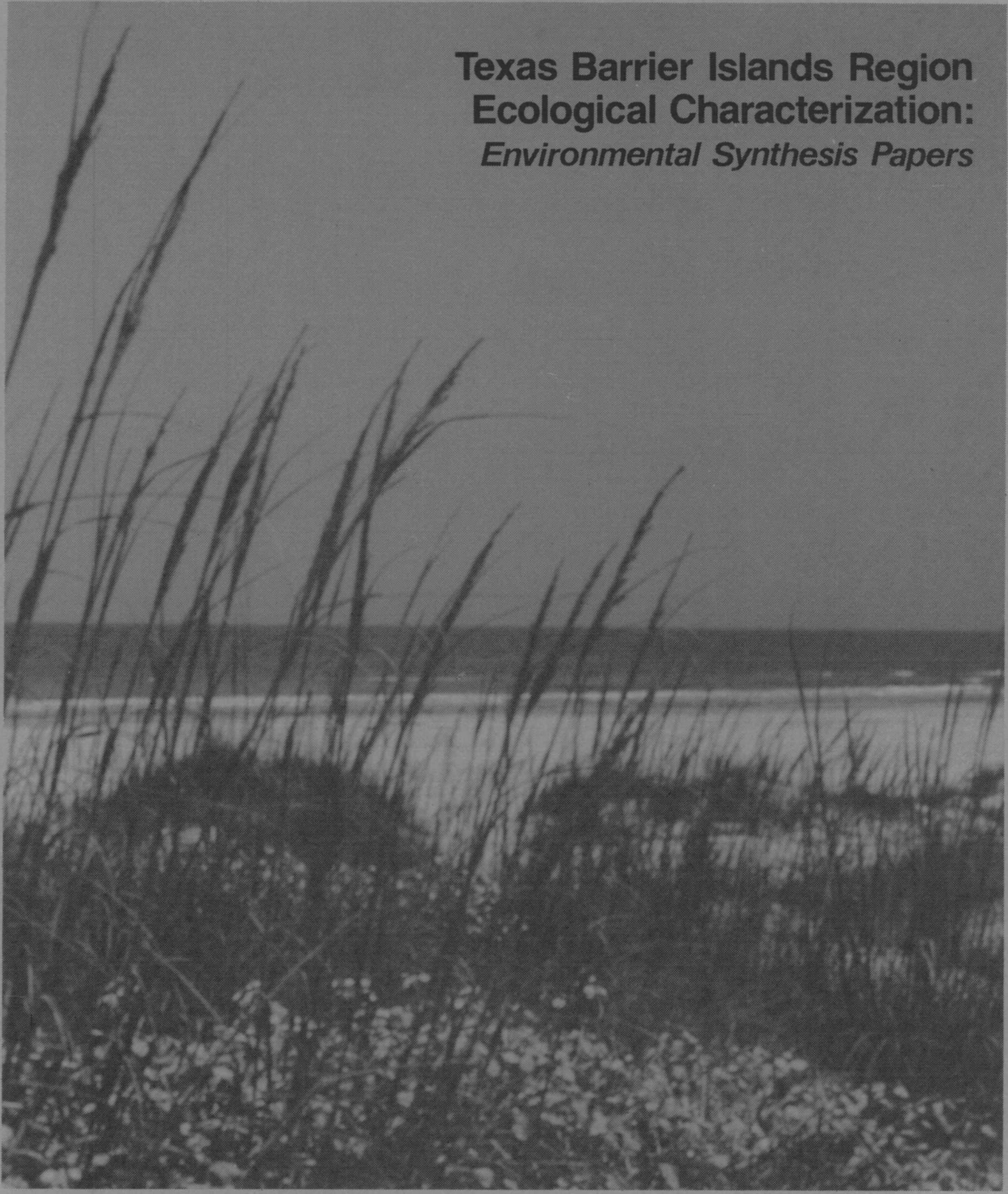
Biological Services Program

FWS/OBS-81/32
September 1981

Texas Barrier Islands Region Ecological Characterization:

Environmental Synthesis Papers



Bureau of Land Management
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FWS/OBS-81/32
September 1981

TEXAS BARRIER ISLANDS REGION ECOLOGICAL CHARACTERIZATION: ENVIRONMENTAL SYNTHESIS PAPERS

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Performed for
National Coastal Ecosystems Team
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U.S. Department of the Interior
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DISCLAIMER

The opinions and recommendations expressed in this report are those of the authors and do not necessarily reflect the views of the U.S. Fish and Wildlife Service, the Bureau of Land Management, or the U.S. Environmental Protection Agency, nor does the mention of trade names constitute endorsement or recommendation for use by the Federal Government.

This report should be cited as follows:

Shew, D. M., R. H. Baumann, T. H. Fritts, and L. S. Dunn. 1981. Texas Barrier Islands Region ecological characterization: environmental synthesis papers. U.S. Fish and Wildlife Service, Biological Services Program, Washington, D.C. FWS/OBS-81/32. 413 pp.

PREFACE

This report is a synthesis of selected environmental literature for the Texas Barrier Islands Region and is a part of the Texas Barrier Islands Region Ecological Characterization Study. Other products from this Characterization Study include an annotated environmental bibliography on magnetic tape; socioeconomic synthesis papers; 1:24,000 scale habitat maps; an ecological atlas of 1:100,000 scale maps that shows biological resources, socioeconomic features, and oil and gas infrastructure; ecosystem models; and narrative report.

The Texas Barrier Islands Region is defined to include the coastal counties shown in Map 1 and extends 64 km inland and offshore to the State-Federal demarcation.

These papers deal with six drainage basins along the Texas coast: Galveston, Matagorda-Brazos, San Antonio, Copano-Aransas, Corpus Christi and Laguna Madre; as well as, the marine system offshore. The papers address the geology, climate, hydrology and hydrography, and the biology of each basin. This study is intended to serve as a general reference work and as a guide to the literature, and is designed to be used in planning for the requirements of OCS oil and gas development and coastal zone management.

Scientific and common names discussed in the synthesis papers followed the conventions of the American Fisheries Society:

> Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. M. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. 4th ed. American Fisheries Society Special Publication 12, Bethesda, Md. 174 pp.

The authors also followed Cowardin et al. 1979 for classification of wetlands:

> Cowardin, L. M., V. Carter, F. C. Golet, and E. T. La Roe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Fish and Wildlife Service, Office of Biological Services, Washington, D.C. FWS/OBS-79/31. 103 pp.

This project was conducted by the U.S. Fish and Wildlife Service's Denver Wildlife Research Center at Belle Chasse, Louisiana. Funding was provided by the Bureau of Land Management, the U.S. Environmental Protection Agency, and the U.S. Fish and Wildlife Service. The U.S. Fish and Wildlife Service's National Coastal Ecosystems Team assumes full responsibility for the technical content of these papers.

Questions regarding this publication or requests for copies should be directed to:

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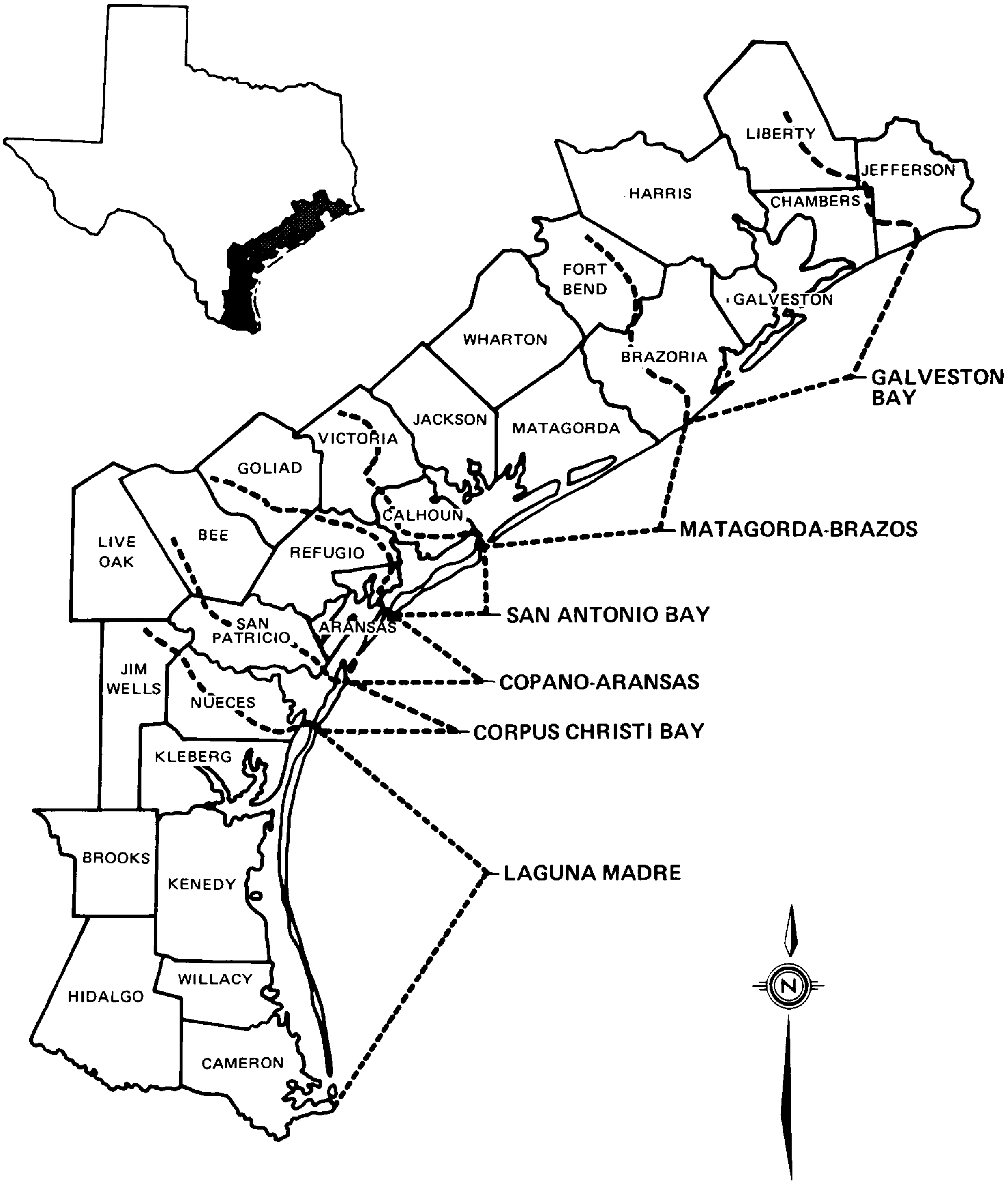

Map 1. The Texas Barrier Islands Region.

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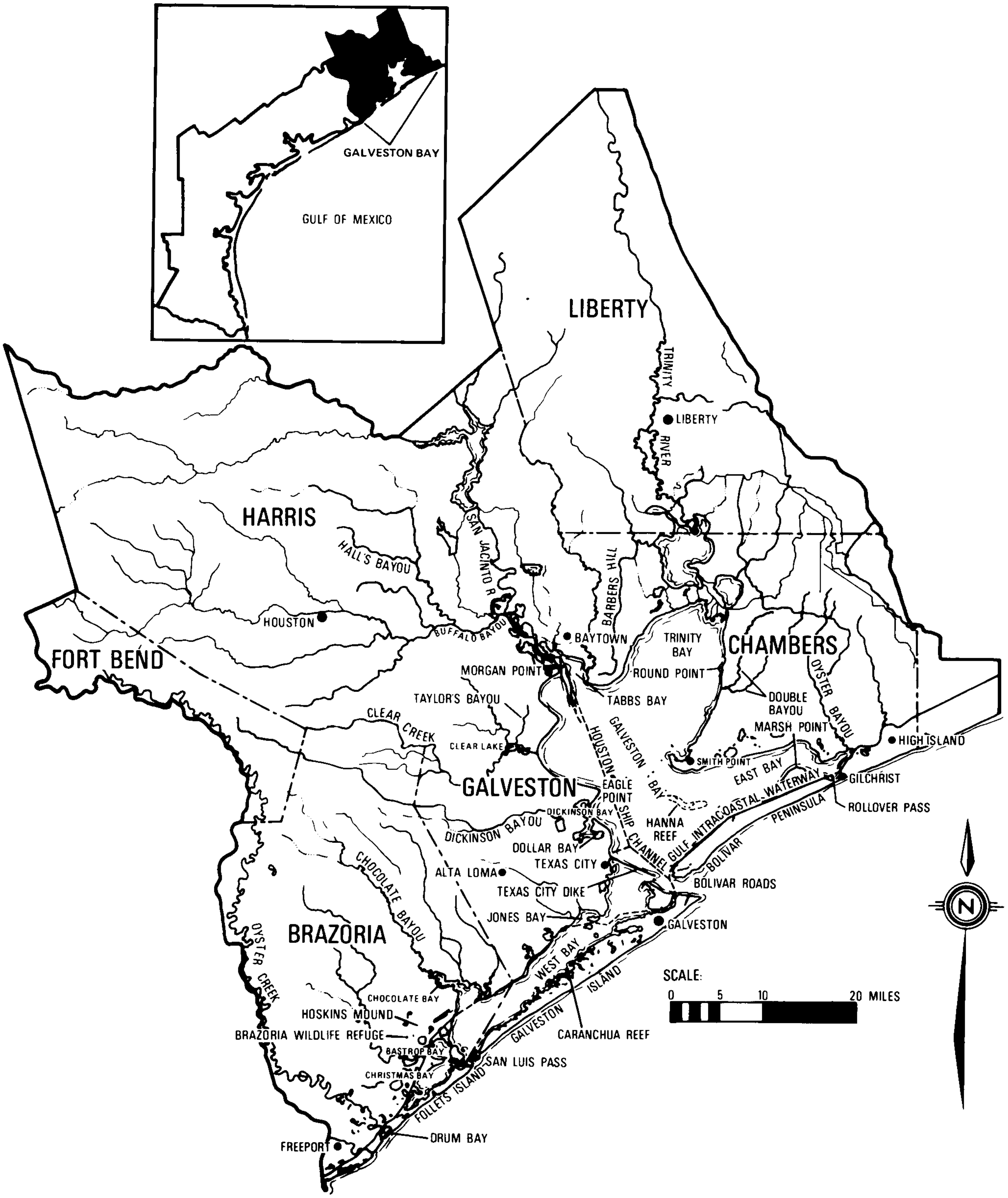
ACKNOWLEDGMENTS

We gratefully acknowledge the many individuals who assisted in the preparation of these synthesis papers. In particular, Ernest G. Simmons, Texas Parks and Wildlife Department, Austin, Texas, and B. D. King, III, U.S. Fish and Wildlife Service, Austin, served as painstaking and tireless reviewers. We wish to thank also the library staffs of the Texas Parks and Wildlife Department, Austin, and of Texas A&M University, Galveston. Others who provided help were Wayne Hoffman, Robert P. Reynolds, and Leland Roberts.

Maps of Texas were prepared by Graham Golden.

Editorial expertise was provided by Gaye Farris. Typing was done by Barbara Carney, Pam Cooper, Susan Frederickson, Joan Randell, and Daisy Singleton. Elizabeth Krebs compiled and typed the final manuscript.

GALVESTON BAY STUDY AREA SYNTHESIS



Map 2. Galveston Bay study area.

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1.0 INTRODUCTION

Of the six bay systems in the Texas Barrier Islands Region, the Galveston Bay system is most affected by human activity, most graphically exhibited in its estuarine community. The development of the Galveston Bay complex as a major port, an extensive industrial and oil refining center, and a major urban center has resulted in chemical, hydrocarbon, and domestic pollution. In fact, the Houston Ship Channel has been called one of the most polluted bodies of water in the entire United States (Carter 1970). Pollutants enter the estuary daily from many sources in addition to the Houston Ship Channel: the mouths of the Trinity and San Jacinto Rivers, the Texas City Harbor, and numerous bayous and tertiary bays. The cumulative effect of these daily effluents plus occasional severe incidents (i.e., oil spills and phytoplankton blooms) is an unknown that may be causing irreversible damage to one of the most naturally productive areas along the Texas coast.

The Galveston Bay system is also distinctive, relative to other coastal regions to the west and south, in having emergent marshes instead of submerged grassbeds as the major estuarine vegetative form. These marshes and contiguous inland areas exhibit characteristics similar to those of estuaries to the east, supporting the American alligator and various furbearing mammals. These animals persist in significant concentrations in the least disturbed areas of Galveston Bay. The humid climate of the central gulf coast is evidenced in natural areas by swamp forest and in agricultural areas by rice fields.

The Trinity and San Jacinto Rivers together provide the largest average freshwater inflow of any Texas drainage basin. This volume of freshwater is partially responsible for the large shellfish harvests. The greatest yields of these invertebrates typically occur where largest freshwater inflows are. Precipitation is also considerable in the Galveston Bay system where, on the average, precipitation exceeds evapotranspiration.

In spite of surface freshwater availability, the large Houston and Galveston populations depend upon groundwater supplies. Excessive withdrawal of groundwater in this area is largely responsible for severe man-induced subsidence. Removal of shallow oil deposits in the vicinity adds to the subsidence problem. Much land from Houston to Texas City has undergone subsidence at rates considerably greater than that characteristic of this section of Texas coast. Areas of maximum subsidence closely correlate with large declines in the groundwater aquifers (Turner, Collie, and Braden, Inc. 1966, cited by W. L. Fisher et al. 1972). Continued development promises to add to the problem, but short-term economics exert considerable influence. For example, a proposed deepwater port and crude oil distribution system in Galveston Bay would provide a big economic boost to the area, but the effects of construction, the potential for oil spillage from the facility, and associated population growth will undoubtedly add their impacts to an already highly stressed estuary. The ecological costs of such a project are potentially great and must be weighed against both short- and long-term economic factors.

2.0 GEOLOGY

2.1 GEOLOGIC ORIGIN AND PROCESSES - ESTUARINE AND RIVERINE TRANSPORT OF SEDIMENT

As with other bay systems along the Texas coast, the surface sediments of the Galveston Bay study area have been deposited within the Quarternary period, and nearly all sediments of the study area have formed from the late Pleistocene to the present (W. L. Fisher et al. 1972). Thus, in terms of geologic time, the area is young, and if we compressed the known geologic history of the earth into a 24-hour period, the Galveston Bay system and surrounding landscape would have formed during the past second.

Not surprisingly, geologic processes operative today have been intermittently in effect throughout the period of formation of the Galveston Bay study area. Sea level and rivers are the two key elements responsible for much of the morphologic character of the area. Large-scale changing of sea level through time and the responses of rivers in terms of adjustment in grade are results of changes in global climate. During the past million or so years, the global climate has been dominated more by ice ages than by warm periods, such as the present (National Academy of Sciences 1975). During glacial episodes, sea level dropped by a maximum of at least 50 m in the gulf, moving the coastline some 80 km seaward of the present-day city of Galveston (W. L. Fisher et al. 1972). Ancestral rivers of the present-day Trinity and Brazos-Colorado systems responded by becoming entrenched in the Galveston Bay study area, forming deltas and deltaic plains in the vicinity of the new coastline (Bernard and LeBlanc 1965). During intermittent interglacial periods, sea level rose, moving the coastline landward, and rivers aggraded. This cyclical pattern, with variation in the extent of the rises and falls of sea level, has been repeated at least several times throughout the Quarternary period (National Academy of Sciences 1975), with the exact number of occasions unknown and the subject of much debate.

Before the last major glacial epoch, sea level was approximately at the same level as present (W. L. Fisher et al. 1972). During this period, the predecessors of the present Trinity and Brazos-Colorado River systems deposited much of the uplands in the study area. This depositional system is referred to as the Beaumont Formation and consists of fine-grained interdistributary muds, fluvial silts and sands, and reworked marine deposits (Bernard and LeBlanc 1965).

With the beginning of the last major glacial epoch, sea level fell and processes forming the surface deposits of the Beaumont Formation ceased. Several lesser rises and falls in sea level occurred during the last glacial epoch, and during one high stand the Ingleside sands developed. While more conspicuous along the central Texas coast, the Ingleside feature appears in the Galveston Bay area at the surface from Smith Point northeast to the settlement of Double Bayou, and also south of Dollar Bay and east and west of Chocolate Bay (W. L. Fisher et al. 1972). Graf (1966), in his investigations of the Ingleside at Smith Point, determined that its maximum age was 58,000 years B.P. (Before Present), but a more recent study by Wilkinson et al. (1975) indicated the feature may be somewhat younger. Although some controversy exists as to whether the Ingleside was a series of barrier islands or a strandplain deposit, the function of either would have been the same in present-day barrier island formation (see Corpus Christi Bay synthesis for further discussion on the Ingleside sands).

The beginning of sea level rise to its present level, about 18,000 years B.P. (W. L. Fisher et al. 1972), marked the termination of the Pleistocene. With the rise in sea level, the Trinity and San Jacinto Rivers began to fill their valleys. As sea level rose faster than the rivers' capability to supply sediment, marine transgression was dominant, and unfilled segments of the Trinity and San Jacinto River valleys became Galveston and Trinity Bays (Lankford and Rehkemper 1969). The early rate of filling of Galveston and Trinity Bays by riverine sediment was probably substantially greater in the past than now. This assumption is based on morphologic evidence of past meandering patterns (W. L. Fisher et al. 1972). The greater meandering pattern of the past indicates that the rivers carried substantially more flow. Due to the erosion of bay shorelines, the areal extent of these bays is larger now than when they first developed (McGowen and Morton 1977, cited by Espey, Huston and Associates 1978).

West and East Bays formed as a result of the development of Galveston Island and Bolivar Peninsula. Galveston Island was formed as an offshore bar approximately 6 km from shore in 2 m of water during the initial period of present sea level (Bernard et al. 1959). The island grew laterally by spit accretion and in width by beach accretion, overwash deposits, tidal deltas, and wind transport. The sand was derived from the erosion and onshore transport of offshore Pleistocene deltaic sands, and the deposition of sands carried by littoral drift from the deltas, rivers, and eroded beaches and bay shorelines (Morton 1977a). Enlargement of Galveston Island and Bolivar Peninsula has continued for several thousand years, but during at least the last century these barriers experienced net erosion (Morton 1974, 1975). This reversal is apparent among all Texas barrier islands, and the exact causes are not clearly understood (for future implications of this reversal see Section 2.1 of the Corpus Christi Bay synthesis). Current processes and activities that cumulatively may have led to this reversal include the following: artificial structures that inhibit littoral drift, damming of rivers reducing sediment supply to the coast, equilibration of the inner shelf profile resulting in a reduced onshore transport of sand by wave action, eustatic (global) sea level rise, and accelerated subsidence (Tanner 1975; Morton 1977a).

Within the Galveston Bay estuarine complex, several processes supply sediments: riverine deposition, wind transport, bay shoreline erosion, tidal and storm transport of gulf sediments, and internal biogenic production and dispersal. The relative contribution of each of the above components to the total sediment input into the Galveston Bay complex is unknown. The sediment input from rivers cannot be accurately assessed because a long-term sampling record does not exist. Based on data reported by Shepard (1953, cited by Diener 1975) and sediment concentrations reported by the U.S. Geological Survey (USGS 1972-1976), the Trinity River has a sediment load comparable to that of the Colorado River. W. L. Fisher et al. (1972) reported that the Trinity River Delta has prograded approximately 15 km during the past 1,000 years. Shepard (1953, cited by Diener 1975) estimated that the net sediment gain in Galveston Bay (from all sources), expressed in terms of a mean shoaling rate, is 0.4 m/century. Espey, Huston and Associates (1978) reported that the contribution of eroded bay shoreline sediments to the shoaling of the Galveston Bay complex was substantial, but no quantitative estimates were made.

While exchanges of sediments between the Gulf and Galveston Bay complex are known to occur, there are no known quantitative assessments of the exchange. Hall (1976, cited by Espey, Huston and Associates 1978) estimated that net littoral transport was approximately 9.3 x 10^4 m^3 to the southwest during winter and 1.8 x 10^4 m^3 to the northeast during summer along Galveston Island and Bolivar Peninsula. Ward et al. (1979), using the shoreline change data of Morton (1977b, cited by Ward et al. 1979), estimated a net littoral transport to the west (southwest) of approximately 2.5 x 10^5 m^3/yr. While these estimates indicate the amount of material moving along this coastline, it is not known where the beach sediment is transported in the process of erosion (i.e., into the bays via the passes or offshore). The sediment exchange through tidal passes and the sediment transport by storms can only be inferred. The tidal deltas formed at San Luis Pass and Bolivar Roads are evidence of sediment deposition; and features such as Marsh Point on the East Bay side of Bolivar Peninsula represent storm washover deposits overlying inactive flood tidal delta deposits (W. L. Fisher et al. 1972).

Due to Galveston Bay's humid climate, wind transport of sediment is relatively unimportant, occurring only during dry periods (W. L. Fisher et al. 1972).

2.2 SOILS

The parent material for soil development in the Galveston Bay study area is the sediments deposited primarily by the Trinity, San Jacinto, and Brazos-Colorado Rivers. Many lesser streams in the area are remnant tributaries and distributaries of these rivers (W. L. Fisher et al. 1972), and the material they transported during the Pleistocene was the same as that of the trunk channels. The material they presently carry results from headward erosion into these Pleistocene deposits.

Major soil differences within the Galveston Bay system are closely associated with morphologic variability and their relationship to the water table. Soil types with similar characteristics are often referred to as soil associations. According to W. L. Fisher et al. (1972) and the U.S. Department of Energy (USDOE 1978), the study area's soil associations correlate with landscape units. The major landscape units and their soil associations include the (1) Pleistocene and Recent (Holocene plus Modern) channel fill deposits, (2) Pleistocene and Recent interdistributary deposits, (3) barrier island and strandplain deposits, and (4) marsh soils.

Except for some differences in the extent of the various soil series, a high degree of similarity exists between the Galveston Bay and Matagorda-Brazos study areas. The description of soil groups and their associated landscape units given in the Matagorda-Brazos synthesis also applies to the Galveston study area. The reader is also referred to Geib et al. (1928), Foster and Moran (1930), Crout et al. (1965), W. L. Fisher et al. (1972, 1973), McGowen et al. (1976), and Wheeler (1976).

2.3 TOPOGRAPHIC AND BATHYMETRIC FEATURES

The Galveston Bay study area has a gentle slope of approximately 0.3 m/km from the inland boundary to the coastline. In general, topographic relief is subtle except where salt domes have uplifted their overburden to about 10 m above the surrounding landscape (also see Section 2.4).

The gentle slope of the uplands continues through the open water bodies. Trinity and upper Galveston Bays average 1.6 m in depth while lower Galveston Bay averages 2 m with areas of up to 4 m. The contiguous West and East Bays are even shallower, averaging slightly more than 1 m in depth (Diener 1975). Natural tidal passes like Bolivar Roads and San Luis Pass typically contain the greatest depths. The main channel of Bolivar Roads normally has depths exceeding 10 m, and the smaller San Luis Pass maintains depths in excess of 5 m (W. L. Fisher et al. 1972). Both tidal passes are over partially buried Pleistocene river valleys, and in the case of Bolivar Roads, the base of this ancient channel is in excess of 80 m in depth (W. L. Fisher et al. 1972). Tidal passes over Pleistocene valleys are common along the Texas coast (W. L. Fisher et al. 1972) and have been active in approximately their present location for thousands of years.

The cross sectional profile of Bolivar Roads has been modified with the construction of the ship channel, and proposals to deepen the channel as part of the deepwater port system will probably lead to the continued modification of natural channels (Espey, Huston and Associates 1978). San Luis Pass, on the other hand, remains one of the few unmodified tidal passes along the Texas coast (W. L. Fisher et al. 1972).

2.4 UNIQUE OR UNUSUAL FEATURES

Although no geologic features are unique to the Galveston Bay study area compared to other areas along the Texas Barrier Islands Region, many of the more interesting features of the area are found in the Galveston study area.

Active river deltas, such as the Trinity River Delta and contiguous floodplain, support a diverse array of habitats including fresh, brackish, and salt marshes, levees, beach ridges, swamps, and shallow low energy lakes (W. L. Fisher et al. 1972). While the San Jacinto River carries a sufficient sediment load, it has not built a substantial bay head delta because of extensive modifications from channelization and spoil disposal (W. L. Fisher et al. 1972).

The Ingleside barrier-strandplain deposit, although present in this study unit, is not as conspicuous and its biological value is probably less here than along the central Texas coast (e.g., Aransas National Wildlife Refuge). While its diminished biological importance is only conjecture, the feature is smaller in the Galveston unit (W. L. Fisher et al. 1972). The live oak vegetation is limited to a few isolated areas and has been largely replaced by grasses (Graf 1966), and the ridge-and-swale topography that results in a high edge ratio between habitats has been naturally modified and reduced in this area. The swales that support marsh vegetation have been reduced to noncontinuous small depressions, and the ridges are no longer as pronounced as in their original state (Graf 1966; W. L. Fisher et al. 1972).

The three passes in the Galveston study area are Rollover Pass on the Bolivar Peninsula, an artificial pass; Bolivar Roads near Galveston, the major natural pass but modified by man; and San Luis Pass in the southwest part of the study area, still in its natural state. All three passes are exchange points for water, nutrients, sediment, and fauna. San Luis Pass contains a highly developed active flood tidal delta. Within this delta complex has evolved a high diversity of habitats, including emergent marshes, tidal flats, and submerged grassbeds (W. L. Fisher et al. 1972). Evidence of this area's importance to fish and wildlife resources is provided by Blacklock et al. (1978). For example, he reported three important fish-eating bird rookeries containing several species in the immediate vicinity of San Luis Pass and its flood tidal delta.

Salt domes are relatively common along the gulf coast. Formed from ancient beds of salt that have risen through faults in the sedimentary column, the domes and their periphery frequently are sources of sulphur, oil, and gas. The comparatively few that have risen above the land surface, often support a vegetation different from that of the surrounding environment. Hoskins Mound, Blue Ridge, Barbers Hill, and High Island are some prominent domes in the Galveston Bay area. High Island, near the coastline east of East Bay, has long been a temporary refuge for migratory birds returning across the Gulf of Mexico from their wintering grounds. As such, it is a regular observation area for the Audubon bird counts.

2.5 MAN-MADE DEVELOPMENTS

Geologically, the Galveston Bay study area is an infamous example of man-induced subsidence. While significant biological changes (such as the change from wetlands to open water and upland prairies to wetlands) are associated with subsidence, attention is usually focused on impacts on the cultural environment. Entire housing subdivisions, as in Baytown, have been abandoned due to subsidence (Kreitler 1977).

The processes involved in subsidence are multiple and complex, and the effects of particular processes are difficult to distinguish. Subsidence occurs naturally in the Galveston Bay study area, as it does along much of the U.S. gulf coast. Swanson and Thurlow (1973) estimated from tide gage records that subsidence near the city of Galveston was 12.8 cm from 1959 to 1970. This figure represents a single geographical point, and subsidence rates are variable over space. For example, the adjusted subsidence rate for the 1959-70 period from tide gage records obtained from the mouth of West Bay was 9.3 cm (Swanson and Thurlow 1973). Both values are within the general range of subsidence values determined for stations along the coast to the east and west (Swanson and Thurlow 1973; Gosselink et al. 1979); and the Galveston Island area does not appear to be one of the more adversely affected areas.

Much of the area from Houston to Texas City has substantially higher subsidence rates. Turner, Collie, and Braden, Inc. (1966, cited by W. L. Fisher et al. 1972) clearly showed that areas of maximum subsidence rates correlate with the centers of maximum decline in groundwater aquifers. By 1964, areas along Buffalo Bayou and in the vicinities of Baytown and Texas City had subsided by nearly 2 m. By the mid-1970's maximum subsidence was 2.5 m in the Baytown area (Kreitler 1977), and projections by Turner, Collie, and Braden, Inc. (1966, cited by W. L. Fisher et al. 1972) indicated that total subsidence would ultimately be greater than 3 m even if excessive groundwater withdrawals were halted by the mid-1960's.

While groundwater withdrawals (see Section 4.4) are clearly the main contributor to man-induced subsidence, the withdrawal of shallow deposits of oil has also resulted in localized surface subsidence. Sheets (1947) attributed the 3 m of subsidence in the Hoskins Mound area to oil extraction. Weaver and Sheets (1962) reported 1 m of surface subsidence from production at the Goose Creek oil field.

Other geologic impacts of man's activities are apparent in the Galveston Bay study area and are, for the most part, similar to those found throughout the Texas Barrier Islands Region. The jetties extending offshore at Bolivar Roads have intercepted the littoral transport of sediment, resulting in accretion along the western end of the Bolivar Peninsula (Seelig and Sorenson 1973; Morton 1975, 1977a, 1977b).

The construction of the Gulf Intracoastal Waterway (GIWW) and Rollover Fish Pass has modified the hydrology of East Bay (see Sections 4.1, 4.2 and 4.5). These channels are avenues for sediment transport. With increased erosion of local streams due to agricultural practices (U.S. Department of Agriculture 1976, cited by Gosselink et al. 1979), the channels have led to increased sedimentation in the eastern end of East Bay (Gosselink et al. 1979).

The filling of the lower San Jacinto River floodplain and the formation of a bay head delta have been greatly modified by man's channelization activities. The maintenance of an artificial deep navigation channel allows sediment to be transported farther downstream, and the creation of spoil banks alongside the channel further inhibits overbank flooding and natural sedimentation (W. L. Fisher et al. 1972). The result is that highly diverse and valuable wildlife habitats that have developed on Trinity River Delta and contiguous floodplain are not well developed on the San Jacinto River below Buffalo Bayou.

The shell-dredging industry has been significant in the Galveston Bay estuarine complex, and oyster mortalities result from sedimentation induced by shell-dredging (Benefield 1976). The effects of the shell-dredging industry are discussed more fully in the San Antonio Bay synthesis.

3.0 CLIMATE

3.1 PRECIPITATION

Galveston Bay is the only humid bay system within the Texas Barrier Islands Region. Rainfall appears more variable over the Galveston Bay area than in other systems, but this may be due to the density of rain gages in this study area. According to the National Oceanic and Atmospheric Administration (NOAA), the Galveston Island area, in the southwest corner of this study area, apparently receives the least rainfall, averaging 1,072 mm/yr (NOAA 1973a). Rainfall is most abundant in the upper Trinity Bay area where normal (30 year mean) annual precipitation is 1,342 mm (NOAA 1973a). In comparison, the Houston area averages 1,224 mm/yr, and 1,264 mm/yr is normal in the inland vicinity of Liberty. Except in the Galveston Island area, precipitation increases in a northeast (upcoast) direction. The Galveston

Island area receives less rainfall than areas upcoast, downcoast, or inland. Whether this is a natural phenomenon or merely reflects instrument placement cannot be assessed as the nearest reporting gages are in Freeport, Angleton, Anahuac, and the greater Houston area.

The seasonal distribution of rainfall in the Galveston Bay study area (Figure 1) differs from other study areas within the Texas Barrier Islands Region. Three seasonal precipitation regions exist along the Texas coast. The largest region covers the coastal area from the northern half of the Laguna Madre study area to the Matagorda-Brazos system. This area experiences a bimodal distribution in rainfall with peaks occurring in spring and fall (late summer). The southern half of the Laguna Madre study area receives most of its rainfall during the late summer. The Galveston Bay study area, with the most precipitation, has a variable seasonal precipitation regime over its geographic extent. Inland and eastern parts of this study area (represented by Liberty in Figure 1) have a fairly uniform seasonal distribution of rainfall which extends east of the Texas Barrier Islands Region into Louisiana (Gosselink et al. 1979). In the Galveston Island area, rainfall gradually increases in abundance throughout the summer. The late summer peak is followed by a rapid decrease. The increase in summer precipitation is due primarily to the decrease in the difference between air temperature and dew point temperature (Carr 1967). That is, as warm gulf air rises and cools, the amount of cooling required to produce condensation is less in the Galveston Island area than it is farther down the coast.

3.2 TEMPERATURE

Mean annual air temperature is 21.0° C at Galveston, 20.5° C at Houston, and 20.3° C at Liberty (NOAA 1973a). The maximum monthly temperature is in August, and the minimum monthly temperature is in January at all three stations. The coastal versus inland difference in mean monthly temperature is apparent only during winter in the Galveston Bay study area. Houston and Liberty are approximately 1° C lower in their mean monthly temperatures than is Galveston during the winter. In summer, however, mean monthly temperatures at all three stations are approximately the same. From the pattern evident in the Corpus Christi through Matagorda-Brazos study areas, one might expect Galveston to be slightly cooler during summer than Houston and Liberty, but the proximity of the Galveston weather station to the downtown urban environment may have a warming effect during summer.

The Galveston Bay system is the coolest of the study areas and the length of its growing season reflects this. The western margins of this study area have a growing season of approximately 270 days, decreasing to 260 days along the eastern boundary.

The combined effect of lower temperature and increased precipitation in the Galveston Bay area in contrast to other study areas is best seen in the climatic water budget approach (Thornthwaite and Mather 1955). Orton (1969), using the noncontinuous method, calculated annual moisture surpluses and deficits for Texas. He showed that the Galveston Bay study area averages a net (surpluses minus deficits) surplus of 100 mm in the area bordering the Matagorda-Brazos study area, increasing to 200 mm along the eastern boundary. Seasonally, surpluses are greatest during winter when evapotranspiration rates

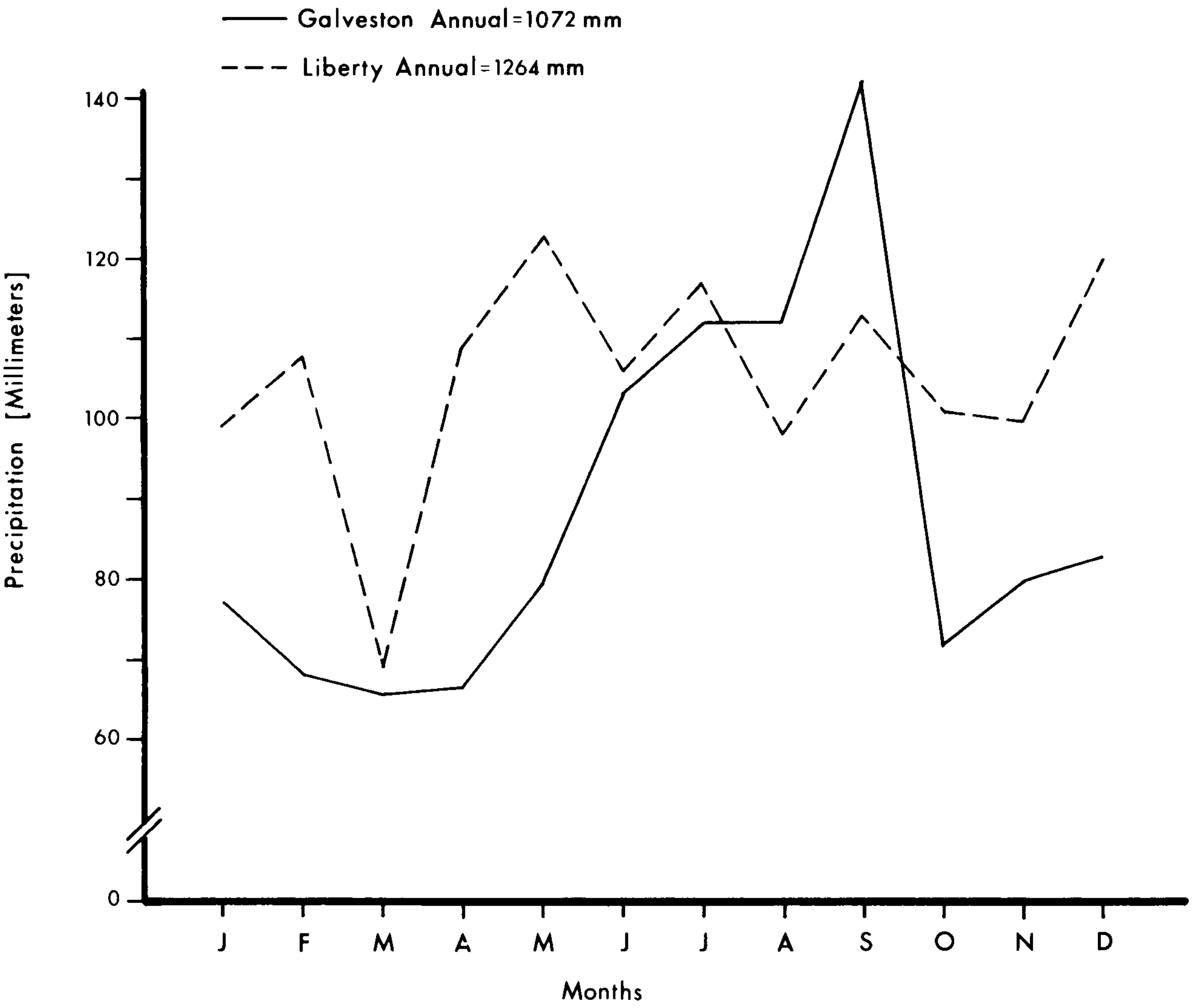

Figure 1. Mean seasonal precipitation for Galveston and Liberty, 1941-1970 (NOAA 1973a).

are low; deficits occur during the summer (Figure 2). Galveston has a greater deficit (annual = 169 mm) than Liberty (annual = 123 mm), and less surplus (189 mm vs. 259 mm). The net annual moisture surpluses are 20 mm for Galveston and 136 mm for Liberty (Orton 1969). This considerable difference emphasizes the relative dryness of Galveston compared to the surrounding environments within the Galveston Bay study area (i.e., Liberty is more representative of the area than Galveston). In comparison with other study areas within the Texas Barrier Island Region, the Galveston Bay study area generates more surpluses and less deficits (for comparative water budgets see Laguna Madre, Copano-Aransas, and Matagorda-Brazos syntheses).

3.3. WIND PATTERNS

The Galveston Bay study area, as well as other Texas coastal basins, is influenced by three distinct wind regimes: southeasterly to southerly, northerly, and the highly variable winds associated with tropical disturbances (see Matagorda-Brazos and Laguna Madre syntheses for general environmental responses). The tropical disturbance weather type is included as a distinct wind regime due to its related rapid changes. While tropical storms occur infrequently and associated wind directions are variable, the winds' strength can produce greater morphological changes than the more persistent wind regimes. This is an important and often overlooked concept which has application beyond wind regimes.

Table 1 points out the relative frequency of wind direction in the Galveston area. Data obtained by the Texas Air Control Board (1978) indicate that wind energy for northerly components is greater than for southerly components, and the mean strength of the northerlies is greater at the more inland station (Houston-east) than the more coastal station (Texas City). Yet mean wind speed in 1978 at Texas City exceeded that of Houston-east (6.8 and 5.4 knots, respectively) because of the greater intensity of southerly components of wind at Texas City. These same patterns probably exist in the other study basins with the possible exception of the lower Texas coast.

Wind is an important part of geologic and hydrologic processes in the Galveston Bay study area (see Sections 2.1 and 4.2) but of lesser significance there than along the lower Texas coast (e.g., Laguna Madre). This diminished significance is due, not only to the decreased intensity of the wind in the Galveston Bay area, but also due to the greater riverine input, local precipitation, and tidal range.

4.0 HYDROLOGY AND HYDROGRAPHY

4.1 TIDAL INFLUENCES - SALINITY REGIMES

Gravitational tides in the Galveston Bay study area average 40 cm in range in lower Galveston Bay, decreasing to approximately 30 cm in East, West, Trinity, and upper Galveston Bays (Diener 1975; Espey, Huston and Associates 1978). The ratio of the two principal daily to the two semidiurnal harmonic constituents at Galveston is 1.80, indicating that tides are mixed diurnal (Marmer 1954). The amplitude of the harmonic constants is approximately

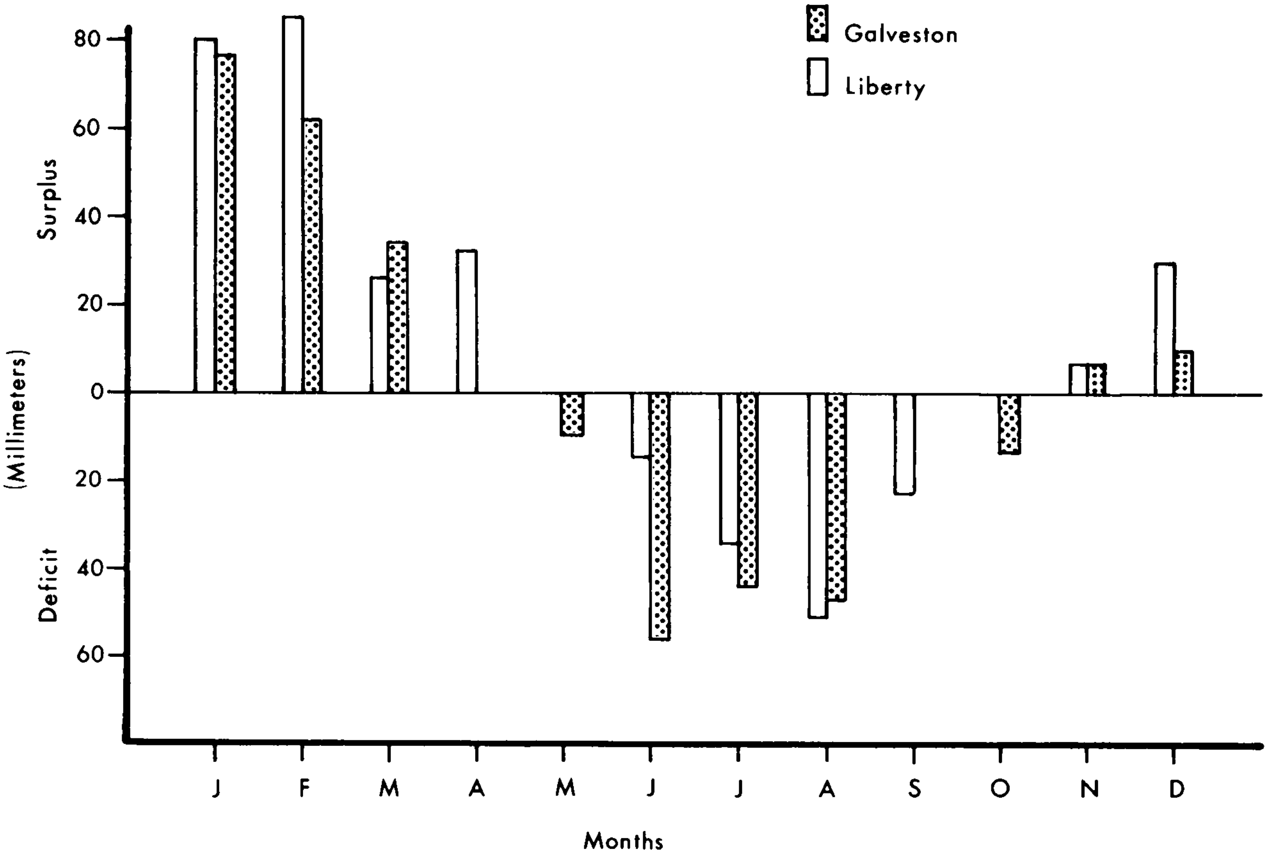

Figure 2. Mean seasonal noncontinuous water budget for Galveston and Liberty, 1941-1970, calculated by using the Thornthwaite and Mather (1955) method. Precipitation and temperature data are from NOAA (1973a).

Table 1. Frequency and direction of wind in the Galveston Bay area, 1978. Direction is that from which the wind is blowing. Frequency is the percentage of time (Texas Air Control Board 1978).

Direction	Texas City frequency	Houston-east frequency
0°	8.0	9.7
22.5°	9.2	7.8
45°	10.2	9.6
67.5°	7.3	4.5
90°	5.7	3.2
112.5°	5.7	2.7
135°	7.7	3.3
157.5°	9.9	4.6
180°	10.5	9.3
202.5°	3.4	13.3
225°	4.5	9.7
247.5°	3.1	5.1
270°	2.2	3.7
292.5°	2.4	2.9
315°	5.3	4.2
337.5°	4.7	5.9

11 cm each for the two principal diurnal components, while the amplitude for the principal semidiurnal lunar component is 10 cm and 3 cm for the principal semidiurnal solar component (Marmer 1954). The 1.80 ratio of diurnal to semidiurnal harmonic constituents was the lowest (least diurnal) of any tide station along the Texas Barrier Island coast (Marmer 1954). The Galveston Bay area favors diurnal tides, as the ratio increases to 1.96 at Gilchrist in East Bay (before Rollover Pass construction), 2.83 at Carancahua Reef in West Bay, 3.13 at Round Point in Trinity Bay, and 4.08 at Morgan Point near the boundary between Tabbs and Galveston Bays.

The greatest range in gravitational tides in the Galveston Bay area is associated with maximum declination of the moon (diurnal) and results in a maximum range of about 1 m (Espey, Huston and Associates 1978). The tidal prism for the Galveston Bay complex from great declination to small declination is on the order of 10^8 m^3 (Espey, Huston and Associates 1978). In comparison, the volume of water discharged from the bay complex as the result of the passage of a strong frontal system is on the order of 10^9 m^3 (Espey, Huston and Associates 1978).

The tide enters the bay system as a progressive wave (stage and current are in phase) and then acquires a standing component (Espey, Huston and Associates 1978). Tidal attenuation is not uniform through the bay complex. Attenuation is generally slight but occurs abruptly in Galveston Bay in the area between Eagle and Smith Points (Espey, Huston and Associates 1978) and between East and Galveston Bays over the Hanna Reef complex (Gosselink et al. 1979).

Tidal exchange occurs through two natural passes and one artificial pass. Bolivar Roads, the largest natural pass, has been modified by man on several occasions, primarily for navigation (Espey, Huston and Associates 1978). Based on investigations by Prather and Sorenson (1972) and modeling of flows through Bolivar Roads by Espey, Huston and Associates(1978), approximately 80% of the tidal exchange through the passes in the Galveston Bay study area occurs through Bolivar Roads.

At the southwest end of Galveston Island, San Luis Pass carries much of the tidal prism for West Bay. This pass, virtually unmodified by man, normally carries less than 20% of the total Galveston Bay complex tidal prism. During periods of small declination (minimum tidal range), however, this pass carries more than 30% of the bay complex tidal prism (Espey, Huston and Associates 1978).

Rollover Pass at Gilchrist is an artificial pass created in 1955. It was designed to improve circulation in East Bay, provide an additional route for fish movements between the estuary and gulf, and provide additional access for recreational fishermen (Reid 1956; W. L. Fisher et al. 1972; Prather and Sorenson 1972). The pass quickly became unstable, necessitating the construction of sills and bulkheads to prevent further scouring (Prather and Sorenson 1972; Espey, Huston and Associates 1978). The area affected by tidal exchange through Rollover Pass is limited and has been estimated at approximately 205 ha for East Bay. The tide is probably attenuated somewhere in the central portions of East Bay, and approximately 1% of the flow through Bolivar Roads is exchanged through Rollover Pass (Prather and Sorenson 1972).

An additional source of tidal exchange occurs between the Galveston and neighboring hydrologic basins through the GIWW. The amount of tidal exchange through the GIWW is small compared to that through the passes. James et al. (1977), however, reported that the difference in tidal phase and amplitude along the GIWW from East Bay to the Sabine Lake area was an important factor in the net flow of water through the GIWW from the Sabine Lake area to East Bay (also see sections 4.3 and 4.5).

Since the magnitude of the tidal range along the northern gulf coast is small, the effect of wind on water flux is proportionately large in comparison to other areas where tidal range is greater. In the Galveston Bay study area, the magnitude of these wind-induced water fluxes is frequently greater than that of gravitational tides (Espey, Huston and Associates 1978), and when the two are out of phase, the regularity of gravitational tides based on water level records is not apparent (Gosselink et al. 1979). During periods when the two are in phase, meteorologic effects can augment tidal range. The common usage of the term "tide" along the northern gulf coast has come to include both tidally and nontidally induced water level changes due to the difficulties in distinguishing the two. The largest change in water flux results from hurricanes. However, the more regularly occurring frontal passages often result in a discharge of water from the Galveston Bay complex that is approximately an order of magnitude greater than the average tidal prism (Espey, Huston and Associates 1978) and roughly equivalent to that induced by a maximum gravitational tide (Ward et al. 1979).

The seasonal pattern of water flux in the Galveston Bay area (Figure 3) is bimodal, a pattern evident throughout the Texas Barrier Islands Region. The change in water level from the winter minimum to the fall maximum is approximately 27 cm at Galveston. From studies in Corpus Christi Bay (Smith 1977), it is apparent that this cycle is important in the flushing of bays (see Section 4.2). While the fall maximum and winter minimum are frequently called high and low tides by gulf coast residents, the seasonal changes in water level are largely associated with regional climatic changes. The seasonal pattern, described by Marmer (1954), is attributed by Whitaker (1971) and Sturges and Blaha (1976) to temporal variability in regional wind stress, seasonal heating and cooling of water, and seasonal variability in river discharge.

The salinity regime of the estuary is determined by (1) the interaction of tidal and freshwater flows combined with other factors contributing to the dispersal of these flows, (2) precipitation added to the bay waters, (3) and evaporation of bay waters. Because of relatively simple methods involved in obtaining salinity readings and the easy access to the Galveston Bay area, a considerable data base has been generated. According to Espey, Huston and Associates (1978), salinity has been regularly monitored in the area by the National Marine Fisheries Service, Texas State Department of Health, Texas Water Development Board, Texas Water Quality Board and the Texas Parks and Wildlife Department (TPWD).

Mean salinity from 1965 through 1975 in the Galveston Bay complex was 17.3 $^0/_{00}$ (Martinez 1975). The large riverine inflow and abundant precipitation account for the lower mean salinity, compared with that of Corpus Christi, Laguna Madre, and Matagorda-Brazos Estuaries. The San Antonio Bay and Copano-Aransas study areas have lower mean salinities (San Antonio Bay,

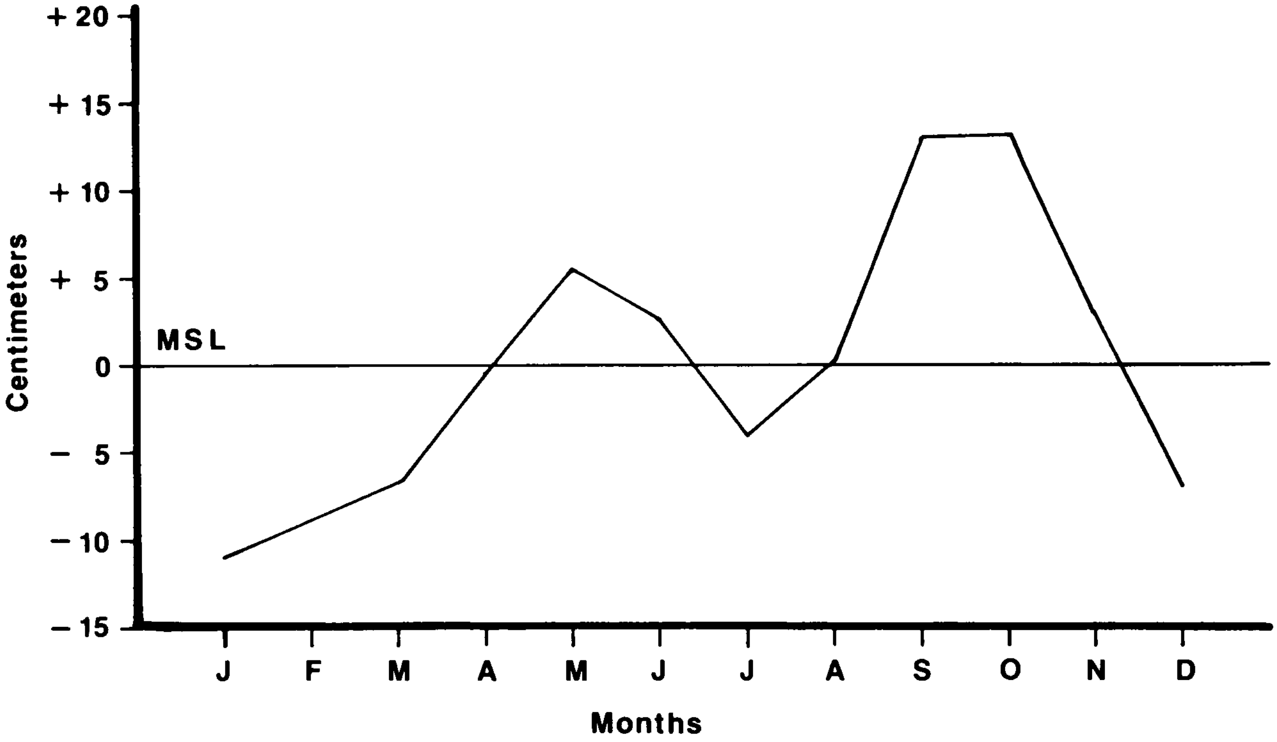

Figure 3. Seasonal variation in sea level at Galveston, 1930-1948 (Marmer 1954).

13.7 $^{o}/oo$; Copano-Aransas 16.4 $^{o}/oo$) (Martinez 1975). Both the San Antonio Bay and Copano-Aransas areas receive less precipitation and less riverine inflow than does the Galveston Bay area, but this is compensated for by the small volume of their respective estuaries in comparison to the Galveston Bay complex (also see Section 4.3).

Mean salinity is spatially variable within the bay complex. Trinity Bay is generally the least saline because of the Trinity River's outflow. Salinity along the western part of Galveston Bay is typically higher than on the east, a factor attributable to the combined influence of Trinity River inflow to the east and the partial barrier formed by the dredge spoil along the Houston Ship Channel (Espey, Huston and Associates 1978). Isohalines plotted by Espey, Huston and Associates (1978) and representing data gathered by several agencies clearly show that the Houston Ship Channel is the primary path for salinity intrusion into Galveston Bay. While vertical stratification is generally absent in the bays, the Houston Ship Channel and other dredged channels are exceptions (Espey, Huston and Associates 1978). In West Bay, salinity gradients are generally small due to the low freshwater input and the large exchange with the gulf at either end (Espey, Huston and Associates 1978). In East Bay, the major flow of freshwater is from the east (Gosselink et al. 1979), and the isohalines plotted by Espey, Huston and Associates (1978) indicate the horizontal salinity gradient is from west to east (high to low). In other words, the dispersion of salinity is primarily affected by Bolivar Roads, while the effect of Rollover Pass on East Bay salinities is limited. This conclusion is supported by the work of Prather and Sorenson (1972) but conflicts with Reid (1956). Reid compared the salinity from a single summer after the opening of Rollover Pass to the salinity from one summer before construction. The resulting salinity increase and associated changes in fish fauna may have resulted from natural variability rather than the opening of the pass. The work of Hofstetter (1977) may indirectly support the work of Reid (1956). Hofstetter noted that the oyster harvest has generally increased in the East Bay area since the mid-1950's, except for a few years during the 1960's, which Benefield (1976) attributes to oyster mortalities resulting from shell-dredging. Gosselink et al. (1979) noted that the presence of oysters and their apparent increase in abundance contradict the poor circulation concept.

Salinity usually fluctuates with time as a result of freshwater inflows that vary by several orders of magnitude (Espey, Huston and Associates 1978). The salinity data of Martinez (1975) clearly show a relationship between seasonal freshwater inflows and seasonal salinity. Mean maximum seasonal salinity change (high month, to low month) based on the data of Martinez (1967, 1970-1975) was 11 $^{o}/oo$, while the range in mean annual salinity was 11.8 $^{o}/oo$ from a high of 23.6 $^{o}/oo$ in 1967 to a low of 11.8 $^{o}/oo$ during the 1965-75 interval (Martinez 1975).

4.2 CURRENT AND WATER CIRCULATION PATTERNS

The most important influences on circulation in the Galveston Bay complex are meteorologic in origin (Espey, Huston Associates 1978), consistent with the other estuaries along the Texas coast. The reasons are the alinement of the bays with the prevailing wind regimes, the relative shallowness of the bays, the small amplitude and diurnal character of gravitational tides, and in some cases, the comparatively low freshwater inflow.

As outlined in Section 4.1, the flushing induced by gravitational tides is approximately an order of magnitude less than the volume of water discharged by a mid-latitude frontal passage in the Galveston Bay area. The higher incidence and greater intensity of the "cold fronts" during the winter, combined with intervening gulf winds, increase flushing of the bays, in contrast to summer months when winds are more unidirectional. East Bay has comparatively poor circulation because of its alinement perpendicular to the prevailing winds (Gosselink et al. 1979) and limited interaction of tidal flows originating from Bolivar Roads and Rollover Pass (Prather and Sorenson 1972). West Bay, alined similarly to East Bay, has been described as having better circulation due to the greater volume of tidal flow entering from San Luis Pass and Bolivar Roads (Espey, Huston and Associates 1978). The construction of the Texas City Dike, in existence in various forms since 1915, has had a pronounced effect on ebb current direction. The dike deflects the current toward Bolivar Roads and away from the northeast end of Galveston Island (Espey, Huston and Associates 1978), resulting in reduced flow towards West Bay.

The Galveston Bay complex receives the largest volume of freshwater inflow of any estuary along the Texas Barrier Islands coast (see Section 4.3). Even during low flow periods, a horizontal salinity gradient is maintained (Espey, Huston and Associates 1978). The gradient indicates that density currents are regularly maintained and are a significant component of circulation in the system. The inland flow of saline waters is primarily through the dredged ship channels, especially the Houston Ship Channel (Espey, Huston and Associates 1978). The deep artificial channels, alined with the normal horizontal salinity gradients, probably augment density current development, and alter the natural density current flow. The inland flow of saline waters requires a return flow under steady state conditions; in deep and narrow east coast estuaries, the return flow occurs in the surface waters, forming a two-layered effect with net bottom currents flowing inland and net surface currents flowing outward toward the Atlantic Ocean. During high freshwater inflow periods in the Galveston Bay complex, there is typically a vertical salinity stratification over the bay waters of approximately 5 o/oo or greater, providing favorable conditions for the development of density currents (Espey, Huston and Associates 1978). Normally, vertical stratification in the shallow bay waters is absent, and the deep artificial channels result in density current flow conditions different from those in the east coast estuaries. The inland saline flow is fairly well confined to the Houston Ship Channel, (Espey, Huston and Associates 1978), but the return flow occurs primarily over the shallow bay waters. This type of flow produces the so called "tongue of salinity" in Galveston Bay, where the surface salinities of the Houston Ship Channel are markedly greater than the surface salinities of nearby shallow bay waters.

In East and West Bays, density currents are not believed to be well developed because of comparatively small freshwater input and the alinement of these bays. A study by James et al. (1977) indicated, however, that under certain conditions the input of freshwater into the east end of East Bay by the GIWW can be as much as 113 m^3/sec, a flow approximately three times greater than the average discharge of the San Jacinto River (see Section 4.3).

GIWW's role in the circulation of East Bay and West Bay has yet to be adequately examined to resolve the apparent controversy concerning the circulation in East Bay.

The breaking of wavetrains along the coastline generates a longshore current known as littoral drift, an important transport mechanism of sediment and a key process in the barrier island formation. The dominant direction of littoral drift throughout the Texas Barrier Islands Region is toward the southwest with the exception of the vicinity of lower Padre Island (Laguna Madre study area), where drift occurs in the opposite direction. Recent studies along the Galveston Bay area coastline (Hall 1976; Morton 1977a, 1977b) provide evidence that net littoral drift is to the southwest, contradicting several earlier studies that concluded that it was to the east. Ward et al. (1979) discussed these earlier references and the reasons for their discredit. Morton (1977b) examined shoreline changes along Galveston Island and Bolivar Peninsula and estimated net littoral drift was 2.5 x 10^5 m^3/yr to the west (southwest). Hall (1976, cited by Espey, Huston and Associates 1978), using four sampling sites along Galveston Island and Bolivar Peninsula, found net littoral drift to be 2.5 x 10^4 m^3/yr to the southwest. The order of magnitude difference between the two studies is not surprising in light of the differences in experimental design. In terms of gross littoral drift, Hall (1976, cited by Espey, Huston and Associates 1978) found that 5.9 x 10^3 m^3 of sediment was transported to the northeast during the summer months, while 3.1 x 10^4 m^3 was transported to the southwest during the rest of the year.

4.3 DRAINAGE PATTERNS AND FRESHWATER INFLOWS, RIVERINE FLOODING PATTERNS

Of the bays along the Texas Barrier Islands Coast, Galveston Bay area receives the largest amount of freshwater inflow into the estuarine system. The Trinity River and San Jacinto River (including Buffalo Bayou) average 55 m^3/sec, and smaller gaged inflows contribute 12 m^3/sec (Diener 1975, supplemented with data from USGS 1969-1976). Oyster Creek, in the extreme southwestern part of the Galveston Bay area, flows at a mean rate of 6.1 m^3/sec near Angleton and empties into the GIWW near the Brazoria National Wildlife Refuge. A portion of its flow probably mixes with the waters of Christmas and Drum Bays and surrounding marshes via the GIWW. James et al. (1977) found that a considerable amount of freshwater originating from the Sabine Basin makes its way into East Bay via the GIWW. Due to factors described by James et al. (1977), the net flow is from the Sabine Basin towards East Bay, and maximum flow rates of 113 m^3/sec have been recorded. These maximum flow rates rival the average discharges of many major rivers along the Texas coast. Since the maximum flow measurements from the Sabine Basin were obtained during a high discharge period, average flow must be considerably less than the reported maximum. Their contribution is still significant enough to affect the horizontal salinity gradient in East Bay (Martinez 1975). While no studies are available concerning the effects of freshwater discharge into West Bay via the GIWW, the proximity of the Brazos River leads one to suspect that some portion of this second largest river along the Texas coast affects the West Bay area, even through control structures divert much of the flow into the Gulf of Mexico.

In addition to the gaged flows, a considerable portion of the local drainage area into the Galveston Bay complex is not monitored. Extrapolating from the average discharge per unit area of the gaged streams flowing into the Galveston Bay complex to the ungaged area provides an additional average inflow of 21.4 m^3/sec. The ungaged average discharge into the East Bay area (excluding the effects of the input of the GIWW) has been calculated to be 2.1 x 10^8 m^3/yr (6.7 m^3/sec) (Rice Center for Community Design and Research 1974, cited by Gosselink et al. 1979).

Another source of freshwater to the bays is rainfall. Yearly rainfall normally exceeds the evaporation rate, generating a surplus (see Figure 1, Section 3.1). The Galveston Bay system is the only bay system within the Texas Barrier Islands Region where this can be expected to occur.

Seasonally, the inflows of the rivers into Galveston Bay vary greatly (Figure 4), making this area unusual in comparison to other estuaries along the Texas coast. In addition, if inflows (Figure 4) are compared with seasonal distribution of precipitation over the Galveston Bay area (Figure 1, Section 3.1), the correlation, again, is not clear. These comparisons are misleading for several reasons. First, the drainage area of the Trinity River, and to a lesser extent the San Jacinto River, extends well inland of the study area boundary into a different precipitation regime. The pronounced May peak for the Trinity River primarily results from an increase in the abundance of precipitation. Another factor influencing this peak discharge is a precipitation surplus generated by low evaporation rates during winter. The winter surplus requires up to several months to appear as river flow along the lower reaches of the Trinity River. This same lag factor accounts for the increased discharge during the last 3 months of the year, which reflects a September increase in precipitation (Espey, Huston and Associates 1978). Second, the San Jacinto River, with a smaller drainage basin than the Trinity River, responds more quickly to the effects of precipitation increases and decreases. The seasonal pattern of river flow, as shown in Figure 4, is modified due to the impounding effects of Lake Houston (Espey, Huston and Associates 1978). Third, the seasonal pattern of flow in the considerably smaller Chocolate Bayou drainage basin reflects agricultural practices in addition to natural flow (Espey, Huston and Associates 1978). This is particularly evident during the summer (Figure 4) when peak monthly discharge occurs despite no precipitation increase and an evapotranspiration increase. The increased discharge is caused by the increased use of irrigation waters. Another aspect of the runoff of irrigation waters is the related input of additional nutrients and toxins to the receiving basin (see Section 4.5).

While the inflow examples used (Figure 4) are misleading in that they do not clearly show natural variability, the fact remains that they are the expected patterns of flow. The Trinity and San Jacinto Rivers supply 88% of the estimated total inflow (excluding precipitation into the bays and unknown flows entering via the GIWW) and therefore dominate the system, affecting the salinity regime of the overall bay complex (see Section 4.1). Smaller tertiary bays, like Chocolate Bay, may have different seasonal patterns in freshwater inflow and salinity. The resulting changes in the seasonal biotic assemblages can only be inferred.

4.4 GROUNDWATER

The Galveston Bay area has the largest surface supply of freshwater of all the other basins studied. Additional freshwater, used primarily for

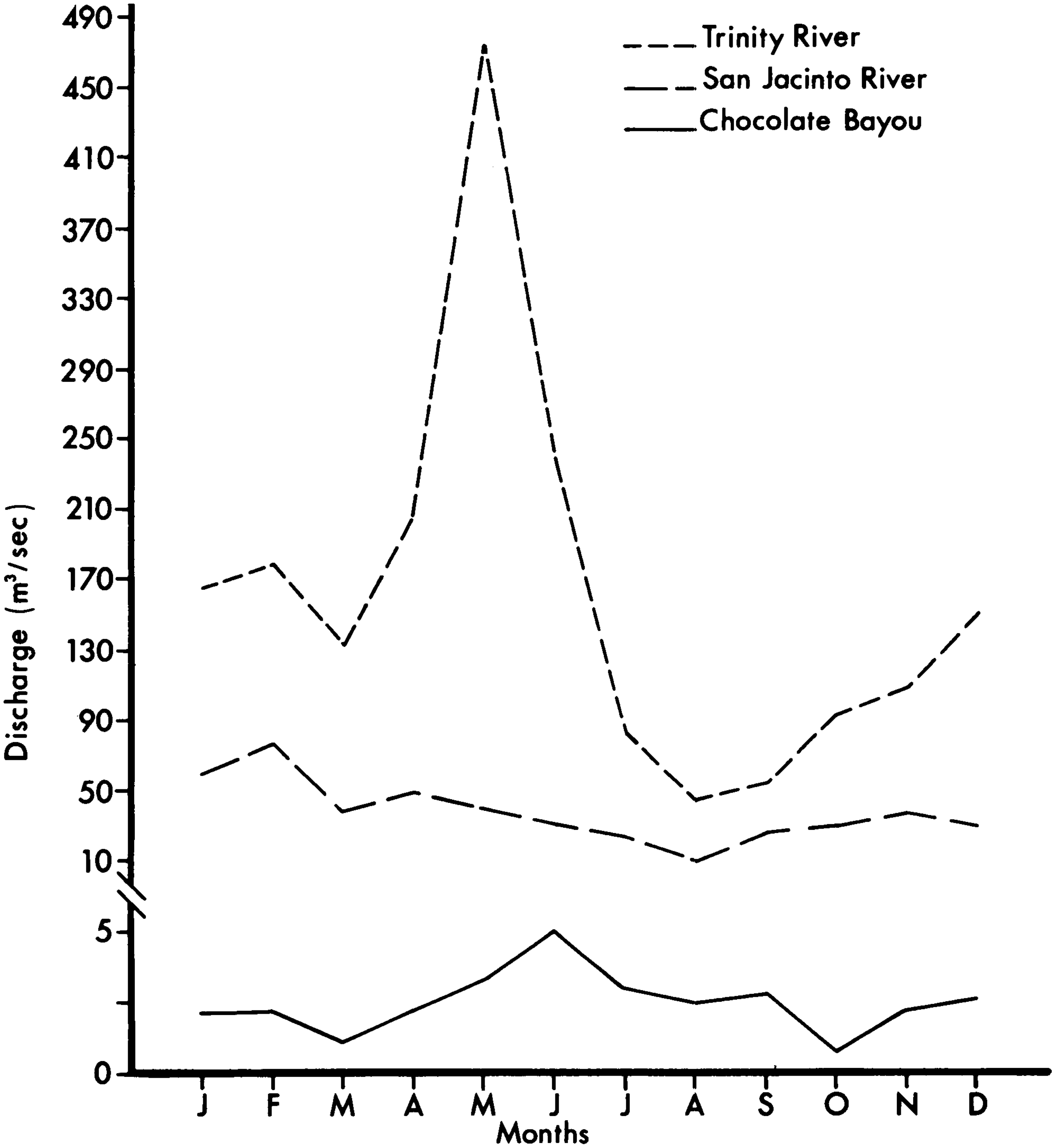

Figure 4. Mean daily discharge by months for selected inflows to the Galveston Bay study area. Means for USGS data obtained from Diener (1975).

agriculture because of its high salt content (USDOE 1978), is obtained from the nearby Brazos River. Groundwater is the principal source of water for the Houston-Galveston area (Jorgenson 1975), with over 1.9 x 10^9 liters (5 x 10^8 gallons) extracted each day (Kreitler 1977). This extensive use of groundwater resources relates to dense human population. The human population in counties within the Galveston Bay area represents 72% of the total human population in the entire Texas Barrier Islands Region (estimate based on data reported by Liebow et al. 1980).

The groundwater is obtained from subsurface beds of sand separated by beds of clay. The aquifers now exploited represent deposits of Pliocene and Pleistocene ages (Jorgenson 1975). Aquifers are interconnected in many areas of southeast Texas: for this reason they are collectively known as the Gulf Coast Aquifer, although the Pliocene aquifer is often referred to as the Evangeline, and the Pleistocene aquifer as the Chicot (Jorgenson 1975).

The present rate of groundwater withdrawal exceeds the discharge rate, and has led to subsidence problems in the area (see Section 2.5). Kreitler (1977) showed that the water table of the Gulf Coast Aquifer in the Houston area dropped 27 m (90 ft) between 1932 and 1972. In Texas City, water levels declined 6 m (20 ft) from 1960 to 1970, and in the Alta Loma area the decline is approximately 1.2 m/yr (Espey, Huston and Associates 1978). The void created by the removal of groundwater is replaced, to some extent, by the water from adjacent clay layers. The dewatering of highly compressible clays causes compaction, with resulting subsidence at the surface. Kreitler (1977) documented 2.5 m of subsidence in the Baytown area. Subsequent socioeconomic problems include the displacement of roads and broken sewer and gas lines. Excess extraction of groundwater was documented by Zack (1973, cited by Gosselink et al. 1979) as leading to a reversal in the hydraulic gradient of the Chicot Aquifer in nearby southwest Louisiana, with resulting movement of saline waters into the aquifer. In the Galveston Bay area, saltwater intrusion into groundwater aquifers is not now a major problem except in the lightly populated Bolivar Peninsula area and in the Alta Loma area (water supply for the city of Galveston), where surface supplies had to be brought in, beginning in 1973, to stabilize the groundwater withdrawal rate (Espey, Huston and Associates 1978).

4.5 WATER QUALITY

Water temperature, like salinity (Section 4.1), is an important water quality variable that affects biological resources. Since both types of data are easy to obtain, the spatial and temporal coverage of these variables is generally more complete than that of other water quality variables. While several agencies (i.e., Texas Department of Water Resources, U.S. Army Corps of Engineers, and USGS) regularly obtain water temperature data in the Galveston Bay complex and inflowing streams, only the data obtained by TPWD from 1965 through 1975 (cited by Martinez 1967, 1970-1975) are included here.

Mean water temperature for the entire Galveston Bay complex for the period 1965 through 1975 was 22.0° C (Martinez 1975). This value is approximately the same as that for other Texas estuaries north of Corpus Christi Bay (Martinez 1975). Seasonally, water temperatures in the Galveston Bay complex closely follow the seasonal change in air temperature. The minimum monthly mean temperature occurs between December and February (approximately 12° C), and maximum monthly mean temperature occurs in August or September (approximately 29° C) (Martinez 1967, 1970-1975).

The data of Martinez (1975) indicate that, at any given time, water temperature differs as much as 8.0° C within the bay complex. Typically, the lowest temperatures are recorded near the outflow of the Trinity River while highest temperatures are recorded in tertiary bays during low outflow periods. Vertical temperature stratification is normally negligible in the shallow bay waters but is typically more pronounced and characteristic of the dredged channels (Espey, Huston and Associates 1978).

Dissolved oxygen (DO) concentrations reported by Martinez (1974, 1975) and Espey, Huston and Associates (1978) indicated that the bay complex has an annual DO concentration level of approximately 8.0 mg/liter. Vertical stratification is normally somewhat greater during summer, ranging from 1 to 3 mg/liter (Espey, Huston and Associates 1978). Data representing values for the bottom of the dredged channels are limited; the stratification there is probably greater.

Seasonally, DO levels are inversely related to water temperature. The comparatively few years of data do not substantiate an inverse relationship between DO concentrations and salinity through time, and the data of Martinez (1974, 1975) do not clearly indicate that intra bay salinity variability affects DO concentrations. Increased photosynthesis may cause the slight rise in DO concentrations during the growing season for several stations in the Galveston Bay complex (Martinez 1974, 1975), but inadequacy of the sampling design precludes meaningful conclusions.

