80/4/11-12, prepared for NOAA Office of Marine Pollution Assessment. Columbia, South Carolina. 89 pages.

Hayes, M. O. and A. J. Scott. 1964. Environmental complexes, south Texas coast. Trans. Gulf Coast Assoc. Geol. Soc. 14: 237-240.

Henley, D. E. and D. G. Rauschuber. 1978. Studies of freshwater needs of fish and wildlife resources in the Nueces-Corpus Christi Bay area, Texas. Hensington, Durham and Richardson, Inc. and North Texas State Univ. Rept. to US Dept. Interior, Contract No. 14-16-009-77-074. Denton, Texas. 2 vols.

Herber, J. P. 1981. Holocene sediments under Laguna Madre, Cameron County, Texas. M.A. Thesis, Univ. of Texas. Austin, Texas. 664 pages.

Hicklin, P. W. and P. C. Smith. 1984. Selection of foraging sites and invertebrate prey by migrant Semipalmated Sandpipers, *Calidris pusilla* (Pallas), in Minas Basin, Bay of Fundy. Can J. Zool. 62: 2201-2210.

Hildebrand, H. and D. King. 1978. A biological study of the Cayo del Oso and Pita Island area of the Laguna Madre. Final Rept. to Central Power and Light Company (CPL), Vol. 1. Corpus Christi, Texas.

Hockey, P. A. R., R. A. Navarro, B. Kalejta, and C. R. Velasquez. 1992. The riddle of the sands: why are shorebird densities so high in southern estuaries. Amer. Nat. 140: 961-979.

Horodyski, R. J. 1977. *Lyngbya* mat at Laguna Mormona, Baja California, Mexico: comparison with Proterozoic stromatolite. J. Sed. Petrol. 47: 1305-1320.

Howarth, R. W. and J. M. Teal. 1980. Energy flow in a salt marsh ecosystem: the role of reduced inorganic sulfur compounds. Amer. Nat. 116: 862-872.

Howe, M. A., P. H. Geissler, and B. A. Harrington. 1989. Population trends of North American shorebirds based on the International Shorebird Survey. Biol. Conserv. 49: 185-199.

Hsü, K. J. and C. Siegenthaler. 1969. Preliminary experiments on hydrodynamic movement induced by evaporation and their bearing on the dolomite problem. Sedimentology 12: 11-26.

Humble Oil and Refining Co. and H. N. Fisk. 1949. Map offered as exhibit in Humble Oil and Refining Co. et al. v Sun Oil Co.

Humble Oil and Refining Co. et al. v. Sun Oil Co. 1951. 190 Federal Reporter, 2nd Series. Pages 191-199. (No. 13312, U.S. Court of Appeals, Fifth Circuit, 20 June 1951).

Humm, H. J. and S. R. Wicks. 1980. Introduction and guide to the marine blue-green algae. John Wiley and Sons. New York, New York. 194 pages.

Hull, S. C. 1987. Macroalgal mats and species abundance: a field experiment. Est. Coast. Shelf Sci. 25: 519-532.

Hurlburt, E. M. 1956. The phytoplankton of Great Pond, Massachusetts. Biol. Bull. 110: 157-168.

Hurlburt, E. M. 1963. The diversity of phytoplankton populations in oceanic, coastal, and estuarine regions. J. Mar. Res. 21: 81-93.

Jones, K. 1974. Nitrogen fixation in a salt marsh. J. Ecology 62: 553-565.

Kenedy Memorial Foundation v. Garry Mauro and State. 1995. Cause No. 03-00517-CV in the Third Court of Appeals District, Austin, Texas. The John G. and Marie Stella Kenedy memorial foundation and the corpus christi Diocese of the Roman Catholic, Appellants, v. Garry Mauro, Commissioner of the General land Office, and the State of Texas, Appellees. On Appeal from the 345th Judicial District Court of Travis County, Texas (current).

Kukert, H. and C. R. Smith. 1992. Disturbance, colonization and succession in a deep-sea sediment community: artifical-mound experiments. Deep-Sea Res. 39: 1349-1371.

Kylin, H. 1927. Über die karotinoiden Garbstoffe der Algen. Zeitschr. physiol Chemie 166: 39-77.

Leach, J. H. 1970. Epibenthic algal production in an intertidal mudflat. Limnol. Oceanogr. 15: 514-521.

Leatherman, S. P. and P. J. Godfrey. 1979. The impact of off-road vehicles on coastal ecosystems in Cape Cod National Seashore: an overview. The Environmental Institute, Univ. Mass./NPS Coop. Res. Unit UM/NPSCRU Rept. 34. Amhearst, Massachusetts. 34 pages.

Lind, O. T. 1974. Handbook of common methods in limnology. C. V. Mosby Co. 154 pages.

Little, D. I. and D. L. Scales. 1987. The effectiveness of a new type III dispersant in the treatement of weathered crude and emulsified fuel oils on saltmarshes and sandflats. Pages 217-219 *in* Kuiper, J. and W. J. Van den Brink (eds.) Fate and effects of oil in marine ecosystems. Martinus Nijhoff Publ. Dordrecht, Netherlands.

Logan, B. W., P. Hoffman, And D. C. Gebelein. 1974. Algal mats, cryptalgal fabrics and structures, Hamelin Pool, Western Australia. Pages 140-194 *in* Evolution and diagenesis of Quaternary carbonate sequences, Shark Bay, Western Australia. Amer. Assoc. Petrol. Geol. Mem. 22.

Lohse, E. A. 1958. Buena Vista mudflats. Pages 58-60 *in* Sedimentology of south Texas. Gulf Coast Assoc. Geol. Socs. Ann. Field Trip.

Long, D. T. and R. Gudramovics. 1983. Major-element geochemistry of brines from the wind tidal flat area, Laguna Madre, Texas. J. Sed. Petrol. 53: 797-810.

Longley, W. L., W. B. Brogden, and S. N. James. 1989. Texas barrier island region characterization: conceptual models. USFWS NWRC Open File Rept. 89-05. 418 pages.

Luttes, J. W. et al. v. State of Texas. 1958. 324 South Western Reporter, 2nd Series, Texas, Pages 167-200.

Lyles, S. D., L. E. Hickman, Jr., H. A. DeBaugh, Jr. 1988. Sea level variations for the United States 1855-1986. NOAA.

Lyons, W. B. and H. E. Gaudette. 1979. Sulfate reduction and the nature of organic matter in estuarine sediments. Organ. Geochem. 1: 151-155.

Maddox, F. M. 1907. Field notes of Maddox survey of 1904 incorporated into patent of Big "La Barreta" Grant from State of Texas to Jose Francisco Balli, heir and assigns. Vol 2, Pages 521-522, Deed Records of Kenedy County and archives of TGLO.

Marshall, N., C. A. Oviatt, and D. M. Skanen. 1971. Productivity of the benthic microflora of shoal estuarine environments in southern New England. Int. Rev. Gesamten Hydrobiol. 56: 947-956.

Masson, P. H. 1955. An occurrence of gypsum in southwest Texas. J. Sed. Petrol. 25: 72-77.

Maurer, L. G. 1971. The nearshore distribution and macromolecular contents of the dissolved organic matter of Texas estuarine and Gulf of Mexico water. Ph.D. Dissertation, Univ. of Texas. Austin, Texas. 96 pages.

McLusky, D. S. 1982. The impact of petrochemical effluent on the fauna of an intertidal estuarine mudflat. Est. Coast. Shelf. Sci. 14: 489-499.

McLusky, D. S. and M. McCrory. 1989. A long-term study of an estuarine mudflat subject to industrial pollution. Scient. Mar. 53: 717-724.

McGowen, J.H., L.F. Brown, Jr.., T.R. Calnan, J.L. Chin, J.P. Herber, and C.L. Lewis. 1977. History and processes involved in development of South Padre Island, Laguna Madre, and Los Bancos de Enmedio. Rept. Submitted to Texas General Land Office by Bur. Econ. Geol., Univ. Tex., Austin.

McGowen, J. H., C. V. Proctor, Jr., L. F. Brown, Jr., T. J. Evans, W. L. Fisher, and C. G. Groat. 1976. Environmental geologic atlas of the Texas coastal zone: Port Lavaca area. Bur. Econ. Geol., Univ. Texas. Austin, Texas 107 pages., 9 maps.

McIntyre, A. D. 1969. Ecology of marine meiobenthos. Biol. Rev. 44: 245-290.

Meire, P. and E. Kuyken. 1984. Relations between the distribution of waders and the intertidal benthic fauna of the Oosterschelde, Netherlands. Pages 55-68 *in* Evans, P. R., J. D. Goss-Custard, and W. G. Hale (eds.), Coastal waders and wildfowl in winter. Cambridge Univ. Press. Cambridge, England.

Merritt, R. W. and K. W. Cummins. 1984. An introduction to the aquatic insects of North America. Kendall Hunt Publ. Co., Dubuque, Iowa.

Miller, J. A. 1975. Facies characteristics of Laguna Madre wind-tidal flats. Pages 67-73 *in* Ginsburg, R. N. (ed.), Tidal deposits, a casebook of recent examples and fossil counterparts. Springer-Verlag. New York, New York.

Monty, C. 1967. Distribution and structure of recent stromatolitic algal mats, eastern Andros Island, Bahamas. Ann. Soc. Geol. Belgium Bull. 90: 55-100.

Moore, S. F. and R. L. Dwyer. 1974. Effects of oil on marine organisms: a critical assessment of published data. Water Res. 8:819-827.

Morton, R. A. And L. E. Garner. 1993. Geological investigation of the wind-tidal flat area, Kenedy County, Texas. Rept. to Texas Office of the Attorney General, Contract No. IAC(92-93)2170. Bureau of Economic Geology, Univ. Of Texas at Austin. Austin, Texas. 99 pages.

Morton, R. A. and J. H. McGowen. 1980. Modern depositional environments of the Texas coast. Bur. Econ. Geol., Univ. Tex., Guidebook 20. 167 pages.

Morton, R. A., W. A. White, R. S. Kerr and W. D. Kuenzi. 1977. Geological aspects of barrier island development: Mustang and north Padre islands, Texas. Chap. III *in* Kier, R. S. and E. G. Fruh (eds.) Environmental and economic impacts of recreational community development, Mustang Island and north Padre Island, vol. 2. Univ. Texas. Austin, Texas.

Nicholls, D. J., C. R. Tubbs and F. N. Haynes. 1981. The effect of green algal mats on intertidal communities and their predators. Kieler Meeresforsch. Sonderh. 5: 511-520.

Nicholls, J. L. and G. A. Baldassarre. 1990. Winter distribution of Piping plovers along the Atlantic and Gulf coasts of the United States. Wilson Bull. 102:400-412.

NOAA (Ocean and Lake Levels Division). 1994. Tidal characteristics and datums of Laguna Madre, Texas: Draft final report. Ocean and Lake Levels Division, Office of Ocean and Earth Sciences, Silver Spring, Maryland. 47 pp.

O'Conner, R. J. and R. A. Brown. 1977. Prey depletion and foraging strategy in the oystercatcher *Haematopus ostralegus*. Oecologia 27: 75-92.

Odum, E. P. and A. A. de la Cruz. 1967. Particulate organic detritus in a Georgia salt-marsh-estuarine ecosystem. Pages 383-388 *in* G. H. Lauff (ed.), Estuaries. Amer. Assoc. Adv. Sci. Publ. 83.

Odum, H. T. and C. M. Hoskins. Metabolism at a laboratory stream microcosm. Publ. Inst. Mar. Sci., Univ. Tex. 4 (2): 115-133.

Odum, H. T., W. McConnell, and W. Abbott. 1958. The chlorophyll "a" of communities. Publ. Inst. Mar. Sci., Univ. Tex. 5: 65-96.

Odum, H. T. and R. F. Wilson. 1962. Further studies on reaeration and metabolism of Texas bays, 1958-1960. Publ. Inst. Mar. Sci., Univ. Tex. 8: 23-55.

Odum, W. E. 1970. Insidious alteration of the estuarine environment. Trans. Am. Fish. Soc. 99: 836-847.

Onuf, C. P., M. L. Quammen, G. P. Shaffer, C. H. Peterson, J. W. Chapman, J. Cermak, and R. W. Holmes. 1980. An analysis of the values of central and southern California. I*n* National Symposium on wetlands. Amer. Water. Res. Assoc.

Oppenheimer, C. H. and M. Master. 1965. On the solution of quartz and precipitation of dolomite in seawater during photosynthesis and respiration. Zeit. Fur Allg. Mikrobiol. 5: 48-51.

Oppenheimer, C. H. and R. A. Ward. 1963. Release and capillary movement of phosphorus in exposed tidal sediments. Pages 664-673 *in* Oppenheimer, C. H. (ed.) Symposium on marine microbiology. Amer. Soc. Microbiology Meeting, 1961.