The DO concentrations of the Galveston Bay complex as a whole are in the same range as those of several other estuarine complexes along the Texas Barrier Island coast. The Laguna Madre complex has slightly lower concentrations due to higher water temperatures and salinities, and the Corpus Christi Estuary has substantially lower concentrations, perhaps indicative of the estuary's relatively poor water quality.

The Galveston Bay complex has the highest surface area to volume ratio along the Texas coast (Diener 1975). This ratio, important in maintaining high DO levels, increases the ability of the bay complex (compared with that of smaller water bodies) to recover from oxygen depletion associated with waste discharge.

While the bay complex has DO concentrations near saturation levels, a high incidence of fish kills are related to oxygen depletion. Fish kills are usually isolated events confined to small areas, but due to their high incidence, may be considered expected events. From 1970 to 1978, 68 fish kills were reported for the bay waters in the vicinity of the proposed Galveston deepwater port and associated pipeline crossings (Texas Department of Water Resources 1978, cited by Espey, Huston and Associates 1978). Of the 68 incidents, 53 (78%) were caused by oxygen depletion. Only one incident was directly attributed to petroleum spillage, with the bulk of the remaining incidents attributed to pesticides, non-oil chemical spills, and unknown factors (TDWR 1978, cited by Espey, Huston and Associates 1978). Some dramatic fish kills from oxygen depletion include the 6.2×10^7 fish which perished in

Houston Ship Channel on 25 October 1977, and the 5.8 x 10^6 (including 4.1 x 10^5 game fish) in Taylor Lake on 8 August 1973. Based on the fish kill data (TDWR 1978, cited by Espey, Huston and Associates 1978), areas repeatedly having oxygen depletion problems include Taylor's Bayou, Hildebrandt Bayou, Dickinson Bayou, Texas City Harbor and associated outflows (both natural and man-made), Houston Ship Channel, Hall's Bayou, and Chocolate Bayou. The relationship between repeated fish kills and high levels of man-related activity is obvious, although undetected fish kills in less developed areas may occur.

The number of fish killed directly by high pesticide levels during the 1970-78 period was comparatively low, but this pollution type does not usually result in mass mortalities over a short period of time at a small geographic site. All five fish kills documented as resulting directly from pesticides have occurred in Hall's Bayou, and pesticides are suspected (included as unknown causes) for other fish kills in Hall's Bayou as well as in Chocolate and Taylor's Bayous.

Limited phytoplankton blooms resulting from high nutrient loading commonly occur in the bay complex. These blooms, associated with the oxygen depletion, occur most frequently at the outflows of the Trinity and San Jacinto Rivers, areas of municipal outflows, and in tertiary bays which receive agricultural runoff (Espey, Huston and Associates 1978).

While the total input of pesticides, nutrients, petroleum spillage, etc., is probably greater in the Galveston Bay complex than in any other estuarine areas along the Texas coast, the documentation of their impacts upon biological resources (e.g., fish kills) is restricted to single cause and effect events occurring in small geographic areas. This documentation gives the impression that a few areas are plagued at times with severe water quality problems, but that on the whole, the bay complex is largely unaffected. Although this interpretation may be the case, little attention has been focused on the possible cumulative effects of all the isolated cases. There is only one documented case during the 1975-77 period in the Galveston Bay complex where petroleum discharge was directly responsible for a loss in the wildlife resources. This case was only one of 179 oil spill incidents during the 3-year period and represented 6% of the total spillage volume in the area (TDWR 1977, cited by Espey, Huston and Associates 1978). The 178 incidents for which no impacts were documented were cases involving no immediate or obvious impacts (e.g., fish kills). The longer-term impacts, the less obvious impacts, and the cumulative impacts of all spills combined with other types of discharges have yet to be adequately treated.

5.0 BIOLOGY

5.1 ESTUARINE COMMUNITY

The 1.3 x 10^5 ha comprising Trinity, Galveston, East, and West Bays make the areal extent of the major bay waters in the Galveston Bay area the largest of the six Texas estuarine systems. The bays of this system are subjected to high levels of human activity that result in serious pollution in some areas. The worst pollution tends to occur in shipping channels and sites close to effluent outfalls, but none of the bays can be considered unaltered. A proposed deepwater port for the Galveston system may increase the risk of additional pollution of an already highly stressed system.

Interestingly enough, the benefits of freshwater inflow in this area may overcome the somewhat lower water quality in the Galveston system to result in the largest shellfish harvest of all bay systems along the Texas coast. Pollutants produced in the problem areas of the bay may be dissipated by freshwater inflow and tidal action within a relatively small distance from their source. Shellfish production is enhanced by the large freshwater inputs into the system from the Trinity and San Jacinto Rivers. The Galveston Bay system receives the greatest amount of freshwater inflow of all six bay systems, although (as in most areas) inflow varies seasonally. Inflow, combined with the high precipitation in this area, results in the estuarine complex having an average salinity of 17.3 o/oo (Martinez 1975). Historically, harvests of blue crab (Callinectes sapidus) have been greatest in those estuarine areas with largest freshwater inflows (More 1969). Shrimp production is similarly influenced. Childress et al. (1975) found that largest harvests of white shrimp (Penaeus setiferus) in the San Antonio Bay system coincide with years of greatest input from the Guadalupe-San Antonio Rivers.

Vascular flora in the estuarine community is dominated by emergent marshes; submerged spermatophytes were abundant until the 1970's when they became less common. This occurrence represents the culmination of a trend of decreasing seagrass abundance and increasing marsh species abundance as one progresses northward along the Texas coast from Laguna Madre to Galveston. These changes are attributable to an integrated group of factors of which precipitation, climate, and salinity are only a few.

Subsidence in the estuarine community is probably the most obvious man-induced change in the estuarine areas. Caused primarily by extensive tapping of underground water supplies, subsidence has probably caused significant environmental alterations such as conversion of wetlands to open water areas and upland grasslands to wetlands. In the literature, more emphasis is placed on data relating to property loss than on alteration of habitat.

5.1.1 Vegetation

Compared to bay systems on the central and southern Texas coasts, Galveston Bay has few acres of submerged spermatophytes. Two seagrass species typically found in the bays of the Galveston Bay area are shoal grass (Halodule beaudettei), most common in West Bay along the margin of Galveston Island; and widgeongrass (Ruppia maritima), typically found off the Trinity Delta and Clear Creek (W. L. Fisher et al. 1972). Scattered dense stands of both species were reported in Christmas Bay (TPWD 1972). Turtle grass (Thalassia testudinum) also grows in the Galveston Bay system (W. L. Fisher, et al. 1972), but precise locations are not reported (Espey, Huston and Associates 1978). The habitat requirements of turtle grass, clear water with relatively high salinity (Moore 1963), make the occurrence of this grass unlikely in most areas of the Galveston Bay system. The seagrasses that do occur in the system are concentrated around the margins of the bays in water generally less than 1.5 m deep (TPWD 1972). East Bay, Trinity Bay, and Cedar Lake support little aquatic vegetation.

Seagrass distribution depends on interrelated environmental factors, including temperature, water depth, turbidity, and salinity. These factors are discussed in the Copano-Aransas synthesis, Section 5.1.1.

No standing crop values or primary production estimates for the seagrasses in the Galveston Bay area were available. McRoy and McMillan (1977, cited by Ward et al. 1979), however, reported the mean standing crop of shoal grass in bays along the entire Texas coast to be 100-200 g dry wt/m^2. Based on the turtle grass standing crop measurements reported by Parker et al. (1971, cited by Ward et al. 1979), turtle grass is more productive than shoal grass. The mean standing crop value for Texas as a whole was 3,000 g dry wt/m^2 for turtle grass.

Seagrasses have minor value as a direct food source for herbivores; most of the plant material enters the food web as detritus. Grassbeds attract many small mollusks that are an important food source for many fish and penaeid shrimp and indirectly are a valuable link in the estuarine food web. The shelter and sites of attachment provided by these submerged aquatics are also substantial. Hoese (1960) reported that in the Galveston Bay area juvenile pink shrimp (Penaeus duorarum) were found only in grassbeds.

In Galveston Bay, phytoplankton show relatively low species diversity. The variability in environmental conditions, especially temperature and salinity, limits plankton occurring here to those species with wide tolerance limits. Populations are often large, and these unspecialized plants contribute the bulk of primary production to the system. Turbidity is so high in most study area bays that benthic seagrasses are restricted to the shallow borders of the bays, and their total primary production is therefore much less than that of phytoplankton.

The bays of the Galveston area often operate at a photosynthetic deficit; that is, gross primary production is outweighed by community respiration. Odum (1967, cited by Espey, Huston and Associates 1978) reported that the phytosynthetic deficit suggests a detritus-based food web with organic matter imported from the Trinity River and Delta marshes.

Galveston Bay proper is deeper, more stable, and less turbid than most bays in the area. This favorable environment supports a more diverse assemblage of phytoplankton, upon whose production, in large measure, herbivores depend for food (Espey, Huston and Associates 1978). The gross primary production by phytoplankton in the open waters of Galveston Bay ranges from 20 to 58 g organic matter/m^2/day. In Trinity Bay the rate is estimated between 3 and 14 g/m^2/day (Odum 1967, cited by Espey, Huston and Associates 1978).

Diatoms are the dominant phytoplankton throughout the Galveston Bay system (General Land Office 1976, cited by Espey, Huston and Associates 1978). Species of greatest abundance include Chaetoceros spp., Skeletonema spp., Nitzschia spp., and Thalassiothrix spp. The blue-green algae (Oscillatoria spp., Nostoc spp., and Anabaena spp.) are also common.

When environmental conditions are appropriate, ephemeral mats of blue-green algae grow on wind tidal flats located behind Bolivar Peninsula, Galveston Island, and Follets Island (W. L. Fisher et al. 1972). Moisture is the most important environmental factor in algal development, and because the flats are flooded only occasionally by wind-induced tides, they are barren of vegetation most of the year. During and shortly after flooding, algal mats flourish (W. L. Fisher et al. 1972). Following evaporation of flood waters, the mats die and decompose. Nutrients such as nitrogen, phosphorus, and carbon are released to the estuary with the next flood (Dawson 1975).

The diversity of benthic algal flora in the Galveston Bay area is considerably less than in bays farther south. Edwards and Kapraun (1973) reported 89 species in the Port Aransas area (see Copano-Aransas synthesis); Lowe and Cox (1978) collected only 28 species in the Galveston Bay area. The decreasing number of species in the northern section of the gulf is usually attributed to a loss of tropical algae due to the cooler climate. In Galveston, as elsewhere along the Texas coast, the availability of hard, natural substrates for attachment of algae is limited. Typically, jetties and groins support the largest and most diverse algal populations. In contrast, fewer species occur in the wide expanses of saltmarsh along the bay shore of Galveston. Lowe and Cox (1978) recorded 19 species on hard substrates and 12 associated with the salt marshes or oyster reefs. Table 2 lists representative algal species. The dominant algal assemblage on hard substrates during summer, *Cladophora-Bryocladia-Ceramium*, is replaced by *Enteromorpha-Bangia-Gelidium* in winter. Along the bay shores, where little hard substrate is available, an *Enteromorpha-Ectocarpus* assemblage prevails during winter. This area is barren of algae in summer.

Table 2. Representative algal species in the Galveston Bay area, their period of maximum growth, and type of substrate where found. SF = summer-fall maximum, WS = winter-spring maximum, J = jetty or groin, M = salt marsh or oyster reef, - = no data (Lowe and Cox 1978).

Scientific name	Period of maximum growth	Location
Enteromorpha clathrata	WS	J, M
E. lingulata	WS	J
Ulva lactuca	WS	J, M
Chaetomorpha linum	SF	J
Cladophora dalmatica	SF	J
Ectocarpus siliculosus	WS	J, M
Petalonia fascia	WS	J, M
Erythrotrichia carnea	SF	J
Bangia fuscopurpurea	WS	J
Bryocladia cuspidata	SF	J
Gelidium crinale	WS	J
Ceramium strictum	SF	J
Polysiphonia denudata	SF	J
Gracilaria foliifera	-	M

No production estimates were available for the algal assemblages in the Galveston Bay area.

Salt marshes dominated by smooth cordgrass (Spartina alterniflora) at their lowest elevations are most common on the delta of the Trinity River, along the inshore sides of the barrier islands, and on the mainland side of East, West, and Bastrop Bays. In the low marsh, vegetation remains perennially wet. Water salinity here ranges above and below normal marine salinity (W. L. Fisher et al. 1972). Substrate salinity is comparable to that of the water. In the high marsh, typical species include saltgrass (Distichlis spicata), glasswort (Salicornia bigelovii, and S. perennis), shoregrass (Monanthochloe littoralis), and maritime saltwort (Batis maritima).

There is some debate over the description of vegetative assemblages of W. L. Fisher et al. (1972). Based on their descriptions, approximately 142 km^2 of salt marsh occur in the study area. The more recent work of Harcombe and Neaville (1977) suggested that salt marshes are not as prevalent in Chambers County as W. L. Fisher et al. (1972) proposed. The problem centers around the small amount of smooth cordgrass occurring in this area. W. L. Fisher et al. (1972) apparently designated the grasses and succulents growing behind the narrow fringe of smooth cordgrass as high marsh and therefore a part of the salt marsh habitat. Harcombe and Neaville (1977) used the term brackish marsh for this area although no mention was made of its mean salinity. Gosselink et al. (1979) took an intermediate ground in their study of the Chenier Plain. They proposed that brackish marshes were more widespread than salt marshes; they also suggested that salt marshes in their study area were dominated by saltgrass rather than smooth cordgrass.

W. L. Fisher et al. (1972) estimated brackish to freshwater marshes to be considerably greater in extent than salt marshes, covering approximately 195 km^2 along the mainland shoreline of the bays in the system and along the Trinity River Delta. According to W. L. Fisher et al. (1972) and Harcombe and Neaville (1977), vegetation includes coastal sacahuista (Spartina spartinae), marshhay cordgrass (S. patens), big cordgrass (S. cynosuroides), saltgrass (Distichlis spicata), bulrush (Scirpus spp.), and narrow-leaved cattail (Typha angustifolia).

Standing crop or production data specifically for the entire Galveston Bay area were unavailable. Gosselink et al. (1979) estimated primary production for the salt marsh of East Bay to be 2,270 g dry wt/m^2/yr. This value is substantially higher than the 1,084 g dry wt/m^2/yr estimated by Espey, Huston and Associates (1977, cited by Ward et al. 1979) for Lavaca, San Antonio and Nueces Bays. Numerous methods for estimating production may result in variable estimates, and one cannot be certain that primary production in the Galveston Bay area salt marshes is actually more than twice that of bays farther south. Considering the disparity between the two estimates, one can probably safely assume that Galveston area salt marshes are more productive than other Texas marshes to the south. Brackish marshes may have a slightly higher primary production than salt marshes in the East Bay area. Gosselink et al. (1979) estimated the production of these marshes to be 2,760 g dry wt/m^2/yr.

The importance of salt marshes as habitats for many species of finfish and shellfish has been well documented. The brackish marshes of the Galveston Bay area tend to function as the salt marshes of other coastal Texas areas, serving as nursery grounds for finfish and shellfish (Gosselink et al. 1979).

Presently, freshwater marshes occur primarily on the Trinity River Delta and consist of common reed (*Phragmites communis*), Jamaica sawgrass (*Cladium jamaicense*), bulrush (*Scirpus* spp.), sloughgrass (*Spartina pectinata*), and common cattail (*Typha latifolia*). W. L. Fisher et al. (1972) estimated 41 km^2 of freshwater marshes in the Galveston Bay area. The primary production rates of freshwater marshes appear less than those of brackish marshes. Gosselink et al. (1979) estimated 2,230 g dry wt/m^2/yr primary production in freshwater marshes of East Bay. As late as the mid-1950's, extensive stands of freshwater marshes thrived near the mouth of Oyster Bayou, but since then freshwater marshes have become scarce for three primary reasons: (1) much of the marsh was sacrificed outright for rice production, (2) nearby areas gradually became terrestrial in character as water was drained and impounded in adjacent ricefields, and (3) other segments of freshwater marsh took on brackish marsh characteristics as subsidence resulted in saltwater intrusion (Harcombe and Neaville 1977).

The U.S. Department of Interior has proposed the acquisition of six areas within the Galveston Bay system, primarily for their value as migratory waterfowl habitat. The upper Texas coast is heavily used by waterfowl as the relatively high rainfall helps maintain marshes through prevention of an evapotranspiration deficit (USFWS 1977).

Other important natural areas include the (1) Anahuac National Wildlife Refuge, a prime wintering and breeding ground for ducks, geese, and wading birds; (2) Trinity River Delta, a spawning ground for fish and shrimp, and a wintering and feeding area of the bald eagle (*Haliaeetus leucocephalus*); (3) lower Cedar Bayou Estuary, a spawning area for fish, shrimp, and oysters, and a wintering area for waterfowl and the endangered bald eagle; and (4) Hanna Reef, with sparse live oyster beds (Texas Natural Area Survey n.d.). Because of its areal extent and diversity of habitats, the Galveston Bay complex is a vital nursery ground for shellfish and finfish. In fact, Curington et al. (1966, cited by Bechtel and Copeland 1970) estimated that over 80% of the fishery in the Gulf of Mexico used the Galveston Bay system as a nursery ground.

5.1.2 Fauna

Mammals. The bottlenose dolphin (*Tursiops truncatus*), spotted dolphin (*Stenella plagiodon*), and West Indian manatee (*Trichechus manatus*) may occasionally be seen in bays of the Galveston area (Espey, Huston and Associates 1978). Whales are infrequently seen within the confines of the bay waters.

Salt, brackish, and freshwater marshes typically support a variety of terrestrial mammals, several commercially important for their fur. Table 3 is a representative list of mammals and their habitats.

Table 3. Representative mammals of the estuarine community, Galveston Bay system. SM = saltmarsh, BFM = brackish to freshwater marsh, FM = freshwater marsh (Davis 1974; Espey, Huston and Associates 1978; Webb et al. 1978; and Gosselink et al. 1979).

Scientific name	Common name	Habitat		
		SM	BFM	FM
Procyon lotor	Raccoon	X	X	X
Mustela vison	Mink		X	X
Myocastor coypus	Nutria	X	X	X
Ondatra zibethicus	Muskrat	X	X	X
Sylvilagus floridanus	Eastern cottontail	X	X	X
S. aquaticus	Swamp rabbit		X	X
Mus musculus	House mouse	X	X	X
Rattus norvegicus	Norway rat	X	X	X
Oryzomys palustris	Northern rice rat	X	X	X
Sigmodon hispidus	Hispid cotton rat			X
Odocoileus virginianus	White-tailed deer		X	X
Dasypus novemcinctus	Nine-banded armadillo	X	X	X

Webb et al. (1978) reported three sightings of a single river otter (*Lutra canadensis*) in the marsh of Bolivar Peninsula and signs of opossum (*Didelphis virginiana*) activity.

Birds. The most common birds in this estuarine community are shore birds, gulls, wading or fish-eating birds, and terns, together constituting approximately 25% of the avian species in the Galveston Bay area (Espey, Huston and Associates 1978). Shorebirds, including the sanderling (*Crocethia alba*), willet (*Catoptrophorus semipalmatus*), and least sandpiper (*Erolia minutilla*), hunt the shores for crustaceans, mollusks, and marine worms. Common gulls in the Galveston Bay area, such as the laughing gull (*Larus atricilla*), ring-billed gull (*L. delawarensis*), and herring gull (*L. argentatus*), have flexible feeding behavior; they feed as readily on garbage and refuse as on live fish. Common fish-eating birds of the estuarine community, and their 1973-76 nesting populations are given in Table 4. Wading birds, like the herons and egrets listed in this table, feed primarily on fish. Terns prey on small crustaceans and fish (Oberholser et al. 1974; Espey, Huston and Associates 1978).

The estuarine community is important as a wintering ground for many species of migratory waterfowl, and a permanent residence for others. Espey, Huston and Associates (1978) estimated 21 species of wintering migratory waterfowl likely to occur in the area. The Canada goose (*Branta canadensis*), white-fronted goose (*Anser albifrons*), and snow goose (*Chen caerulescens*) feed in this upper coastal area. They use marsh vegetation by grubbing for tubers, but seem to prefer rice stubble from coastal prairie (Glazener 1946; Oberholser et al. 1974). The ducks frequent all types of marshes (see Copano-Aransas synthesis, Section 5.1.2), feeding on vegetation on the periphery of the marsh (Oberholser et al. 1974). Hall et al. (1959) presented an extensive species list for birds on Galveston Island. Included are passerine birds common on the island.

Table 4. Pairs of colonial fish-eating birds, Galveston Bay system (adapted from Blacklock et al.1978).

Scientific name	Common name	1973	1974	1975	1976	Historical population trend for all of Texas
Phalacrocorax olivaceus	Olivaceous cormorant	300	200	211	530	Always small, peripheral species
Ardea herodias	Great blue heron	103	178	301	758	Stable
Florida caerulea	Little blue heron	50	56	13	1,025	Primarily inland; stable
Bubulcus ibis	Cattle egret	1,735	2,255	1,255	6,790	First arrived 1954; rapid increase
Dichromanassa rufescens	Reddish egret	2	41	62	70	Long-term decline but stable since 1960's
Casmerodius albus	Great egret	2,028	860	794	729	1910, near extinction; currently stable
Leucophoyx thula	Snowy egret	3,016	562	2,204	997	1910, near extinction; currently stable
Hydranassa tricolor	Louisiana heron	2,740	4,298	1,805	764	Rapid increase during past 10 years
Nycticorax nycticorax	Black-crowned night heron	785	332	44	438	Trend unknown
Nyctanassa violacea	Yellow-crowned night heron	10	0	0	0	Trend unknown
Plegadis chihi	White-faced ibis	140	46	337	982	Stable since 1974

Continued

Table 4. Concluded.

Scientific name	Common name	1973	1974	1975	1976	Historical population trend for all of Texas
Eudocimus albus	White ibis	12	50	3,601	5,268	Stable to increasing during last 20 years
Ajaia ajaja	Roseate spoonbill	1,112	1,097	594	990	1910 near extinction; currently stable
Larus atricilla	Laughing gull	35,860	25,805	15,514	20,573	Stable
Gelochelidon nilotica	Gull-billed tern	5	20	0	0	Stable to decreasing
Sterna forsteri	Forster's tern	1,757	128	421	1,018	Slow decline since 1940's
S. albifrons	Least tern	1,659	2,035	755	62	Rapid decrease
S. maxima	Royal tern	2,900	4,500	0	0	Always abundant
S. sandvicensis	Sandwich tern	250	2,000	0	0	Stable below San Antonio Bay
S. caspia	Caspian tern	33	0	63	50	Slow decline
Rynchops nigra	Black skimmer	1,651	4,193	2,569	3,394	Trend unknown

As the Galveston Bay area is an important harbor handling petrochemicals, oil spills are a potential threat. Avian species are the most likely to suffer directly from a spill. Ducks, gulls, terns, pelicans, and grebes rest and/or feed directly on the water. Once coated with oil, birds are unable to fly. They also lose their ability to maintain a constant body temperature and often die as a result. A major spill could devastate entire resident or migratory populations (Espey, Huston and Associates 1978).

Fish-eating birds also tend to be affected by toxins which accumulate in the fauna they consume as food. The highly industrialized state of the Galveston Bay system makes this area one of the most potentially dangerous for coastal Texas birds. The toxins DDT and PCB are the best examples of the problem. Birds, after eating fish and crustaceans with accumulations of these toxins, develop impaired reproductive capacity caused by eggshell thinning. This phenomenon is one major reason the brown pelican (*Pelecanus occidentalis*) is now an endangered species. The Environmental Protection Agency's ban on DDT in 1972 has eased the problem somewhat, but PCB's are still in many ecosystems in varying amounts (Espey, Huston and Associates 1978).

Although the environment seems deteriorating, and habitats for birds are decreasing, studies have been carried out on procedures for vegetating dredge spoil, thus creating new habitats for fauna. Marsh and upland sites and the birds attracted there are discussed in Section 5.2.2.

Reptiles and amphibians. Texas salt marshes are typically inhabited by only one turtle species, the Texas diamondback terrapin (*Malaclemys terrapin littoralis*) (Conant 1975). The National Fish and Wildlife Laboratory (1980) reported that three species of sea turtles, the green turtle (*Chelonia mydas*), Kemp's ridley (*Lepidochelys kempi*), and leatherback turtle (*Dermochelys coriacea*), are seen rarely in the estuarine community. The common snapping turtle (*Chelydra serpentina serpentina*) is restricted to brackish and fresh marshes.

Snakes common in the salt or brackish marsh are the gulf salt marsh snake (*Nerodia fasciata clarki*), marsh brown snake (*Storeria dekayi limnetes*), and speckled kingsnake (*Lampropeltis getulus holbrooki*). The first two species are essentially restricted to a saline environment. The speckled kingsnake inhabits the fringes of these marshes.

The endangered American alligator (*Alligator mississippiensis*) inhabits fresh, brackish, and salt marshes in the Galveston Bay area. Texas Parks and Wildlife Department (1975) estimates suggest this area supports the largest Texas coast alligator population. The humid climate of this system in conjunction with the plentiful marsh habitat makes the environment similar to that of the Chenier Plain in southwestern Louisiana, where Gosselink et al. (1979) reported the highest concentrations of alligators within a 10-state area. No lizards are common to the salt marsh.

A few amphibians are found occasionally in the salt or brackish marshes, including the green treefrog (*Hyla cinerea*) and southern leopard frog (*Rana utricularia*). Marshes are not preferred habitats, however, so amphibian populations are small (Conant 1975).

Environmental conditions in the freshwater marshes are conducive to reptile and amphibian habitation. Species diversity is proportionately higher in this habitat than in the other kinds of marshes. Table 5 lists representative species of this habitat.

Table 5. Representative reptiles and amphibians in the freshwater marsh, Galveston Bay system (Raun and Gehlbach 1972; Conant 1975).

Scientific name	Common name
Kinosternon subrubrum hippocrepis	Mississippi mud turtle
Chrysemys floridana hoyi	Missouri slider
C. scripta elegans	Red-eared turtle
Sternotherus odoratus	Stinkpot
Deirochelys reticularia miaria	Western chicken turtle
Lampropeltis getulus holbrooki	Speckled kingsnake
Nerodia cyclopion cyclopion	Green water snake
Thamnophis sirtalis sirtalis	Eastern garter snake
Sistrurus milarius streckeri	Western pygmy rattlesnake
Pseudacris triseriata feriarum	Upland chorus frog
Bufo woodhousei woodhousei	Woodhouse's toad
Rana utricularia	Southern leopard frog
Gastrophryne carolinensis	Eastern narrow-mouthed toad

Fish. The mean annual commercial finfish harvest in Galveston and Trinity Bays during the 10 years 1968-77 was 2.3 x 10^6 kg, the third largest harvest of the six Texas bay systems (USFWS and TPWD 1968; NOAA and TPWD 1970; NOAA 1971, 1972, 1973b, 1974, 1975, 1977, 1978a, 1978b). Only the Laguna Madre and Copano-Aransas Bay areas had larger harvests during this period. Six fish species are commercially important in the bays of the Texas Barrier Islands Region. When the mean annual harvests of these species in the Galveston Bay area are compared to those in the other five bay systems, the following harvests ranked fourth: black drum (*Pogonias cromis*), 2.5 x 10^4 kg; sheepshead (*Archosargus probatocephalus*), 1.3 x 10^4 kg; and unclassified flounder, 1.0 x 10^4 kg. Red drum (*Sciaenops ocellatus*), 2.5 x 10^4 kg, and spotted seatrout (*Cynoscion nebulosus*), 7.1 x 10^4 kg ranked third among the six bay systems. The Galveston Bay area had the largest mullet (*Mugil* sp.) harvest, 1.6 x 10^4 kg, of all the systems.

Sport fishing data in the Galveston Bay area include catches from Trinity, Galveston, East, West, Dickinson, Chocolate, Christmas, Bastrop, and Drum Bays, plus Clear, Moses, and Jones Lakes (Heffernan et al. 1977). During the 1-year period, September 1974 - August 1975, the Galveston complex had the largest sport catch, 1.3 x 10^6 kg, of the six systems. The yield rate of 308 g per man-hour fished was the second highest of the Texas bays. The sport fishery was concentrated on spotted seatrout; the yield of 5.1 x 10^5 kg was approximately 40% of the total sport harvest. The sand seatrout (*Cynoscion arenarius*) and Atlantic croaker (*Micropogonias undulatus*) were of secondary importance, with sport yields of 2.1 x 10^5 and 1.6 x 10^5 kg, respectively (Heffernan et al. 1977).

Although commercial and sport yields in this area do not appear to be depressed, considerable evidence shows declining finfish species diversity in some parts of the Galveston Bay system. Bechtel and Copeland (1970) suggested that declining fish species diversity can indicate pollution, just as the declining diversity of other aquatic organisms has in the past. Fish diversity apparently follows the accepted principle that as distance from a pollution source increases, species diversity correspondingly increases. According to species diversity indices (Shannon-Weaver, log p_i) calculated by Bechtel and Copeland (1970), Trinity Bay and upper Galveston Bay are highly stressed due both to natural variability in environmental factors and to pollution from industries along the Houston Ship Channel above Baytown. Little dissipation of the pollutants occurs in the short distance to the upper Galveston Bay, where Bechtel and Copeland (1970) estimated diversity at 0.02. At Texas City, in lower Galveston Bay, diversity was 2.2.

As species diversity declines, the bay anchovy (Anchoa mitchilli) becomes a dominant species. This fish feeds on zooplankton, detritus, and microbenthos, and pollutant-loading in an area would not significantly alter its food supply. If water conditions remain in a deteriorated state, no large fish species will survive, leaving the anchovy at the top trophic level of a limited aquatic food web (Bechtel and Copeland 1970). This species does have market value although it is not now harvested in the Galveston Bay system. It is not, however a desirable replacement for larger finfish of sport and commercial value (Bechtel and Copeland 1970).

Invertebrates. The small commercial finfish harvest in the Galveston Bay area is compensated for by the shellfish industry. Of the six Texas bay systems, Galveston Bay had the largest harvests of blue crab (Callinectes sapidus), American oyster (Crassostrea virginica), pink and brown shrimp (Penaeus duorarum and P. aztecus), and white shrimp (P. setiferus) during the 10 years, 1968-77 (USFWS and TPWD 1968; NOAA and TPWD 1970; NOAA 1971, 1972, 1973b, 1974, 1975, 1977, 1978a, 1978b). The mean annual harvests of these species, by weight and monetary value, are given in Table 6.

Table 6. Mean annual shellfish harvest by weight and monetary value in Galveston and Trinity Bays, 1968-77. (USFWS and TPWD 1968; NOAA and TPWD 1970; NOAA 1971, 1972, 1973b, 1974, 1975, 1977, 1978a, 1978b).

Scientific name	Common name	Weight (kg)	Value (millions of dollars)
Callinectes sapidus	Blue crab	8.7×10^5	0.25
Crassostrea virginica	Oyster	1.2×10^6	1.69
Penaeus setiferus	White shrimp	1.5×10^6	2.22
P. duorarum and P. aztecus	Pink and brown shrimp combined	5.9×10^5	0.52

In addition to commercially important invertebrates, a diverse assemblage of species that are not of commercial value do play a role in the overall functioning of the estuarine community. Holland et al. (1973), Moffett (1975), and McEachron et al. (1977) provided checklists of these invertebrates.

Use of benthic invertebrates as pollution indicators has received more attention than similar procedures in which finfish are the indicators. One of the more recent studies (Holland et al. 1973) specifically concerned Galveston Bay. Using macroinvertebrates, Holland et al. concluded that water quality was typically good in middle to lower Galveston Bay, East Bay, and West Bay. The area studied in Trinity Bay was highly stressed. The only area showing signs of pollution was the Texas City Ship Channel. Conditions appeared poorest in summer when species diversity was lowest.

Whereas Bechtel and Copeland (1970) calculated ichthyofaunal diversity to be relatively high in the vicinity of Texas City, Holland et al. (1973) reported low diversity of macroinvertebrates. These two findings suggest radically different levels of water quality in the same area. The basic premise proposed by Wilhm and Dorris (1966), that community structure of aquatic organisms may provide a more accurate assessment of water quality than standard chemical and physical analyses, is probably true. Further investigation is needed to determine which organisms are the most accurate indicators of water quality.

5.2 BARRIER ISLAND COMMUNITY

Three land masses constitute the barrier island community of the Galveston Bay system: Bolivar Peninsula, Galveston Island, and Follets Island. One of the most obvious values of these land masses is the protection they afford the mainland, buffering storm surge and lessening erosion on the mainland. Barrier islands also offer valuable protection to the fragile estuarine community.

Here, as elsewhere along coasts with barrier islands, residential and commercial construction increases the need for stability of the barrier island environment, when by its very nature a barrier island is a dynamic migrating entity. Under natural conditions the environment is fairly severe. Freshwater is limited to ephemeral ponds. Salt spray is common with any onshore wind, and saltwater flooding occurs periodically. The species of flora and fauna adapted to these variable conditions are limited in diversity as well as numbers. Species able to thrive in association with man may increase in population, but overall fauna suffer by the loss of habitat which accompanies human encroachment.

5.2.1 Vegetation

The vegetation of each barrier island community varies with the dominant topographic features of the island. Although no two islands are identical, Galveston Island can serve as a model, the cross-sectional profile of which includes the following: (1) beach; (2) foredune ridge, beach ridge, and barrier flat; (3) wind tidal flat; (4) salt marsh; and (5) grassflats (W. L. Fisher et al. 1972).

The approximately 10 km^2 of beach is sparsely vegetated along its back margin (away from the surf) with a few culms of sea oats (*Uniola panicultata*) and some halophytes. Along sections of Galveston Island and Bolivar Peninsula, the beach is presently accreting, whereas some segments of Bolivar Peninsula and Follets Island are eroding (W. L. Fisher et al. 1972).

The beach ridge and barrier flat habitat constitutes the major environment of this community and covers 106 km^2 on Bolivar Peninsula, and Galveston and Follets Islands. The terrain is a series of ridges and swales parallel or subparallel to the shoreline. Each ridge represents a former shoreline present earlier in the island development. Beach ridges may approach a height of 3 m (10 ft) above sea level. In addition to the ridge-and-swale topography are vegetated barrier flat areas with sloping elevations up to 1.5 m above sea level on the gulf side. The barrier flat is composed of wind-blown sand from the beach ridge and of sediment deposited as washover. Vegetation in the ridge and flat area of the island is predominantly grasses tolerant of salt spray and able to survive infrequent flooding. Species include seacoast bluestem (*Schizachyrium scoparium littoralis*), singlespike paspalum (*Paspalum monostachyum*), and sea oats (*Uniola paniculata*). Small mottes of live oak (*Quercus virginiana*) are present as are scattered mesquite (*Prosopis* sp.) and saltcedar (*Tamarix gallica*) (W. L. Fisher et al. 1972; Webb et al. 1978).

Washover fans, caused by breaching of the island during storm or hurricane surge, are common on Follets Island. As late as 1972, these fans were largely unvegetated sand. On Bolivar Peninsula, washover fans and tidal deltas have formed together but are stabilized by salt marsh vegetation.

In 1978 the U.S. Army Corps of Engineers completed 2.5 years of experimental propagations of marsh and upland vegetation on dredge material (Webb et al. 1978). Similar plantings on overwash areas probably could speed recovery of barren fans. Sprigged culms of smooth cordgrass (*Spartina alterniflora*) and marshhay cordgrass (*S. patens*) survived best when planted in their preferred habitats, i.e. lower elevations for smooth cordgrass and higher elevations (0.46 m above mean sea level) for marshhay cordgrass. Fertilizer applications did not affect survival rates appreciably. The most important factor appeared to be protection of sprigs from wave action. Upland vegetation showed good survival. After nearly 1 year, live oak (*Quercus virginiana*) showed a 96.5% survival rate; winged sumac (*Rhus copallina*), 66%; and both sand pine (*Pinus clausa*) and saltcedar (*Tamarix gallica*), 30% (Webb et al. 1978).

In addition to stabilizing loose sand, vegetative propagation enriches the community as a whole, enabling a diverse array of aquatic and terrestrial fauna to thrive.

5.2.2 Fauna

Mammals. Webb et al. (1978) during their propagation studies on Bolivar Peninsula made mammal counts and collections. Rodents were the most common mammals in the barrier island community (Table 7).

Table 7. Representative mammals of the barrier island community, Galveston Bay system (Davis 1974; Webb et al. 1978).

Scientific name	Common name
Sigmodon hispidus	Hispid cotton rat
Mus musculus	House mouse
Oryzomys palustris	Northern rice rate
Rattus norvegicus	Norway rat
Sylvilagus floridanus	Eastern cottontail
Didelphis virginiana	Opossum
Dasypus novemcinctus	Nine-banded armadillo

Old World rodents, the house mouse (Mus musculus) and Norway rat (Rattus norvegicus), apparently have become fairly well established on Bolivar Peninsula, perhaps making their way from Galveston Island. These species inhabited Galveston Island in the early 1800's when they were introduced through the seaport. The relatively high rainfall supplied sufficient freshwater to allow their survival (Baker and Lay 1938). With the influx of human habitation, the island's capacity for rodent populations grew due to increased availability of food, water, and shelter. The hispid cotton rat (Sigmodon hispidus) is the most common native rodent in the barrier island community (Webb et al. 1978).

Domestic cattle and goats were still on Bolivar Peninsula as late as 1978 (Webb et al. 1978). The area has been used for grazing since the early 1900's, but this practice's ecological effects have not been adequately studied (Gosselink et al. 1979).

One sighting of red fox (Vulpes vulpes) has been made on the southern end of Bolivar Peninsula (Webb et al. 1978). Davis (1974), however, did not report this species in the barrier island community of the Galveston area. Island populations, if present, are probably small.

Birds. The barrier islands of the Galveston Bay system are important feeding, resting, and nesting sites for resident and migratory birds. The islands provide a variety of habitats, from beach to grass-dominated barrier flats, to oak mottes. With increasing human habitation, environments for birds (and most other fauna) are being altered or lost entirely. As early as 1958, Hall et al. (1959) noted reduced numbers of purple gallinule (Porphyrula martinica) and Wilson's phalarope (Steganopus tricolor) in the Galveston area, apparently due to the filling of ponds for housing developments.

In the midst of continuing habitat loss, Webb et al. (1978) investigated to what degree birds would use a man-made marsh and upland constructed from a dredge spoil substrate sprigged with vascular flora. During the first year of vegetative propagation, a total of 135 species were recorded on or flying over the study site. More species used the experimental marsh than the natural (control) marsh during all seasons, although this observation may be misleading since the experimental marsh was considerably larger. No difference in preference was noted between the experimental upland and the control upland. Overall species densities were low throughout the peninsula, although in the control marsh gregarious species such as the laughing gull (Larus atricilla) reached densities as high as 25 birds per ha in the fall of 1977. Bird diversities, on the other hand, were highest in the spring of 1977 for both the marsh and upland area. These peaks represented for the most part steady increases in avian species diversity from the beginning of the experiment (Webb et al. 1978).

Species typically found on the barrier flat of barrier islands in the Galveston Bay area include the killdeer (Charadrius vociferus), mourning dove (Zenaida macroura), red-winged blackbird (Agelaius phoeniceus), and common grackle (Quiscalus quiscula). Species associated with the beach habitat rather than the barrier flats are the black skimmer (Rynchops niger), herring gull (Larus argentatus), laughing gull, royal tern (Sterna maxima), Caspian tern (S. caspia), and spotted sandpiper (Actitis macularia) (Webb et al. 1978).

Reptiles and amphibians. Species diversity of reptiles and amphibians is low in the barrier island community. Representative amphibian species are the gulf coast toad (*Bufo valliceps*) and Woodhouse's toad (*B. woodhousei woodhousei*) (Conant 1975; Gosselink et al. 1979).

The ornate box turtle (*Terrapene ornata ornata*), the only terrestrial turtle frequenting the barrier island community, escapes summer heat by burrowing into the sand. The species is much more conspicuous after a rain when large numbers appear (Conant 1975).

Several lizard species are fairly common on the Galveston area barrier islands. The Texas horned lizard (*Phrynosoma cornutum*) and six-lined racerunner (*Cnemidophorus sexlineatus sexlineatus*) are typical species reported by Webb et al. (1978) and Gosselink et al. (1979). The horned lizard is especially well adapted for hot climates; in fact, high temperatures are required to initiate feeding behavior.

Webb et al. (1978) reported the speckled kingsnake (*Lampropeltis getulus holbrooki*) and eastern hognose snake (*Heterodon platyrhinos*) as occurring on Bolivar Peninsula. According to Conant (1975), other species likely to be found on the barrier islands of the Galveston system include the eastern coachwhip (*Masticophis flagellum flagellum*) and western diamondback rattlesnake (*Crotalus atrox*).

There are no population estimates of amphibians or reptiles on Bolivar Peninsula.

5.3 RIVERINE AND LACUSTRINE COMMUNITIES

Rivers, in addition to supporting a flora and fauna of their own, exert important influences on surrounding communities. In the floodplain community, rivers determine floodplain development by the magnitude of their flow in relation to the size of their meander belts. The riverine community of the Galveston Bay system, consisting of the Trinity and San Jacinto Rivers, has formed a well-developed floodplain with habitats for diverse assemblages of flora and fauna.

The riverine community is also the life line of the Galveston Bay estuarine community. Of the rivers in all six bay systems, the Trinity and San Jacinto Rivers provide the greatest freshwater inflow to the estuary. The water and its associated biotic and abiotic components influence all aspects of the estuary. Riverine inflows make three major contributions to the Galveston estuarine community: (1) freshwater inflow which produces moderate salinities, (2) inorganic sediments which maintain existing wetlands and form new marsh areas, and (3) nutrients which enable survival and growth of the estuarine community.

Negative aspects of inflow from the Trinity and San Jacinto Rivers are related to man's activities either on or surrounding these rivers. Dumping of chemical wastes in the rivers upstream of the Galveston Bay complex introduces some pollutants into the estuary. Nutrient loading from agricultural runoff and municipal wastewater results in frequent phytoplankton blooms that are sometimes followed by oxygen depletion and fish kills (TDWR 1978, cited by Espey, Huston and Associates 1978; Espey, Huston and Associates 1978).

The most extensive man-induced problem within the riverine community that affects the estuarine community is the permanent flooding of marshes and subsequent loss of valuable nursery grounds for finfish and shellfish. Such a loss was narrowly averted in the case of the U.S. Army Corps of Engineers' (USACE) Wallisville Lake project, a proposed dam and reservoir on the lower reaches of the Trinity River. The project was designed to prevent saline intrusion up the Trinity River and to supply a freshwater source for metropolitan Houston. Construction was 80% complete by 1973 when litigation procedures deemed that the project would cause extensive losses of brackish marsh and marsh-related habitat which are important nursery grounds. Baldauf et al. (1970, cited by USFWS 1976) had estimated that 5,060 ha of nursery habitat would be lost to the reservoir. Since the construction moratorium, several alternative plans have been proposed. Plan 2A that the USACE has selected for recommendation to Congress would not flood any of the 2,900 ha of critical brackish marsh. No predictions on the likelihood of its passage were made (Ray Proctor, USACE, Galveston, Texas; pers. comm. 1980).

5.3.1 Vegetation

Water-tolerant grasses and grass-like vegetation such as common reed (*Phragmites communis*), rush (*Juncus* spp.), and cattail (*Typha* spp.) may be found along the Trinity River banks, but the predominant plant life in the Trinity and San Jacinto Rivers is phytoplankton . C. D. Fisher et al. (1973) surveyed the Trinity River and reported representative phytoplankton in the lower reaches as including *Cyclotella menghiniana*, *Melosira granulata*, and *Navicula rhyncocephala*. The first two species are generally indicators of low levels of organic nutrients.

C. D. Fisher et al. (1973) reported that the water of the Trinity River below Lake Livingston is of high quality. The lake and its vegetation apparently take up most of the nitrogen and phosphorus-containing effluents from the Dallas metropolitan area. Although monitoring stations on the Trinity River downstream of Lake Livingston have recorded ammonium levels which, according to Vollenweider (1968, cited by C. D. Fisher et al. 1972), would constitute bloom concentrations, those levels were always below 1 ppm, much less than concentrations in the upper reaches of the river. Nitrite levels at these lower stations were very low, less than 0.01 ppm. Nitrate levels, however, were eutrophic, averaging 3.7 ppm at a station near Liberty. This latter value suggests that the water in this river never completely recovers from the concentrated nitrogen effluent contributed by the metropolitan areas farther upstream (C. D. Fisher et al. 1972).

Levels of orthophosphates downstream of Lake Livingston are consistently low (0.16 ppm), whereas input to the lake may be as high as 12.5 ppm. C. D. Fisher et al. (1972) suggested that the excess phosphorus is taken up by lake vegetation and subsequently deposited in the sediment where it is unavailable to the riverine community. The low phosphorus levels are perhaps the major factor protecting the lower Trinity River from episodes of eutrophication (C. D. Fisher et al. 1972).

5.3.2 Fauna

Mammals. No aquatic mammals frequent the Trinity or San Jacinto Rivers. Semi-aquatic mammals are discussed in the floodplain community of this paper (Section 5.4.2).

Birds. See Section 5.4.2.

Reptiles and amphibians. According to Conant (1975), representative turtles in the riverine community include the alligator snapping turtle (Macroclemys temmincki), Texas slider (Chrysemys concinna texana), and midland smooth softshell (Trionyx muticus muticus). Whereas the other turtles are common in at least one other Texas bay system, the alligator snapping turtle is typical only of the Galveston Bay system where it reaches the southwestern limit of its range. This species, the largest freshwater turtle in the United States, usually lies on the river bottom where it feeds primarily on fish (Conant 1975).

Other species in the river, but which show considerable breadth of habitat, include the common snapping turtle (Chelydra serpentina serpentina), yellow mud turtle (Kinosternon flavescens flavescens), stinkpot (Sternotherus odoratus), and the pallid spiny softshell (Trionyx spiniferus pallidus).

A discussion of amphibians, lizards, and snakes likely in or around the rivers may be found in the floodplain community section of this synthesis (Section 5.4.2).

Fish. According to USGS (1973), salinity in the Trinity River, as measured by chlorinity, is effectively dissipated at the first monitoring station above the mouth of the river. The air distance to this station is approximately 80 km above Trinity Bay. Average salinity during the water year 1973 was 0.04 ⁰/oo. Since the arbitrary inland boundary of the Texas Barrier Islands Region is 64 km from the coast, salinities in the Trinity Bay area can be expected to be somewhat higher, but the river is still essentially fresh within the established bounds. Freshwater fish can be expected to occur in the lower Trinity River. No monitoring stations on the San Jacinto River were close enough to the inland boundary of the study area to provide salinity data. In Conroe, in Montgomery County, the mean salinity during the water year 1973 was 0.04 ⁰/oo.

C. D. Fisher et al. (1972) investigated the freshwater and marine ichthyofauna of the lower Trinity River; Conner (1977) studied freshwater species of the entire Galveston Bay drainage system. Table 8 gives 16 freshwater and 6 marine species common to the lower Trinity River. Both studies suggested that the paddlefish (Polyodon spathula) in the Galveston drainage has declined, perhaps to complete extirpation, in the past 20 years. C. D. Fisher et al. (1972) believed that, in Texas, the paddlefish probably exists only in the Sabine and Red River drainages.

The Galveston Bay drainage has strong faunal affinities with the Calcasieu and Sabine Lake drainages to the northeast and the Brazos drainage to the southwest. Within the Galveston Bay drainage itself, the differences between the Trinity and San Jacinto Rivers are marked. In fact, of the three Texas drainages, comprising two rivers emptying into a common estuary, the Galveston Bay system exhibits the highest degree of difference between the component rivers. Twelve freshwater species in the Trinity River were not recorded in the San Jacinto River. The primary cause for the difference is the greater length of the Trinity; the river extends into the upland and supports species common only to that type of riverine habitat (Conner 1977).

Table 8. Representative ichthyofauna of the lower Trinity River drainage system (C. D. Fisher et al. 1972; Conner 1977).

Scientific name	Common name
Freshwater	
Amia calva	Bowfin
Hybopsis amnis	Pallid chub
Notropis atrocaudalis	Blackspot shiner
N. shumardi	Silverband shiner
N. lutrensis	Red shiner
Pimephales vigilax	Bullhead minnow
Erimyzon sucetta	Lake chubsucker
Ictalurus natalis	Yellow bullhead
Noturus nocturnus	Freckled madtom
Fundulus chrysotus	Golden topminnow
F. olivaceous	Blackspotted topminnow
Micropterus salmoides	Largemouth bass
Ammocrypta vivax	Scaly sand darter
Lepomis punctatus	Spotted sunfish
L. macrochirus	Bluegill
L. megalotis	Longear sunfish
Marine	
Brevoortia gunteri	Finescale menhaden
Anchoa mitchilli	Bay anchovy
Mugil cephalus	Striped mullet
Dorosoma petenense	Threadfin shad
Menidia beryllina	Tidewater silverside
Cyprinodon variegatus	Sheepshead minnow

5.4 FLOODPLAIN (PALUSTRINE) COMMUNITY

Floodplains are well developed along the Trinity and San Jacinto Rivers but are not nearly as extensive as those of the Colorado and Brazos Rivers of the neighboring Matagorda-Brazos system. Floodplain vegetation varies with the frequency and duration of flooding. Swamps, flooded for extended periods throughout the year, occur along both rivers. At higher elevations and in soil with better drainage, more typical floodplain habitats predominate. The various habitats within the floodplain result in a high species diversity of the resident fauna.

Human intervention in the form of agriculture, logging, and residential development in the floodplain around and north of Liberty was moderate in the early 1970's during the studies of C. D. Fisher et al. (1972). Higher levels of perturbation, consisting primarily of residential development, were found south of Liberty. As early as 1972, higher elevated bottomlands and forested areas along the Trinity River were being converted to agriculture, pasture, and residential areas. At that time, timber production was the main use of the floodplain along the lower Trinity River; much of the land nearest the river was second growth and of low lumber quality (C. D. Fisher et al. 1972). With the rapid growth of Houston during the 1970's, it is likely that more change has occurred in the landscape of the floodplain community.

5.4.1 Vegetation

Along the banks of the Trinity and San Jacinto Rivers, vegetation growing at the water's edge includes rush (*Juncus* spp.), bulrush (*Scirpus* spp.), cattail (*Typha* spp.), and willow (*Salix* spp.), which form a frequently flooded fluvial area (C. D. Fisher et al. 1972). The dominant vegetation is a floodplain hardwood forest growing in a typically flat, poorly drained landscape (Harcombe and Neaville 1977).

C. D. Fisher et al. (1972), in their investigation of the environmental and cultural resources of the Trinity River, established two study areas which fall within the bounds of the Galveston Bay system. One was from south of State Highway 162 to south of U.S. Highway 90 in Liberty. The second extended from Liberty south to Interstate Highway 10 in Chambers County. The majority of the floodplain in the first area was either forested, grazed by cattle, or logged. Housing developments were moderate and clustered around oxbow lakes. This portion of the floodplain, at the time of the report, was the least disturbed of any area along the Trinity River (C. D. Fisher et al. 1972). The area below Liberty has been subjected to a higher level of residential development. Some areas of bottomland forest are still undisturbed, but the more scenic floodplain vegetation is farther south.

Within these two areas were reported 79 species of trees, shrubs, and woody vines (C. D. Fisher et al. 1972). Representatives of these three groups are listed in Table 9. Vegetative species diversity in the floodplain community is probably greater than in any other community in this system. Although no data were available on the San Jacinto floodplain, its proximity to the Trinity makes a similar flora likely.

Harcombe and Neaville (1977) described the forests as relatively open, with an open canopy of water oak (*Quercus nigra*) and a subcanopy of cedar elm

Table 9. Representative vascular flora of the floodplain hardwood forest of the floodplain community, Galveston Bay system (C. D. Fisher et al. 1972).

Scientific name	Common name
	Trees
Acer negundo	Box elder
Carya aquatica	Water hickory
C. illinoensis	Pecan
Cornus drumondii	Roughleaf dogwood
Diospyros virginiana	Persimmon
Fraxinus pennsylvanica	Green ash
Liquidambar styraciflua	Sweetgum
Platanus occidentalis	Sycamore
Populus deltoides	Eastern cottonwood
Quercus lyrata	Overcup oak
Q. nigra	Water oak
Salix nigra	Black willow
Sapium sebiferum	Chinese tallow tree
Taxodium distichum	Bald cypress
Ulmus americana	American elm
U. crassifolia	Cedar elm
	Shrubs
Celtis laevigata	Texas sugarberry
Crataegus spathulata	Pasture haw
Gleditsia triacanthos	Honey locust
	Vines
Ampelopsis arborea	Pepper vine
Campsis radicans	Trumpet creeper
Parthenocissus quinqefolia	Virginia creeper
Rhus toxicodendron	Poison ivy
Rubus aboriginum	Dewberry-blackberry
Vitis mustangensis	Mustang grape

(Ulmus crassifolia), sugarberry (Celtis spp.), and red haw (Crataegus spp.). The understory varied from stands of dwarf palmetto (Sabal minor) to a thick cover of grass and herbs. Vines were a component throughout the floodplain forest.

In the lowest areas of the floodplain, where water inundates the land most of the year, cypress swamps have developed. The swamps cover approximately 73 km^2 along the two rivers of Galveston Bay System (C. D. Fisher et al. 1972). Bald cypress (Taxodium distichum), once established on exposed mineral soil, can tolerate extended periods of inundation by freshwater but periodic drying is essential for new generations to become established (Hall et al. 1946, cited by Harcombe and Neaville 1977). The species is quite sensitive to saline water and is not found where saltwater intrusion occurs (O'Neil 1949, cited by Harcombe and Neaville 1977). Other typical species include willow (Salix spp.), water elm (Palanera aquatica), and buttonbush (Cephalanthus occidentalis) (Harcombe and Neaville 1977).

The upper terraces of the floodplains of the Trinity and San Jacinto Rivers support an assemblage referred to as an oak pine forest (Harcombe and Neaville 1977). The assemblage's primary distinguishing feature is the loblolly pine (Pinus taeda), typically not found in any of the other five Texas bay systems. Earlier studies reported the longleaf pine (P. palustris) and shortleaf pine (P. echinata) in this area (C. D. Fisher et al. 1972, 1973). According to Harcombe and Neaville (1977), these reports are erroneous. Other canopy level vegetation here includes sweetgum (Liquidambar styraciflua), willow oak (Quercus phellos), water oak (Q. nigra), southern red oak (Q. falcata), and hickories (Carya spp.). The understory includes yaupon (Ilex vomitoria) and American beautyberry (Callicarpa americana) (C. D. Fisher et al. 1972; Harcombe and Neaville 1977).

The predominance of loblolly pine and sweetgum in the oak-pine forest indicates that fire or lumbering has affected succession. With 75 to 150 years post-perturbation, a mixed forest of predominantly hardwoods will develop. The constituent hardwoods will vary with the moisture of the site. Drier areas will support southern red oak, post oak (Quercus stellata), and hickories. In areas with greater soil moisture, magnolia (Magnolia grandiflora) and basket oak (Quercus prinus) will be typical (Monk 1965, cited by Harcombe and Neaville 1977).

5.4.2 Fauna

Mammals. The white-tailed deer (Odocoileus virginianus) is one of the most popular game species in this bay system. It reaches large numbers in the floodplain hardwood forests where hunting pressure is high. Landowners frequently lease floodplain areas for deer-hunting. According to data for counties lying within or overlapping into the Galveston Bay system (i.e., Chambers, Galveston, Harrison, Liberty, Jefferson, Brazoria, and Fort Bend Counties), average annual hunting pressure from 1973 through 1977 was 105.5 hunters per 1,000 ha (TPWD 1978c). This value is well above the average 28.6 hunters per 1,000 ha in TPWD's Ecological Area 2 (Gulf Prairies and Marshes), the Ecological Area in which most of the Texas Barrier Islands Region lies. This value for hunting pressure does not pertain solely to the floodplain, as a considerable amount of the pressure is in the upland and estuarine areas.

The mean annual harvest during the 1973-77 period was 747 antlered and antlerless deer. This figure is considerably below the harvest in the smaller Corpus Christi Bay and San Antonio Bay systems.

Other game species in the area include the fox squirrel (*Sciurus niger*) and eastern gray squirrel (*S. carolinensis*). Largest populations of the fox squirrel are in the oak-pine forests of the upper floodplain (Davis 1974). Feeding and nesting requirements of this species are discussed in the Corpus Christi synthesis, Section 5.4.2. The eastern gray squirrel is most abundant in the lower terraces of the floodplain hardwood forests where it requires an almost entirely closed canopy (McCarley 1959). Mast (acorns, nuts, etc.) is the mainstay of its diet. This squirrel is an especially popular game animal in east Texas (Davis 1974).

The beaver (*Castor canadensis*) is more common in the Trinity River watershed than anywhere else in Texas (C. D. Fisher et al. 1972). Trapping in east Texas during the early 1900's devastated local populations, but transplants from west Texas, when protected by law, were responsible for a strong comeback. Trapping is now legal, but the trapping industry for all furbearers appears declining in the Trinity River region (C. D. Fisher et al. 1972). According to TPWD (1979c), the statewide beaver harvest has increased dramatically, from 128 pelts in the 1972-73 season to 2,702 in the 1977-78 season. No data were available on harvest trends in the Galveston Bay area.

Other common furbearers include the mink (*Mustela vison*), nutria (*Myocastor coypus*), coyote (*Canis latrans*), raccoon (*Procyon lotor*), opossum (*Didelphis virginiana*), and muskrat (*Ondatra zibethicus*) (C. D. Fisher et al. 1972; Davis 1974).

The location of the Trinity River is ecologically important in that the river and its surrounding floodplains support a diverse array of species (C. D. Fisher et al. 1972). Eastern forest mammals (and birds) overlap with western prairie species in this area, each group reaching its respective range limits. Although most of this overlap exists on the upper Trinity River, some of these peripheral species probably also occur in the lower reaches. Table 10 lists representative mammals of the floodplain community in the Galveston Bay system. As the table shows, rodents are the most abundant mammalian order.

Birds. Fish-eating birds and water birds typically use swamps within the floodplain community as breeding grounds. Nest sites are in shrubs and trees of varying heights; the number of nesting pairs is generally proportionate to the number of available nest sites. The cattle egret (*Bubulcus ibis*) and little blue heron (*Florida caerulea*) usually represent the majority of the birds present. In a 1972 census along the lower reaches of the Trinity River, however, the white ibis (*Eudocimus albus*) was second in abundance following the cattle egret (C. D. Fisher et al. 1972). C. D. Fisher et al. (1972) observed a rookery in lower Liberty County and provided the abundance estimates shown in Table 11.

Table 10. Representative mammals of the floodplain community, Galveston Bay system (McCarley 1959; C. D. Fisher et al. 1972; Schmidly et al. 1977).

Scientific name	Common name
Didelphis virginiana	Opossum
Blarina brevicauda	Short-tailed shrew
Pipistrellus subflavus	Georgia bat
Lasiurus borealis	Red bat
Nycticeius humeralis	Evening bat
Dasypus novemcinctus	Nine-banded armadillo
Sylvilagus floridanus	Eastern cottontail
S. aquaticus	Swamp rabbit
Sciurus carolinensis	Eastern gray squirrel
S. niger	Fox squirrel
Glaucomys volans	Eastern flying squirrel
Perognathus hispidus	Hispid pocket mouse
Peromyscus gossypinus	Cotton mouse
Baiomys taylori	Pygmy mouse
Oryzomys palustris	Northern rice rat
Sigmodon hispidus	Hispid cotton rat
Neotoma floridana	Florida wood rat
Mus musculus	House mouse
Rattus rattus	Roof rat
Rattus norvegicus	Norway rat
Castor canadensis	Beaver
Ondatra zibethicus	Muskrat
Myocastor coypus	Nutria
Canis latrans	Coyote
Urocyon cinereoargenteus	Gray fox
Procyon lotor	Raccoon
Mustela vison	Mink
Lutra canadensis	River otter
Lynx rufus	Bobcat
Odocoileus virginianus	White-tailed deer

Table 11. Estimates of breeding populations of fish-eating birds at the Old River rookery in lower Liberty County (C. D. Fisher et al. 1972).

Scientific name	Common name	Number of individuals	Percent of total
Bubulcus ibis	Cattle egret	4219	64.0
Eudocimus albus	White ibis	1526	23.1
Florida caerulea	Little blue heron	335	5.1
Hydranassa tricolor	Louisiana heron	266	4.0
Anhinga anhinga	Anhinga	100	1.5
Casmerodius albus	Great egret	61	0.9
Ardea herodias	Great blue heron	50	0.8
Nyctanassa violacea	Yellow-crowned night heron	17	0.3
Mycteria americana	Wood ibis	7	0.1
Leucophoyx thula	Snowy egret	5	0.1
Ajaia ajaja	Roseate spoonbill	4	0.1
Nycticorax nycticorax	Black-crowned night heron	3	0.0
Butorides virescens	Green heron	1	0.0
		6594	100.0

The banks of the Trinity River are also an important feeding ground for the anhinga (*Anhinga anhinga*), little blue heron, snowy egret (*Leucophoyx thula*), great blue heron (*Ardea herodias*), and great egret (*Casmerodius albus*). These birds feed on crustaceans and fish. An herbivore common on the the lower Trinity River is the wood duck (*Aix sponsa*), which feeds on aquatic vegetation and nuts and seeds on the nearby shore.

Raptors, feeding primarily on small terrestrial mammals, patrol extensive areas in the swamp and bottomland hardwoods in search of prey. Common species include the red-tailed hawk (*Buteo jamaicensis*), red-shouldered hawk (*B. lineatus*), and barred owl (*Strix varia*) (Oberholser et al. 1974). Unlike these rapacious birds, which occur throughout the coastal area of Texas, the saw whet owl (*Aegolius acadicus*) is reported only from Chambers and Harris Counties of the Galveston Bay system. It is a solitary species, most often frequenting conifer-dominated forests (Oberholser et al. 1974).

Reptiles and amphibians. Some lizards common in the floodplain community, like the green anole (*Anolis carolinensis carolinensis*), are arboreal. Others, including the ground skink (*Scincella lateralis*) and six-lined racerunner (*Cnemidophorus sexlineatus sexlineatus*), are terrestrial. The latter species, especially conspicuous due to its bold nature, can afford the floodplain habitat better than some lizards as its quickness usually allows rapid escape. The ground skink does not hesitate to enter shallow water to avoid predators (Conant 1975).

Snakes abound in the various floodplain community habitats and in the adjacent river. Water snakes, like the green water snake (*Nerodia cylopion cylopion*), Graham's crayfish snake (*Regina grahami*), diamondback water snake (*N. rhombifera rhombifera*), and glossy crayfish snake (*Regina rigida*), are especially common along rivers, streams, or swamps. Other nonvenomous snakes include the eastern garter snake (Thamnophis sirtalis sirtalis), rough green snake (Opheodrys aestivus), and eastern coachwhip (Masticophis flagellum flagellum). Venomous snakes in this community are the Texas coral snake (Micrurus fulvius tenere), southern copperhead (Agkistrodon contortrix contortrix), western cottonmouth (A. piscivorus leucostoma), and timber rattlesnake (Crotalus horridus) (Conant 1975).

Common amphibians in the floodplain and swamp are also diverse. Environmental conditions are excellent, with an abundance of food and moisture in a warm, humid habitat. Representative species include those listed in Table 12.

Table 12. Representative amphibians of the floodplain community, Galveston Bay system (Raun and Gehlbach 1972; Conant 1975).

Scientific name	Common name
Amphiuma means	Two-toed amphiuma
Eurycea quadridigitata	Dwarf salamander
Notophthalmus viridescens louisianensis	Central newt
Rana clamitans clamitans	Bronze frog
R. palustris	Pickerel frog
R. catesbeiana	Bullfrog
Acris crepitans crepitans	Northern cricket frog
Hyla cinerea	Green treefrog
H. crucifer crucifer	Northern spring peeper
H. squirella	Squirrel treefrog
H. versicolor	Gray treefrog
H. chrysoscelis	Cope's gray treefrog
Pseudacris streckeri streckeri	Strecker's chorus frog
P. triseriata feriarum	Upland chorus frog
Bufo woodhousei woodhousei	Woodhouse's toad
B. woodhousei fowleri	Fowler's toad
Gastrophryne carolinensis	Eastern narrow-mouthed toad

5.5 UPLAND COMMUNITY

The upland community comprises those areas within 64 km (40 mi) of the coast which are at sufficient elevations and distances from the bays and rivers to preclude flooding under normal conditions. Because of its proximity to the Houston area, this community has undergone and is continuing to undergo severe man-induced changes, including residential, commercial, and agricultural development. Although highly populated metropolitan areas are near, the majority of the land was used for agriculture in 1972. Rice is the major cultivated crop. Some hay and grain are also grown, primarily for cattle feed. Rangeland and pasture constitute approximately 30% of agricultural land in the study area (W. L. Fisher et al. 1972).

The upland community influences the estuarine community in several ways. Its primary benefit is supplying sediments and nutrients to the rivers which carry them to the estuary. The negative effects of the uplands result from human intervention. For example, water diversion for agriculture robs the estuary of freshwater inflow and the resultant organic and inorganic materials in the water column. Most human activity, however, adds chemicals of one form or another to the water. Included are pesticides, herbicides, and excessive nutrient runoff from agricultural fields; municipal sewage from urban centers; and chemical wastes from local industry (Carter 1970). These effluents frequently are responsible for poor water quality in Galveston and Trinity Bays.

5.5.1 Vegetation

If Chambers County is used as a representative area, the predominant natural vegetation of the upland community can be considered to be a bluestem prairie. W. L. Fisher et al. (1972) and Harcombe and Neaville (1977) reported the major species to include big bluestem (*Andropogon gerardi*), seacoast bluestem (*Schizachyrium scoparium littoralis*), indiangrass (*Sorghastrum avenaceum*), switchgrass (*Panicum virgatum*), and eastern gamagrass (*Tripsacum dactyloides*). On drier, sandy soils seacoast bluestem is most abundant. The other species occur more commonly on moist sites, typically with a clay or loam substrate. Under natural conditions these prairies are uniform stands 1-2 m in height, interrupted by occasional clumps of forbs such as ragweed (*Ambrosia* spp.), sumpweed (*Iva* spp.), thistle (*Cirsium* spp.), and clover (*Melilotus* spp.).

Most of the upland has been altered extensively by municipal and residential development, agriculture, and pasture. Cultivated fields are dominated by rice (W. L. Fisher et al. 1972). Cropping patterns are generally 2 years of cultivation followed by 2-3 years of lying fallow. During the first year following cessation of cultivation, barnyard grass (*Echinochloa crusgalli*) and various sedges colonize the fallow soil. In subsequent years, forbs and woody plants like sumpweed (*Iva* spp.), rattlebush (*Sesbania drummondii*), and groundsel tree (*Baccharis halimifolia*) begin to invade. Pasture vegetation is predominantly vasey grass (*Paspalum urvillei*), unless serious overgrazing has occurred. In such cases, smutgrass (*Sporobulus indicus*) and carpetgrass (*Axonopus affinis*) are dominant (Harcombe and Neaville 1977).

Tracts of land that have been permanently removed from cultivation and protected from fire are typically invaded by the woody species, groundsel tree, and to a lesser extent by Chinese tallow (*Sapium sebiferum*) and huisache (*Acacia farnesiana*) (Harcombe and Neaville 1977).

In Chambers County along the northern border of East Bay, the dominant vegetation, gulf cordgrass or coastal sacahuista (*Spartina spartinae*), forms a monotypic stand. This grass becomes increasingly prevalent farther south along the Texas coast.

The oak-pine forests mentioned previously in the floodplain community could just as well be categorized with the upland community, especially those forests on the drier, higher sites. Categorizing these forests as part of the floodplain commonly was a subjective decision, based on Harcombe and Neaville's (1977) discussion.

5.5.2 Fauna

Mammals. From Davis' (1974) work, it appears that the upland community of the Galveston Bay system supports considerably fewer rodent species than do the uplands of more southerly systems. According to the ranges given by Davis (1974), 14 rodent species occur in the upland area of the Corpus Christi Bay system, whereas only 5 species are common in the Galveston uplands. These latter species are given in Table 13.

Table 13. Representative rodents in the upland community, Galveston Bay system (Davis 1974).

Scientific name	Common name
Geomys bursarius	Plains pocket gopher
Perognathus hispidus	Hispid pocket mouse
Reithrodontomys fulvescens	Fulvous harvest mouse
Baiomys taylori	Pygmy mouse
Sigmodon hispidus	Hispid cotton rat

Schmidly et al. (1979) studied the mammals of east Texas and listed several species common in the upland community that were valued as furbearers by commercial trappers. They include the coyote (*Canis latrans*), red fox (*Vulpes vulpes*), gray fox (*Urocyon cinereoargenteus*), raccoon (*Procyon lotor*), eastern spotted shunk (*Spilogale putorius*), striped skunk (*Mephitis mephitis*), opossum (*Didelphis virginiana*), and bobcat (*Lynx rufus*). No data on the extent and value of the fur industry in the upland community of the Galveston Bay system per se were available. Data from TPWD (1979c) analyzed by Schmidly et al. (1979) showed a 69% increase in the number of trappers in east Texas between the 1976-77 and 1977-78 seasons. East Texas includes counties other than those within the Galveston Bay system; therefore, the percentage is only approximate, as is the following discussion of harvests of furbearing species.

According to Schmidley et al. (1979), raccoon and opossum are the most frequently harvested furbearers in east Texas. Of the two, raccoon pelts are of greater value ($16 versus $1.75 in the 1977-78 season) (TPWD 1979c).

Other furbearers, such as the red fox, gray fox, coyote, and bobcat, are harvested less frequently. Since these species are at the top of the food web, smaller and generally more scattered populations of carnivores are supported. The foxes and bobcat are more frequently harvested in oak-pine forests; coyotes are more prevalent in the coastal prairie (Schmidly et al. 1979).

Other species in the upland community include the white-tailed deer (see Section 5.4.2), eastern cottontail (*Sylvilagus floridanus*), California jackrabbit (*Lepus californicus*), least shrew (*Cryptotis parva*), and eastern mole (*Scalopus aquaticus*).

In Texas, populations of the endangered red wolf (*Canis rufus*) formerly were concentrated in the Galveston Bay system. This species' survival is threatened, not only because of man's agriculture and hunting, but also through hybridization with the coyote, whose range is expanding with agricultural development (Paradiso 1968). In fact, preparations have begun to declare that species extinct in its last stronghold in Texas and Louisiana (USFWS 1980). The red wolf is discussed further in Section 5.6.1 of this synthesis.

Birds. The Canada goose (*Branta canadensis*), white-fronted goose (*Anser albifrons*), and snow goose (*Chen caerulescens*) use rice fields more heavily than all other upland habitats. During the fall and winter, they feed on waste grain in rice fields, as well as on tubers in the marshes of the estuarine community.

Other birds frequenting the uplands include killdeer (*Charadrius vociferus*), cattle egret (*Bubulcus ibis*), upland plover (*Bartramia longicauda*), mountain plover (*Eupoda montana*), and sandhill crane (*Grus canadensis*). Of these species, only the cattle egret and killdeer are common nesters in coastal Texas. Formerly, the sandhill crane nested sporadically in the State, but no documented records of its breeding here in this century exist. Populations of the sandhill crane are comparable to those of 100 years ago, but the southerly nesting races have declined. The little brown sandhill crane (*Grus canadensis canadensis*), which breeds in the Arctic, is steadily increasing its fall and winter populations in Texas (Oberholser et al. 1974).

The mourning dove (*Zenaida macroura*) is the most popular game bird in Texas. It is a ubiquitous species, present in all 254 counties of the State. Population estimates for individual counties are not available, but TPWD (1979e) reported population estimates by Ecological Areas. The Galveston Bay system, as well as most of the other estuarine systems, is within Ecological Area Two, the Gulf Prairies and Marshes. According to TPWD (1979e) data, mourning dove populations appear declining, as the 1978 call-count value was 25.5% below the 12-year mean. The 1978 call-count for this Ecological Area decreased 35.3% from the 1977 call-count. Of the 10 Ecological Areas, only 3 declined, and of these the Gulf Prairies and Marshes exhibited the sharpest drop (TPWD 1979e). No explanation for this apparent trend was offered.

Rapacious birds of Galveston Bay upland are similar to those frequenting the other bay systems. For representative species, see the Copano-Aransas synthesis Section 5.5.2.

Reptiles and amphibians. Around permanent and semipermanent bodies of water within the upland community are a diverse assemblage of reptiles and amphibians. Mostly, they are typical of those species frequenting the floodplain, bayous, swamps, and freshwater marshes discussed earlier. Those species found in the upland some distance from bodies of water make up an entirely different assemblage, more suited to extended periods without water. Terrestrial turtles like the ornate box turtle (*Terrapene ornata ornata*) and three-toed box turtle (*T. carolina triunguis*) are found in different habitats within the upland community. The ornate box turtle prefers open, treeless areas; the three-toed box turtle frequents brushlands and thickets, or, more often, wooded areas such as the oak-pine forest discussed in Section 5.4.1 (Carr 1952; Conant 1975).

Lizards common to this upland community are listed in Table 14. The six-lined racerunner (*Cnemidophorus sexlineatus sexlineatus*) is well known because of its bold nature. It relies on its speed and quickness to escape predators. The western slender glass lizard (*Ophisaurus attenuatus attenuatus*) is another bold species. Although easier for predators to catch, it struggles vigorously when restrained and often breaks off its tail in an attempt to escape (Conant 1975). All lizard species in Table 14 are adapted to their hot and often dry habitats and are not restricted to areas of permanent water. In the upland of the Galveston Bay system, humidity is great enough to form substantial amounts of dew, an important water source for these lizards. The small amounts of water on which these lizards exist is adequate due to their highly efficient thermoregulatory abilities. They alternate between basking in the sun and cooling in the shade to maintain their body temperature within a narrow optimum range.

Of the eight representative species of snakes listed in Table 14, only the buttermilk racer (*Coluber constrictor anthicus*) and eastern coachwhip (*Masticophis flagellum flagellum*) are not typically found in other sections of the Texas Barrier Islands Region (Conant 1975). The buttermilk racer is a subspecies with a distribution limited to open areas in northern and western Louisiana and extreme eastern Texas. The eastern coachwhip also reaches the western limit of its range in eastern Texas. This species is similar to the speckled kingsnake (*Lampropeltis getulus holbrooki*), thriving in habitats ranging from dry, sandy areas to swamps (Conant 1975).

Four species of amphibians commonly found in the upland community of the Galveston Bay system are Hurter's spadefoot toad (*Scaphiopus holbrooki hurteri*), gulf coast toad (*Bufo valliceps*), spotted chorus frog (*Pseudacris clarki*), and Strecker's chorus frog (*Pseudacris streckeri streckeri*). Amphibians are more water dependent than lizards and are restricted to at least temporary bodies of water during breeding season. They must be opportunistic breeders to use ephemeral rain ponds. It is also a definite asset for metamorphosis of the tadpoles to be completed in a short time. This characteristic is exemplified by the gulf coast toad. Wright and Wright (1949) reported that only 21 days after eggs were laid, metamorphosis of the young toads could be completed.

Table 14. Representative lizards and snakes in the upland community, Galveston Bay system (Conant 1975).