Page, D. S., E. S. Gilfillan, J. C. Foster, E. Pendergast, L. Gonzalez, and D. Vallas. 1985. Compositional changes in dispersed crude oil in the water column during a nearshore test spill. Pages 521-530 *in* Proc. 1985 Oil Spill Conf. Amer. Petrol. Inst. Publ. 4385. Washington, D.C.

Pamatmat, M. M. 1968. Ecology and metabolism of a benthic community on and intertidal sand flat. Int. Rev. Gesamten Hydrobiol. 53: 211-298.

Parker, P. L. and R. F. Leo. 1965. Fatty acids in blue-green algal mat communities. Science 145: 373-374.

Pearson, T. H. and R. Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanog. Mar. Biol. Ann. Rev. 16: 229-311.

Perkins, E. J. and O. J. Abbott. 1972. Nutrient enrichment and sandflat fauna. Mar. Poll. Bull. 3: 70-72.

Peterson, C. H. 1981. The ecological role of mud flats in estuarine systems. Pages 184-192 *in* Carey, R. C., P. S. Markovits, and J. B. Kirkwood (eds.), Proc. USFWS Work. Coastal Ecosystems of the Southeastern United States. USFWS Off. Biol. Serv. FWS/OBS-80/59.

Peterson, C. H. 1991. Intertidal zonation of marine invertebrates in sand and mud. Amer. Sci. 79: 237-249.

Peterson, C. H. and N. M. Peterson. 1979. The ecology of intertidal flats of North Carolina: a community profile. USFWS Off. Biol. Serv. FWS/OBS-79/39. 73 pages.

Pfeiffer, W. J. and R. G. Wiegert. 1981. Grazers on *Spartina* and their predators. Pp. 87-112 *in* Pomeroy, L. R. and R. G. Wiegert (eds.), The ecology of a saltmarsh. Springer-Verlag. New York.

Pienkowski, M. W. 1981. How foraging plovers cope with environmental effects on invertebrate behaviour and availability. Pages 179-192 *in* N. V. Jones and W. J. Wolff (eds.), Feeding and survival strategies of estuarine organisms. Plenum Press. New York, New York.

Pomeroy, L. R. 1959. Algal productivity in salt marshes of Georgia. Limnol. Oceanogr. 4: 386-397.

Prouty, J. S. and D. B. Prouty. 1989. Historical back barrier shoreline changes, Padre Island National Seashore, Texas. Trans. Gulf Coast Assoc. Geol. Soc. 39: 481-490.

Pulich, W., Jr., C. Blair, and W. A. White. 1997. Current status and historical trends of seagrasses in the Corpus Christi Bay National Estuary Region. CCBNEP-20. TNRCC. Austin, Texas. 131 pages.

Pulich, W., Jr. and S. Rabalais. 1982. Primary production and nutrient fluxes on south Texas tidal flats. Rept. to USFWS, Off. Environ. Reg. 2, Albuquerque, New Mexico. 30 pages.

Pulich, W. Jr. and S. Rabalais. 1986. Primary production potential of blue-green algal mats on southern Texas tidal flats. Southwest Nat. 31: 39-47.

Pulich, W. Jr., S. Rabalais, and S. Wellso. 1982. Food chain components on Laguna Madre tidal flats. UTMSI Contrib. No. 572. Port Aransas, Texas. 20 pages.

Pulich, W. M., Jr. and R. S. Scanlan. 1987. Organic carbon and nitrogen flow from marine cyanobacteria to semiaquatic insect food webs. Contrib. Mar. Sci. 30: 27-37.

Pulich, W. M. and W. A. White. 1991. Decline of submerged vegetation in the Galveston Bay System: chronology and relationships to physical processes. J. Coast. Res. 7: 1125-1138.

Purdy, E. G. 1963. Recent calcium carbonate facies of the Great Bahama bank. J. Geol. 71: 472-497.

Pyle, D. 1991. Map of Blind Oso, Oso Bay. Prepared for City of Corpus Christi Engineering Services.

Quammen, M. L. 1984. Predation by shorebirds, fish, and crabs on invertebrates in intertidal: an experimental test. Ecology 65: 529-537.

Raffielli, D. and S. Hawkins. 1996. Intertidal ecology. Chapman and Hall. London, U.K. 355 pages.

Raffielli, D., S. Hull, and H. Milne. 1989. Long-term changes in nutrients, weed mats and shorebirds in an estuarine system. Cah. Biol. Mar. 30: 259-270.

Raffielli, D. and C. F. Mason. 1981. Pollution monitoring with meiofauna using the ratio of nematodes to copepods. Mar. poll. Bull. 12: 158-163.

Ramsey, K. E. and S. Penland. 1989. Sea-level rise and subsidence in Louisiana and the Gulf of Mexico. Trans. Gulf Coast Assoc. Geol. Soc. 39: 499-500.

Rathbun, M. J. 1918. The grapsid crabs of America. U.S. Natl. Mus. Bull. 97. 461 pages.

Reichert, A. and Dörjes, J. 1980. Die bodenfauna des Crildumersiel wattes (Jade, Nordsee) und ihre veränderung nach dem eiswinter 1978/79. Senckenbergiana marit. 12: 213-245. (English abstract).

Reise, K. 1984a. Experimental sediment disturbances of a tidal flat: responses of free-living Platyhelminthes and small Polychaeta. Hydrobiologia 118: 73-81.

Reise, K. 1984b. Indirect effects of sewage on a sandy tidal flat in the Wadden Sea. Pages 159-165 *in* Laane, R. W. P. M. and W. J. Wolff (eds.) The role of organic matter in the Wadden Sea. Neth. Inst. Sea Res. Publ. Ser. 10.

Ricklis, R. A. 1995. Environmental and human adaptive change on the Nueces Bay shoreline: phase I archaeological data recovery at Koch Refining Company Middle Plant, Nueces County, Texas. Coastal Archaeological Research Inc. Corpus Christi, Texas. 190 pages.

Ricklis, R. A. and M. D. Blum. 1997. The geoarchaelogical record of Holocene sea level change and human occupation of the Texas Gulf Coast. Geoarchaeology 12: 287-314.

Roper, D. S., S. F. Thrush, and D. G. Smith. 1988. The influence of runoff on intertidal mudflat benthic communities. Mar. Environ. Res. 26: 1-18.

Rowland, S. J., P. J. C. Tibbetts, D. Little, J. M. Baker, and T. P. Abbiss. 1981. The fate and effects of dispersant-treated compared untreated crude oil, with particular reference to sheltered intertidal sediments. Pages 283-293 *in* Proc. 1981 Oil Spill Conf. Amer. Petrol. Inst. Publ. 4334. Washington, D.C.

Rusnak, G. A. 1960. Sediments of Laguna Madre, Texas. Pages 153-196 *in* Shepard, F. P., F. B. Phelger, and T. J. van Andel (eds.), Recent sediments, northwestern Gulf of Mexico. Amer. Assoc. Petrol. Geol. Tulsa, Oklahoma. 394 pages.

Salinas, L. M., R. D. DeLaune, and W. H. Patrick, Jr. 1986. Changes occurring along a rapidly submerging coastal area: Louisiana, USA. J. Coast. Res. 2: 269-284.

Savidge, W. B. and G. L. Taghon. 1988. Passive and active components of colonization following two types of distrubance on intertidal sandflat. J. Exp. Mar. Biol. Ecol. 115: 137-155.

Schneider, D. 1973. Equalization of prey numbers by migratory shorebirds. Nature 271: 353-354.

Schneider, D. C. and B. A. Harrington. 1981. Timing of shorebird migration in relation to prey depletion. Auk 98: 801-811.

Sellner, K. G., and R. G. Zingmark. 1976. Interpretations of the ^{14}C method of measuring the total annual production of phytoplankton in a South Carolina estuary. Bot. Mar. 19: 119-125.

Senner, S. E. and M. A. Howe. 1984. Conservation of nearctic shorebirds. Pages 370-415 *in* Burger, J. and B. L. Olla (eds.), Shorebirds: breeding behaviour and population. Plenum Press. New York, New York.

Settles and Claunch, S.P.I. 1967. Report on survey, 34,907.69 acres on Padre Island, Willacy & Kenedy Counties, Texas. Surveyed for South Padre Island Investment Corp., Settles and Claunch, Brownsville, Texas. Private survey files of Mr. Tom Stovall, Weslaco, Texas. 98 pages.

Shine, D. D. 1995. Map titled "Survey of east boundaries of Big and Little Barreta Grants along the western margin of Laguna Madre, Kenedy County Texas". Surveyed March-April 1993 acompanying report dated August 18, 1995 certification by D. D. Shine dated September 14,1995. Recorded in Vol. 1, page 21, Plat Records of Kenedy County, Texas.

Siefert, W. 1990. Sea-level changes and tidal flat characteristics. Pages 105-112 *in* Beukema, J. J., W. J. Wolff, and J. J. W. M. Brouns (eds.) Expected effects of climatic change on marine coastal ecosystems. Kluwer Academic Publ. Dordrecht, Netherlands.

Simmons, E. G. 1957. A ecological survey of the upper Laguna Madre of Texas. Publ. Inst. Mar. Sci., Univ. Tex. 3: 156-200.

Skerman, V. D., V. McGowan and P. A. Sneath (eds.). 1989. Approved lists of bacterial names. American Soc. Micro. Washington, D.C. 188 pages.

Smith, E. H., T. R. Calnan, and S. A. Cox. 1997. Potential sites for wetland restoration, enhancement, and creation: Corpus Christi/Nueces Bay area. CCBNEP-15. TNRCC. Austin, Texas.

Smith, N. P. 1978. Intracoastal tides of upper Laguna Madre, Texas. Tex. J. Sci. 30: 85-95.

Smith, R. L. 1980. Ecology and field biology. Harper and Row. New York, New York. 835 pages.

Sollins, P. 1969. Measurement and simulation of oxygen flows and storages in a laboratory blue-green algal mat ecosystem. M.A. Thesis, Univ. North Carolina. Chapel Hill, North Carolina.

Sorenson, L. O. and J. T. Conover. 1962. Algal mat communities of *Lyngbya confervoides* (C. Agardh.) Gioment. Publ. Inst. Mar. Sci., Univ. Tex. 8: 61-74.

Soulsby, P. G., D. Lowthion, and M. Houston. 1982. Effects of macroalgal mats on the ecology of intertidal mudflats. Mar. Poll. Bull. 13(5): 162-166.

Soulsby, P. G., D. Lowthion, M. Houston, and H. A. C. Montgomery. 1985. The role of sewage effluent in the accumulation macroalgal mats on intertidal mudflats in two basins in southern England. Neth. J. Sea Res. 19: 257-263.

State v. Spohn. 1904. 83 South Western Reporter 1135 (Texas Civil Appeals).

Sun Oil Company. 1949. Maps offered as exhibit in Humble Oil and Refining Co. et al. v. Sun Oil Company.

Thistle, D. 1981. Natural physical disturbances and communities of marine soft bottoms. Mar. Ecol. Prog. Ser. 6: 223-228.

Thrush, S. F., R. D. Pridmore, J. E. Hewitt, and V. J. Cummings. 1991. Impact of ray feeding disturbances on sandflat macrobenthos: do communities dominated by polychaetes or shellfish respond differently? Mar. Ecol. Prog. Ser. 69: 245-252.

Titus, J. G. 1990. Greenhouse effect, sea level rise, and barrier islands: case study of Long Beach island, New Jersey. Coast. Manage. 18: 65-90.

Tunnell, J. W., Jr. 1989. Wind-tidal flats and wind tides of the south Texas coast. In-house report, Coastal Zone Consultants. Corpus Christi, Texas. 6 pages.

Uebelacker, J. M. and P. G. Johnson, (eds.). 1984. Taxonomic guide to the polychaetes of the northern Gulf of Mexico. MMS 14-12-001-29091. Barry A. Vittor & Associates, Inc. Mobile, Alabama. 7 vols.

van den Hoek, C. 1976. Algologisch onderzoek. Pages 29-50 *in* Voordrachten gehouden tijdens de informatiedag Biologisch Onderzoek Veenkoloniaal Afvalwater. Intern Verslag biologisch Onderzoek Veenkoloniaal Afvalwater 1976-1.

Van Es, F. B., M. A. Van Arkel, L. A. Bouwman, and H. G. J. Schröder. 1980. Influence of organic pollution on bacterial, macrobenthic and meiobenthic populations in intertidal flats of the Dollard. Neth. J. Sea Res. 14: 288-304.

Van Impe, J. 1985. Estuarine pollution as a probable cause of increase of estuarine birds. Mar. Poll. Bull. 16: 271-276.