Scientific name	Common name
Phrynosoma cornutum	Texas horned lizard
Eumeces septentrionalis obtusirostris	Southern prairie skink
Cnemidophorus sexlineatus sexlineatus	Six-lined racerunner
Ophisaurus attenuatus attenuatus	Western slender glass lizard
Coluber constrictor flaviventris	Eastern yellow-bellied racer
C. constrictor anthicus	Buttermilk racer
Heterodon nasicus gloydi	Dusty hognose snake
Lampropeltis calligaster calligaster	Prairie kingsnake
L. getulus holbrooki	Speckled kingsnake
Masticophis flagellum flagellum	Eastern coachwhip
Crotalus atrox	Western diamondback rattlesnake
Micrurus fulvius tenere	Texas coral snake

5.6 RARE AND ENDANGERED VERTEBRATES AND INVERTEBRATES OF THE GALVESTON BAY STUDY AREA[1]

5.6.1 Mammals

Canis rufus - red wolf. The Galveston Bay study area is considered the westernmost location of the present range of the red wolf (National Fish and Wildlife Laboratory 1980). The present range is not considered as extending eastward beyond Cameron and Calcasieu Parishes, Louisiana, and is limited in a northward direction to the coastal prairie (Russel and Shaw 1971; TPWD 1973; National Fish and Wildlife Laboratory 1980). The Sabine Lake area (on the Texas-Louisiana border) appears to be a canid-free zone; therefore, genetic linkage between the Louisiana and Texas populations appears absent (TPWD 1973). The near decimation in red wolf numbers and range area is attributed to several factors. Bounty hunters are chiefly responsible for extirpating the red wolf from Oklahoma, Kansas, most of Texas, and the range east of the Mississippi River by the 1920's (Nowak 1972, cited by National Fish and Wildlife Laboratory 1980). During agricultural expansion, the coyote replaced the red wolf over much of its range, and hybridization of the two species contributed to the demise of pure red wolves (McCarley 1962, cited by National Fish and Wildlife Laboratory 1980). Hybridization remains a major problem, and disease and hunters continue to decrease the population (National Fish and Wildlife Laboratory 1980). As of mid-July 1980, the Beaumont field office of the red wolf recovery program closed; preparations are in progress to declare the species extinct in Texas and Louisiana, the last known area of its natural occurrence (USFWS 1980). In the Galveston Bay study area, isolated red wolf populations were formerly found in Brazoria and Harris Counties, and a major population group had existed in Chambers County (TPWD 1973). Major emphasis of the recovery program will now be directed toward propagation of captives and eventual release to the wild (USFWS 1980). A captive red wolf gene pool, maintained in Tacoma, Washington, consists of 29 adults and 13 young (National Fish and Wildlife Laboratory 1980). TOES = E, USFWS = E.

Lutra canadensis texensis - river otter. The river otter is considered threatened by TOES. Surveys conducted by TPWD (1979d) east of the Trinity River indicate recently increasing populations. Recent Texas fur harvest data tend to support this although the total harvest remains small (Table 15) and may merely reflect increased effort.

Table 15. Texas river otter fur harvest, 1972/73 through 1977/78 seasons (TPWD 1979d).

	1972/73	1973/74	1974/75	1975/76	1976/77	1977/78
Number of pelts	0	60	3	62	201	190

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[1] The status of each rare and endangered species is listed for three agencies: Texas Organization for Endangered Species (TOES), Texas Parks and Wildlife Department (TPWD), and the U.S. Fish and Wildlife Service (USFWS). Status designations include Endangered (E), Threatened (T), and except for the USFWS, Peripheral (P). Additional designations of Status Undetermined (SU) and Not Considered (NC) are from Gustavson et al. (1978).

Ursus americanus - black bear. This bear is considered endangered by TOES and is believed to be extirpated from this area of Texas. Records of the black bear exist for areas west (Matagorda-Brazos study area) and east of the Galveston Bay study area (Hall and Kelson 1959). Davis (1974) reported black bear wandering into east Texas (north of study area), probably from Louisiana release sites.

Trichechus manatus latirostris - West Indian manatee. Although considered endangered in Texas by all three agencies, the manatee's presence in Texas waters has probably been rare (Husar 1977). Records exist in Texas both up and down the coast from the Galveston Bay study area (Davis 1974; Husar 1977). Also see Laguna Madre and Marine syntheses.

Lynx rufus texensis - bobcat. The bobcat is presently under consideration for endangered status by the USFWS. However, TPWD (1977) reports large and stable populations (see San Antonio Bay synthesis).

5.6.2 Birds

Haliaeetus leucocephalus leucocephalus - southern bald eagle. No nesting is currently known in the Galveston Bay study area (TPWD 1979b). Nesting occurred east of the area as late as 1975 in Jefferson County and 1973 in Orange County. Currently two nesting concentrations are downcoast from the Galveston Bay area in the Matagorda-Brazos and San Antonio Bay study areas (TPWD 1979b). Bald eagles from these areas are believed to account for sightings over the Galveston Bay study area. The reader is referred to the above two area syntheses for details. TOES = E, TPWD = E, USFWS = E.

Grus americana - whooping crane. According to TPWD (1979a), there have been no recent sightings of this bird over the Galveston Bay area. The current Texas population is largely confined to the Aransas-Copano and San Antonio Bay study areas (see those syntheses). TOES = E, TPWD = E, USFWS = E.

Pandion haliaetus carolinensis - osprey or fish hawk. Occasional osprey migrants occur in the area (TPWD 1979b). See the Matagorda-Brazos synthesis for further information. TOES = E, TPWD = NC, USFWS = SU.

Falco peregrinus tundrius - Arctic peregrine falcon. A winter migrant, this falcon is typically present in low numbers. High Island, in the southeastern section of the Galveston Bay study area, is one of three survey areas along the Texas coast monitored by TPWD. Some 16 individuals were observed at High Island in 1973 and 9 individuals in 1974 (TPWD 1978a). This survey area was abandoned after 1974. See Matagorda-Brazos, San Antonio Bay, and Laguna Madre syntheses. TOES = E, TPWD = E, USFWS = E.

Pelecanus occidentalis carolinensis - brown pelican. No nesting brown pelicans are currently in the Galveston Bay study area (Blacklock et al. 1978). Historically, colonies have been on Pelican Island in Galveston Bay, and on South Deer, Shell, and Bird Islands in West Bay (TPWD 1978b). The last known nesting was in 1961 on the latter three islands (TPWD 1978b). See Corpus Christi Bay, San Antonio Bay, and Copano-Aransas syntheses for current nesting colonies. TOES = E, TPWD = E, USFWS = E.

Tympanuchus cupido attwateri - Attwater's greater prairie chicken. The present range of this species includes areas of Galveston, Harris, and Chambers Counties within the Galveston Bay area. Its total present range is restricted to these areas and sections of the Matagorda-Brazos, San Antonio Bay, and Copano-Aransas areas (National Fish and Wildlife Laboratory 1980). See the Matagorda-Brazos synthesis for the population estimates, causes of decline, etc. TOES = E, TPWD = E, USFWS = E.

Picoides borealis borealis - red-cockaded woodpecker. This species is associated largely with the pine forests of the Southeastern United States. Its Texas distribution is in the Big Thicket area of east Texas. Although the southernmost extent of the Big Thicket is just north of the Galveston Bay study area, Oberholser et al. (1974) reported several post-1950 records of this bird, including one breeding pair, within the study area. The primary reason for its endangered status is the decrease in quantity and quality of habitat due to land clearing and short-term rotation timber management practices (National Fish and Wildlife Laboratory 1980). Most of the current Texas population resides in the national forests north and east of the Galveston study area. The closest of these, the Sam Houston National Forest, is approximately 50 km north of Houston and supports an estimated 87 to 225 colonies (National Fish and Wildlife Laboratory 1980). The term "colony" refers to a group of cavity trees which the clan (family) uses. The total population of this nonmigrant is estimated to be between 2,800 and 3,600 colonies, with the national forest in Texas containing a minimum of 482 and a maximum of 696 colonies. TOES = E, TPWD = E, USFWS = E.

Chen rossii - Ross' goose. This goose is relatively rare but a regular winter migrant along the upper Texas coast (Oberholser et al. 1974). Individuals observed in the Galveston Bay area are regarded as strays, as are most of the wintering population migrates to the Central Valley of California (Oberholser et al. 1974). When observed in Texas, Ross' goose is frequently in association with the snow goose, a species with which it is often confused. It is listed as threatened in Texas by TOES, but is not under consideration by either TPWD or USFWS.

Campephilus principalis - ivory-billed woodpecker. This woodpecker is probably an extinct species that has been associated with the area. It is or was a resident of the Big Thicket area and bottomland hardwood forests. The last confirmed Texas specimen was obtained in 1904 (Oberholser et al. 1974).

Numenius borealis - Eskimo curlew. This bird may also be extinct. It formerly could be seen in abundance migrating through the area as it returned from its wintering grounds to the south. The last Texas sighting of this bird was in 1968 (Oberholser et al. 1974).

A partial listing of species of birds generally in the Galveston Bay area in low numbers is provided in the Matagorda-Brazos synthesis. These species are generally more abundant elsewhere, with the Texas coast representing an extension or the periphery of their normal range.

5.6.3 Amphibians

The only known endangered amphibian in the Galveston Bay study area is the Houston toad (*Bufo houstonensis*). For discussion, see the Matagorda-Brazos synthesis.

5.6.4 Reptiles

Alligator mississippiensis - American alligator. Joanen (1974, cited by National Fish and Wildlife Laboratory 1980) and TPWD (1975) reported alligators present in all counties within the Galveston Bay study area. Both reports indicate increasing local populations. Table 16 gives population estimates for the area. TOES = E, TPWD = E, USFWS = E.

Table 16. Estimated alligator populations for counties in the Galveston Bay study area, 1974 (TPWD 1975). Totals for counties include areas overlapping into the other bay areas. The total estimated population is 12,239 or approximately one-third of the estimated statewide population.

County	Population	Trend estimates
Brazoria	5,000	Increasing
Chambers	6,500	Increasing
Galveston	390	Increasing
Harris	224	Unknown
Liberty	225	Increasing

Malaclemys terrapin littoralis - Texas diamondback terrapin. This species is considered threatened by TOES but is not under consideration by the other agencies. A dark turtle, the species is indigenous to the salt and brackish waterways and marshes along the Texas coast from Sabine Lake to Corpus Christi Bay. This terrapin is suspected of occurring farther south into Laguna Madre and the Mexican coast (Raun and Gehlback 1972; Conant 1975), but the lack of specimens and suitable habitat precludes confirmation. The demise of this species is largely attributed to overharvesting and destruction of habitat (Conant 1975; Gustavson et al. 1978). The status of local populations is unknown.

The western smooth green snake (Opheodrys vernalis blanchardi) is another species listed by TOES as threatened but is not under consideration by the other agencies. It is discussed in the Matagorda-Brazos synthesis.

For discussion on endangered sea turtles, see the Laguna Madre and Marine syntheses.

5.6.5 Fish

There are no reported findings of any of the threatened or endangered species listed, proposed, or under review by the USFWS (USFWS 1978; Deacon et al. 1979).

5.6.6 Invertebrates

None of the invertebrates listed (USFWS 1978) are indigenous to the Texas coast. See the Matagorda-Brazos synthesis for references consulted.

5.7 RARE AND ENDANGERED PLANTS OF THE GALVESTON BAY STUDY AREA

The only known rare plant in the Galveston system which is not known to be more widely distributed elsewhere is the Texas bitterweed (*Hymenoxys texana*). This sunflower family member is known from the Houston area, but no specimen has been collected since 1900 (Gustavson et al. 1978).

Several species are locally threatened with extinction but have a wider geographic range. Some include giant sedge (*Carex gigantea*), Baldwin stone-rush (*Scleria baldwinii*), bristlebract or sand sedge (*Carex tribuloides*), and pinebarren ruellia (*Ruellia pinetarum*). See Gustavson et al. (1978) for a more complete listing.

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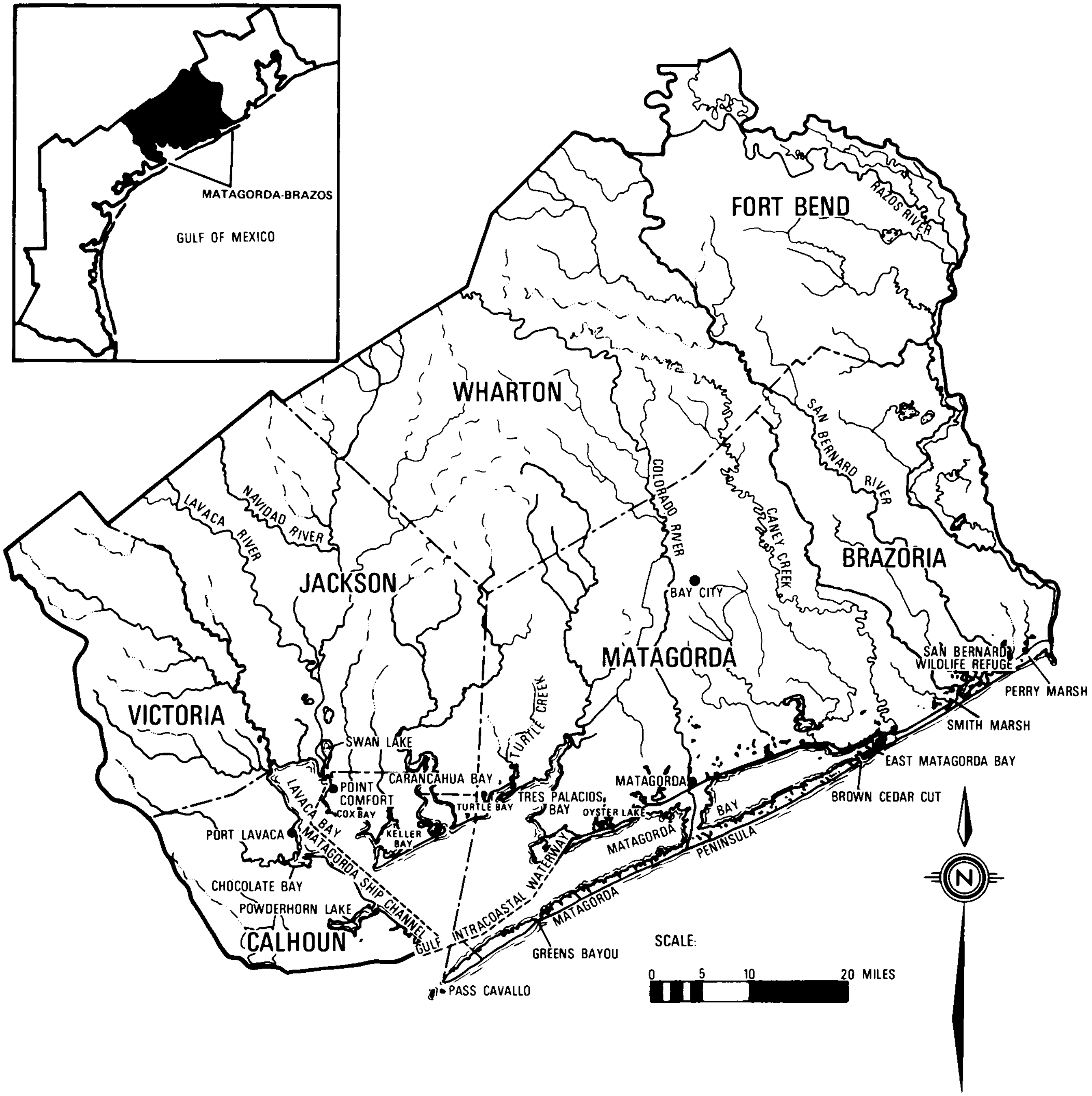
MATAGORDA-BRAZOS STUDY AREA SYNTHESIS



Map 3. Matagorda-Brazos study area.

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1.0 INTRODUCTION

The Matagorda-Brazos study area of east Texas transcends the humid climate of the extreme northeast Texas coast and grades to an increasingly arid climate in a downcoast direction. The humid climate of east Texas, combined with a large drainage area, has resulted in a substantial riverine input into the area. The development of extensive floodplains along the rivers has taken place through several millennia, resulting in a relatively heterogeneous landscape with a corresponding high species diversity.

Several examples of biotic parallels to the climatic transition are evident. Woody shrubs are present in fewer numbers than in study areas to the south, giving way to extensive grasslands along the upland prairie. Several species characteristic of bottomlands of the humid Southeastern United States, e.g., water oak (Quercus nigra) and bald cypress (Taxodium distichum), are present in the Matagorda-Brazos study area. The floodplain of the Brazos and historic Colorado Rivers contains the largest bottomland hardwood habitat in the Texas Barrier Islands Region. The ichthyofauna of the Colorado and Brazos Rivers is significantly different from that of rivers of the south and central Texas coast.

The relatively large riverine input has moderated estuarine salinities, and a large number of fish utilize the Matagorda estuary, with the species composition varying with seasonal freshwater discharge and water temperature. The sediment loads of the large rivers flowing through the study area are substantial and have resulted in the formation of three active deltas which serve as valuable nursery areas.

Man's use of the Colorado, Brazos, and Lavaca-Navidad Rivers has affected the freshwater and sediment input into the estuaries. While the reduced flows are well documented, the effects on production and flushing are not well known.

2.0 GEOLOGY

2.1 GEOLOGIC ORIGIN AND PROCESSES-ESTUARINE AND RIVERINE TRANSPORT OF SEDIMENT

The surface deposits of the Matagorda-Brazos study area consist mostly of Pleistocene fluvial-deltaic sediments. In the immediate vicinity of the open bays, reworked Pleistocene and Recent (also described in the literature as Holocene plus Modern) deposits are more prevalent. The eastern portion of the study area is dominated by Recent deposits of the Colorado and Brazos Rivers (McGowen et al. 1976a, 1976b). Thus, in terms of geologic time, the surface deposits are quite young.

During glacial episodes in the Pleistocene, the Colorado-Brazos, Lavaca-Navidad, and Guadalupe-San Antonio River systems underwent extensive downcutting in response to lowered sea level. During the last major glacial episode (Wisconsin), the base of these river systems was 30 to 40 m lower than at present; and the discharge of their sediments at the shoreline was as much as

80 km seaward of the present shoreline (McGowen et al. 1976a, 1976b). The late Pleistocene barrier-strandplain along much of the central Texas coast is evident in the Port O'Connor area. (See Corpus Christi synthesis for discussion of strandplain formation.) With the termination of the Pleistocene and the beginning of sea level rise to its present position, the rivers experienced a corresponding adjustment in grade. In a geologic sense, the rise in sea level was rapid, and only those rivers which transported substantial amounts of sediment were able to fill in their previously eroded river valleys. The Colorado and Brazos Rivers are two of three present river systems along the Texas coast that have completely filled their ancient valleys since the present stand of sea level (Fisk 1959). Those river systems or subsystems that have not entirely filled their Pleistocene valleys are represented, in part, by Matagorda and neighboring bays. These systems include the Lavaca-Navidad River and tributaries and distributaries of the Colorado and Guadalupe-San Antonio Rivers (McGowen et al. 1976a, 1976b).

When sea level reached its approximate present position several thousand years ago, the Matagorda Bay complex was an estuary open to the Gulf of Mexico, and the Brazos-Colorado deltaic fill was prograding seaward from a point approximately 35 km inland of the present shoreline (McGowen et al. 1976a). As the delta complex enlarged, it also supplied sediment to Matagorda Bay via littoral drift. Additional supplies of sediment arrived in Matagorda Bay from the erosion of bay shorelines by wave and current action, and the onshore transport of eroded and submerged Pleistocene deltaic sediments (McGowen et al. 1976a, 1976b). According to McGowen et al. (1976a), the major source of sediment comprising the initial formation of Matagorda Peninsula was the onshore transport of eroded Pleistocene deltaic sediments. The sediments began to accumulate approximately 4,000 years ago on topographic highs, forming shoals and eventually, discontinuous barrier islands. When the Brazos-Colorado Estuary was filled about 1,800 years ago, the input of fine sands to the peninsula increased greatly via littoral drift, leading to the coalescence of the barrier islands and the formation of the peninsula. Approximately 1,000 years ago the ancestral Colorado River (Caney Creek) was pirated by a headward eroding stream near Wharton, resulting in the discharge of the Colorado River into Matagorda Bay. For at least the past 120 years, the combined effects of changing natural processes and man-induced perturbations (see Section 2.5) have resulted in a predominantly erosional shoreline above the Matagorda Peninsula (Morton et al. 1976).

At present, the sources of inorganic sediments to the system are largely riverine. These include the following: (1) the direct deposition of riverine sediments at the heads of bays (several deltas such as Brazos, Colorado, and Lavaca-Navidad are present in the area); (2) the erosion of older riverine and reworked riverine-deposited bay shorelines; and (3) the onshore, offshore, and littoral transport of Pleistocene and Recent deltaic deposits.

According to the U.S. Army Corps of Engineers (USACE), the Colorado River provides the greatest direct riverine input of sediment into the Matagorda system. Historically, only the Rio Grande and the Brazos River supplied more sediment to the Texas coast than the Colorado River (USACE 1967, cited by Ward et al. 1979). Presently the Colorado River supplies an average of 544 x 10^6kg/yr, and the combined flows of the Lavaca and Navidad Rivers supply an additional 91 x 10^6 kg/yr (Ward et al. 1979). The formation of the present Colorado Delta in Matagorda Bay was an episodic event. From 1929 to 1938, the delta grew at an annual rate of 225 ha/yr (Wadsworth 1966; also see Section 2.5). Since 1938, delta growth has been minimal.

Approximately 104 x 10^8 kg/yr of sediment are carried by the Brazos River past Richmond, Texas, according to the U.S. Geological Survey (USGS 1966-1975). This load is more than an order of magnitude greater than that of the Rio Grande and the Colorado River. The Brazos is presently forming a delta into the Gulf of Mexico. How much of this input presently interacts with the Matagorda Bay system is unknown although Mason and Sorenson (1971) stated that the western littoral transport of sediment from the Brazos Delta is negligible. The contribution of lesser streams (such as the San Bernard River and Turtle, Tres Palacios and Carancahua Creeks) is unknown.

McGowen and Brewton (1975) investigated both long- and short-term shoreline changes along Matagorda Bay. Based on their erosional rate data, Ward (1978, cited by Ward et al. 1979) estimated the annual volume of sediment contributed to the system by bay erosion to be 2 x $10^5 m^3$/yr. If we assume that the grain size distribution of these sediments is roughly equivalent to that of the present suspended load of the Colorado River, shoreline erosion contributes approximately an additional two-thirds as much sediment to the system as the Colorado River.

The movement of sediment through the tidal passes, nearshore littoral transport, and onshore and offshore movements of sediment are important elements of the overall sediment budget, but there are few studies quantifying these processes. Ward et al. (1979) provided an adequate summary of the few littoral transport studies conducted in the area. The results of these studies indicated that there is an apparent sediment deficit within the confines of this segment of the coast (Ward et al. 1979). Whether this loss is to the offshore, through the tidal passes, transported down coast, or a combination of all three, is unknown. A final regime involved in sediment transport, deposition, and erosion is hurricanes and less intensive storms. Hurricane surges frequently breach Matagorda Peninsula, washing sediments into the bay system; when the storm surge ebbs, large quantities of sediments exit from the bay (McGowen et al. 1976a).

A portion of the incoming sediment supply to the system is in a sense negated by subsidence. In other words, before wetland areas can enlarge and aggrade, a certain quantity of sediment must be dispersed just to maintain the elevation of land with respect to the sea. Swanson and Thurlow (1973) estimated the subsidence rate at Freeport to be 11 mm/yr from 1959 to 1971. While rates vary considerably throughout the area, the above figure can be used as a relative guideline for interbasin comparisons. The value is adjusted for eustatic sea level rise, but it is impossible to differentiate all the components that contribute to subsidence. In comparison to other areas along the Texas coast, the 11-mm/yr rate is about average.

2.2 SOILS

The parent material for the soil of virtually the entire area is similar in origin, and soil types are similar to those found throughout the central gulf coastal plain. The largest group of soils is one which developed on ancient and Modern bottomlands (McGowen et al. 1976a, 1976b). The relatively large area of bottomland reflects the areal influence of the Brazos and

Colorado Rivers, which have deposited their sediment loads throughout much of the system. The largest continuous area of this group of soils is found on the present floodplain bounded by Oyster Creek to the east and Caney Creek to the west with a maximum width in the study area of approximately 40 km. These soils are predominantly clayey sands and silts, and are generally saturated as they are topographically close to the water table (McGowen et al. 1976a, 1976b). These same types of deposits, but Pleistocene in age, are scattered throughout the level uplands and include the Edna, Crowley, and Bernard Series and, in areas of better drainage, include the Pledger, Miller, Bruno, Yhola, and Asa Series (McGowen et al. 1976a).

Another large component of the upland area consists of clay soils with low permeability. This group, which supports natural prairie grasses, is used intensively for rice cultivation and consists largely of the Lake Charles Series (McGowen et al. 1976a). Where these deposits are somewhat loamy, the Bernard and Midland Series have developed (McGowen et al. 1976a).

Sandy soils, with corresponding high permeability, typically dominate Matagorda Peninsula and the area west of Port O'Connor, continuing into the San Antonio system (McGowen et al. 1976b). This latter area is associated with the Ingleside sand barrier. Small discontinuous areas of similar soils are associated with point bar deposits (McGowen et al. 1976a). The remaining major soil types include the saturated soils supporting marsh vegetation, and the undifferentiated and young soils developing on spoil deposits.

2.3 TOPOGRAPHIC AND BATHYMETRIC FEATURES

As with other Texas coastal systems and the gulf coast in general, the area is flat, with maximum elevations at the inland boundary of approximately 20 m, resulting in a gentle slope to the coast of about 0.3 m/km. The most conspicuous topographic relief in the area is the salt domes. While there are numerous domes in the area, especially in the eastern half (McGowen et al. 1976a, 1976b), most are subsurface and only two are obvious at ground level. Bryan Mound near Freeport, close to the coastline, rises 4 m above the surrounding near sea level marshes. Damon Mound, located near West Columbia, rises approximately 12 m over the surrounding area to reach an elevation of 33 m (also see Section 2.4).

Inshore bathymetry generally reflects the same pattern as upland slopes. Matagorda Bay seldom exceeds 4 m in depth (except where artificial channels have been dredged) and gradually shoals in an eastward direction where Colorado River sediments and pro-delta reefs are abundant. Contiguous bays are somewhat shallower, averaging no more than 2 m in depth in their central portions; East Matagorda, Keller, Cox, Carancahua, and Turtle Bays are the shallowest. The deepest natural areas are associated with the tidal passes. Pass Cavallo (the deepest) is listed on navigation charts as having depths in excess of 6 m. It should be emphasized that these passes are dynamic, with morphologic characteristics that may change within the span of a tidal cycle.

2.4 UNIQUE OR UNUSUAL STRUCTURES

A conspicuous feature of the Matagorda-Brazos system is the extensive area of bottomland habitat. Formed through time by the meandering Brazos and

Colorado Rivers, it is the largest continuous floodplain habitat within the Texas Barrier Islands Region. One result of the processes involved in floodplain development is a diverse array of woody vegetation grading from swamp forest to bottomland hardwood to live oak mottes. The corresponding fauna is equally diverse and includes, among others, bald eagles (Haliaeetus leucocephalus).

In close association with the floodplain, three major deltas are currently active in this area. The Lavaca-Navidad Delta is prograding at the head of Lavaca Bay; the quickly developed Colorado Delta has segmented Matagorda Bay into two bays and also supplies sediment to the nearshore gulf; and the Brazos Delta is extending the shoreline into the Gulf of Mexico. All three are creating new and differing wetland habitats.

A late Pleistocene sand barrier, although common along the central Texas coast, is a relatively uncommon feature here. Known locally as the Ingleside barrier-strandplain complex, one such feature is located near Port O'Connor and extends westward into the San Antonio system. These ridge and swale sand barriers typically contain small pockets of discontinuous fresh marsh and open water areas that are intensively used by waterfowl (also see Corpus Christi, Copano-Aransas, and San Antonio syntheses).

Salt domes, although common along the gulf coastal plains, generally do not have surface expression. Two domes with considerable relief are located in the area: Bryan and Damon Mounds (also see Section 2.3). Salt domes are unusual in several respects: (1) they are a geologic feature; (2) those which have surface expression often support an unusual floral assemblage; (3) oil and gas deposits are frequently discovered in the subsurface around the periphery of the dome; (4) sulphur is frequently extracted from the caprock and to a lesser extent from associated oil; (5) they are a source of salt; and (6) they are used by the U.S. Department of Energy (USDOE) in the Strategic Petroleum Reserve Program of which the Bryan Dome is a part (USDOE 1978).

More accurately described as an unusual event rather than feature was the closing of Brown Cedar Cut in September 1977 (Ward et al. 1979). Under normal energy conditions, this pass (cut) represents the only significant exchange point between East Matagorda Bay and the Gulf of Mexico. The closing of the pass, presumably due to deposition of sediment from the eroding beach north of Sargent, via littoral transport, combined with the lack of sufficient hydraulic head between the bay and the gulf (Ward et al. 1979), probably has resulted in reduced circulation in East Matagorda Bay.

2.5 MAN-MADE DEVELOPMENTS

Throughout past millennia the Colorado River has been a dominant factor in shaping the present landscape of the Matagorda system. The history of man's efforts to control the Colorado River is long and complex and has been the subject of numerous authors. Clay (1949) provided the historian's perspective; Wadsworth (1966), followed by Bouma and Bryant (1969), provided the geologic perspective; and often-quoted Gunter et al. (1973) provided a shortened and perhaps jounalistic account (the accuracy of which is questioned by Ward et al. 1979).

In summary these works stated that a massive series of log jams extending from just above Matagorda to Bay City effectively blocked river traffic, acted as a sediment trap, and was a partial barrier to floods, thereby constituting a threat to several floodplain communities. After abortive efforts through several decades, the log jams partially were removed in the period from 1925 to 1929. The flood of 1929 provided the necessary free energy to clear the remaining debris. The more hydraulically efficient river then carried its sediment load to Matagorda Bay, where, Wadsworth (1966) estimated, the delta grew from 41 ha to 727 ha in the year following the flood of 1929. Rapid growth of approximately 200 ha/yr continued through 1938, when the delta extended to Matagorda Peninsula. A negative impact of the delta-building was the marked decline in oyster production in the immediate vicinity of the delta. While the increase in sediment was responsible for this decline, it can only be assumed that natural processes eventually would have led to the same result; and in this instance man simply acted as a catalyst.

Subsequent actions by man, however, have retarded delta growth. The dredging of a channel through the delta, bay, and peninsula in the 1930's (to relieve flooding along the lower Colorado River) resulted in a diversion of flow directly to the gulf, thereby decreasing the rate of the bay-delta growth. The channel also acts as a tidal pass, although Ward et al. (1979) presented evidence indicating that the exchange rate is low. During low discharge periods, the mouth frequently shoals at a rapid rate, which in turn adds to maintenance dredging costs. Since 1941, when the subaerial delta consisted of some 2,900 ha, delta growth has been minimal. The decreased growth is attributed to the following combined effects: (1) the creation of the artificial channel, (2) the accompanying spoil that retarded overbank flow, (3) the 1940 dredging of the Gulf Intracoastal Waterway (GIWW) perpendicular to the axis of the delta, and (4) the upstream diversion of flow (for irrigation purposes) and sediment (e.g., Highland Lakes system of dams). Weeks (1945, cited by Diener 1975) pointed out that dredging of the GIWW caused an additional decline in oyster beds just west of the delta. Gunter et al. (1973) stated that the locks in the GIWW at the Colorado River forced flow and accompanying sediments westward through the GIWW, destroying oyster reefs at its outflow in the Palacios Point-Oyster Lake area.

The USACE (1977a, 1977b) is currently considering a diversion plan that will allow the discharge and accompanying sediment to be dispersed through Matagorda Bay. According to van Beek et al. (1980), a full diversion would result in an average delta growth of 1,233 m^3/yr, provided that hydrologic conditions in the Colorado River drainage basin were not further altered. An average reduction in bay salinity of 2 $^0/_{00}$ is predicted, although salinities may be depressed by 15 $^0/_{00}$ during flood periods (van Beek et al. 1980). Turbidity levels are expected to increase, but oyster production is not expected to be affected except at Dog Island Reef, which probably will be buried by the advancing delta. The plan also includes mitigation measures to prevent severe erosion and possible breaching of Matagorda Peninsula near the present mouth of the Colorado River.

There are several other documentations of man's impact on geologic and related processes in the Matagorda-Brazos area. The artificial diversion of the mouth of the Brazos River in 1929 resulted in the formation of a delta at the new mouth and over 1,400 m of erosion in 30 years at the former mouth (McGowen et al. 1976a). Dams along the Brazos River have reduced the sediment input into the nearshore gulf, a factor that is at least partially responsible for the dominance of erosion along Matagorda Peninsula (McGowen et al. 1976a). The construction of the Matagorda Ship Channel resulted in salt water intrusion and reduced water exchange in Pass Cavallo (see Section 4.1).

The Matagorda Bay area supports a limited shell-dredging industry. Its impacts have been closely monitored by Texas Parks and Wildlife Department (TPWD), which has adopted several mandatory guidelines for dredgers (Clements 1975). Apparently of greatest concern is the effect of suspension and resettling of sediments upon oyster populations. Other benthic organisms, including submerged aquatics, can be expected to experience similar adverse impacts. While the suspension period for much of the sediment may be short-lived, Burg (1973, cited by Clements 1975), working in San Antonio Bay, found a 3-cm layer of silt 460 m distant from the dredge site. Using the shell-dredging data reported by Burg (1974) and Clements (1975), one can estimate the resuspension of sediment in Matagorda Bay. For the period 1969 through 1975, an estimated annual mean of 108 x 10^6 kg/yr of bay sediments was dredged and returned to the bay. For comparison, this represents an amount approximately equivalent to the annual sediment input of the Lavaca and Navidad Rivers.

3.0 CLIMATE

3.1 PRECIPITATION

The climate of the Matagorda-Brazos study area can be classified as sub-humid, grading to humid in the Brazos River area. A pronounced precipitation gradient exists with decreasing abundance occurring in a southwest or downcoast direction. According to the National Oceanic and Atmospheric Administration (NOAA) (1973a), the Freeport-Angleton area receives an annual mean rainfall of some 1,245 mm, Matagorda receives 1,075 mm, and the western shore of Matagorda and Lavaca Bays receive approximately 970 mm. This represents a decreasing rate of approximately 2.4 mm/km.

Using Matagorda and Danevang as examples, the seasonality of rainfall can be examined (Figure 1). The distribution at Matagorda is fairly uniform except during the late summer months. The increase in precipitation during late summer is associated with the increase in tropical easterly waves (including tropical disturbances) and the increase in the interaction of gulf air with polar and Pacific marine air masses. Ward et al. (1979) noted that there is a distinct change in the seasonal distribution of precipitation in an inland direction (compare Danevang with Matagorda on Figure 1). Specifically, there is an increase in precipitation during the spring months and a decrease in precipitation during the late summer (fall) months. During the spring, the polar fronts weaken and gulf air strengthens. This generally results in increased precipitation, but due to the weakened state of the polar fronts, they may not affect the weather along the coast. During late summer, tropical disturbances expend much of their energy along the coast with a decreasing influence in an inland direction. One important exception is areas of pronounced relief. In such localities, tropical air is lifted; as the air rises, it cools, and precipitation is normally generated.

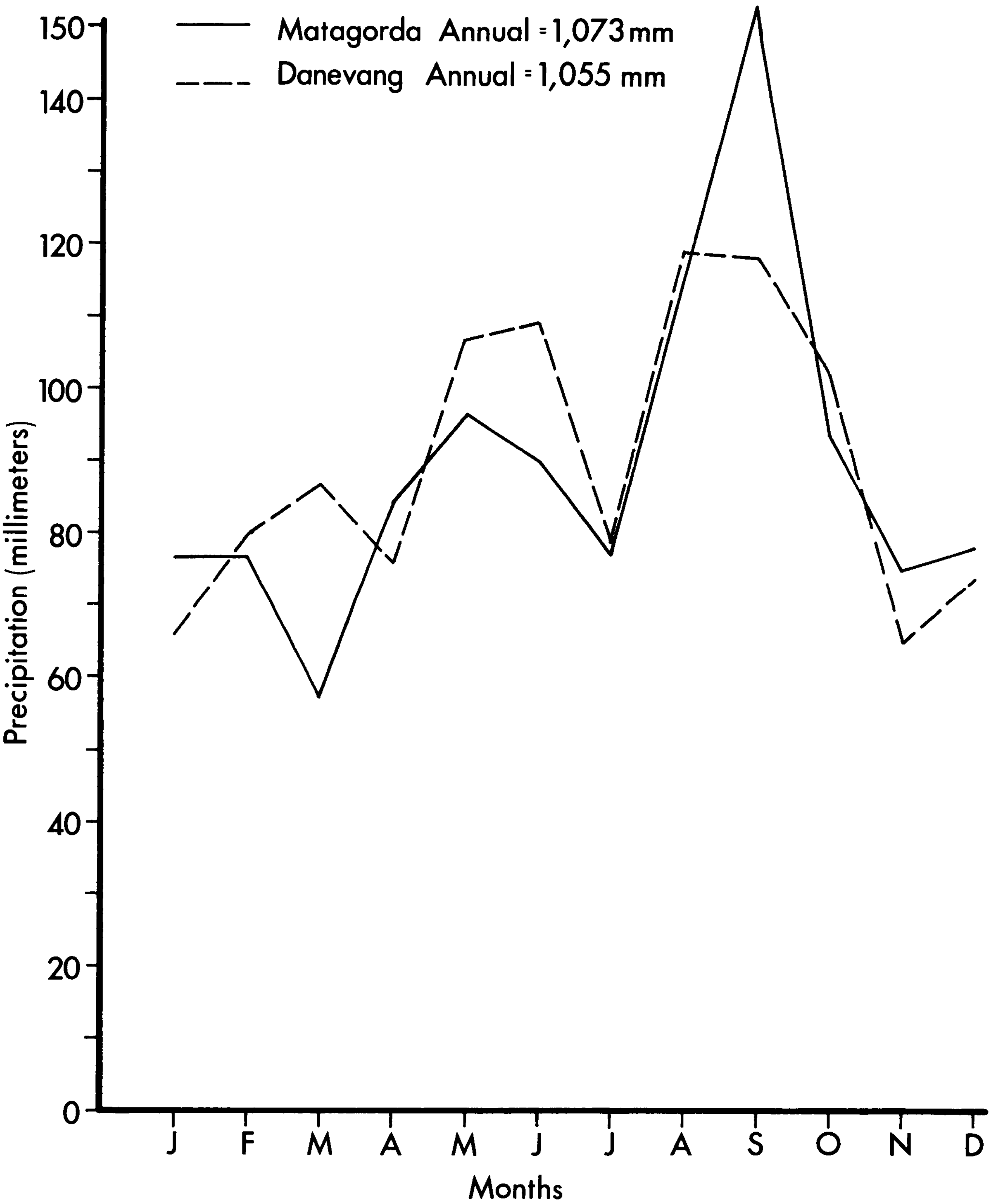

Figure 1. Mean seasonal precipitation for Matagorda and Danevang, 1941-1970 (NOAA 1973a).

3.2 TEMPERATURE

The mean annual air temperature is approximately 21.1° C in this study area; the west Matagorda Bay area is a few tenths of a degree warmer, and the Freeport-Angleton area is colder by a similar margin. While mean annual temperatures are approximately the same along the coast as inland, a seasonal difference can be observed. Due to the mitigating effects of the gulf, temperatures along the coast are slightly cooler in summer and warmer in winter. This is reflected in the length of growing season, approximately 300 days along the coast, decreasing to some 280 days along the inland boundary of the study area (Orton 1964).

Utilizing both rainfall and temperature data, one can calculate a theoretical climatic water budget (Thornthwaite and Mather 1955) that provides a representation of the water demand in the natural environment. Orton (1969), using the noncontinuous method, calculated annual moisture surpluses and deficits for Texas. He showed that the Matagorda-Brazos system averages a net surplus (surpluses minus deficits) of some 100 mm in the Freeport-Angleton area, decreasing to a mean annual net deficit of 225 mm in the Port O'Connor-Port Lavaca area. This rather abrupt change in the hydroclimate over space has long been recognized by climatologists.

In addition to the expectation of paralleling changes in the biota, one should envision changes in resource management possibilities. For example, the use of weirs for impoundments, which depend on local rainfall for their water supply, generally is not practical where net annual mositure deficiencies are consistently expected. Similarly, the irrigated growing of rice becomes increasingly more energy-inefficient as moisture deficiencies increase.

Using NOAA pan evaporation data for Point Comfort and adjusting these values with standard pan coefficients (Ward et al. 1979), one can estimate the seasonal distribution of surpluses and deficits (Figure 2). Winter months generally result in surpluses due to the low potential evapotranspiration. The mean surplus for September results from the occasional large surplus due to heavy rains generated by either tropical storm activity or a strong interaction between early outbreaks of polar air and gulf-originating air. A long deficit period typically begins in early spring and increases in magnitude through summer. Pan evaporation data (NOAA 1972-1979) show that Point Comfort's surplus periods are of a lesser magnitude and its deficit periods are of a greater magnitude than those of Thompsons (northeast extreme of study area). This supports the annual values determined by Orton (1969).

3.3 WIND PATTERNS

Matagorda-Brazos, as well as the other Texas coastal systems, is primarily influenced by three distinct wind regimes. The prevailing winds over the Matagorda system range from the southeast to south (Orton 1964). This flow is associated with the Bermuda High and is typically strongest during summer months when the high pressure system is located at its farthest north and west position. It is the southeasterly (onshore) wind regime and associated waves and currents that primarily are responsible for the net southwest longshore drift (McGowen et al. 1976a, 1976b). The predominance (energy) of the southeast winds is generally less in the Matagorda-Brazos system than in

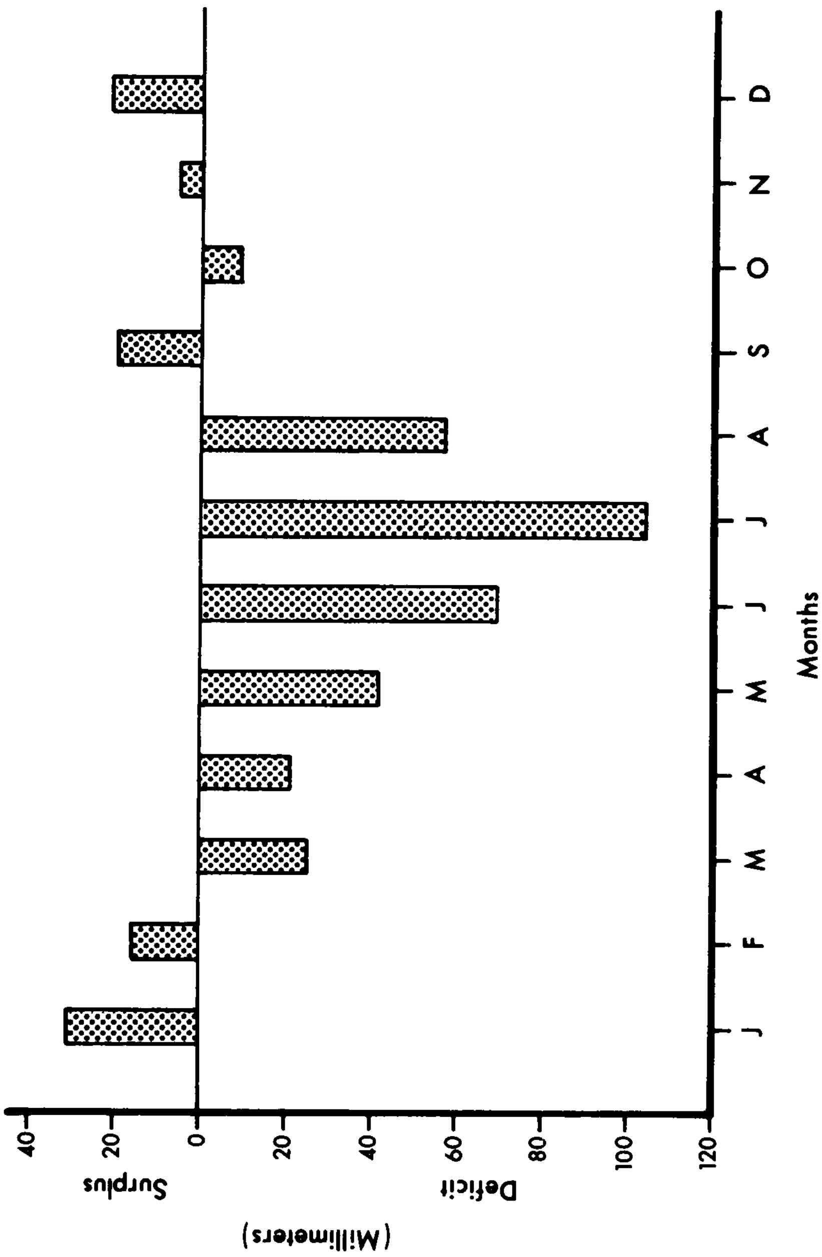

Figure 2. Mean seasonal noncontinuous water budget for the Matagorda area, calculated by subtracting mean monthly adjusted pan evaporation at Point Comfort (1958-1970) from mean monthly precipitation at Matagorda (1941-1970). Adjusted pan evaporation data are from Ward et al. (1979) and precipitation data are from NOAA (1973a).

systems farther to the south. This is due to the lessened strength and frequency of occurrence. (See Galveston and Corpus Christi syntheses for comparative wind frequencies.)

Northerly components comprise the second type of wind regime. Although they occur with less frequency, they typically are more intense (Ward et al. 1979). The passage of cold fronts during winter is a well-known phenomenon. McGowen et al. (1976b) and Ward et al. (1979) attributed the erosion along the west shore of Matagorda Bay to these polar outbreaks. The responses of water to these northerly winds in Matagorda Bay have been documented by Ward et al. (1979). The responses described are similar to those found in several Louisiana estuaries analyzed by Wax (1977), where there appears to be a general regional response with slight variations dependent upon estuarine morphology, including orientation and other factors. As the cold front approaches, an increase in southerly air flow with an accompanying inflow of gulf water to the estuary can be expected. With the passage of the front, the wind shifts abruptly to the north. The combined effects of the reversed wind-stress, plus the inverse barometer effect, pushes water out of the estuary and into the gulf. With the presence of an offshore barrier and constricted tidal passes such as in Matagorda, water levels are depressed in the northern part of the bay and the nearshore gulf and are raised along the southern shore of the bay. This situation creates a large gradient from the south shore of the bay to the gulf and results in high velocity currents in the passes. As the front moves east and south, a return to southerly flow is initiated (see Ward et al. 1979 for examples of hydrographs).

The third wind regime is the highly variable tropical disturbance. This infrequent, warm-water season event greatly accelerates coastal processes. Monitoring of environmental effects of hurricanes is inadequate, and no studies (with the exception of morphological changes) are available for Matagorda Bay proper. A discussion of the expected impacts of a hurricane are included in the Laguna Madre synthesis paper.

4.0 HYDROLOGY AND HYDROGRAPHY

4.1 TIDAL INFLUENCES-SALINITY REGIME

True (lunar) tides in the Matagorda Bay complex, as in other Texas estuaries, are of small magnitude and are largely diurnal (McGowen et al. 1976a, 1976b; Ward et al. 1979). A strong diurnal period of 8 days is usually followed by a mixed semidiurnal period of 5 to 6 days (Holliday 1973). At South Jetty, at the mouth of the Matagorda Ship Channel, and at Pass Cavallo, tides have a mean range of 0.4 m and an average fortnightly fluctuation in range from 0.2 to 0.8 m (McGowen et al. 1976b; Ward et al. 1979). This latter range is due to the changing declination of the moon with respect to the earth rather than the change in moon phase. There are several tide gages dispersed throughout the area except in East Matagorda Bay where tides are minimal (Ward et al. 1979). Data obtained from these gages indicate that tidal attenuation is slight (Holliday 1973). In Lavaca Bay, the mean tidal range is reduced to 0.3 m (McGowen et al. 1976b), and the tidal wave travels through the bay (i.e., from Pass Cavallo to Port Lavaca) in approximately 1 hour during periods when riverine input is low and winds are slack (Holliday 1973). Holliday

(1973) attributed the similarity in the character of the period and magnitude of the tide throughout the bay to the relative deepness of Matagorda Bay (in comparison to other Texas estuaries). The dredging of the Matagorda Ship Channel to a depth of 12 m (approximately three times deeper than surrounding natural depths) cannot be overlooked as a factor contributing to the lack of tidal attenuation.

Exchange between bay and gulf waters occurs primarily at Pass Cavallo, the Matagorda Ship Channel, and Brown Cedar Cut. The latter represents the major exchange point of East Matagorda Bay, which has been effectively segmented from Matagorda Bay since the development of the Colorado Delta. The temporary natural closing of this pass in 1977 should have resulted in drastically reduced circulation (Ward et al. 1979). Greens Bayou provides an alternative avenue for intermittent exchange, effective primarily during highest tide (E. G. Simmons, Texas Parks and Wildlife Department, Austin, Texas; pers. comm. 1980). Limited exchange occurs through the Colorado Delta during low flows, and remnant channels such as Maverick Bayou may reopen during tropical storm activity (McGowen et al. 1976a, 1976b). Interbay exchange occurs between the Matagorda complex and Espirtu Santo Bay via several tidal bayous and the GIWW.

Harwood (1973, cited by McGowen et al. 1976b) discussed the physical changes that have occurred in Pass Cavallo during the past century, including those since the dredging of the Matagorda Ship Channel. The net result with respect to tidal exchange is that the creation of the ship channel did not augment circulation. Since 1965 the tidal prism at Pass Cavallo has been 1.6×10^8 m^3 and 1.2×10^8 m^3 at the Ship Channel; whereas in 1856, with the same tidal conditions, the tidal prism was 3.5×10^8 m^3 at Pass Cavallo (Harwood 1973, cited by McGowen et al. 1976b). Clearly, the Matagorda Ship Channel has served to reduce tidal exchange at Pass Cavallo. Masch and Associates (1970) used the Matagorda example to develop a model that will aid in predicting changes resulting from planned channels in other gulf coast estuaries.

Another common use of the term "tide" along the gulf coast is associated with the effect of wind on water flux. Known locally as "wind tides," the resulting changes in water flux often dominate over lunar tides (Marmer 1954). The response of bay waters to the passage of a cold front is well known to gulf coast residents. Ward et al. (1979) provided examples of hydrographs for various tide gage stations in the Matagorda Bay complex during a period of a polar frontal passage that resulted in water levels' being depressed some 45 cm (also see Section 3.3). As a rule, a moderate frontal passage will force a volume of water out of the bays, equivalent to that forced by a maximum astronomical tide (Ward et al. 1979). The frequency of these frontal passages with intervening southerly flows results in overall greater water movement and flushing during winter (Ward et al. 1979).

Seasonal water flux in the Matagorda Bay complex is similar to that experienced throughout the northern Gulf of Mexico (see Laguna Madre and Galveston syntheses for examples). The spring and fall maxima and summer and winter minima are the results of variable wind stress and seasonal heating and cooling of water over the entire northern Gulf of Mexico (see Sturges and Blaha 1976). In the Matagorda Bay complex, the magnitude of this phenomenon is approximately equivalent to mean tidal range. This cycle, combined with the seasonal tidal range cycle, plays an important role in the frequency and duration of seasonal flooding of marshes. For example, during late September when water levels are high and tidal range is minimal (due to the fall equinox), inundation will be of long duration but of low frequency. In the marshes of Matagorda Bay, and presumably elsewhere, this change in the inundation regime is suspected of having a major role in the nutrient exchange between marsh sediments and the water column, but the resulting changes are not clearly understood (Ward et al. 1979).

There are considerable salinity data for the area. The Texas Water Development Board (TWDB) in cooperation with USGS, TPWD, and the Texas Department of Health all monitor salinity, although methods of sampling are variable. Ward et al. (1979) have synthesized these data.

Average annual salinity for the entire bay complex is approximately 20 °/oo (Martinez 1975). Harry and Littleton (1973) concluded that the foraminiferal assemblage in Matagorda Bay, compared to Galveston Bay, suggests that Matagorda Bay has a higher average salinity; but hypersaline conditions are extremely rare (Ward et al. 1979) and the seasonal pattern is strongly influenced by streamflow. In East Matagorda Bay average annual salinity (approximately 17 °/oo) generally is lower than in Matagorda Bay (McGowen et al. 1976a; Ward et al. 1979), partially because East Matagorda Bay receives significant inflow from local drainage and Caney Creek (B. D. King, III, USFWS Ecological Services, Austin, Texas; pers. comm. 1980). Salinities in the Matagorda Bay complex are lowest during late spring and early summer, corresponding to high flows; and salinities peak during late summer when streamflow is at a minimum and evaporation rates are at a maximum (Martinez 1975). The magnitude of this change decreases with distance from the freshwater outflows. Near the passes the seasonal change is minimal (Ward et al. 1979).

During extended periods of low freshwater discharge, salinities are relatively uniform in the horizontal dimension (Ward et al. 1979). In East Matagorda Bay, the horizontal salinity gradients are weak due to the limited tidal exchange through Brown Cedar Cut (Ward et al. 1979). In the smaller secondary bays where freshwater inflows are large relative to the receiving bay volume (i.e., Lavaca, Carancahua, and Tres Palacios Bays), horizontal salinity gradients are more pronounced (Ward et al. 1979). Strong horizontal gradients also normally occur at Pass Cavallo and at the mouth of Matagorda Ship Channel (Ward et al. 1979).

Vertical stratification of salinity is minimal except in the confines of the Matagorda Ship Channel. Stratification in the channel is more pronounced during high freshwater inflow periods and is minimal during low flow periods (Ward et al. 1979). The lack of pronounced vertical stratification is due to the large water surface area relative to volume, which allows for strong wind-induced mixing (Ward et al. 1979).

Ward et al. (1979) analyzed salinity data for Lavaca Bay and the western portion of Matagorda Bay to determine possible effects of dredging of the Matagorda Ship Channel. A statistically significant rise in salinity occurred immediately after the completion of the channel in 1963. The last stage of construction involved dredging through Matagorda Peninsula; thus there was no direct connection with the gulf prior to the last stage, and a rapid salinity rise, rather than a gradual one, was to be expected. Ward et al. (1979)

estimated the rise to be 2 to 5 ‰, independent of freshwater inflow. The impact on the remaining bay area was not analyzed.

4.2 CURRENT AND WATER CIRCULATION PATTERNS

The dominant controlling factor of circulation in this system is wind (Ward et al. 1979). The effects of prevailing and changing winds have been discussed in Section 3.3 and Section 4.1. While streamflow is considerable (see Section 4.3), it is substantially less on an inflow to volume basis than in the neighboring humid Galveston system. The effects of true tides in the estuary are minimal in comparison to what is normally expected on a global basis, but are comparable to other gulf systems (also see Section 4.1).

In discussing circulation, we are restricted to the relative importance of such variables as Coriolis acceleration, wind, river discharge, tides, and the geometry of the estuary. Ward et al. (1979) stated that density currents may be of greater importance in total circulation for Matagorda and other gulf estuaries than has been previously recognized.

Several circulation models have been developed for the area. Masch and Associates (1970) attempted to address changes in tidal activity resulting from artifically created passes; Rhodes and Boland (1962) used a circulation model to help engineers plan the specific design of ship channels; and Holliday (1973) tried to interrelate pollution dispersal with circulation patterns in Matagorda Bay. Using fragmented current data, Holliday (1973) concluded that the ebb tide builds to the west, resulting in strong ebb currents along the western shore. This pattern is typical of many of the Texas Barrier Islands estuaries. The high erosion rates along the western shore of Matagorda Bay (McGowen and Brewton 1975) may be attributable partially to this ebb current pattern.

The above models imply a complex and highly variable circulation pattern, one that in reality is too complex for the available models. While the models have many practical applications, perhaps the most useful will be an impetus for verification.

In the nearshore zone of the Gulf of Mexico and to a lesser extent in the bay complex, the prevailing winds and wave refraction produce longshore currents. Along Matagorda Peninsula, the dominant direction of longshore drift is to the southwest (McGowen et al. 1976a, 1976b). This littoral transport of sediment is a major process behind the dynamic nature of beach habitat. Most of the sediments presently involved in this mechanism of transport are eroded beach deposits (Morton et al. 1976). In Matagorda Bay, waves generated by southeasterly winds erode windward shorelines and set up a westerly moving current. Along shorelines transverse to the wind, a northerly moving current is set in motion (Holliday 1973; McGowen et al. 1976a, 1976b).

4.3 DRAINAGE PATTERNS AND FRESHWATER INFLOWS, RIVERINE FLOODING PATTERNS

Numerous rivers and streams flow into the Matagorda system; the most noteworthy is the Colorado River. The total annual mean gaged and ungaged inflow to the system has been calculated by Ward et al. (1979) as 157.1 m^3/sec of which the Colorado River averages 68.8 m^3/sec. The flow is generated over an area of some 116 x 10^3 km^2, with the Colorado drainage basin comprising some 90% of this area. Present outflow of the Colorado River is principally into the Gulf of Mexico. Alteration of its natural outflow and delta formation is currently a major management concern (see Section 2.5).

Other gaged flows entering the Matagorda system include those of the Lavaca River and Tres Palacios, Garcitas, Placedo, Big Boggy and Caney Creeks. As is the case of nearly all the Texas coastal plain rivers, the creeks and rivers flowing into the Matagorda-Brazos system are heavily utilized for irrigation purposes; consequently, the outflows are less than natural flow conditions. An example of this is the USGS Bay City gage on the Colorado River which records lower flows than the upstream USGS gage at Wharton (Ward et al. 1979). Due to the complex and extensive nature of diversion channels, pumping stations, control structures, etc., it is impossible to determine how much flow actually is diverted.

To provide some perspective to the discharge data, we will employ the Laguna Madre system as the comparative base. This extremely low-flow system contains approximately the same amount of the estuarine surface water area and length of coastline as the Matagorda-Brazos system (Diener 1975). Primarily due to the differences in climate and drainage area, however, the Matagorda-Brazos system receives 2.75 times the freshwater inflow of the Laguna Madre system (including the Rio Grande). When drainage area differences are adjusted, the Matagorda system generates 11 times the flow of the surface discharge of the Laguna Madre system on a per-unit area basis. The relative significance of the impact that freshwater inflow has on circulation, turnover rates, and salinity can be inferred by a simple comparison of the ratio of discharge to volume (expressed as days to fill) of the receiving basin (estuary). Whereas it would require 26 months for the Rio Grande and lesser streams to fill the Laguna Madre complex to the mean low water (MLW) level (see Laguna Madre), it would require only 5.3 months for the Colorado River and lesser streams to fill the Matagorda Bay complex, and only 3.8 months to fill the Laguna Madre complex.

A pronounced seasonal distribution of streamflow is apparent (Figure 3). The spring peak is typical for the northern gulf from the upper Texas coast through the panhandle of Florida. The seasonal hydrograph does not correspond exactly to the seasonal precipitation pattern, but to an expected lag factor with the seasonal surplus precipitation pattern (see Section 3.1). The September-October maximum, the only peak along the lower Texas coast (see Laguna Madre synthesis), is less pronounced here. The increase in the spring peak and the decrease in the fall peak occur on a gradient from Mexico to Louisiana and are indicative of an increasingly humid climate and less dependency on tropical disturbances to generate precipitation. The greatest year-to-year variability occurs during September and October (Ward et al. 1979) and is associated with the variability of tropical storm activity and associated intense rainfall.

Expectedly, the seasonal surface salinity pattern closely corresponds to the seasonal freshwater inflow pattern. Record low salinities, however, are associated with flash floods resulting from tropical storm activity (Ward et al. 1979).

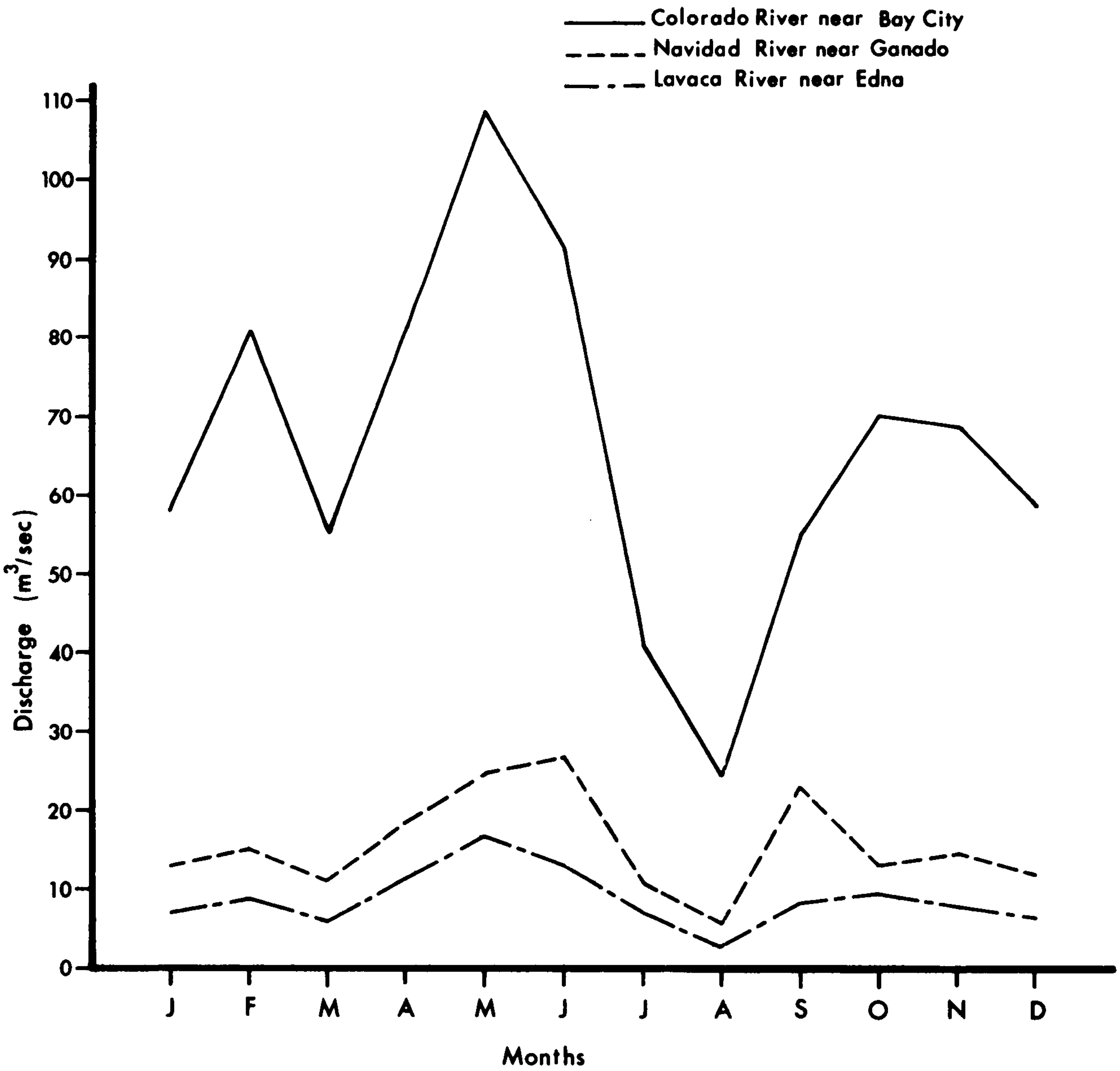

Figure 3. Mean daily discharge by months for selected rivers (modified from Ward et al. 1979).

The effects of a group of several reservoirs on the Colorado River have been examined by Ward et al. (1979). This group, known collectively as the Highland Lakes, is inland of the study area and impounds water for municipal and agricultural needs. Kane (1967, cited by Ward et al. 1979) estimated that evaporation loss from the impoundments is equivalent to 8 m^3/sec. However, when Ward et al. (1979) compared natural flow conditions (pre-impoundment) with those actually occurring since reservoir construction, there was no statistically significant difference. Still, the seasonal disbursement in the Colorado flow is significantly affected by the Highland Lakes. As shown by van Beek et al. (1980), the peak in the spring flood is severely reduced by the reservoirs. Ward et al. (1979) predicted that, if five proposed reservoirs on the Colorado River are constructed and if water demands increase as they have in the past, the freshwater input of the Colorado River will be reduced to 53% of its present (1979) input by the year 2030. The completion of the Palmetto Bend Reservoir (already in progress) will reduce the Lavaca-Navidad inflow to Matagorda Bay to 75% of present flow by the year 2010 (Ward et al. 1979).

The Brazos River and lesser streams located on the modern Brazos floodplain discharge most of their flow directly into the Gulf of Mexico. Their effect on the Matagorda Bay complex is presently indirect, via the Gulf of Mexico and GIWW, and generally is regarded as minimal (McGowen et al. 1976a). The Brazos is the largest river along the Texas Barrier Islands coast in terms of discharge and sediment load. Over the past decade the Brazos (near Rosharon) has contributed a mean flow of 229 m^3/sec (USGS 1969-1978), more than three times the flow of the Colorado and more than twice the total flow into the Matagorda Bay complex. Additionally, the San Bernard River (near Boling) contributes a mean flow of 16.3 m^3/sec (USGS 1969-1978) plus a component of ungaged flow. The seasonal distribution of the Brazos River discharge (Figure 4) is similar to that in the Matagorda system (Figure 3). Surpluses generated throughout the winter months, combined with the slight increase in precipitation in the spring months (see Figure 1), result in the spring flood. Also, most of the drainage basin of the Brazos River lies inland of the study area and has a different climate. In particular, the peak in the seasonal distribution of rainfall occurs in the spring (NOAA 1973a). The decreasing magnitude of the September precipitation peak in an inland direction is due to the decreasing influence of tropical disturbances.

4.4 GROUNDWATER

In spite of the presence of several substantial rivers within and neighboring the Matagorda-Brazos system, the utilization of groundwater supplies is necessary to maintain man's current level of activity in the area. Details of groundwater extraction in the area are covered fully by Marvin et al. (1962), Baker (1965, 1973), TWDB (1966a, 1966b, 1966c, 1966d), Cronin and Wilson (1967), Hammond (1969), Beffort (1972), and Sandeen and Nesselman (1973).

Groundwater reserves are extensive, as is the case along much of the gulf coastal plain. In the Matagorda-Brazos study area and neighboring systems, the various water-bearing sand layers are collectively known as the Gulf Coast Aquifer. The largest user in the Matagorda area is agriculture (approximately 91%), with substantial amounts also withdrawn for municipal (approximately

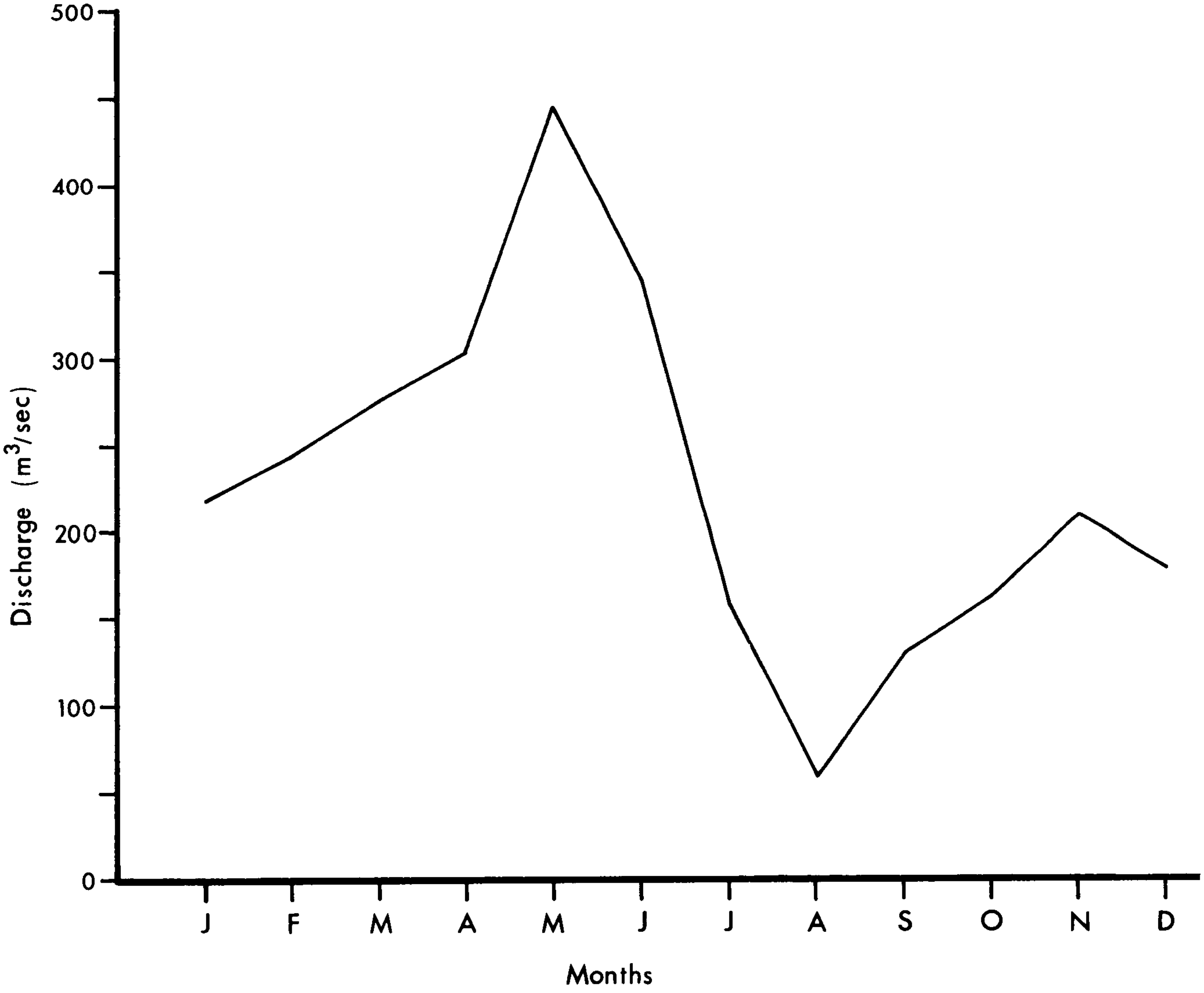

Figure 4. Mean daily discharge by months for the Brazos River near Rosharon (USGS 1969-1978).

5.5%) and industrial (approximately 3.5%) needs. Based on several investigations, groundwater withdrawal rates are increasing, but most studies conclude that with proper well design and spacing the most recent pumpage rates can probably be maintained indefinitely without excessive piezometric decline or saltwater encroachment. Vetter and Miloy (1973), using TWDB recharge rates and assuming that the 1958-1970 increase in groundwater usage will continue into the future, predicted that extraction will exceed recharge by the year 2000.

Many authors cite varying degrees of subsidence that have occurred as the result of groundwater withdrawals. Most estimates are a few millimeters per year. The Port Lavaca area probably has experienced the greatest amount of subsidence, a maximum of 30 cm (Baker 1965; Baker and Follett 1973; Brown et al. 1974). However, as Brown et al. (1974) and Baker (1965) pointed out, it is often difficult, along the Texas coast, to distinguish between subsidence induced by groundwater extraction and that produced by oil and gas extraction.

Well abandonment due to saltwater encroachment has not been widespread though Vetter and Miloy (1973) reported that salt concentrations became a problem in municipal water supplies by 1970 in Calhoun and southeastern Jackson Counties.

Baker and Follett (1973) indicated that base flows of the rivers have probably decreased though a complete loss of base flow seems unlikely.

A portion of the extracted groundwater supply undoubtedly returns to the system as surface flow (e.g., dewatering of rice fields). What effect this has on surface water quality is not known.

4.5 WATER QUALITY

While USGS and the Texas Department of Water Resources (TDWR) monitor water quality and their data are available, we have chosen to use a secondary reference, Ward et al. (1979), which synthesized much of the raw data. Much of these data, however, were obtained from the inflowing rivers. The Texas Parks and Wildlife Department conducts water-quality surveys of the estuaries, though not on a regular basis, and only a few variables are measured. Where available, we have supplemented the Ward et al. synthesis with TPWD survey data.

Generally, there is no persistent water quality problem in the overall Matagorda-Brazos system though localized problems exist (Ward et al. 1979), as evidenced by the periodic closing of waters to shellfishing, especially in portions of Lavaca, Carancahua, and Tres Palacios Bays (Diener 1975).

Point source effluent discharges include 13 domestic wastewater treatment facilities, 7 industrial facilities, and 16 permitted saline discharges associated with oil and gas production and exploration (modified from Diener 1975 and Ward et al. 1979).

The major nonpoint sources of input to the system arise from agricultural runoff (Ward et al. 1979). In addition to the natural runoff generated by excess rainfall, some irrigation water originating from both ground and surface sources returns to the natural hydrologic system via the agricultural fields.

Water temperature and salinity (discussed in Section 4.1) are the two water quality parameters that have the best temporal and areal sampling coverage. Martinez (1975) reported an 11-year mean water temperature for the entire bay complex as 22.0° C. The annual mean for the same period varied from a low of 21.2° C to a high of 23.3° C. Ward et al. (1979) reported that temperature variations between stations within the bay complex are statistically insignificant, and that vertical stratification, even within the Matagorda Ship Channel, is negligible. According to the data reported by Martinez (1967, 1970, 1972, 1973, 1975) a typical seasonal temperature pattern exists with a February low (13.7° C) and an August high (29.7° C).

Dissolved oxygen (DO) concentrations in Matagorda Bay average 8 mg/l, (i.e., near or in excess of saturation levels), with slightly higher values recorded in the secondary bays (Ward et al. 1979). The large surface area of the bays, upon which winds can reaerate and mix waters through wave action, and the low levels of waste discharge undoubtedly are key factors for the relatively high DO levels. Data presented by Martinez (1967, 1970, 1972, 1973, 1975) indicated that a seasonal cycle is present, with peak values occurring in winter and minimal values some 2 to 2.5 mg/l lower occurring in summer. This is to be expected due to the inverse relationship between DO and salinity and temperature, with the latter appearing to be the greater controlling factor of the two (Ward et al. 1979).

The somewhat higher DO concentrations in the secondary bays (e.g., Turtle Bay, Carancahua Bay, and Powderhorn Lake) are a curious phenomenon. These areas are the recipients of high nutrient inflow. They also contain abundant submerged aquatics; thus, photosynthesis may be responsible for the increased DO concentrations (Ward et al. 1979).

Vertical stratification is generally negligible as the shallowness of the bay, combined with the large fetch, results in strong wind-induced mixing and relatively homogeneous DO concentrations in the water column. Some degree of stratification occurs in the Matagorda Ship Channel, but even at depths of 9 m, DO concentrations still exceed 5 mg/l (Ward et al. 1979).

The available nutrient data are too fragmentary for a detailed temporal and areal evaluation. The TDWR and the USGS monitor the input of nutrients for several of the inflowing rivers. Ward et al. (1979) summarized these data for organic nitrogen (N); N as ammonia, nitrite, and nitrate; phosphorous (P) as orthophosphate and total P; and total organic carbon (C).

Total riverine input of nutrients is only moderate. This is particularly true of the larger rivers like the Colorado and Lavaca. Caney Creek contains the highest average P concentration (0.76 mg/l), probably reflecting its drainage through intensive agricultural areas. In comparison, the remaining inflows have a weighted average of 0.17 mg/l of total P (weighted for differing discharges). Ward et al. (1979) estimated that 90% of the external input of nitrogen and 74% of the external input of phosphorous to Matagorda Bay come from surface flow. Emergent marshes were estimated to contribute 7.2% of the external phosphorous and 0.6% of the external nitrogen. No estimates of internal production (within the bay) were available. Ward et al. (1979) estimated that the input of organic carbon into the estuary by rivers in this area amounts to 3 x 10^4 kg/day, or 69% of the total estimated external sources of carbon to the estuarine community. While substantial, this quantity represents only 1% of the combined allochthonous and autochthonous sources of inorganic carbon to the estuarine community (Ward et al. 1979).

Ward et al. (1979) summarized the nutrient concentration data from within the bay complex collected by the TDWR, as follows: nutrient concentrations are relatively uniform throughout the open bays; the concentrations of various sources of N are similar in bay and river waters; and total P levels are considerably higher in the river waters than the bay. Espey, Huston and Associates (1977, cited by Ward et al. 1979) reported that the deltaic marshes of the Lavaca River generally act as nutrient traps except during periods of peak flood when there is a net export of nutrients from marsh to bay. Dawson and Armstrong (1975), Armstrong and Brown (1976), and Armstrong and Gordon (1977) further discussed the exchange of nutrients between marsh and bay for the Lavaca and Colorado deltaic marshes. Limited data presented by Espey, Huston and Associates (1977, cited by Ward et al. 1979) for Pass Cavallo show a large net export of organic N, total P, and total organic C, but concentrations of ammonia, nitrite, nitrate, and orthophosphate were below detectable levels.

Turbidity readings are obtained by TPWD and reported by Martinez (1967, 1970, 1972, 1973, 1975) in the Coastal Fisheries Project Report series. The following is a synopsis of these reports.

Under natural conditions the Matagorda Bay complex has low turbidity levels on the island side of the bays, often comparable to the Laguna Madre in water clarity. Typically, turbidity increases during peak flood periods in late spring. Strong winds associated either with polar frontal activity or late summer, gulf-originating air often lead to the resuspension of bottom sediments by wave action, resulting in high turbidity levels. Additionally, Martinez (1967, 1970, 1972, 1973, 1975) noted perturbations that increase turbidity: maintenance dredging of navigation channels, laying of pipelines, and oil exploration and extraction activities. Burg (1974) presented data indicating that the shell dredging industry resuspends a large volume of sediment (see Section 2.0), thereby contributing to a decrease in water clarity.

In the early 1960's an Alcoa Aluminum plant at Point Comfort was found to be discharging mercury directly into Lavaca Bay. Pollution levels exceeded those considered safe by the U.S. Food and Drug Administration, so the area was closed to shellfish harvests by TPWD and the State health department. By 1966 Alcoa established acceptable disposal methods (Ward et al. 1979). Presently Lavaca Bay is one of the most important areas for oysters within the Matagorda-Brazos system. However, traces of mercury remain in sediments of the bay (B. D. King, III, USFWS, Austin, Texas; pers. comm. 1980).

Ahr and Caubenspeck (1973) examined pesticide concentrations in the surface sediments of western Matagorda Bay. They concluded that: (1) pesticide concentrations were low (range of combined DDT and DDE was 2-64 ppb), (2) the primary source of chlorinated hydrocarbons was agricultural runoff, (3) the Lavaca-Navidad Delta was a sink for those chlorinated hydrocarbons, and (4) the Matagorda Ship Channel acted as a flume for pesticide dispersal.

5.0 BIOLOGY

5.1 ESTUARINE COMMUNITY

The estuarine community of the Matagorda-Brazos is composed of three basic habitats: (1) aquatic, consisting of 115,768 ha (Diener 1975); (2) tidal flats, estimated at 2,319 ha; and (3) emergent wetland, consisting of 29,315 ha bordering the Matagorda Bay complex (TDWR 1978) and approximately 5,000 ha east of East Matagorda Bay to the Galveston study area boundary (McGowen et al. 1976a). The floodplain can be considered a fourth habitat of the estuarine community, but we have chosen to give it separate community status (see Section 5.4).

While the number of species present in the Matagorda-Brazos estuarine community is large, populations are moderate. Commercial fish catch data indicate that production is low in comparison with the Laguna Madre and Galveston study areas, and is average, compared with the remaining study areas (also see Section 5.1.2). Recent catch and effort data may be misleading because the Matagorda area was probably more productive relative to the remaining Texas coast prior to World War II than it is now (Ward et al. 1979).

Nutrients reach the estuary from riverine inflow and are exported to the gulf (see Section 4.5). Within the estuary, the aquatic habitat provides the bulk of primary productivity and nutrients, with emergent marshes and tidal flats contributing less (Ward et al. 1979; also see Section 4.5) because of their more limited area.

5.1.1 Vegetation

Three species of submerged spermatophytes, commonly called seagrasses because of their grasslike appearance, are present in the Matagorda-Brazos system. Shoal grass (*Halodule beaudettei*) is one of the more abundant forms, growing along almost the entire bay shoreline of Matagorda Peninsula, the northern margin of Matagorda Bay between Carancahua and Tres Palacios Bays, and along the shores of Carancahua and Turtle Bays. Widgeongrass (*Ruppia maritima*) thrives in essentially the same areas. Turtle grass (*Thalassia testudinum*) is less common, and reports of its location in the Matagorda complex are apparently contradictory. Moore (1963) reported it along the Peninsula near Pass Cavallo. Day (1959), however, found none in either section of Matagorda Bay or in Lavaca Bay. The apparent contradiction possibly may reflect a real difference in distribution due to the different examination years. For example, in Laguna Madre annual variation in salinity results in widespread changes in the distribution of seagrasses (see Laguna Madre synthesis).

One can speculate that the survival of shoal grass and widgeongrass in the area is related to the wide tolerance limits for salinity which have evolved in these species. Shoal grass can survive in salinities from 3.5 to 52.5 $^{o}/oo$ (McMahan 1968), and widgeongrass in 0 to 45 $^{o}/oo$. Turtle grass is less tolerant, living in salinities from 10 to 48 $^{o}/oo$ (Zieman 1968, cited by Ward et al. 1979). Since secondary bays receive high seasonal fluxes of freshwater, salinity is subject to considerable fluctuation (McGowen et al. 1976b), enough to eliminate turtle grass from some areas of the Matagorda complex. Van Beek et al. (1980) showed that the damming of the rivers flowing into the Matagorda Bay complex has reduced the freshwater input. While mean annual salinity has increased only slightly since dam construction, the largest decrease in freshwater input has occurred during the spring (flood) period and a corresponding decrease in the annual variation of salinity has followed. Although the effect of salinity changes on seagrass distribution is not documented, some changes through time should be expected. In addition to salinity, other factors influencing the distribution of seagrasses are substrate type, turbidity, and water depth (see Copano-Aransas synthesis).

Submerged aquatics provide valuable food and shelter resources for a number of finfish, shellfish, and waterfowl. Spotted seatrout (*Cynoscion nebulosus*), for example, use widgeongrass for shelter (Ward et al. 1979), whereas juvenile southern flounder (*Paralichthys lethostigma*) prefer areas dominated by shoal grass (Stokes 1973). Immature shrimp using the estuaries as nursery ground take refuge among the culms of aquatics, and feed on detrital material and plankton which accumulate there (Johnson and Fielding 1956). McMahan (1970) has determined that in Laguna Madre wintering waterfowl, such as redhead ducks (*Aythya americana*) and pintails (*Anas acuta*), feed almost exclusively on shoal grass. No estimates of primary production of seagrasses are available for the Matagorda-Brazos study area. Due to the shorter growing season, deeper water, and moderately higher turbidities, primary production is suspected to be less in the Matagorda-Brazos study area than the values obtained in studies of Laguna Madre (see Laguna Madre synthesis).

Although phytoplankton are responsible for most of the primary production of the estuarine community, studies examining the phytoplankton in the Matagorda-Brazos system are extremely limited. Diatoms are the most abundant type of phytoplankton in the open water of the estuary, with the most common genera being *Melosira*, *Navicula*, *Nitzschia*, and *Chaetoceros*. Dinoflagellates and microflagellates are also common (USDOE 1978).

Day (1959) provided an abbreviated listing of the benthic marine algae in Matagorda Bay. Conover (1964) found that *Laurencia poitei* and *Digenia simplex* were common benthic algae during summer throughout Texas bays. During late winter-early spring, species present were different and the numbers fewer. Among those that commonly occurred throughout the Texas bays during this season were *Petalonia fascia*, *Bangia fuscopurpurea*, and *Porphyra leucosticta* (Conover 1964). The summer bloom was greater than that of late winter and peaked with maximum solar radiation from late June to early July. Both the summer and late winter increases in growth correlate with seasonal lows in turbidity.

Ward et al. (1979), using primary productivity data acquired by Odum and Wilson (1962) and Davis (1971), estimated primary productivity in the aquatic habitat of the Matagorda Bay complex. Converting the estimates of Ward et al. (1979) to grams dry weight per-unit area results in 1,330 to 1,380 g/m^2/yr for Lavaca, Matagorda, and East Matagorda Bays. These values are substantially greater than those estimated for the more turbid Galveston Bay (see Galveston synthesis), but are comparable to those of central Texas coast bays. A relatively minor proportion of the primary productivity in the aquatic habitat is directly consumed. Most of it dies and becomes part of the detrital food web where it is ingested primarily by benthic consumers.

The wind-tidal flat habitat alternates in function between an aquatic habitat and a more terrestrial habitat depending on water level. The vegetation is composed of several species of algae of which the blue-green alga Lyngbya confervoides is the most abundant (Sorenson and Conover 1962; Dawson and Armstrong 1975). During times of inundation, primary productivity increases. When light is in the optimal range, algal photosynthesis is temperature- and nutrient-dependent (Dawson and Armstrong 1975). This work is consistent with studies carried out in east coast marshes by Conover (1958) and Pomeroy (1959). No primary production estimates are available for the Matagorda-Brazos study area. Pomeroy (1959) estimated annual production of algal mats in a Georgia salt marsh to be 200 gC/m^2. During periods of sufficient inundation, the algal mats can be directly consumed. Following withdrawal of wind-generated tides and evaporation of ponded water, the algae die and decompose. With the next inundation phosphorous, nitrogen, and carbon are released into the water. Dawson (1975) found that the amounts of nutrients released increased with increased drying time (decomposition) and that release of nutrients was unusually high during the initial period of subsequent flooding. The algal mats released more nitrogen and phosphorous per unit area than did emergent marsh, but less carbon (Dawson 1975).

Emergent salt marshes fringe the margins of Matagorda and lesser bays, and the distal portions of the Colorado and Lavaca-Navidad Rivers. The zonation of emergent salt marsh vegetation on the landward side of the bay is due to a number of factors, some of which are interrelated. Elevation, edaphic conditions, frequency and duration of inundation, and freshwater input all play a role in the resulting character of the marsh (Adams 1963).

Smooth cordgrass (Spartina alterniflora) dominates the low (mean low water to mean spring high water) marsh (Ward et al. 1979; van Beek et al. 1980). Within this vegetational band bordering the bays, smooth cordgrass grows in short and tall forms, with the tall form closest to the water (Ward et al. 1979). These height forms in east coast marshes are the subject of considerable study and debate. The prevailing view is that the highly limited nitrogen is removed from the water by the tall form, depleting the available supply for culms farther from the bay (Valiela and Teal 1974). Smooth cordgrass has spurred productivity studies, primarily because of its generally accepted importance to larval and juvenile forms of commercially valuable finfish and shellfish. Salt marshes dominated by S. alterniflora have long been considered vital nursery grounds, providing a direct or indirect food source and a protective cover for immature animal species. In the Matagorda Bay area, primary productivity of the low marsh (S. alterniflora) has been estimated at 1,087 g/m^2/yr (Adams and Tingley 1977; TDWR 1978).

A group of low-growing halophytic species frequently borders S. alterniflora. The major species of this zone in the Matagorda-Brazos system include maritime saltwort (Batis maritima), woody glasswort (Salicornia virginica), dwarf saltwort or Bigelow glasswort (S. bigelovii), and shoregrass (Monanthochloe littoralis) (Ward et al. 1979; van Beek et al. 1980). Adams and Tingley (1977) estimated that the primary production of this high marsh zone is 600 g/m^2/yr.

Another vegetational zone in the salt marsh is a band of marshhay cordgrass (Spartina patens). In the study area this grass is found in the upper reaches of small bays, on the mainland side of Matagorda Bay, and in the East

Matagorda Bay lowlands north of GIWW (Ward et al. 1979). *Spartina patens* is also found on dunes on the gulf side of Matagorda Peninsula (see Section 5.2.1). Net primary productivity estimates for *S. patens* in Texas approach 1,329 g/m^2/yr (Keefe 1972).

Scattered on the landward side of Matagorda and East Matagorda Bays, along the many creeks draining into the Matagorda Bay complex, and in parts of the active Colorado and Lavaca-Navidad Deltas, brackish to freshwater marshes have developed. Their elevations are generally slightly higher than those of neighboring salt marshes. The lowered mean salinity results from increased input of freshwater from streams and from upland runoff. However, these marshes are subject to extreme fluctuations in salinity. Dry periods can result in soil salinities greater than 35 $^{o}/oo$, while abundant rainfall may result in virtually fresh surface water. Lower marshes have a higher mean salinity but one which is less variable. McGowen et al. (1976a) suggested that the flora of the high marshes is determined predominantly by the substrate salinity and its variability. In the Matagorda-Brazos system, the flora of such marshes includes rush (*Juncus* sp.), big cordgrass (*Spartina cynosuroides*), cattails (*Typha* spp.), bulrush (*Scirpus* sp.), coastal sacahuista (*Spartina spartinae*), and marshhay cordgrass (McGowen et al. 1976a, 1976b).

Brackish to freshwater marshes are poorly developed in the western portions of the study area. In Matagorda Bay proper there are very few brackish to fresh marshes. As one progresses east the amount of marsh increases. Although not as productive as saltwater marshes, these areas are still quite productive. Estimated primary productivity for *Juncus roemerianus*, an important rush in these marshes, is 499 g dry weight/m^2/yr (Espey, Huston and Associates 1977, cited by Ward et al. 1979). In the easternmost section of the study area, the area of brackish to fresh marsh is considerable. The San Bernard Wildlife Refuge, located on the relict Brazos-Colorado Delta, is primarily brackish to fresh marsh.

To the east and west of the refuge, there are two marshes that are areas of ecological concern to the State of Texas and the U.S. Fish and Wildlife Service (USFWS). Perry Marsh (4,268 ha), just east of the refuge, is considered the most vital of 25 areas of concern in Texas (USFWS 1977). It is considered to be under imminent threat of destruction, primarily because of its proximity to the city of Freeport, the GIWW, and activities associated with the Strategic Petroleum Reserve program at Bryan Mound. In addition, offshore deepwater port pipelines may be laid across this area in the future. Perry Marsh is an important nursery ground for finfish and shellfish and is a critical migratory waterfowl habitat. Canada (*Branta canadensis*) and white-fronted geese (*Anser albifrons*) utilize this marsh more than any other in Brazoria County; and, as a buffer area for the refuge, it aids in lessening the severity of eatouts by these species (USFWS 1977) as well as by snow geese (*Chen caerulescens*). To the west of the San Bernard Wildlife Refuge is the 2,400-ha Smith Marsh, which is in less danger of immediate destruction, but possesses similar assets (USFWS 1977).

Organic detrital input to the estuary is another contribution attributed to emergent marshes. This role, however, is presently being reevaluated. For example, Haines (1977), working in Georgia, suspects that the major source of organic carbon in the estuary is from phytoplankton production and riverine transport of terrestrial plant detritus. Ward et al. (1979) are in general agreement, as they have estimated that 98.6% of organic carbon is autochthonous. Marshes were estimated to contribute 23.5% of the allochthonous source (0.4% of the total).

Averaging the primary productivity of low marsh (1,087 g/m^2/yr) with high marsh (600 g/m^2/yr) and weighting for area differences result in a deltaic marsh primary productivity estimate of 914 g/m^2/yr (TDWR 1978) in the Matagorda-Brazos study area. In comparison with the estimated primary productivity of the aquatic habitat (1,330 to 1,380 g/m^2/yr) in the Matagorda-Brazos area, the production of marshes is less. This is consistent with areas to the south and west along the Texas coast, but is in contrast with the Galveston study area. Gosselink et al. (1979) estimated that the primary productivity of the marshes in the Chenier Plain system of southeast Texas and southwest Louisiana exceeds that of the aquatic environment. The Matagorda-Brazos area, then, represents the transition area. The change cannot be explained in terms of an increase in the primary productivity in the aquatic habitat over space, but rather to a substantial decrease in the productivity of the emergent marshes over space. At least part of this reduction can be attributed to high soil salinities. During summer when primary productivity would be expected to be high, water levels are typically low in the Matagorda Area, and evapotranspiration rates are high (see Figure 2). The reduced freshwater input and the decreased duration in tidal flooding, combined with high evaporation rates, allow for a build-up of soil salts, thereby inhibiting plant growth. McGowen (1976a) reported that soil salinities may exceed 35 $^o/oo$ in the higher marshes of the study area.

5.1.2 Fauna

Mammals. The bottlenose dolphin (Tursiops truncatus) is the only cetacean common in the Matagorda Bay area. In a recent aerial census of bottlenose dolphins (Barham et al. 1980), Matagorda Bay proved to be an area of high density. Barham et al. (1980) sighted dolphins most frequently in ship channels and shallow areas of Matagorda Bay. There have been several reports of beached whales near Freeport, including the pilot whale (Globicephala melaena) and northern right whale (Eubalaena glacialis). The entire world population of the latter species is estimated to be less than 1,000 and is protected from further commercial harvest by the International Whaling Convention (Davis 1974).

Two rodent species occur in salt, brackish, and fresh marshes of the study area. The northern rice rat (Oryzomys palustris) lives in a semiaquatic environment and may spend a considerable amount of time in shallow water. Although it feeds primarily on green vegetation, the rice rat also eats seeds of marsh grasses and sedges. However, its predilection for rice accounts for its common name (Davis 1974). The second species, the hispid cotton rat (Sigmodon hispidus), also feeds upon and dwells in marsh grasses such as Spartina alterniflora and in sedges (Carex sp.). The cotton rat prefers habitats drier than does the rice rat, such as old fields, natural prairies, and other sites not subject to flooding, but where vegetation grows tall (Davis 1974).

The fur-bearing nutria (*Myocastor coypus*) is a South American rodent, which was accidentally introduced into Louisiana in 1938 (Lowery 1974). It was subsequently introduced into Texas for control of vegetation-choked ponds (Davis 1974), but additional populations have probably spread into Texas from Louisiana. The species is found throughout wetland habitats, but is most abundant in fresher marshes (Palmisano 1972). Davis (1974) believes that the nutria is replacing the muskrat, an idea currently the subject of debate.

The raccoon (*Procyon lotor*) is the primary carnivore found in the marshes bordering the estuary. The occurrence of this species depends much less on the available food supply than on water. It can subsist on a wide variety of food, such as plant material, insects, crayfish, birds, and snakes; but it seldom strays far from its water supply.

The mink (*Mustela vison*) also may be found in brackish to fresh water marshes. Flexible in its feeding habits, it takes prey ranging from clams and mussels to muskrats (Davis 1974). This species is trapped for its fur, but no data were available on the extent of the industry in the Matagorda-Brazos study area.

In fresh marshes where spoil banks, levees, or other topographic highs are interspersed, the river otter (*Lutra canadensis texensis*) and white-tailed deer (*Odocoileus virginianus*) can be found.

Birds. Annual surveys conducted by TPWD provide recent population estimates of resident fish-eating birds (plus cattle egret) along the Matagorda-Brazos study area (Table 1). Virtually all of the species are an integral part of other communities as well as the estuarine community. For example, many terns also feed in the gulf, and nesting frequently occurs on the barrier islands.

The estuarine environment of the Matagorda-Brazos study area provides important habitat for wintering waterfowl. Ducks such as pintail, lesser scaup (*Aytha affinis*), and mottled duck (*Anas fulvigula*), and American coot (*Fulica americana*) are common in this community. The marshes east of East Matagorda Bay support large winter populations of sandhill cranes (*Grus canadensis*), Canada geese, white-fronted geese, and snow geese.

Reptiles and amphibians. With the possible exceptions of the endangered green turtle (*Chelonia mydas*) and Kemp's ridley turtle (*Lepidochelys kempi*), no reptiles or amphibians frequent estuarine open waters in this area. According to the National Fish and Wildlife Laboratory (1980), these species of sea turtles have been sighted in the waters off Brazoria, Calhoun, and Matagorda Counties (also see Marine synthesis). Both species feed in shallow estuarine areas. The green turtle prefers submerged aquatics; the ridley prefers invertebrates.

Along the borders of the bays in the salt marshes, additional reptiles can be found. The Texas diamondback terrapin (*Malaclemys terrapin littoralis*) is probably the only turtle present. The species is considered threatened by the Texas Organization for Endangered Species because of habitat destruction and drowning in shrimp trawls.

Table 1. Pairs of colonial fish-eating birds - Matagorda-Brazos System (adapted from Blacklock et al. 1978).

Scientific name	Common name	Year 1973	 1974	 1975	 1976	Historical population trend for all of Texas
Pelecanus occidentalis	Brown pelican	0	3	0	0	See endangered species
Phalacrocorax olivaceus	Olivaceous cormorant	4	0	2	0	Always small, peripheral species
Anhinga anhinga	Anhinga	56	12	0	100	Long-term decline
Ardea herodias	Great blue heron	95	182	345	696	Stable
Florida caerulea	Little blue heron	239	29	44	2,859	Primarily inland; stable
Bubulcus ibis	Cattle egret	5,774	7,325	10,450	42,326	First arrival 1954; rapid increase
Dichromanassa rufescens	Reddish egret	121	221	195	327	Long-term decline; stable since 1960's
Casmerodius albus	Great egret	431	598	800	1,250	1910, near extinction; currently stable
Leucophoyx thula	Snowy egret	519	817	914	1,025	1910, near extinction; currently stable
Hydranassa tricolor	Louisiana heron	1,544	2,342	4,786	6,111	Rapid increase during past 10 years
Nycticorax nycticorax	Black-crowned night heron	84	96	123	110	Insufficient data

Continued

Table 1. Concluded.

Scientific name	Common name	Year				Historical population trend for all of Texas
		1973	1974	1975	1976	
Plegadis chihi	White-faced ibis	1,262	897	1,307	2,600	Stable since 1974 decline
Endocimus albus	White ibis	1,440	1,600	1,838	1,465	Stable to increasing over last 20 years
Ajaia ajaja	Roseate spoonbill	202	176	525	322	1910, near extinction; currently stable
Larus articilla	Laughing gull	4,241	2,935	4,210	4,520	Stable
Gelochelidon nilotica	Gull-billed tern	71	48	75	6	Stable to decreasing
Sterna forsteri	Forster's tern	611	360	741	188	Slow decline since 1940's
S. albifrons	Least tern	145	170	143	60	Rapid decrease
S. maxima	Royal tern	3,450	5,202	4,000	4,000	Always abundant
S. sandvicensis	Sandwich tern	1,350	2,620	1,700	1,750	Stable below San Antonio Bay
S. caspia	Caspian tern	460	170	210	197	Slow decline
Rynchops nigra	Black skimmer	2,042	1,182	1,574	937	Insufficient data

Snakes in salt and brackish marshes include the gulf salt marsh snake (*Nerodia fasciata clarki*) and marsh brown snake (*Storeria dekayi limnetes*). The major food of the gulf salt marsh snake is fish; the marsh brown snake feeds primarily on insects (Conant 1975).

The American alligator (*Alligator mississippiensis*) is an opportunistic carnivore found in the fresher marshes and wet bottomlands of the Matagorda-Brazos study area (see Section 5.6.3 for local population estimates).

The Texas diamondback terrapin and the common snapping turtle (*Chelydra serpentina*) both may be found in brackish marshes. Common turtles in freshwater marshes include the stinkpot (*Sternotherus odoratus*), Mississippi mud turtle (*Kinosternon subrubrum hippocrepis*), western chicken turtle (*Deirochelys reticularia miaria*), and the common snapping turtle (Conant 1975). Fresh marshes have several species of snakes (see Section 5.5.2).

Amphibians are more commonly found in brackish to fresh marshes. The representative species include the eastern narrow-mouthed toad (*Gastrophryne carolinensis*), Blanchard's cricket frog (*Acris crepitans blanchardi*), and the southern leopard frog (*Rana utricularia*) (Conant 1975). The first two species are not reported in brackish water, but they thrive in fresh marshes with abundant vegetation (Wright and Wright 1949). The southern leopard frog is found occasionally in brackish water though its preferred habitat is freshwater (Conant 1975).

Fish. Several fish of sport and commercial value are found in the emergent salt marsh vegetation and submerged aquatics in the Matagorda-Brazos area. Commercial fishing in the Matagorda Bay complex ranks fourth behind Laguna Madre, Copano-Aransas, and Galveston, and provides an average of 7% of the coastal commercial catch by weight (USFWS and TPWD 1968a, 1968b; NOAA and TPWD 1970; NOAA 1971, 1972, 1973b, 1974, 1975, 1977, 1978a, 1978b).

Spotted seatrout (*Cynoscion nebulosus*) was the largest commercial finfish catch by weight in the bay from 1967 through 1977. The average annual reported catch during that 11-year span was 6.2 x 10^4 kg (USFWS and TPWD 1968a, 1968b; NOAA and TPWD 1970; NOAA 1971, 1972, 1973b, 1974, 1975, 1977, 1978a, 1978b). Spotted seatrout prefer areas with a good stand of widgeongrass. Larval forms are found mainly in Carancahua Bay; juveniles are abundant in Powderhorn Lake, Matagorda Bay, Carancahua Bay, Turtle Bay, and Tres Palacios Bay. Adults are found throughout Matagorda Bay proper, and especially in Powderhorn Lake (Ward et al. 1979). Although year round residents of bays, spotted seatrout move to deeper, warmer waters during the coldest part of winter (Miles 1950). For detailed discussion of the life history of this species, see Guest and Gunter (1958) and the Laguna Madre synthesis, Section 5.1.2.

Red drum (*Sciaenops ocellatus*), also called redfish, prefer secondary and tertiary bays such as Oyster Lake, Cox Lake, and Swan Lake. Although red drum spawn in the gulf, the larvae utilize inshore grassy areas with muddy bottoms. There is apparently little coastal or interbay movement of young or adults (Moffett and Murray 1963). Trammel net collections along the Texas coast by TPWD suggest that Matagorda Bay supports one of the largest populations of red drum in the State (Matlock and Weaver 1979). For a detailed discussion of the life history of the red drum, see Laguna Madre synthesis, Section 5.1.2.

During the 11-year span from 1967 through 1977, undifferentiated flounder harvested in the Matagorda bay area averaged 19.7% of the annual mean commercial catch by weight for all the Texas bays (USFWS and TPWD 1968a, 1968b; NOAA and TPWD 1970; NOAA 1971, 1972, 1973b, 1974, 1975, 1977, 1978a, 1978b). The southern flounder (*Paralichthys lethostigma*) is not nearly as abundant in the Matagorda complex as in some other Texas bays (Matlock and Weaver 1979), and the commercial values reflect catches of several species of flat bottom-dwelling fish, including *Paralichthys* and *Citharichthys*. Optimum inshore habitat requirements for adult southern flounder are estuaries of fine-grained bottom with peripheral stands of *Spartina alterniflora* (Stokes 1973). Adults move offshore to spawn from September to December (E. G. Simmons, Texas Parks and Wildlife; pers. comm. 1980). Small fry begin to enter the estuaries in February. Juveniles prefer shallow, muddy bottoms as nursery areas (Gloyna and Malina 1964, cited by Ward et al. 1979).

Black drum (*Pogonias cromis*), another fish of sport and commercial value, utilizes muddy substrate marshes as a nursery ground. Adults spawn in the gulf, passes, and at the mouths of bays; and larval forms subsequently move into the upper bays where marsh vegetation is plentiful (E.G. Simmons, TPWD; pers. comm. 1980). Juveniles also utilize marshes with muddy bottoms where they develop adult feeding habits, consuming primarily bivalves (Ward et al. 1979). See Laguna Madre synthesis paper, Section 5.1.2, for a more detailed discussion of this species.

Other finfishes in the Matagorda complex include forage species such as spot (*Leiostomus xanthurus*), Atlantic croaker (*Micropogonias undulatus*), and striped mullet (*Mugil cephalus*). The gulf menhaden (*Brevoortia patronus*) is common in the secondary bays of the study area and feeds mainly on phytoplankton, although it is flexible in its feeding habits (Ward et al. 1979). Menhaden are not fished commercially in Matagorda Bay, but do constitute a large percentage of the offshore catch.

The gafftopsail catfish (*Bagre marinus*) is of considerably more value as a sport species than a commercial one. During a 2-year period ending in 1977, sportfishermen in the Matagorda-Brazos study area took almost the entire Texas sport harvest of this catfish. Landings of some extremely large individuals are responsible for spring peaks in catch weights (Ward et al. 1979).

The Matagorda-Brazos area ranks third in sport landings behind the Galveston and Laguna Madre areas. Green et al. (1978, cited by Ward et al. 1979) suggested that the Matagorda area provides a sport catch per unit of fishing effort higher than the State average. Fall is the most productive season for sport fisheries in Matagorda Bay, but the area leads all other Texas bays in winter fishing (Ward et al. 1979).

Invertebrates. In the 1930's the Matagorda Bay area produced almost 50% of the American oysters (*Crassostrea virginica*) harvested in Texas. They were highly prized for their size and taste. Production peaked in 1942 when 2.1 x 10^5kg were harvested (Ward et al. 1979). Commercial harvests for the 11-year period from 1967 through 1977 averaged 1.2 x 10^5 kg/yr, 7.4% of the total Texas harvest (USFWS and TPWD 1968a, 1968b; NOAA and TPWD 1970; NOAA 1971, 1972, 1973b, 1974, 1975, 1977, 1978a, 1978b). The Galveston Bay area is the only one to harvest more oysters, accounting for over 75% of the Texas catch. Although oyster production over the past decade has remained fairly constant, the harvest has fallen off considerably since the early 1900's. This trend has been noted coastwide and is generally attributed to destruction of reefs by shell dredging and overharvesting (Ward et al. 1979). An additional factor in the Matagorda Bay area is the formation of the Colorado River Delta and diversion of the Colorado River into the Gulf of Mexico, which have destroyed many reefs by siltation and increased salinities. (B.D. King, III, USFWS, Austin, Texas; pers. comm. 1980). Also see Section 2.5.

Adult oysters grow best at 15.6° to 20° C (Maghan 1967, cited by Ward et al. 1979), but can tolerate a range from 4.4° to 31.7° C. A salinity range of 5 to 40 ‰ is tolerated, but an optimum range for growth lies between 5 and 20 ‰ (Hofstetter 1977). Larval oysters are somewhat more sensitive to lower salinities, and their growth is adversely affected by salinities less than 12.5 ‰ (Davis 1958, cited by Ward et al. 1979).

Adult oysters spawn as many as six times per season, beginning in early spring (Hopkins et al. 1954, cited by Ward et al. 1979). Spat permanently attach to the substrate 2 to 3 weeks after hatching and begin the transition to the adult form (Ward et al. 1979).

In the Matagorda-Brazos area, oyster reefs are most abundant in the areas receiving some freshwater inflow. Reefs are found along most of the landward side of Matagorda Peninsula, adjacent to the Colorado River Delta, and in Oyster Lake, Tres Palacios Bay, Turtle Bay, and Carancahua Bay (Ward et al. 1979). Lavaca Bay has some of the most extensive reefs in the area and supplies nearly half of the Matagorda Bay area harvest (B. D. King, III, USFWS, Austin, Texas; pers. comm. 1980).

Blue crab (Callinectes sapidus) harvests in the Matagorda-Brazos area have averaged 3.5×10^5 kg/yr during the period 1967-1977, equivalent to 13% of the total Texas catch (USFWS and TPWD 1968a, 1968b; NOAA and TPWD 1970; NOAA 1971, 1972, 1973b, 1974, 1975, 1977, 1978a, 1978b). Historically, the largest production occurs in those bays with the greatest freshwater inflow (More 1969). This provides a partial explanation for the greater harvests in the Galveston and San Antonio Bay study areas, which both receive a larger freshwater inflow per unit area of the receiving basin (estuary) than the Matagorda-Brazos study area.

Based on harvests, blue crab populations are subject to severe annual fluctuations. The Matagorda catch in 1970 was 3.5×10^5 kg; and in 1972 the harvest had climbed to 4.0×10^5 kg (USFWS and TPWD 1968a, 1968b; NOAA and TPWD 1970; NOAA 1971, 1972 1973b, 1974, 1975, 1977, 1978a, 1978b). The cause has not been determined, but it does not appear to be related to fishing pressure (Walburg 1963, cited by More 1969), nor to the numbers of spawning females (Henry 1968, cited by Ward et al. 1979).

Blue crabs prefer muddy bottoms and are most abundant in the salt flats and shallow estuarine areas. They possess broad tolerance limits for salinity and temperature. Optimum conditions are water temperatures between 10° and 35° C, and salinities between 10 and 27 ‰ (Costlow and Bookhout 1959). Females spawn in the gulf or in Matagorda Bay, but only in waters where salinities exceed 20 ‰. Eggs hatch into plankton-feeding zoea. The next stage is the megalops, which in turn develops into the juvenile crab. Optimum salinities for larval crabs are 25 to 29 ‰ (Sandoz and Rogers 1944). Juvenile crabs thrive in salinities below 20 ⁰/oo (Tagatz 1968, cited by Ward et al. 1979) and generally migrate to estuarine areas of lower salinity where they reach maturity in approximately 1 year (More 1969). After maturity, the females move to waters of higher salinity (optimum 26 to 36 ⁰/oo), while males tend to stay in salinities of 10 to 20 ⁰/oo. Work by Tan and van Engel (1966, cited by More 1969) in Chesapeake Bay showed that waters of low salinity result in osmo-regulatory problems for adult females. These findings offer an explanation for the segregation of males and females into areas of lower and higher salinities, respectively.

The shrimping effort in the Matagorda-Brazos area is decidedly weighted toward white shrimp (Penaeus setiferus). The mean yearly catch between 1967 and 1977 was 7.5 x 10^5 kg, or 23.6% of the average catch for all Texas bays (USFWS and TPWD 1968a, 1968b; NOAA and TPWD 1970; NOAA 1971, 1972, 1973b, 1974, 1975, 1977, 1978a, 1978b). White shrimp are more common along the northern Texas coast where greater precipitation results in a lower water deficit (Ward et al. 1979). For this reason, it is not surprising that only the Galveston Bay area has a larger catch of white shrimp than Matagorda-Brazos.

Spawning and early larval development of white shrimp occur in the gulf, during which time salinity levels do not affect their growth or survival. Larval development lasts from 3 to 5 weeks, after which the new postlarvae begin to enter the estuary (Kutkuhn 1966). During postlarval development, salinity becomes a critical factor (Ward et al. 1979). Young shrimp grow best in salinities less than 10 ⁰/oo (Williams 1955, cited by Ward et al. 1979), but greater than 0.3 ⁰/oo (Joyce 1965, cited by Ward et al. 1979), if one assumes temperature and other environmental factors are not limiting. It must be stressed, however, that shrimp, even postlarval forms, are tolerant of a wide range of salinities. Gunter et al. (1964) found postlarval white shrimp could tolerate a salinity range from 0.4 to 40 ⁰/oo. In some cases, the quantity and quality of vegetation upon which the shrimp depend for part of their subsistence are more affected by salinity than are the shrimp themselves (Kutkuhn 1966).

Johnson and Fielding (1956) studied the food of young shrimp in relation to salinity and found that postlarval and young penaeids feed on plankton and organic detritus which concentrate in bay margin waters. They suggested that the lower salinities of the bay margin waters are probably a coincidental factor; food availability is more critical than salinity levels.

Chapman (1960) stressed the value of Spartina alterniflora-dominated salt marsh along the edges of bays for the survival and growth of young shrimp. The vegetation offers abundant protection and food. Further, there is some indication that the detritus in water flowing from S. alterniflora marshes following high tides provides high levels of vitamin B_{12}, an important growth promoter (Starr 1956).

In the Matagorda Bay area, pink shrimp (Penaeus duorarum) and brown shrimp (P. aztecus) are harvested in smaller quantities than are white shrimp. The combined 11-year average harvest for 1967 through 1977 is 2.1 x 10^5 kg, 17.8 % of the total Texas inshore catch of pink and brown shrimp (USFWS and TPWD 1968a, 1968b; NOAA and TPWD 1970; NOAA 1971, 1972, 1973b, 1974, 1975, 1977, 1978a, 1978b). The life histories of the pink and brown shrimp are similar to that of the white shrimp, except that the waves of juvenile white shrimp usually enter the bays in June and August (Moffet 1968, cited by Ward et al. 1979), whereas the waves of brown and pink juveniles occur in April and July (Murray 1965, cited by Ward et al. 1979).

Representative invertebrates which comprise a portion of the diet of several important sport and commercial finfish are presented in Table 2.

5.2 BARRIER-PENINSULA COMMUNITY

Most of the gulf shoreline along Matagorda Peninsula has been undergoing erosion for over a century (also see Sections 2.1 and 2.5). The profile of an erosional beach is different from one that is accreting. The reduced sand supply means there is less material available for the wind to transport, resulting in reduced dune formation. This is fundamentally different from the poor dune formation along the extreme southern end of Padre Island (Laguna Madre study area) where the lack of vegetation (primarily due to the arid climate) precludes the inhibition of saltation (process of eolian transport of sand) and dune formation.

The peninsula serves as a control for the exchange of bay and gulf waters and absorbs much of the energy of storm waves and tidal surges.

The barrier from East Matagorda Bay to the northeastern border of the Matagorda-Brazos study area is unique for the Texas Barrier Islands coast. The broad shallow bays usually found landward of the barrier are absent, being replaced by emergent marsh. The bays that once existed have been filled by Brazos River and Colorado River sediments.

5.2.1 Vegetation

Viewing the peninsula from the gulf, one sees a narrow band of sea oats (Uniola paniculata) and perhaps some halophytes such as sumpweed (Iva sp.). This vegetation grows at the base of the foredunes if the beach is sandy, or at the toe of a shell ramp if the beach is composed primarily of shell (McGowen et al. 1976a). Sandy beaches are more common on the southwestern portion of the peninsula.

It is also in the southwest that the foredunes are best developed, especially from Greens Bayou to Pass Cavallo. Along the more northeasterly section of the peninsula, from the Colorado River to approximately 13 km east, there is a continuous foredune ridge (McGowen et al. 1976a). The typical vegetative zonation on the dunes includes marshhay cordgrass, morning glory (Ipomoea sp.), and sea purslane (Sesuvium portulacastrum) on the gulfward lower face of the dunes, and panic grass (Panicum sp.) and Croton sp. on the upper portions. The leeward side of these dunes is usually vegetated primarily by seacoast bluestem (Schizachyrium scoparium littoralis), according to McGowen et al. (1976b).

Along part of northeastern Matagorda Peninsula, where foredunes do not occur, the shell beach grades into shell ramps reaching an average height of 1.5 to 2 m above mean sea level (MSL). Formed by storm activity, shell ramps initially consist of shell and sand deposited on shore. With a return to

Table 2. Representative invertebrates present in the estuarine community of the Matagorda-Brazos system (Pulley 1952; Harry and Littleton 1973).

Gastropods

Littorina irrorata

Cerithium variabile

Turbonilla interrupta

Crepidula plana

Caecum pulchellum

Odostomia impressa

Pelecypods

Nuculana concentrica

Crassostrea virginica

Ostrea equestris

Mulinia lateralis

Rangia cuneata

Rangia flexuosa

Anomalocardia cuneimeris

Macoma mitchelli

Ostracod assemblages

Candona sp. - *Cyprideis* sp. - *Perissocytheridea brachyformis*
Cytherura johnsoni

Perissocytheridea johnsoni - *Cytherura* sp.

Aurila sp. - *Loxoconcha purisubrhomboidea*

Loxoconcha australis - *Perissocytheridea brachyformis*

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normal wind and water activity, the fine-grained sands are gradually winnowed out, leaving only shell hash. Vegetative cover is mainly grasses such as coastal sacahuista and bluestem (*Andropogon* sp. or *Schizachyrium* sp.), various cacti, mottes of saltcedar (*Tamarix gallica*), and rarely mesquite (*Prosopis juliflora*).

Barrier flats densely vegetated with bluestem, Indiangrass (*Sorghastrum* sp.) coastal sacahuista, and sunflowers (*Helianthus* spp.) are found behind the shell ramps. Fine sand originating from the shell ramps is the dominant sediment of barrier flats (McGowen et al. 1976a). In the southwestern portion of the Matagorda Peninsula, foredunes are bordered by vegetated barrier flats and by low beach ridges and swales. The vegetative character is similar to the flats on the northeastern segment of the peninsula.

Locally, fresh to brackish water marshes dot the landscape of the barrier flats. Coastal sacahuista, marshhay cordgrass, big cordgrass, bulrush (*Scirpus* sp.), cattails, and rush (*Juncus* sp.) are major species present (McGowen et al. 1976a, 1976b). Descriptions of the salt marshes located on the inland side of the barrier and bordering the bays are included in Section 5.1.1.

5.2.2 *Fauna*

Mammals. The diversity of mammals along the barrier islands of Texas is, in general, low. In addition to small rodents, the nine-banded armadillo (*Dasypus novemcinctus*), raccoon, and opossum (*Didelphis virginiana*) can be found frequently on Matagorda Peninsula. None of the mammals present are dependent on this kind of habitat. Along the beach, east of Matagorda Peninsula, it would not be surprising to see any species of mammal indigenous to the area. The beach here borders the marsh, and the transverse natural levees of the Brazos, San Bernard, and older river courses provide an avenue of access to the shore for those species usually associated with the uplands.

Birds. The year-round resident, fish-eating species are listed elsewhere in this synthesis. Numerous species utilize Matagorda Peninsula seasonally. Among these, several plovers (*Charadrius* spp.) and sandpipers (*Calidris* spp.) feed on crustaceans, insects, and worms on the beach face. Birds of prey including the uncommon osprey (*Pandion haliaetus*), merlin (*Falco columbarius*), and peregrine falcon (*Falco peregrinus*) can be observed in the area. The osprey feeds primarily on fish in the neighboring estuaries and nearshore gulf, but the peregrine falcon and merlin feed on small mammals and birds of the barrier community (see Section 5.6.4).

Reptiles and amphibians. Reptiles in the area include the Texas horned lizard (*Phyrnosoma cornutum*), discussed in the Laguna Madre synthesis paper; six-lined racerunner (*Cnemidophorus sexlineatus sexlineatus*); and western slender glass lizard (*Ophisaurus attenuatus attenuatus*).

Common snakes include the western coachwhip (*Masticophis flagellum testaceus*) and western diamondback rattlesnake (*Crotalus atrox*). East of the peninsula the Louisiana milk snake (*Lampropeltis triangulum amaura*) becomes more abundant.

The ornate box turtle (*Terrapene ornata ornata*) occurs on Matagorda Peninsula. It survives the warm and dry periods by burrowing to escape the heat; insects are its main food item (Conant 1975).

According to the U.S. Fish and Wildlife Service (1978), Matagorda Peninsula has not been utilized by any nesting sea turtles in recent years.

Due to the edaphically controlled xeric conditions, few species of amphibians are present on the peninsula. The gulf coast toad (Bufo valliceps) is the only amphibian commonly found on the barrier island habitat of the Matagorda study area. It uses a variety of temporary water supplies for breeding (Conant 1975).

5.3 RIVERINE COMMUNITY

The character of the mainland portion of the Matagorda-Brazos system through geologic time has been shaped largely by the rivers which have cut and recut their way down to the coast. The two major flows, the Brazos and Colorado, have changed their courses several times as evidenced by the remains of ancient oxbow lakes presently scattered throughout the grasslands and bottomlands in the study area.

The major contributions of these rivers to the estuarine community include the following: (1) inflow of freshwater to maintain low salinities; (2) supply of inorganic sediment to maintain existing wetlands and build new wetlands, thereby increasing the habitat diversity of the area; and (3) source of nutrients to the estuarine and nearshore gulf communities.

5.3.1 Vegetation

Primary productivity in the riverine community is phytoplankton based (Reid 1961). Turbidity is an important factor controlling the depth to which primary production will occur. A concentration of inorganics is required, as nutrients necessary for primary production are adsorbed onto the suspended particles (Williams 1973). In addition to internal production, a substantial amount of carbon and other nutrients enter the community as detritus from the neighboring floodplain community (Clapham 1973). In contrast to the estuarine community, the bulk of the phytoplankton does not become part of the complex riverine benthic community upon dying. Water velocities of the major rivers of the Matagorda-Brazos system are sufficient to transport this organic carbon source to the estuarine community.

In quiet water areas on the floodplain, macrophytes, including various pondweeds, duckweeds, and water lilies, are common (USDOE 1978).

5.3.2 Fauna

Except for fish, the fauna associated with the riverine community is not bound to the aquatic environment. Instead, these organisms depend on both the river and floodplain in combination to satisfy their needs for food, shelter, and nesting. Separation of these environments into two distinct communities is the subject of considerable debate in the scientific community (Cowardin et al. 1979). At best, such a separation is highly artificial and, like most arbitrary boundaries, is one the faunal component does not observe.

Mammals. There are no aquatic mammals in the riverine community in the Matagorda-Brazos study area. Semiaquatic mammals are discussed as part of the floodplain community.

Birds. See Section 5.4.2.

Reptiles and amphibians. Many species of turtles spend considerable time in the water, basking on protruding logs or in muddy banks along the sides of water. Some turtles such as the common snapping turtle and stinkpot are tolerant of a wide range of aquatic conditions. These species can be expected to occur in ponds, ditches, marshes, and creeks, in addition to rivers. Other species with more specific habitat requirements binding them more strictly to rivers are the Texas slider (*Chrysemys concinna texana*), red-eared turtle (*C. scripta elegans*), and midland smooth softshell turtle (*Trionyx muticus muticus*), according to Raun and Gehlbach (1972) and Conant (1975). Members of the genus *Chrysemys* are the most conspicuous turtles on the river because they bask for extended periods if the weather is not extreme. When basking sites are in short supply, it is not uncommon for them to be stacked two or three deep (Conant 1975).

Other semiaquatic reptiles and amphibians are included in Section 5.4.2.

Fish. Investigations by Johnson (1977) on the lower stretches of the San Bernard and Brazos Rivers show that the saline influence continues farther upstream in the San Bernard River than it does in the Brazos River. At the most inland station on the San Bernard (41.8 km upstream), the mean surface and bottom salinities in 1973 were 3.5 °/oo and 11.3 °/oo, respectively; the range in bottom salinity was 0 to 20 °/oo. The following year those mean salinities had dropped to 1.1 and 8.6 °/oo, respectively. Because of these salinities, most of the San Bernard River within the study area can be considered estuarine. As a result, for a considerable distance upstream from the mouth of the San Bernard there are few fish classified as strictly freshwater. Some freshwater species include the green sunfish (*Lepomis cyanellus*) and blue catfish (*Ictalurus furcatus*). Fish known to thrive in both fresh and saltwater (Gallaway et al. 1972), which were sampled in the San Bernard River, were the striped mullet, darter goby (*Gobionellus boleosoma*), sheepshead (*Archosargus probatocephalus*), and gizzard shad (*Dorosoma cepedianum*).

In the Brazos River, Johnson (1977) found that the salt wedge is effectively dissipated 40.2 km upstream. In 1973, the average surface and bottom salinities at this point were 0.9 and 1.1 °/oo, respectively. The highest recorded bottom salinity was 2.2 °/oo, measured in September. The following year the average values had both dropped to 0.6 °/oo. The difference in the salinities along the lower reaches of the Brazos and San Bernard Rivers is associated with the substantial difference in their respective freshwater discharges (see Section 4.3).

The lowest reaches of the Brazos River are essentially estuarine in nature, but 40 km upstream the species composition is predominantly freshwater. A typical finfish assemblage in this river includes the entire gamut from fresh to marine. Common freshwater fish caught by Johnson (1977) included speckled chub (*Hybopsis aestivalis*), silverband shiner (*Notropis shumardi*), blue catfish, bullhead (*Ictalurus* sp.), and freshwater drum (*Aplodinotus grunniens*). Fish caught that thrive in both salt and freshwater included striped mullet, violet goby (*Gobioides broussonneti*), threadfin shad (*Dorosoma petenense*), and pinfish (*Lagodon rhomboides*). Representative finfish defined as marine but known to frequently enter freshwater (Hoese and Moore 1977) were bay anchovy (*Anchoa mitchilli*), hardhead catfish (*Arius* felis), spot, and red drum. Marine species absent during sampling in the Brazos but present in the San Bernard included the southern flounder, hogchoker (Trinectes maculatus), Atlantic croaker, gulf menhaden, and sand seatrout (Cynoscion arenarius).

Work by Conner (1977) shows that the Brazos River and the more westerly Colorado River form one of two natural breaks in the faunal component of rivers along the Louisiana and Texas coasts. The Brazos and Colorado have a similar finfish composition, evidenced by an ichthyofaunal affinity (similarity) of 82.6%. Furthermore, between the two drainages, 26 species of finfish reach their southwestern range limit; six others reach their northeastern limit. Conner (1977) suggested that the Brazos-Colorado divide marks the boundary between the northern and central Texas coastal ichthyofauna. The second natural faunal break occurs at the Nueces River, the boundary between the central and southern Texas coastal ichthyofauna (see Corpus Christi synthesis).

5.4 FLOODPLAIN COMMUNITY

The Brazos and Colorado Rivers, and to a lesser extent the Lavaca-Navidad system, have been subjected to processes of meandering and stream piracy for thousands of years. One result is the extensive development of floodplain habitat. The over 1,700 km^2 of bottomlands in this area (McGowen et al.1976a, 1976b) is by far the most extensive of any of the study areas along the Texas Barrier Islands coast.

Processes controlling floodplain development are variable; and the resulting morphological characteristics, such as habitat heterogeneity and high species diversity, reflect this variability. The damming of the major rivers in the study area to help satisfy man's water needs has adversely affected the diversity of floodplain development. As van Beek et al. (1980) illustrated, most of the reduced flow occurs during what previously was flood period. Thus, the peak flood is severely reduced with a corresponding reduction in the amount of seasonally flooded lands. The decrease in flooding means a decrease in exchange of nutrients and ultimately a decrease in productivity. The decrease in flooded lands also historically has led to clearcutting and cultivation of these fertile lands. This, in turn, may result in decreased water quality through the introduction of excessive nutrient loads from agricultural runoff; the situation may be further compounded by the decreased area of seasonally flooded lands capable of absorbing nutrients. Cost to the public increases through the construction of flood-control projects to prevent episodic flooding of the newly claimed lands. Less measurable is the likely decrease in the quality of other indirectly affected habitats, resulting in reduced harvests of fish, oysters, and furbearers.

5.4.1 Vegetation

The floodplains of this study area are dominated by water-tolerant hardwoods (McGowen et al. 1976a). No strict zonation occurs, but generally those species most tolerant of flooding occur in the lowest reaches of the floodplain. As elevations gradually increase away from the river, soils are better drained, and less water-tolerant species appear.

True swamps comprise a comparatively small area of the floodplain, constituting some 16 km^2 (McGowen et al. 1976a, 1976b). Cypress (*Taxodium distichum*) and sour-gum (*Nyssa* sp.) are the most representative species, being highly water-tolerant. Cypress, particularly, is well adapted to its aquatic environment: its buttressed base provides increased stability in the muddy substrate; and its aboveground roots, commonly called "knees," perhaps augment aeration for the tree (Jensen and Salisbury 1972).

In somewhat less flooded areas, water oak (*Quercus nigra*), willow (*Salix* sp.), ash (*Fraxinus* sp.), and sweet bay (*Magnolia virginiana*) dominate (McGowen et al. 1976a, 1976b). Dwarf palmetto (*Sabal minor*) is an important understory species that approaches its southwestern range limit in this study area (Vines 1960; Correll and Correll 1975).

Along areas of higher elevations, including natural levees, sweet-gum (*Liquidambar styraciflua*), water hickory (*Carya aquatica*), live oak (*Quercus virginiana*), and pecan (*Carya illinoensis*) are present (McGowen et al. 1976a, 1976b; USDOE 1978).

Along the best drained areas of the floodplain, a mixture of levee type and upland species (see Section 5.5.1) is present.

Vines such as grape (*Vitis* sp.) and green-briar (*Smilax* spp.) are common throughout (except in the lowest areas), as is shrubby understory like red haw (*Crataegus viburnifolia*), hackberry (*Celtis laevigata*), and yaupon (*Ilex vomitoria*) (McGowen et al. 1976a, 1976b). No productivity estimates are known for these species in Texas.

5.4.2 *Fauna*

Mammals. Several valuable furbearing species are common to the floodplain and swamp of the Matagorda-Brazos study area, including bobcat (*Lynx rufus*), raccoon, opossum, mink, gray fox (*Urocyon cinereoargenteus*) and nutria (Davis 1974; USDOE 1978). No data are published on harvests by habitat or county. On a per-pelt basis, the bobcat, followed by the gray fox and raccoon, is the most valuable of the six (TPWD 1979c). Based on the number of trapping licenses issued for the region in which the Texas Barrier Islands Region lies, the furbearing harvest is not as important as in some other areas of the State; but the rapidly increasing number of licensed trappers is evidence that the venture is feasible (TPWD 1978c, 1979c).

Other common mammals in the community are the white-tailed deer, eastern gray squirrel (*Sciurus carolinensis*), eastern flying squirrel (*Glaucomys volans*), fox squirrel (*Sciurus niger*), and eastern cottontail (*Sylvilagus floridanus*) (Davis 1974). Squirrels are not harvested to any extent for their fur, nor are they considered (with the exception of the fox squirrel) major game species by local residents. Harvests of the first two species of squirrel are light, and fluctuations in populations probably reflect the availability of food (TPWD 1968, 1969, 1971, 1974a).

The floodplain provides suitable habitat for several bats that show a preference for foraging near watercourses. The evening bat (*Nycticeius humeralis*) utilizes the area not only for feeding, but also for roosting and nursery sites; hollow trees are preferred for these purposes (Davis 1974). Two other species using the floodplain for food and/or shelter are the red bat (Lasiurus borealis) and Georgia bat (Pipistrellus subflavus) (Davis 1974).

Several species of rodents, an important food source for birds of prey and larger mammals, are a part of this community. These include the white-footed mouse (Peromyscus leucopus) and Florida wood rat (Neotoma floridana) among others (USDOE 1978).

Birds. The many species of ducks, although primarily associated with water, are nonetheless included in the floodplain community because their nesting is terrestrial (mainly in Canada). The common mallard (Anas platyrhynchos platyrhynchos) is a common winter immigrant to the floodplain area of Matagorda (Oberholser et al. 1974). Mallards have shown considerable ability to survive man's encroachment on their preferred freshwater pond and swamp habitat. Other activities of humans, however, may be more detrimental to their survival. Mallards and many other ducks residing primarily along the coast have the unfortunate tendency to take in spent lead shot pellets, perceiving them either as seeds or grit to aid the grinding of food in their gizzards (Oberholser et al. 1974). If too much shot is ingested, lead poisoning results and kills the duck. Investigations by TPWD (1974b) showed that on a statewide basis ducks in the coastal area of Texas had the highest levels of ingested lead.[1] Preliminary results did not show any ducks to be overtly in poor health; that is, they did not suffer from loss of body fat or any emaciated condition. However, the long-term effects of this ingestion are unknown. The use of steel shot is now required by Federal law in many coastal areas of Texas.

Other common wintering ducks in the floodplain and swamp are the ring-necked duck (Aythya collaris) and common red-breasted merganser (Mergus serrator serrator). Another dabbling duck, the wood duck (Aix sponsa), is essentially a resident. Its nesting habits are different from other dabblers due to its consistent selection of tree cavities in which to lay its eggs. Nests may be as high as 15 m, and when ducklings are ready to enter the water, they simply jump out and join their mother on the ground (Oberholser et al. 1974).

Several species of geese, including the white-fronted goose and snow goose, frequent rice fields within the Matagorda-Brazos system (Flickinger and King 1972). There has been considerable problem with geese being poisoned by eating stubbles of rice seeds treated with aldrin-dieldrin. Brains of geese as well as numerous species of ducks (e.g., see Section 5.6.4) dying from aldrin-dieldrin poisoning were found to average 10 ppm of the toxin (Flickinger and King 1972).

Herons and egrets, such as the great blue heron (Ardea herodias), little blue heron (Florida caerulea), American egret (Casmerodius albus egretta), and northern Louisiana heron (Hydranassa tricolor ruficollis), are equally adapted to this community as well as the salt and brackish marsh communities. Their

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[1] Ingestion was considered to have occurred if pellets in the gizzards had undergone erosion.

feeding habits are flexible to accommodate their movements between salt and freshwater. Food items include fish, shrimp, frogs, and a wide variety of insects (Oberholser et al. 1974).

The anhinga (*Anhinga anhinga*) is more closely bound to freshwater than are the herons and egrets. It may be observed in brackish or salt water during the winter or in migration, but wooded swamps are its preferred habitat.

The floodplain provides suitable habitat for several birds of prey. The most popular of these is the southern bald eagle (see Section 5.6.2). Others include the sharp-shinned hawk (*Accipiter striatus*), Cooper's hawk (*A. cooperi*), red-tailed hawk (*Buteo jamaicensis*), red-shouldered hawk (*B. lineatus*), broad-winged hawk (*B. platypterus*), barn owl (*Tyto alba*), great horned owl (*Bubo virginanus*), and barred owl (*Strix varia*).

The USDOE (1978) lists 67 species of birds in the Brazos floodplain, including many seed- and insect-eating species not listed here.

Reptiles and amphibians. Common lizards in the floodplain include green anole (*Anolis carolinensis carolinensis*), which spends much time in trees, shrubs, or vines; five-lined skink (*Eumeces fasciatus*), which may be found either in trees or in damp habitats such as under rotting logs; spotted whiptail (*Cnemidophorus gularis gularis*), and six-lined racerunner, both adaptable to a variety of habitats ranging from rocky hillsides to floodplains (Conant 1975; USDOE 1978).

Many species of snakes are a part of this community. At least four species of water snakes (*Nerodia spp.*) occur here as well as several other nonvenomous snakes, for example the Texas rat snake (*Elaphe obsoleta lindheimeri*), western mud snake (*Farancia abacura reinwardti*), Louisiana milk snake, and speckled kingsnake (*Lampropeltis getulus holbrooki*) (Conant 1975; USDOE 1978). Food habits vary strikingly from one species to the next, another indication of the diversity of the floodplain community.

Venomous snakes are also present in the floodplain community. Swamps are a preferred habitat of the western cottonmouth (*Agkistrodon piscivorus leucostoma*), but other species like the western pygmy rattlesnake (*Sistrurus miliarius streckeri*), canebrake rattlesnake (*Crotalus horridus atricaudatus*), southern copperhead (*Agkistrodon contortrix contortrix*) (Conant 1975) and Texas coral snake (*Micrurus fulvius tenere*) (Wright and Wright 1957) are not uncommon in the area.

The floodplain provides a favored habitat for the endangered American alligator. For further discussion of this species, see Section 5.6.4. Because the more common turtles in this community spend most of their time in the river, they are discussed in Section 5.3.2.

The physical character of the floodplain and swamp makes it an ideal habitat for amphibians. Permanent bodies of freshwater, abundant vegetation for protective cover, and a plentiful food supply enhance population diversity. Table 3 presents a listing of the major species of amphibians in the floodplain.

Table 3. Representative amphibian species present in the floodplain of the Matagorda-Brazos study area (Conant 1975; USDOE 1978).

Scientific name	Common name
Notophthalmus viridescens louisianensis	Central newt
Gastrophryne carolinensis	Eastern narrow-mouthed toad
Bufo woodhousei woodhousei	Woodhouse's toad
B. woodhousei fowleri	Fowler's toad
Hyla cinerea	Green treefrog
H. squirella	Squirrel treefrog
H. versicolor	Gray treefrog
H. chrysoscelis	Gray treefrog
Pseudacris streckeri streckeri	Strecker's chorus frog
P. triseriata feriarum	Upland chorus frog
Acris crepitans blanchardi	Blanchard's cricket frog
Rana utricularia	Southern leopard frog
R. areolata areolata	Southern crawfish frog
R. catesbeiana	Bullfrog

5.5 UPLAND COMMUNITY

The term upland in this study is used for areas not subject to flooding by astronomical tides, wind-induced tides, or riverine flooding. The uplands constitute the largest area within the Matagorda-Brazos study area and extend beyond the inland limit (64 km) of this study.

5.5.1 Vegetation

The upland community in undisturbed areas supports a grass-dominated flora of which bluestem, Indiangrass, panic grass, and muhly (*Muhlenbergia* sp.) are representative. Scattered throughout the landscape are clumps of mesquite, hackberry, huisache (*Acacia farnesiana*) and various species of cacti (McGowen et al. 1976a, 1976b). Much of the grassland (approximately 2,385 km^2) has been converted to agriculture. Rice and cotton fields, orchards, and silage crops for cattle are the principal uses (McGowen et al. 1976a). The majority of the remaining upland (approximately 4,180 km^2) is utilized as range-pasture (McGowen et al. 1976a, 1976b).

Oak mottes do not occur in the eastern two-thirds of the Matagorda-Brazos system and are an uncommon feature in the western third. Their most concentrated occurrence is in Jackson County along well-drained sections of the Lavaca and Navidad Rivers (McGowen et al. 1976a, 1976b). Live oak dominates these mottes, forming a thick canopy which effectively reduces the understory.

A third habitat, limited in the study area to locales in the immediate vicinity of the Lavaca and Navidad Rivers, is the fluvial grassland. The dominant grasses are bluestem and coastal sacahuista; primary brush vegetation includes huisache, catclaw (*Acacia greggii*), and mesquite (McGowen et al. 1976b). A large portion of this habitat is grazed, and it can be expected that the grass will gradually diminish, giving way to shrubby vegetation.

Inland freshwater marshes also occur occasionally in the landscape of the upland grasslands. This vegetation is typical of that of coastal freshwater marshes; cattails, rush, bulrush, and sloughgrass (*Spartina pectinata*) are common (McGowen et al. 1976a, 1976b).

5.5.2 Fauna

Mammals. Rodents are the most abundant mammals in the uplands. Only in agricultural lands does their presence present any problem. The northern rice rat, for example, becomes prevalent in rice fields. Because of its prolific nature, it can seriously damage rice crops (Davis 1974). Table 4 lists the most common rodents in the uplands.

Other small mammals are the eastern cottontail, opossum, nine-banded armadillo, least shrew (*Cryptotis parva*), striped skunk (*Mephitis mephitis*), eastern spotted skunk (*Spilogale putorius*), and raccoon. The skunk, raccoon, and opossum are of some economic value for fur harvest. While opossum or striped skunk pelt brings, on the average, less than $2, the raccoon brings $16 per pelt (TPWD 1979c).

Table 4. Representative rodent species in the upland community of the Matagorda-Brazos study area (Davis 1974).

Scientific name	Common name
Spermophilus tridecemlineatus	Thirteen-lined ground squirrel
Geomys bursarius	Plains pocket gopher
Perognathus hispidus	Hispid pocket mouse
Reithrodontomys fulvescens	Fulvous harvest mouse
R. humulis	Dwarf harvest mouse
Baiomys taylori	Pygmy mouse
Peromyscus leucopus	White-footed mouse
Sigmodon hispidus	Hispid cotton rat
Oryzomys palustris	Northern rice rat
Neotoma floridana	Florida wood rat

Larger fur-producing mammals of the uplands are the coyote (*Canis latrans*), gray fox, and bobcat (Davis 1974; TPWD 1979c). A further note on the bobcat along the Texas coastline is in order. Bobcats are under review by USFWS (National Fish and Wildlife Laboratory 1980) for endangered species status. This review is based primarily on low populations in the Northeastern and Northwestern United States (TPWD 1979a). In the South, numbers of bobcat appear to be increasing, and fur-harvesting in this region of the Nation is big business. No county data on abundance or economic value of furbearers are available.

Big-game hunting in the Matagorda-Brazos area focuses on the white-tailed deer. Counties under consideration are those within, or overlapping into, the study area: Wharton, Calhoun, Jackson, Victoria, Brazoria, Fort Bend, and Matagorda. Based on the average number of hunters per-unit area during the 5 years from 1973 through 1977, Brazoria County has the greatest hunting pressure (80 hunters per 1,000 ha), followed by Victoria and Fort Bend Counties. Lowest pressure is recorded for Calhoun County, with a mean value of 20 hunters per 1,000 ha (TPWD 1978d). Hunting pressure appears to be increasing in Wharton and Fort Bend Counties and declining in Calhoun and Victoria.

Average yearly harvest of antlered and antlerless deer is highest in Victoria County (1,893) and lowest in Calhoun County (381). For the study area as a whole, an average of 7,161 deer was harvested annually during the 5-yr period, 1973 through 1977. The yearly harvest, however, has been steadily decreasing from 8,041 deer bagged in 1973 to 5,961 in 1977. On a county basis, the harvest either decreased during the sampling period or showed no definite trend. Only in Calhoun County did the harvest show an upward trend (TPWD 1978d). No explanation for the decreased harvest in these counties has been offered, but loss of habitat is a likely factor.

Two exotic ungulates, the axis deer (*Axis axis*) and sambar deer (*Cervus unicolor*), have been introduced into Texas and are potential competitors for food with white-tailed deer. The native species prefers forbs and woody vegetation for forage; axis deer prefer grasses and sedges. Competition arises only when those herbaceous species are limited in their availability; shortages usually arise in winter and force the axis deer to seek out the forbs and woody vegetation preferred by the white-tailed deer. Acorns are another food item sought by both species (Smith 1971). Richardson (1972) found that sambar deer also vary their diet from woody browse in winter to grasses in the summer. Thus, competition with the native deer is likely to be a seasonal phenomenon.

Experimental plots established by TPWD (1978e), in which white-tailed and axis deer co-exist, have shown the exotic species to have a much higher survival rate at the expense of the native deer. Axis deer are quite flexible in their feeding habits; and while they tend to prefer grasses, they can subsist and reproduce viable young on all three classes of forage (grass, forbs, browse). White-tailed deer are more rigid in their feeding behavior and their populations suffer when preferred foods are not available.

Birds. The mourning dove (Zenaida macroura) is considered the most important game bird in Texas. Populations are not estimated on a habitat or county basis, so no statement can be made about their numbers in the Matagorda-Brazos system; but, in the ecological region in which the study area is located, trends in populations for the 12 years from 1966 through 1978 show a general decline in numbers (TPWD 1979f).

Other game birds include bobwhite (Colinus virginianus), sandhill crane, and ring-necked pheasant (Phasianus colchicus). The sandhill crane has been considered a game bird in Texas since 1961. The ring-necked pheasant prefers little-tended grainfields, fallow fields, windbreaks, and edges of freshwater marshes. This species has maintained its numbers since its introduction to Texas from Asia in the early 1900's. Decades of good health are usually followed by as long a declining period (Oberholser et al. 1974).

Egrets are common in the upland community. For a discussion of representative species, see Section 5.4.2. The upland plover (Bartramia longicauda), common to this community, is less attracted to water than its other sandpiper relatives. Agriculturally detrimental insects such as grasshoppers, beetles, and weevils consitute its primary diet. Present populations are stable, but at the turn of the century the species was almost decimated by unlimited hunting (Oberholser et al. 1974). For a more complete discussion of the birdlife, especially songbirds in the upland community, the reader is referred to Oberholser et al. (1974).

Reptiles and amphibians. Common lizards in the moister areas of the upland community are likely to be the same species typical of the floodplain community. In drier sections, the Texas horned lizard (also see Laguna Madre synthesis), Texas spiny lizard (Sceloporus olivaceus), and six-lined racerunner are representative species (Conant 1975).

Snakes common to the floodplain are also typical of the wetter areas of the upland community. In drier areas the eastern yellow-bellied racer (Coluber constrictor flaviventris), prairie kingsnake (Lampropeltis calligaster calligaster), western coachwhip, western massasauga (Sistrurus catenatus tergeminus), and western diamondback rattlesnake are commonly found (Conant 1975). These species are flexible in their diet, eating frogs, lizards, young birds, and (most important to farmers) rodents (Wright and Wright 1957; Conant 1975).

Two species of terrestrial turtles are common in the uplands of this study area: the ornate box turtle (*Terrapene ornata ornata*) and the three-toed box turtle (*T. carolina triunguis*). Both species can survive extended periods without water, presumably deriving considerable amounts from their food sources. Following periods of deprivation, they consume large amounts of water. Carr (1952) relates an experiment performed on a captive (from Colorado) three-toed box turtle, in which it received no water for 2 weeks. Upon receiving approximately 250 grams of water, the turtle began drinking steadily and did not stop for 1 hour. During the second half hour a stream of water was emitted from the cloaca, but the turtle continued to drink until all the water was consumed.

Turtles common to the coastal freshwater marshes are found in ponds, marshes, and boggy areas within the upland. For a discussion of those species see Section 5.1.2.

All the amphibians listed in Table 3 are likely to be found in the wetter areas of the upland community (e.g., around freshwater ponds and marshes). Additional species better adapted to less moist habitats include Hurter's spadefoot toad (*Scaphiopus holbrooki hurteri*), Great Plains narrow-mouthed toad (*Gastrophryne olivacea*), and spotted chorus frog (*Pseudacris clarki*), according to Conant (1975).

5.6 RARE AND ENDANGERED VERTEBRATES AND INVERTEBRATES OF THE MATAGORDA-BRAZOS STUDY AREA[2]

5.6.1 *Mammals*

Canis rufus - red wolf. Hall and Kelson (1959) include the Matagorda-Brazos area as part of the red wolf's former range. Currently, no red wolves are believed to occur in this area (National Fish and Wildlife Laboratory 1980), although the floodplain of the Brazos River contains suitable habitat (refer to the Galveston synthesis for a more complete discussion). TOES = E, TPWD = E, USFWS = E.

Ursus americanus - black bear. The black bear is believed to be extirpated from the area (Davis 1974). Suitable habitat is located along the extensive floodplain of the present Brazos and former Colorado Rivers. According to Hall and Kelson (1959), a record of *U. a. luteolus* exists. The specimen was taken from Wharton County. TOES = E.

Felis yagouaroundi cacomitli - jaguarundi. While the jaguarundi is generally regarded as presently being restricted to the lower Texas coast and Rio Grande Valley (Hall and Kelson 1959; Davis 1974; National Fish and Wildlife

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[2] The status for each rare and endangered species is listed for three agencies: Texas Organization for Endangered Species (TOES), Texas Parks and Wildlife Department (TPWD), and the U.S. Fish and Wildlife Service (USFWS). Status designations include Endangered (E), Threatened (T), and except for the USFWS, Peripheral (P). Additional designations of Status Undetermined (SU) and Not Considered (NC) are from Gustavson et al. (1978).

Laboratory 1980), three sightings of the same individual have recently been reported from Brazoria County along the San Bernard River (TPWD 1979d). TOES = P, TPWD = NC.

Lutra canadensis texensis - river otter. The river otter, classified as threatened by TOES, is considered indigenous to the area by Hall and Kelson (1959) and Davis (1974). The Texas Parks and Wildlife Department (1979e) did not survey the Matagorda-Brazos area. Trapping records (see Galveston synthesis) indicate that there is no short-term decline in the Texas population.

Lynx rufus texensis - bobcat. The bobcat is under review by the USFWS; however, TPWD (1977) concludes that the species is fairly abundant and populations are stable (see San Antonio synthesis).

5.6.2 Birds

Haliaeetus leucocephalus leucocephalus - southern bald eagle. The floodplain of the Brazos River represents one of two bald eagle nesting concentrations in Texas. The other area is along the San Antonio-Guadalupe floodplain in the San Antonio study area (TPWD 1979b). Of the seven active nests in Texas during 1977 and 1978, three are located in the Matagorda-Brazos study area. In 1977 these nests produced five juveniles and in 1978 six juveniles out of a statewide total of ten and nine respectively (TPWD 1979b). There apparently has been a slight increase in both the number of nests and nesting activity during this decade in both the Matagorda-Brazos and San Antonio study areas (TPWD 1979b). The bald eagle in this area nests in tall trees and feeds primarily on fish, rabbits, and other small birds (Oberholser et al. 1974). The demise of our Nation's national symbol is attributed primarily to lowered reproductive success due to the accumulation of pesticides obtained through the ingestion of fish. The destruction of habitat (land-clearing practices), illegal shooting, and nest disturbance also have been contributing factors (Oberholser et al. 1974; National Fish and Wildlife Laboratory 1980). Also see San Antonio synthesis. TOES = E, TPWD = E, USFWS = E.

Pandion haliaetus carolinensis - osprey or fish hawk. The osprey is a migrant with peak concentrations passing through Texas in April and October (TPWD 1976). A few will occasionally winter in Texas, but no reports of recent nestings (1971 through 1976) have been made (TPWD 1979b). Band recoveries in Texas indicate some birds come from California, New York, and Wisconsin (TPWD 1976). One hundred six sightings of transients were made during the period 1971 through 1976 in counties within and overlapping the Matagorda-Brazos study area (TPWD 1976). In comparison, a total of 1,324 sightings occurred statewide during the 5-year period. It is not known how many are repeat sightings. Pesticides ingested via fish are generally blamed for the decline of this species. TOES = E, TPWD = NC, USFWS = SU.

Falco peregrinus tundrius - Arctic peregrine falcon. This species is a winter migrant throughout the Texas Barrier Islands Region. Surveys conducted by TPWD (1978a) from 1973 through 1976 indicate that wintering and migrant populations increase slightly in a downcoast direction (i.e., more sightings on Padre Island than Matagorda Island or High Island). The Texas Parks and Wildlife Department (1978a) provides a list of prey items of these falcons along the Texas coast. Other birds are their chief food item; the cattle egret (Bubulcus ibis) and mourning dove were the highest frequency prey items observed. Ingested pesticides and (locally) the illegal trapping of these falcons are generally given as reasons for their apparent decline (Oberholser et al. 1974). Also see Galveston, Laguna Madre, and San Antonio syntheses. TOES = E, TPWD = E, USFWS = E.

Pelecanus occidentalis carolinensis - brown pelican. There are presently no nesting brown pelicans in the Matagorda-Brazos study area (Blacklock et al. 1978). Historically, colonies have been located at Dressing Point Island in East Matagorda Bay, Coon Island in Tres Palacios Bay, and Pelican and Sundown Islands in Matagorda Bay (TPWD 1978b). The last known nesting colony in this study was at Sundown Island in 1974 (TPWD 1978b). See Corpus Christi, Copano-Aransas and San Antonio syntheses for current nesting sites. TOES = E, TPWD = E, USFWS = E.

Tympanuchus cupido attwateri - Attwater's greater prairie chicken. Prairie chickens still occur in the northern part of the Matagorda-Brazos system where Austin, Colorado, Wharton, and Fort Bend Counties border one another (National Fish and Wildlife Laboratory 1980). Local populations appear stable over the past 15 years. The Attwater's Prairie Chicken National Wildlife Refuge in Colorado County consists of 3,200 ha of prime habitat. Former abundance over its entire range is believed to have approached 1,000,000 individuals, decreasing to approximately 8,700 in 1937 (Lehmann 1941, cited by National Fish and Wildlife Laboratory 1980), to 1,335 in 1963 (Lehmann and Mauermann 1963, cited by National Fish and Wildlife Laboratory 1980). The population is presently estimated at 1,500, the decline attributable to the conversion of its natural tall-grass prairie habitat to agriculture and to large-scale hunting, legal until 1937 (National Fish and Wildlife Laboratory 1980). TOES = E, TPWD = E, USFWS = E.

Dendrocygna bicolor - fulvous tree duck or fulvous whistling duck. Populations of the fulvous tree duck began to fall rapidly with the 1960 advent of pesticides such as aldrin used to control rice water weevil larvae (Flickinger and King 1972). Although other birds were affected, the fulvous tree duck especially was impacted because of its strong preference for rice fields during nesting, coupled with its high susceptibility to aldrin poisoning. Poisoning can occur directly through ingestion of the treated rice seed or indirectly through a contaminated prey organism in the food web. Aldrin is also suspected of affecting reproduction rates of surviving adults (Flickinger and King 1972). From the late 1940's to mid 1950's Audubon Christmas counts sometimes showed national high counts in areas of Texas, but following the introduction of aldrin, dieldrin, etc., into rice fields of coastal Texas, numbers dropped sharply and remained low. The present distribution along the Texas coast is essentially limited to the area south of Corpus Christi (Oberholser et al. 1974). TOES = E, TPWD = NC, USFWS = NC.

Campephilus principalis - ivory-billed woodpecker. The ivory-billed woodpecker has been on the verge of extinction for some time and may presently be extinct. While its Texas distribution was generally associated with the Big Thicket area of Texas, J. J. Audubon noted many sightings in the hardwood forests of Fort Bend County on the floodplain of the Brazos River (Oberholser et al. 1974). The last confirmed Texas specimen was obtained in 1904 (Oberholser et al. 1974).

5.6.3 Amphibians

Bufo houstonensis - Houston toad. The entire known range of this species is located within seven Texas counties (National Fish and Wildlife Laboratory 1980). No specimens are known from within the Matagorda-Brazos study area, although one sighting near Fresno is geographically near the border of the study area, and several other records are from within the drainage basin of the Brazos and Colorado Rivers (National Fish and Wildlife Laboratory 1980). The Houston toad requires sandy soils supporting heavily vegetated woods interspersed with open grassy areas. Intermittent ponds are preferred breeding sites (National Fish and Wildlife Laboratory 1980). Population estimates range from 300 to 1,500 individuals, with this number remaining constant during the past decade (National Fish and Wildlife Laboratory 1980). Loss of habitat (due to alterations of floodplain), hybridization with B. valliceps and B. woodhousei woodhousei, and natural inability for adaptation are the primary reasons for the historical decline (National Fish and Wildlife Laboratory 1980). TOES = E, TPWD = E, USFWS = E.

5.6.4 Reptiles

Alligator mississippiensis - American alligator. Joanen (1974, cited by National Fish and Wildlife Laboratory 1980) reported alligators were present in all the counties within the Matagorda-Brazos study area. This same report concludes that local populations are relatively large and increasing. Data (Table 5) gathered by TPWD (1975) support Joanen's (1974) findings. TOES = E, TPWD = E, USFWS = E.

Table 5. Estimated alligator populations for counties in the Matagorda-Brazos study area, 1974. Totals for counties include areas overlapping into other study areas. The total estimated population is 7,034 or approximately 19% of the estimated statewide populations (TPWD 1975).

County	Population	Trend estimate
Brazoria	5,000	Increasing
Calhoun	317	Stable
Fort Bend	400	Stable
Jackson	200	Increasing
Matagorda	725	Increasing
Victoria	217	Increasing
Wharton	175	Decreasing

Opheodrys vernalis - western smooth green snake. The Texas Organization of Endangered Species (cited by Gustavson et al. 1978) lists the western smooth green snake as threatened, but neither TPWD or USFWS have this species under consideration. Primarily found in the Upper Plains States and in grassy meadow areas of the Rocky Mountain States (Conant 1975), the disjunct Texas population is confined to a seven-county area including parts of Matagorda-Brazos and Galveston study areas (Raun and Gehlbach 1972; Conant 1975). The primary reason for concern is the threat that agricultural practices pose in destroying its natural habitat of moist grasslands (Conant 1975; Gustavson et al. 1978).