Van Raalte, C. D., I. Valiela, E. J. Carpenter, and J. M. Teal. 1974. Inhibition of nitrogen fixation in salt marshes measured by acetylene reduction. Est. Coast. Mar. Sci. 2: 301-305.

van Walsum, E. 1987. Developing the Fundy tidal power resource. Pages 378-383 *in* Proc. Oceans 87. Halifax, Nova Scotia, Canada.

Varon, R. and D. Thistle. 1988. Response of a harpacticoid copepod to a small-scale natural disturbance. J. Exp. Mar. Biol. Ecol. 118: 245-256.

Volkmann, C. M. and C. H. Oppenheimer. 1962. The microbial decomposition of organic carbon in surface sediments of marine bays of the central Texas Gulf Coast. Publ. Inst. Mar. Sci., Univ. Tex. 8: 80-96.

von Blucher, F. 1861. El Peñascol Grant, Kenedy County, map and field notes of confirmation. Survey recorded in Vol. 1, Pages 180-181, Surveyor's Records of Kenedy County, and archives of TGLO.

von Blucher, F. 1869. Los Mirasoles Grant, Kenedy County, map and field notes of confirmation. Survey recorded in Vol. 1, Pages 227-229, Surveyor's Records of Kenedy County, and archives of TGLO. Patent from State to Villarreal, Vol. "A", Pages 336-337, Kenedy County Deed Records.

Warshaw, S. 1975. Water quality segment report for segment No. 2491 Laguna Madre. Texas Water Quality Board Rept No. WQS-14. 38 pages.

Warwick, R. B. 1981. The nematode/copepod ratio and its use in pollution ecology. mar. Poll. Bull. 12: 329-333.

Watson, R. L., J. W. Tunnell, Jr., W. N. Lothrop, and S. H. Ratliff. 1990. Shoreline determination along gently sloping shore: a multi-disciplinary approach. Pages 755-764 *in* W. M. Wise, (ed.), Proc. 12th Intl. Coastal Soc. Conf. San Antonio, Texas.

Weise, B. R., and W. A. White. 1980. Padre Island National Seashore: a guide to the geology, natural environments, and history of a Texas barrier island. Guidebook 17. Bur. Econ. Geol., Univ. Texas. Austin, Texas. 94 pages, 1 map.

Welsh, B. L. 1980. Comparative nutrient dynamics of a marsh-mudflat ecosystem. Est. Coast. Mar. Sci. 10: 143-164.

Weston, F. M. and E. A. Williams. 1965. Recent records of the Eskimo curlew. Auk. 82:493-496.

Wetzel, R. G. and D. F. Westlake. 1969. Periphyton. Pages 33-40 *in* Vollenweider, R. A. (ed.), A manual on methods for measuring primary production in aquatic environments. IBP Handbook 12. Blackwell Sci. Publ. Oxford, England.

Wheeler, N. 1978. Effects of off-road vehicles on the infauna of Hatches Harbor, Cape Cod National Seashore. The Environmental Institute, Univ. Mass./NPS Coop. Res. Unit UM/NPSCRU Rept. 28. Amhearst, Massachusetts.

White, W. A. In Preparation. Status and trends of wetlands in the CCBNEP study area. CCBNEP characterization report. Corpus Christi, Texas.

White, W. A. and W. B. Brogden. 1977. Descriptions of land and water resources. Appendix A *in* Kier, R. S. and E. G. Fruh (eds.) Environmental and economic impacts of recreational community development, Mustang Island and north Padre Island, vol. 1. Univ. Texas. Austin, Texas

White, W. A., T. R. Calnan, R. A. Morton, R. S. Kimble, T. G. Littleton, J. H. McGowen, H. S. Nance, and K. E. Schmedes. 1983. Submerged lands of Texas, Corpus Christi area: sediments, geochemistry, benthic macroinvertebrates, and associated wetlands. Bur. Econ. Geol., Univ. Tex. Austin, Texas. 154 pages, 6 maps.

White, W. A., T. R. Calnan, R. A. Morton, R. S. Kimble, T. G. Littleton, J. H. McGowen, H. S. Nance. 1989. Submerged lands of Texas, Kingsville area: sediments, geochemistry, benthic macroinvertebrates, and associated wetlands. Bur. Econ. Geol., Univ. Tex. Austin, Texas. 137 pages, 6 maps.

White, W. A., R. A. Morton, R. S. Kerr, W. D. Kuenzi, and W. B. Brogden. 1978. Land and water resources, historical changes, and dune criticality: Mustang and north Padre islands, Texas. Bur. Econ. Geol, Univ. Tex. Rept. of Invest. No. 92. Austin, Texas. 46 pages.

White, W. A. and W. E. Galloway. 1977. Guide to modern barrier environments of Mustang and north Padre islands and Jackson (Eocene) barrier/lagoon facies of south Texas Uranium District. Bur. Econ. Geol., Univ. Tex. Res. Note 7. Austin, Texas. 51 pages.

Whitlach, R. B. 1982. The ecology of New England tidal flats: a community profile. USFWS Biol. Serv. Prog. FWS/OBS-81/01. 125 pages.

Wilson, W. H., Jr. 1990. Relationship between prey abundance and foraging site selection by Semipalmated Sandpipers on a Bay of Fundy mudflat. J. Field Ornith. 61: 9-19.

Withers, K. 1994. The relationship of macrobenthic prey availability to shorebird use of blue-green algal flats in the upper Laguna Madre. Ph.D. Dissertation, Texas A&M Univ. College Station, Texas. 117 pages.

Withers, K. 1996. An evaluation of recovery of benthic invertebrate communities in vehicle tracks and restored oil and gas impacted areas on wind-tidal flats in the upper Lagna Madre, Padre Island National Seashore, Texas. Rept. to Padre Island National Seashore, Contract No. 1443PX749050162. Corpus Christi, Texas. 12 pages.

Withers, K. and B. R. Chapman. 1993. Seasonal abundance and habitat use of shorebirds on an Oso Bay mudflat, Corpus Christi, Texas. J. Field Ornithol. 64: 382-392.

Wolff, W. J. 1969. Distribution of non-breeding waders in an estuarine area in relation to the distribution of their food organisms. Ardea 57: 1-28.

Yeo, R. K. and M. J. Risk. 1979. Intertidal catastrophes: effect of storms and hurricanes on intertidal benthos of the Minas Basin, Bay of Fundy. J. Fish. Res. Board Can. 36: 667-669.

Zupan, A. W. 1971. Surficial sediments and sedimentary structures: Middleground, Padre Island, Texas. Texas A&M Univ. Dept. Oceanogr. Rept. 71-12-T. College Station, Texas 71 pp.

APPENDIX 1

Appendix 1. Macroinvertebrate species found on the blue-green algal flats on Padre and Mustang Islands and on mudflats in Oso Bay; presence is denoted by "X". Padre Island - I = Withers (1994), II = the present study; Mustang Island - CC = Corpus Christ Pass, Withers (1994), New = Newport Pass, the present study, Fish = Fish Pass, the present study; Oso Bay - I = Blind Oso, Barrera (unpubl.), II = Blind Oso, the present study.

	Padre Island		Mustang Island			Oso Bay	
Taxa	I	II	CC	New	Fish	I	II
P. Rhynchocoela	X			X	X	X	X
P. Nematoda						X	
P. Platyhelminthes							
C. Turbellaria			X		X		X
P. Annelida							
C. Oligochaeta					X	X	X
C. Polychaeta							
F. Phyllodocidae							
Eteone heteropoda	X	X	X	X	X	X	X
F. Glyceridae							
Glycera americana						X	
F. Spionidae							
Dispio uncinata						X	
Paraprionospio pinnata						X	
Polydora sp.	X	X		X	X		X
Polydora ligni	X	X	X		X	X	X
Prionospio heterobranchia	X		X	X	X		X
Prionospio cirrifera	X						
Prionospio (Minuspio) sp.						X	X
Spio setosa			X				
Streblospio benedicti			X	X		X	X
Scolelepsis squamata			X				
F. Capitellidae							
Capitella capitata	X		X	X	X	X	X
Capitomastus aciculatus	X		X				
Mediomastus californiensis						X	
Notomastus hemipodus			X				
F. Maldanidae							
Asychis elongatus			X				
Clymenella mucosa	X		X				
Clymenella torquata	X						
F. Arenicolidae							
Arenicola cristata	X		X			X	

Appendix 1. Continued.

Taxa	Padre Island I	Padre Island II	Mustang Island CC	Mustang Island New	Mustang Island Fish	Oso Bay I	Oso Bay II
F. Sabellidae							
Sabella micropthalma	X		X	X	X		
Sabella sp. A	X		X	X			
Hypsicomus sp.				X			
Chone duneri	X		X				
Sabellastarte sp.			X				
F. Ampharetidae							
Melinna maculata			X	X			
F. Lumbrineridae							
Lumbrineris tenuis			X				
F. Eunicidae							
Marphysa sanguinea			X	X			X
F. Orbiniidae							
Haploscoloplos foliosus	X	X	X	X	X		X
Naineris laevigata	X		X				X
F. Dorvilleidae							
Dorvillea rubra	X		X				
F. Terebellidae							
Neoleprea sp. A			X				
F. Paranoidae							
Aricidea taylori			X				
Aricidea fragilis			X				
F. Nereidae							
Laeonereis culveri			X		X	X	X
Neanthes succinea						X	
Platynereis dumerilii						X	
Steininonereis sp.							X
P. Mollusca							
C. Gastropoda							
F. Bullidae							
Bulla striata	X		X	X			
F. Acteocinidae							
Acteon punctostriatus	X						
F. Cerithidae							
Cerithium lutosum			X				
C. Bivalvia							
F. Solenidae							
Ensis minor			X			X	

Appendix 1. Continued.

Taxa	Padre Island		Mustang Island			Oso Bay	
	I	II	CC	New	Fish	I	II
F. Solecurtidae							
Tagelus plebius						X	
F. Mactridae							
Mulinia lateralis	X		X			X	X
F. Tellinidae							
Tellina tampaensis	X		X		X		
F. Veneridae							
Chione cancellata						X	
Anomalocardia auberiana	X		X	X			X
F. Mytilidae							
Amygdalum papyria	X		X				
F. Lyonsiidae							
Lyonsia hyalina							
F. Corbiculidae							
Polymesoda maritima	X		X				
F. Cardiidae							
Laevicardium mortoni			X				
SP. Crustacea							
C. Malacostraca							
O. Ostracoda						X	X
O. Copepoda						X	X
O. Cumacea							
F. Diastylidae							
Oxyurostylis smithi	X		X				
O. Isopoda							
F. Cymothoidae							
Aegothoa oculata						X	
F. Idoteidae							
Edotea montosa						X	
F. Sphaeromatidae							
Ancinus depressus						X	
Dynamenella perforata						X	
Sphaeroma quadridentatum	X	X					
Sphaeroma walkeri						X	
O. Amphipoda							
F. Aoridae							
Grandidierella bonnieroides						X	
F. Ampeliscidae							
Ampelisca sp.						X	

Appendix 1. Continued.

Taxa	Padre Island I	Padre Island II	Mustang Island CC	Mustang Island New	Mustang Island Fish	Oso Bay I	Oso Bay II
F. Atylidae							
Atylus sp.						X	
F. Amphitoidae							
Cymadusa compta					X		
F. Corophiidae							
Corophium acherusicum	X	X	X	X	X	X	
Corophium louisianum	X		X	X	X	X	X
Corophium tubularis						X	
F. Hyalellidae							
Hyale frequens						X	
Hyalella azteca						X	
F. Melittidae							
Melita sp.	X					X	
Melita dentata						X	
F. Pleustidae							
Stenopleustes gracilis						X	
F. Gammaridae							
Gammarus sp.	X						
Gammarus mucronatus						X	
F. Taltridae							
Orchestia grillus						X	
Orchestia platensis			X				
O. Tanaidacea							
F. Paratanaidae							
Hargeria rapax	X		X	X			X
SP. Insecta							
O. Diptera							
F. Canaceidae	X	X	X	X	X		X
F. Ceratopogonidae	X	X	X	X	X		
F. Chironomidae			X			X	
F. Dixidae						X	
F. Simulidae			X				
F. Empididae	X						
F. Ephydridae						X	
F. Dolichopodidae	X	X	X	X	X	X	X
O. Coleoptera							
F. Carabidae			X	X	X		
F. Curculionidae	X						

Appendix 1. Continued.