Threatened and endangered turtles. The Texas diamondback terrapin is listed by TOES as threatened and is known to occur in the area. A more complete discussion is included in the Galveston synthesis. For endangered sea turtles see the Laguna Madre and Marine syntheses.

5.6.5 Fish

There are no reported findings of any of the threatened or endangered species listed, proposed, or under review by the USFWS (1978; Deacon et al. 1979).

5.6.6 Invertebrates

It was concluded that none of the threatened or endangered species listed, proposed, or under review by the USFWS (1978) are indigenous to the Texas coast after review of the following sources: Freeman (1969), Scott (1974), Strenth (1974), Federal Register (1975, 1976), and Cole (1976).

5.7 RARE AND ENDANGERED PLANTS OF THE MATAGORDA-BRAZOS STUDY AREA

According to a compilation of sources by Gustavson et al. (1978), there are no rare plants which are indigenous only in the immediate and nearby areas. A supplemental list (USFWS 1979) supports the earlier work (USFWS 1978). Two species of holly are listed by Gustavson et al. (1978) as rare and endangered in the area: dahoon holly (*Ilex cassine*) which is recorded from Brazoria County, although Vines (1960) feels the record is probably erroneous, and myrtle holly (*I. myrtifolia*), also from Brazoria County. Corkwood (*Leitneria floridana*) is a threatened species found in the floodplain of the lower Brazos River near Lake Jackson (Gustavson et al. 1978). Vines (1960) also includes High Island and the Port Arthur vicinity in southeast Texas as part of its Texas distribution.

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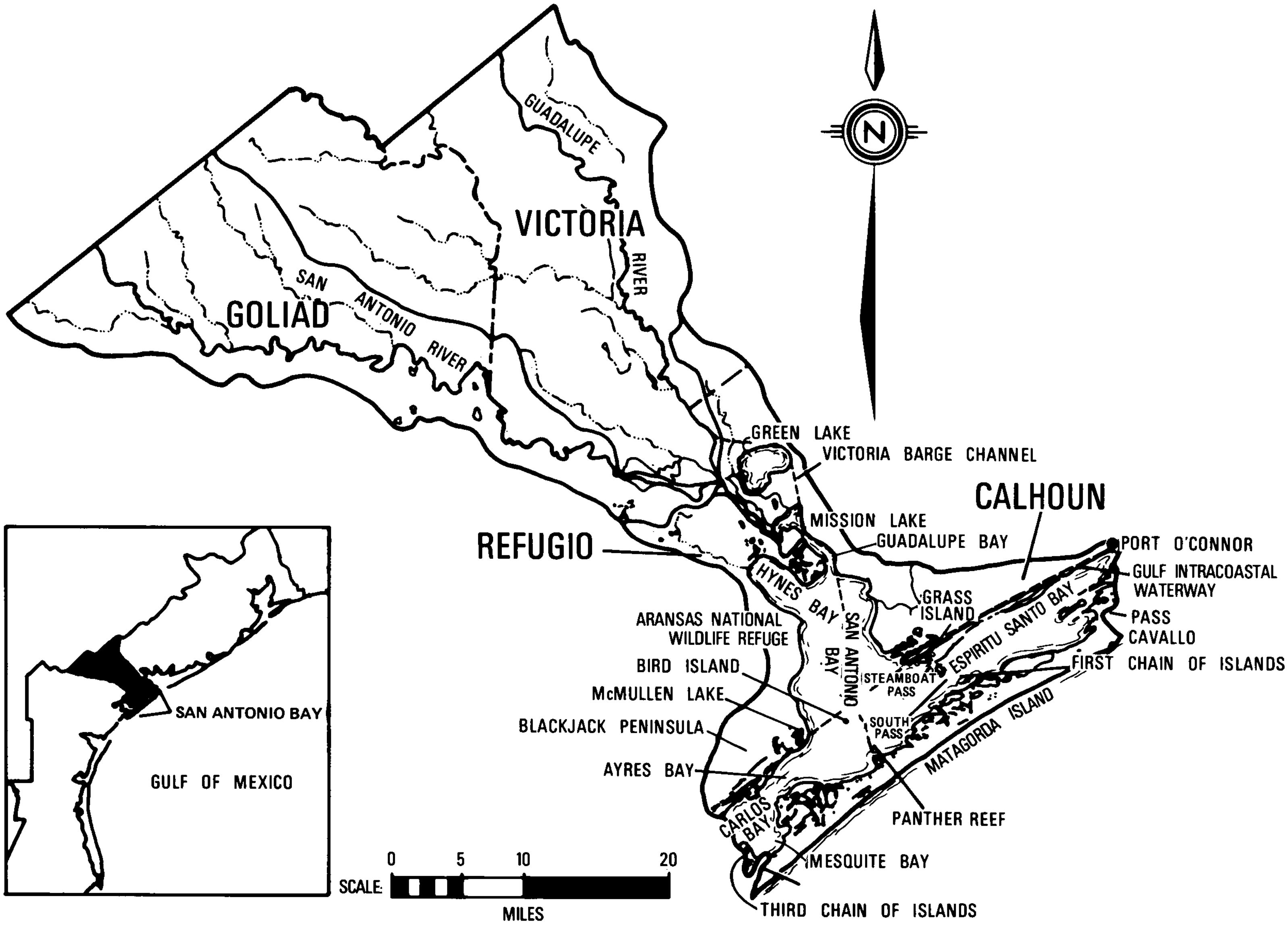
SAN ANTONIO BAY STUDY AREA SYNTHESIS



Map 4. San Antonio Bay study area.

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1.0 INTRODUCTION

In contrast to several other coastal areas of Texas, the San Antonio Bay system remains in a relatively natural state. Human populations are small, and human exploitation of terrestrial and aquatic communities is less intense than in other areas. The sewage inflow from communities bordering the bay is relatively high due to inadequate sewage treatment, but eutrophication in the rivers and bays has not been documented. The loss of natural grassland habitats to agriculture contributes to the nutrient load of the aquatic communities to an undetermined degree. Annual freshwater inflow, at present averaging 2.0 x 10^9 to 3.0 x 10^9 m^3 (1.6 x 10^6 to 2.4 x 10^6 acre feet), adequately maintains finfish and shellfish nursery grounds in bay areas (Childress et al. 1975). As in other Texas coastal areas, these economically important organisms and forage species are affected by diversion of freshwater for agricultural purposes.

Dredging operations associated with shell extraction and maintenance of navigational channels pose a threat to grassbeds and oysters. Because of management, silt from dredging rarely inundates these resources. Instead, silt causes more subtle changes such as increased turbidity which decreases light penetration and photosynthesis, factors that, along with intrusion of salinity, influence the food web in bay systems.

The isolation and modest human use of the San Antonio Bay study area have altered it less than any of the six hydrologic systems of the Texas coast. Significant changes in agricultural irrigation, human population distribution, and alteration of riverine or estuarine areas will all threaten the natural condition of the San Antonio Bay study area.

2.0 GEOLOGY

2.1 GEOLOGIC ORIGIN AND PROCESSES - ESTUARINE AND RIVERINE TRANSPORT OF SEDIMENT

Similar to other study areas within the Texas Barrier Islands Region, riverine processes from the Pleistocene to the present are responsible for surface deposits over much of the San Antonio Bay study area.

The confluence of the Guadalupe and San Antonio Rivers presently is just west of Green Lake, but during late Pleistocene interglacial periods the two rivers were independent (McGowen et al. 1976). The prairie west of Lavaca Bay was formed largely by an older course of the Guadalupe River, and the prairie west of the present San Antonio-Guadalupe floodplain comprises mainly sediments deposited by the San Antonio River (McGowen et al. 1976). These deltaic deposits are believed by Wilkinson et al. (1975) to be of Sangamon age.

The development of these deposits was followed by a drop in sea level and a subsequent rise. During the rise, the Ingleside barrier-strandplain formed (Wilkinson et al. 1975). This sand body is represented in the San Antonio Bay area by the Blackjack Peninsula and the area north of the Gulf Intracoastal Waterway from a point north of the Grass Island vicinity east to Matagorda Bay (the morphogenesis of the Ingleside is described in detail in the Corpus Christi Bay synthesis).

After the Ingleside formed, the sea level dropped again, and the Guadalupe and San Antonio Rivers became deeply entrenched. Data of Shepard and Moore (1960) indicate that the base of the Guadalupe River west of the town of Seadrift was approximately 22 m below present sea level and, according to McGowen et al. (1976), the coastline was approximately 80 km seaward of its present position. The much greater width of incised meanders cut into the valley walls of the floodplain indicates that the discharge of the Guadalupe and San Antonio Rivers was considerably greater during the Pleistocene than now (McGowen et al. 1976). With the last rise in sea level to its present stage, from about 18,000 to 2,800 years Before Present (B.P.) (McGowen et al. 1976), the Guadalupe and San Antonio Rivers began filling in their incised river valleys. During this period of marine transgression, four intervals of temporary stillstands occurred, the last from 10,000 to 7,500 years B.P. at a depth of approximately 9 fathoms (Frazier 1974). During this fourth stillstand, marine transgression into San Antonio Bay had begun (Shepard and Moore 1960); thus the bay was receiving estuarine, marine, and wave-eroded shoreline sediments along with the continuing input of riverine deposits.

By 2,500 years B.P., when sea level already was established at its approximate present level, Matagorda Island began developing in a manner similar to Padre and Mustang Islands and the Matagorda Peninsula (see Laguna Madre, Corpus Christi, and Matagorda-Brazos syntheses). Wilkinson (1973) provides details about the origin and development of Matagorda Island. After Matagorda Island became a continuous feature (by 1,800 years B.P.), the input of marine sediments was greatly reduced and Mesquite and Espiritu Santo Bays were formed (Wilkinson 1973). From 1,800 years B.P. to approximately 1850 A.D., Matagorda Island slowly accreted seaward, with sand supplied largely by the Brazos River and the onshore transport of offshore Pleistocene deltaic sands (McGowen and Brewton 1975). According to McGowen et al. (1976) and Morton and Pieper (1976), Matagorda Island and most of the Texas coastline along the barrier islands have been undergoing slight erosion since 1850 (for discussion of the impacts of this reversal from long-term accretion to recent erosion, see Corpus Christi synthesis).

A subaerial bay head delta has been forming in the San Antonio Bay complex since about 2,000 years B.P. (Shepard and Moore 1960) and has prograded approximately 12 m/yr (Donaldson et al. 1970, cited by McGowen et al. 1976). The combined sediment load of the Guadalupe and San Antonio Rivers is 916×10^6 kg/yr (Cook 1970, cited in Childress et al. 1975). Although the San Antonio River typically has a lower freshwater input (see Section 4.3), it contributes 55%, on the average, of the sediment input of the two rivers. Diversion projects have reduced the sediment input by only 1% (Childress et al. 1975). This is in marked contrast to the results of diversions along major rivers flowing into the Laguna Madre, Corpus Christi and Matagorda Estuaries. The present average annual input of sediment by these two rivers is approximately 1.7 times that of the Colorado River. Approximately 40 years ago, before the widescale damming of the Texas coastal plain rivers, the sediment input of the Colorado River exceeded that of the Guadalupe-San Antonio River system threefold (Shepard 1953).

Other present sources of sediment to the San Antonio estuarine complex include (1) erosion of bay shorelines; (2) flood tidal deltas (e.g., Cedar Bayou and Pass Cavallo); (3) sources internal to the estuary (e.g., reef formation and reef erosion); and (4) storm overwash deposits. There are few data to indicate the relative contribution of each source. Although riverine deposited sediment is believed to provide the bulk of the total sediment input (McGowen et al. 1976), the possible significance of other sources should not be overlooked.

Ward (1978), in a study of Matagorda Bay, used shoreline erosion data obtained largely by McGowen and Brewton (1975) and estimated the contribution of eroded bay shoreline sediments. Converting these values to a mass equivalent, Ward estimated the contribution to be two-thirds that of the Colorado River sediment input (see Section 2.1 of Matagorda synthesis). Because of reduced fetch in the prevailing direction of wind, the numerous oyster reefs in the central portions of San Antonio Bay (which partially dissipate wave energies), and the decrease in total shorelines, the contribution of eroded bay shorelines as part of the total sediment input into San Antonio Bay is probably less than in Matagorda Bay.

The contribution of sediment to the estuary from flood tidal deltas and storm washover deposits is important at the seaward margins of the estuary, and several conspicuous examples exist in the San Antonio region. The active Pass Cavallo flood delta has formed a partial barrier between the northeast end of Espiritu Santo and Matagorda Bays. Along the subaerial portions of this tidal delta, ecologically important habitats, such as emergent salt marsh and algae-coated sand flats, are forming (Wilkinson 1973). A large inactive flood tidal delta northeast of Mesquite Bay was formed by the predecessor of the currently active Cedar Bayou tidal pass. The abandoned tidal pass partially was filled in with sediment but remained low lying. Hurricanes and lesser storms frequently have breached Matagorda Island in the vicinity of the abandoned tidal pass, resulting in washover deposits overlying the inactive tidal delta (Wilkinson 1973). This deposit, partially separating Mesquite Bay from San Antonio Bay, is one of the largest washover deposits along the Texas Barrier Islands coast and contains (1) sandy ridges vegetated by woody shrubs and dune grasses, (2) emergent salt marsh, (3) algal mats, and (4) seagrasses along the edges (McGowen et al. 1976). A similar and even larger deposit, described by Andrews (1970), is located southwest of Mesquite Bay on San Jose Island along the boundary of the San Antonio study area (also see Section 2.4 of Copano-Aransas synthesis). Smaller deposits of similar origin occur along most of the bay side of Matagorda Island from the vicinity of Panther Reef to Pass Cavallo (Wilkinson 1973).

2.2 SOILS

The soils within the San Antonio Bay study area are primarily soil groups that have developed on the late Pleistocene fluvial and deltaic sediments. Soils of the Trinity and Victoria Series have developed on the fine-grained Pleistocene sediments (McGowen et al. 1976). These deposits represent the ancient interdistributary areas and mud-filled lakes and creeks. Soils of the Lake Charles and Edna Series are dominant on top of the coarser-grained Pleistocene fluvial sediments. These soil series typically are found in ancient channels. A second place where the Lake Charles and Edna soil types prevail is landward of the Ingleside formation. This area's increased sand content results from the reworking of delta front sands by marine processes and the recent contribution of sands from the Ingleside being transported by surface flow to this low-lying bordering area (McGowen et al. 1976). Soils of the Goliad, Bienville, and Miram Series have developed on similar distributary environments of younger age, including presently active floodplains (McGowen et al. 1976).

Soils of the Galveston, Mustang, Rahal, Port Alto, Roemer, and Veston Series have developed on deposits containing a very high sand content (McGowen et al. 1976). These groups are found primarily near the coast, dominating Mustang Island and the Ingleside. Small discontinuous areas of these groups appear farther inland on point bar deposits along the presently active rivers (McGowen et al. 1976).

The third largest type is the soil groups which have developed on wetland surfaces. The fresh marsh and swamps soils, mostly located farther inland, generally comprise finer-grained sediments and contain a higher percentage of organics than the brackish and saline marshes. The flooding regime is another factor affecting soil formation.

Other areas in the San Antonio region include the young, highly variable, and undifferentiated soils developing on spoil deposits and landfill areas, and areas where soil development is generally absent, such as on actively migrating dunes along segments of Matagorda Island.

2.3 TOPOGRAPHIC AND BATHYMETRIC FEATURES

Perhaps the most conspicuous aspect of topographic relief in the San Antonio Bay study area is the absence of relief, consistent with the entire coastal plain within the Texas Barrier Islands Region. Maximum elevations at the inland boundary of the San Antonio Bay study area are approximately 30 m, resulting in a slope to the Gulf of Mexico of about 0.5 m/km. The greatest topographic relief occurs along the incised valleys of the Guadalupe and San Antonio Rivers where the bluff rises 20 m above the present floodplain (McGowen et al. 1976), and along the beach where well-developed dunes rise 3.0-4.5 m, and occasionally reach a 9-m elevation (Wilkinson 1973).

Water bodies in this study area are typically shallow with the most bathymetric relief occurring at tidal passes and oyster reefs. Espiritu Santo and San Antonio Bays are the deepest water bodies in the San Antonio region, averaging 1.8 and 1.4 m respectively (Diener 1975). Guadalupe and Hynes Bays are somewhat shallower, averaging 0.7 m in depth (Diener 1975). The decreased depth in these bays is attributed to shoaling resulting from the progradation of the Guadalupe-San Antonio River Delta. The Mesquite and Ayers Bay complex averages 1.0 m in depth (Diener 1975) and is somewhat shallower than the neighboring San Antonio Bay due to sediment deposits associated with flood tidal deltas and storm washover deposits.

2.4 UNIQUE OR UNUSUAL STRUCTURES

Washover deposit features are common to barrier islands, but the washover deposit northeast of Mesquite Bay is unusually large. Its extensive development is related to the presence of underlying flood tidal delta deposits which provided a base for its development. An even larger washover feature of similar developmental history is located southwest of Mesquite Bay on San Jose Island (see Section 2.4 of Copano-Aransas synthesis).

The Modern Guadalupe-San Antonio River Delta is one of the most extensive bay head deltas along the Texas coast. Virtually all sediment carried by the Guadalupe and San Antonio Rivers reaches the lower floodplain and the delta (Childress et al. 1975), accounting for the delta's relatively large size compared to those of other river deltas entering Texas bays. These active deltas would receive much greater amounts of sediment if numerous dams and other diversions were not present upstream.

The Ingleside barrier-strandplain supports a diverse array of wetland and upland habitats (see Section 2.4 of Corpus Christi synthesis). Much of the Aransas National Wildlife Refuge, located on Blackjack Peninsula which overlaps the San Antonio and Copano-Aransas study areas, is on this formation. Wilkinson (1973) and McGowen et al. (1976) refer to this area as probably the most pristine Texas barrier island environment. The area's near-pristine nature can be attributed to its isolation and the relatively low human population density on neighboring uplands.

2.5 MAN-MADE DEVELOPMENTS

Compared to several estuaries in the Texas Barrier Islands Region, the San Antonio Bay region has received lesser impacts. This situation is attributed by Childress et al. (1975) to the relatively sparse human population with associated limited industrial development. The impacts of man are similar to those throughout the Texas Barrier Islands Region.

Oyster reef development in the San Antonio Bay complex is extensive. Diener (1975) estimated that there are over 2,900 ha of active oyster reefs in San Antonio and Espiritu Santo Bays. McGowen et al. (1976) reported that approximately 6,500 ha of active reefs, plus shell-containing reef flanks, cover the bay bottoms in the area. The shell dredging industry has made extensive use of this resource, removing over 38×10^6 m^3 of shell from 1959 to 1974 (Burg 1974). Much shell is removed in the form of inactive deposits which subsequently have been buried; consequently, a considerable amount of overburden must be removed and returned to the bay as slurry. The dredging process results in high turbidities (Burg 1974). Burg (1973, 1974) and Clements (1975) reported oyster mortality resulting from the resettling of suspended sediments. High turbidities can also result in reduced productivity or even destruction of seagrass beds (e.g., Odum 1963); this is a potential threat to the abundant seagrass beds of San Antonio Bay. To indicate the extent of the problem of the re-introduction and settling of sediment, the data of Burg (1974) are used. From 1959 to 1974, an estimated total of 504×10^9 kg of nonshell material was returned to the bay. To place this amount in perspective, the annual average for the 15 years is 336×10^8 kg/yr or 37 times the combined average annual sediment input of the Guadalupe and San Antonio Rivers (Burg 1974). Benefield (1976) studied effects of siltation on oyster reefs from shell dredging activities in San Antonio and Galveston Bays. He found the distance of a dredge from an oyster reef was not as important as other factors such as reef contour, sediment composition, and current direction. Reefs are near as 91 m (300 ft) from a dredge received no sedimentation, while some over 1,800 m (5,900 ft) away received substantial sedimentation (also see Section 5.1).

Land use practices for agriculture, including crops and rangeland, have altered natural habitats in the San Antonio Bay area. Little natural prairie remains, and agriculture has increased erosion, adding sediment to the system (McGowen et al. 1976).

The San Antonio Bay complex contains several dredged waterways. Spoil deposits from the Gulf Intracoastal Waterway and the Victoria Channel have covered several formerly active oyster reefs, and the reworking of spoil by currents has resulted in siltation on nearby reefs and seagrass beds (McGowen et al. 1976). The contribution of reworked spoil sediments to the estuarine sediment budget often exceeds all other sources combined in the shallow bays of the Texas coast (McGowen et al. 1976).

3.0 CLIMATE

3.1 PRECIPITATION

Mean annual precipitation in the subhumid San Antonio Bay area is approximately 935 mm (NOAA 1973a). Precipitation decreases slightly as one moves inland, and Victoria receives a mean annual precipitation of 870 mm. Rainfall is more abundant than in the Copano Aransas study area to the southwest, and less abundant than in the Matagorda-Brazos study area to the northeast.

The seasonal distribution of rainfall over the area is bimodal (Figure 1). The weather regimes responsible for the maxima in precipitation and the differences in the magnitude of the maxima are explained in the Corpus Christi Bay and Matagorda-Brazos syntheses.

3.2 TEMPERATURE

Mean annual air temperature for 1941 through 1970 was 21.5° and 21.2° C at Austwell Refuge and Victoria, respectively (NOAA 1973a). Seasonally, the inland station of Victoria was cooler in winter and warmer in summer by approximately 0.8° C than the 50-km distant Austwell Refuge. This coastal versus inland seasonal difference in mean temperature is evident throughout the Texas Barrier Island Region and is common globally. The difference in the winter is reflected in the length of the growing season. A freeze-free period of 310 consecutive days usually occurs in the San Antonio Bay area, decreasing to 290 days in the Victoria area (Orton 1964).

Orton (1969), using the noncontinuous method, calculated moisture surpluses and deficits in Texas. This climatic water budget approach combines rainfall and temperature (or measured evaporation data) and provides a representation of the demand for water by the natural environment. The San Antonio Bay area averages a net deficit (surpluses minus deficits) of 225 mm along the coastal area bordering the Matagorda-Brazos study area. The net deficit increases to the southwest (downcoast) and to the west inland to approximately

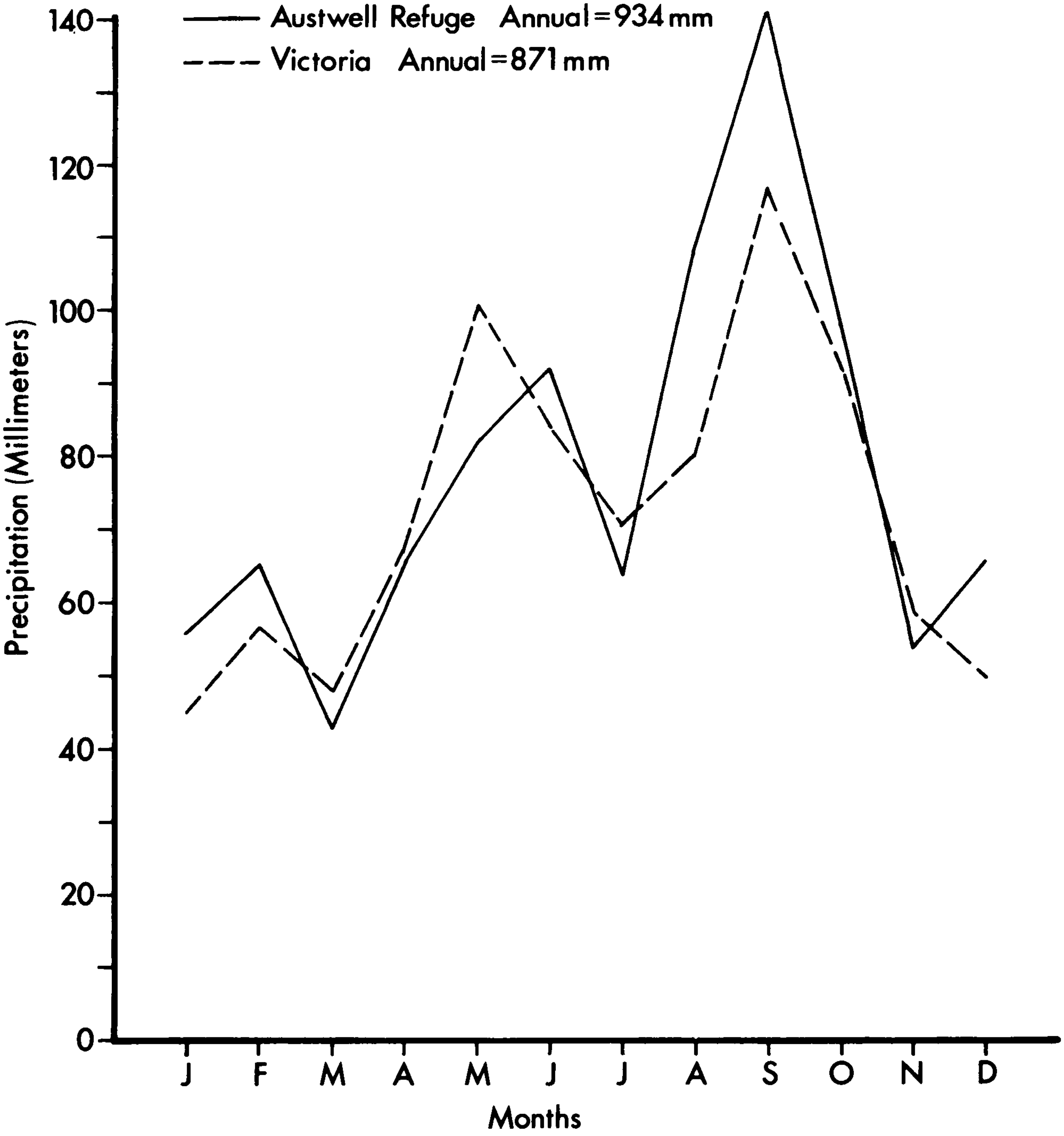

Figure 1. Mean seasonal precipitation for Austwell Refuge and Victoria, 1941-1970 (NOAA 1973a).

330 mm on an annual basis (see Matagorda-Brazos and Copano-Aransas syntheses for comparison of annual rates and the seasonal distribution of deficits and surpluses).

3.3 WIND PATTERNS

The San Antonio Bay study area and other Texas coastal basins are influenced primarily by three distinct wind regimes: southeasterly to southerly, northerly, and the highly variable winds associated with tropical disturbances (see Matagorda-Brazos and Laguna Madre syntheses for general environmental responses; Galveston and Corpus Christi syntheses for comparative wind frequencies along the coast; and sections 2.1 and 4.2 for the influence of wind on geologic and hydrologic processes, respectively, in the San Antonio Bay study area).

4.0 HYDROLOGY AND HYDROGRAPHY

4.1 TIDAL INFLUENCES - SALINITY REGIMES

The lunar tidal range in the San Antonio Bay system is extremely small, averaging 7.5 cm (Hall et al. 1976). As in other bays within the Texas Barrier Islands Region, diurnal tides dominate (Marmer 1954; Hall et al. 1976). During periods when the principal harmonic components favor semidiurnal tides (approximately 6 days per lunar month), tidal range normally is reduced and the volume of water exchange during 1 day does not exceed that which occurs on the average during diurnal tidal flux (Masch 1971). The tide typically enters the San Antonio Bay area from the northeast via Pass Cavallo (Matagorda area), and flows through Espiritu Santo Bay into San Antonio Bay (Shepard and Rusnak 1957). After entering San Antonio Bay, the tide moves counter-clockwise. Outflowing currents along the western shore typically are stronger than the inflowing current along the eastern shore because of additional input of river flow. This factor also creates salinities lower on the west side than on the east side of the bay (Hall et al. 1976) and is probably partially responsible for the erosion along the western shore (McGowen et al. 1976). After leaving San Antonio Bay, the tide moves west where some flow exits to the gulf via Mesquite Bay and Cedar Bayou, and the remainder flows into Aransas Bay (Shepard and Rusnak 1957; Hall et al. 1976).

The construction of the Gulf Intracoastal Waterway (GIWW) and the intersecting Victoria Barge Channel (VBC) has provided an avenue of reduced drag for the tidal wave (Masch 1971). Masch (1971) and Hall et al. (1976) indicate that the volume of water arriving in San Antonio Bay via the GIWW and then proceeding north through the VBC is considerable, although no available data indicate changes in the arrival and amplitude of the tide passing through the comparatively deep artificial channel versus the tide passing through the natural water bodies. The depths of the GIWW and VBC also enhance salinity stratification and the magnitude of tidal velocities over natural conditions (Hall et al. 1976). Discontinuous spoil deposits paralleling the VBC inhibit water movement into the central part of San Antonio Bay and augment the counter-clockwise tidal flow around the periphery of the bay (Hall et al. 1976). Depending on their orientation, dredged access channels and excavation areas associated with the shell-dredging industry have a mixed effect on tidal movements, but the movement of the tide through the channels in the central portion of the bay is generally sluggish (Hall et al. 1976).

Because of the extremely small amplitude of lunar tides, the effect of wind on water flux becomes an important factor (Marmer 1954). Most dramatic are responses to tropical storm systems which can occasionally result in surges of approximately 7 m in the San Antonio Bay area (Brown et al. 1974). More common is the passage of a cold front from the north, followed by a return to a more southerly air flow.

Hall et al. (1976) showed that within 3 hours after passage of a typical cold front, the water level dropped 0.6 m (2 ft) near Seadrift in upper San Antonio Bay and rose about the same amount in the lower part of the bay. In a shallow, barrier-bounded estuary with few tidal passes, the water pushed from the upper estuary typically is piled up against the bay side of the barrier (Ward et al. 1979). If this situation persists for several days, water levels can be expected to fall in the lower bay as water exits to the Gulf of Mexico. When southerly air flow is reestablished, water can be expected to oscillate back to upper portions of the bay (Hall et al. 1976).

This series of weather events is common in winter, and frequent wind reversals partially are responsible for the general increase in water circulation (see Section 4.2). Although these changes of water level in response to wind are not tidal changes according to classical definitions (e.g., Marmer 1954), the term "tide" is commonly used along the gulf coast to denote the daily change in water level, regardless of cause.

Salinities within the San Antonio Bay study area are comparatively low because of the large riverine input of the Guadalupe and San Antonio Rivers. Martinez (1975) reported that mean annual salinity over the area covered by Hynes, Guadalupe, Espiritu Santo and Mesquite Bays was 13.7 $^{o}/oo$ from 1965 through 1975. Average annual salinities are highest in Espiritu Santo Bay due to the lack of freshwater input, the dominant flow of gulf waters entering this bay from the northeast and flowing southwest, and the lack of substantial flow of less saline San Antonio Bay waters into this bay (Childress et al. 1975; Martinez 1975). The lowest average annual salinities typically are recorded in Guadalupe and Hynes Bays where the presence of riverine input frequently reduces salinities to zero (Martinez 1975).

Data obtained by Childress et al. (1975) and Martinez (1967, 1970, 1975) indicate that the seasonal change in surface salinity (Figure 2) is closely related to river discharge (Figure 3; Section 4.3). Childress et al. (1975) found that the closest relationship between river discharge and salinity was a 1-month lag in salinity response to inflow in the middle and lower segments of the bay, and a 2-month lag in the upper portions of the bay. The station near Steamboat Pass generally has higher salinities than the station south of McMullen Lake (Figure 2) although both stations are approximately the same distance from the mouth of the Guadalupe-San Antonio Rivers. This salinity difference suggests a counter-clockwise circulation pattern which would result in more river water flowing towards the station below McMullen Lake than towards Steamboat Pass. Analysis of the data in Figure 2 also indicates that salinity variability is large spatially and temporally. This conclusion is supported by Hall et al. (1976), who reported annual salinity extremes in San

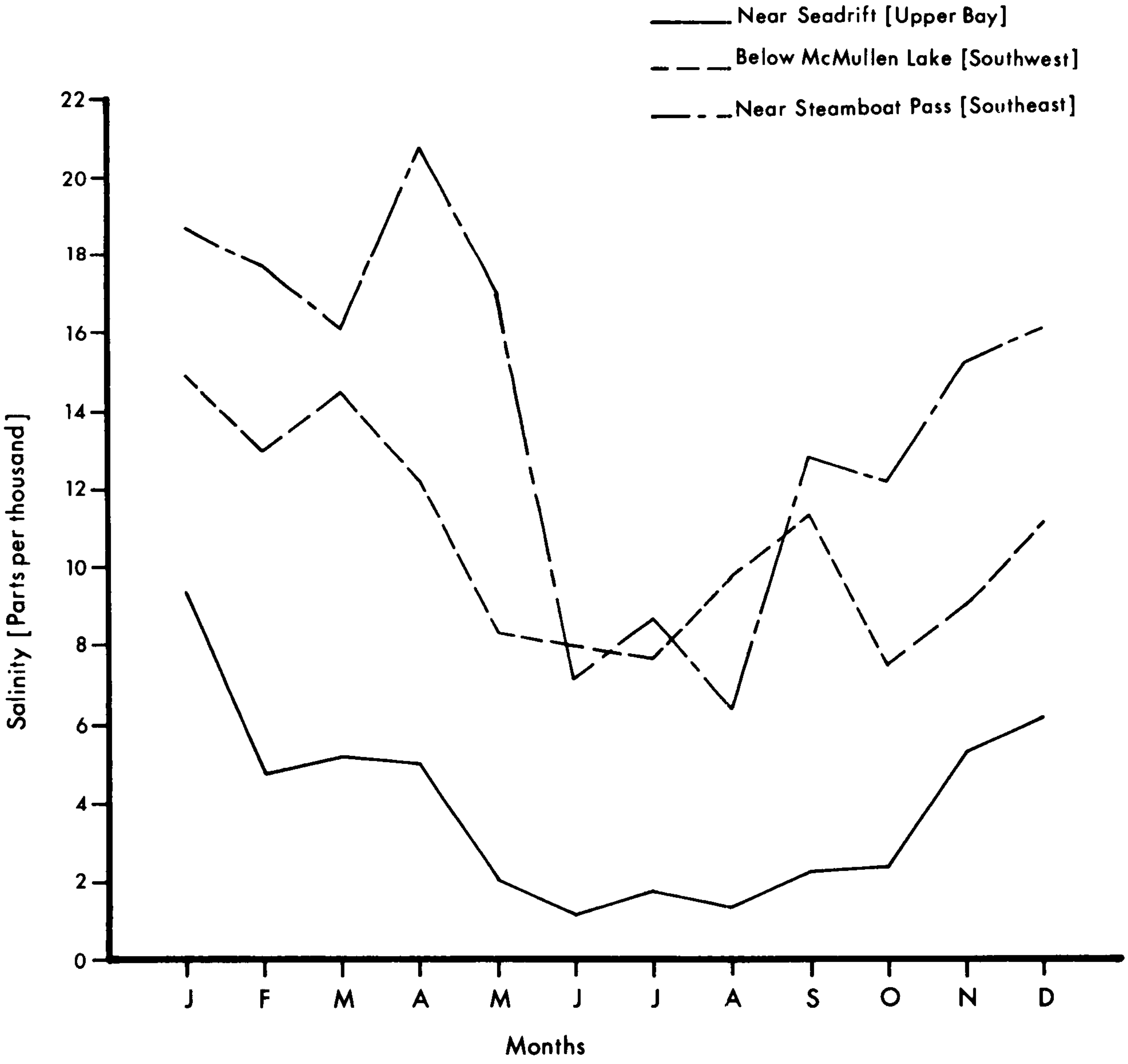

Figure 2. Mean seasonal surface salinity for three stations in San Antonio Bay, 1971-1974 (Childress et al. 1975).

Antonio Bay of 0 to 41 ^{o}/oo and salinities of 0 to 25^{o}/oo for 16 km (10 mi) upstream on the Guadalupe River.

Childress et al. (1975) found that density currents of saline water flow west through the GIWW and then north into the VBC until reaching the point where the VBC cuts into the mainland. At this restriction, upwelling occurs and the saline waters are dispersed in the southern part of Guadalupe Bay, the extreme north northeast segment of San Antonio Bay, and into southern Hynes Bay via the dredge cut connecting extreme southern Guadalupe Bay with Hynes Bay. This upwelling phenomenon may explain the higher salinities found by Hall et al. (1976) in southern Hynes Bay in comparison to northwestern San Antonio Bay. Childress et al. (1975) also found that surface salinities in the GIWW, VBC, and the dredged channel along the west side of San Antonio Bay were higher than surface salinities of surrounding bay waters.

4.2 CURRENT AND WATER CIRCULATION PATTERNS

As discussed in Section 4.1, true lunar tides are negligible throughout most of the San Antonio Bay complex. The Gulf Intracoastal Waterway, Victoria Barge Channel, and several unnamed artificial channels associated with the shell-dredging industry allow the tide and accompanying saline waters to progress farther inland and at higher velocities than under natural conditions, but the total contribution of true tides to circulation is small. As Hall et al. (1976) illustrated, the counter-clockwise tidal wave (see Section 4.1) often is modified by wind or riverine inflow. During periods of flood, river water flows down the eastern shore of San Antonio Bay, resulting in pronounced stratification with a maximum salinity difference between the overlying fresh river water and the saline tidally induced bottom waters of 15^{o}/oo along the eastern side of the bay (Hall et al. 1976). This reversal of the normal flow pattern also may result in a saltwater flow from Aransas Bay to San Antonio Bay via the GIWW (Hall et al. 1976).

Overall circulation, including flushing, is greatest during the winter (Childress et al. 1975; Hall et al. 1976), because of combined effects of the frequent changes in wind direction (e.g., cold fronts followed by southerly winds, followed by cold fronts, etc.), increased diurnal tidal range (due to maximum declination of the sun), and a small increase in river discharge during January and February. In contrast, flushing is slowest during summer because of low river discharge and the persistence of southerly components of wind (Hall et al. 1976). Steed (1971, cited in Childress et al. 1975) estimated that a flushing time of 2 months can be expected during high river flow periods, decreasing to 6 months during low flow periods.

The numerous oyster reefs play an important role in the circulation of San Antonio Bay (Childress et al. 1975). The reefs provide a partial barrier and are effective in maintaining major flow patterns around the periphery of the bay (Childress et al. 1975).

Cedar Bayou, which separates Matagorda and San Jose Islands, plays a comparatively small role in the circulation and water exchange in the San Antonio Bay complex (Childress et al. 1975). Salinity data from Mesquite Bay and southwestern San Antonio Bay (Martinez 1967, 1970, 1975) indicate that Cedar Bayou does not ordinarily play an important role in water exchange beyond

Mesquite Bay. Ayers Reef and other reefs extending south from the GIWW spoil banks as well as the overwash deposit of lower Matagorda Island partially bar flow between Mesquite and San Antonio Bays. No well-developed channel exists between the two barriers, a further indication that substantial flow does not normally occur. Cedar Bayou was formerly the principal tidal channel between San Antonio Bay and the Gulf of Mexico; but since historical times this pass has only functioned intermittently (McGowen et al. 1976), and maintenance dredging is occasionally required to keep the pass open (e.g., U.S. Army Corps of Engineers 1974). Cedar Bayou acts as a major seasonal outlet for bay waters during periods of high river discharge and during passages of cold fronts (Simmons and Hoese 1959). During low river flow periods and depressed bay water levels, flow may occur continuously for several days from the gulf to Mesquite Bay. Although the contribution of Cedar Bayou to the circulation of the San Antonio Bay complex is small, its importance as a fish pass has been well documented (Simmons and Hoese 1959; King 1971).

Another factor, whose effect on flushing only can be inferred, is the seasonal change in water flux. Along the northern Gulf of Mexico, bay waters typically rise in spring and fall and drop in summer and winter. The fall maximum is the greater of the two rises, and the winter minimum is the most pronounced of the two minima (see Laguna Madre and Galveston syntheses for examples of seasonal hydrographs). Sturges and Blaha (1976) attributed this bimodal cycle to the seasonally variable wind stress over the Gulf of Mexico, combined with the seasonal heating and cooling of gulf waters. The temperature variability partially accounts for the difference in the two maxima and minima. The difference between the fall maximum and the winter minimum is on the order of 30 cm for the shallow estuaries of the northern gulf (Marmer 1954), a substantial amount of water when compared to the average volume of the bay complex. This seasonal water flux cycle also affects the inundation regime of emergent marshes and wind-tidal flats. For example, during September and October, when water levels are high and tidal range is at a seasonal low (due to the solar equinox), inundation will be of long duration and low frequency, a factor which may effect nutrient exchange between the marsh surface and bay waters.

In the nearshore zone of the Gulf of Mexico, the prevailing southeasterly winds set up waves which are refracted, and a southwesterly littoral current is initiated (McGowen et al. 1976). Although winds from other quadrants may modify or even reverse the direction of littoral drift, the net annual movement is to the southwest (downcoast). This process has been an important factor in the formation of Matagorda Island by initiating lateral growth of small, individual islands until they coalesced, forming Matagorda Island. The continual supply of sand to the beaches provides a source for dune formation (which in turn may be reworked by storms into a washover deposit) and beach maintenance.

Sand transported by littoral drift is derived from a number of sources, including rivers (the Brazos and Colorado have provided a source historically), onshore-offshore transport between the nearshore and the surf zone, and the erosion and deposition of beaches. There are no known measurements of littoral drift for Matagorda Island, but a few limited estimates of littoral transport have been made for the neighboring Matagorda Peninsula (see Matagorda-Brazos synthesis).

4.3 DRAINAGE PATTERNS AND FRESHWATER INFLOWS, RIVERINE FLOODING PATTERNS

The major source of freshwater to the San Antonio Bay complex is the combined flow of the Guadalupe and San Antonio Rivers. Their confluence, with a combined drainage area of 26,548 km^2, occurs west of Green Lake (Childress et al. 1975). The combined gaged average annual flow is 60.8 m^3/sec with the Guadalupe River contributing 74% of the total (Diener 1975). Annual variation in flow is substantial, with a maximum of 6×10^9 m^3 (190.3 m^3/sec) of inflow in 1973 and a minimum of 2×10^8 m^3 (6.5 m^3/sec) of inflow in 1956 during the 40 years from 1934 through 1973 (Childress et al. 1975; Diener 1975). Four small watersheds in Calhoun and Refugio Counties, totaling 25,994 ha (Childress et al. 1975), plus the ungaged watershed of the Guadalupe and San Antonio Rivers, provide an additional average annual flow of approximately 20 m^3/sec.

In comparison with that of other bay complexes on the Texas coast, the discharge into the San Antonio Bay complex is large in relation to the volume of its receiving basin. The combined freshwater inflow could fill an empty San Antonio and contiguous bays to mean low water in approximately 112 days. Only the Galveston Bay area (not including the contiguous East and West Bays) has a higher freshwater input-to-receiving basin volume ratio, although both the Galveston and Matagorda study areas receive a greater freshwater input.

The seasonal distribution of streamflow is trimodal (in February, March, and September, Figure 3), and the high discharges closely follow, with only a slight lag, the seasonal distribution of precipitation (see Figure 1, Section 3.1). The winter peak in streamflow results from the low evapotranspiration demands on winter rainfall, which are associated primarily with cold fronts. The spring flow peak is a response to more abundant rainfall, resulting mainly from the interaction of weaker cold fronts with warm, moist gulf air. The fall streamflow peak is associated with the most abundant rainfall period, which is the result of cold front-gulf air interactions and tropical storm activity. Although total rainfall is considerably more abundant in the fall, in comparison with the spring peak (Figure 1, Section 3.1), the peaks in river discharge during these two periods are very similar (Figure 3). This similarity indicates that a larger portion of the fall rainfall is used to recharge depleted soil moistures and to supply the climatic demand for water (evapotranspiration) than is the situation in the spring.

The seasonal salinity cycle (Figure 2, Section 4.1) is negatively correlated with streamflow (Childress et al. 1975). During July and August when river discharge is low, salinities generally remain depressed in San Antonio Bay, indicating that spring floodwaters remain in the bay several months.

The high degree of variability in seasonal and yearly discharge is an important aspect of the San Antonio Bay Estuary. Above-average floods may lead to oyster mortalities, as occurred in 1972 and probably seven times or more since 1924 (Hall et al. 1976). During abnormally low discharge periods, oyster mortalities may increase due to predation (Childress et al. 1975). Attempts to increase withdrawal of surface flow for man's needs and to release water more uniformly may lead to decreased variability in oyster harvests. A study by Childress et al. (1975), however, shows that a reduction in total flow entering the system or a change in the normal seasonal distribution of flow, or both, can be expected to affect brown and white shrimp and blue crab production adversely (also see Section 5.1.2).

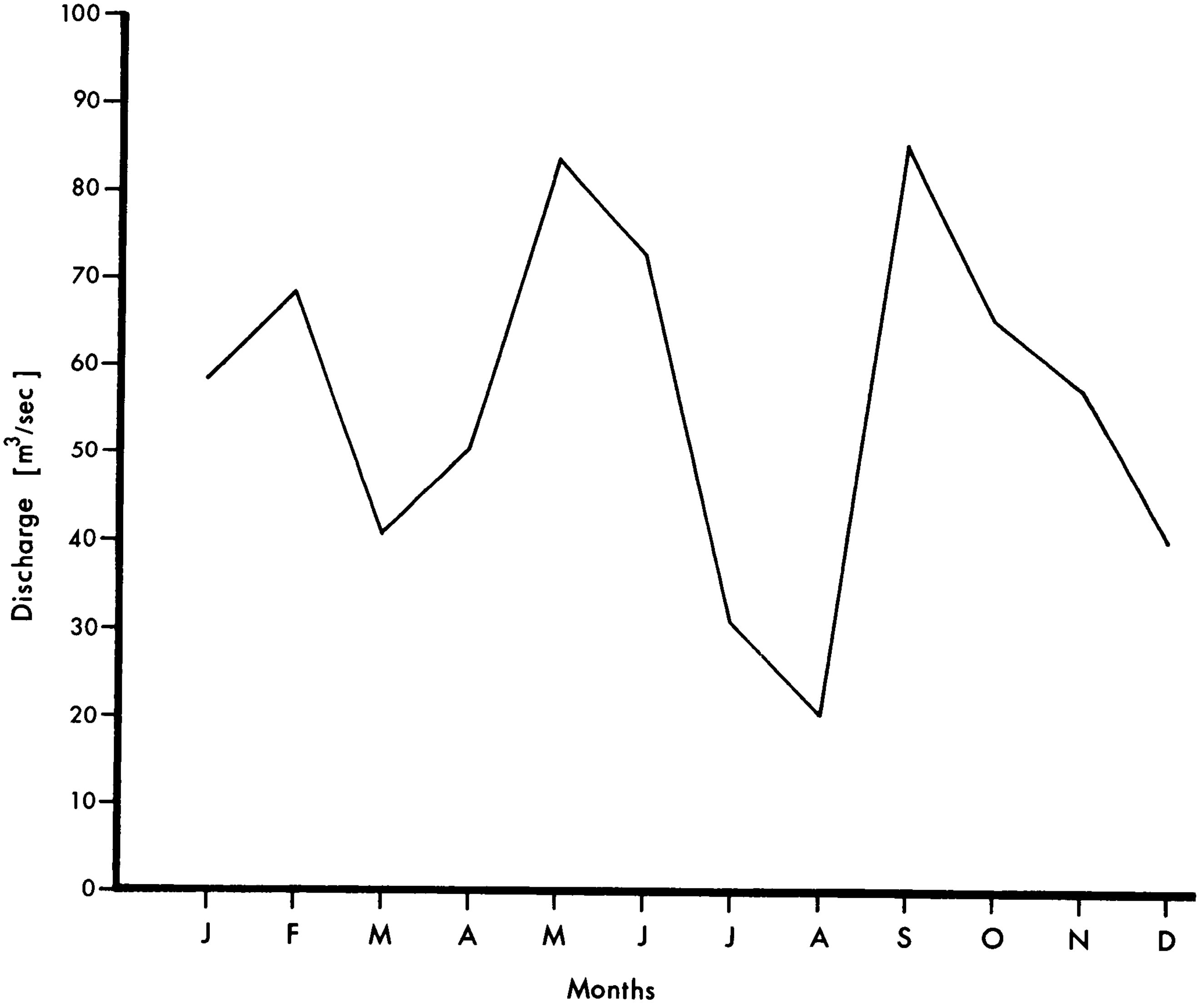

Figure 3. Mean daily discharge by months for the combined gaged flows of the San Antonio and Guadalupe Rivers, 1934-1968 (Diener 1975).

4.4 GROUNDWATER

Relatively large surface water supplies and comparatively little industrial and urban development in the San Antonio Bay area apparently have kept the withdrawal of groundwater within recharge rates (Mason 1963; Brown et al. 1974; McGowen et al. 1976). The main use of groundwater in the San Antonio Bay study area is for agriculture. Although declines have been reported for several intensively welled areas (Mason 1963), the declines have not been sufficient to result in significant subsidence of the land surface (Brown et al. 1974; McGowen et al. 1976). Most groundwater reservoirs contain substantial amounts of minerals; therefore, the intensive use of groundwater leads to a salt build-up in the soil which must be leached if crop production is to remain high. For this reason, there is a definite preference and increasing demand for diversion of surface water (San Antonio and Guadalupe Rivers) for irrigation purposes.

4.5 WATER QUALITY

Water is a common denominator which links habitats together into a system, and water quality is an important variable affecting the type and diversity of community assemblages. Unfortunately, current sampling programs in the San Antonio Bay Estuary and elsewhere do not provide adequate spatial or temporal coverage for a complete and accurate assessment of the effects of water quality parameters on biological resources. Discussion here is limited to the studies of Steed (1971), Langdon and Davis (1972), Childress et al. (1975), and Bouma (1976), supplemented by the data of Hahl and Ratzlaff (1970, 1972, 1973), Blakey and Kunze (1971), and the U.S. Geological Survey (1970-1976).

The quality of water in the San Antonio Bay complex is greatly influenced by the freshwater inflows of the Guadalupe-San Antonio River system, nonmonitored streamflow, and industrial and municipal outflows.

Nutrient levels in the estuary indicate the biochemical base for primary productivity. Nutrient data have been collected in the San Antonio and Guadalupe Rivers and in the San Antonio Bay complex for various sources of nitrogen and phosphorous and, less extensively, for organic carbon.

Nutrient levels in the San Antonio and Guadalupe Rivers often exceed expected natural levels (Langdon and Davis 1972). The major source of excess nutrients is agricultural runoff (Steed 1971; Langdon and Davis 1972; Childress et al. 1975). As industrial and municipal development is not substantial in the bay area and along the lower watershed, input from these sources is apparently not beyond the assimilative capacity of the bay system (Langdon and Davis 1972). The municipal input per unit population is rather large, however, and attributed by Landgon and Davis (1972) to the fact that only 9 of 20 wastewater treatment plants in the San Antonio Bay area were found by Classen (1970) to be in satisfactory working order. These municipal inputs often lead to temporary closing of waters to oystering in parts of the upper estuary (Langdon and Davis 1972; Diener 1975). No follow-up report to the conditions described by Classen (1970) is known but enforcement of discharge regulations undoubtedly would improve the quality of municipal outflows.

A direct relationship exists between nutrient levels in the upper San Antonio Bay complex and river discharge (Steed 1971; Langdon and Davis 1972; Childress et al. 1975). Childress et al. (1975) determined that not only was the total input of nitrites positively related to river flow, but also that river water concentrations of nitrites were positively related to river flow. Thus, an increase in river discharge will exponentially rather than linearly increase nitrite input into the San Antonio Bay estuary. Childress et al. (1975) found that various forms of phosphorus and nitrogen remained at above average levels in upper and central San Antonio Bay for 1 or more months following floods, but those levels were still within the natural range. Few lag relationships between levels of various forms of nitrogen and phosphorus in lower San Antonio Bay waters and discharge were reported by Childress et al. (1975), which supports the rapid nutrient uptake capacity of the bay reported by Langdon and Davis (1972).

In summary, the nutrient loads to the San Antonio Bay Estuary do not appear excessive, and no long-term or widespread evidence of eutrophic conditions exists. Nutrient cycling in the San Antonio Bay Estuary remains largely in a natural state (Langdon and Davis 1972), and man's impact, in terms of nutrient-loading, is small compared to that in other Texas coastal waters.

Dissolved oxygen (DO) concentrations vary highly through time but not over space in the San Antonio Bay Estuary (Hahl and Ratzlaff 1970, 1972, 1973; Martinez 1970, 1975; Childress et al. 1975). The relative uniformity of surface concentrations throughout the bay complex indicates that the effects of salinity upon DO are compensated for by other factors (e.g., wind mixing, and turbidity). An inverse relationship between temperature and DO is apparent with highest DO levels typically occuring during winter. Compared to those of other Texas bays, winter DO levels are normally higher in San Antonio Bay (Hahl and Ratzlaff 1970, 1972, 1973; Martinez 1970, 1975) with a January mean in excess of 12 mg/liter not uncommon throughout the bay (Martinez 1970, 1975; Childress et al. 1975).

Surface DO levels frequently exceed saturation, especially during winter. The only periods when DO levels are consistently below saturation levels are during spring and fall floods.

Vertical DO concentrations are fairly uniform due to the shallowness of the estuary and wind-induced mixing. Data from Hahl and Ratzlaff (1970, 1972, 1973) indicate that DO concentrations are typically lower in the deeper portions of the Gulf Intracoastal Waterway and Victoria Barge Channel than at the surface. Values in these channels generally remain around 75% of saturation level and typically exceed Texas Water Quality Board minimum standards (5.0 mg/liter). Analysis of bottom samples did not indicate concentrations sufficiently low to kill commercially important fish species (Childress et al. 1975). Biological and chemical oxygen demand loading was low during 1971-1974 (Childress et al. 1975), indicating that levels of industrial, municipal, and other effluents were not high. This conclusion supported the earlier work of Davis (1971, cited by Childress et al. 1975).

Water temperature data reported by Martinez (1970, 1975) from 1965 through 1970 and again in 1975 indicate a seasonal temperature pattern in the San Antonio Bay complex: highest temperatures generally occur in July ($\bar{x}$ = 29.5° C ± 0.8) and lowest temperatures in December ($\bar{x}$ = 10.0° C ± 0.9). This winter minimum is the lowest for any of the bay complexes in the Texas Barrier Islands Region. In comparison, the December mean water temperature was 17.0° C ± 0.1 and 16.6° C ± 0.5 in the neighboring Matagorda and Copano-Aransas Bay complexes, respectively (Martinez 1975). Temperatures in the San Antonio Bay complex are lower because the water is shallower than in the Matagorda complex, the air temperatures are slightly lower than in the Copano-Aransas area, the input of warmer gulf waters is less than in either the Copano-Aransas or Matagorda study areas, and the discharge of the relatively cooler San Antonio and Guadalupe Rivers is slightly increased. The depressed water temperatures during winter account for San Antonio Bay's having the lowest mean annual water temperature, 21.2° C ± 1.2, (Martinez 1975) of all the Texas bays.

Turbidity levels in the San Antonio Bay complex are within the middle range of those measured in the estuaries of the Texas Barrier Islands Region (Martinez 1975). Childress et al. (1975) found a general pattern of decreasing turbidity seaward from the Guadalupe-San Antonio River Delta. Although turbidity levels are positively correlated with rates of streamflow, no distinct seasonal pattern is evident (Childress et al. 1975). Shell-dredging activities and strong winds associated with cold fronts also result in high turbidity levels (see Section 2.5) and contribute to the lack of a distinct seasonal pattern (Martinez 1975).

Data reported by Martinez (1970, 1975) indicate that, in nonstressed estuarine areas along the Texas coast, the pH of bay waters is slightly basic, a finding consistent for most temperate estuaries. In San Antonio Bay, Martinez (1975) found a low pH reading of 7.1 and a high of 8.4, with a mean of 7.8 during 1975. Childress et al. (1975) obtained pH values ranging from 7.7 to 8.9 with a mean of 8.4 for the 3-year period, 1971 through 1974. No seasonal or spatial patterns were evident. The consistently basic pH indicates that acidic industrial effluents have not led to a large-scale change in the pH of the bay complex, but localized problems occasionally are encountered.

Trefy et al. (1976) examined heavy metal concentrations in the bottom sediments of San Antonio Bay and concluded that concentrations were low, even in comparison to those of other similar natural areas. Analyzing cores representing several centuries of bay bottom deposits, they found heavy metals uniformly distributed, indicating that artificial sources (e.g., industrial) in the area had not substantially increased baseline levels.

Levels of dichlorodiphenyltrichloroethane (DDT), dieldrin, and other chlorinated hydrocarbons in the San Antonio Bay Estuary were examined by Ahr (1976) and Petrocelli and Anderson (1976). Ahr found that chlorinated hydrocarbons in San Antonio Bay sediments generally increased with the fall peak in river discharge, a phenomenon which also coincides with peak levels in agricultural activities. Spatially, the upper bay complex contained considerably higher values, which Ahr (1976) attributed to the abundance of fine-grained sediments to which chlorinated hydrocarbons are adsorbed. The maximum levels found by Ahr (1976) were 60 parts per billion (ppb) of DDT, 12 ppb of dieldrin, and 170 ppb of polychlorinated biphenyls (PCB's). Levels reported usually were considerably lower, indicating generally low chlorinated hydrocarbon content in the sediments of the bay. Petrocelli and Anderson (1976) showed, however, that these substances become concentrated from one trophic level to the next. Their laboratory experiments indicated that Rangia cuneata accumulated dieldrin residues in its tissues to a level 54 times the concentration in algae that it was fed. Lesser accumulations occurred in the American oyster (Crassostrea virginica) and blue crab (Callinectes sapidus). Field sampling indicated that levels of contamination were low in the species examined. The low contamination levels were attributed by Petrocelli and Anderson (1976) to the low levels in the sediments and water. Despite this apparent lack of a problem, the incidence of some level of contamination was high. Blue crabs had the greatest incidence (94% containing DDT and 32% dieldrin) followed by Rangia cuneata (68% and 31%), American oysters (60% and 25%) and penaeid shrimp (13% and 25%).

5.0 BIOLOGY

5.1 ESTUARINE COMMUNITY

Of all the estuarine communities in the Texas Barrier Islands Region, the San Antonio Bay system is the least altered by human activity. Freshwater inflow carries relatively few pollutants because industrial utilization of the area is small. Municipal waste disposal is also relatively slight since only four communities of approximately 4,000 total residents occur along the shorelines of the San Antonio Bay system (Matlock and Weaver 1979). Municipal dumping and agricultural runoff are the major sources of pollution. These pollutants have not resulted in major or long-term eutrophication.

Low commercial finfish harvests suggest that this area is less productive than other Texas estuaries. This conclusion is doubtful because of the unusually plentiful and high quality of freshwater inflow from the Guadalupe and San Antonio Rivers, but no commercial fishing-pressure data exist. Low sportfishing harvest reported by Heffernan et al. (1977) probably reflects low fishing pressure rather than low productivity. Limited estuary access and absence of lighted piers reduce sport fishermen's use. Harvest per man-hour of fishing in the San Antonio Bay area is the highest of the six Texas bay systems discussed in this volume, a fact indicating productivity in the area is certainly not low.

Shellfish production also depends upon freshwater inflows; shrimp, in particular, respond to changes in freshwater input. For example, the years of the largest harvests of white shrimp coincide with years of greatest inflow from the Guadalupe and San Antonio Rivers (Childress et al. 1975). The present production level of the estuarine community is greatly influenced by riverine input. Any major water diversion projects will undoubtedly alter the established ecological relationships operating within this vulnerable bay system.

5.1.1 Vegetation

According to Diener (1975), approximately 6,620 ha of submerged vegetation exists in the San Antonio Bay system. Shoal grass (Halodule beaudettei), the most abundant species, grows in areas of low turbidity and shallow water, primarily in lower San Antonio Bay, Espiritu Santo Bay, and the system of sloughs and shallow lakes along the northern bay margin of Matagorda Island (Matlock and Weaver 1979). The Pass Cavallo area also supports stands of shoal grass (Childress et al. 1975). Widgeongrass (Ruppia maritima) is secondary in abundance. Its salinity tolerance is not as great as that of shoal grass; therefore, it is more common after a large influx of freshwater (McGowen et al. 1976). Childress et al. (1975) reported stands of widgeongrass along the margin of upper San Antonio Bay, Espiritu Santo Bay, and Pass Cavallo. McGowen et al. (1976) listed turtle grass (*Thalassia testudinum*) and manatee grass (*Cymodocea filiformis*), but provided no details about their locations.

Investigations of salinity tolerance of submerged seagrasses (McMillan and Moseley 1967) indicated shoal grass was the most tolerant of salinity fluctuations and survived the highest salt concentrations. Following shoal grass in tolerance to salinity are turtle grass, widgeongrass, and manatee grass, respectively. Other environmental factors influencing the distribution and survival of submerged spermatophytes are discussed in the Copano-Aransas synthesis, Section 5.1.1.

Primary production estimates for submerged spermatophytes of the San Antonio area are not available, but mean standing crop values for seagrasses and algae combined between June 1971 and April 1974 were as follows: (1) Pass Cavallo area, 290.8 g/m^2; (2) Espiritu Santo Bay, 209.2 g/m^2; (3) lower San Antonio Bay, 169.7 g/m^2; and (4) upper San Antonio Bay, 58.4 g/m^2. Childress et al. (1975) interpreted these values to suggest that the highest seagrass production probably occurs in clear water with a salinity range between 20 and 30 $^{0}/oo$.

Primary productivity studies in the aquatic habitat of the bay system are concerned with the following: (1) total photosynthesis of phytoplankton, including diatoms, dinoflagellates, and green, red, brown, and blue-green algae; (2) community respiration of all flora and fauna in the water column; and (3) P/R, the ratio of total photosynthesis to community respiration to arrive at an overall productivity estimate for the entire community. A P/R value of 1.0 is interpreted to mean that the community is in a "steady state." Values greater than 1.0 denote net production, whereas values less than 1.0 occur in communities which have a photosynthetic deficit (Langdon and Davis 1972).

Utilizing the diurnal oxygen curve method, Langdon and Davis (1972) conducted productivity studies of the aquatic habitats in the San Antonio Bay system. Their investigations suggested that the P/R value in the Guadalupe River was 1.06, or very nearly steady state. Community production was only 0.87 in upper San Antonio and Hynes Bays. An explanation for this phenomenon was that photosynthesis by the freshwater phytoplankton was inhibited by intrusion of saline water. The waters of Mesquite Bay supported the greatest amount of primary production with a P/R value of 1.24.

Drift algae and benthic algae occur in the San Antonio Bay system, but have not been studied in this area. The neighboring Copano-Aransas area, on the other hand, has been the site of exhaustive studies of algal species composition and habitat requirements, and these data are relevant to the San Antonio area. Redfish Bay was studied by Edwards and Kapraun (1973) and Cowper (1978). Conover (1964) concentrated on benthic algae along the Texas coast from Corpus Christi south to the Mexican border. Little work has been done on Texas bays north of Aransas. For a discussion of species present in San Antonio area, the reader is referred to the Copano-Aransas synthesis, Section 5.1.1. Childress et al. (1975) found red algae (*Spyridia filamentosa* and *Polysiphonia gorgoniae*) in San Antonio and Mesquite Bays and red algae (*Spyridia filamentosa* and *Gracilaria foliifera*) and green algae (*Ulva lactuca* and *U. fasciata*) in Espiritu Santo Bay. The low turbidity and the resulting greater light penetration enable green algae to thrive in Espiritu Santo Bay.

Blue-green algae form extensive mats on wind-tidal flats located on the bay side of Matagorda Island between the vegetated barrier flats and the salt marshes. Formation of these mats is a sporadic event, occurring only during and for a short time after wind-tides have flooded the flats; with the ebbing of the tide the algae soon die and decompose. The algal mats release nitrogen and phosphorus to the estuary with the next wind-generated tide (Dawson 1975). Usually, the flats are barren of vegetation (McGowen et al. 1976), and a salty film resulting from the evaporation of the flood waters frequently covers them.

Emergent salt marshes in the San Antonio Bay area occur primarily on the Guadalupe River Delta and on the bay margin of Matagorda Island. Relatively little is known about these marshes since they are privately owned (Childress et al. 1975). Vegetational zonation of marshes on barrier islands and river deltas has been described in other syntheses (see Copano-Aransas and Corpus Christi syntheses, Section 5.1.1). Zones of vegetation are rarely distinct because they depend on a host of environmental variables, including duration and frequency of saltwater inundation, water column salinity, substrate salinity, elevation, and nutrient availability. Trends in the occurrence of species across a saltmarsh have been reported; the species lists provided in other syntheses summarize those trends. In the past few years, marshes in the Pass Cavallo area have begun to support extensive stands of black mangroves (*Avicennia nitida*) in addition to the more typical salt marsh vegetation (McGowen et al. 1976).

No data estimating the primary production of the low-marsh dominant, smooth cordgrass (*Spartina alterniflora*), were available for the San Antonio Bay system. Investigations into the productivity of this species in Lavaca, San Antonio, and Nueces Bays suggested that approximately 1,084 g dry wt/m^2/yr were produced (Espey, Huston and Associates 1977, cited in Ward et al. 1979).

Data from brackish and freshwater marshes are virtually nonexistent in the San Antonio Bay system (McGowen et al. 1976). Freshwater marshes, however, abound along the Guadalupe and San Antonio Rivers and in the Green Lake area. From data adapted from McGowen et al. (1976), approximately 16 km^2 of freshwater marshes in the San Antonio area can be estimated. Representative vegetation includes cattail (*Typha* spp.), sloughgrass (*Spartina pectinata*), bulrush (*Scirpus* spp.), and rush (*Juncus* spp.). No productivity estimates for freshwater marshes are available.

5.1.2 Fauna

Mammals. The bottlenose dolphin (*Tursiops truncatus*) is the only mammal commonly found in bay waters of the San Antonio Bay system. Barham et al. (1980), in five replicate flights along a single transect over Mesquite Bay during late April 1978, spotted only one herd composed of five dolphins. They flew six transects, five times each, over San Antonio Bay and recorded 33 dolphin herds with a total of 201 individuals.

A more diverse array of terrestrial mammals frequents the various marsh habitats. Table 1 shows mammals found in the estuarine area and their likely habitat(s). The nutria (*Myocastor coypus*), raccoon (*Procyon lotor*), river otter (*Lutra canadensis*), and mink (*Mustela vison*) are the most commercially important furbearers in the salt, brackish, and freshwater marshes of the estuarine community (Davis 1974). White-tailed deer (*Odocoileus virginianus*) in the marshes occur primarily on Blackjack Peninsula in the Aransas National Wildlife Refuge.

Table 1. Representative species of mammals of the estuarine community, San Antonio Bay system. SM=salt marsh, BFM=brackish to freshwater marsh, FM=freshwater marsh (Davis 1974).

Scientific name	Common name	Habitat SM	 BFM	 FM
Procyon lotor	Raccoon	x	x	x
Mustela vison	Mink		x	x
Myocastor coypus	Nutria	x	x	x
Lutra canadensis	River otter		x	x
Oryzomys palustris	Northern rice rat		x	x
Sigmodon hispidus	Hispid cotton rat			x
Sylvilagus aquaticus	Swamp rabbit		x	x
Odocoileus virginianus	White-tailed deer		x	x

Birds. According to the Texas Natural Area Survey (n.d.), Second Chain-of-Islands, located in Ayres Bay, is one of the largest waterbird rookeries on the Texas coast. The area supports breeding colonies of reddish egrets (*Dichromanassa rufescens*), brown pelicans (*Pelecanus occidentalis*), roseate spoonbills (*Ajaia ajaja*), and the more common gulls, terns, and skimmers. The area is also one of the few Texas nesting grounds for American oystercatchers (*Haematopus palliatus*).

Table 2 provides data on nesting pairs of common fish-eating birds observed in the area between 1973 and 1976. For further discussion of birds frequenting the estuarine community, see the Corpus Christi synthesis, Section 5.1.2.

Reptiles and amphibians. The Texas diamondback terrapin (*Malaclemys terrapin littoralis*) is the only turtle (except for marine ones) tolerant of high salinities of salt marshes; it is also common in brackish marshes but rarely found in freshwater marshes. The common snapping turtle (*Chelydra serpentina serpentina*) tolerates brackish salinities and is also common in freshwater marshes (Conant 1975). According to the literature, snappers should be common as far south as the Copano-Aransas area, but sight records of Raun and Gehlbach (1972) suggest the species is no longer common south of the Matagorda area. The U.S. Fish and Wildlife Service (USFWS) reported sightings of sea turtles in waters of the San Antonio Bay system (National Fish and Wildlife Laboratory 1980). Three endangered species, the green turtle (*Chelonia*

Table 2. Pairs of colonial fish-eating birds, San Antonio Bay system (adapted from Blacklock et al. 1978).

Scientific name	Common name	1973	1974	1975	1976	Historical population trend for Texas
Pelecanus occidentalis	Brown pelican	6	4	0	8	See endangered species section of this synthesis
Anhinga anhinga	Anhinga	0	10	60	35	Long-term decline
Ardea herodias	Great blue heron	321	316	335	648	Stable
Florida caerulea	Little blue heron	350	85	400	400	Primarily inland; stable
Bubulcus ibis	Cattle egret	4,197	370	2,640	19,055	First arrived 1954; rapid increase
Dichromanassa Rufescens	Reddish egret	182	69	36	34	Long-term decline, but stable since 1960's
Casmerodius albus	Great egret	720	715	735	1,098	1910 near extinction; currently stable
Leucophoyx thula	Snowy egret	278	356	312	289	1910 near extinction; currently stable
Hydranassa tricolor	Louisiana heron	475	446	209	141	Rapid increase during past 10 years
Nycticorax nycticorax	Black-crowned night heron	55	89	37	50	Trend not clear
Eudocimus albus	White ibis	50	5	20	0	Stable to increasing during last 20 years

Continued

Table 2. Concluded.

Scientific name	Common name	1973	1974	1975	1976	Historical population trend for Texas
Ajaia ajaja	Roseate spoonbill	150	356	185	104	1910 near extinction; currently stable
Larus atricilla	Laughing gull	3	104	25	30	Probably stable
Gelochelidon nilotica	Gull-billed tern	103	13	35	73	Stable to decreasing
Sterna forsteri	Forster's tern	51	150	44	159	Slow deline since 1940's
S. albifrons	Least tern	97	18	40	25	Rapid decrease
S. maxima	Royal tern	0	0	4,000	4,000	Abundant
Hydroprogne caspia	Caspian tern	142	119	265	79	Probable decline
Rynchops nigra	Black skimmer	477	295	506	475	Trend not clear

mydas), Kemp's ridley turtle (Lepidochelys kempii), and the leatherback turtle (Dermochelys coriacea), were recorded (National Fish and Wildlife Laboratory 1980).

In the salt and brackish marshes of the study area, two species of snakes are commonly found: the gulf salt marsh snake (Nerodia fasciata clarki) and the speckled kingsnake (Lampropeltis getulus holbrooki). The kingsnake has broad ecological tolerances; the species thrives in coastal marshes, river swamps, and upland woods. The gulf salt marsh snake, as its name implies, is more limited in its habitat choice and rarely is encountered outside the salt or brackish marsh (Conant 1975).

The American alligator (Alligator mississippiensis) appears in the brackish and freshwater marshes of the San Antonio Bay system. With Federal and State protection, the numbers of this species are increasing in most gulf and Atlantic States where it was formerly abundant (Joanen 1974, cited in National Fish and Wildlife Laboratory 1980). Lizards are not common in the salt or brackish marshes of this area (Conant 1975).

A few amphibians occasionally may be seen in the salt or brackish marshes of the study area. Conant (1975) reported the southern leopard frog (Rana utricularia) and green treefrog (Hyla cinerea) in these marshes.

Freshwater marshes offer a less taxing habitat for reptiles and amphibians than either brackish or salt marshes. The more favorable environment results in greater species diversity (Table 3).

Table 3. Representative reptiles and amphibians in the freshwater marsh habitat of the estuarine community, San Antonio Bay system (Raun and Gehlbach 1972; Conant 1975).

Scientific name	Common name
Chelydra serpentina serpentina	Common snapping turtle
Kinosternon flavescens flavescens	Yellow mud turtle
K. subrubrum hippocrepis	Mississippi mud turtle
Chrysemys scripta elegans	Red-eared turtle
Lampropeltis getulus holbrooki	Speckled kingsnake
Farancia abacura reinwardti	Western mud snake
Nerodia erythrogaster transversa	Blotched water snake
Storeria dekayi texana	Texas brown snake
Pseudacris triseriata feriarum	Upland chorus frog
Bufo woodhousei woodhousei	Woodhouse's toad
Rana utricularia	Southern leopard frog
Gastrophryne olivacea	Great Plains narrow-mouthed toad
Hyla cinerea	Green treefrog

Fish. Commercial landings data collected by the U.S. Fish and Wildlife Service, Texas Parks and Wildlife Department, and the National Oceanic and

Atmospheric Administration (USFWS and TPWD 1968; NOAA and TPWD 1970; NOAA 1971, 1972, 1973b, 1974, 1975, 1977, 1978a, 1978b) indicate that during 1967-1977, the five most important finfish species by weight were the red drum (Sciaenops ocellatus), with an average annual catch of 4.4 x 10^4 kg; spotted seatrout (Cynoscion nebulosus), 3.4 x 10^4 kg; black drum (Pogonias cromis), 2.2 x 10^4 kg; unclassified flounder, 6.4 x 10^3 kg; and sheepshead (Archosargus probatocephalus), 6.3 x 10^3 kg. The total commercial harvest of all fish in the San Antonio Bay area suggests an overall increase in yield during the past decade. A lack of data on fishing pressure, however, precludes an estimate of finfish productivity in this bay system.

The value of the commercial fishery in this area is traditionally less than that of either adjacent drainage. The 10-year average harvest between 1968 and 1977 was 1.3 x 10^6 kg, a close third behind the 1.8 x 10^6 kg harvest in the Corpus Christi Bay area. The Copano-Aransas Bay area harvest (3.1 x 10^6 kg) was equivalent to the combined yields of the other two areas.

A comparison of the commercial finfish harvest in the six Texas coastal bay systems shows the San Antonio Bay system to have the smallest yield. The areal extent of the bays surveyed within this system was 5.0 x 10^4 ha (Diener 1975), the third smallest area sampled by USFWS, TPWD, and NOAA. Although the relatively small area of the San Antonio Bay system can help explain the low harvest, it is in no way a sufficient explanation, because the surveyed waters of the more productive Copano-Aransas system contain considerably less area than was surveyed in the San Antonio system. An examination of harvest data suggests that the San Antonio Bay system is less productive than other Texas coastal bays, but the level of fishing pressure is not known and outlaw fishing is not reported.

Sportfishing in the San Antonio Bay system is primarily for spotted seatrout, red drum, southern flounder (Paralichthys lethostigma), sheepshead, and gafftopsail catfish (Bagre marinus). From September 1974 through August 1975, 1.1 x 10^5 kg of spotted seatrout were landed by sport fishermen; the mean harvest rate was 294.4 g/hr, the greatest harvest per man-hour fished in the San Antonio Bay system. The total sport harvest in this bay system (1.9 x 10^5 kg) was the lowest of the six bays described in all the syntheses. The harvest per man-hour fished, however, was the greatest of the six bays (489.2 g/hr) (Heffernan et al. 1977). The disparity between harvest weight and rate data suggests sportsfishing pressure is low in the San Antonio area. Further evidence of this is in Bouma and Sidner's (1976) discussion of San Antonio Bay as a tourist attraction. They suggested that the shallow water, absence of beach, and lack of access to Matagorda Island limit the value of San Antonio Bay as a sportfishing area.

Life history discussions of the spotted seatrout, red drum, and black drum are in the Laguna Madre synthesis, Section 5.1.2. The life history of the southern flounder, an important representative of the flatfish, is in the Matagorda-Brazos synthesis.

Finfish in the San Antonio Bay system may be undergoing some man-induced changes in their feeding habits due to shell-dredging in the bay. Dineen and Darnell (1976) postulated that the short-term environmental effects of dredging resulted in suspension of sediment, which caused reduced photosynthesis by plants and increased the oxygen requirements, reduced visibility, and impaired functioning of gill membranes of fish species. Their data showed shifts in food habits of fish collected in muddy areas, and the authors suggested that reduced visibility and food availability influenced fish-feeding behavior. Organisms in the bay regularly are confronted with local episodes of temporary perturbation (Dineen and Darnell 1976). Long-term effects of dredging would be more serious and might create deep dredge holes. The bottoms of such holes tend to consist of fine-grained sediment which deters colonization by many benthic invertebrate populations. The absence of many invertebrate species for extended periods reduces food supply for many fish species (Dineen and Darnell 1976).