Taxa	Padre Island I	Padre Island II	Mustang Island CC	Mustang Island New	Mustang Island Fish	Oso Bay I	Oso Bay II
F. Dysticidae							
Laccophilus sp.	X						
F. Hydrophilidae			X				
Hydrocharus sp.	X						
F. Melyridae	X						
F. Salpingidae	X		X				
F. Staphylinidae		X		X		X	
Bledius sp.	X		X				
Bryothinusa sp.	X		X				
Stenus sp.	X		X				
O. Collembola							
F. Entomybryidae							
Seira sp.	X		X				
F. Cyphoderidae							
Cyphoderus sp.	X						
O. Hemiptera							
F. Corixidae							
Hesperocorixa sp.						X	
F. Saldidae							
Pentacora sp.	X		X		X		
F. Nabidae	X						
F. Hebridae							
Lipogomphus sp.			X				
O. Hymenoptera							
F. Eulophidae			X				
F. Scelionidae	X						
F. Pteromalidae	X		X				
O. Odonata							
F. Aeshnidae							
Gomphaeschna sp.			X				
O. Plecoptera							
F. Leuctridae							
Leuctra sp.	X						
SP. Chelicerata	X		X				
Total Number of Taxa	51	11	65	22	21	27	24

Table of Contents

APPENDIX 2

SPECIES CHECKLIST

The following species checklist encompasses a taxonomic listing of all species reported from wind-tidal flats within the Corpus Christi Bay National Estuary Program (CCBNEP) study area. The tidal flats species list consists of references from the CCBNEP species checklist (Tunnell, 1996) combined with references found through database searches to create a checklist specifically for wind-tidal flats in the CCBNEP study area. References of species listed in the CCBNEP checklist as occurring on flats were found and included if specific mention was made of the species occurring on tidal flats within the study area.

The tidal flats checklist consists of taxonomic listings in phylogenetic order, of all reported species inhabiting wind tidal flats within the CCBNEP study area, as well distribution within the study area, relative abundance and references. Phylogenetic order, classification scheme and acronyms used for bay system and relative abundance follow that used in the CCBNEP checklist. Relative abundance was included as reported by the author of the reference cited. If no indication was given, then the abundance was reported as unknown.

The checklist is separated into two sections. The first section consists of all species, except birds, reported from wind tidal flats and includes a preface stating phylogenetic order and classification scheme utilized, acronyms for bay system and relative abundance and comments. The second section includes bird species reported on wind-tidal flats and includes a similar preface. Authorities and dates of description are included for most species, except for algae and birds, for which dates are not typically used. Scientific names are used throughout, except for birds which include common names as well.

Tidal Flats Species Checklist-Section I

Phylogenetic order / classification follows:

Bacteria:	Skerman et al. (1989)	Mollusca:	Vaught (1989) and Abbott (1974)
Cyanophyta:	Humm and Wicks (1980)	Decapoda:	Williams (1984)
Bacillariophyta:	Round et al. (1990)	Amphipoda:	Barnard (1969)
Spermatophyta:	Hatch et al. (1990)	Isopoda:	Schultz (1969)
Platyhelminthes:	Hyman (1951)	Insecta:	Merrit and Cummins (1985), Ortiz (1976)
Annelida:	Fauchald (1977)		

Bay system acronyms:

ACB	Aransas-Copano Bay	NCCB	Nueces-Corpus Christi Bay
BBLM	Baffin Bay-Laguna Madre	OB	Oso Bay
MAI	Matagorda Island	+	missing information
MI	Mustang Island		

Relative abundance acronyms:

A	abundant	R	rare
C	common	#	missing information
U	uncommon		

Comments: When older literature uses a binomen which is no longer valid or in use, the current binomen is listed alongside a synonym designated by an "=" and enclosed within parentheses.

Species	Reference	System (Abundance)
KINGDOM MONERA		
DOMAIN BACTERIA		
Order Beggiatoales		
BEGGIATOACEAE		
Beggiatoa spp.	Sorenson and Conover (1962)	MI(#), BBLM(#)
	Armstrong and Odum (1964)	BB(#)
CHROMATIACEAE		
Desulfovibrio spp.	Armstrong and Odum (1964)	BB(#)
DIVISION CYANOPHTYA		
Class Cyanophyceae		
Order Chroococcales		
CHROOCOCCALES		
Chroococcus spp	Brogden et al. (1977)	BBLM(#),MI(#)
Order Oscillatoriales		
OSCILLATORIACEAE		
Lyngbya sp.	Fisk (1959)	BBLM(#)
	Birke (1974)	BB(#)
	Pulich et al. (1982)	BBLM(A)
	Pulich and Rabalais (1986)	BBLM(A)
	Withers (1994)	BBLM(A)
	Gotto et al. (1981)	ACB(A)
Microcoleus sp.	Fisk (1959)	BBLM(#)
	Armstrong and Odum(1964)	BBLM(#)
	Pulich et al. (1982)	BBLM(C)
	Pulich and Rabalais (1986)	BBLM(C)

Species	Reference	System (Abundance)
Lyngbya confervoides (=*Microcoleus*	Zupan (1970)	BBLM(A)
lyngbyaceus)	Herber (1981)	BBLM(A)
	Sorenson and Conover (1962)	MI(A),BBLM(A)
Oscillatoria spp.	Sorenson and Conover (1962)	MI(#),BBLM(#)
	Armstrong and Odum(1964)	BBLM(#)
	Pulich and Rabalais (1986)	BBLM(C)
Microcoleus chthonoplastes (=*Schizothrix*	Herber (1981)	BBLM(A)
arenaria)	Fisk (1959)	BBLM(A)
Schizothrix calcicola	Zupan (1970)	BBLM(A)
Schizothrix sp.	Sorenson and Conover (1962)	MI(#),BBLM(#)
	Armstrong and Odum(1964)	BBLM(#)
	Pulich et al. (1982)	BBLM(C)
KINGDOM PLANTAE		
DIVISION BACILLARIOPHYTA		
Class Bacillariophyceae		
Subclass Bacillariophycidae		
Order Naviculales		
Suborder Naviculineae		
NAVICULACEAE		
Navicula punctigera	Brogden et al. (1977)	BBLM(#),MI(#)
Navicula sp.	Simmons (1957)	BBLM(#)
	Hildebrand and King (1974)	OB(#)
	Pulich and Rabalais (1986)	BBLM(C)
	Withers (1994)	BBLM(U)
PLEUROSIGMATACEAE		
Pleurosigma angulatum (Queckett) W. Smith	Simmons (1957)	BBLM(#)
Gyrosigma balticum (Ehrenberg) Rabh.	Simmons (1957)	BBLM(#)
Pleurosigma sp.	Hildebrand and King (1974)	OB(#)
	Pulich and Rabalais (1986)	BBLM(C)
Order Bacillariales		
BACILLARIACEAE		
Nitzchia seriata Cleve	Simmons (1957)	BBLM(#)
Nitzchia longissima (Brebisson) Ralfs	Simmons (1957)	BBLM(C)
Nitzchia closterium (Ehrenberg) W. Smith	Simmons (1957)	BBLM(C)
Nitzchia sp.	Pulich and Rabalais (1986)	BBLM(C)
DIVISION CHLOROPHYTA		
Class Chlorophyceae		
Order Dasycladales		
DASYCLADACEAE		
Acetabularia sp.	Fisk (1959)	BBLM(#)
	Zupan (1970)	BBLM(U)
DIVISION SPERMATOPHYTA		
Subdivision Angiospermae		
Class Monocotyledoneae		
POACEAE		
Chloris petraea Swartz. (not in Hatch et al. 1990)	Carls et al. (1991)	BBLM(#)
Eragrostis secundiflora Presl. ssp. *oxylepis* (Torr.) S.D. Koch [E. oxylepis (Torr.) Torr.]	Carls et al. (1976)	BBLM(#)

Species	Reference	System (Abundance)
Monanthochloe littoralis Engelm.	Warshaw (1975)	BBLM(#)
	Pulich and Scalan (1987)	BBLM(#)
	Carls et al. (1990)	BBLM(C)
	Carls et al. (1991)	BBLM(#)
Panicum sp.	Pulich and Scalan (1987)	BBLM(#)
Paspalum monostachyium Vasey	Pulich and Scalan (1987)	BBLM(#)
Schizachyrium scoparius (Michx.) Nash [*Andropogon scoparium* (Michx.]	Pulich and Scalan (1987)	BBLM(#)
Spartina patens (Ait.) Muhl.	Pulich and Scalan (1987)	BBLM(#)
Sporobolus pyramidatus (Lam.) Hitchc.	Carls et al. (1976)	BBLM(#)
Sporobolus virginicus (L.) Kunth.	Drawe et al. (1981)	BBLM(C)
	Pulich and Scalan (1987)	BBLM(#)
CYPERACEAE		
Eleocharis sp.	Pulich and Scalan (1987)	BBLM(#)
Fimbristylis caroliniana (Lam.) Fern.	Pulich and Scalan (1987)	BBLM(#)
Class Dicotyledoneae		
AMARANTHACEAE		
Bluetaparon vermicularis (L.) Mears [*Philoxerus vermicularis* (L.) R. Br. ex J.E. Smith]	Carls et al. (1991)	BBLM(#)
BATIDACEAE		
Batis maritima L.	Pulich and Scalan (1987)	BBLM(#)
	Carls et al. (1991)	BBLM(#)
CHENOPODIACEAE		
Salicornia biglovii (Torr.)	Brogden et al. (1977)	BBLM(C),MI(C)
	Jones (1982)	+(C)
	Pulich and Scalan (1987)	BBLM(#)
	Carls et al. (1990)	BBLM(C)
	Carls et al. (1991)	BBLM(#)
Salicornia virginica L.	Brogden et al. (1977)	BBLM(C),MI(C)
	Jones (1982)	+(A)
	Pulich and Scalan (1987)	BBLM(#)
	Carls et al. (1990)	BBLM(C)
	Carls et al. (1991)	BBLM(#)
Salicornia sp.	Warshaw (1975)	BBLM(#)
Suaeda conferta (Small) I.M. Johnst.	Jones (1982)	+(A)
Suaeda linearis (Ell.) Moq.	Jones (1982)	+(C)
	Pulich and Scalan (1987)	BBLM(#)
AIZOACEAE		
Sesuvium erectum Correll	Jones (1982)	+(A)
Sesuvium trianthemoides Correll	Pulich and Scalan (1987)	BBLM(#)
EUPHORBIACEAE		
Euphorbia serpens Kunth in H.B.K. [*Chamaesyce serpens* (Kunth in H.B.K.) Small]	Carls et al. (1991)	BBLM(#)
ONAGRACEAE		
Calylophus serrulatus (Nutt.) Raven [*C. australis* Tower & Raven, *Oenothera lavandulifolia* T.&G. var. *glandulosa* Munz.]	Carls et al. (1991)	BBLM(#)
PLUMBAGINACEAE		
Limonium nashii Shinner	Pulich and Scalan (1987)	BBLM(#)

Species	Reference	System (Abundance)
BORAGINACEAE		
Heliotropium curassavicum L.	Pulich and Scalan (1987)	BBLM(#)
	McAlister & McAlister (1993)	MAI(C)
SCROPHULARIACEAE		
Agalinis maritima Raf. var. *grandiflora* (Benth.) Shinners [*Gerardia maritima* Raf. var. *grandiflora* (Benth.)]	Carls et al. (1991)	BBLM(#)
Bacopa monnieri (L.) Wettst.	Pulich and Scalan (1987)	BBLM(#)
ASTERACEAE		
Borrichia frutescens	Pulich and Scalan (1987)	BBLM(#)
Flaveria brownii Power [*F. oppositifolia* of Texas authors, not (DC.) Rydb.]	Pulich and Scalan (1987)	BBLM(#)
Haplopappus phyllocephalus DC.	Carls et al. (1991)	BBLM(#)
[*Machaeranthera phyllocephalus* (DC.)	Pulich and Scalan (1987)	BBLM(#)
Shinners]	Carls et al. (1990)	BBLM(C)
KINGDOM ANIMALIA		
PHYLUM PLATYHELMINTHES		
Class Turbellaria	Withers (1994)	MI(#)
	Withers (1996)	BBLM(R)
PHYLUM NEMERTEA		
Rhyncocoela sp.	Withers (1994)	BBLM(#)
	Withers (1996)	BBLM(R)
	Barrera (unpubl. data)	OB(#)
PHYLUM NEMATODA	Barrera (unpubl. data)	OB(#)
PHYLUM ANNELIDA		
Class Oligochaeta	Barrera (unpubl. data)	OB(#)
Class Polychaeta		
Order Orbiniida		
ORBINIIDAE		
Leitoscoloplos (=*Haploscoloplos*) *foliosus*	Withers (1994)	BBLM(#),MI(#)
Hartman, 1951	Withers (1996)	BBLM(R-U)
Naineris laevigata (Grube, 1855)	Withers (1994)	BBLM(#),MI(#)
	Withers (1996)	BBLM(R)
PARAONIDAE		
Aricidea fragilis Webster, 1879	Withers (1994)	MI(#)
Aricidea taylori Pettibone, 1965	Withers (1994)	MI(#)
Order Spionida		
SPIONIDAE		
Dispio uncinata Hartman, 1951	Barrera (unpubl. data)	OB(#)
Polydora cornuta (=*P. ligni*) Bosc, 1802	Withers (1994)	BBLM(#),MI(#)
	Barrera (unpubl. data)	OB(#)
Polydora spp.	Withers (1996)	BBLM(R)
Prionospio heterobranchia Moore, 1907	Withers (1994)	BBLM(#),MI(#)
	Withers (1996)	BBLM(R)
Prionospio (=*Minuspio*) *cirrifera* Wirén, 1883	Withers (1994)	BBLM(#)
Prionospio (=*Minuspio*) sp.	Barrera (unpubl. data)	OB(#)
Paraprionospio (=*Prionospio treadwelli*)	Withers (1996)	BBLM(R)
Pinnata (Ehlers, 1901)	Barrera (unpubl. data)	OB(#)
Scolelepis squamata (O.F. Müller, 1806)	Withers (1994)	MI(#)
Spio setosa Verrilli, 1873	Withers (1994)	MI(#)