Invertebrates. Blue crabs (Callinectes sapidus) and American oysters (Crassostrea virginica) are two commercially valuable invertebrates in the San Antonio Bay system. Data for 1968 through 1977 (USFWS and TPWD 1968; NOAA and TPWD 1970; NOAA 1971, 1972, 1973b, 1974, 1975, 1977, 1978a, 1978b) reveal that the average annual harvests, by weight and by monetary value, of both of these invertebrates were the second largest of the six Texas bay systems considered in this study. Only Galveston Bay had higher yields of these invertebrates than San Antonio Bay. The blue crab and oyster industries each averaged 1.75 x 10^5 dollars in value. Historically, the highest production of blue crab in Texas has occurred in areas of greatest freshwater inflow, a fact that helps explain the large harvests in the Galveston and San Antonio Bay areas. Oyster harvest is also correlated with freshwater inflow (Ward et al. 1979).

White shrimp (Penaeus setiferus) averaged the highest dollar value for shellfish in the San Antonio Bay system during the same decade. Compared with those of the rest of the coast, however, the harvest weight and corresponding value ranked fourth behind Galveston, Copano-Aransas, and Matagorda. Brown shrimp (Penaenus aztecus) and pink shrimp (P. duorarum) constitute the smallest shellfish harvest in the San Antonio Bay area, averaging 1.1 x 10^5 kg and 7.2 x 10^4 dollars annually for the 10-year study period (USFWS and TPWD 1968; NOAA and TPWD 1970; NOAA 1971, 1972, 1973b, 1974, 1975, 1977, 1978a, 1978b).

Invertebrates, many of commercial value, have been the focus of several studies on the effects of shell-dredging in the estuarine community. Harper and Hopkins (1976) reported that turbidity, whether natural or dredging-induced, does not deter nektonic organisms from using their habitat; there is even some indication that turbidity is occasionally beneficial, providing protection from predators. Benthic invertebrate communities subjected to dredging suffer decreases in the number of species and in population sizes within those species. For example, in May 1972 a 60.75-cm^2 site in San Antonio Bay supported an average of 4.3 species and 25 individuals before dredging. By August, after 1 month's dredging, the number of species decreased to an average of 1.6 and the number of individuals decreased to an average of 5. Dredging ceased in December, and by February 1973 averages of 5.5 species and 21 individuals were attained. This data indicate that recovery of the benthos following cessation of the perturbation may be rapid (Harper and Hopkins 1976). The effects on oysters of siltation and high density mud flow from dredging appear minimal unless the oysters are totally buried. McKinney et al. (1976) reported that mud flows affect only organisms on the bottom; oyster reefs typically are raised far enough off the bottom to avoid burial. If low reef flanks are killed by burial, the mud is washed off in a relatively short time and repopulation begins soon thereafter. Many reefs in San Antonio, Matagorda and Galveston Bays, however, have been permanently damaged by dredging (B. D. King III, U.S. Fish and Wildlife Service, Austin, Texas; pers. comm. 1980).

Although the particular studies mentioned in this synthesis were performed within the confines of San Antonio Bay, the reader should not assume that this area is subjected to higher rates of dredging than other major bays on the Texas coast. Dredging, especially for navigation, is widespread along the coast. Although the effects of dredging are not idential in each bay, the overall effects are probably comparable. The majority of invertebrates in the study area are of little or no direct commercial value but are vital links in the food web of the estuary. Brief discussions of these species are presented in the Corpus Christi Bay and Copano-Aransas Bay system syntheses. More detailed discussions are presented in Parker (1959) and Ladd (1951).

5.2 BARRIER ISLAND COMMUNITY

The proximity of the barrier islands associated with the Corpus Christi, Copano-Aransas, and San Antonio Bay systems, as well as their resulting biological and ecological similarities, precludes the necessity of separate detailed discussions of all three barrier island communities. The reader is referred to the Corpus Christi Bay synthesis, Section 5.2, for a discussion of the flora and fauna on these barrier islands, including Matagorda Island in the San Antonio Bay system. Characteristics of Matagorda Island which vary from those of the island communities of the Corpus Christi area are discussed below.

5.2.1 Vegetation

Although vegetation in the Corpus Christi and San Antonio Bay systems does not differ significantly, the topography differs. Matagorda Island is characterized by a series of beach ridges and swales incorporated into the vegetated barrier flat. Each ridge represents the position of a previous shoreline formed during an earlier developmental stage of the island. Beach ridges on Matagorda Island begin at Pass Cavallo on the northern end of the island. They are most numerous in the Pass Cavallo area, becoming smaller and less frequent southward on San Jose Island (Copano-Aransas system). The ridge-and-swale topography is not found to any extent south of San Jose Island because increased eolian activity has altered the character of the islands (McGowen et al. 1976). Washover fans are also more common on Matagorda Island than Mustang Island. A large fan has developed on an abandoned tidal delta located just northeast of Cedar Bayou (McGowen et al. 1976).

5.2.2 Fauna

Mammals. Matagorda Island appears to represent a distributional break from the two islands to the south. Davis (1974) reported essentially the same mammalian species on both Mustang and San Jose Islands but listed only two of those species in the San Antonio Bay area: the hispid cotton rat (Sigmodon hispidus), found throughout Texas; and the short-tailed grasshopper mouse (Onychomys leucogaster), whose range extends up the Texas coast to Aransas and Refugio Counties. Davis (1974) did not mention a record of the short-tailed grasshopper mouse on Matagorda Island, but its preference for sandy soil suggests it might be found there. According to Davis (1974) and Hall and Kelson (1959), the ranges of other rodents occurring on Mustang Island do not extend north to Matagorda Island. Since human access to Matagorda Island is limited, the area may have been less extensively studied than the other islands, and what appears to be a distributional break may, in fact, be the result of the remoteness of the area for study.

5.3 RIVERINE COMMUNITY

The confluent Guadalupe and San Antonio Rivers have been discussed as influential factors in the formation of estuarine nursery grounds; however, these rivers are productive communities in their own right.

Saltwater influx into the lower reaches of these rivers influences the riverine community, primarily in determining the species of phytoplankton, vascular flora, and fish found there. Species thriving in this estuarine area must tolerate salinity fluctuations such as those occurring during storm surge or upland flooding. Hall et al. (1976) reported salinities ranging from 0 to 25 $^{o}/oo$ at a point 16 km upstream on the Guadalupe River.

Saltwater intrusion does not extend far upstream. Approximately 48 km upstream from the mouth of the San Antonio and Guadalupe Rivers, the average salinity[1] was less than 0.1 $^{o}/oo$ during the water years 1972 and 1973 (U.S. Geological Survey 1972, 1973). The maximum salinity in either river was 0.23 $^{o}/oo$, measured in April 1972 in the San Antonio River. Therefore, within the bounds of the San Antonio Bay system, freshwater riverine assemblages do occur. Major emphasis in this report will be placed on the ichthyofauna since the Guadalupe-San Antonio drainage system has a high species diversity relative to its small drainage area (Conner 1977).

5.3.1 Vegetation

No data on vegetative species in the San Antonio and Guadalupe Rivers are available; however, phytoplankton and detritus are the basis of the riverine food web (Clapham 1973). Although the detrital food web functions in the riverine community, massive amounts of detritus providing vital nutrients to the estuaries are carried by the rivers. Agricultural runoff also contributes considerable nutrients to the riverine and ultimately the estuarine communities. Childress et al. (1975) estimated average daily supplies of phosphorus and nitrogen to the estuaries of the San Antonio Bay area to be 22 and 26 metric tons, respectively.

Turbidity is important in this riverine community because it reduces light penetration, a limiting factor for primary productivity. Some turbidity, however, benefits the community because necessary nutrients tend to be adsorbed onto suspended particles (Williams 1973).

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[1] The original data were presented as chlorinity. The conversion is as follows: Salinity = Chlorinity x 1.80655 (Gross 1972)

5.3.2 Fauna

Of the vertebrates only ichthyofauna are restricted to the aquatic environment. Other vertebrates move between the river and floodplain, securing necessary food, water, and shelter from one community or the other. Separation of the two environments into distinct communities is arbitrary and debated in the scientific community (Cowardin et al. 1979).

Mammals. No aquatic mammals frequent the riverine community. Semi-aquatic species likely to occur in this study area will be discussed with the floodplain community (Section 5.4.2).

Birds. See Corpus Christi and Copano-Aransas syntheses (Section 5.4.2) for a listing of birds.

Reptiles and amphibians. Although not truly aquatic, several turtle species are closely associated with the riverine community because they spend most of their time either in the river or resting on protruding logs or masses of vegetation. Species common in the rivers of the San Antonio Bay system are the same typically found in the neighboring Copano-Aransas Bay system. Table 4 lists these species; for a brief discussion of turtle habitat preferences, see the Copano-Aransas synthesis (Section 5.3.2).

Table 4. Representative species of turtles in the riverine community, San Antonio Bay system (Raun and Gehlbach 1972; Conant 1975).

Scientific name	Common name
Chelydra serpentina serpentina	Common snapping turtle
Chrysemys concinna texana	Texas slider
C. scripta elegans	Red-eared turtle
Kinosternon flavescens	Yellow mud turtle
Trionyx spiniferus asperus	Gulf coast spiny softshell

Lizards, semi-aquatic snakes, and amphibians are discussed with the floodplain community (Section 5.4.2).

Fish. Saltwater intrusion extends up the Guadalupe River and, by inference, up the San Antonio River, at least 16 km (Hall et al. 1976). Thus, the lower reaches of the Guadalupe and San Antonio Rivers would be expected to support many marine fish common to Hynes and Guadalupe Bays. This conclusion especially applies to species designated by Hoese and Moore (1977) as marine and frequently entering freshwater. These fish include the southern flounder (Paralichythys lethostigma), spotted seatrout (Cynoscion nebulosus), red drum (Sciaenops ocellatus), Atlantic croaker (Micropogonias undulatus), and sheepshead (Archosargus probatocephalus).

Strictly freshwater species collected by Conner (1977) from the San Antonio and Guadalupe Rivers above tidal influence but within the confines of the Gulf Coastal Plain are presented in Table 5. Conner (1977) collected over 50 fish species in the entire San Antonio River drainage. Although the species diversity of this system is greater than that of the Nueces River system (see Corpus Christi synthesis, Section 5.3.2), the ichthyofauna of these two neighboring drainages have a high affinity (82.6%).

The San Antonio Bay drainage is of particular interest for two reasons. First, the Guadalupe River drainage supports three endemic species: two mosquito fish (Gambusia spp.) and one darter (Etheostoma sp.), all found in springs outside of the Gulf Coastal Plain. Second, the southwesternmost occurrences of several disjunct fish populations from the Mississippi Valley are found in the Guadalupe and San Antonio Rivers (Conner 1977).

Table 5. Representative freshwater fish of the lower San Antonio and Guadalupe Rivers (Conner 1977).

Scientific name	Common name
Astyanax mexicanus	Mexican tetra
Hybopsis aestivalis	Speckled chub
Notemigonus crysoleucas	Golden shiner
Notropis buchanani	Ghost shiner
N. texanus	Weed shiner
Opsopoeodus emiliae	Pugnose minnow
Pimephales vigilax	Bullhead minnow
Carpiodes carpio	River carpsucker
Ictiobus bubalus	Smallmouth buffalo
Ictalurus furcatus	Blue catfish
I. punctatus	Channel catfish
Pylodictis olivaris	Flathead catfish
Noturus gyrinus	Tadpole madtom
Fundulus (Zygonectes) notatus	Blackstripe topminnow
Chaenobryttus gulosus	Warmouth
Lepomis punctatus	Spotted sunfish
L. cyanellus	Green sunfish
Micropterus punctulatus	Western spotted bass
Micropterus salmoides	Largemouth bass
Etheostoma chlorosomum	Bluntnose darter
E. garcile	Slough darter
Percina sciera	Dusky darter

5.4 FLOODPLAIN (PALUSTRINE) COMMUNITY

The floodplain is well developed along the Guadalupe and San Antonio Rivers and has not been altered significantly by agricultural irrigation, the primary justification for water diversion. If the numbers of diversion projects increase, the diversity and abundance of floodplain flora and fauna can be expected to decrease. Vegetative populations begin to decline when deprived of seasonal inputs of nutrient-laden freshwater. Dependent fauna, in turn, are affected by declining quality or quantity of food and shelter, or both. In extreme circumstances, water diversion results in the replacing of a highly productive natural floodplain community with a less productive, cultivated field. Presently, the overall floodplain community of the San Antonio Bay system remains unchanged partly because of the small human population in the area.

Most land along the Guadalupe and San Antonio Rivers is considered floodplain because of seasonal flooding, but small areas along the Guadalupe River are perennially inundated by freshwater. Such areas, dominated by water-tolerant trees, are considered swamps.

5.4.1 Vegetation

The lowest lying areas of the floodplain support grasslike species including rush (*Juncus* spp.), bulrush (*Scirpus* spp.), and common reed (*Phragmites communis*) (McGowen et al. 1976). Other common species are willow (*Salix* spp.) and cattail (*Typha* spp.). Wooded areas at slightly higher elevations consist of a water-tolerant canopy which includes ash (*Fraxinus* spp.), elm (*Ulmus* spp.) and willow (*Salix* spp.). At still higher elevations, such as along levees, the canopy includes pecan (*Carya illinoensis*), hickory (*Carya* spp.), and live oak (*Quercus virginiana*). Understory shrubs, vines, and grasses throughout the floodplain include red haw (*Crataegus viburnifolia*), hackberry (*Celtis* spp.), yaupon (*Ilex vomitoria*), greenbriar (*Smilax* spp.), grape (*Vitis* spp.), Bermudagrass (*Cynodon dactylon*), and carpetgrass (*Axonopus* sp.).

Swamps, covering approximately 1.3 km^2, constitute a small portion of the floodplain community along the Guadalupe River. The tree-dominated vegetation is water tolerant, and one of the major species is bald cypress (*Taxodium distichum*). Cypress, once established, thrives in standing water. This species' distribution is limited mainly by its requirement of exposed mineral soils for germination. Other typical species of the swamp include dwarf palmetto (*Sabal minor*), blackgum (*Nyssa sylvatica*), redbay (*Persea borbonia*), and willow (*Salix* spp.). Swamps in the study area are supplied with water from stream overbanking during floods, and year-round seepage from the Guadalupe River system (McGowen et al. 1976).

5.4.2 Fauna

Mammals. Common mammals in the San Antonio Bay system are similar to those in the floodplain community of the Corpus Christi Bay system. Differences in the fauna of the two systems revolve around the furbearers. The river otter (*Lutra canadensis*) reaches its southern limit in the San Antonio Bay system. Also, the mink (*Mustela vison*) is probably more common in this area than in the Corpus Christi area since the San Antonio Bay system is not on the periphery of the mink's natural range (Davis 1974).

Lagomorphs such as the swamp rabbit (*Sylvilagus aquaticus*) and eastern cottontail (*S. floridanus*) live in the swamp along the Guadalupe River (Davis

1974). The nutria (*Myocastor coypus*), a large rodent introduced to the United States from South America, is also found there.

Birds. See Corpus Christi and Copano-Aransas syntheses (Section 5.4.2) for a listing of birds.

Reptiles and amphibians. All species of reptiles and amphibians discussed in the Corpus Christi synthesis can be expected to occur in the San Antonio Bay area. However, the Corpus Christi area represents a southernmost limit for several species, including the five-lined skink (*Eumeces fasciatus*), mud snake (*Farancia abacura*), speckled king snake (*Lampropeltis getulus holbrooki*), western cottonmouth (*Agkistrodon piscivorous leucostoma*), Woodhouse's toad (*Bufo woodhousei woodhousei*), and Fowler's toad (*B. woodhousei fowleri*) (Raun and Gehlbach 1972; Conant 1975). Densities and population sizes of these species may be slightly larger in the nonmarginal habitats of the more northerly San Antonio Bay area.

The squirrel treefrog (*Hyla squirella*) and Strecker's chorus frog (*Pseudacris streckeri streckeri*) are common in the San Antonio Bay area but do not extend as far south as the Corpus Christi area. The squirrel treefrog is common in the wooded floodplain and, within its range, thrives anywhere adequate food, water, and shelter are available. Strecker's chorus frog, an early spring breeder, also uses a variety of habitats, including floodplains and swamps (Conant 1975).

5.5 UPLAND COMMUNITY

The term "upland," as used in these syntheses, includes those areas at elevations and distances far enough from bays and rivers to avoid flooding under normal conditions. Because the established boundaries of the San Antonio Bay system follow the general course of the confluent San Antonio and Guadalupe Rivers, the area of upland in this system is relatively small. A portion of the Aransas National Wildlife Refuge is within the upland area of the San Antonio Bay system. The coastal grasslands and scattered oak mottes of the refuge provide excellent habitat for a variety of mammals and birds.

The upland community is used predominantly for agriculture and pasture. Extensive irrigation systems have been developed in agricultural areas, particularly for rice fields (McGowen et al. 1976). Any nutrient losses to the estuarine community because of diverted water flow for irrigation are more than replaced by runoff from cultivated fields and municipal effluents.

5.5.1 Vegetation

Although the areal extent of the upland community in the San Antonio Bay system is less extensive than that of either the Corpus Christi or Copano-Aransas Bay areas, the same general vegetational elements are found in all three. According to McGowen et al. (1976), grasses are the major vegetation, with Mann's (1975) bunchgrass-annual forb assemblage the dominant vegetative association. According to these authors, typical species include seacoast bluestem (*Schizachyrium scoparium littoralis*), indiangrass (*Sorghastrum* spp.), and balsamscale (*Elyonurus tripsacoides*).

In the upland area between the San Antonio and Guadalupe Rivers, brushy vegetation, including live oak (Quercus virginiana), is predominant. With Mann's (1975) designations, shrub areas would be termed mesquite-buffalograss or chaparral-bristlegrass associations. Chaparral is a general term for scrubby vegetation forming a shrub canopy. Collectively, species such as huisache (Acacia farnesiana), blackbrush (A. rigidula), agarito (Berberis trifoliolata), and brasil (Condalia hookeri), all occurring in the area, are considered chaparral (Mann 1975). A more detailed account of upland vegetation, its recent changes, and reasons for those changes are given in the Copano-Aransas synthesis, Section 5.5.1.

Oak mottes and oak brushlands are common on Blackjack Peninsula within the Aransas National Wildlife Refuge. Although live oak is predominant, blackjack oak (Quercus marilandica), laurel oak (Q. laurifolia), redbay (Persea borbonia), wax myrtle (Myrica cerifera), and yaupon (Ilex vomitoria) are common (White 1973).

5.5.2 Fauna

Mammals. Predators in the upland community include the coyote (Canis latrans), bobcat (Lynx rufus), and occasionally the gray fox (Urocyon cinereoargenteus) (White 1973). Outside the Aransas National Wildlife Refuge, these species are hunted or trapped for their fur. Other commercially valuable furbearers in this study area are the opossum (Didelphis virginiana), raccoon (Procyon lotor), striped skunk (Mephitis mephitis), and eastern spotted skunk (Spilogale putorius) (Davis 1974). The Texas Parks and Wildlife Department (TPWD 1979b) lists harvests only by Ecological Area; consequently, no estimates of dollar value or number of pelts can be made for the San Antonio Bay system.

One trophic level below the carnivores, the highly prolific rodents and lagomorphs provide a vital food source for predaceous mammals and birds. Table 6 lists species typical of the San Antonio Bay system. When rodents common to the three neighboring drainages of Corpus Christi, Copano-Aransas, and San Antonio Bays are compared, a trend of decreasing diversity, from south to north, appears to exist.

Table 6. Representative rodents and lagomorphs in the upland community, San Antonio Bay system (Davis 1974).

Scientific name	Common name
Spermophilus mexicanus	Mexican ground squirrel
Geomys bursarius	Plains pocket gopher
Perognathus hispidus	Hispid pocket mouse
Reithrodontomys fulvescens	Fulvous harvest mouse
Baiomys taylori	Pygmy mouse
Peromyscus maniculatus	Deer mouse
P. leucopus	White footed mouse
Sigmodon hispidus	Hispid cotton rat
Neotoma micropus	Gray wood rat
Lepus californicus	California jackrabbit
Sylvilagus floridanus	Eastern cottontail

The major big game species in the community is the white-tailed deer (Odocoileus virginianus). From 1973 through 1977, the average annual harvest of antlered and antlerless deer from counties lying within, or overlapping into, the San Antonio Bay area was 803 (TPWD 1978c). Hunting pressure for the area averaged 30.5 hunters per 1,000 ha, slightly above the 28.6 average for the gulf prairies and marshes (TPWD's Ecological Area in which the majority of the Texas Barrier Islands Region is located). A discussion of deer populations in the Aransas National Wildlife Refuge and Welder Wildlife Refuge located in the Copano-Aransas area (see Copano-Aransas synthesis, Section 5.5.2) illustrates the variability of the white-tailed deer diet in different habitats. The flexibility of its diet helps explain the success of this species in the face of large-scale habitat decline.

Birds. See Corpus Christi and Copano-Aransas synthesis, Section 5.5.2, for a listing of birds.

Reptiles and amphibians. Reptilian species in the upland community of this study area are nearly identical to those in the more southerly Copano-Aransas area. Those few species whose ranges do not extend north as far as the San Antonio Bay system are mentioned in the Copano-Aransas synthesis, Section 5.5.2. A discussion of amphibians adapted to the dry upland community is presented in the Corpus Christi Bay synthesis, Section 5.5.2.

5.6 RARE AND ENDANGERED VERTEBRATES AND INVERTEBRATES OF THE SAN ANTONIO BAY STUDY AREA[2]

5.6.1 Mammals

No currently endangered or threatened mammal listed by USFWS (1978) is known to occur presently in the area, but two species currently are being considered for endangered status: the river otter and the bobcat.

Lutra canadensis texensis - river otter. The marshes and floodplains of the San Antonio Bay system are considered the southwesternmost extent of the normal range of the river otter by Hall and Kelson (1959) and Davis (1974). A recent survey of the Texas population of this species (TPWD 1979c) did not extend to this area. Trapping records (see Galveston synthesis) indicate no short-term decline in the Texas population of this species.

Lynx rufus texensis - bobcat. The TPWD (1977) estimated a minimum of 125,000 and a maximum of 300,000 bobcats in the State, including the north Texas subspecies Lynx rufus baileyi. The TPWD (1977) discusses several Texas studies which indicate that the population did not decline as a result of either predator control (killing or live-trapping of a species to protect livestock, poultry, or other wildlife species) or fur-trapping. The latter is

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[2] The status for each rare and endangered species is listed for three agencies: Texas Organization for Endangered Species (TOES), Texas Parks and Wildlife Department (TPWD), and the U.S. Fish and Wildlife Service (USFWS). Status designations include: Endangered (E), Threatened (T), and except for the USFWS, Peripheral (P). Additional designations of Status Undertermined (SU) and Not Considered (NC) are from Gustavson et al. (1978)

a relatively recent phenomenon, and until 1972 few pelts were sold. Table 7 includes data on the Texas harvest and average price paid per pelt. Although the data indicate that the number harvested has increased, TPWD (1977) explains that in previous years kills went unreported because there was no economic incentive to bring in pelts or report kills. Those bobcats taken by licensed trappers also have not increased in terms of the percentage of total fur harvest in the area. The TPWD concludes (1977) that bobcat harvest by fur trappers is restricted to incidental catch, and the apparent increase in total number of bobcat pelts reflects the increased economic incentive to bring in the pelts.

Table 7. Texas bobcat harvest and average prices paid per pelt for selected years (TPWD 1977).[a]

Year	No. pelts	Average price paid ($)
1926	0	0.00
1936	25	0.00
1946	1,508	0.00
1956	3	0.00
1966	16	0.00
1971	Unknown	0.00
1972	1,393	12.00
1973	7,145	20.00
1974	11,874	25.00
1975	9,454	40.00
1976	15,898	75.00

[a] Other years and average price paid/pelt include: 1939 ($0.63); 1940 ($1.00); 1941 ($0.60); 1963 ($1.00); and 1964 ($1.00). More recently TPWD (1979d) estimated that $1.5 million were paid by fur dealers to Texas trappers during the 1977-1978 harvest season.

Ursus americanus americanus and U. a. luteolus - black bear. The black bear is believed to be extirpated from the area (Davis 1974). Due to the paucity of suitable habitat, it is doubtful whether large populations ever existed in the San Antonio Bay study area. TOES = E, TPWD = NC, USFWS = NC.

Felis yagouaroundi cacomitli - jaguarundi; and F. pardalis albescens - ocelot. These species are thought to have been extirpated from this area for some time (Davis 1974), but the TPWD (1979d) recently reported sightings of both. One jaguarundi and one ocelot were observed in Aransas County in 1977, and five sightings of jaguarundi have been made at the Aransas National Wildlife Refuge, the last being made in 1969 (TPWD 1977). The National Fish and Wildlife Laboratory (1980) reported two jaguarundis at Aransas National Wildlife Refuge, but does not acknowledge the ocelot sighting (also see Laguna Madre synthesis). Jaguarundi: TOES = P, TPWD = NC; Ocelot: TOES = P, TPWD = E.

Felis concolor stanleyana - cougar. Two cougar sightings have been made at the Aransas National Wildlife Refuge (TPWD 1979d). These sightings represent the northeasternmost confirmed sightings within the Texas Barrier Islands Region (TPWD 1979d). TOES = E, TPWD = NC, USFWS = NC.

For rare and endangered marine mammals, see the Laguna Madre and Marine syntheses.

5.6.2 Birds

Haliaeetus leucocephalus leucocephalus - southern bald eagle. The floodplain of the San Antonio and Guadalupe Rivers is one of two southern bald eagle nesting concentrations in Texas. The other is along the floodplain of the Brazos River in the neighboring Matagorda-Brazos study area (TPWD 1979a). Of the seven active nests in Texas during 1977 and 1978, four were in the San Antonio Bay study area. In 1977, these nests produced five juveniles and, in 1978, three juveniles, out of statewide totals of ten and nine, respectively (TPWD 1979a). Since 1971 when the TPWD began monitoring bald eagle nesting activity, the number of nests and degree of nesting activity have increased slightly (TPWD 1979a). Also, see Matagorda-Brazos study area synthesis. TOES = E, TPWD = E, USFWS = E.

Grus americana - whooping crane. The San Antonio and Copano-Aransas study areas are the wintering grounds for 69 of the 75 individuals which constitute the world's population of wild whooping cranes (National Fish and Wildlife Laboratory 1980). A detailed account of this species appears in the Copano-Aransas synthesis. TOES = E, TPWD = E, USFWS = E.

Pandion haliaetus carolinensis - osprey or fish hawk. This species typically migrates through the area twice a year. One hundred and twenty-seven sightings have been recorded for counties within and overlapping into the San Antonio Bay study area from 1971 through 1976 (TPWD 1976). According to these sighting records, many of which are repeat sightings, the San Antonio and Matagorda-Brazos study areas and the lower Rio Grande River valley appear to have the highest concentrations. Also see the Matagorda-Brazos synthesis. TOES = E, TPWD = NC, USFWS = SU.

Falco peregrinus tundrius - arctic peregrine falcon. This winter migrant regularly appears in the area although its populations are low. Matagorda Island is one of three survey areas along the Texas coast monitored by the TPWD. In 1973, 195 individuals were recorded there, but by 1976 the number decreased to 84 (TPWD 1978a). Also see Matagorda-Brazos, Galveston, and Laguna Madre syntheses. TOES = E, TPWD = E, USFWS = E.

Pelecanus occidentalis carolinensis - brown pelican. One of the two active brown pelican colonies in 1976 was on Second Chain of Islands in San Antonio Bay near Mesquite Bay (Blacklock et al. 1978). The population that year consisted of eight breeding pairs. In comparison, there were no breeding pairs the previous year, four pairs in 1974, and six pairs in 1973 (Blacklock et al. 1978). The TPWD (1978b) reports that brown pelican nesting sites historically were located on First Chain of Islands and Steamboat Island in Espiritu Santo Bay, Bird Island in San Antonio Bay, and Belden Cut and Third Chain of Islands in Mesquite Bay. See Corpus Christi and Copano-Aransas syntheses for additional nesting sites and discussion of events leading to the present small population. TOES = E, TPWD = E, USFWS = E.

Tympanuchus cupido attwateri - Attwater's greater prairie chicken. The present range of this species extends into the San Antonio Bay system and covers parts of Victoria, Goliad, Refugio, and Aransas Counties (National Fish and Wildlife Laboratory 1980). See Matagorda-Brazos synthesis for population estimates and causes of decline. TOES = E, TPWD = E, USFWS = E.

Other rare birds. Several additional species are rare in the area but more abundant elsewhere. These peripheral species are listed in the discussions on the Laguna Madre, Matagorda-Brazos, and Galveston study areas.

5.6.3 Amphibians

No rare, threatened, or endangered amphibians listed in USFWS (1978) or Gustavson et al. (1978) are indigenous to the area.

5.6.4 Reptiles

Alligator mississippiensis - American alligator. Joanen (1974, cited in National Fish and Wildlife Laboratory 1980) and TPWD (1975) reported that alligators were present in all the counties within the San Antonio Bay study area. Both reports indicated that local populations are increasing. Table 8 presents population estimates for the area. TOES = E, TPWD = E, USFWS = E.

Table 8. Estimated alligator populations for counties in the San Antonio study area, 1974 (TPWD 1975).[a]

County	Population	Trend estimate
Aransas	114	Increasing
Calhoun	317	Stable
Goliad	26	Increasing
Refugio	154	Increasing
Victoria	217	Increasing

[a] Totals for counties include areas overlapping into other study areas. The total estimated population is 828 or approximately 2% of the estimated statewide population.

Malaclemys terrapin littoralis - Texas diamondback terrapin. This species is listed by TOES as threatened and is known to occur in the area. A complete discussion is included in the Galveston synthesis.

For endangered sea turtles, see Laguna Madre and Marine syntheses.

5.6.5 Fish

There are no reported findings of any of the threatened or endangered fish species listed, proposed, or under review by the USFWS (USFWS 1978; Deacon et al. 1979).

5.6.6 Invertebrates

No invertebrates listed (USFWS 1978) are indigenous to the Texas coast (see Matagorda-Brazos synthesis for references consulted).

5.7 RARE AND ENDANGERED PLANTS OF THE SAN ANTONIO BAY STUDY AREA

Gustavson et al. (1978) provided a listing of rare and endangered plants along the Texas coast which includes several that are rare in the San Antonio bay system as well as in the State, but which are more broadly distributed elsewhere.

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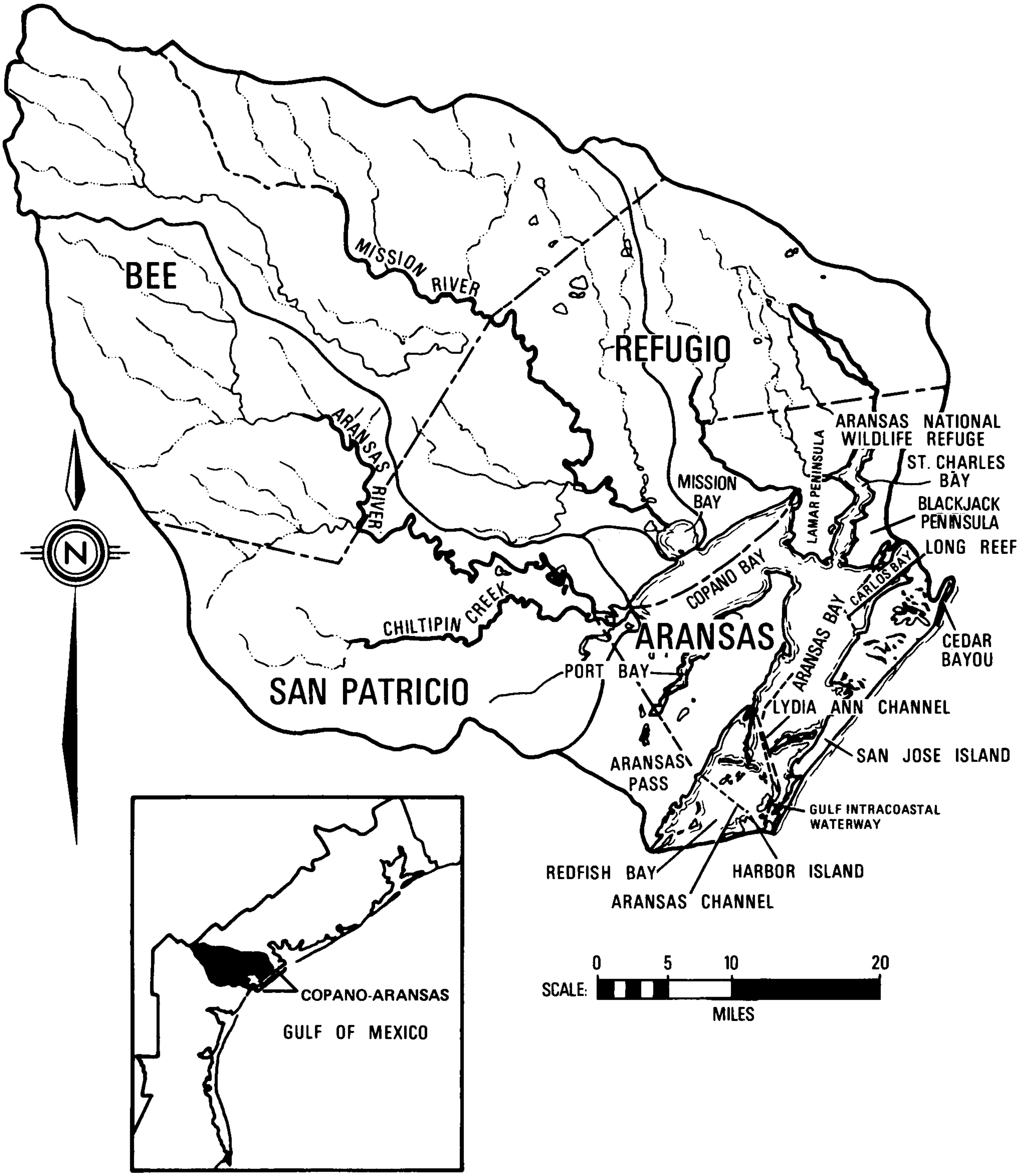
COPANO-ARANSAS STUDY AREA SYNTHESIS



Map 5. Copano-Aransas study area.

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1.0 INTRODUCTION

The most distinguishing feature of the Copano-Aransas system is the paucity of riverine input by the Mission and Aransas Rivers to the estuarines. Copano-Aransas averages the lowest absolute freshwater inflow of the six coastal Texas systems (Martinez 1975). On a ratio of riverine inflow to volume of the receiving basin, the Copano-Aransas system ranks fifth, having a smaller input ratio than all study areas except Laguna Madre.

Salinities fluctuate rapidly in the bays of the study area. However, hypersaline conditions, so prevalent in Laguna Madre, usually do not occur in Copano-Aransas, partially through increased rainfall, but primarily through the continuous influx of low salinity water from the San Antonio Bay system. The salinity stabilization afforded by the San Antonio Bay area helps make the Copano-Aransas system productive in commercially important finfish, although shellfish harvests are lower.

Just as the rivers help shape the character of the estuaries, rivers also influence terrestrial areas. In this system, the rivers formed small floodplains because of their limited flows and narrow meander belts. Fluvial land provides habitats for diverse fauna, but the small area limits viable populations to relatively small numbers. More elevated and drier habitats constitute the upland community, a more extensive area than the floodplain.

Floral and faunal components of this system closely resemble those of two neighboring systems: San Antonio Bay to the north and Corpus Christi Bay to the south. These three areas have definitely separate drainages, but the latitudinal proximity precludes any major species differences in terrestrial organisms. For this reason the reader frequently is referred to one or the other of the neighboring systems for pertinent discussions.

Human populations are relatively small in this study area. As a result, water quality problems caused by the three municipal wastewater treatment plants are less severe than in more highly populated areas. Industrialization is also minor in the Copano-Aransas system, with no commercial outfalls on the bays themselves (Matlock and Weaver 1979). Herbicide and pesticide runoff from agricultural lands does cause some pollution, but cattle grazing is more dominant than cultivation. According to the Texas Parks and Wildlife Department (TPWD), the problems related to cattle grazing are upland erosion and subsequent shoaling of bays, which occur only with overgrazing (TPWD 1975a).

2.0 GEOLOGY

2.1 GEOLOGIC ORIGIN AND PROCESSES - ESTUARINE AND RIVERINE TRANSPORT OF SEDIMENT

The morphogenesis of the surface deposits in the Copano-Aransas system is similar to that discussed in the Corpus Christi and San Antonio syntheses. The landscape of the Copano-Aransas study area has been formed largely by riverine processes from the late Pleistocene to the present. Most present drainage systems, including the Aransas and Mission Rivers, occupy distributaries of ancient courses of the Nueces and San Antonio-Guadalupe systems (Brown et al. 1976; McGowen et al. 1976).

At the end of the Pleistocene, the Aransas and Mission Rivers joined and flowed eastward from the present Copano Bay across the Continental Shelf (Brown et al. 1976). The Holocene rise in sea level flooded the Aransas-Mission River Valley, and subsequent riverine depositions, erosion of bay shoreline, and the formation of San Jose Island are responsible for the present configuration.

The collection of suspended sediment data for the Aransas and Mission Rivers has been fragmentary, and no long-term average can be derived. Data presented by Cook (1970) indicate that the suspended sediment load is probably less than 100 x 10^6 kg/yr and represents the smallest riverine input of sediment into any of the drainage areas in the Texas Barrier Islands Region.

While sediment transport through tidal passes obviously occurs (e.g., Harbor Island tidal delta), no estimates of the amount of transport are available. Similarly, hurricanes and lesser storms are known to transport sediment through the passes and over the barrier islands, but no data quantifying their contribution are known. Examples providing evidence of this latter process are sometimes striking, as is the upper portion of San Jose Island, surficially largely composed of a washover fan overlying a tidal delta (Andrews 1970, cited in McGowen et al. 1976).

San Jose Island is separated from Mustang Island by Lydia Ann Channel and Aransas Pass, and from Matagorda Island by Cedar Bayou. The island was formed in the same manner as the other barrier islands (see Corpus Christi synthesis) and is currently in an erosional phase (McGowen et al. 1976).

The late Pleistocene barrier-strandplain, known as the Ingleside, is represented in the Copano-Aransas study area by Live Oak Ridge and Live Oak Peninsula to the southwest of Copano Bay, Lamar Peninsula between St. Charles and Copano Bays, and Blackjack Peninsula, located between St. Charles and Mesquite Bays and extending to San Antonio Bay. The alternating live oak and fresh marsh communities on the Ingleside provide important habitat (also see Section 2.1 and 2.4 of the Corpus Christi Bay synthesis). The lineation of these communities is more pronounced here than to the south, because of the lessened influence of wind activity (Brown et al. 1976; McGowen et al. 1976), which tends to erode the ridges (live oak community) and fill in the swales (fresh marsh community).

2.2 SOILS

As the dominant geologic processes involved in the formation of the Copano-Aransas study area are the same as those of the Corpus Christi Bay study area, their soil development is similar. While no major changes in soil groups occur, the influence of wind-driven processes gradually declines in an upcoast direction. In the Copano-Aransas study area, the discontinuous loess mantle evident in the southern portion of the Corpus Christi Bay study area is absent (Brown et al. 1976; McGowen et al. 1976). The reader is referred to the Corpus Christi Bay synthesis for a review of major soil types and associated geologic formations.

2.3 TOPOGRAPHIC AND BATHYMETRIC FEATURES

Consistent with the other basins in the Texas Barrier Islands Region, topographic relief is slight in the Copano-Aransas system. Burkes Ridge in Bee County reaches an elevation of nearly 50 m along the inland boundary of the Copano-Aransas system and is one of the highest elevations in the Texas Barrier Islands Region. A maximum elevation of 30 m is more typical of the inland boundary and results in a slope of 0.5 m/km to the present coastline.

The various bays comprising the Copano-Aransas study area are shallow and are comparable to other bays along the Texas coast. Mission Bay is the shallowest, averaging only 0.6 m in depth (Diener 1975). The progradation of the bay head delta of the Mission River provides evidence that Mission Bay gradually is being altered in favor of more terrestrial environments. Port Bay is only slightly deeper, averaging 0.7 m, while St. Charles Bay averages 1.1 m in depth (Diener 1975). Nearly one-third of Copano Bay exceeds 2.5 m in depth, but the numerous reefs which aggrade nearly to the water's surface result in an average depth of 1.2 m (Diener 1975; McGowen et al. 1976). Aransas Bay is somewhat deeper, averaging 2.3 m in depth, with maximum depths of 8 m occurring in Lydia Ann Channel (Diener 1975; McGowen et al. 1976). Between the deeper Aransas and Corpus Christi Bays lies the shallow (average = 0.6 m) Redfish Bay area which contains dense seagrass beds and extensive tidal flats (also see Section 2.4 and 5.1.1).

Other than Burkes Ridge, which rises nearly 20 m above the surrounding area, few examples of conspicuous topographic relief exist. At the entrenched valleys of the Aransas and Mission Rivers, a bluff face with a maximum rise of 10 m may be observed along the lower reaches. The Ingleside barrier-strandplain complex commonly rises a few meters above the surrounding marshes.

2.4 UNIQUE OR UNUSUAL STRUCTURES

The fresh marshes and live oak groves on the Ingleside barrier-strandplain are extensively used by diverse fauna. The Aransas National Wildlife Refuge is on a segment of this geologic feature (see Section 2.1 and 2.4 of Corpus Christi Bay synthesis).

Before the dredging and construction of jetties along Aransas Pass, a naturally maintained, unstable channel had been in the vicinity for 2,000 years (Hoover 1968, cited in Brown et al. 1976). Although the formation of flood and ebb tidal deltas is typical of well-established passes along barrier island coasts, the size of the Harbor Island flood tidal delta is unusual. A complex vegetational community of emergent marsh, algae-covered wind-tidal flats, and submerged seagrasses has evolved on this tidal delta (also see Section 5.1.1). One key element associated with the size and emergence of this tidal delta is sediment deposited during abnormally high water stages associated with storm activity (Hoover 1968, cited in Brown et al. 1976).

Along the upper end of San Jose Island, an abandoned flood tidal delta has been covered by a large washover deposit (Andrews 1970, cited in McGowen et al. 1976). The development of this feature is associated with hurricanes, which frequently breach the island in this area and transport barrier island sands to the lee side of the island and into the bay. In comparison to the

Harbor Island tidal delta, the northeastern San Jose Island washover fan has lower species diversity. Wind-tidal flats are extensive, but emergent marshes and seagrass beds are not abundant (McGowen et al. 1976). Beach ridge habitat containing grasses and woody vegetation which are less water tolerant (see Section 5.2.1) is more prevalent on the washover fan feature than in the tidal delta.

2.5 MAN-MADE DEVELOPMENTS

Man's impact as a geologic agent in the Copano-Aransas study area has been comparatively small in relation to the rest of the Texas Barrier Islands Region. The impacts are similar to those discussed in several of the other syntheses and include dredging of channels and disposal of associated spoil; the use of fresh water surface flow for agricultural, municipal, and industrial needs; and the conversion of natural upland prairie to agriculture. The Harbor Island-Redfish Bay area is an important finfish and macroinvertebrate nursery and a concentrated waterfowl wintering area (TPWD 1975b). This area also has a high concentration of artificial channels and associated spoil deposits. The natural Lydia Ann Channel has been altered by the dredging of Aransas Pass. The Corpus Christi Ship Channel and Aransas Channel are joined with Aransas Pass, and the Gulf Intracoastal Waterway (GIWW) intersects the other two major dredged channels in Redfish Bay. The spoil deposits associated with these channels inhibit estuarine sediment transport over the tidal flats and reduce access to the area by aquatic fauna (Brown et al. 1976). The Port Aransas Causeway almost completely divides the Aransas Bay side from the Corpus Christi Bay side (Brown et al. 1976) and retards circulation, sediment transport, and movements of aquatic fauna.

3.0 CLIMATE

The Copano-Aransas system is transitional between the semi-arid climatic zone to the west and southwest and the subhumid climatic zone to the north and northeast. On a larger scale, the entire Texas Barrier Islands Region is an example of the transition from a humid climate (Galveston Bay system) to a semi-arid climate (Laguna Madre system). Although abrupt changes in climate inland from coastlines are fairly commonplace (especially where mountains are present), the variations in climate along this geomorphically similar coast are relatively uncommon.

The increasing aridity as one proceeds in a downcoast direction along the Texas Barrier Islands Region is caused by a decreasing precipitation and increasing mean temperature. These climatic features, in turn, are caused primarily by the position of this coastline in relation to the Bermuda high pressure cell and the general path of midlatitudinal frontal activity (e.g., cold fronts).

3.1 PRECIPITATION

According to the National Oceanic and Atmospheric Administration (NOAA), the annual precipitation normal in the Copano-Aransas Bay is 835 mm (NOAA

1973a). The length of coastline within this study area is not sufficient to determine if rainfall decreases in a downcoast direction, but comparison with annual precipitation over the coastal areas of the neighboring San Antonio Bay and Corpus Christi Bay study areas indicates that such a trend probably exists. Precipitation also decreases in an inland (northwesterly) direction from the coast, as the annual precipitation normal for Beeville (approximately 90 km inland from the coastline) is 734 mm.

The seasonal distribution of precipitation over the Copano-Aransas study area is bimodal (Figure 1). The weather regimes responsible for the maxima in precipitation and the differences in the magnitude of the maxima are addressed in the Corpus Christi Bay and Matagorda-Brazos syntheses.

3.2 TEMPERATURE

Mean annual temperature in the Copano-Aransas Bay area is 21.5° C (NOAA 1971-1979, 1973a). Mean annual temperature at the inland location of Beeville is nearly the same, 21.4° C. The two areas differ slightly seasonally: Beeville is 0.7° C lower in winter and 0.9° C higher in summer than the immediate coastal area.

The milder winter temperatures along the coast are reflected by the length of the growing season, which averages 310 days. Inland, in the Beeville area, the average growing season is 290 days (Orton 1964).

The climatic water budget (Thornthwaite and Mather 1955) better represents the demand for water by the natural environment than either temperature or precipitation data alone. Orton (1969), using the noncontinuous method, showed that the Copano-Aransas study area averages a net (surpluses minus deficits) annual moisture deficiency of 330 mm along its eastern margins and 410 mm along its western and inland boundaries.

Figure 2 shows the seasonal distribution of the 330-mm net annual moisture deficit. A long deficit period begins in March and extends through October. While small surpluses normally can be expected during the winter months, the soil is seldom fully saturated (see Laguna Madre, Matagorda-Brazos, and Galveston Bay syntheses for comparative seasonal water budgets).

3.3 WIND PATTERNS

The Copano-Aransas study area and other Texas coastal basins are influenced primarily by three distinct wind regimes: southeasterly to southerly, northerly, and the highly variable winds associated with tropical disturbances. (See the Matagorda-Brazos and Laguna Madre syntheses for general environmental responses; Galveston Bay and Corpus Christi Bay syntheses for comparative wind frequencies along the coast; and Sections 2.1 and 4.2 of this synthesis for the influence of wind on geologic and hydrologic processes, respectively, in the Copano-Aransas study area.)

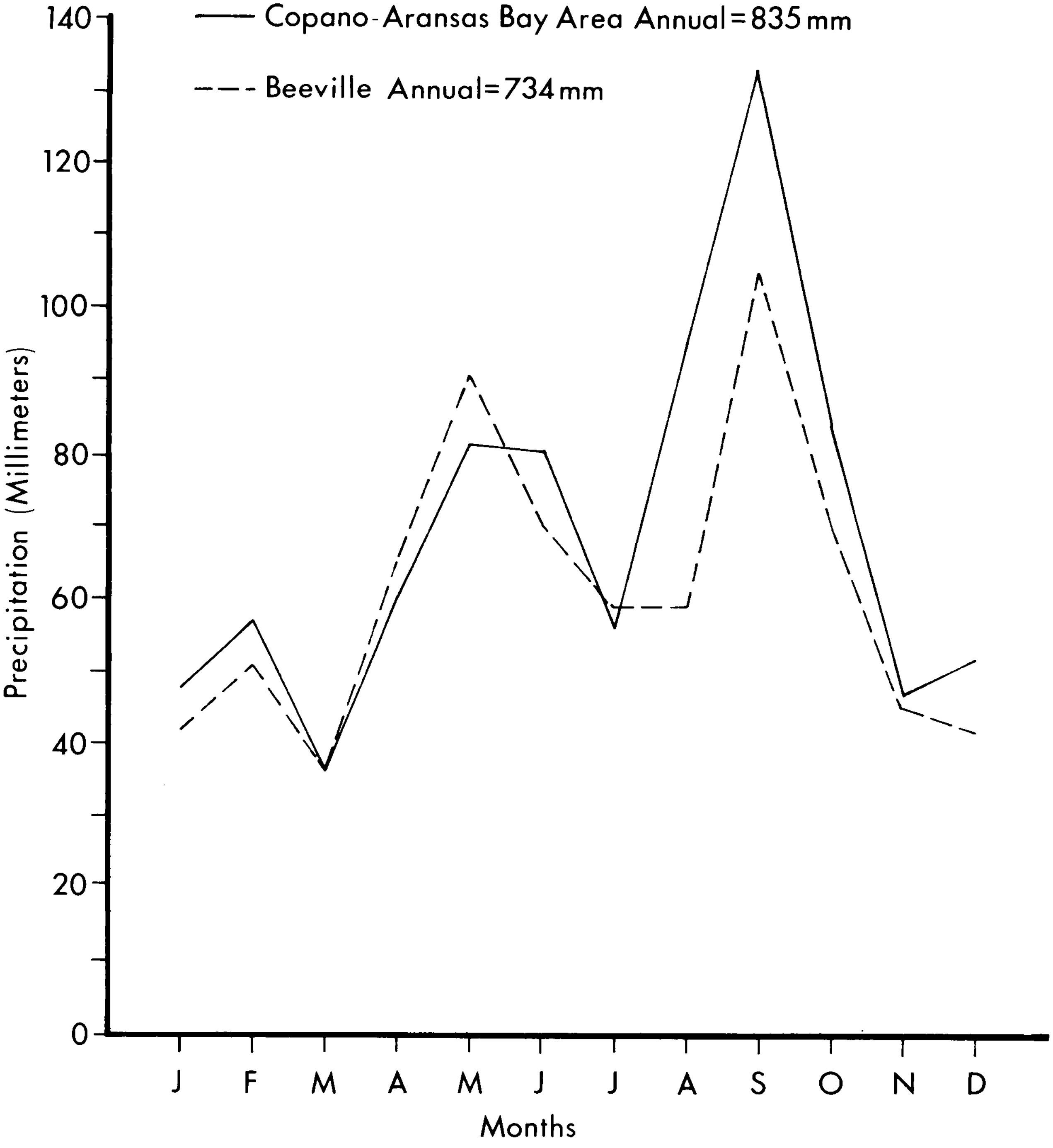

Figure 1. Mean seasonal precipitation in the Copano-Aransas area. Copano-Aransas Bay area rainfall was determined by comparison of the precipitation normals at Corpus Christi and Austwell Refuge with shorter period data sets from Aransas Pass, Fulton, and Rockport (NOAA and ESSA 1960-1978; NOAA 1973a).

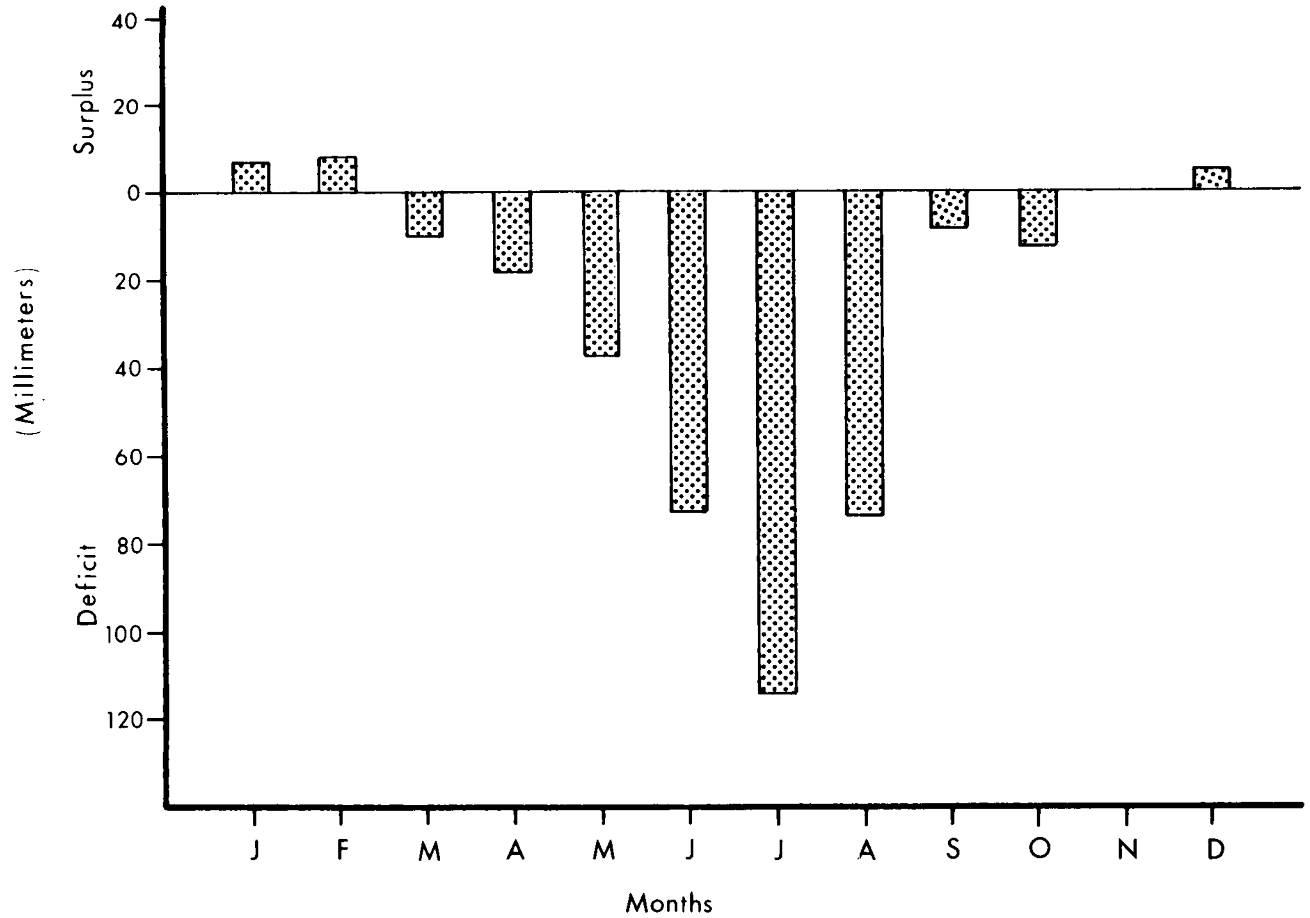

Figure 2. Mean seasonal noncontinuous water budget for the eastern Copano-Aransas area, 1941-1970, calculated using the Thornthwaite and Mather (1955) method. Precipitation and temperature data from NOAA and ESSA (1960-1978) and NOAA (1973a).

4.0 HYDROLOGY AND HYDROGRAPHY

4.1 TIDAL INFLUENCES - SALINITY REGIMES

Gravitational tides in the Copano-Aransas estuary are similar to those in all the estuaries along the Texas coast. Tides are small in magnitude and generally have a diurnal period. Maximum tidal range occurs in the Aransas Pass area, but the average tidal range is only 25 cm (TPWD 1975a). Most of the tidal pulse enters and exits from the system through Aransas Pass, and a substantial but unknown amount of tidal exchange occurs between the Copano-Aransas and the San Antonio Bay study areas via Mesquite Bay (TPWD 1975a).

Although Aransas Bay is one of the deeper bays along the Texas coast, it is still relatively shallow, averaging 2.3 m (Diener 1975). This shallowness contributes to tidal attenuation, resulting in a mean tidal range nearly 50% of that occurring at Aransas Pass (Diener 1975). Copano Bay is located farther from the gulf than Aransas Bay. This increased distance and the generally shallow nature ($\bar{x}$ depth = 1.1 m) of Copano Bay reduces mean tidal range to 9 cm (Diener 1975). Secondary bays, like Port, St. Charles, and Mission, generally have tidal ranges less than 6 cm (Diener 1975).

The effects of the deepening of Aransas Pass and the dredging of the Gulf Intracoastal Waterway (GIWW) on tidal exchange in the Copano-Aransas study area have not been adequately addressed. Impact studies pertaining to the proposed Harbor Island Deepwater Port project do not address possible perturbations in the tidal exchange specifically, but Henley and Rauschuber (1978) predicted an increase in the magnitude of density currents within the dredged channels and therefore an increase in saltwater intrusion. Based on studies examining the effects of dredged channels elsewhere along the Texas coast (see Laguna Madre, Corpus Christi Bay, Matagorda-Brazos and Galveston Bay syntheses), one can expect the construction of deeper tidal passes and the GIWW to reduce the rate of tidal attenuation.

The effect of wind and related variables on water flux is often greater than that of gravitational tides along the Texas coast. The prevalence of both north and south winds and the relatively rapid change from one direction to the other result in frequent and often large-scale changes in water flux.

Although northerly winds are commonly associated with cold fronts in winter, Muller (1977) and Muller and Wax (1977) showed that northerly components of wind occur year-round with a fairly high incidence along the Louisiana coast. The incidence of northerly winds during summer is not as great along the coastal bend region of Texas as along the Louisiana coast; but these winds do occur with greater regularity (e.g., wind direction frequencies at Port Aransas) than the reports of several investigators tend to indicate (e.g., Brown et al. 1976). According to Brown et al. (1976) northerly winds result in depressed water levels throughout much of the Copano-Aransas area, except along the bay shoreline of San Jose Island (also see Section 4.2). Although no known reported measurements document the magnitude of change in water level resulting from the wind direction changes for the Copano-Aransas study area, these water level changes are expected to be of the same magnitude as those of the neighboring Corpus Christi Bay and San Antonio Bay study areas, where a strong cold front can result in a water level of 45 cm.

Seasonal changes in water levels are fairly regular from year to year, and the magnitude of these changes typically exceeds average tidal range for estuaries along the northern Gulf of Mexico. This seasonal cycle is a gulf-wide phenomenon and, though some intraregional differences occur, the cycle is typically bimodal, with maximum monthly mean water levels in the spring and fall, and minimal levels in winter and summer (see Laguna Madre and Galveston Bay syntheses for examples). The water level cycle was first described by Marmer (1954), and the processes responsible for the seasonal change in water flux were discussed by Whitaker (1971) and Sturges and Blaha (1976). The importance of the seasonal cycle to biological resources has never been adequately documented. The abrupt change from fall maximum to winter minimum may, for example, be a factor that induces faunal movements. The fall maximum and the early stages of the spring maximum correspond with the solar equinoxes and, therefore, periods of minimum tidal range. This combination of high water and minimum tidal range results in maximum inundation, which creates maximum access to emergent marshes by aquatic fauna.

Mean annual salinity for the Copano-Aransas Bay area was 16.4 ^{o}/oo from 1965 through 1975 (Martinez 1975), the second lowest value for the entire Texas Barrier Islands Region. Local riverine input is comparatively small (see Section 4.3) and, thus, can not completely explain this low salinity value. One possible explanation is that the Copano-Aransas study area is the only estuarine complex along the Texas coast not having a major navigation channel dredged from the gulf to the mouths of the inflowing rivers. This probably results in comparatively less saltwater intrusion. Another possibility is influence by the less saline waters of the neighboring San Antonio Bay complex. Martinez (1967, 1970-1975) occasionally obtained lower salinity readings in northeast Aransas Bay than at other bay locations. Whether the exchange indicated by the Martinez data has been augmented by the creation of the GIWW is unknown; however, the role of the GIWW as a conduit of freshwater has been documented in East Bay (Galveston Bay study area) and Laguna Madre, and the same role is strongly suspected here.

Copano Bay, because of its proximity to riverine inflow, is typically fresher and has less salinity variability than Aransas Bay. Gunter (1945) found that surface salinities in Copano Bay averaged 9.2 ^{o}/oo, while in Aransas Bay they averaged 20.0 ^{o}/oo. Bottom salinities were slightly greater (9.7 and 21.7 ^{o}/oo, respectively) and indicated some vertical stratification.

The salinity regime in the Copano-Aransas study area is more variable than those in other estuaries along the Texas coast (Martinez 1967, 1970-1975). Because of the small drainage area of the principal rivers (Mission and Aransas) flowing into the study area, salinity response to local rainfall is rapid and a major factor contributing to this variability. Lowest daily salinities, usually recorded in the summer or fall, are associated with short but intense rainfall. It is not unusual, however, for hypersaline conditions to develop during the same months, when periods of little or no rainfall persist for several weeks and coincide with high evapotranspiration rates (Gunter 1945; TPWD 1975a).

4.2 CURRENT AND WATER CIRCULATION PATTERNS

Published reports of circulation in the Copano-Aransas study area are few. Although a considerable amount of local work has been done within the boundaries of the Copano-Aransas area (e.g., Redfish Bay), fewer circulation studies have been done here than in any other estuary along the Texas coast.

The chief avenue for water transport is the Aransas Pass complex (TPWD 1975a; Brown et al. 1976; Henley and Rauschuber 1978). As discussed in the Corpus Christi Bay synthesis, there is a net movement of water from gulf to bay in Aransas Pass. There is also a net movement of water into the Copano-Aransas complex from the San Antonio estuary (TPWD 1975a). These flow movements, combined with local riverine input, necessitate a net flow from Aransas Bay into Corpus Christi Bay via Redfish Bay.

The high rate of erosion along the southwestern shores of Copano and Aransas Bays, compared to that of other shorelines along these bays, indicates that currents may be stronger along the southwestern half of the bay complex. Ward et al. (1979) believed this to be a typical pattern for many Texas estuaries (see Matagorda synthesis, Section 4.2).

Net circulation in the Copano-Aransas complex is probably counterclockwise, implied by the high erosion rate along the southwestern shores. The net movement of flow into the area from the San Antonio Bay complex and out of the Copano-Aransas complex to the southwest also supports a generally counterclockwise circulation.

The diurnal character of the tide in this system and the extremely small tidal range (even in comparison to those of many other Texas estuaries) place importance on nontidal factors such as wind. Circulation in the Copano-Aransas complex, as in the other study areas along the Texas coast, is wind-dominated (Brown et al. 1976). The importance of wind to circulation is a relative factor, however, and not constant.

The bidirectional predominance of wind (north and south) increases the rate of flushing, but the highest degree of flushing is associated with hurricanes. Hurricanes easily can double the volume of water in the bay complex within hours. This increase may be caused by a surge from the gulf due to high winds and the inverse barometric effect, and by a large freshwater inflow due to riverine input and intense rainfall over the bay complex. Heffernan (1971) noted that salinities in Port Bay declined from over 30 $^{0}/oo$ to 0 $^{0}/oo$ as a result of heavy rains associated with tropical storm "Fern" during September 1971. Depending on the geographical relationship of the hurricane to the study area, the wind direction can change 180° in a brief time and induce a mass movement of water from bay to gulf. The permanent tidal passes (e.g., Aransas Pass) are usually incapable of handling these mass movements of water, and ephemeral tidal passes (e.g., North Pass) become functional.

Midlatitudinal frontal passages do not produce the dramatic changes associated with hurricanes but are important in enhancing circulation and are partially responsible for a seasonal increase in flushing during the winter (see Matagorda-Brazos Bay synthesis). The high incidence of polar fronts and the resulting large volume of water which leaves the bay complex are the major factors controlling the orientation of Lydia Ann Channel (Brown et al. 1976).

The predominance of northerly and southerly wind components also results in longshore drift in the nearshore zone of the gulf. The net movement of longshore drift is to the southwest. During summer, winds are predominantly from the southeast, and a convergence zone of longshore drift occurs in the Aransas Pass area (Brown et al. 1976). In other words, longshore drift is to the northwest below this area and to the southwest above it, resulting in sediment deposits in the Aransas Pass area during the summer. As the incidence of northerly and other directional winds increases, the zone of convergence migrates in a southwesterly direction (also see Laguna Madre and Corpus Christi Bay syntheses).

Density currents are believed to be an integral part of circulation in the estuaries of the Texas coast (Ward et al. 1979) but have not been well documented. In Galveston Bay, where reporting is probably the most complete, density current development has been augmented by the Houston Ship Channel (see Galveston Bay synthesis, Section 4.2). The Copano-Aransas study area does not have a major ship channel dredged from the gulf, and density current development is probably less intense here.

In the Copano-Aransas study area, as in other parts of the Texas Barrier Islands Region, man has altered the natural water circulation pattern. Man-induced perturbations include the alteration of natural tidal passes, dredging of the GIWW, spoil disposal, and activities associated with the development of the Harbor Island area. The road constructed from Aransas Pass to Port Aransas restricts water circulation in Redfish Bay (TPWD 1975a). Although this road is not a continuous barrier (in four areas water exchange does occur), it has greatly reduced the areas where water exchange can occur. This and other proposed harbor development projects in the area are serious issues because the Redfish Bay area supports extensive submerged grassbeds and is an important nursery area (TPWD 1975a, 1975b; Henley and Rauschuber 1978).

4.3 DRAINAGE PATTERNS AND FRESHWATER INFLOWS, RIVERINE FLOODING PATTERNS

Of all the study area basins, Copano-Aransas Estuary has the lowest total riverine inflow. Mean riverine inflow of the gaged drainage area (Upper Aransas and Mission Rivers) is only 5.7 m^3/sec (U.S. Geological Survey data, cited in Diener 1975). If the ungaged drainage area is assumed to produce the same amount of surface flow per unit area as the gaged area, the resulting total surface inflow is approximately 12 m^3/sec. This figure results in a ratio of riverine inflow to volume of receiving basin that is the second lowest of all basins in the Texas Barrier Islands Region. This estimated average riverine inflow would take about 2 years to fill an empty Copano-Aransas Bay complex to the mean low water level. In dramatic contrast, the average Mississippi River discharge would fill the same volume in about 14 hours.

Only the Laguna Madre complex receives less riverine inflow than Copano-Aransas. One would expect average salinity values in the Copano-Aransas area to approach those of the hypersaline Laguna Madre. Actually, only the San Antonio complex has a lower mean annual salinity (Martinez 1975). While local rainfall over the Copano-Aransas Bay complex is somewhat greater than over Laguna Madre and may reduce salinities to some extent, the influence of fresher waters originating from the San Antonio Bay complex is more important in maintaining low salinities (TPWD 1975a).

The seasonal distribution of riverine flow into the Copano-Aransas study area is illustrated in Figure 3. The relatively minor spring peak corresponds to the lesser maximum in precipitation (see Section 3.1). The abrupt rise in river discharge in September corresponds to increasing precipitation generated by tropical disturbances. Over 42% of the Mission River discharge and 78% of the Aransas River discharge for the years examined occurred during September.

The average conditions shown in Figure 3 do not indicate yearly variability. This variability is best illustrated by the month of September for both rivers. The average values in Figure 3 include the extremely high September discharge in 1967, the result of rains generated by hurricane "Beulah." The average discharge for September 1967 on the Mission River at Refugio was 216 m^3/sec, while on the Aransas River near Skidmore it was 67 m^3/sec. The available record from the Mission River indicates the next highest mean September discharge from 1951 through 1968 occurred in 1952 when it was 24 m^3/sec, nearly an order of magnitude less than in 1967. In 11 out of the 18 records for September, mean discharge was less than 1 m^3/sec, more than two orders of magnitude less than in September 1967. Variability during the spring peak is not as large, and the difference between high and low years represents approximately two orders of magnitude. The high degree of variability in discharge of these rivers is due to the combined effects of a highly variable precipitation regime, a small drainage basin, and the lack of a base flow (no flow conditions have been occasionally recorded).

4.4 GROUNDWATER

The lack of adequate surface water supplies within this study area necessitates the use of groundwater resources as well as the diversion of water from the neighboring Nueces River. The limited municipal and industrial development in the Copano-Aransas study area makes agriculture the principal user of groundwater reserves. Agricultural water use is reported by county and, as the counties within the Copano-Aransas study area overlap into both the Corpus Christi and San Antonio Bay study areas, the reader is referred to those syntheses for further discussion.

4.5 WATER QUALITY

The shallowness of the waters within the Copano-Aransas study area permits a rapid response of bay waters to changing air temperatures. This response results in a large seasonal range in water temperatures, from a low of approximately 10° C (usually in January or February) to a high of approximately 30° C (usually in July or August) (Martinez 1967, 1970-1975). These values represent bay-wide monthly averages, and there is considerable intrabay variation. For example, Gunter (1945) found temperatures as high as 35° C in the shallower tertiary bays in July. The quick response of this shallow bay system to changing temperature is reflected in a comparison of its average water temperatures with those of the neighboring gulf. The seasonal range in the gulf waters off San Jose Island is approximately 13.5° C while in the Copano-Aransas Bay complex, where water temperatures are lower in winter and higher in summer, the range is nearly 20° C (Martinez 1967, 1970-1975; TPWD 1975a). While absolute values vary with each estuary, the water temperature characteristics discussed above are common throughout the Texas Barrier Islands Region.

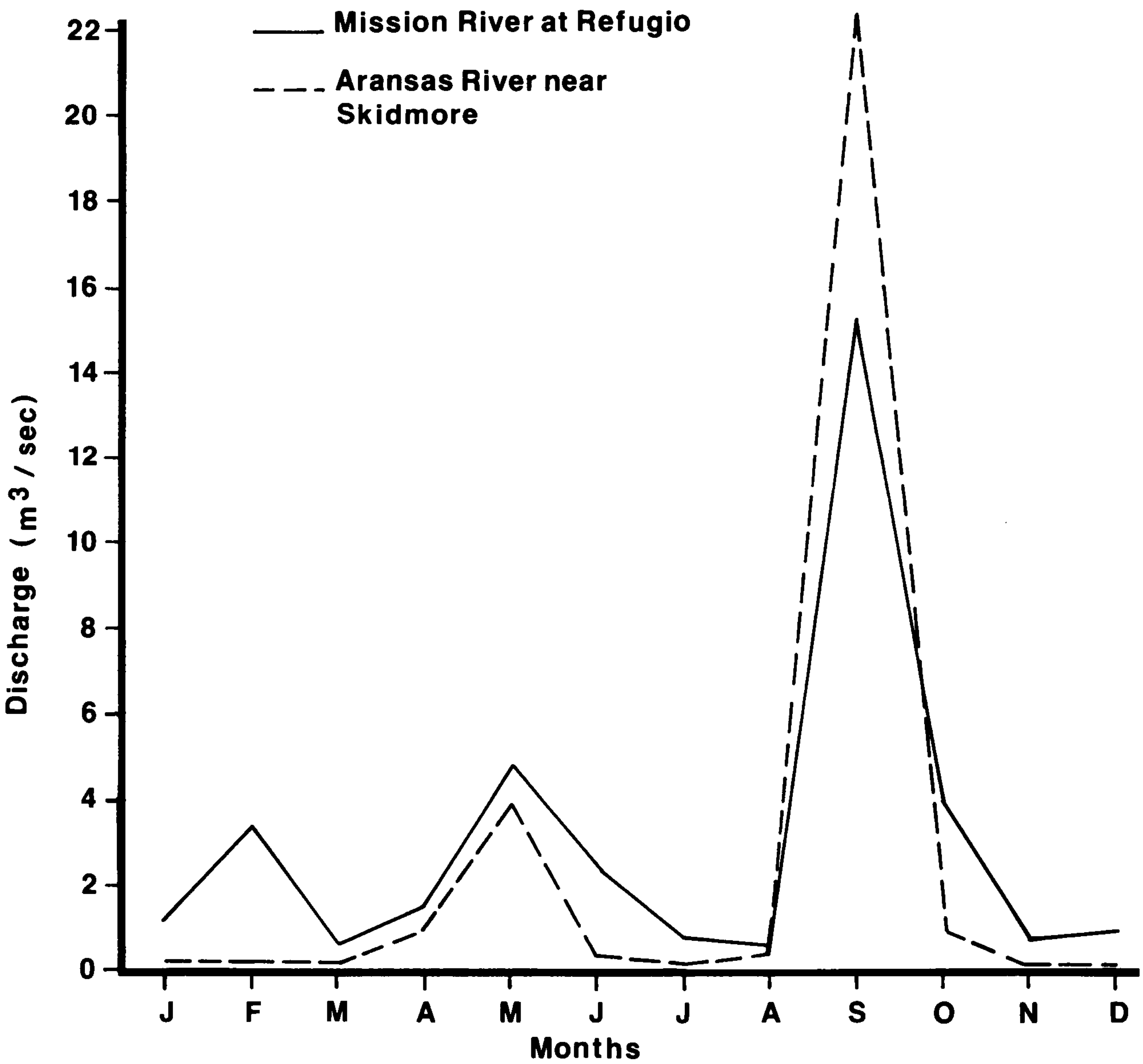

Figure 3. Mean daily discharge, by month, of the Aransas River (1964-68) and Mission River (1951-58) (Diener 1975).

Dissolved oxygen (DO) concentrations in the Copano-Aransas Bay waters average 8.2 mg/liter (Martinez 1974, 1975) and are generally at or exceeding saturation levels. Dissolved oxygen levels are highest during winter, frequently exceeding 10 mg/liter, and reflect the inverse relationship between DO concentrations and water temperature. Levels appear to plummet during spring, remain below or at average levels during summer, and rise again in September. While the available data are insufficient to conclude that this is a typical annual cycle, it is fairly consistent with the cycles of the other estuaries along the Texas coast. The increase in water temperature and salinity during summer probably results in a continued decline in DO levels, but the increased rate of primary production mitigates the decline and helps maintain fairly stable DO concentrations. The secondary rise in DO levels during September corresponds to peak river discharge which results in lower salinity and water temperature. The lack of major municipal and industrial development and associated discharges allows DO levels to remain high although localized discharges occur, such as those at the municipal outfalls in Redfish Bay and along the western shoreline of Aransas Bay (TPWD 1975a).

Turbidity levels in the Copano-Aransas area are somewhat higher than those in most estuaries along the Texas coast, but they are substantially lower than those in Galveston Bay and the turbid estuaries of Louisiana. In 1975, turbidity levels in the Copano-Aransas complex averaged 45 parts per million (ppm) (Martinez 1975). Turbidity levels are neither spatially nor temporally constant. In Aransas Bay, turbidity is low, approaching normal Laguna Madre levels. In contrast, turbidity is high in Copano Bay, reflecting its location relative to the mouths of the Aransas and Mission Rivers as well as those of lesser streams. Seasonally, high turbidity levels are usually associated with the peak river discharge periods during spring and September. A secondary rise in turbidity may occur during the winter, resulting from the combined effects of the resuspension of sediments from the predominantly clay bottom (Gunter 1945) and moderate increases in river discharge, both of which can be associated with the passage of polar fronts. Although the discharge into this bay complex is considerably less than that into the neighboring Corpus Christi Bay and San Antonio Bay study areas, the shoaling of St. Charles Bay, Mission Bay, and portions of Copano Bay indicates that the sediment load of the inflowing rivers and streams is considerable on a per unit volume basis (Diener 1975; TPWD 1975a, 1975b; Brown et al. 1976).

Overall, poor water quality within the Copano-Aransas study area is not a widespread problem. Approximately 10% of the bay area is consistently closed by the public health department to oyster harvesting; these closed areas are in the vicinity of the local municipal outfalls (TPWD 1975a). Overgrazing practices have resulted in erosion of uplands and an increase in the shoaling rates of the smaller bays (TPWD 1975a). Most land area is used for livestock production rather than crop production (Brown et al. 1976), and problems associated with pesticides, herbicides, and nutrient-loading are likely to be minimal. The effects of the disposal of brine into Chiltipin Creek and the Mission River were examined by Spears (1970, cited in TPWD 1975a; Spears 1972, cited in Heffernan 1972), Heffernan et al. (1971), and Heffernan (1972). These reports showed that brine disposal has resulted in particularly acute problems relative to river water salinities, hydrocarbon levels, and thermal pollution. Concentrated disposal areas have often resulted in lethal physical barriers for aquatic fauna regardless of stream flow conditions. The detrimental impacts of brine disposal on the lower Mission River nursery area and

Chiltipin Creek were eliminated in 1973 when brine disposal operations were terminated (TPWD 1975a). In 1975, 10 oil separators were discharging brine directly into Copano and Aransas Bays. The degree to which bay waters dilute the toxic brine has not been reported (TPWD 1975a).

5.0 BIOLOGY

5.1 ESTUARINE COMMUNITY

The major bays in the estuarine community of the Copano-Aransas system are Redfish, Aransas, and Copano Bays. The most outstanding physical characteristic of these bays is their variable salinity regimes. Riverine input into the estuarine community, a controlling factor of salinity levels, is the lowest of the six Texas bay systems and is quite variable seasonally. Large salinity fluctuations can occur in a relatively short time, and extended periods without rain may cause hypersaline conditions. The frequency of such occurrences is decreased, however, by regular natural inflow of low salinity waters from the San Antonio Bay system.

Pollutant levels within the bay waters are relatively low since industrialization and human habitation in the area are limited. In addition, most farming operations consist of livestock grazing rather than traditional agriculture, a fact related to the low levels of herbicide, pesticide, and nutrient runoff into the rivers and, eventually, the bays.

In consideration of the overall high water quality, it is not surprising that the Copano-Aransas estuarine community supports the second largest commercial finfish industry (second only to Laguna Madre) on the entire Texas coast. The shellfish harvest is considerably lower, ranking fourth among the six bay systems. According to the U.S. Fish and Wildlife Service and Texas Parks and Wildlife Department (USFWS and TPWD), only Corpus Christi Bay and the hypersaline Laguna Madre have smaller shellfish harvests (USFWS and TPWD 1968; NOAA and TPWD 1970; NOAA 1971, 1972, 1973b, 1974, 1975, 1977, 1978a, 1978b). The small shellfish harvest in the Copano-Aransas system can be partly explained by the absence of dependable freshwater inflow. Historically, freshwater input has been associated with large blue crab (_Callinectes sapidus_) populations. The poor oyster harvest can also be attributed to a lack of freshwater in addition to fungal infestations which have decimated populations in the past.

This estuarine community is unusual because of its extensive grassbeds which occur in Redfish Bay. This particular bay supports a species association more diverse than that of the rest of the Texas coast. The assemblage resembles more closely that of west Florida than that of other coastal areas in Texas (Hoese and Jones 1963).

5.1.1 Vegetation

In the 3,900 ha of Redfish Bay, large grassbeds, rivaled only by the great expanses of seagrasses in Laguna Madre, make up a major segment of the vegetation. Brown et al. (1976) reported that shoal grass (_Halodule beaudettei_), widgeongrass (_Ruppia maritima_), and turtle grass (_Thalassia testudinum_) were abundant in Redfish Bay. In addition, Halophila engelmanni was present, as were sparse stands of manatee grass (Cymodocea filiformis). Along the Port Bay shoreline and the bay margin of San Jose and Harbor Islands are narrow bands of shoal grass which usually grade into adjacent salt marshes or wind-tidal flats (Brown et al. 1976; McGowen et al. 1976). In Aransas Bay, turtle grass is the predominant submerged spermatophyte (West 1969, cited in Brown et al. 1976) with R. maritima abundant occasionally. McMillan and Moseley (1967) reported manatee grass growing in the deeper Aransas Channel.

Salinity is one of the primary variables determining the distribution and abundance of the seagrasses within the Copano-Aransas study area. McMillan and Moseley (1967) demonstrated that shoal grass was adapted to a wide range of salinities. Of the seagrasses they studied, shoal grass tolerated the highest salinities, followed by turtle grass, widgeongrass, and manatee grass, respectively. The position of Halophila engelmanni was not determined, but its salinity tolerance appears to lie between the extremes. Shoal grass tends to occur monotypically in the shallowest water where salinity and temperature fluctuate most. It is also found intermixed with other seagrasses, showing its competitive ability in less harsh environments. Manatee grass, on the other hand, is most abundant in the deeper water of the Aransas Channel where salinities do not tend to vary markedly. Plants like turtle grass, although able to tolerate high salinities, grow best at moderate salt concentrations (McMillan and Moseley 1967). Widgeongrass thrives in low salinities and has been reported to have replaced shoal grass in nearby Mesquite Bay (San Antonio Bay study area) following a post-drought salinity drop (Hoese 1960, cited in Henley and Rauschuber 1978).

Other environmental variables which affect grassbeds in the area include temperature, water depth, and turbidity. Work by Zieman (1970, cited in Henley and Rauschuber 1978) on turtle grass in Florida suggests 29° C as the optimum temperature for maximum photosynthesis. Depth zonation has received somewhat more attention than temperature variation. For example, den Hartog (1970, cited in Henley and Rauschuber 1978) suggested that Halophila and widgeongrass grow from the mid-eulittoral to lower sublittoral zones, turtle grass grows from mean low water to the upper sublittoral zone, and shoal grass is found from the mid-eulittoral zone to mean low water.

Turbidity, especially that resulting from dredging operations, also delimits seagrasses. Odum (1963) reported lowered primary productivity for turtle grass beds in areas of Redfish Bay where the GIWW was dredged in 1959. Such findings, in conjunction with the higher production of turtle grass beds in nearby clear waters, suggest that decreased light penetration due to dredging was instrumental in causing reduced gross productivity (4.7 g dry wt/m^2/day). Extremely high gross productivity values, averaging 23.4 g dry wt/m^2/day, were recorded during the year following the dredging (Odum 1963). These high values have been attributed, in part, to a possible nutrient release from dredged sediments (Odum and Wilson 1962).

No annual primary production estimates for the grassflats in the Copano-Aransas study area are available, but Parker et al. (1971, cited in Ward et al. 1979) measured a standing crop of 568 g dry wt/m^2 for shoal grass in Redfish Bay. They also reported a mean standing crop of 3,000 g dry wt/m^2 for turtle grass along the Texas coastline as a whole. (Comparable data for widgeongrass in Texas are unavailable.) When one considers that standing crop values are generally underestimates of primary production, the productivity of turtle grass rivals that of terrestrial systems traditionally considered highly productive (e.g., tropical rainforests).

Despite high productivity of the seagrasses, these plants have only limited value as a direct food source for animals. Most seagrass biomass enters the higher trophic levels indirectly as detritus which is consumed by microbes. It is these microbes that enter the estuarine food web directly as the food of many animal species (Henley and Rauschuber 1978).

Grassbeds have considerable value as shelter and nursery ground for other species. Adult and juvenile finfish use submerged aquatics to varying degrees. Adult southern flounder (Paralichthys lethostigma), spotted seatrout (Cynoscion nebulosus), red drum (Sciaenops ocellatus), black drum (Pogonias cromis), and sheepshead (Archosargus probatocephalus) are associated with widgeongrass, shoal grass, and turtle grass. Juvenile fish are somewhat more selective: spotted seatrout use widgeongrass; southern flounder use both widgeongrass and shoal grass; and young black drum are seldom sampled in the grassbeds (Schultz 1961, cited in TPWD 1975a).

Seagrasses obtain nutrients from both the sediment and the water column. Phosphate reserves in the sediment and interstitial water help satisfy phosphorus requirements. Nitrogen sources are less clearly understood. The reserve of nitrogen in sediment is limited, but nitrogen-fixing bacteria probably augment nitrogen availability around the roots of turtle grass (Patriquin 1972, cited in Henley and Rauschuber 1978). The blue-green epiphytic algae which typically grow on all the seagrasses may perform a similar role (Goering and Parker 1972).

Hoese and Jones (1963) reported a distinct species association within the confines of Redfish Bay. The pink shrimp, dominant on the Florida west coast, was the only penaeid collected from Pedfish Bay (Hoese and Jones 1963). In most Texas Bays, brown and white shrimp are the dominant species. The Atlantic croaker, rare in Florida bays and absent in Redfish Bay, is a common finfish in most Texas bays. Lastly, seagrasses are the dominant vegetation in the Redfish Bay area as well as in Florida bay areas.

The dominant phytoplankton in the Copano-Aransas Bay system are the diatoms, which Holland et al. (1975) found to represent 63% of all phytoplankton species collected (collections were from Corpus Christi, Copano, and Aransas Bays). Diatoms are followed in abundance by dinoflagellates (18%) and green algae (11%). In Copano Bay, standing crop values for phytoplankton were usually below those from Aransas or Corpus Christi Bays, and averaged 4.7 X 10^4 cells/liter between May and August 1974. Blooms were also less common in Copano Bay. The average standing crop in Aransas Bay was 8.4 x 10^4 cells/liter during that same period. According to Holland et al. (1975), seasonal patterns in phytoplankton of the Copano-Aransas Bay system are apparently influenced more by salinity and predation than by water temperature, perhaps because those temperatures are relatively stable (rarely lower than 15° C or greater than 30° C). Table 1 lists representative genera of phytoplankton in the Copano-Aransas Bay system.

Table 1. Representative phytoplankton in the estuarine community, Copano-Aransas Bay system (Holland et al. 1975).

Cyanophyta (blue-green algae)
- *Anabaena* sp.
- *Anabaenopsis* sp.
- *Merismopedia* spp.
- *Oscillatoria* spp.

Chrysophyta (diatoms)
- *Chaetoceros* spp.
- *Navicula* spp.
- *Rhizosolenia* spp.
- *Thallasionema* spp.
- *Thallosiothrix* spp.

Chlorophyta (green algae)
- *Scenedesmus* spp.
- *Stichococcus* sp.

Pyrrophyta (dinoflagellates)
- *Ceratium* spp.
- *Gonyaulax* spp.
- *Gymnodinium* spp.

Odum and Wilson (1962) determined an average gross production rate of 6.5 g O_2/m^2/day for Aransas Bay and 6.6 g O_2/m^2/day for Copano Bay. Estimates were made at various times in the spring, summer, and fall of 1957, 1959 and 1960. At the time of these measurements, the mean respiration values exceeded gross production values for both bays, indicating that community production was represented as a deficit.

Drift algae are a significant feature of grassbeds in Redfish Bay because they shade submerged vegetation. They also constitute a food supply for the invertebrate fauna (Cowper 1978). Drift algae begin their existence as benthic forms, sometimes attached to substrates like bits of shell. If the attachment is lost, benthic algae become drift algae. Because Cowper (1978) found few attached algae in the grassbeds, she suggested that the origin of the drift algae was probably oyster reefs. Major taxa of drift algae in the bay were *Hypnea* spp., *Gracilaria* spp., *Laurencia* spp., *Dictyota dichotoma*, and *Soliera tenera*.

In most grassbeds, drift algae tend to increase the overall primary production of the estuary (Conover 1964). In waters with dense stands of seagrasses, however, drift algae may decrease total production because their small biomass in no way compensates for the loss in production resulting from a shading out of the seagrasses (Cowper 1978). For example, Cowper estimated the productivity of *Hypnea* spp., the most abundant of the drift algae in this area, to be 2.1 g dry wt/m^2/day, whereas unshaded turtle grass (*Thalassia testudinum*) produced up to 34 g dry wt/m^2/day. Conover (1964) estimated that during calm weather a 20% reduction in surface irradiation reduced maximal photosynthetic rates by 50%.

Drift algae provide a food source and shelter for small invertebrates like the juvenile gastropod (*Cerithidea pliculosa*) and blue crab (*Callinectes sapidus*), but, in large part, most algae enter the detrital food chain.

Benthic algae along most of the Texas coast have not been studied in detail. Several detailed investigations have been undertaken in the Aransas-Redfish Bay area by investigators from the University of Texas Marine Science

Institute. An ecological study from 1967 through 1969 by Edwards and Kapraun (1973) reported that the southwest jetty at Port Aransas supported 48 algal species; Aransas Bay, 34 species; and Redfish Bay, 29 species. The jetty supported the highest number of species probably because it offered solid substrate. Less secure substrates used by algae in the study area include seagrasses, other algae, and small shells. A total of 89 species was collected by Edwards and Kapraun (1973), in spite of the fact that their study was performed in predominantly hyposaline waters. Since those forms present under drought conditions were probably not represented, Edwards and Kapraun (1973) extrapolated that the total number of species present was closer to 100. Table 2 lists representative species and their location in the study area.

Seasonal distribution of algae is determined primarily by temperature and, to a lesser degree, by photoperiod. Species growing in the study area during one part of the year often appear to die out during the rest of the year. These species frequently persist as inconspicuous holdfasts during unfavorable seasons. Table 2 indicates the period of maximum growth for representative species.

The ecology of algal species is complex and has received much attention. Seasonal distributions and life history studies have been of special interest, so quantitative investigations of primary production have been neglected. No productivity estimates for the benthic algae of this area are available.

As in the Corpus Christi Bay area, the largest expanses of salt marsh in the Copano-Aransas system are along prograding river deltas (i.e., the Chiltipin-Aransas Delta and Mission Delta). Narrow bands of salt marsh are also found along the margins of Port, Copano, and Mission Bays. The general zonation of these marshes from the bay margin inland is (1) smooth cordgrass (Spartina alterniflora); (2) maritime saltwort (Batis maritima), glasswort (Salicornia bigelovii and S. perennis), and saltgrass (Distichlis spicata); and (3) coastal sacahuista (Spartina spartinae). Marshes on the deltas grade into freshwater marsh assemblages (Brown et al. 1976; McGowen et al. 1976). It should be noted that Benton (1977, cited in Henley and Rauschuber 1978) found marsh zonations less clear cut than did Brown et al. and McGowen et al.

Extensive salt marsh on Harbor Island, as well as narrow fringes of marsh on the back side of San Jose Island, exhibit some zonation, but assemblages are slightly different (Brown et al. 1976), with considerable black mangrove (Avicennia nitida) on Harbor Island (D. Meineke, USFW Ecological Services, Corpus Christi, Texas; pers. comm. 1980). From the shoreline of Aransas Bay toward higher elevations on San Jose Island, the zones include (1) smooth cordgrass; (2) maritime saltwort, glasswort, and saltgrass; (3) sea-oxeye daisy (Borrichia frutescens) and shoregrass (Monanthochloe littoralis); and (4) sparse marsh vegetation (Brown et al. 1976).

Salt marsh zonation is a function of the duration and frequency of saltwater inundation, elevation, substrate salinity, and nutrient availability. The low marsh is dominated by Spartina alterniflora growing at the water's edge, usually in several centimeters of water. The high marsh behind this is less frequently flooded by tides (Brown et al. 1976).

Sampling sites in Redfish Bay (Benton 1977, cited in Henley and Rauschuber 1978) provided general information on standing crop of Spartina alterniflora

Table 2. Representative algal species with their locations and periods of maximum growth in the Copano-Aransas system. An X indicates the presence of a species, T = throughout year, W = winter and spring, S = summer and autumn (adapted from Edwards and Kapraun 1973).

Scientific name	Period of maximum growth	S.W. jetty Port Aransas	Aransas Bay	Redfish Bay
Enteromorpha clathrata	W	X	X	X
E. flexuosa	W	X	X	X
Cladophora delicatula	S	X	X	X
Dictyota dichotoma	S	X	X	X
Hypnea cornuta	S	X	X	X
Gracilaria foliifera	T	X	X	X
Ulva lactuca	W	X	X	
Cladophora dalmatica	T	X	X	
Gelidium crinale	T	X	X	
Ceramium fastigiatum	S	X	X	
Polysiphonia tepida	S	X	X	
Chaetomorpha linum	S	X		X
Corallina cubensis	S	X		X
Acetabularia crenulata	S		X	X
Digenia simplex	S		X	X
Ulva fasciata	S	X		
Petalonia fascia	W	X		
Bangia fuscopurpurea	W	X		
Porphyra leucosticta	W	X		
Polysiphonia denudata	T	X		
Ceramium strictum	S	X		
Polysiphonia havanensis	W		X	
Chondria littoralis	T		X	
Acrochaetium virgatulum	S			X
Gracilaria debilis	S			X
Chondria cnicophylla	T			X
Laurencia poitei	S			X

marshes. The information showed higher standing crop in the bay than in the neighboring Nueces River Delta but provided no numerical values. The production estimate for *Spartina alterniflora* in nearby Lavaca, San Antonio, and Nueces Bays averages 1,084 g dry wt/m^2/yr (Espey, Huston and Associates 1977, cited in Ward et al. 1979). Because of the proximity of Redfish Bay to these marshes, it is likely that Redfish Bay has similar production by *Spartina alterniflora*.

Much has been said concerning the value of salt marshes for growth and development of commercially important species of finfish and shellfish. These marshes provide food, either as green material or detritus, for larvae and juveniles.

The marsh vegetation tends to support epiphytic algae and phytoplankton, important sources of nutrition for small finfish and shellfish. *Spartina alterniflora* culms provide shelter and points of attachment for epifauna.

The bays in the study area are nursery grounds for white shrimp (*Penaeus setiferus*), brown shrimp (*P. aztecus*), blue crab (*Callinectes sapidus*), and many finfish including spotted seatrout (*Cynoscion nebulosus*), striped mullet (*Mugil cephalus*), Atlantic croaker (*Micropogonias undulatus*), and southern flounder (*Paralichthys lethostigma*). Many adult species also use these bays as seasonal habitat and/or spawning areas (Henley and Rauschuber 1978).

Some areas on Harbor Island, with a vegetative assemblage including *Salicornia* spp., fringes of *Spartina alterniflora*, and *Halodule beaudettei*, also support bands of black mangroves (*Avicennia nitida*) which may be a quarter to half mile wide and up to 3 mi long. Mangrove seeds germinate on the parent plant, and then fall into the water and take root. Seedling development is limited by water turbulence, which inhibits root growth. Salinity is not critical for black mangroves (McMillan 1971, cited in Henley and Rauschuber 1978), but Morrow and Nickerson (1973, cited in Henley and Rauschuber 1978) found this species typically in areas with a substrate salinity greater than 40 ^{o}/oo.

The area around Port Bay has a considerable expanse of brackish to freshwater marsh (Brown et al. 1976). Representative vegetation includes coastal sacahuista (*Spartina spartinae*), marshhay cordgrass (*S. patens*), big cordgrass (*S. cynosuroides*), bulrush (*Scirpus* sp.), and cattail (*Typha* sp.). These marshes occur at slightly higher elevations and at slightly greater distances from bodies of saltwater than do salt marshes. The saltwater influence comes from infrequent inundation due to wind-driven tides. The freshwater influence is derived from runoff and overbanking of streams during flooding. The fluctuations in salinity that can occur have the greatest physical impact on these marshes. During periods of drought, water and substrate salinity may rise above that of seawater (i.e., 35 ^{o}/oo), and during excessive rains the surface water salinity is likely to drop to 0 ^{o}/oo. Substrate salinity appears to be the most important factor in determining which vegetative species are successful in the brackish to freshwater marsh (Brown et al. 1976).

Freshwater marshes are found further inland, closely associated with the Aransas and Mission Rivers. Representative vegetation includes rush (*Juncus* spp.), cattail (*Typha* spp.), sloughgrass (*Spartina pectinata*), and bulrush (*Scirpus* spp.).

Several areas within the Copano-Aransas system are considered important habitats for finfish and shellfish. They include (1) Redfish Bay and Harbor Island, (2) St. Charles Bay and its Willow Creek complex, (3) Copano Creek, (4) Mission River - Mission Bay complex, (5) Aransas River - Chiltipin Creek complex, (6) Port Bay area, (7) Aransas Pass, and (8) Cedar Bayou (TPWD 1975a). Areas seven and eight provide pathways for seasonal migrations of finfish and shellfish. Areas two, three, and six are vital nursery areas, which in 1975 were relatively undisturbed (TPWD 1975a). Another important nursery ground, area one, is the proposed site of a deep-draft port involving dredging and filling of more than 120 ha of prime estuarine habitat (TPWD 1975a; Henley and Rauschuber 1978). Areas four and five were subjected to oil brine discharge until 1973. In this case, the most apparent damage resulted from oil and associated hydrocarbon pollution rather than altered salinities. Juveniles of commercially important blue crabs and brown shrimp were especially sensitive to oil in the environment (Heffernan et al. 1971; Heffernan 1972). By 1975, these areas were recovering, with yields of commercially important species increasing.

5.1.2 Fauna

Mammals. The bottlenose dolphin (Tursiops truncatus) is the only marine mammal common in the study area. This species is moderately abundant in Aransas Bay but much less so in Copano Bay (Barham et al. 1980). Four transects were flown over Copano Bay in 1978 and a total of only five herds was sighted. During five transects over Aransas Bay, 34 herds were sighted. Greatest density of dolphins was in the channels, primarily the Corpus Christi Ship Channel in the neighboring Corpus Christi Bay system (Barham et al. 1980).

Several terrestrial mammals are associated with the salt, brackish, and fresh marsh. Table 3 lists representative species and their frequent habitats. Raccoon (Procyon lotor), mink (Mustela vison), and nutria (Myocastor coypus) are the important furbearing species in the community (Davis 1974). The muskrat (Ondatra zibethicus), another furbearer in Texas, does not occur along the central and southern coastline.

A dense population of white-tailed deer (Odocoileus virginianus) inhabits the Aransas National Wildlife Refuge, located on Blackjack Peninsula. Although most of the habitat is typical of the upland community, 323 ha of marsh in the Refuge also support deer. For a more complete discussion of deer in the refuge, see the San Antonio Bay synthesis, Section 5.5.2.

Table 3. Representative species of mammals of the estuarine community, Copano-Aransas system. An X indicates the following habitats: SM = salt marsh, BFM = brackish to freshwater marsh, FM = freshwater marsh.

Scientific name	Common name	Habitat SM	 BFM	 FM
Procyon lotor	Raccoon	X	X	X
Mustela vison	Mink		X	X
Myocastor coypus	Nutria	X	X	X
Oryzomys palustris	Northern rice rat		X	X
Sigmodon hispidus	Hispid cotton rat			X
Sylvilagus aquaticus	Swamp rabbit		X	X
Odocoileus virginianus	White-tailed deer		X	X

Birds. The most noted bird in the Copano-Aransas system is the whooping crane (*Grus americana*), which winters in marshes, salt flats, and bays of the Aransas National Wildlife Refuge and ranges to San Jose Island (Oberholser et al. 1974). For a discussion of its status as an endangered species, see Section 5.6.2.

Data on the most common fish-eating birds, as well as the cattle egret (*Bubulcus ibis*), are given in Table 4. Of the herons and egrets listed, the Louisiana heron (*Hydranassa tricolor*) is the most abundant and is largely restricted to the coastal region. Only the reddish egret (*Dichromanassa rufescens*) is more closely associated with that environment.

Waterfowl using the various habitats of the estuarine community during winter migration include the Canada goose (*Branta canadensis*), white-fronted goose (*Anser albifrons*), snow goose (*Chen caerulescens*), pintail (*Anas acuta*), shoveler (*Anas clypeata*), redhead (*Aythya americana*), canvasback (*Aythya valisineria*), and mottled duck (*Anas fulvigula*). Ducks tending to frequent freshwater rather than saline habitats are the common mallard (*Anas platyrhynchos platyrhynchos*), green-winged teal (*Anas crecca*), cinnamon teal (*Anas cyanoptera*), gadwall (*Anas strepera*), and ring-necked duck (*Aythya collaris*) (Oberholser et al. 1974; TPWD 1978e, 1979d).

Shorebirds also frequent the marshes and mud flats. The sanderling (*Crocethia alba*), marbled godwit (*Limosa fedoa*), least sandpiper (*Erolia minutilla*), and willet (*Catoptrophorus semipalmatus*) are representative species. Only the willet regularly nests in Texas (Oberholser et al. 1974).

Reptiles and amphibians. Only one species of turtle, the Texas diamondback terrapin (*Malaclemys terrapin littoralis*), is common in the salt marsh. It also frequents brackish marshes but is rarely seen in freshwater marsh (Conant 1975). The common snapping turtle (*Chelydra serpentina serpentina*) frequents brackish and freshwater marshes but not salt marshes. According to Raun and Gehlbach (1972), the literature records the snapping turtles as extending to Bee and Refugio Counties, but in 1972 they found snapping turtles only as far down the coast as Jackson County. These findings suggest the snapping turtle may no longer be common within the Copano-Aransas system. The National Fish and Wildlife Laboratory (1980) reported sightings of three endangered turtle species in bay waters of the Copano-Aransas system: the green turtle (*Chelonia mydas*), Kemp's ridley turtle (*Lepidochelys kempi*), and the leatherback turtle (*Dermochelys coriacea*). The latter species, the most pelagic of the three, comes inshore less frequently.

The only species of snakes commonly frequenting the salt marshes of the Copano-Aransas system are the gulf salt marsh snake (*Nerodia fasciata clarki*) and the speckled kingsnake (*Lampropeltis getulus holbrooki*). No lizards are common.

The endangered American alligator (*Alligator mississippiensis*) inhabits brackish and freshwater marshes in the Copano-Aransas system. The population appears increasing here, as elsewhere, due to Federal and State protection (Joanen 1974, cited in National Fish and Wildlife Laboratory 1980).

Amphibians occasionally found in the salt or brackish marsh include the green treefrog (*Hyla cinerea*) and southern leopard frog (*Rana utricularia*) (Conant 1975).

Table 4. Pairs of colonial fish-eating birds in the Copano-Aransas system (adapted from Blacklock et al. 1978).

Scientific name	Common name	1973	1974	1975	1976	Historical population trend for all of Texas
Phalacrocorax olivaceus	Olivaceous cormorant	26	0	0	0	Long-term decline until recently; peripheral species
Ardea herodias	Great blue heron	236	248	305	426	Stable
Florida caerulea	Little blue heron	0	5	2	1	Primarily inland; stable
Bubulcus ibis	Cattle egret	1,425	125	128	900	First arrived in 1954; rapid increase
Dichromanassa rufescens	Reddish egret	148	153	385	312	Long-term decline; stable since 1960's
Casmerodius albus	Great egret	370	157	216	133	1910, near extinction; currently stable
Leucophoyx thula	Snowy egret	1,685	764	590	349	1910, near extinction; currently stable
Hydranassa tricolor	Louisiana heron	2,016	1,037	1,351	1,132	Rapid increase during past 10 years
Nycticorax nycticorax	Black-crowned night heron	175	53	150	135	No apparent trend
Plegadis chihi	White-faced ibis	900	500	55	503	Stable since 1974 decline
Ajaia ajaja	Roseate spoonbill	0	115	225	75	1910, near extinction; currently stable

Continued

Table 4. Concluded.

Scientific name	Common name	1973	1974	1975	1976	Historical population trend for all of Texas
Larus atricilla	Laughing gull	10,807	5,589	3,786	5,146	Stable?
Gelochelidon nilotica	Gull-billed tern	25	25	99	134	Stable to decreasing
Sterna forsteri	Forster's tern	0	25	23	90	Slow decline since 1940's
S. albifrons	Least tern	0	1	104	158	Rapid decrease
S. maxima	Royal tern	915	355	140	200	Always abundant
S. sandvicensis	Sandwich tern	40	970	500	900	Stable below San Antonio Bay
Hydroprogne caspia	Caspian tern	20	440	144	211	Slow decline?
Rynchops nigra	Black skimmer	269	270	514	562	No apparent trend

Freshwater marshes support a much more diverse fauna because of their more favorable environmental conditions. Table 5 gives a representative list of reptiles and amphibians found in the freshwater marsh of the Copano-Aransas system.

Table 5. Representative reptiles and amphibians of the freshwater marsh habitat of the estuarine community, Copano-Aransas study area (Raun and Gehlbach 1972; Conant 1975).

Scientific name	Common name
Kinosternon flavescens flavescens	Yellow mud turtle
K. subrubrum hippocrepis	Mississippi mud turtle
Chrysemys scripta elegans	Red-eared turtle
Lampropeltis getulus holbrooki	Speckled kingsnake
Storeria dekayi texana	Texas brown snake
Nerodia erythrogaster transversa	Blotched water snake
Pseudacris triseriata feriarum	Upland chorus frog
Bufo woodhousei woodhousei	Woodhouse's toad
Rana utricularia	Southern leopard frog
Gastrophryne olivacea	Great Plains narrow-mouthed toad
Hyla cinerea	Green treefrog

Fish. From 1968 through 1977, red drum (*Sciaenops ocellatus*), with 2.1 x 10^5 kg, provided the largest mean annual commercial harvest in Copano and Aransas Bays. It was followed by spotted seatrout (*Cynoscion nebulosus*) with 9.0 x 10^4 kg, black drum (*Pogonias cromis*) with 4.8 x 10^4 kg, unclassified flounder with 1.9 x 10^4 kg, and sheepshead (*Archosargus probatocephalus*) with 1.6 x 10^4 kg. The flounder harvest in the Copano-Aransas area was the largest of all the Texas coastal study areas (USFWS and TPWD 1968; NOAA and TPWD 1970; NOAA 1971, 1972, 1973b, 1974, 1975, 1977, 1978a, 1978b). Of the three adjacent drainages (Corpus Christi, Copano-Aransas, and San Antonio Bays), the Copano-Aransas area had the largest total finfish harvest during this time period. Of the six coastal study areas, the Copano-Aransas system ranked second after Laguna Madre. Upper and Lower Laguna Madre combined averaged a yearly harvest of 1.1 x 10^7 kg, and Copano-Aransas averaged 3.1 x 10^6 kg. Over the 10-year period, the annual harvests in the Copano-Aransas area were relatively stable. No data on fishing pressure were available, so an accurate estimate of total production cannot be provided.

Data are inadequate for detailed comparison of sport and commercial fish catches. For example, the sport yield in the study area for September 1974 through August 1975 was 2.3 x 10^5 kg, and the average commercial harvest for 1974 and 1975 was 3.2 x 10^5 kg. The difference is more marked than it appears at first glance because the commercial value includes catches only from Copano and Aransas Bays, whereas the sport yield represents all bays within the system (USFWS and TPWD 1968; NOAA and TPWD 1970; NOAA 1971, 1972, 1973b, 1974, 1975, 1977, 1978a, 1978b; Heffernan et al. 1977).

The total sport yield in the Copano-Aransas area ranks fifth of those in the six systems along the coast (Heffernan et al. 1977). From September 1974 through August 1975, the average yield per man-hour fished in this area was 235.6 g/hr, the lowest of all the bay systems. The spotted seatrout composed 49.6 % of the total sport harvest during this time. Other important species were the red drum, sheepshead, sand seatrout (Cynoscion arenarius), and gafftopsail catfish (Bagre marinus).

As important as the major sport and inshore commercial species are, work by Gunter (1945) suggests the biomass of these species is not as great as that of the bay anchovy (Anchoa mitchilli), menhaden (Brevoortia sp.), striped mullet (Mugil cephalus), and Atlantic croaker (Micropogonias undulatus). Although Gunter's study of the Copano-Aransas Bay system was carried out before the dredging of the Gulf Intracoastal Waterway, Schultz (1961, cited in TPWD 1975a) reported that the faunal composition, abundance, and seasonal distribution had not been altered significantly. Moore's (1978) investigation of Aransas Bay ichthyofaunal diversity from 1966 through 1973 suggests that this bay is one of the most diverse estuarine communities along the Texas and Atlantic coasts. No data are available on the effects of additional human impact subsequent to Moore's work.

Invertebrates. From 1968 through 1977, blue crabs (Callinectes sapidus) were the predominant shellfish, by weight, harvested in the Copano-Aransas system. The average yearly harvest during this period was 4.3 x 10^5 kg, valued at $153,000. Compared to the harvests in other bays, this was the third largest in Texas. The shellfish of greatest economic importance during this period was the white shrimp (Penaeus setiferus), with an annual harvest of 3.9 x 10^5 kg, valued at $640,000. Brown shrimp (Penaeus aztecus) and pink shrimp (Penaeus duorarum) together yielded an average of 1.3 x 10^5 kg annually. Oysters (Crassostrea virginica) yielded the smallest mean annual harvest, 1.0 x 10^4 kg. When the average value of these five shellfish over the 1968-1977 period is considered, Copano-Aransas ranks fourth of the six systems, with a mean annual value of $338,000. Only Laguna Madre and Corpus Christi have smaller shellfish harvests (USFWS and TPWD 1968; NOAA and TPWD 1970; NOAA 1971, 1972, 1973b, 1974, 1975, 1977, 1978a, 1978b).

Historically, blue crab production is greatest in bays receiving the most freshwater, a fact providing some explanation for the larger harvest in the Galveston Bay and San Antonio Bay areas. In the Copano-Aransas system, salinity appears to be the predominant limiting factor for blue crab production. A drought in the early 1960's is generally accepted as the cause of low harvests between 1963 and 1966 (TPWD 1975a).

The Texas Parks and Wildlife Department (1975a) reported white and brown shrimp nursery grounds along the shorelines of Copano, Aransas, and St. Charles Bays, and throughout the waters of the tertiary Port and Mission Bays. Hoese and Jones (1963) reported Redfish Bay as the habitat for pink shrimp.

Major oyster reefs in Copano and Aransas Bays have an areal extent of 218 ha. Commercial harvest is impeded by an erratic availability of quality oysters caused by periodic oyster infestations of two fungi: Labyrinthomyxa marina and a second species causing the "Aransas Bay oyster disease." Oyster populations have plummeted because of infections by these fungi as early as 1960 (TPWD 1975a).

Macro-invertebrates of no commercial value, but of great importance in the trophic dynamics of the estuarine community, occur in the Copano-Aransas system. They include a wide variety of pelecypods, gastropods, crustaceans, and echinoderms. These animals fill niches in the various aquatic habitats of the estuarine community (Daughterty 1952; Parker 1959).

5.2 BARRIER ISLAND COMMUNITY

The barrier islands associated with the three drainages of Corpus Christi, Copano-Aransas, and San Antonio Bays lie within less than a single latitudinal degree of each other. Although Mustang Island, a part of the Corpus Christi Bay system, has undergone more development than has San Jose (formerly St. Joseph) or Matagorda Islands, the three islands were originally similar in character. The elevation and topography of these areas are also comparable.

In view of the proximity and similarity of Mustang, San Jose, and Matagorda Islands, a single discussion of the barrier island community, using Mustang Island as a focal point, is appropriate. Thus the reader is referred to the Corpus Christi Bay synthesis, Section 5.2, for the bulk of discussion on flora and fauna of San Jose Island. Characteristics of San Jose Island which diverge from Mustang Island are presented below.

5.2.1 Vegetation

Although the same components of the topographic profile seen on Mustang Island are present on San Jose Island, they are not as well developed. This is particularly true of the foredunes, generally less than 4.5 m high. Progressing across San Jose Island toward Aransas Bay, washover fans are more abundant than on Mustang Island. In fact, most of northern San Jose Island is an inactive vegetated fan (see Section 2.1). The southernmost occurrence of beach ridge-and-swale topography, typical of the islands on the upper Texas coast, is found on the southern end of this island. The vegetative character of these various features does not differ significantly because all species must tolerate salt spray and occasional flooding.

5.3 RIVERINE COMMUNITY

Of the six coastal systems under consideration, the Copano-Aransas system has the least riverine input. The Aransas and Mission Rivers, the system's two primary flows, have discharge rates considerably below the major flows of other systems along the Texas coast (Diener 1975). For the water years between 1951 and 1968, the average discharge rate of the Mission River was 2.94 m^3/ sec; the Aransas River averaged 2.37 m^3/sec during the water years 1964 through 1968. These discharge rates are extremely small compared to the 68.8 m^3/sec average rate for the Colorado River (see Matagorda-Brazos synthesis, Section 4.3). Riverine flow can be extremely variable in the Copano-Aransas system. For example, the Aransas River on 22 September 1967 had a discharge rate of 2,318 m^3/sec; at other times it has had absolutely no flow.

Although the average discharge rates of the Aransas and Mission Rivers are low, the rivers provide some freshwater inflow to aid in controlling salinity, to supply inorganic sediments for maintenance and development of wetlands, and to provide nutrients to Mission and Copano Bays.

5.3.1 Vegetation

Within the bounds of the Aransas River, algae are more common than vascular flora. Two algal species reported by Renfro (1958) were a blue-green alga *Phormidium* sp. and a green alga *Cladophora* sp. Algal species like these are the basis for the riverine food web (Clapham 1973). Because the flow rate of the Aransas River is low compared to that of larger rivers on the Texas coast and sometimes ceases entirely, the detrital food web may not contribute significant input to the trophic dynamics of the riverine community.

5.3.2 Fauna

Separation of the river and the areas immediately adjacent to it into riverine and floodplain communities is arbitrary and the subject of considerable debate (Cowardin et al. 1979). Except for fish, the vertebrate fauna of the two communities rely on both environments for food, shelter, and nesting. The reader will therefore be referred to the floodplain community for pertinent discussions of some fauna.

Mammals. No aquatic mammals frequent the riverine community in the Copano-Aransas system. For a discussion of the semi-aquatic mammals, refer to the floodplain community (Section 5.4.2).

Birds. See Section 5.4.2.

Reptiles and amphibians. Several turtle species frequent the river and the logs protruding from it more so than they do the terrestrial floodplain. The gulf coast spiny softshell (*Trionyx spiniferus asperus*) and the Texas slider (*Chrysemys concinna texana*) are particularly common in rivers. The latter, however, may frequently be found in less natural bodies of water like ditches or cattle tanks. Red-eared turtles (*Chrysemys scripta elegans*), on the other hand, typically prefer quiet waters. The flow rate of the Aransas River is usually low, providing a habitat for this species. Common snapping turtles (*Chelydra serpentina serpentina*) and yellow mud turtles (*Kinosternon flavescens flavescens*) exhibit considerable flexibility in their habitat requirements. Snapping turtles thrive in any permanent body of water, fresh or brackish; yellow mud turtles are restricted to freshwater but tolerate either natural or artificial aquatic habitats (Conant 1975).

Lizards, semi-aquatic snakes, and amphibians are discussed in the floodplain community, Section 5.4.2.

Fish. Salinity of the Aransas River is influenced primarily by precipitation and evaporation, and to a lesser degree by saltwater intrusion caused by winds and tides in Copano Bay. Before 1973, pollution in the form of oil brine dumped into Chiltipin Creek also added to the salinity in the river (see also Section 5.1). Renfro (1958) measured salinities as high as 75 ^{o}/oo in this creek. As late as 1973, salinities of 66.8 ^{o}/oo were recorded by the U.S. Geological Survey (1972, 1973). These measurements were taken approximately 20 miles upstream from the confluence of the creek and Aransas River, apparently near the source of the dumping. Oil field brine disposal in Chiltipin Creek was halted 1 March 1973.

Renfro (1958) studied the ichthyofauna of the Aransas River from September 1956 through November 1957. He seined at three stations along the river, with the most inland station located 40 km upstream from the mouth of the river. The 26 species of fish he collected included euryhaline, freshwater, and marine forms. The freshwater species were not found in large numbers in the Aransas River, probably because of the variable salinity in the lower reaches of the river and the inability of the freshwater species to satisfactorily compete with established euryhaline species. Except for the bay anchovy (Anchoa mitchilli), strictly marine species were not common in the river. Those collected were primarily juvenile stragglers (Renfro 1958). Table 6 provides a representative listing of fishes in the Aransas River.

Table 6. Representative species of fish in the Aransas River (Renfro 1958).

Scientific name	Habitat	Common name
	Freshwater	
Notropis lutrensis		Red shiner
Ictalurus furcatus		Blue catfish
Gambusia affinis		Mosquito fish
Lepomis macrochirus		Bluegill
	Marine	
Brevoortia patronus		Gulf menhaden
Anchoa mitchilli		Bay anchovy
	Euryhaline	
Dorosoma cepedianum		Gizzard shad
Lepisosteus spatula		Alligator gar
Cyprinodon variegatus		Sheepshead minnow
Micropogonias undulatus		Atlantic croaker

The neighboring Mission River was also the site of oil brine disposal before 1 June 1973. Spears (1959, cited in Heffernan 1972) found freshwater fish only at the headwaters of Blanco and Medio Creeks, upstream of all oil brine disposal sites. Studies by Heffernan (1970) substantiated Spears' findings. Heffernan reported that marine organisms did not use upstream portions of the river as nursery grounds, apparently because of the oil and brine there. Euryhaline and marine species in the river included the bay anchovy (Anchoa mitchilli), menhaden (Brevoortia patronus and B. gunteri), Atlantic croaker (Micropogonias undulatus), and the gizzard shad (Dorosoma cepedianum).

5.4 FLOODPLAIN COMMUNITY

The Aransas and Mission Rivers occupy the abandoned courses of the Nueces and San Antonio-Guadalupe River drainages. Because of their entrenched nature and low flows, the Aransas and Mission Rivers have undergone only minor meandering. The resulting floodplains are small and poorly developed.

Plant and animal diversity is considerable due to the various favorable environments, but populations should be expected to be low. According to McGowen et al. (1976) and Brown et al. (1976), no mappable swamps occur in the

Copano-Aransas floodplain. Species that prefer swamp habitats probably have even lower populations.

Although a portion of the flows of the Aransas and Mission Rivers is diverted for agricultural irrigation, major losses of flow are not incurred. Further, since these rivers have low mean flows, it is unlikely that any major diversion projects are planned for the future. Unless such projects are undertaken, or unless agricultural or residential development in the area greatly increases, the floodplain community will maintain itself.

5.4.1 Vegetation

Water-tolerant species in the small areal extent of floodplain along the Aransas and Mission Rivers and their feeder creeks are comparable to the floodplain species of the Corpus Christi Bay system (Brown et al. 1976). The Aransas River, the more southerly of the two major flows in the Copano-Aransas system, is less than 40 km north of the Nueces River, the primary river of the Corpus Christi Bay system. Because of this proximity, the floodplain communities of the two systems are understandably similar. For a discussion of representative plant species in the floodplain of the Copano-Aransas system, see the Corpus Christi Bay synthesis, Section 5.4.1.

5.4.2 Fauna

Mammals. The furbearers, game species, and rodents discussed in the floodplain community of the Corpus Christi Bay system are also present in the Copano-Aransas floodplain. Populations, however, likely are smaller in the Copano-Aransas system because its smaller area of floodplain habitat cannot support as many individuals. A mammal occasionally present in the floodplain of the Copano-Aransas system but not typically found in the Corpus Christi Bay system is the mink (Mustela vison). The Texas Parks and Wildlife Department provides no data on furbearing populations of individual riverine systems. The small, sluggish rivers of the Copano-Aransas area, were they not at the southern limit of the mink's range, would provide an ideal environment for these commercially important furbearers, according to Davis' (1974) account of preferred mink habitat.

Birds. The floodplain and riverine communities together provide the preferred habitat for several species of ducks, including the black-bellied tree duck (Dendrocygna autumnalis), mallard (Anas platyrhynchos platyrhynchos), and wood duck (Aix sponsa). Oberholser et al. (1974) reported sight records of nesting by the black-bellied tree duck and mallard within the bounds of the Copano-Aransas system although neither species is a common breeder in Texas. Tree ducks nest primarily in Mexico, and mallards in Canada. Wood ducks, one of the most southerly nesting species of Nearctic waterfowl, are common inland nesters in Texas. Oberholser et al. (1974), however, reported no nest sightings within the Copano-Aransas system.

Of the herons and egrets listed in Table 4 (Section 5.1.2), only the cattle egret (Bubulcus ibis), reddish egret (Dichromanassa rufescens), and Louisiana heron (Hydranassa tricolor) are not generally considered common to the floodplain. The feeding habits of those found in both the floodplain and the estuary are flexible; favored items include crayfish, fish, shrimp, snakes, frogs, turtles, and a variety of insects.

Rapacious birds common to the floodplain of the Copano-Aransas system are largely the same species common to the floodplain of the neighboring Corpus Christi Bay system. Two are the red-shouldered hawk (Buteo lineatus) and barred owl (Strix varia), which prefer open woodland areas to prairie or brushland. While both species feed on rodents and other small mammals, their niches do not overlap. Whereas the owl is a nocturnal hunter, the hawk feeds during daylight (Oberholser et al. 1974).

Reptiles and amphibians. The species of reptiles and amphibians in the Copano-Aransas and Corpus Christi Bay systems differ little, and the discussion in the Corpus Christi Bay synthesis can be applied to both. In the Corpus Christi Bay system, however, several species reach their range's southern limit. They include the five-lined skink (Eumeces fasciatus), mud snake (Farancia abacura), speckled kingsnake (Lampropeltis getulus holbrookia), western cottonmouth (Agkistrodon piscivorus leucostoma), Woodhouse's toad (Bufo woodhousei woodhousei), and Fowler's toad (B. woodhousei fowleri) (Conant 1975). Populations of these species may thus be somewhat more limited in the Corpus Christi Bay system than in the more northerly Copano-Aransas area. The study area is within a broad zone of intergradation between Fowler's and Woodhouse's toads and the distinction between individual populations is unclear. The range of the squirrel treefrog (Hyla squirella) does not extend south beyond the Copano-Aransas system; the species occurs only as far south as Aransas County (Raun and Gehlbach 1972).

5.5 UPLAND COMMUNITY

The upland community is arbitrarily designated as those areas at elevations and distances far enough removed from the bays and rivers to preclude flooding under normal circumstances. The discussion of this community is limited to two representative tracts of land. The first is approximately 3,120 ha of grassland on the Welder Wildlife Refuge, located 12 km northeast of Sinton, Texas. Since the refuge has, for over 120 years, been more lightly grazed than most surrounding areas, it is somewhat closer to a true climax community than the majority of the upland in the central Texas coast. The second tract of land comprises the oak motte areas of the Aransas National Wildlife Refuge.

5.5.1 Vegetation

Detailed vegetational analysis of selected areas within the Welder Wildlife Refuge led Box (1957) to divide the coastal prairie into nine vegetational types. Variation in vegetation was linked primarily to soil type and, to a lesser degree, lack of drainage, past use, and brush control procedures. It is not within the scope of this synthesis paper to discuss all nine vegetational associations. The major associations are as follows: (1) mesquite-buffalograss, (2) chaparral-bristlegrass, (3) prickly pear-shortgrass, and (4) bunchgrass-annual forb. Since Box's work (1957, 1959 cited in Mann 1975), Mann (1975) has made a comparative study of the change in the land between 1957/1958 and 1973. His investigation showed that the first three vegetative associations, which are in clay soil, changed more dramatically than did the fourth association, which is in sandy soil. A brief description of important changes, their possible causes, and management implications are in order. The following discussion is based on Mann (1975).

The mesquite-buffalograss association has been greatly altered from 1957 to 1973. In 1957, buffalograss (Buchloe dactylodies) represented 30% of all grasses present, but by 1973 this species had been reduced to 2%. Buffalograss and three other short grasses had made up over 75% of the herbaceous vegetation in the initial study. Fifteen years later, these short grasses had only minor importance, and the dominant forms were midgrasses like meadow dropseed (Sporobolus asper) and silver beardgrass (Bothriochloa saccharoides). Such species replacement represents successional progression. The spread of meadow dropseed is a good example of the rapid change. In the 1957/1958 sampling it was not detected, but by 1973 it was dominant. Changes in forbs and woody vegetation have been less spectacular, but forbs are increasing in importance. Woody vegetation appears to be decreasing, although the decline over the 15-year study interval was not statistically significant.

The chaparral-bristlegrass association has undergone its most dramatic change in the woody species. The brush canopy increased by 18 percentage points to 38.4%. Agarito (Berberis trifoliolata) is the dominant chaparral-type vegetation, followed by mesquite and blackbrush (Acacia rigidula), although blackbrush appears to be one of the few brush species losing dominance. Changes in the grass and forb species in this association closely resemble those of the mesquite-buffalograss assemblage. Both assemblages typically occur on the same soil type.

The prickly pear-shortgrass association of 1957/1958 was almost nonexistent in 1973 and had become no different from other chaparral types. Only scattered cacti (Opuntia lindheimeri) remained, and the short grasses like tumble-windwill grass (Chloris verticillata), curly mesquite (Hilaria belangeri), and buffalograss had been all but replaced by midgrasses like Texas wintergrass (Stipa leucotricha), silver beardgrass, and meadow dropseed. While the brush canopy increase of 6.6 percentage points does not represent a significant change, the decrease in mesquite is significant, although it remains as the dominant woody vegetation.

Of the four associations considered by Mann (1975), the bunch grass-annual forb, growing in sandy soil, changed least. During the 15-year interval, seacoast bluestem (Schizachyrium scoparium littoralis) remained dominant. Fringeleaf paspalum (Paspalum setaceum) and balsamscale (Elyonurus tripsacoides) are other important species. Forbs are equally important species, varying with the season. Woody vegetation in the form of huisache (Acacia farnesiana) grows only around the fringe of this assemblage.

Mann (1975) considered that three factors have a potential role in the observed vegetational changes: climate, fire history, and grazing pressure. A period of increased precipitation in the 15 years, 1958 to 1972, appears partially responsible for some changes. For example, in the prickly pear-shortgrass area the increased moisture enabled forbs to compete for survival with grasses. In the chaparral-bristlegrass association, increased precipitation and an absence of fire appear responsible for the increase in brush species. Grazing is another mechanism of change in the coastal prairie. With the establishment of the refuge in 1954, direct evidence of changes due to cessation of grazing was provided by exclosures constructed in the mesquite-buffalograss area. Comparison of vegetation outside and inside the exclosures demonstrated that silver beardgrass (*Bothriochloa saccharoides*) was most susceptible to grazing pressure. Similar results were obtained by Launchbaugh (1955, cited in Mann 1975). The reduction in cattle grazing on the refuge helps explain the increase of midgrass species in the mesquite-buffalograss association. Deer prefer forbs over browse as foods, and the low grazing pressure on browse may explain the increase of brush species in the prickly pear-shortgrass and chaparral-bristlegrass associations.

Changes in the vegetational associations could be caused by rodents or insects (Weaver 1968, cited in Mann 1975) as well as interspecific competition for light among plant species. Successional trends are also mechanisms of change. Mann (1975) suggested that the increasing importance of Texas wintergrass and silver beardgrass in the mesquite-buffalograss, chaparral-bristlegrass, and prickly pear-shortgrass associations indicates that all these communities are developing in a unidirectional succession, ultimately progressing toward a climax bunchgrass-annual forb association dominated by seacoast bluestem.

The most common management practice for this upland brush-grass complex is controlled burning. Tracts of land used for cattle grazing may benefit from controlled burning if brushy species are increasing at the expense of grasses. Low stocking rates of cattle are also necessary to prevent over-grazing. Areas set aside as wildlife habitat may or may not benefit from controlled burning. Some species like white-tailed deer (*Odocoileus virginianus*) and Rio Grande turkey (*Meleagris gallopavo intermedia*) thrive in fairly open habitats while many prefer denser brush cover.

On Live Oak Peninsula and in the Aransas National Wildlife Refuge, vegetation is dominated by oak mottes and oak brushland. The most common species is live oak (*Quercus virginiana*). Other abundant species are laurel oak (*Q. laurifolia*), blackjack oak (*Q. marilandica*), redbay (*Persea borbonia*), wax myrtle (*Myrica cerifera*), and prickly-ash (*Xanthoxylum hirsutum*) (White 1973).

Although oaks may be scattered in other sections of the upland community of Copano-Aransas, Live Oak and Blackjack Peninsulas support the largest expanses of oaks. Brown et al. (1976) reported live oaks in the upland area in the vicinity of the Welder Wildlife Refuge, but neither Box (1957) nor Mann (1975) reported oaks within his study area.

5.5.2 Fauna

Mammals. Carnivores are found primarily in the dense brushland and oak mottes. Coyotes (*Canis latrans*) and bobcats (*Lynx rufus*) are common in these habitats; gray foxes (*Urocyon cinereoargenteus*) are seen infrequently (White 1973). Although coyotes exhibit the greatest flexibility in their diet, all three species show a seasonal propensity for rodents and lagomorphs as prey (Davis 1974). The diversity and abundance of these prey species provide a vital link in the trophic dynamics of the upland community. Table 7 lists representative rodents and lagomorphs of the area.

Table 7. Representative rodents and lagomorphs in the upland community, Copano-Aransas system (Davis 1974).

Scientific name	Common name
Spermophilus mexicanus	Mexican ground squirrel
S. spilosoma	Spotted ground squirrel
Geomys bursarius	Plains pocket gopher
G. personatus	South Texas pocket gopher
Perognathus hispidus	Hispid pocket mouse
Reithrodontomys fulvescens	Fulvous harvest mouse
Baiomys taylori	Pygmy mouse
Peromyscus maniculatus	Deer mouse
P. leucopus	White-footed mouse
Dipodomys ordi	Ord kangaroo rat
Sigmodon hispidus	Hispid cotton rat
Neotoma micropus	Gray wood rat
Lepus californicus	California jackrabbit
Sylvilagus floridanus	Eastern cottontail

In addition to the carnivores mentioned previously, furbearing species include the opossum (Didelphis virginiana), raccoon (Procyon lotor), striped skunk (Mephitis mephitis), and eastern spotted skunk (Spilogale putorius) (Davis 1974). No surveys of fur harvests by county or habitat are performed by TPWD (1979b), and no estimate of the value of this industry in the Copano-Aransas system is available.

Of the hoofed mammals, javelina (Dicotyles tajacu) and white-tailed deer are considered big game species. According to TPWD (1978d), javelina are not yet subject to heavy hunting pressure in Texas, but an increase is anticipated. Ellisor and Harwell (1976, cited in TPWD 1978d) suggested that although this species exhibits a high reproductive potential, predation on the young causes low net productivity. This phenomenon, in addition to Day and Smith's (1976, cited in TPWD 1978d) findings that heavy hunting pressure inhibits herd productivity, necessitates limited harvests as the species becomes a more popular game animal.

Sport harvest of white-tailed deer by county is reported by TPWD (1978c). From 1973 through 1977, the average annual harvest from counties lying within or overlapping the Copano-Aransas study area was 694, the lowest of the three central study areas; the San Antonio Bay system averaged 803 deer harvested annually, and the Corpus Christi Bay area averaged 1,176. Hunting pressure in the Copano-Aransas system is also the lowest of the three areas, averaging 15.9 hunters per 1000 ha. This figure is considerably lower than the average 28.6 hunters per 1000 ha in the Gulf Prairies and Marshes (TPWD's Ecological Area in which the majority of the Texas Barrier Islands Region is located).

Chamrad (1966) reported that white-tailed deer in his study area on the Welder Wildlife Refuge were predominantly grazers during the winter and spring. Forbs and grasses constituted almost 90% of this deer's diet. Browse, including mast, was taken when green herbaceous material was unavailable. Only from mid-April through May did browse exceed grasses in the deer's diet, and remained much less important than forbs throughout the year.

White (1973) investigated food habits of white-tailed deer in the Aransas National Wildlife Refuge. He found mast constituted 44% of the annual diet of the deer; forbs and grasses, 33%; and browse, 23%. The majority of the mast and browse was derived from live oaks.

The disparity in diets of deer from differing habitats and the seasonal variation in diet of those in one habitat emphasize this species' adaptability to its environment.

Birds. The mourning dove (Zenaida macroura) and bobwhite quail (Colinus virginianus) are important game birds along the coast and throughout the State. As would be expected, these species exhibit little specificity in their habitat requirements. Within the bounds of the Copano-Aransas system and the other areas of the Texas Barrier Islands Region, the mourning dove thrives on seashores equally as well as in the coastal grassland. Along the coast, the bobwhite quail is nearly as ubiquitous as the mourning dove, as long as some woody and herbaceous vegetation is present to provide shelter, nesting sites, and food (Oberholser et al. 1974). No population estimates are available for either species by county or habitat. However, TPWD annually conducts call counts for mourning doves in each of its Ecological Areas with the State. The study areas in the Texas Barrier Islands Region lie within the Gulf Prairies and Marshes Ecological Area. According to TPWD (1979c), this region had the second lowest mean call-count for mourning doves of the 10 Ecological Regions from 1966 through 1978. Relative densities in this region have been below the State average for all 12 years surveyed, and the general trend appears to be a decline. Such figures, however, provide no direct information concerning the population status for mourning dove in the Copano-Aransas system.

Chamrad (1966) reported the Rio Grande turkey (Meleagris gallopavo intermedia) to be relatively common in the Welder Wildlife Refuge. No information is available concerning the populations of this bird on unprotected land.

Carrion feeders like turkey vultures (Cathartes aura) and black vultures (Coragyps atratus) are probably more abundant in the Aransas National Wildlife Refuge than elsewhere in coastal Texas (White 1973; Oberholser et al. 1974). Audubon Christmas bird counts suggest a population decline of both species although black vulture numbers seem to be declining more drastically; the general decline is probably caused by a widespread loss of habitat and a decreasing food supply due to removal or burning of dead cattle by ranchers (Oberholser et al. 1974). The black vulture is faring worse than the turkey vulture because of its weaker flying abilities, which limit the areal extent of its daily hunt for food, and its poor sense of smell, which make the visual stimulus the primary means of locating carrion.

Predaceous birds of the upland include the barn owl (Tyto alba), great horned owl (Bubo virginianus), burrowing owl (Speotyto cunicularia), short-eared owl (Asio flammeus), white-tailed kite (Elanus leucurus), Swainson's hawk (Buteo swainsoni), white-tailed hawk (Buteo albicaudatus), and marsh hawk (Circus cyaneus). The abundant rodents of the community provide the main dietary items of these species. Ground roosting is not uncommon among rapacious birds. The burrowing owl, Swainson's hawk, and the marsh hawk all use the ground during resting hours (Oberholser et al. 1974).

The importance of oak mottes and their associated wetlands is briefly discussed in the Corpus Christi synthesis (Section 5.4). These areas provide habitat for a variety of migrating songbirds as well as year-round habitat for the black-bellied whistling duck (*Dendrocygna autumnalis*) and the mottled duck (*Anas fulvigula*).

Reptiles and amphibians. In the dry uplands of the Copano-Aransas system, only two land turtles are common. The Texas tortoise (*Gopherus berlandieri*) is generally associated with sandy soils, preferring open woodland, although it thrives in chaparral and mesquite (Carr 1952). The Texas tortoise has not been sighted in eastern Texas north of Lavaca county (Raun and Gehlbach 1972). Although its occurrence in the Matagorda-Brazos system is questionable, it probably does occur in the San Antonio Bay system. The ornate box turtle (*Terrapene ornata ornata*), common throughout the six study areas, is also common in sandy areas, probably because of its habit of burrowing to escape heat (Raun and Gehlbach 1972; Conant 1975).

Most lizards common to the Copano-Aransas system also live in the adjacent drainages of Corpus Christi and San Antonio Bays (Conant 1975). Table 8 is a list of representative lizards and snakes in the study area. The two earless lizards reach the northern coastal limit of their range in the San Antonio Bay system (Raun and Gehlbach 1972).

Table 8. Representative lizards and snakes of the upland community, Copano-Aransas system (Wright and Wright 1957; Raun and Gehlbach 1972; Conant 1975).

Scientific name	Common name
Holbrookia propinqua propinqua	Keeled earless lizard
H. lacerata subcaudalis	Southern spot-tailed earless lizard
Phrynosoma cornutum	Texas horned lizard
Cnemidophorus gularis gularis	Spotted whiptail
C. sexlineatus viridis	Prairie racerunner
Ophisaurus attenuatus attenuatus	Western slender glass lizard
Leptotyphlops dulcis dulcis	Plains blind snake
Lampropeltis calligaster calligaster	Prairie kingsnake
L. getulus holbrooki	Speckled kingsnake
Masticophis flagellum testaceus	Western coachwhip
Pituophis melanoleucus sayi	Bullsnake
Rhinocheilus lecontei tessellatus	Texas long-nosed snake
Sonora episcopa taylori	South Texas ground snake
Thamnophis marcianus marcianus	Checkered garter snake
Crotalus atrox	Western diamondback snake
Micrurus fulvius tenere	Texas coral snake

For the most part, snake species in the Copano-Aransas system are also present in the two neighboring drainages. Raun and Gehlbach (1972), however, reported sightings of the Texas long-nosed snake (Rhinocheilus lecontei tessellatus) in the coastal counties only as far north as the Copano-Aransas system. Snakes typically associated with aquatic habitats, like water snakes (Nerodia spp.), are common around ponds and streams in the upland community.

Amphibians common in the upland community of the Copano-Aransas system are essentially the same species as those in the Corpus Christi Bay area to the south (see Corpus Christi Bay synthesis, Section 5.4.2). Reproductive strategy is often one of opportunism, in which spawning is effected through the stimulus of heavy rainfall. In some species, such as the eastern green toad (Bufo debilis debilis), metamorphosis is completed less than 3 weeks after oviposition. Around permanent or semipermanent streams or ponds of the upland, amphibians requiring more constant moisture are evident. Their larval development is frequently a lengthy one, the most dramatic being that of the bullfrog (Rana catesbeiana) which requires 2 years before its metamorphosis into the adult form (Wright and Wright 1949).

5.6 RARE AND ENDANGERED VERTEBRATES AND INVERTEBRATES OF THE COPANO-ARANSAS STUDY AREA[1]

5.6.1 Mammals

The endangered mammals within this study area are the same as those discussed in the San Antonio Bay synthesis. Subtle differences between natural populations of these species might be expected between the San Antonio Bay and Copano-Aransas systems. The river otter (Lutra canadensis texensis), for example, would not be expected to normally occur in abundance in the Copano-Aransas area owing to scarcity of suitable habitat. No specimens are reported from the area (Hall and Kelson 1959; Davis 1974). TOES = T, TPWD = NC, USFWS = NC.

5.6.2 Birds

Haliaeetus leucocephalus leucocephalus - southern bald eagle. The Copano-Aransas study area is considered by TPWD (1976) to be part of the present nesting range of the southern bald eagle. According to TPWD (1979a), presently no nesting exists within this study area although four known nests are in the neighboring San Antonio Bay study area. Between the winters of 1971/

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[1] The status for each rare and endangered species is listed for three agencies: Texas Organization for Endangered Species (TOES), Texas Parks and Wildlife Department (TPWD), and the U.S. Fish and Wildlife Service (USFWS). Status designations include: Endangered (E), Threatened (T), and except for the USFWS, Peripheral (P). Additional designations of Status Undetermined (SU) and Not Considered (NC) are from Gustavson et al. (1978).

1972 and 1975/1976, there were 26 sightings of this species in the Copano-Aransas study area. See San Antonio Bay and Matagorda-Brazos syntheses for nesting areas. TOES = E, TPWD = E, USFWS = E.

Grus americana - whooping crane. The Copano-Aransas and San Antonio Bay study areas are the wintering grounds for 69 of the 75 individuals which make up the world population of wild whooping cranes (National Fish and Wildlife Laboratory 1980). The remaining six are an experimentally transplanted disjunct group whose wintering grounds are in the Rio Grande Valley of New Mexico (National Fish and Wildlife Laboratory 1980). Another 27 individuals are in captivity, 22 of which are at the Patuxent Wildlife Research Center in Maryland (National Fish and Wildlife Laboratory 1980). The disjunction of these populations is to lessen the possibility of a single perturbation resulting in extinction of the species.

Historical populations are relatively unknown, although Allen (1952, cited in National Fish and Wildlife Laboratory 1980) estimated them to be about 1,500. By 1941/1942, the total world population reached a low of 21 individuals. The near extinction of the whooping crane is attributed to hunting and the reduction of breeding, wintering, and migration route habitats. Natural factors, such as low reproduction rates and unfavorable weather conditions during migration, have partially negated attempts to raise population levels.

Food does not appear to be a limiting factor as the whooping crane is omnivorous and takes advantage of locally abundant foods. Allen (1952, cited in National Fish and Wildlife Laboratory 1980) included acorns, insects, marine worms, crustaceans, mollusks, fish, amphibians, and reptiles among the species' winter food.

Since the establishment of the Aransas National Wildlife Refuge in 1937 to protect the species, the USFWS, Audubon Society, and TPWD have closely monitored the whooping crane. The TPWD (1978b) surveys indicate that the whooping cranes' movements extend considerably beyond the refuge and include most of the estuarine area of the Copano-Aransas and San Antonio Bay systems. That study concluded that human interference with the species outside the refuge was minimal. Of considerable concern is the possible detrimental effect of hunters. While the TPWD (1978b) study found no incidents of major concern during the winter of 1976/1977, the confusion of whooping cranes with sandhill cranes (Grus canadensis) and snow geese (Chen caerulescens) have resulted in accidental shootings (Whooping Crane Recovery Team 1977, cited in National Fish and Wildlife Laboratory 1980). TOES = E, TPWD = E, USFWS = E.

Panlion haliaetus carolinensis - osprey or fish hawk. Between 1971 and 1976, 73 sightings of this migrant species were recorded for counties within and overlapping the Copano-Aransas system (TPWD 1976). It is unknown how many were repeat sightings. (See Matagorda-Brazos synthesis.) TOES = E, TPWD = NC, USFWS = SU.

Falco peregrinus tundrius - Arctic peregrine falcon. These winter migrants are known to occur in the Copano-Aransas study area. See Matagorda-Brazos, Galveston Bay, Laguna Madre, and San Antonio Bay syntheses. TOES = E, TPWD = E, USFWS = E.

Pelecanus occidentalis carolinensis - brown pelican. From 1969 through 1976, there were no nesting pairs of brown pelicans in the Copano-Aransas study area (TPWD 1978a). A colony of nine pairs was located on Long Reef in Aransas Bay in 1977. Based on the data presented by Blacklock et al. (1978) and TPWD (1978a), the colony did not represent a population increase, but merely indicated the movement of pairs from either of the neighboring two study areas, as the total state population from 1976 to 1977 only increased by one pair. In addition to Long Reef, colonies have previously existed on Dunham Island and several other islands and spoil banks in Aransas Bay (TPWD 1978a). Also see Corpus Christi Bay and San Antonio Bay syntheses. TOES = E, TPWD = E, USFWS = E.

Tympanuchus cupido attwateri - Attwater's greater prairie chicken. The Copano-Aransas study area is the southwesternmost limit of the present distribution of this species (National Fish and Wildlife Laboratory 1980). See Matagorda-Brazos synthesis for a species account. TOES = E, TPWD = E, USFWS = E.

Other rare birds. For peripheral species (species rare in the study area but more abundant elsewhere) see Laguna Madre, Matagorda-Brazos, and Galveston Bay syntheses.

5.6.3 Amphibians

No rare, threatened, or endangered amphibians listed in USFWS (1978) or Gustavson et al. (1978) are indigenous to the Copano-Aransas study area.

5.6.4 Reptiles

Alligator mississippiensis - American alligator. Joanen (1974, cited in National Fish and Wildlife Laboratory 1980) and TPWD (1975c) reported alligators in all counties within the Copano-Aransas study area. Both reports indicate that, statewide, populations are increasing. Table 9 indicates that the same trend is apparent for counties within and bordering the Copano-Aransas area. TOES = E, TPWD = E, USFWS = E.

Table 9. Estimated alligator populations for counties in the Copano-Aransas study area during 1974 (TPWD 1975c). Totals for counties include areas overlapping into other study areas. The total estimated population is 544 or approximately 1.5% of the estimated statewide population.

County	Population	Trend estimate
Aransas	114	Increasing
Bee	155	Stable
Refugio	154	Increasing
San Patricio	121	Stable

Malaclemys terrapin littoralis - Texas diamondback terrapin. According to Raun and Gehlbach (1972), there are at least two records of this species from the Copano-Aransas study area. (See Galveston synthesis.) TOES = T, TPWD = NC, USFWS = NC.

Other endangered reptiles. For endangered sea turtles, see the Laguna Madre and Marine syntheses.

5.6.5 Fish

There are no reported findings of any of the threatened or endangered species listed, proposed, or under review by the USFWS (USFWS 1978; Deacon et al. 1979).

5.6.6 Invertebrates

No invertebrate listed (USFWS 1978) is indigenous to the Texas coast. See Matagorda-Brazos synthesis for references consulted.

5.7 RARE AND ENDANGERED PLANTS OF THE COPANO-ARANSAS STUDY AREA

There are no known rare or endangered plants which do not have a more abundant distribution elsewhere. Two of the species whose Texas distribution is limited to this and the neighboring area are gray ragweed (*Ambrosia cheiranthifolia*) and mexican pepperwort (*Marsilea mexicana*). See Gustavson et al. (1978) for a more complete listing.

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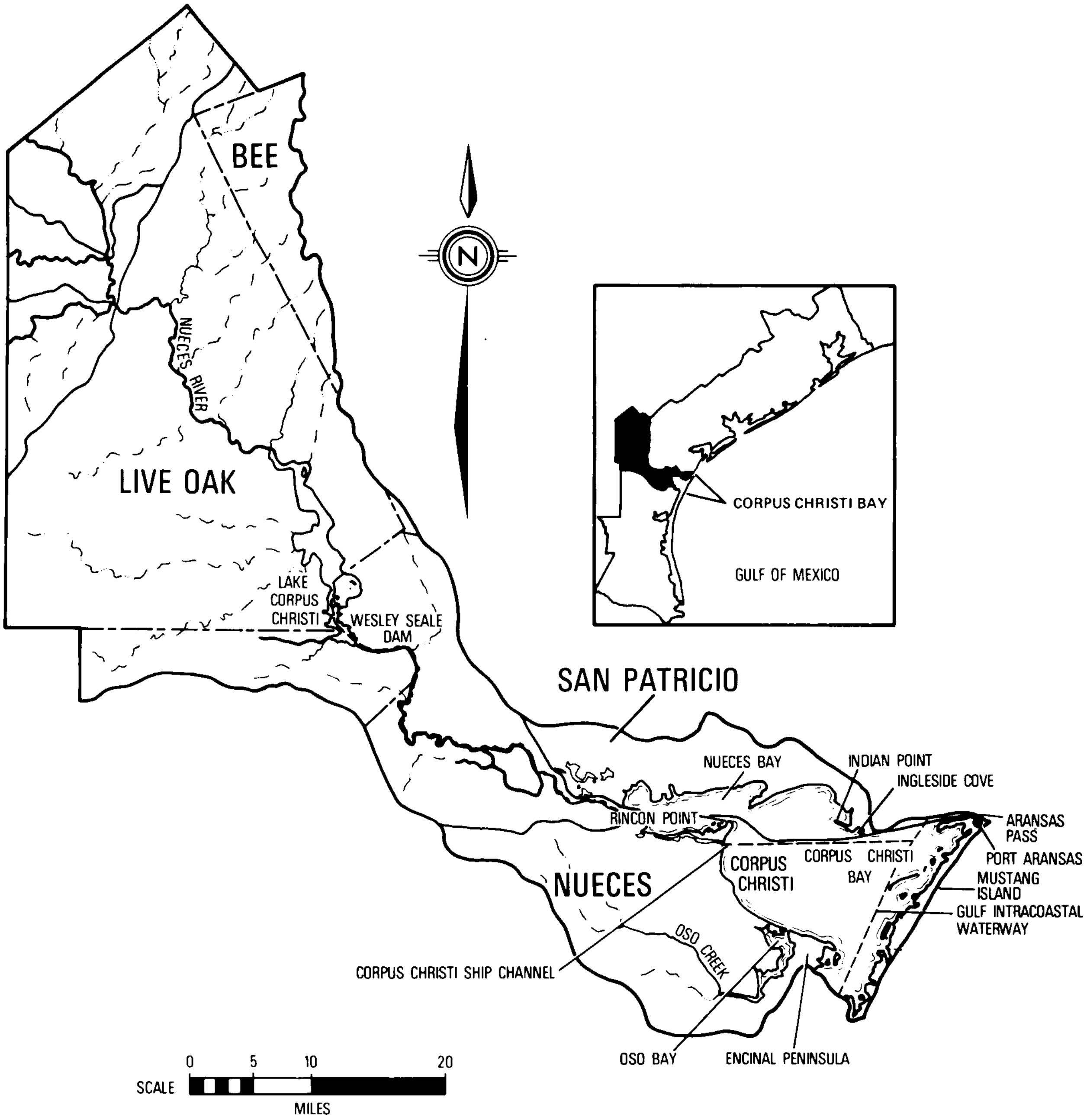
CORPUS CHRISTI BAY STUDY AREA SYNTHESIS



Map 6. Corpus Christi Bay study area.

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1.0 INTRODUCTION

The Corpus Christi Bay study area is an excellent example of the expansion of man's culture to a point which requires substantial alterations in the natural renewal regime of resources. The most striking part of the example is what man has done, is doing, and will be doing to supply his freshwater needs. The Nueces River is the major source of fresh water to the estuary in this study area and is the principal reason why the Corpus Christi Bay area is not usually hypersaline. The quantity of river flow is highly variable, both seasonally and yearly, and this inherent variability has been related to the numbers of species present and fishery production in the estuary (e.g., Henley and Rauschuber 1978). Higher freshwater inflows generally result in higher production of those species of sport and commercial value. Present diversions of Nueces River flow by man amount to approximately 4% of average annual flow; but by 2010, diversions have been projected to be as high as 43.5% of average annual flow, with other estimates projecting a 35% diversion (Henley and Rauschuber 1978). However, the percent reduction in annual flow is not as important as the percentage of time that flow has been below a certain critical level. For instance, the flow may be nil for several months but one flood can bring up the average annual flow to near normal (E.G. Simmons, Texas Parks and Wildlife Department; pers. comm. 1980). In any case, the projections are an order of magnitude greater than present levels of diversion, and the impact on the estuarine habitats is projected as substantial. Since the magnitude of the diversion projects clearly represents substantial change from the natural regime, there is considerable effort being made to obtain adequate data bases to evaluate more fully potential impacts.

Our emphasis on freshwater diversions is not intended to overshadow man's other impacts. The large oil and gas and petrochemical industries have helped to increase the population in the area, spurring additional impacts such as industrial and municipal waste disposal, the need for deepwater ports in a naturally shallow estuary, and a heavy demand on recreational facilities. Agriculture has also had large scale effects, from changing natural vegetation in the uplands to adding nutrients and toxins to the estuary.

While the data are not conclusive, primary productivity estimates and fishery biomass estimates indicate that the Corpus Christi estuary is now less productive per unit area than other bays along the central Texas coast. If this is true, the question of whether this is a reflection of natural conditions or an impact of man's activities or a combination of factors has yet to be resolved.

2.0 GEOLOGY

2.1 GEOLOGIC ORIGIN AND PROCESSES-ESTUARINE AND RIVERINE TRANSPORT OF SEDIMENT

No surface deposits of the Corpus Christi Bay study area are older than Pleistocene. Pleistocene deltaic and fluvial sediments originating from ancient courses of the Nueces and San Antonio-Guadalupe systems cover most of the study area (Brown et al. 1976). Variability in these deposits is similar to that occurring along presently active floodplains and deltas in Texas. A detailed account of the morphogenesis of the Corpus Christi Bay study area is collectively provided by Price (1933, 1958), Shepard and Moore (1955), Bernard and LeBlanc (1965), Aronow (1971), Wilkinson (1973), Wilkinson et al. (1975), and Brown et al. (1976). While the number of glacial and interglacial periods during the Pleistocene is presently the subject of much debate, there is overwhelming agreement in the literature that most of the Pleistocene deposits in the Corpus Christi Bay study area are Sangamon in age (interglacial period before the last major glacial period known as Wisconsin). Delta-plain sediments deposited during this age are known as the Beaumont Formation in Texas (analogous to the Prairie Formation in Louisiana). This age of delta-building during a high sea level stand lasted for perhaps 125,000 years (Bernard and LeBlanc 1965), after which a new glacial period and sea level fall occurred. The Nueces and other rivers along the coast eroded into their previously deposited floodplains in order to adjust their grade to the lowered sea level. Borings indicate that the base of the Nueces River was 30 to 40 m lower during this interval than at present (Brown et al. 1976). The Corpus Christi Bay study area was indeed different during this period, with high-cliffed river valleys and a coastline as much as 80 km distant from the present shoreline.

During the Wisconsin (glacial) period the climate fluctuated periodically with subsequent rises and falls in sea level. During one interstadial (a temporary period during a glacial epoch when the ice mass retreats and sea level rises) within the Wisconsin, a curious feature formed and persists on the landscape today. It was originally recognized by Price (1933) as a "live oak mature offshore bar" and later termed the "Ingleside barrier" (Price 1958). There is, however, considerable doubt whether the feature is truly a remnant Pleistocene barrier island or, according to McGowen et al. (1972) with supportive evidence by Wilkinson et al. (1975), a strandplain (also see Section 2.4).

With the termination of the Pleistocene, approximately 18,000 years ago, the sea level began to rise and achieved the present level approximately 4,500 years ago (Brown et al. 1976). The capacity of the Nueces River to carry sediment and fill its river valley did not keep pace with sea level rise; marine transgression occurred, and the lower Nueces River Valley was drowned by an invading gulf. Corpus Christi and Nueces Bays represent drowned portions of the Nueces River Valley. These bays have been gradually filling with a mixture of riverine, estuarine, marine, and eroded bay shoreline sediments. Estimates of the relative contribution of sediments to the Corpus Christi Estuary by each of these components have not been made. Marine sediments are, for the most part, buried beneath other sequences as the contribution from the open gulf environment has decreased with the formation of Mustang Island.