Species	Reference	System (Abundance)
Spio pettibonniae Foster, 1971	Withers (1996)	BBLM(R)
Streblospio benedicti Webster, 1879	Withers (1994)	MI(#)
	Withers (1996)	BBLM(R)
	Barrera (unpubl. data)	OB(#)
Order Capitellida		
CAPITELLIDAE	Withers (1996)	BBLM(R)
Capitella capitata (Fabricius, 1790)	Withers (1994)	BBLM(#),MI(#)
	Barrera (unpubl. data)	OB(#)
Capitomastus aciculatus Hartman, 1959	Withers (1994)	BBLM(#),MI(#)
Mediomastus californiensis Harman, 1944	Barrera (unpubl. data)	OB(#)
Notomastus hemipodus Hartman, 1945	Withers (1994)	MI(#)
ARENICOLIDAE		
Arenicola cristata Stimpson, 1865	Zupan (1970)	BBLM(#)
	Withers (1994)	BBLM(#),MI(#)
	Barrera (unpubl. data)	OB(#)
MALDANIDAE	Withers (1996)	BBLM(R)
Asychis elongatus (Verrilli, 1873)	Withers (1994)	MI(#)
Axiothella (=*Clymenella*) *mucosa* (Andrews, 1891)	Withers (1994)	BBLM(#),MI(#)
Clymenella torquata calida Hartman, 1951	Withers (1994)	BBLM(U)
Order Phyllodicida		
PHYLLODOCIDAE		
Hypeteteone (=*Eteone*) *heteropoda*	Withers (1994)	BBLM(#),MI(#)
(Hartman, 1951)	Withers (1996)	BBLM(R)
	Barrera (unpubl. data)	OB(#)
SYLLIDAE		
Exogone atlantica	Barrera (unpubl. data)	OB(#)
Exogone dispar (Webster, 1879)	Withers (1994)	BBLM(#),MI(#)
	Withers (1996)	BBLM(R)
Syllis (=*Ehlersia*) *cornuta* Rathke, 1843	Withers (1994)	BBLM(#),MI(#)
	Withers (1996)	BBLM(R)
NEREIDAE		
Laeonereis culveri (Webster, 1880)	Brogden et al. (1977)	BBLM(#),MI(#)
	Withers (1994)	MI(#)
	Barrera (unpubl. data)	OB(#)
Neanthes (=*Nereis*) *succinea* (Frey & Leuckart, 1847)	Barrera (unpubl. data)	OB(#)
Platynereis dumerilii (Audouin & Edwards, 1833)	Barrera (unpubl. data)	OB(#)
GLYCERIDAE		
Glycera americana Leidy, 1855	Barrera (unpubl. data)	OB(#)
Order Eunicida		
EUNICIDAE		
Marphysa sanguinea (Montagu, 1815)	Withers (1994)	MI(#)
LUMBRINERIDAE		
Scoletoma (=*Lumbrineris*) *tenuis* (Verrilli, 1873)	Withers (1994)	MI(#)
DORVILLEIDAE		
Dorvillea rubra (Grube, 1865)	Withers (1994)	BBLM(#),MI(#)
Order Terebellida		
AMPHARETIDAE		
Melinna maculata Webster, 1879	Withers (1994)	MI(#)
TEREBELLIDAE		
Neoleprea sp. A	Withers (1994)	MI(#)

Species	Reference	System (Abundance)
Order Sabellida		
SABELLIDAE		
Chone duneri Malmgen, 1867	Withers (1994)	BBLM(#),MI(#)
Sabella micropthalma Verrilli, 1873	Withers (1994)	BBLM(#),MI(#)
	Withers (1996)	BBLM(R)
Sabella sp.	Withers (1994)	BBLM(#),MI(#)
	Withers (1996)	BBLM(R)
Sabellastarte sp.	Withers (1994)	MI(#)
PHYLUM MOLLUSCA		
Class Gastropoda		
Order Mesogastropoda		
CERITHIIDAE		
Cerithium lutosum Menke, 1828	Withers (1994)	MI(#)
	Morton and Garner (1993)	BBLM(C)
POTAMIDIDAE		
Cerithidea pliculosa (Menke, 1829)	Morton and Garner (1993)	BBLM(R)
CREBBLMDULIDAE		
Crepidula convexa Say, 1822	Morton and Garner (1993)	BBLM(R)
Order Neogastropoda		
COLUMBELLIDAE		
Anachis sp.	Morton and Garner (1993)	BBLM(R)
Subclass Opisthobranchia		
Order Cephalaspidea		
ACTEONIDAE		
Acteon (=*Rictaxis*) *puntostriatus* (C.B. Adams,	Withers (1994)	BBLM(U)
1840)	Morton and Garner (1993)	BBLM(R)
BULLIDAE		
Bulla striata Bruguiere, 1792	Withers (1994)	BBLM(U)
Class Bivalvia		
Subclass Pteriomorphia		
Order Mytiloida		
MYTILIDAE		
Amygdalum papyrium (Conrad, 1846)	Withers (1994)	BBLM(R)
	Withers (1996)	BBLM(R)
Subclass Heterodonta		
Order Veneroida		
CARDIIDAE		
Laevicardium mortoni (Conrad, 1830)	Withers (1994)	BBLM(R)
	Morton and Garner (1993)	BBLM(R)
MACTRIDAE		
Mulinia lateralis (Say, 1822)	Fisk (1959)	BBLM(#)
	Dalrymple (1965)	BBLM(U)
	Brogden et al (1977)	BBLM(#),MI(#)
	Herber (1981)	BBLM(C)
	Morton and Garner (1993)	BBLM(A)
	Withers (1994)	BBLM(U)
	Barrera (unpubl. Data)	OB(#)
SOLENIDAE		
Ensis minor Dall, 1900	Brogden et al (1977)	BBLM(#),MI(#)
	Withers (1994)	BBLM(U)
	Barrera (unpubl. Data)	OB(#)

Species	Reference	System (Abundance)
PSAMMOBIIDAE		
Tagelus plebius (Lightfoot, 1786)	Barrera (unpubl. Data)	OB(#)
Tagelus gibbus Spengler, 1794	Brogden et al (1977)	BBLM(#),MI(#)
TELLINIDAE		
Tellina tampaensis Conrad 1866	Withers (1994)	BBLM(A)
Tellina sp.	Withers (1996)	BBLM(R)
CORBICULIDAE		
Polymesoda maritima (=*P. floridana*) (Orbigny,	Morton and Garner (1993)	BBLM(R)
1842)	Withers (1994)	BBLM(U)
VENERIDAE		
Anomalocardia auberiana (Orbigny, 1842)	Fisk (1959)	BBLM(#)
(=*A. cuneimeris* Conrad, 1846)	Dalrymple (1965)	BBLM(U)
	Brogden et al (1977)	BBLM(#),MI(#)
	Morton and Garner (1993)	BBLM(A)
	Withers (1994)	BBLM(C)
	Withers (1996)	BBLM(R)
Anomalocardia sp.	Herber (1981)	BBLM(C)
Chione cancellata (Linné, 1767)	Barrera (unpubl. Data)	OB(#)
PHYLUM ARTHROPODA		
Subphylum Crustacea		
Class Ostracoda	Barrera (unpubl. data)	OB(#)
Class Malacostraca		
Order Decapoda		
Infraorder Penaeidea		
PENAEIDAE		
Penaeus aztecus Ives, 1891	Barrera (unpubl. data)	OB(#)
Penaeus duorarum Burkenroad, 1939	Barrera (unpubl. data)	OB(#)
Penaeus setiferus (Linné, 1767)	Barrera (unpubl. data)	OB(#)
Infraorder Caridea		
PALAEMONIDAE		
Palaemonetes vulgaris (Say, 1818)	Barrera (unpubl. data)	OB(#)
Palaemonetes intermedius Holthius, 1949	Barrera (unpubl. data)	OB(#)
Palaemonetes pugio Holthius, 1949	Barrera (unpubl. data)	OB(#)
Palaemonetes sp.	Brogden et al. (1977)	BBLM(#),MI(#)
Infraorder Anomura		
CALLIANASSIDAE		
Lepidophthalmus louisianensis (Schmitt, 1935)	Felder & Rodrigues (1993)	ACB(#), NCCB(#)
DIOGENIDAE		
Clibanarius vittatus (Bosc, 1802)	Brogden et al. (1977)	BBLM(#),MI(#)
PAGURIDAE		
Pagurus longicarpus Say, 1817	Brogden et al. (1977)	BBLM(#),MI(#)
Infraorder Brachyura		
PORTUNIDAE		
Callinectes sapidus Rathbun, 1896	Brogden et al. (1977)	MI(#),BBLM(#)
	Barrera (unpubl. data)	OB(#)
XANTHIDAE		
Panopeus (=*Eurypanopeus*) *turgidus* Rathbun, 1930	Withers (1994)	BBLM(U)

Species	Reference	System (Abundance)
OCYPODIDAE		
Uca panacea Novak and Salmon, 1974	Brogden et al. (1977)	BBLM(C),MI(C)
	Pulich et al. (1982)	BBLM(#)
Uca subcylindrica (Stimpson, 1859)	Rathbun (1918)	ACB(#), NCCB(#)
	Felder (1973)	ACB(#), NCCB(#)
	Pulich et al. (1982)	BBLM(#)
	Withers (1994)	BBLM(#)
Uca sp.	Zupan (1970)	BBLM(A)
	Morton and Garner (1993)	BBLM(C)
Order Isopoda		
CYMOTHOIDAE		
Aegothoa (=*Rocinela*) *oculata* Harger, 1883	Barrera (unpubl. data)	OB(#)
SPHAEROMATIDAE		
Ancinus depressus (Say, 1818)	Barrera (unpubl. data)	OB(#)
Sphaeroma quadridentatum Say, 1818	Withers (1994)	BBLM(#)
Sphaeroma walkeri	Barrera (unpubl. data)	OB(#)
Dynamenella perforata (Moore)	Barrera (unpubl. data)	OB(#)
IDOTEIDAE		
Edoteo montosa (Stimpson, 1853)	Barrera (unpubl. data)	OB(#)
Order Tanaidacea		
PARATANAIDAE		
Hargeria (=*Leptochelia*) *rapax* (Harger, 1879)	Withers (1994)	BBLM(#),MI(#)
	Withers (1996)	BBLM(R-A)
	Barrera (unpubl. data)	OB(#)
Order Mysidacea		
MYSIDEA		
Mysidopsis almyra (Bowman, 1964)	Barrera (unpubl. data)	OB(#)
Order Cumacea		
DIASTYLIDAE		
Oxyurostylis smithi Calman, 1912	Withers (1994)	BBLM(#),MI(#)
Order Amphipoda		
AMPELISCIDAE		
Ampelisca sp.	Barrera (unpubl. data)	OB(#)
AYTLIDAE		
Atylus sp.	Barrera (unpubl. data)	OB(#)
COROPHIDAE		
Corophium acherusicum Costa, 1857	Withers (1994)	BBLM(#),MI(#)
	Withers (1996)	BBLM(R)
	Barrera (unpubl. data)	OB(#)
Corophium louisianum Shoemaker, 1934	Withers (1994)	BBLM(#),MI(#)
	Withers (1996)	BBLM(R-U)
	Barrera (unpubl. data)	OB(#)
Corophium tubularis	Barrera (unpubl. data)	OB(#)
Grandidierella bonnieroides Stephensen, 1948	Barrera (unpubl. data)	OB(#)
Corophium volutator (Pallas)	Barrera (unpubl. data)	OB(#)

Species	Reference	System (Abundance)
GAMMARIDAE		
Gammarus mucronatus Say, 1818	Withers (1994)	BBLM(R)
	Withers (1996)	BBLM(R)
	Barrera (unpubl. data)	OB(#)
Gammarus sp.	Withers (1994)	BBLM(#)
HYALELLIDAE		
Hyalella azteca Saussure 1857	Barrera (unpubl. data)	OB(#)
HYALIDAE		
Hyale frequens	Barrera (unpubl. data)	OB(#)
MELITIDAE		
Melita dentata (Kroyer)	Barrera (unpubl. data)	OB(#)
Melita sp.	Withers (1994)	BBLM(#)
	Barrera (unpubl. data)	OB(#)
PLEUSTIDAE		
Stenopleustes gracilis (Holmes, 1905)	Barrera (unpubl. data)	OB(#)
TALTRIDAE		
Platorchestia (=*Orchestia*) *platensis* (Kroyer, 1845)	Withers (1994)	MI(#)
Orchestia grillus Bosc, 1802	Barrera (unpubl. data)	OB(#)
Class Copepoda	Barrera (unpubl. data)	OB(#)
PHYLUM ARTHROPODA		
Subphylum Insecta		
Class Insecta		
Order Odonata		
AESHNIDAE		
Gomphaeschna sp.	Withers (1994)	MI(#)
Order Orthoptera		
GRYLLIDAE		
Gryllus sp.	Pulich and Scalan (1987)	BBLM(#)
	Pulich et al. (1982)	BBLM(U)
Nemobius sp.	Pulich and Scalan (1987)	BBLM(#)
Order Hemiptera		
MIRIDAE	Pulich et al. (1982)	BBLM(R)
HEBRIDAE		
Lipogomphus sp.	Withers (1994)	MI(R)
CORIXIDAE		
Hesperocorixa sp.	Barrera (unpubl. data)	OB(#)
Trichocorixa sp.	Pulich et al. (1982)	BBLM(A)
SALDIDAE		
Pentacora sphacelata (Uhler)	Pulich et al. (1982)	BBLM(A)
	Pulich and Scalan (1987)	BBLM(#)
Pentacora sp.	Withers (1994)	MI(U),BBLM(U)
NABIDAE	Withers (1994)	BBLM(#)
	Withers (1996)	BBLM(R)
LYGAEIDAE	Pulich and Scalan (1987)	BBLM(#)
PENTATOMIDAE	Pulich and Scalan (1987)	BBLM(#)

Species	Reference	System (Abundance)
Order Coleoptera		
CARABIDAE	Withers (1994)	MI(#)
Tachys pallidus	Pulich et al. (1982)	BBLM(U)
	Pulich and Scalan (1987)	BBLM(#)
Tachys sp.	Pulich and Scalan (1987)	BBLM(#)
Diplochaetus lecontei	Pulich et al. (1982)	BBLM(U)
	Pulich and Scalan (1987)	BBLM(#)
Scarites subterranean	Pulich et al. (1982)	BBLM(U)
	Pulich and Scalan (1987)	BBLM(#)
DYTISCIDAE		
Laccophilus sp.	Withers (1994)	BBLM(R)
STAPHYLINIDAE	Pulich and Scalan (1987)	BBLM(#)
	Barrera (unpubl. data)	OB(#)
Bledius sp.	Withers (1994)	BBLM(R),MI(C)
Brythinusa sp.	Withers (1994)	BBLM(#),MI(R)
Stenus sp.	Withers (1994)	BBLM(R),MI(R)
CURCULIONIDAE	Withers (1994)	BBLM(R)
SALPINGIDAE	Withers (1994)	BBLM(C),MI(C)
HYDROPHILIDAE	Withers (1994)	MI(R)
Berosus sp.	Withers (1996)	BBLM(R)
Hydrocharus sp.	Withers (1994)	BBLM(R)
LIMNICHIDAE	Pulich et al. (1982)	BBLM(A)
	Pulich and Scalan (1987)	BBLM(#)
HYDRAENIDAE	Pulich et al. (1982)	BBLM(U)
TENEBRIONIDAE	Pulich et al. (1982)	BBLM(U)
CHRYSOMELIDAE	Pulich and Scalan (1987)	BBLM(#)
CICINDELIDAE		
Cicindela pamphila	Pulich and Scalan (1987)	BBLM(#)
Cicindela hamata	Pulich and Scalan (1987)	BBLM(#)
Cicindela togata	Pulich and Scalan (1987)	BBLM(#)
Cicindela sp.	Pulich et al. (1982)	BBLM(U)
MELYRIDAE	Withers (1994)	BBLM(#)
	Withers (1996)	BBLM(R)
Order Hymenoptera		
EULOPHIDAE	Withers (1994)	MI(#)
PTEROMALIDAE	Withers (1994)	BBLM,MI(#)
SCELIONIDAE	Withers (1994)	BBLM(#)
FORMICIDAE	Pulich and Scalan (1987)	BBLM(#)
Order Diptera		
CHIRONOMIDAE	Withers (1994)	MI(R)
	Barrera (unpubl. data)	OB(#)
EMPIDIDAE	Withers (1994)	BBLM(R)
DOLICHOPODIDAE	Withers (1994)	BBLM(C),MI(A)
	Withers (1996)	BBLM(R)
	Barrera (unpubl. data)	OB(#)
CANACEIDAE	Withers (1994)	MI(A),BBLM(A)
	Withers (1996)	BBLM(R)
CERATOPOGONIDAE	Withers (1994)	BBLM(R),MI(#)
	Withers (1996)	BBLM(R-C)
SIMULIDAE	Withers (1994)	MI(R)

Species	Reference	System (Abundance)
SPHAEROCERIDAE	Pulich et al. (1982)	BBLM(U-A)
	Pulich and Scalan (1987)	BBLM(#)
EPHYDRIDAE	Pulich et al. (1982)	BBLM(U)
	Pulich and Scalan (1987)	BBLM(#)
	Withers (1996)	BBLM(R)
	Barrera (unpubl. data)	OB(#)
BOMBYLIIDAE	Pulich and Scalan (1987)	BBLM(#)
ASILIDAE	Pulich and Scalan (1987)	BBLM(#)
DIXIDAE	Barrera (unpubl. data)	OB(#)
Order Collembola		
ENTOMYBRYIDAE		
Seira Sp.	Withers (1994)	BBLM(R),MI(R)
CYPHODERIDAE	Withers (1994)	BBLM(R)
Cyphoderus sp.	Withers (1994)	BBLM(R)
PODURIDAE	Pulich and Scalan (1987)	BBLM(#)
Order Plecoptera		
LEUCTRIDAE		
Leuctra sp.	Withers (1994)	BBLM(R)
Class Arachnida	Withers (1994)	BBLM(A)
Order Areneae	Withers (1994)	BBLM(A)
ARANEIDAE	Pulich and Scalan (1987)	BBLM(#)
LYCOSIDAE	Pulich and Scalan (1987)	BBLM(#)
	Pulich et al. (1982)	BBLM(#)
CLUBIONIDAE	Pulich et al. (1982)	BBLM(#)
PHYLUM CHORDATA		
Class Osteichthyes		
Order Elopiformes		
ELOPIDAE		
Elops saurus Linné, 1766	Barrera (unpubl. data)	OB(#)
Order Clupeiformes		
CLUPEIDAE		
Brevoortia patronus Goode, 1878	Barrera (unpubl. data)	OB(#)
Order Aulopiformes		
SYNODONTIDAE		
Synodus foetens (Linné, 1766)	Pulich et al. (1982)	BBLM(U)
Order Atheriniformes		
CYPRINODONTIDAE	Zupan (1970)	BBLM(A)
Cyprinodon varigatus Lacepede, 1803	Odum (1967)	BBLM(A)
	Birke (1974)	BB(#)
	Warshaw (1975)	BBLM(A)
	Brogden et al. (1977)	MI(#),BBLM(#)
	Pulich et al. (1982)	BBLM(A)
	Ecoservices (1993)	BBLM(#)
	Barrera (unpubl. data)	OB(#)
Fundulus grandis Baird and Girard, 1853	Barrera (unpubl. data)	OB(#)
	Warshaw (1975)	BBLM(A)
Fundulus similis (Baird and Girard, 1853)	Warshaw (1975)	BBLM(A)
	Pulich et al. (1982)	BBLM(C)
Fundulus sp.	Brogden et al. (1977)	MI(#),BBLM(#)

Species	Reference	System (Abundance)
ANTHERINIDAE		
Membras martinica (Valenciennes, 1853)	Barrera (unpubl. data)	OB(#)
Menidia beryllina (Cope, 1866)	Warshaw (1975)	BBLM(A)
	Brogden et al. (1977)	MI(#),BBLM(#)
	Pulich et al. (1982)	BBLM(U)
	Barrera (unpubl. data)	OB(#)
Order Perciformes		
SPARIDAE		
Lagodon rhomboides (Linné, 1766)	Brogden et al. (1977)	MI(#),BBLM(#)
SCIAENIDAE		
Leiostomous xanthurus Lacepede, 1802	Barrera (unpubl. data)	OB(#)
MUGILIDAE		
Mugil cephalus Linné, 1758	Brogden et al. (1977)	MI(#),BBLM(#)
	Barrera (unpubl. data)	OB(#)
GOBIIDAE		
Gobionellus boleosoma (Jordan & Gilbert, 1882)	Barrera (unpubl. data)	OB(#)
Order Pleuronectiformes		
BOTHIDAE		
Paralichthys lethostigma Jordan & Gilbert, 1884	Barrera (unpubl. data)	OB(#)
PHYLUM VERTEBRATA		
Class Mammalia		
Order Lagomorpha		
LEPORIDAE		
Sylvilagus floridanus (J.A. Allen, 1890)	Withers (1996a)	BBLM(#)
Order Carnivora		
CANIDAE		
Canis latrans Say, 1823	Withers (1996a)	BBLM(#)
Urocyon cinereoargenteus (Schreber, 1775)	Withers (1996a)	BBLM(#)
PROCYONIDAE		
Procyon lotor (Linnaeus, 1758)	Withers (1996a)	BBLM(#)
Order Artiodactyla		
CERVIDAE		
Odocoileus virginianus (Zimmerman 1780)	Withers (1996a)	BBLM(#)

Phylogenetic order/classification follows: AOU Check-list (1983) through the 39th supplement

***Relative abundance acronyms**:

C	common - see >5 a day in habitat	A	accidental - usually not recurring
U	uncommon - see <5 a day in habitat	*	breeding
R	rare - not likely seen in habitat	#	missing information
I	irregular - few per decade		

*Relative abundance acronyms for species referenced in Pulich et al. (1982) are as follows: c = common (more than 3 individuals each sampling date), u = uncommon (not present every sampling date).

Species	Reference	System (Abundance)
PHYLUM CHORDATA		
Class Aves		
Order Ciconiiformes		
ARDEIDAE		
Ardea herodias Linnaeus	Brogden et al. (1977)	MI(C),BBLM(C)
Great Blue Heron	Pulich et al. (1982)	BBLM(U)
	Withers (1996)	BBLM(U)
	Withers (1996a)	BBLM(#),MI(#)
	Barrera (unpublished)	OB(#)
Casmerodius albus (Linnaeus)	Brogden et al. (1977)	MI(U),BBLM(U)
Great Egret	Withers (1996a)	BBLM(#),MI(#)
	Barrera (unpublished)	OB(#)
Egretta caerulea (Linnaeus)	Brogden et al. (1977)	MI(U),BBLM(U)
Little Blue Heron	Withers (1996a)	BBLM,MI(#)
Egretta thula (Molina)	Brogden et al. (1977)	MI(U),BBLM(U)
Snowy Egret	Pulich et al. (1982)	BBLM(U)
	Withers (1996a)	BBLM(#)
	Barrera (unpublished)	OB(#)
Egretta rufescens (Gmelin)	Brogden et al. (1977)	MI(C),BBLM(C)
Reddish Egret	Pulich et al. (1982)	BBLM(C)
	Ecoservices (1993)	BBLM(#)
	Withers (1996)	BBLM(U)
	Withers (1996a)	BBLM,MI(#)
	Barrera (unpublished)	OB(#)
Egretta tricolor (Muller)	Brogden et al. (1977)	MI(U),BBLM(U)
Tricolor Heron	Pulich et al. (1982)	BBLM(U)
	Withers (1996a)	BBLM,MI(#)
	Barrera (unpublished)	OB(#)
THRESKIORNITHIDAE		
Ajaia ajaja (Linnaeus)	Brogden et al. (1977)	BBLM(#),MI(#)
Roseate Spoonbill	Barrera (unpublished)	OB(#)

Species	Reference	System (Abundance)
Order Anseriformes		
ANATIDAE		
Anas crecca Linnaeus Green-winged Teal	Brogden et al. (1977)	BBLM(#),MI(#)
Anas fulvigula Ridgway Mottled Duck	Brogden et al. (1977)	BBLM(#),MI(#)
Anas acuta Linnaeus Northern Pintail	Brogden et al. (1977)	BBLM(#),MI(#)
Anas discors Linnaeus Blue-winged Teal	Brogden et al. (1977)	BBLM(#),MI(#)
Anas clypeata Linnaeus Northern Shoveler	Brogden et al. (1977)	BBLM(#),MI(#)
Anas americana Gmelin American Wigeon	Brogden et al. (1977)	BBLM(#),MI(#)
Aythya valisineria (Wilson) Canvasback	Withers (1996)	BBLM(U)
Order Falconiformes		
ACCIPITRIDAE		
Pandion haliaetus (Linnaeus) Osprey	Ecoservices (1993)	BBLM(#)
Circus cyaneus (Linnaeus) Northern Harrier		
FALCONIDAE		
Falco peregrinus Tunstall Peregrine Falcon	Ecoservices (1993)	BBLM(#)
Order Charadriiformes		
CHARADRIIDAE		
Pluvialis dominica (Muller) American Golden-Plover	Pulich et al. (1982)	BBLM(U)
Pluvialis squatarola (Linnaeus) Black-bellied Plover	Pulich et al. (1982) Ecoservices (1993) Withers and Chapman (1993) Withers (1994)	BBLM(C) BBLM(#) OB(#) BBLM(#),MI(#)
Charadrius alexandrinus Linnaeus Snowy Plover	Pulich et al. (1982) Ecoservices (1993) Withers and Chapman (1993) Withers (1994)	BBLM(U) BBLM(#) OB(#) BBLM(#),MI(#)
Charadrius wilsonia Ord Wilson's Plover	Pulich et al. (1982) Bergstrom (1986) Ecoservices (1993) Withers and Chapman (1993) Withers (1994) Withers (1996)	BBLM(C) MAI(#) BBLM(#) OB(#) BBLM(#),MI(#) BBLM(A)

Species	Reference	System (Abundance)
Charadrius semipalmatus Bonaparte	Withers and Chapman (1993)	OB(#)
Semipalmated Plover	Withers (1994)	BBLM(#),MI(#)
Charadrius melodus Ord	Pulich et al. (1982)	BBLM(U)
Piping Plover	Nicholls and Baldassarre (1990)	ACB(#),BBLM(#), MAI(#),NCCB(#)
	Ecoservices (1993)	BBLM(#)
	Haig and Plissner (1993)	ACB(#),BBLM(#), MAI(#), MI(#)
	Withers and Chapman (1993)	OB(#)
	Withers (1994)	BBLM(#),MI(#)
	Withers (1996)	BBLM(A)
Charadrius vociferus Linnaeus	Brogden et al. (1977)	BBLM(#),MI(#)
Killdeer	Withers and Chapman (1993)	OB(#)
RECURVIROSTRIDAE		
Haematopus palliatus Temminck	Brogden et al. (1977)	BBLM(#),MI(#)
American Oystercatcher	Withers (1994)	BBLM(#),MI(#)
Himantopus mexicanus (Muller)	Brogden et al. (1977)	BBLM(#),MI(#)
Black-necked Stilt	Withers and Chapman (1993)	OB(#)
	Withers (1994)	BBLM(#),MI(#)
Recurvirostra americana Gmelin	Brogden et al. (1977)	BBLM(#),MI(#)
American Avocet	Pulich et al. (1982)	BBLM(C)
	Withers and Chapman (1993)	OB(#)
	Withers (1994)	MI(#)
SCOLOPACIDAE		
Tringa melanoleuca (Gmelin)	Brogden et al. (1977)	BBLM(#),MI(#)
Greater Yellowlegs	Withers and Chapman (1993)	OB(#)
	Withers (1994)	BBLM(#),MI(#)
	Withers (1996)	BBLM(U)
Tringa flavipes (Gmelin)	Brogden et al. (1977)	BBLM(#),MI(#)
Lesser Yellowlegs	Withers and Chapman (1993)	OB(#)
	Withers (1994)	BBLM(#),MI(#)
	Withers (1996)	BBLM(U)
Tringa spp.	Pulich et al. (1982)	BBLM(U)
Yellowlegs		
Catoptrophorus semipalmatus (Gmelin)	Brogden et al. (1977)	BBLM(#),MI(#)
Willet	Pulich et al. (1982)	BBLM(C)
	Withers and Chapman (1993)	OB(#)
	Withers (1994)	BBLM(#),MI(#)
	Withers (1996)	BBLM(U-C)
Actitis macularia (Linnaeus)	Withers and Chapman (1993)	OB(#)
Spotted Sandpiper	Withers (1994)	MI(#)
Numenius phaeopus (Linnaeus)	Weston and Williams (1965)	ACB(#)
Whimbrel	Withers and Chapman (1993)	OB(#)

Species	Reference	System (Abundance)
Numenius americanus Bechstein	Weston and Williams (1965)	ACB(#)
Long-billed Curlew	Brogden et al. (1977)	BBLM(#),MI(#)
	Pulich et al. (1982)	BBLM(U-C)
	Withers and Chapman (1993)	OB(#)
	Withers (1994)	BBLM(#),MI(#)
	Withers (1996)	BBLM(U-C)
Numenius borealis	Weston and Williams (1965)	ACB(R)
Eskimo Curlew		
Limosa fedoa (Linnaeus)	Brogden et al. (1977)	BBLM(#),MI(#)
Marbled Godwit	Withers and Chapman (1993)	OB(#)
	Withers (1994)	BBLM(#),MI(#)
Arenaria interpres (Linnaeus)	Withers and Chapman (1993)	OB(#)
Ruddy Turnstone	Withers (1994)	BBLM(#),MI(#)
Calidris canutus (Linnaeus)	Ecoservices (1993)	BBLM(#)
Red Knot	Withers (1994)	BBLM(#),MI(#)
Calidris alba (Pallas)	Brogden et al. (1977)	BBLM(#),MI(#)
Sanderling	Pulich et al. (1982)	BBLM(U)
	Ecoservices (1993)	BBLM(#)
	Withers and Chapman (1993)	OB(#)
	Withers (1994)	BBLM(#),MI(#)
	Withers (1996)	BBLM(U-C)
Calidris pusilla (Linnaeus)	Withers and Chapman (1993)	OB(#)
Semipalmated Sandpiper	Withers (1994)	BBLM(#),MI(#)
Calidris mauri (Cabanis)	Pulich et al. (1982)	BBLM(C)
Western Sandpiper	Ecoservices (1993)	BBLM(#)
	Withers and Chapman (1993)	OB(#)
	Withers (1994)	BBLM(#),MI(#)
	Withers (1996)	BBLM(U)
Calidris minutilla (Vieillot)	Brogden et al. (1977)	BBLM(#),MI(#)
Least Sandpiper	Pulich et al. (1982)	BBLM(C)
	Ecoservices (1993)	BBLM(#)
	Withers (1994)	BBLM(#),MI(#)
	Withers (1996)	BBLM(C)
Calidris bairdii (Coues)	Pulich et al. (1982)	BBLM(C)
Baird's Sandpiper	Withers and Chapman (1993)	OB(#)
	Withers (1994)	BBLM(#),MI(#)
Calidris melanotos (Vieillot)	Withers and Chapman (1993)	OB(#)
Pectoral Sandpiper		
Peep spp.	Withers (1996)	BBLM(C)

Species	Reference	System (Abundance)
Calidris alpina (Linnaeus)	Brogden et al. (1977)	BBLM(#),MI(#)
Dunlin	Pulich et al. (1982)	BBLM(U)
	Ecoservices (1993)	BBLM(#)
	Withers and Chapman (1993)	OB(#)
	Withers (1994)	BBLM(#),MI(#)
	Withers (1996)	BBLM(C)
Calidris himantopus (Bonaparte)	Brogden et al. (1977)	BBLM(#),MI(#)
Stilt Sandpiper	Withers and Chapman (1993)	OB(#)
Limnodromous spp.	Brogden et al. (1977)	BBLM(#),MI(#)
Dowitchers	Withers and Chapman (1993)	OB(#)
	Withers (1994)	BBLM(#),MI(#)
Phalaropus tricolor (Vieillot)	Pulich et al. (1982)	BBLM(C)
Wilson's Phalarope	Withers and Chapman (1993)	OB(#)
	Withers (1994)	BBLM(#),MI(#)
LARIDAE		
Larus atricilla Linnaeus	Brogden et al. (1977)	BBLM(#),MI(#)
Laughing Gull	Pulich et al. (1982)	BBLM(U-C)
	Withers (1996)	BBLM(C)
Larus delawarensis Ord	Brogden et al. (1977)	BBLM(#),MI(#)
Ring-billed Gull		
Larus argentatus Pontoppidan	Brogden et al. (1977)	BBLM(#),MI(#)
Herring Gull		
Sterna nilotica Gmelin	Brogden et al. (1977)	BBLM(#),MI(#)
Gull-billed Tern	Pulich et al. (1982)	BBLM(U)
Sterna caspia Pallas	Brogden et al. (1977)	BBLM(#),MI(#)
Caspian Tern	Pulich et al. (1982)	BBLM(U)
Sterna maxima Boddaert	Brogden et al. (1977)	BBLM(#),MI(#)
Royal Tern	Pulich et al. (1982)	BBLM(U)
Sterna sandvicensis Latham	Brogden et al. (1977)	BBLM(#),MI(#)
Sandwich Tern		
Sterna forsteri Nuttall	Brogden et al. (1977)	BBLM(#),MI(#)
Forester's Tern		
Sterna atillarum (Lesson)	Brogden et al. (1977)	BBLM(#),MI(#)
Least Tern	Pulich et al. (1982)	BBLM(C)
	Ecoservices (1993)	BBLM(#)
Rynchops niger Linnaeus	Brogden et al. (1977)	BBLM(#),MI(#)
Black Skimmer		

Species	Reference	System (Abundance)
Order Passeriformes		
ALAUDIDAE		
Eremophila alpestris (Linnaeus)	Brogden et al. (1977)	BBLM(#),MI(#)
Horned Lark	Withers (1996)	BBLM(U-C)

APPENDIX 3

DRAFT

The Piping Plover
In Texas

Winter Survey Guidelines

Prepared by Ted L. Eubanks Jr. for the Great
Lakes/Northern Great Plains
Piping Plover Recovery Team

Piping Plover (Charadrius melodus)
Winter Site Appraisal Guidelines

The following guidelines have been prepared by the Great Lakes/Northern Plains Piping Plover Recovery (Team) to aid surveyors in determining the presence of this endangered species on sites in winter along the Texas coast. Consultations with a number of agencies and interested parties have resulted in a set of criteria that, while stringent to a degree that assures the U.S. Fish and Wildlife Service (Service) that each respective site has been thoroughly surveyed , should not inflict any landowner with an overly onerous burden, Comments and questions concerning these criteria should be directed to the Service offices in Clear Lake and Corpus Christi.

STEP I. Named Essential Site

Consult the listing of the known Piping Plover wintering sites in the Texas that has been compiled by the Tea. A brief description of these sites has been included with these survey guidelines (Attachment 1). County maps that delineate these sites are available for inspection at the Service offices in Corpus Christi and Clear Lake, and the U.S. Army Corps of Engineers (Corps) office in Galveston. Projects involving named essential Piping Plover winter sties require formal Section 7 consultation with the Service. Applicants with projects not involving names essential Piping Plover winter sites should proceed to II.a.

STEP II Site Assessment

a. Correlation with know Piping Plover habitat profiles

The applicant should conduct a single-day inspection, and assess and delineate the habitats contained within the site being considered for permitting. A map should be created that outlines these general habitat types. Applicants with sites that correlate with the Piping Plover habitat profiles (Attachment 2) should proceed to II.b. Projects on sites with no correlation should receive a "no-effect" finding.

b. Presence of Guild Members

The applicant should conduct a series of field surveys extending over a contiguous 30-day period, during which the site should be inspected for the absence or presence of members of the maritime shorebird guild (Attachment 3). Surveys may be conducted on a weekly basis (one survey per week), or a semimonthly basis (two sequential survey days during each semimonthly period). Applications for sites which are found to contain no members of the winter maritime shorebird guild (as confirmed by the Service) should receive a "no-effect" finding. Applicants with sites that are found to contain members of the winter maritime shorebird guild should proceed to II.c. Survey time accumulated at the end of the 30-day study period will be credited toward the extended study required by II.c.

c. Presence of the Piping Plover

The applicant should conduct a series of field surveys extending over a 90-day period (which includes the 30-day survey period required by II.b.), during which the site should be inspected for the absence or presence of Piping Plovers. One month of this period must fall with a single migratory window (1 August - 15 October, 15 February - 1 May). Surveys may be conducted on a weekly basis (one survey per week), or a semimonthly basis (two sequential survey days during each semimonthly period). Applications for sites which are found to contain no Piping Plovers (as confirmed by the Service) should receive a finding of "no-effect". Applicants with sites that are found to contain Piping Plovers will proceed at the moment of their discovery to formal Section 7 consultation with the Service.

Piping Plover Winter Survey Criteria

In an effort to standardize the methods for and the results of Piping Plover site assessments in Texas, the following criteria have been developed. It is important to recognize, however, that the purpose of this style of survey is to simply determine whether or not Piping Plovers are present at a given location, An estimation of the relative value of a given site for Piping Plovers will require additional investigation.

I. Expertise of the Surveyor

Surveyors should be knowledgeable about bird identification, and must be capable of discerning all members of the maritime shorebird guild. Surveyors should be familiar with Piping Plover winter ecology, as well as the varying habitat types that may be encountered along the Texas coast (refer to list of suggested reading for further information A list of recommended Piping Plover surveyors is available for the Service offices in Clear Lake and Corpus Christi.

II. Observations Conditions

A. Observation in feeding habitats should be conducted during falling or low tides to increase the exposure of mud and/or sand flats.

B. Wind speed during surveys should be less than 25 mph, and inclement weather conditions (heavy rain, severe cold) should be avoided.

C. If birds vacate a site due to disturbance (human, predator), the observation and the disturbance should be so noted.

III. Survey Criteria

A. Surveys should be restricted to nine-month period beginning 1 August and ending 1 May. Surveys should be conducted either on a weekly basis, or a semimonthly with two sequential survey days within each semimonthly period.

B. One month (four surveys) should fall within a single migratory window (1August - 15 October, 15 February - 1 May).

C. We've found the observations at sunrise and sunset are critical to establishing the existence of roosting areas. Make sure the project site in particular is observed during these periods. Surveys should be conducted from 30 minutes after sunrise to 30 minutes before sunset. The surveyor should allocate observation time to a minimum of five one-hour blocks evenly apportioned across the survey day. This observation time should be allocated in such a way as to encompass all proximate tidal regimes and habitat types. The amount of time necessary to survey each respective tract will obviously vary with the amount and type of habitat to be covered. The intent should be to thoroughly survey each site for the Piping Plover, and the surveyor should make every effort to achieve that goal regardless of the time involved.

D. Laguna Madre/South Bay Survey Sites

1. The wind tidal flats of the Laguna Madre pose a difficult set of conditions upon the surveyor. Strong winds will push the bay waters far onto the flats, particularly during the passage of polar frontal systems. After these winds subside, the recently inundated sand and algal flats offer optimal feeding conditions for Piping Plovers.

2. Conversely, strong prevailing winds (from the southeast) will force water in tidal pools and upon wind-tidal flats to gather at the leeward edge. The substrate on the windward side, therefore, will be gradually uncovered. These recently exposed sand or algal flat edges also offer optimal feeding conditions for the Piping Plover.

IV. Recording of Data

A. Data should be recorded upon maps and forms similar to those provided with these guidelines (Attachments 4,5).

B. One data form should be completed for each one-hour segment. Each day's survey (Forms (a minimum of five per day) should be summarized on a separate sheet. A map indicating specific areas of shorebird use within the tract should be provided for each survey day.

C. One map delineating the habitat types contained within the tract being surveyed should be completed at the initiation of the site assessment (see II.a). This map should updated during the survey period if alterations to the site occur.

D. The daily summary sheets, the map delineating habitat types and the maps indicating specific area of high use by shorebirds should be provided to the Service at the end of the survey period.

SUGGESTED READING

Blacklock, G. And J. Rappole. 1985. Birds of the Texas coastal bend. Texas A&M University Press, College Station, Texas.

Chapman, B. R. 1985. Seasonal abundance and habitat-use patterns of coastal bird populations on Padre and Mustang islands barrier beaches. U.S. Fish and Wildlife Service FWS/OBS-83/31.

Federal Register. 1985. Endangered and threatened wildlife and plants; determination of endangered status for Piping Plover; final rule 50: 50726-50734.

Haig, S. M. 1992. American Ornithologists' Union Avian Species Biography Series: The Piping Plover (Charadrius melodus). Allen Press, Lawrence, Kansas.

Haig, S. M. And L. W. Oring. 1985. The distribution and status of the Piping Plover throughout the annual cycle. J. Field Ornith. 56:334-345.

_____and _____. 1988b. Distribution and dispersal in the Piping Plover. Auk 105: 630-638.

_____, W. Harrison, R. Lock. L. Pfanmuller, E. Pike, M. Ryan, and J. Sidle. 1988. Great Lakes and Northern Great Plains Piping Plover recovery plan. U.S. Fish and Wildlife Service.

Johnson, C. M. And G. A. Baldassarre. 1988. Aspects of the wintering ecology of the Piping Plover in coastal Alabama. Wilson Bull. 100:214-233.

Leavens, W. R. 1979. Habitat selection in shorebirds on Bolivar Peninsula. Texas A&M University, M.S. thesis.

Nicholls, J. L. And G. A. Baldassarre. 1990a. Winter distribution of Piping Plovers along the Atlantic and Gulf coast of the United States. Wilson Bull. 102: 400-412.

_____and_____. 1990b. Habitat selection and interspecific associations of Piping Plovers wintering in the U.S. Wilson Bull. 102:581-590.

Pulich, Jr., W. And Rabalais, S. Primary production potential of blue-green algal mats on southern Texas tidal flats. 1986. Southwestern Naturalist 31:9-17.

Attachment 1

1991 INTERNATIONAL PIPING PLOVER CENSUS

Susan M. Haig

Jonathan H. Plissner

U.S.FISH AND WILDLIFE SERVICE

Attachment 2

The Piping Plover in Texas
Habitat Profiles

I. Sandy Beach

Sand dominates the shores of the western Gulf of Mexico (Britton & Morton, 1989). For most of Texas, the outer faces of barrier islands are fringed by sandy beach. Sandy beach extends from the mean low water point landward to the mean high tide line (or the point where permanent vegetation predominates). Sandy beach can be subdivided horizontally based upon the amount of water retained by the substrate above the water line (Recher 1966). Beach can be divided into three zones: wet sandy beach (Recher's Zone A), damp sandy beach (Recher's Zone B), and dry sandy beach. Wet sandy beach extends from the water's edge to the point where the surface film of water is no longer visible. The substrate in damp sandy beach lacks a surface film of water but retains visible moisture from the most recent high tide. Dry sandy beach encompasses the area that begins at the most recent high tide line, and extends landward to the vegetation line. The Piping Plover utilizes all three of these zones. Plovers feed on wet sandy beach, and roost in depressions or among debris on dry sandy beach. The damp sandy beach should be considered a transitional zone, since plovers, depending on the given tidal regime, may be moving between feeding and roosting sties at any given moment of survey time.

II. Bay/Barrier Island Margin

Zonation of bay margins is similar to that described above for sandy beach. Tidal fluctuations are typically less extreme along bay margins, and therefore the distance from the water's edge to permanent vegetation may be quite reduced. Winter polar frontal systems, however, may generate significant tidal shifts within the bays. Immense expanses of bay margin substrate may be exposed by these strong north winds, and shorebirds will exploit these normally inundated mudflats during these periods.

III. Barrier Island Flat

As defined by Britton and Morton (1989), "barrier island flats occupy the region extending from behind the barrier island dune fields to the bayshores". Padre Island wind-tidal flats, particularly those with significant blue-green algal growth (algal "flats"), are especially important for wintering Piping Plovers. Zonick and Ryan have preliminary concluded the "algal flats appear to be the highest quality habitat for both Piping Plovers and Snowy Plovers" (1992). Tidal exchanges on these flats are often wind induced, therefore the exposed substrate (the zone attracting feeding plovers) will be found on the side of the flat or tidal pool facing the prevailing winds.

IV. Intertidal Sand/Mud Flat

Intertidal flats along the Texas coast are associated with river mouths, bay passes, hurricane washover channels or manmade structures such as jetties, fish cuts, (such Rollover Pass in Galveston County) or navigation channels or passes (such as the Mansfield Pass through Padre Island). Strong longshore currents along the Texas coast prevent gulfside (ebb-tital) flats from being emergent except for those sites where manmade structures have trapped the longshore sediments (such as Bolivar Flats at the base of the North Jetty in Galveston County). These area are characterized by little or no emergent vegetation, and they experience regular lunar-tidal inundated by a rising tide. Mabie (1989), and Zonick & Ryan (1992) have noted regular bay-to-beach (as well as the reverse) movement across Texas barrier islands.

Manmade (Artificial) Sites

Manmade sites, such as spoil islands, will present similar zonation as comparable natural habitats. The shores of spoil islands attract feeding plovers, and the upland areas are attractive to roosting birds. Spoil island and disposal sites, therefore, should be surveyed for wintering plovers under the same regimen and with the same scrutiny as natural sites.

Conclusions

Optimal sites for Piping Plovers in Texas may be generally characterized as containing extensive, sparsely vegetated algal flats, sand flats and/or sandy beaches. Piping Plovers must depend upon a blend of these habitats throughout the winter season, however, depending upon the tidal regime, whether conditions, disturbance or period of the year (such as during migration, when plovers may appear in greater numbers on sandy beaches). Winter surveys, therefore, should be structured to assess a cross section of suitable habitats and conditions for the presence of the species.

References

Britton, J.C. and B. Morton. 1989. Shore Ecology of the Gulf of Mexico. University of Texas Press, Austin. 387 pp.

Mabie, D.W. 1989. Job No 64: Piping Plover and Peregrine Falcon coastal habitat use. Federal Aid Project No. W-103R-19, Nongame Wildlife Investigations. Texas Parks and Wildlife Dept. 8 pp.

Recher, H. F. 1966. Some aspects of the ecology of migrant shorebirds. Ecology 47: 393-407.

Zonick, C. and M. Ryan. 1992. Ecology and conservation of nonbreeding Piping Plovers and Snowy Plovers. Unpub. progress report. Univ. of Missouri. 24 pp.

The Piping Plover in Texas
Winter Maritime Shorebird Guild

Black-bellied Plover (*Pluvialis squatarola*)
*Snowy Plover (*Charadrius alexandrinus*)
*Wilson's Plover (*C. wilsonia*)
Semipalmated Plover (*C.semipalmatus*)
Piping Plover (*C.melodus*)
*American Oystercatcher (*Haematopus palliatus*)
American Avocet (*Recurvirostra americana*)
*Willet (*Catoptrophorus semipalmatus*)
Long-billed Curlew (*Numenius americanus*)
Marbled Godwit (*Limosa fedoa*)
Ruddy Turnstone (*Arenaria intepres*)
Red Knot (*Calidris canutus*)
Sanderling (*C. alba*)
Western Sandpiper (*C. mauri*)
Least Sandpiper (*C.minutilla*)
Dunlin (*C.alpina*)
Short-billed Dowitcher (*Limnodromus griseus*)

The presence or absence of guild members may be helpful in assessing the probability of Piping Plovers frequenting a specific coastal site. Species marked with an astrix (*) breed along the Gulf coast, and, in the case of the Wilson's Plover, may migrate in winter to areas largely south of the United States.

Attachment 4

Piping Plover Survey Segment Form

County: Location

U.S. Geological Survey Topographic Map (Quadrangle name):

Name of surveyor:

Date of Observation:

Sunrise: Sunset:

High Tide (s): Low tide (s):

Tidal conditions during survey segment:

Wind speed and direction during survey segment:

Time segment begins: Time segment ends:

Total number of Piping Plovers observed during segment:

	HABITATS					
SPECIES	A	B	C	D	E	TOTAL
PIPING PLOVER						
SNOWY PLOVER						
WILSON'S PLOVER						
SEMIPALMATED PLOVER						
AMERICAN OYSTERCATCHER						
AMERICAN AVOCET						
WILLET						
LONG-BILLED CURLEW						
MARBLED GODWIT						
RUDDY TURNSTONE						
RED KNOT						
SANDERLING						
WESTERN SANDPIPER						
LEAST SANDPIPER						
DUNLIN						
SHORT-BILLED DOWITCHER						

HABITAL TYPES

A: D:

B: E:

C:

To Top

Attachment 5