Riverine transport of sediment primarily comes from the Nueces River drainage. The Nueces River Delta has extended 15 km into Nueces Bay during the past 2,500 years (Brown et al. 1976). Oso Creek and other less organized drainage around Corpus Christi and Nueces Bays contribute some lesser amount of sediment; unfortunately, suspended load or bedload samples are not regularly obtained for any of the drainage into Nueces or Corpus Christi Bays. Prior to the completion of the Wesley Seale Dam in 1958, the average suspended sediment input of the Nueces River was 161 x 10^6 kg/yr (Diener 1975). While the present annual average input is probably substantially less, the above value represents the second lowest riverine input of sediment into the six study areas along the Texas Barrier Islands coast. The Copano-Aransas study area receives less riverine sediment than the Corpus Christi Bay study area. If one can assume that most of the entire suspended sediment input of the Rio Grande at Brownsville is deposited into the Gulf of Mexico, then the Laguna Madre study area would receive the least input of suspended sediment.

The contribution of eroded bay shoreline sediments to the Corpus Christi Estuary has not been quantitatively addressed, but in Matagorda Bay the contribution by this component was estimated to be equivalent to two-thirds of the Colorado River input (see Matagorda-Brazos synthesis). While specific shoreline erosion data for Corpus Christi and Nueces Bays are not available, Brown et al. (1976) indicate that erosion is extensive, especially along the northwestern shore (related to persistent southeasterly winds) of Corpus Christi Bay. In other words, the contribution of eroded bay sediments is probably substantial, and it would not be surprising if the contribution exceeded that of the Nueces River.

The movement of sediments by hurricanes, nearshore littoral transport, onshore and offshore transport, and the transport of sediment through tidal passes are important aspects of an overall estuarine sediment budget; unfortunately, there are too few data to estimate their relative contributions.

To a lesser extent, eolian processes (wind-transported) have eroded subaerial exposures and contributed sediment to the bays. South of the bay complex, the Beaumont formation is discontinuously covered by a thin veneer of loess (wind-deposited silts). North of Corpus Christi Bay, the loess mantle is generally absent and dune migration is not as pronounced as areas to the south (Brown et al. 1976). These features indicate the increasing importance of eolian processes as one proceeds in a southerly direction along the coast. The increased wind domination results from increasing aridity and persistence of the southeasterly winds.

The offshore barrier from Corpus Christi Bay is known as Mustang Island, and its morphogenesis is similar to that of Padre Island (Laguna Madre study area) and the Matagorda Peninsula (Matagorda-Brazos study area). Mustang Island assumed its present position about 2,500 years B.P. (Before Present); it was a group of discontinuous islands then. Onshore transport of offshore Pleistocene deltaic sands, plus longshore transport of riverine (mostly Brazos) and eroded Pleistocene headland deposits, provided a sufficient source of sediment, enabling many of the islands to coalesce and enlarge (Brown et al. 1976).

An apparent change in this long-term accretionary trend has occurred since the middle 19th century when Mustang Island began experiencing net erosion (Morton and Pieper 1976b). This trend appears to be characteristic of the Texas Barrier Island coast as a whole, as Seelig and Sorenson (1973), Morton and Pieper (1976a), and Morton et al. (1976) agree that most of the Texas coast has been experiencing net erosion over approximately the past century. Whether erosion will continue to dominate or is an aberrant phase within a longer-term accretionary period is unknown.

While the reported rates of erosion do not pose any immediate cause for alarm (except for individual property owners), the reason(s) for the reversal from 2,500 years of net accretion to 125 years of erosion is not understood. If erosion persists, this barrier island coast will undergo gradual change.

The numerous unknowns preclude meaningful projections; the effects upon the recreation industry, however, would be deleterious. The decreased sand supply to the beach ultimately will limit dune formation and affect the stability of the islands. Erosional beaches have a different profile and composition from beaches that are accreting. Do erosional processes, for example, affect beach preference by nesting sea turtles, or feeding and nesting habits of shorebirds?

While the causal agents for the net erosional trend are not documented, a few factors are probably more involved than others. Morton et al. (1976) attributed some of the erosion along the Matagorda Peninsula to the reduced sand load of the Brazos River. The reduced load is a direct result of the damming along the Brazos. As most major rivers emptying into the estuaries along the Texas coast are dammed to some extent, a significant reduction in the sand supply to the coast is likely. The global rise in sea level (eustatic), especially during the past 50 years (e.g., Hicks and Crosby 1974), may account for erosion without any change in the sediment supply. Subsidence, an important process along the Texas Barrier Islands coast for countless millenia, may be increasing regionally due to groundwater and oil and gas extractions. Finally, the net erosional trend may be due to the cumulative effect of all of the above.

The Corpus Christi Bay study area, like the entire Texas coast, lies within a geologic region known as the Gulf Coast Geosyncline. This crustal downwarping is only one of several processes operating in the area that result in subsidence. If aggradational processes are less than the subsidence rate, the elevation of the land diminshes with respect to sea level. One visual change that net subsidence will produce is the loss of emergent marsh to a more aquatic environment. White et al. (cited by Brown et al. 1976) noted that submerged vegetation areas increased at the expense of wind tidal flats from 1938 to 1974. This increase is attributed to the combined effects of sea level rise and subsidence. Swanson and Thurlow (1973) estimated that the subsidence rate (not including eustatic sea level rise) at Port Aransas was approximately 13 mm/yr from 1959 to 1969. This represents the highest rate among the stations examined along the Texas Barrier Island coast. While the exact cause(s) of the apparently high rate of subsidence cannot be pinpointed, the extraction of oil and gas and possibly groundwater has been associated with localized subsidence in this study area (see Section 4.4).

2.2 SOILS

Soil types in the uplands of the Corpus Christi Bay area are transitional between those of the Laguna Madre study area and those of the north. Much of the upland portion of the study area represents interdistributary Pleistocene deposits composed of a high percentage of fine-grained sediments. The general lack of slope of these areas leads to poor drainage, and the sediments have a high water-holding capacity with low permeability (Brown et al. 1976). The major soil types that have developed from these sediments are the Victoria and Banquette Series (Brown et al. 1976). The remaining area in the uplands consists largely of grain sediments coarser than those of the interdistributary areas. These areas represent ancient channel deposits, crevasse splays, etc. Similar soils, but younger in age, are developing on the margins of the present Nueces and other active floodplains. The major soil groups that have developed on these lands include the Miguel, Willacy, Clareville, Trinity, Frio, Orelia, and Banquette Series (Brown et al. 1976).

Sandy soils with high permeability characterize much of Mustang Island and the Ingleside barrier-strandplain deposits of the Encinal Peninsula and Live Oak Ridge. Small, discontinuous areas of these soils also occur along some of the bay shorelines and on point bar deposits along the Nueces River floodplain. Representative soil groups include the Mustang and Galveston Series, with the former occupying wetter areas (Brown et al. 1976).

Undifferentiated soils developing on spoil deposits compose a relatively large segment of the Corpus Christi Bay study area. In addition to the linear deposits along dredged waterways, large areas of subaerial spoil are located along the western shore of Nueces Bay. Most of these latter areas are associated with land fill for structural expansion (Brown et al. 1976).

The remaining area consists of wetland soils, of which the largest continuous area is on the bay side of Mustang Island. Soils here contain a high percentage of sand and have low organic content. Areas inland of Live Oak Ridge and the Encinal Peninsula are subject to periodic but irregular flooding. Soils there are variable in texture and contain a much greater proportion of organics than the wetland soils surrounding the bays.

2.3 TOPOGRAPHIC AND BATHYMETRIC FEATURES

The Corpus Christi Bay study area has a gentle slope of approximately 0.5 m/km with the inland boundary attaining elevations of 30 m. Water bodies are shallow, although Corpus Christi Bay, with a mean depth of 3.1 m, is the deepest bay in the Texas Barrier Islands Region (Diener 1975). In comparison, Oso and Nueces Bays have an average depth of 0.5 and 0.7 m, respectively (Diener 1975).

The most conspicuous topographic relief is along Nueces Bay where the bluffed shoreline reaches a maximum elevation of 20 m. Somewhat less obvious is the Pleistocene barrier-strandplain with a maximum elevation of 8 m above the surrounding marshes.

2.4 UNIQUE OR UNUSUAL FEATURES

The Ingleside barrier-strandplain is a discontinuous feature that is most evident from the northern Laguna Madre study area to Port O'Connor in the Matagorda-Brazos study area. The strandplain is also found farther up the coast in the Galveston study area where it is considerably less easy to distinguish as a surface feature from surrounding environments (Graf 1966; Fisher et al. 1972). In the Corpus Christi study area, the strandplain is a distinctive feature known as Live Oak Ridge to the north of Corpus Christi Bay and the Encinal Peninsula to the south of the bay. While questions regarding its morphogenesis are still unresolved, the diverse array of habitats which the Ingleside supports is unquestioned. The topographic highs and lows support a live oak community and intervening ephemeral wetland communities, respectively. The live oaks represent the first cluster of trees that northerly moving migrant birds encounter after traversing the Gulf of Mexico; and the proximity of live oaks to fresh, brackish, and saline marsh facilitates a faunal mix that might not otherwise be possible.

The prograding Nueces River Bay Delta and adjacent floodplain habitats represent the first substantial area of these types of habitats for a distance of 200 km in a northerly direction from the Rio Grande (see Section 5.4 and beginning of Section 5.5).

2.5 MAN-MADE DEVELOPMENTS

Man is a measurably more significant geologic agent in the Corpus Christi Bay system than in the neighboring Laguna Madre and Copano-Aransas systems of the study region because of the comparatively larger developed sector in the Corpus Christi Bay study area. Several projects that will further alter the biological resources of the Corpus Christi system are being considered (Henley and Rauschuber 1978). Impacts changing the morphology and altering geologic processes fall into three categories: (1) damming of the Nueces River; (2) construction of waterways and associated spoil deposits; and (3) direct conversion of nonaquatic habitats to developed structures.

The damming of the Nueces River, largely due to the Lake Corpus Christi system, was necessary to satisfy man's demand for water. This system reduced the average annual freshwater input into the Corpus Christi estuary by about 4% (Henley and Rauschuber 1978). The changes resulting since the dam's completion in 1958 cannot be addressed here, but Henley and Rauschuber (1978) evaluated probable changes that will result from the construction of the Choke Canyon Reservoir. Continued population growth, largely due to the direct and indirect growth of oil and gas activities, may have exceeded the capacity of the Lake Corpus Christi system to provide sufficient surface water supplies. While groundwater reserves filled initial needs, the resulting problems of subsidence and saltwater intrusion have placed pressure on further utilization of surface flow. The construction of the Choke Canyon Reservoir in conjunction with the Lake Corpus Christi system will reduce the average annual inflow by 35% (Henley and Rauschuber 1978). Predicted impacts of this reduced inflow include (1) significant increases in salinity in Nueces and upper Corpus Christi Bays, (2) vegetation composition change in the Nueces River Delta, (3) increased hypersalinity in the estuary, (4) major reduction in populations of fish species, (5) change in the species composition of fish, (6) a net reduction in the biomass or a change to more individuals of fewer species of fish and other fauna inhabiting the aquatic and marsh habitats, and (7) a change in species composition and a decrease in areal coverage of seagrasses and emergent marsh vegetation (Henley and Rauschuber 1978). Henley and Rauschuber (1978) did not specifically address the reduction in sediment input that will accompany the reduced surface flow. Possible impacts may include (1) decreased growth rate of the Nueces River Delta and (2) decrease in nutrients. Sediment and nutrient concentrations actually may increase but, due to the reduced flow, the total sediment and nutrient input probably will decrease (see Section 5.1).

Based on data reported by Diener (1975), the Corpus Christi Bay system contains the largest area of spoil per unit estuarine area within the boundaries of the Texas Barrier Islands Region. In addition to spoil associated with waterway construction, a large portion is used for fill and the creation of land for industrial expansion in Nueces Bay (Brown et al. 1976). According to the Texas Parks and Wildlife Department (TPWD), much of the spoil has been deposited in shallow portions of Corpus Christi Bay and has been responsible for destroying grassbeds in these areas (TPWD 1975). Although an inventory of colonial waterbird colony sites (Blacklock et al. 1978) indicated that spoil islands are extensively used, and a study by Soots and Landin (1978) stated that several locally nesting species prefer spoil islands over natural areas for nesting, the loss of grassbeds will ultimately reduce food availability for these fish-eating birds. Thus, while nesting habitat may increase, the reduction in food availability can be expected to keep bird populations low.

The Corpus Christi Ship Channel (CCSC), with its associated spurs, and the Gulf Intracoastal Waterway (GIWW) are the two major artificial navigation channels in the Corpus Christi Bay study area. In the Laguna Madre study area to the south, artificial channels allow less saline gulf waters to enter the lagoon, and the comparatively deep channels provide a haven for fish during excessively cold or hot periods. This situation is not nearly so pronounced in the Corpus Christi Bay study area. First, Corpus Christi Bay is comparatively deep; therefore, there is less change in water temperature in response to rapid change in air temperature, and fish are not likely to concentrate in the waterways. Second, hypersalinity is not as typical of the Corpus Christi and Nueces Bays as Laguna Madre, although salinities frequently rise during the summer months, and intrusion of gulf waters through the CCSC does not always reduce salinities. This hypersaline condition may be more prevalent in the future because reduced flow from the Nueces River will increase salinity (Henley and Rauschuber 1978).

Historically, the fresher waters from Corpus Christi Bay have mixed with those of Upper Laguna Madre. While the construction of the GIWW potentially might have increased this exchange, the resulting location of spoil, combined with the construction of the Laguna Madre Causeway, has reduced mixing between these two water bodies (also see Laguna Madre synthesis).

The construction of the Port Aransas Causeway, Aransas Channel, and CCSC has altered water exchange between Aransas Bay and Corpus Christi Bay and has interfered with the development of the extensive seagrass beds on the tidal delta in Redfish Bay (also see Copano-Aransas synthesis).

The dredging of Aransas Pass in 1925 deepened and stabilized Lydia Ann Channel (Copano-Aransas study area). The newly enlarged channel transported a greater volume of water between the gulf and the bays. Since the tidal prism is much the same, the increase in flow through Aransas Pass was at the expense of Corpus Christi Pass, which closed in 1926 (Brown et al. 1976).

The closing of Corpus Christi Pass meant that there was no exchange between the gulf and the southwest portion of Corpus Christi Bay. Subsequently, public monies were spent to create an artificial pass (called Fish Pass, Corpus Christi Water Exchange Pass, or Mustang Island Water Exchange Pass) in this area to increase water exchange and provide additional access for fish (also see Section 4.2). In addition, the Old Corpus Christi Pass area has been developed due to recreation demands. Due to the area's low lying nature, a 4-m seawall was constructed to protect the dwellings. In consideration of the long history of hurricane breaching along Lower Mustang Island (Price 1952, cited by Brown et al. 1976), this recreational development is in a precarious position.

Finally, the direct conversion of nonaquatic habitats to development is seen in the Corpus Christi metropolitan area, which occupies a large segment of the upland along the western shore of Corpus Christi Bay. The growth of this urban sector has been largely at the expense of agricultural lands, themselves previously occupied by natural grassland and woody shrub habitat. Croplands change the natural vegetation, and the use of uplands for grazing often leads to an increase in shrubby vegetation and a change of species of grasses with no clear dominance (Bogusch 1952; Johnston 1955).

3.0 CLIMATE

3.1 PRECIPITATION

The Corpus Christi Bay study area is in the eastern margin of the semiarid climatic zone of Texas. According to the National Oceanic and Atmospheric Administration (NOAA), mean annual precipitation over the area is approximately 725 mm (NOAA 1973a). Precipitation rates vary over the study area, with lowest annual rates averaging 650 mm in the inland portions bordering the Laguna Madre area, increasing to approximately 815 mm along the eastern border with the Copano-Aransas study area (NOAA 1973a). This trend of decreasing precipitation as one moves downcoast (southerly or southwesterly direction) is apparent throughout the entire Texas Barrier Islands coast.

The seasonal distribution of rainfall over the area is bimodal (Figure 1). The spring peak and, to a lesser extent, the fall peak are associated with the increased interaction between warm and moist gulf-originating air and cooler continental or Pacific air masses. More precipitation is associated with the fall (or late summer) because of the increased frequency of tropical disturbances. As shown in Figure 1, the more coastal station (Corpus Christi) receives a greater amount of rainfall during the fall than the inland station (Three Rivers). This is due to the rapidly decreasing influence of tropical disturbances as one progresses inland from the coast (also see Matagorda-Brazos synthesis).

3.2 TEMPERATURE

Mean annual air temperature at Corpus Christi was 22.2° C for 1941-1970 (NOAA 1973a). The mean annual air temperature at Alice, about 60 km west (inland) of Corpus Christi, was 22.3° C, (NOAA 1973a). Seasonally, the two areas are somewhat different. Winter temperatures are warmer and summer temperatures are cooler at Corpus Christi by approximately 1° C (NOAA 1973a) due to the differing proximities of the two areas to the mitigating effects of the Gulf of Mexico. If comparable data were available for a station at the coast (e.g., Port Aransas), the seasonal difference in mean temperature would be expected to be more pronounced in comparison with Alice. In terms of the growing season, Alice usually averages 305 consecutive freeze-free days, compared with 315 days in the Mustang Island area (Orton 1964).

Due to the combined effects of warm temperature and moderate rainfall, moisture deficits in the Corpus Christi area are commonplace. Orton (1969), using the noncontinuous method, calculated annual moisture deficiencies for

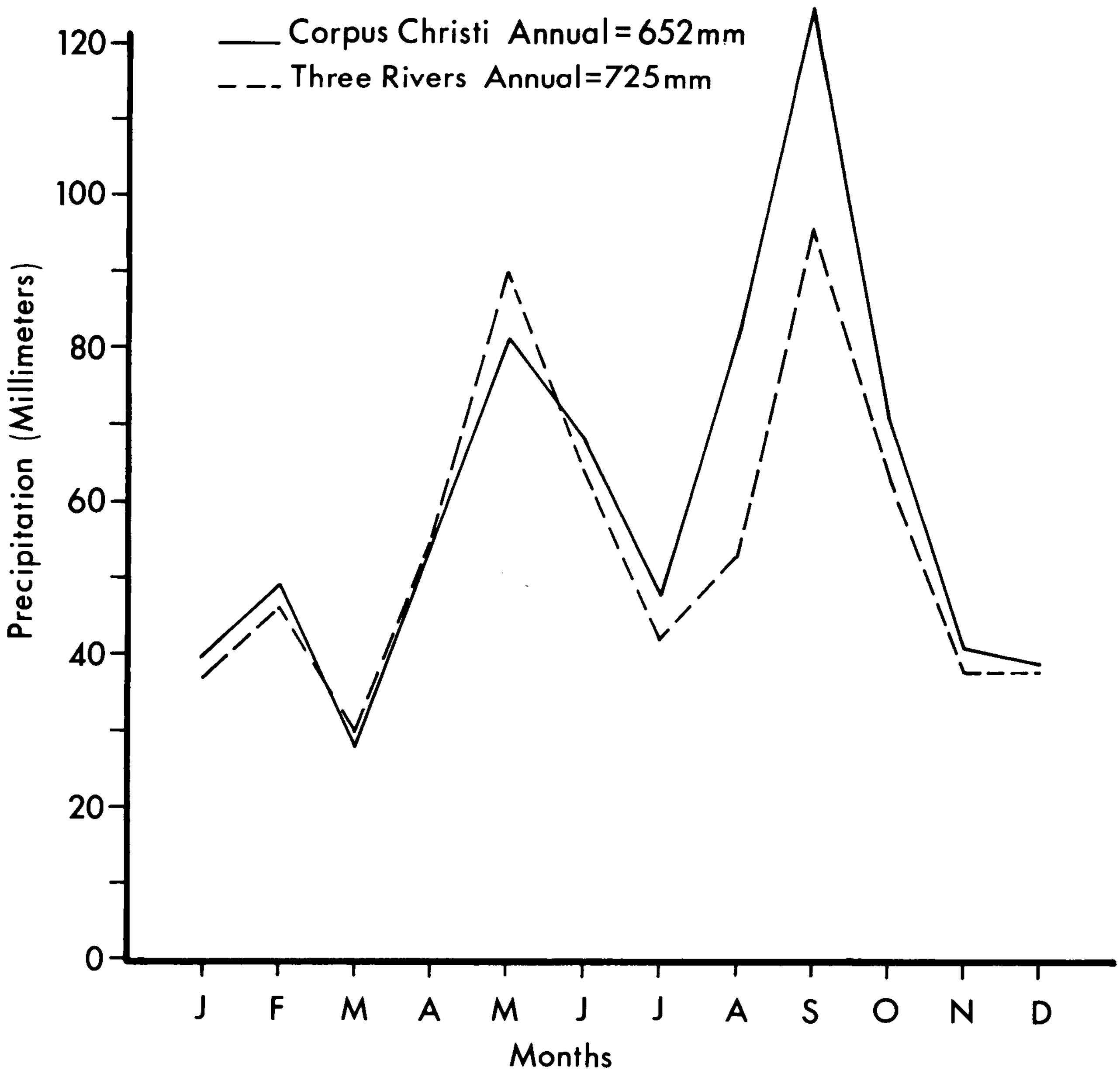

Figure 1. Mean seasonal precipitation for Corpus Christi and Three Rivers, Texas, 1941-1970 (NOAA 1973a).

Texas and showed that the Corpus Christi study area averages a 410-mm net (surpluses minus deficits) deficit in the Port Aransas area and 500-mm in the Three Rivers area (see Laguna Madre and Copano-Aransas syntheses for comparison of annual rates and the seasonal distribution of deficits and surpluses).

3.3 WIND PATTERNS

The Corpus Christi Bay study area, like other Texas coastal basins, is influenced by three distinct wind regimes: southeasterly to southerly, northerly, and the highly variable winds associated with tropical disturbances (see Matagorda-Brazos and Laguna Madre syntheses). Table 1 shows the relative frequency of wind direction in the Corpus Christi Bay area.

Table 1. Frequency and direction of wind in the Corpus Christi Bay study area. Direction is that from which the wind is blowing. Frequency is the percent of time the wind blows (Bureau of Land Management 1974).

Direction	Frequency
0°	19
45°	14
90°	8
135°	26
180°	11
225°	3
270°	3
315°	13
Calm	3

In comparison with the neighboring wind-dominated coast of the Laguna Madre study area, the relative influence of wind is diminished (but still important) in the Corpus Christi Bay study area partially because of the increased influence of riverine input and local precipitation, but also because of the diminished strength (energy) and prevalence (frequency) of the southeasterly winds (Brown et al. 1976).

4.0 HYDROLOGY AND HYDROGRAPHY

4.1 TIDAL INFLUENCES-SALINITY REGIMES

Lunar tides in the Corpus Christi estuary are small in magnitude and primarily diurnal. Mean tidal range in Corpus Christi Bay is 21 cm, decreasing to 12 cm in Nueces Bay (Diener 1975). In comparison, mean tidal range in the gulf at Mustang Island Pass[1] is 50 cm (Behrens et al. 1977) and 60 cm at Port

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[1] Also known as Corpus Christi Water Exchange Pass and Fish Pass. The former names are not used here to avoid possible confusion with Corpus Christi Pass, which is a separate intermittent pass.

Aransas (Henley and Rauschuber 1978), indicating that tidal amplitude undergoes fairly rapid attenuation from the gulf to the bay. When conditions conducive to semidiurnal tides are at a maximum, mixed tides result, with the secondary tide usually less than 20 cm in range at the Mustang Island Pass (Behrens et al. 1977) and approximately 13 cm at Port Aransas (Henley and Rauschuber 1978). Maximum tidal range coincides with maximum lunar and solar declination and is approximately 90 cm at the gulf side of Mustang Island Pass (Behrens et al. 1977) and at Port Aransas (Henley and Rauschuber 1978).

The importance of gravitational tides to flushing is secondary to wind and fresh water inflow but is a key element in controlling salinities and faunal movements within the estuary and between the estuary and the gulf. There is some indication that the tidal pulse into the Corpus Christi Estuary has increased through time, primarily from channel construction activities, but this is difficult to substantiate due to the paucity of data from the prechannel period. Present data indicate that tidal range in the Corpus Christi Ship Channel is less than in neighboring shallower natural waters (Henley and Rauschuber 1978); and modeling efforts by the Texas Water Development Board (TWDB 1970) indicated that the artificial channels allow the tide to progress upstream farther and possibly faster than under natural bottom conditions. Another contributing factor is the reduction in freshwater input (see Section 4.3) which may permit an inland migration of the tide.

Modeling efforts by the TWDB (1970) and the University of Texas Marine Science Institute (1974, cited by TPWD 1975) indicated that net tidal flow is into Aransas Pass and net outflow is into Laguna Madre and, when open, Corpus Christi Pass. The movement of the tidal wave from Aransas Pass through Corpus Christi Bay and into Upper Laguna Madre was examined by Smith (1974, 1977, 1978), who noted that tidal amplitude in Upper Laguna Madre was reduced to 25% of the amplitude at Aransas Pass, with the speed of propagation of the diurnal tide being 4 km/hr. During semidiurnal periods, the speed of propagation increased to approximately 5 km/hr.

Although technically incorrect, the common usage of the term "tide" along the northern gulf coast includes the effect of weather on water flux. As noted by Smith (1977), meteorological effects on water vary in time scales from hours to seasons. The most dramatic responses are associated with hurricanes when water levels may change by several meters in a matter of hours.

While not as dramatic as hurricanes, midlatitude frontal passages occur with much greater frequency and often result in a water level change in excess of 45 cm. Similar to other estuaries along the Texas Barrier Islands coast, water levels drop in Nueces and upper Corpus Christi Bays and rise in lower Corpus Christi Bay because of the limited tidal passes. The setup of water in the lower part of the bay and the setdown in the gulf results in a strong hydraulic gradient. Watson and Behrens (1976) report that the normally flood-dominated Mustang Island Pass becomes ebb-dominated during periods of polar outbreaks.

A seasonal pattern of water flux is consistent throughout the Texas Barrier Islands Region (see Laguna Madre and Galveston syntheses for other examples). The change in water level between the fall maximum and the summer and winter minima is approximately 50 cm in Corpus Christi Bay (Smith 1977). This seasonal variation was described first by Marmer (1954) and subsequently studied by Whitaker (1971) and Sturges and Blaha (1976), who attributed the change to variable wind stress, seasonal heating and cooling of water, and spring runoff.

Superimposed on the seasonal pattern of water flux are a rise and fall in sea level on the order of 10 to 20 cm, occurring approximately every 1 to 2 weeks (Smith 1977, 1978). Such sea level fluctuations are attributed to the slow exchange of water between estuaries and the inner continental shelf in response to regional meteorologic forces (Smith 1977, 1978).

Tidal flux, wind-induced water movements, river flow, and local precipitation and evaporation are primary factors controlling salinity variability. Due to the high degree of variability in the controlling parameters, the salinity range is large in this area, both spatially and temporally. Mean annual salinity throughout Corpus Christi and Nueces Bays was 27.5 $^o/oo$ for 1965 through 1975 (Martinez 1975). The Texas Water Development Board (TWDB 1970), examining the period 1961 through 1971, which included several drought years in the early 1960's, found the average annual salinity to be 29.5 $^o/oo$. Either value is at least 7 $^o/oo$ greater than any of the other estuaries along the Texas Barrier Islands coast, with the exception of Laguna Madre, which is typically hypersaline. Due to the freshwater input from the Nueces River (see Section 4.3), hypersalinity can and does persist for several months at a time, reversing the normal salinity gradient (E.G. Simmons, Texas Parks and Wildlife Department; pers. comm. 1980). Mean monthly salinities for an 11-year period (Figure 2) indicate that hypersalinity is not a seasonally recurring event in either Corpus Christi or Nueces Bays, although during excessively low freshwater input years, the mean salinity for the entire estuarine system may exceed seawater concentrations. For example, during 1963 the mean annual salinity for the Corpus Christi Bay system was 36.9 $^o/oo$ (TWDB 1970).

It should be emphasized that these values represent entire bay complex averages and a considerable degree of variability exists within the area. For example, in southeast Corpus Christi Bay near the Laguna Madre Causeway, stations monitored by Martinez (1967, 1970-1975) typically are hypersaline during July and August when local precipitation and riverine input are low and evapotranspiration rates are high and when the water is blown out of Laguna Madre by southeast winds. The geographic variation in salinity, as well as some temporal variability, is illustrated on a smaller scale in Figure 2. As expected, Nueces Bay, the receiving basin for the Nueces River outflow, has a lower average bay salinity than the more seaward Corpus Christi Bay, but it can have higher salinity at times because of evaporation (E.G. Simmons, TPWD; pers. comm. 1980). Also, seasonal and yearly variability is greater at Nueces Bay in comparison to Corpus Christi Bay because of the mitigating effects of a relatively constant salinity input of seawater into Corpus Christi Bay versus the highly seasonal diluting effects of Nueces River discharge into Nueces Bay. Salinity differences between the two bays are maintained by the comparatively small area for water exchange located between Rincon and Indian Points.

4.2 CURRENT AND WATER CIRCULATION PATTERNS

The small amplitude of gravitational tides and their diurnal pattern increase the importance of wind and river flow on circulation in the Corpus Christi Bay system. Although comparatively deep with respect to other bay systems along the Texas Barrier Islands coast, the Corpus Christi Bay system

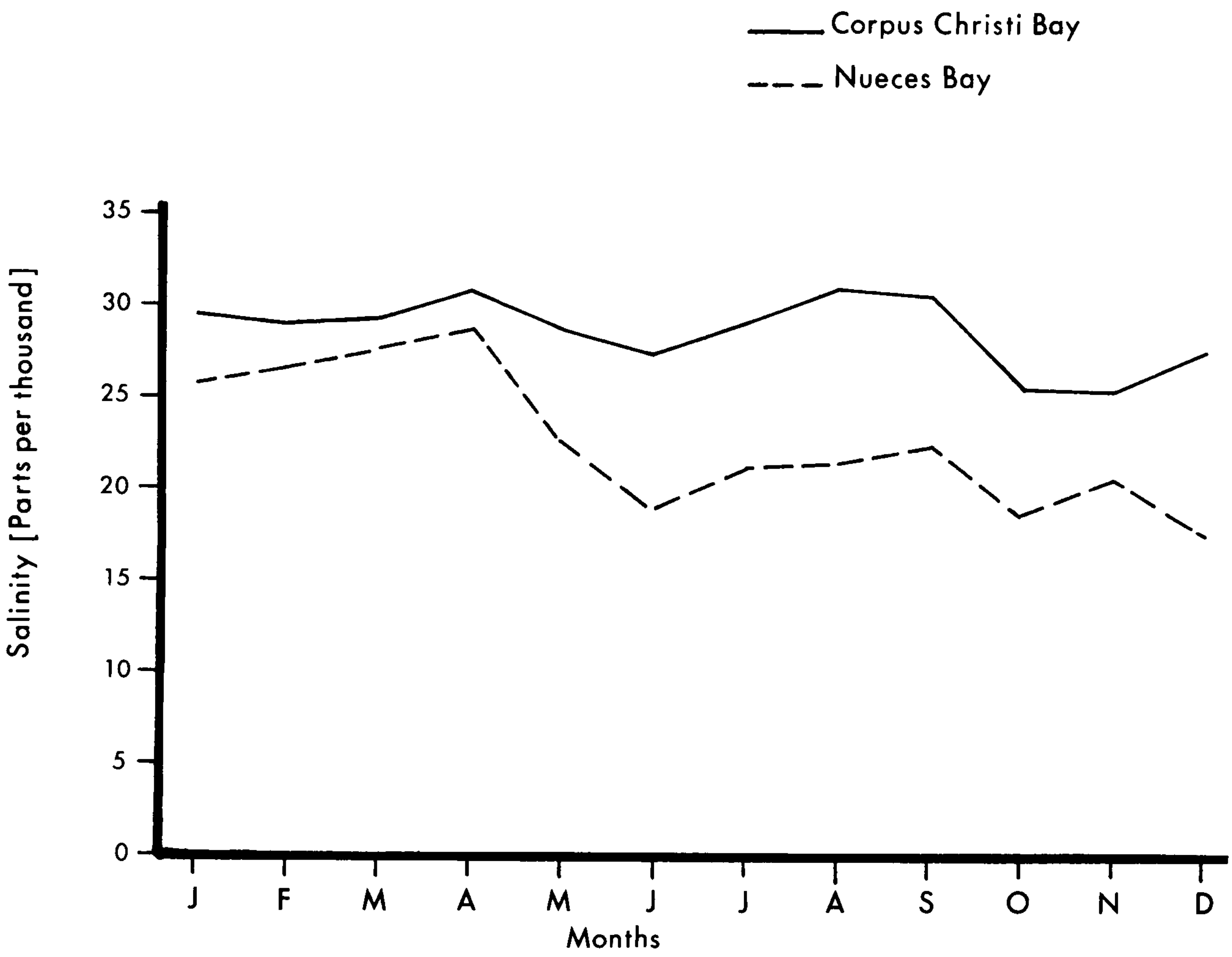

Figure 2. Mean monthly salinities for Nueces and Corpus Christi Bays, 1964-1974 (Henley and Rauschuber 1978).

is a shallow estuary, and vertical homogeneity of the water column is typical with the exception of dredged channels (Henley and Rauschuber 1978).

Existing current measurements are inadequate to establish variability in large scale circulation patterns due to variances in meteorologic conditions and river flow, and little information has been generated to establish net current movements (Henley and Rauschuber 1978). During periods of sustained onshore winds with low river discharges, models (Henley and Rauschuber's 1978 modification of TWDB 1970) indicate that two main gyres, converging near the junction of Nueces and Corpus Christi Bays and diverging in southeastern Corpus Christi Bay, develop in the system.

Analysis of water level variations by Smith (1974, 1977, 1978) and monitoring of ebb and flow currents through Mustang Island Pass (Behrens et al. 1977) and the intermittent Corpus Christi Pass (Davis et al. 1973) indicate there is a net flow from the gulf into Corpus Christi Bay and a movement of water from Aransas Pass into Upper Laguna Madre via Corpus Christi Bay. This is exemplified by current velocities, obtained in Corpus Christi Pass when it was functional in the late 1960's and early 1970's, which were approximately 1.0 m/sec during flood and 0.2 m/sec during ebb (Davis et al. 1973). Morphological evidence, such as the development of large flood tidal deltas (e.g., Harbor Island area), supports the concept of net flow into the bay.

While there is a net gulf-to-bay movement of water through the passes during a typical year, the flow is seasonal. The predominant bayward movement occurs approximately from March to September and is associated with the predominance of onshore winds. During winter months the increased incidence and strength of northerly components of wind induce a bay-to-gulf movement of water (Behrens and Watson 1977).

During periods of large freshwater inflows into the Corpus Christi Bay study area (see Section 4.3), circulation patterns are substantially altered. Without these flows, the general pattern of circulation would be expected to be the two-gyre patterns described previously with net gulf-to-bay movement of water. During flood periods, model studies (TWDB 1970) indicate that there is a reversal in net movement of water through the passes and the river flow augments the convergence of the two gyres, increasing velocities.

Freshwater input also maintains horizontal salinity gradients and augments the development of density currents. Little is known about density current development in Corpus Christi Bay and other Texas bays, yet Ward et al. (1979) feel it contributes significantly to total circulation in Texas bays. While no data exist for measuring density currents in the Corpus Christi Bay complex, the principal factors that result in density currents favor their development in Corpus Christi Bay as opposed to several other bay complexes along the Texas Barrier Islands coast. These principal factors include a pronounced salinity gradient and the relative depth of Corpus Christi Bay.

Since their intensity increases with water depth, density currents are likely to be developed best in dredged ship channels (Henley and Rauschuber 1978). One measure of this is the movement of saltwater up these channels. Henley and Rauschuber (1978) use the shoaling characteristics in the various artificial channels in Corpus Christi Bay as evidence of the existence of density currents and the maximum range of inland transport of sediment.

The Corpus Christi Bay study area is within the zone of bidirectional longshore drift. The seasonal change in the direction of longshore drift is related to the seasonal change in the predominant wind pattern (Brown et al. 1976). During summer months, when the winds are most often from the southeast, the zone of convergence of littoral drift is near Aransas Pass and during winter months shifts south towards lower Padre Island (Brown et al. 1976). Behrens and Watson (1977) monitored alongshore transport of sediment at Mustang Island Pass and determined a net southwestward movement of sediment amounting to about 48 x 10^3m^3 out of a gross transport of 555 x 10^3m^3.

The Corpus Christi Bay study area is yet another example along the Texas Barrier Islands coast where man has affected natural tidal pass hydraulics and has attempted to increase circulation through the construction of artificial passes. The dredging of Aransas Pass in the 1920's enlarged the natural channel there. The enlarged cross sectional area became an increasingly favored water exchange channel, resulting in reduced flows through Corpus Christi Pass and culminating in its seaward end closure between 1926 and 1927 by littoral transport of sediment (Brown et al. 1976). Since that time, according to Davis et al. (1973), Corpus Christi Pass has only been open intermittently following hurricanes such as Carla in 1961 and Beulah in 1967. The opening of the pass during these periods is an indication of the increased flushing resulting from hurricane-induced storm surges combined with associated intense rainfall and runoff.

The increased demand for sportfishing access and the desire to increase circulation led to the construction and completion of Mustang Island Pass (Behrens and Watson 1977). Bathymetric and topographic surveys, as well as circulation-monitoring before and after completion of Mustang Island Pass, provided the data from which Behrens et al. (1977) concluded that the pass has had no significant effect on flushing of Corpus Christi Bay. Behrens and Watson (1977) believe the pass to be unstable and in jeopardy of shoaling and closing at its seaward end. Harrington (1973) monitored the faunal changes associated with the opening of Mustang Island Pass and concluded that (1) the pass provides an additional migration route for several species of fish; (2) it offers excellent access for sport anglers; (3) there is probably an insignificant effect on salinity in Corpus Christi Bay; and (4) increases as well as decreases in numbers of juvenile and adult nekton occurred. Thus, in terms of circulation, the pass has had little effect. This is consistent with similar attempts along this coastal area, such as the creation of Yarborough Pass on Padre Island, which also shoaled at its seaward end shortly after its creation. The shoaling of these additional passes is to be expected since the hydraulic head is not sufficient to maintain them. The proposed Harbor Island Deep-water Port would further deepen and enlarge the Aransas Pass Channel, an action which has led historically to the closure of or reduced flow through other nearby tidal passes. This situation might result in the closure of Mustang Island Pass if natural processes have not already sealed its fate.

4.3 DRAINAGE PATTERNS AND FRESHWATER INFLOWS, RIVERINE FLOODING PATTERNS

The Nueces River is the most important source of freshwater, as well as a vital source of nutrients and sediments, to the Corpus Christi Bay area. Smaller stream systems exist and are important locally (e.g., Oso Creek flowing into Oso Bay system), but individually these streams do not generally have a large impact on the entire estuarine system. Using U.S. Geological Survey discharge data for the station at Mathis (drainage area equals 43 x 10^3 km^2), Henley and Rauschuber (1978) calculated the average inflow of the Nueces River at Mathis to be 24.5 m^3/sec for 1941 through 1974. Based on water budget model results of Henley and Rauschuber (1978), the ungaged segment of the Nueces River (below Mathis) contributes an additional 1.2 m^3/sec, while Oso Creek and other drainage into Corpus Christi and Nueces Bays contribute 1.9 m^3/sec.

In comparison with other study areas along the Texas Barrier Islands coast, the Corpus Christi Bay study area receives a relatively low freshwater input with only the Copano-Aransas system receiving less. This assumes the flow of the Rio Grande is included in the Laguna Madre, when in fact, most of the flow of the Rio Grande is directly into the Gulf of Mexico. Including the Rio Grande, the Laguna Madre study area receives slightly more than twice the freshwater inflow to the Corpus Christi Bay study area. Due to receiving basin volume differences, it would require 26 months of the combined discharge of the Rio Grande and lesser monitored streams to fill an empty Laguna Madre to the mean low water (MLW) level; whereas it would only require 14 months for the Nueces River and Oso Creek to fill Nueces, Corpus Christi, and Oso Bays to MLW. On a ratio of discharge-to-volume basis, the Corpus Christi Bay study area receives nearly twice the freshwater input of Laguna Madre.

The seasonal distribution of streamflow is bimodal (Figure 3) and is highly correlated with the seasonal distribution of rainfall (Figure 1, Section 3.1). The appearance of the spring discharge peak is in contrast to the streamflow pattern in the neighboring Laguna Madre system. The spring peak is the lesser of the two in the Corpus Christi study area, increasing in relative magnitude, whereas the fall peak decreases, as one moves up the coast (see Section 3.1 for the synoptic weather regimes which account for the associated seasonal distribution in rainfall).

Like many rivers emptying at the Texas coast, the Nueces River has had a substantial portion of its flow diverted. The Lake Corpus Christi system and the future Choke Canyon reservoir may divert as much as 45% of the natural flow by the year 2010 (Henley and Rauschuber 1978). One function of streamflow is the maintenance of a salinity gradient in the estuary. The diversions result in an overall salinity increase and may alter the natural seasonal pattern of estuarine salinity. Additionally, the two major diversion systems are expected to produce an increase in the incidence of hypersalinity. The Texas Department of Water Resources (cited by Henley and Rauschuber 1978), utilizing hydrologic data from the Bureau of Reclamation, modeled salinity changes at the mouth of the Nueces River resulting from the full-scale operation of both the Lake Corpus Christi and Choke Canyon systems. Under natural flow conditions, hypersalinity (greater than 35 $^0/oo$) can be expected to occur approximately 13% of the time, whereas it is projected to occur 71% of the time with only the Lake Corpus Christi system, and 82% of the time with both systems. Henley and Rauschuber (1978) predicted large changes in the biotic assemblages in the estuary, and overall detrimental effect to commercially important species (also see Section 2.5 for additional impacts).

4.4 GROUNDWATER

The diversion of flow from the Nueces River supplies much of man's freshwater needs in the Corpus Christi Bay area. In terms of basin-wide water

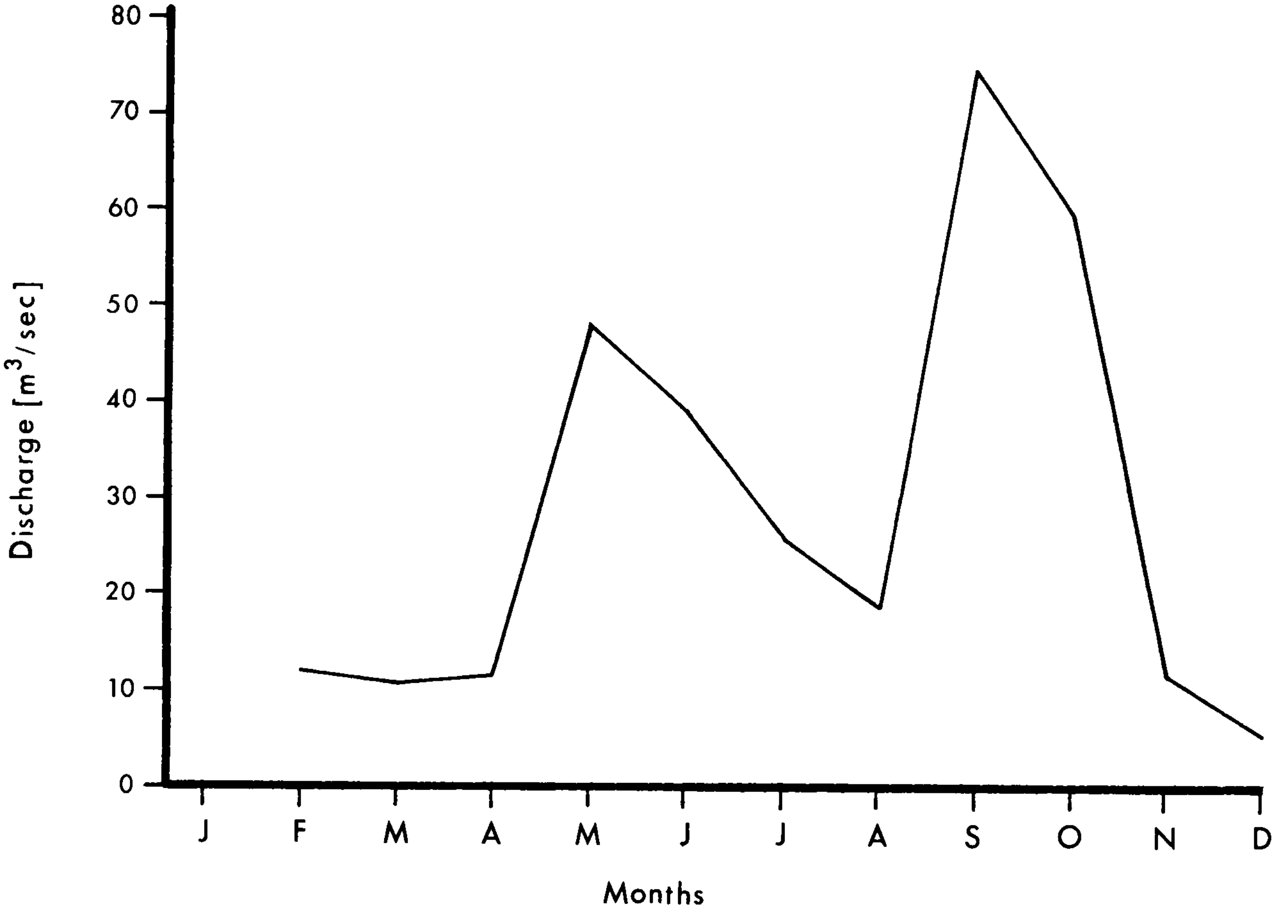

Figure 3. Mean daily discharge by months for gaged and ungaged flows into the Corpus Christi study area. Modified from Henley and Rauschuber (1978).

usage, groundwater can be regarded as a supplemental source although individual cultural sectors may use groundwater supplies extensively.

Industrial use of groundwater in Nueces and San Patricio Counties for 1976 amounted to 1.5 x $10^6 m^3$, approximately 3.2% of the total freshwater used by industry. The remaining freshwater comes from surface water supplies (TDWR 1979, cited by Liebow et al. 1980). Municipal use of groundwater in the area during 1976 was somewhat greater, amounting to 2.4 x $10^6 m^3$ but representing only 2.1% of the total freshwater usage (TDWR 1979, cited by in Liebow et al. 1980). Since 1955, total freshwater usage by both industrial and municipal sectors has increased substantially, but the extraction of groundwater by industry in 1976 is less than half of what it was in 1955, and during the same interval municipal extraction has been reduced by 85% (TDWR 1979, cited by Liebow et al. 1980). Future projections over a somewhat larger geographic area indicate that by the year 2000 industrial groundwater use will continue to decline while municipal use will increase, although not to 1955 levels (TDWR 1977, cited by Liebow et al. 1980). The same study also predicted an increase in both population and industrial development; thus, much of the increase in demand for freshwater will be from surface supplies (e.g., Choke Canyon Reservoir).

Due to areal differences in the data, we cannot make a direct quantitative comparison between industrial-municipal water usage and agricultural water usage within the Corpus Christi Bay study area. A conservative estimate based on TDWR data (1977, cited by Liebow et al. 1980) is that agricultural use for livestock and irrigation is greater than the combined industrial and municipal use. Agriculture is also more dependent on groundwater supplies than the other two categories of users; 93% of the 1974 freshwater requirements was supplied by groundwater in the Corpus Christi region. By the year 2000, freshwater needs for agriculture in the region are projected to increase by 16.4%. These needs are expected to be met from surface supplies, and groundwater usage is predicted to decrease by about 2.9% (TDWR 1977, cited by Liebow et al. 1980).

While the extraction of groundwater is known to result in surface subsidence along the Texas Barrier Islands coast (Brown et al. 1974), and in some areas as much as 3 m of sinking has occurred (see Galveston synthesis), there apparently has not been any major surface subsidence in the Corpus Christi Bay study area resulting from groundwater extraction (Brown et al. 1976). Subsidence in the Corpus Christi area, reaching a maximum of 2 m near McNorten, was attributed to the extraction of shallow oil and gas deposits (Gustavson and Kreitler 1976) . Brown et al. (1976) believe that even with an increase in groundwater extraction, major subsidence probably will not occur in this area due to the greater depths and lithologic differences in the aquifers in comparison to areas farther up the Texas coast.

4.5 WATER QUALITY

Due to cultural impacts in the Corpus Christi Bay study area relative to several other estuaries along the Texas coast, water quality monitoring studies are fairly numerous. Henley and Rauschuber (1978) provided a listing of all agencies, periods of collection, parameters studied, station locations, and other aspects of the water quality programs in the area. They synthesized all known data sources and provided a detailed discussion of water quality in the Corpus Christi Estuary from which this discussion is extracted. Their statistical summary of data obtained through various programs and agencies is provided (Table 2), and the reader is referred to their work to obtain more detailed discussion, data, primary data sources, and information to locate unpublished data.

Table 2. Statistical summary of water quality data for Nueces and Corpus Christi Bays for the 1972-1976 period (Henley and Rauschuber 1978).

Parameter	Mean	Median	Variance	Standard deviation
Temperature (°C)				
Corpus Christi Bay	21.15	22.70	45.47	6.74
Nueces Bay	21.05	22.50	51.90	7.20
Dissolved Oxygen (mg/l)				
Corpus Christi Bay	7.59	7.10	2.17	1.47
Nueces Bay	8.10	8.20	2.45	1.56
Salinity (ppt)				
Corpus Christi Bay	26.16	26.70	19.66	4.43
Nueces Bay	20.34	22.10	53.70	7.32
Organic Nitrogen (mg/l)				
Corpus Christi Bay	0.444	0.430	0.009	0.093
Nueces Bay	0.641	0.620	0.025	0.158
Nitrite (mg/l)				
Corpus Christi Bay	0.017	0.006	0.0003	0.016
Nueces Bay	0.091	0.010	0.029	0.171
Nitrate (mg/l)				
Corpus Christi Bay	0.017	0.006	0.003	0.016
Nueces Bay	0.038	0.030	0.0002	0.0145
Ammonia Nitrogen (mg/l)				
Corpus Christi Bay	0.124	0.100	0.002	0.039
Nueces Bay	0.125	0.100	0.003	0.054
Ortho-Phosphate (mg/l)				
Corpus Christi Bay	0.032	0.030	0.0002	0.014
Nueces Bay	0.057	0.040	0.001	0.036
Total Phosphate (mg/l)				
Corpus Christi Bay	0.059	0.050	0.0006	0.024
Nueces Bay	0.117	0.110	0.002	0.043
Inorganic Carbon (mg/l)				
Corpus Christi Bay	20.19	17.55	43.86	6.62
Nueces Bay	21.84	21.60	52.47	7.24
Organic Carbon (mg/l)				
Corpus Christi Bay	17.64	17.65	109.31	10.45
Nueces Bay	23.32	23.00	412.54	20.31
Turbidity (TTU)				
Corpus Christi Bay	19.03	17.45	110.05	10.49
Nueces Bay	67.34	62.50	2,001.80	44.74
pH				
Corpus Christi Bay	8.42	8.40	0.051	0.226
Nueces Bay	8.35	8.30	0.047	0.218

Mean seasonal water temperature parallels mean seasonal air temperature with maximum water temperatures occurring in August and minimum water temperatures occurring in January for both Corpus Christi and Nueces Bays. Seasonal variability in water temperature is somewhat less in Corpus Christi Bay than Nueces Bay, as January mean water temperatures are 14.7° and 13.5° C respectively, and August values are 30.2° and 30.7° C respectively. The smaller seasonal range of temperature in Corpus Christi Bay can be attributed to its comparatively larger volume and its greater exchange with mitigating gulf waters. Yearly variation in water temperature is expectedly small; the range from high to low years from 1964 through 1974 was 2.0° C for both Nueces and Corpus Christi Bays.

Dissolved oxygen (DO) values were highly variable spatially and temporally. Comparison of DO values from the Corpus Christi Bay complex with other estuaries within the ecosystem (Martinez 1972-1975) shows that the lowest annual mean DO levels are from the Corpus Christi Bay complex. For example, in 1975 the annual mean DO concentration was 4.9 parts per million (ppm) in the Corpus Christi Bay area while the annual means for the other study areas ranged from 6.0 to 7.9 ppm (Martinez 1975). Since water temperatures, salinities, and the mixing of waters by wind are not substantially different in the Corpus Christi Bay study area compared to those of other study areas, the lower DO value may reflect increased respiration and serve as a gross indicator of relative pollutant levels. Martinez (1972-1975) found that DO levels peaked in winter and reached minimum levels in late summer. This seasonal pattern was fairly typical for all the estuaries Martinez examined and can be accounted for by the inverse relationship between DO concentrations and temperature. Henley and Rauschuber (1978) also found that maximum values occurred during the winter months; however, they noted that minimum values occurred during spring months and progressively increased through summer and fall. They attributed this pattern to phytoplankton blooms that possibly originate in Nueces Bay and then progress into Corpus Christi Bay. In light of the better temporal and spatial sampling coverage which Henley and Rauschuber (1978) obtained (including the data of Martinez), the seasonal patterns they observed seem a more accurate representation. Whether this apparent difference can be applied to the other estuaries within the ecosystem is unknown. The data of Martinez (1971-1975) occasionally do show an indication of a rise in DO levels during the growing season at several station locations. These stations appear to coincide with the presence of seagrass beds, but not all stations where seagrass beds are located show this pattern. Further support is provided by Ward et al. (1979), who observed that DO levels were somewhat higher in secondary bays in the Matagorda Bay complex, which they attributed to greater primary production.

The Nueces River is a major source of inorganic nutrients to the Corpus Christi Bay study area. Total loading of nitrogen, phosphorus, and carbon is relatively high, reflecting the agricultural lands which the Nueces drains. Since the peak in Nueces River discharge coincides closely with the beginning and the end of agricultural activity, it is not surprising that total loading is greater during these periods. Henley and Rauschuber (1978) did not find a correlation between bay water concentrations and river discharge. Two factors are probably primarily responsible for the lack of correlation. First, Funicelli (1980) found a net flow of nutrients into the Nueces Delta marshes. Seasonally, the flow of nutrients was variable, but the largest net influx occurred with the late spring flood period. Thus, the sediments of the marsh and presumably of the bay bottom retain much of the nutrient load. Second, the increase in discharge has a diluting effect. An increase in nutrient load does not result in an increase in nutrient concentrations, and bay water concentrations can remain low although loading is high. Eventually, however, concentrations in the bay water will probably increase as the ability of sediments to retain additional nutrients decreases.

In general, Henley and Rauschuber (1978) found that bay water nutrient concentrations decreased in a seaward direction (i.e., from Nueces Bay towards Redfish Bay); seasonal cycles (when evident) were similar throughout; and temporal variability in concentrations decreased in a seaward direction (also see Section 5.1 for discussion of nutrient exchange).

Turbidity, as measured by Martinez (1972-1975), is comparatively low in the Corpus Christi Bay system. For example in 1975 mean turbidity (27.5 ppm) over the entire area was the lowest of any of the Texas estuaries, except for Upper Laguna Madre which had an equivalent mean value. Turbidity is highly variable seasonally relative to the streamflow, while turbidity generally decreases spatially with increasing distance from the mouth of the Nueces River. An exception is Oso Bay, the receiving basin for Oso Creek. This bay receives point source and nonpoint source municipal discharge and is highly turbid, a factor partially responsible for reduced photosynthesis in this water body (Henley and Rauschuber 1978). Because of the Harbor Island area's proximity to the extensive seagrass beds of the Redfish Bay area, there is the potential for reduced photosynthesis due to high turbidity levels and possible destruction of seagrass beds resulting from siltation (e.g., TPWD 1975).

Point source discharges are substantial in the Corpus Christi Bay area, amounting to approximately an additional 9% of the total natural runoff. There are 71 brine discharge points resulting from oil and gas activities, and although individual discharges are small, the cumulative discharge is 8.4 x 10^3 m^3/d (Henley and Rauschuber 1978). More studies examining the cumulative effect of these discharges are needed. The volume of brine can be expected to increase in the future as saltwater production tends to increase with increasing age of the oil field (Gosselink et al. 1979).

The increase in salt concentrations in oil fields can result in species changes and, where the increases are sudden, can cause mortalities. In addition, the ratio of salts in these brines differs from that of seawater, and the difference in ions is often toxic (Gosselink et al. 1979).

Industrial and municipal outflows other than brine and returned flow of cooling waters amount to about 4.1 x 10^4 m^3/d (Henley and Rauschuber 1978). Biological oxygen demand (BOD) concentrations for many inflows are excessive. For example, average BOD levels for the municipal return flow from CPC International No. 1 into Inner Harbor during 1972 was 982 mg/liter. In comparison, BOD levels generally range from 0.5 to 5.5 mg/liter in the waters of the Corpus Christi Bay system (Henley and Rauschuber 1978). While this example is an extreme case, and BOD concentrations were reduced at CPC International No. 1 to 95.4 mg/liter by 1977, the example illustrates the relatively high levels that occasionally occur in the area. Also, the outflow is from only a single source, and in the Inner Harbor area two additional municipal and six industrial outflows had high BOD concentrations from 1970 to 1977 (Henley and Rauschuber 1978). The high BOD concentrations result from the microbial decomposition of organic carbon causing lowered DO levels detrimental to all aquatic resources (Henley and Rauschuber 1978).

Heavy metal concentrations in sediments, especially in the Corpus Christi Ship Channel, are high and frequently exceed screening levels allowed by the Environmental Protection Agency (General Land Office 1977). Their immobility makes American oysters (Crassostrea virginica) susceptible to perturbations and they rapidly respond to introduced foreign substances. The Environmental Protection Agency level for zinc in sediments is 75 mg/kg. Oysters sampled by the Texas Department of Health from 1970 to 1975 (cited by Henley and Rauschuber 1978) contained zinc concentrations over of 100 mg/kg, and oysters in Nueces Bay in 1975 contained levels as high as 2,400 mg/kg.

5.0 BIOLOGY

5.1 ESTUARINE COMMUNITY

A key element affecting species' use of the Corpus Christi Estuary is the variable nature of the Nueces River's inflow. During dry periods, hypersalinity is typical, even at the mouth of the Nueces Delta, and during wet periods essentially fresh water conditions prevail in Nueces Bay, grading to salinities of approximately 10 $^{0}/oo$ in lower Corpus Christi Bay (see Section 4.1). The large temporal range in salinities results in favorable habitat for many species over the long term but considerably fewer species at any given point in time.

Henley and Rauschuber (1978) showed the fishery harvest increases in the Corpus Christi Estuary as a function of increasing river discharge. Existing diversion structures now reduce riverine inflow by a comparatively moderate amount, but projections indicate that by the year 2010 as much as 45% diversion of the natural inflow will have occurred. Decrease in flow is expected to result in an increase in mean salinity, a marked increase in the incidence of hypersalinity (Section 4.1), and a reduced sediment and nutrient input. Cumulatively these factors are expected to result in a decline in the fishery harvest (Henley and Rauschuber 1978). Since the fresher waters of the Corpus Christi Bay system mitigate hypersaline conditions in Upper Laguna Madre, changes in this area's biological resources are also predicted. This expectation, among others, has led TPWD (1975) to identify the water exchange area between Corpus Christi Bay and Upper Laguna Madre as an area of particular concern.

Increased development in this study area has resulted in greater water quality problems than in neighboring study areas where population densities are considerably lower. Projections indicate that the human population and industrial development will continue to grow (TDWR 1977, cited by Liebow et al. 1980). Even if industrial and municipal return flows remain unchanged, they will constitute approximately one-fifth of the total inflow into the estuarine complex once the Lake Corpus Christi and Choke Canyon Reservoir are in full operation. The value of these return flows in the maintenance of a salinity gradient is limited, however, because the waters are so well mixed with the deeper saline waters of Corpus Christi Bay (D. Meineke, USFWS, Ecological Services Division, Corpus Christi; pers. comm. 1980). What future water quality problems and effects on biological resources will occur are unknown.

5.1.1 Vegetation

Submerged aquatic plants, frequently called seagrasses, are less common in Corpus Christi Bay than in neighboring Laguna Madre and Copano-Aransas Bays because of Corpus Christi Bay's greater average depth, i.e., most of the bay bottom is below the photic zone. The contiguous Redfish Bay (Copano-Aransas study area) has one of the most extensive seagrass concentration areas along the Texas coast and is often considered a part of the Corpus Christi Bay complex. A narrow fringe of seagrass beds occurs along the inshore side of Mustang Island and the northeastern shore of Corpus Christi Bay. Shoal grass (Halodule beaudettei) and widgeongrass (Ruppia maritima) are the dominant species (Brown et al. 1976; Matlock and Weaver 1979). In wet years there is a narrow band of shoal grass along the northern shoreline of Nueces Bay (E.G. Simmons, TPWD; pers. comm. 1980).

Although no primary production estimates or standing crop values are available for the Corpus Christi Bay area per se, Parker et al. (1971, cited by Ward et al. 1979) reported a maximum standing crop of 568 g dry wt/m^2 for shoalgrass in the nearby Redfish Bay. In general, grassbeds are considered highly productive (Henley and Rauschuber 1978), especially in comparison to the open ocean environment with its typically low primary production. Determination of primary production in seagrasses is difficult because these plants have a large leaf surface area that characteristically serves as a substrate on which epiphytic algae themselves are primary producers (Henley and Rauschuber 1978). Preliminary studies by McRoy and McMillan (1977, cited by Henley and Rauschuber 1978) suggested high epiphytic production, perhaps as much as 50% of the total aquatic biomass produced by seagrasses. (See Laguna Madre, Copano-Aransas, and Matagorda-Brazos syntheses for additional production estimates for seagrasses, and Section 5.3.2 for fish utilization of seagrass habitat in the Corpus Christi Bay study area).

Phytoplankton in the Corpus Christi Bay study area account for a major portion of the aquatic primary production, with diatoms dominating the phytoplankton assemblage. Thalassionema nitzschioides, Thalassiothrix frauenfeldi, and Chaetoceros sp. are the most abundant species, constituting more than 70% of the standing crop in the study area (Henley and Rauschuber 1978). Seasonally and spatially, however, species dominance often shifts. For example, in Nueces Bay during the summer and fall of 1973, the blue-green algae Oscillatoria sp. and Anabaena sp. were the dominant phytoplankton. The prominence of these species is closely correlated with a series of interrelated phenomena conducive to a blue-green algal bloom. In late summer of 1973, there was a marked resuspension of bay sediments and nutrient loads (i.e., nitrogen and phosphorus) due to relatively high freshwater inflow. This hydrologic occurrence, coupled with a period of warm temperatures and low salinities, created ideal conditions for an algal bloom (Henley and Rauschuber 1978). Davis (1973) reported that nitrogen appeared to be the major limiting nutrient for phytoplankton production, and later studies by Henley and Rauschuber (1978) produced similar results.

In Oso Bay, the dominant phytoplankton were diatoms of which the genera Skeletonema, Chaetoceros, Thalassiosira, and Nitzschia were most common.

Largest populations in Oso Bay were found by Henley and Rauschuber (1978) to occur in the winter; the low summer populations were attributed largely to heightened salinities.

Larger drift algae and benthic algae have been intensively studied in the Copano-Aransas area and are discussed more fully in that synthesis. Conover (1964) examined the seasonal distribution of benthic algae in several Texas bays, from Copano Bay south to the Mexican border, but none of his transects fell within the boundaries of the Corpus Christi Bay study area. Some generalizations of Conover's data, however, can be applied to the Corpus Christi Bay area. The lack of hard substrate in the water bodies of the Corpus Christi Bay study area precludes extensive growth of benthic algae. Around the margins of the bays, seagrasses stabilize the bottom, allowing several algal species to become established. Other algal species use seagrasses as a host substrate (Edwards and Kapraun 1973). Some benthic algae likely to occur in the Corpus Christi Bay study area are the green algae *Enteromorpha clathrata*, *Ulva lactuca*, and *Acetabularia crenulata*, and the red algae *Gelidium corneum*, *Gracilaria cornea*, *Chondria tenuissima*, and *Laurencia poitei* (Conover 1964).

The drift algae community along this section of the Texas coast often largely comprise species that begin their life cycle attached to sand, shell fragments, or a host plant, but later lose this attachment. Some of the more common algae likely to be found in the Corpus Christi Bay study area include *Laurencia poitei*, *Gracilaria cornea*, *Digenia simplex*, *Acetabularia crenulata*, and *Batophora* sp. The drift alga *Sargassum natans*, which may be seen in the area, originates offshore and upon moving into the Corpus Christi Bay area deteriorates rapidly (Conover 1964).

The only available productivity estimates for phytoplankton or larger algae in this area were provided by Davis (1973). His study, however, provided no information concerning species composition. Davis made four estimates from various sections of the Corpus Christi-Nueces Bays by using the 24-hr photosynthesis/respiration method. The mean gross primary productivity for the area was 4.1 g O_2/m^3/day. This estimate is somewhat lower than those reported in several other Texas Bays (see other syntheses for comparative estimates), but is still well above agricultural and other terrestrial habitat production estimates for this latitude. Whether primary productivity in the estuarine open water habitat of the Corpus Christi study area is actually below the average for the Texas coast, or whether the reported values simply reflect experimental error or method differences is unknown.

Emergent tidal marshes in the Corpus Christi Bay area occur primarily in the Nueces River Delta, to a lesser extent along the margins of Nueces Bay on the landward side of Mustang Island, and near Aransas Pass. Salt marsh zonation along Mustang Island comprises four vegetative assemblages at progressively higher elevations: (1) smooth cordgrass (*Spartina alterniflora*); (2) maritime saltwort (*Batis maritima*), glasswort (*Salicornia bigelovii* and *S. perennis*), and saltgrass (*Distichlis spicata*); (3) sea-oxeye (*Borrichia frutescens*), shoregrass (*Monanthochloe littoralis*), and seablite (*Suaeda* sp.); and (4) sparse marsh vegetation (Brown et al. 1976). The work of Benton (1977) in the Aransas Pass area indicated that associations listed by Brown et al. (1976) are simplified, and the relationship between species present and elevation is not well defined. In addition to those reported by Brown et al.

(1976), Benton (1977) also listed black mangrove (Avicennia nitida), marshhay cordgrass (Spartina patens), evening primrose (Oenothera drummondii), mesquite (Prosopis glandulosa), Gaura filiformis, salt-marsh bulrush (Scirpus maritimus), tule (Typha domingensis), seacoast bluestem (Schizachyrium scoparium littoralis), and several other scattered species.

Along the Nueces River Delta, the zonation is somewhat different. Low salt marshes are composed of pure stands of smooth cordgrass which grow at the water's edge. The high marsh directly behind this S. alterniflora zone comprises maritime saltwort, glasswort and saltgrass. At still higher elevations are areas of coastal sacahuista (Spartina spartinae) (Brown et al. 1976). Again, Benton (1977) found that dominance and elevation differences were not as pronounced in the Nueces Delta marshes as Brown et al. (1976) had implied. The salt marsh on the Nueces Delta, covering 5,851 ha, is primarily a high marsh environment according to Espey, Huston and Associates (1977, cited by Henley and Rauschuber 1978). While no estimates of production for the low marsh dominant, S. alterniflora, were presented, Espey, Huston and Associates (1977, cited by Henley and Rauschuber 1978) obtained primary production estimates for several high marsh species. Saltgrass (Distichlis spicata) was ranked as the most productive for the water year 1976 with 1,267 g dry wt/m^2/yr, followed by the salt-marsh bulrush and shoregrass (Monanthochloe littoralis) with 988 and 942 g dry wt/m^2/yr, respectively. Brackish to fresh marshes on the Nueces Delta were found to be somewhat more productive, with coastal sacahuista leading with an annual net primary production of 1,421 g dry wt/m^2/yr. Other species present in the Nueces Delta marshes, according to Brown et al. (1976), include marshhay cordgrass, big cordgrass (S. cynosuroides), rush (Juncus spp.), bulrush (Scirpus spp.), and cattail (Typha spp.).

Infrequently flooded fresh marshes largely comprise coastal sacahuista, seacoast bluestem, singlespike paspalum (Paspalum monostachyum), and huisache (Acacia farnesiana).

Nutrient flow studies indicate that the Nueces Delta marsh acts as a nutrient sink (Espey, Huston and Associates 1977, cited by Henley and Rauschuber 1978; Funicelli 1980). Concentrations of inorganic nutrients typically are higher in the Nueces marsh than in the seagrass beds of the Harbor Island area. Funicelli (1980) attributes this to the large nutrient input of the Nueces River, combined with higher metabolic levels occurring in the seagrass beds, the latter tending to deplete nutrients at a higher rate. This may explain better than preliminary studies have the substantially greater primary productivity of the Nueces marsh versus the seagrass beds (Funicelli 1980).

Seasonally, nutrient flows into the Nueces marsh were greatest during high discharge periods. After the fall flood period, there was a net flow of all nutrients from the marsh into the bay; during winter there was a net export of carbon to the bay, while nitrogen and phosphorous flowed from the bay to the marsh (Funicelli 1980).

Overall, primary productivity on a per unit area basis appears somewhat lower in the Corpus Christi Estuary, compared with that in Texas estuaries farther north. This may contribute to the lower standing crop of finfish and shellfish in Nueces Bay, as compared to those in San Antonio and Lavaca-Matagorda Bays (Espey, Huston and Associates 1977, cited by Henley and Rauschuber 1978).

Of great concern to the U.S. Fish and Wildlife Service (USFWS), according to Henley and Rauschuber (1978), are the effects the full scale operation of the Choke Canyon and Lake Corpus Christi systems will have on the Nueces Delta marsh. The changes that may occur include (1) a change in plant species composition to salt tolerant forms, (2) a decrease in net primary productivity due to a projected large increase in hypersalinity, (3) a decrease in sedimentation that will decrease delta growth and may lead to deltaic deterioration, and (4) a decrease in nutrient supply to the marsh and bay system. The increase in salinities also are expected to result in a shift of seagrass species. Henley and Rauschuber (1978) projected that widgeongrass (Ruppia maritima) initially will be replaced by shoal grass (Halodule beaudettei) and eventually by turtle grass (Thalassia testudinum). Such a succession seems questionable because several studies (e.g., Moore 1963; McMillan and Moseley 1967) suggested that shoal grass is more salt-tolerant than turtle grass.

5.1.2 Fauna

Mammals. Along the Texas coast the only mammal common to the aquatic habitat of the estuarine community is the bottlenose dolphin (Tursiops truncatus). In an aerial census of the Texas bays between Port Aransas and Matagorda Bay, Barham et al. (1980) found that the bottlenose dolphin showed a marked preference for ship channels at the southern extreme of their study site. During five census flights in March and April 1978, they found 28 herds composed of 211 individuals in the Corpus Christi and Aransas ship channels. This figure represents 23% of all dolphins seen during the five flights. The majority of those dolphins spotted in the ship channels were in the Corpus Christi Ship Channel. No explanation for the difference in density patterns was offered.

In the tidal marshes, mammals show considerably more diversity. Table 3, presenting some of the more common species and their habitats, indicates that diversity decreases with increasing salinity. The raccoon (Procyon lotor) and nutria (Myocastor coypus) are the only furbearers common to all these marsh habitats. According to Davis (1974), the mink (Mustela vison) reaches its southern limit in Refugio County, directly north of the Corpus Christi Bay study area. Therefore, this furbearer may be found in the area sporadically. The muskrat (Ondatra zibethicus), however, does not occur this far south in Texas.

Table 3. Representative mammals of the estuarine community, Corpus Christi Bay study area. Habitats included are saltmarsh (SM), brackish to freshwater marsh (BFM), and freshwater marsh (FM) (Davis 1974).

Scientific name	Common name	Habitat SM	 BFM	 FM
Procyon lotor	Raccoon	x	x	x
Oryzomys palustris	Northern rice rat		x	x
Sigmodon hispidus	Hispid cotton rat			x
Myocastor coypus	Nutria	x	x	x
Sylvilagus aquaticus	Swamp rabbit		x	x
Odocoileus virginianus	White-tailed deer		x	x

Birds. Yearly TPWD surveys provide estimates of resident populations of fish-eating birds (see Table 4). Though these species are common to the various habitats in the estuarine community, they also are members of other communities in this study area. For example, Shamrock Island, although small, is important as a rookery for fish-eating birds (Blacklock et al. 1978).

The snowy egret (Leucophoyx thula) and the great egret (Casmerodius albus) are examples of species that have had tremendous population fluctuations. During the 1890's and early 1900's, these egrets were under severe hunting pressure because their white nuptial plumage was prized in the fashion world. By 1910 the breeding populations in Texas and other places in the United States were nearly decimated. Subsequently fashions changed and the two species were spared. Their populations rose rapidly until 1939 when increased industrialization began polluting waterways and their fish; by 1970, Texas had had more fish kills than any other State. A food shortage has the potential to cause egret numbers to decline again, but present populations appear stable. Additionally, the snowy egret has a scarcity of nesting sites and materials, caused by an aggressive introduced species, the cattle egret (Oberholser et al. 1974).

The estuarine community supports wintering populations of waterfowl, including the Canada goose (Branta canadensis), white-fronted goose (Anser albifrons), snow goose (Chen caerulescens), and Ross's goose (Chen Rossii). Ducks common in the community include black-bellied whistling duck (Dendrocygna autumnalis), pintail (Anas acuta), mottled duck (A. fulvigula), and redhead (Aythya americana). The black-bellied whistling duck uses freshwater marshes much more frequently than salt or brackish marshes; the other three are common to all types of marsh (Oberholser et al. 1974). Most of these species feed predominately on vegetable matter including shoal grass, widgeongrass, and seeds of aquatic plants. The redhead duck, the black-bellied whistling duck, and mottled duck have a more varied diet of invertebrates as well as plant material (Bellrose 1976, cited by Henley and Rauschuber 1978).

The harvest estimate for waterfowl in Corpus Christi Bay in 1968 was 2.3×10^4 birds of a State total of 1.4×10^5, according to USFWS (Diener 1975). The lower coast, of which Corpus Christi Bay is a part, supports about 25% of all migratory waterfowl wintering in Texas. Eighty percent of the continental redhead duck population winters in the Coastal Bend bays and Laguna Madre, and in 1968, the season was closed for both the redhead and the canvasback (D. Meineke, USFWS Ecological Services Division, Corpus Christi; pers. comm. 1980). The light hunting pressure on the lower coast also helps to explain the low harvest; man-days of hunting in Corpus Christi Bay were only 7.2% of the State total. Hunting pressure is light in that area because only 6.5% of all active waterfowl hunters are located along the lower Texas coast (TPWD 1977).

The total migratory waterfowl count by USFWS for the lower Texas coast includes dabbling ducks, diving ducks, mergansers, geese, and coot; for 1975 and 1976 the counts were 1.0×10^6 and 1.4×10^6, respectively (Henley and Rauschuber 1978).

Reptiles and amphibians. In comparison to freshwater environments, salt and brackish marshes have relatively few reptile species. However, reptiles that do thrive in salt and brackish marshes, i.e., the Texas diamondback

Table 4. Pairs of colonial fish-eating birds, Corpus Christi Bay system (adapted from Blacklock et al. 1978).

Scientific name	Common name	1973	1974	1975	1976	Historical population trend for all of Texas
Pelecanus occidentalis	Brown pelican	0	0	11	8	See endangered species
Ardea herodias	Great blue heron	254	290	277	304	Stable
Florida caerulea	Little blue heron	30	25	18	41	Primarily inland; stable?
Bubulcus ibis	Cattle egret	334	342	291	658	First arrived 1954; rapid increase
Dichromanassa rufescens	Reddish egret	146	73	88	107	Long term decline, but stable since 1960's
Casmerodius albus	Great egret	164	222	215	174	1910 near extinction; currently stable
Leucophoyx thula	Snowy egret	319	665	378	713	1910 near extinction; currently stable
Hydranassa tricolor	Louisiana heron	352	621	351	914	Rapid increase during past 10 years
Nycticorax nycticorax	Black-crowned night heron	396	242	264	407	?
Plegadis chihi	White-faced ibis	31	100	100	480	Stable since 1974
Ajaia ajaja	Roseate spoonbill	446	360	559	261	1910 near extinction; currently stable

Continued

Table 4 Concluded.

Scientific name	Common name	1973	1974	1975	1976	Historical population trend for all of Texas
Larus atricilla	Laughing gull	8,372	6,773	4,599	4,358	Stable ?
Gelochelidon nilotica	Gull-billed tern	168	179	152	101	Stable to decreasing
Sterna forsteri	Forster's tern	242	238	215	116	Slow decline since 1940's
S. fuscata	Sooty tern	1	6	7	2	Always small, peripheral species
S. albifrons	Least tern	551	237	287	48	Rapid decrease
S. maxima	Royal tern	3,468	1,830	1,842	2,000	Always abundant
S. sandvicensis	Sandwich tern	650	1,000	1,000	1,000	Stable below San Antonio Bay
Hydroprogne caspia	Caspian tern	73	156	120	643	Slow decline
Rynchops nigra	Black skimmer	1,664	3,537	1,971	1,040	?

terrapin (*Malaclemys terrapin littoralis*) and the gulf salt marsh snake (*Nerodia fasciata clarki*), are uncommon in freshwater areas (Conant 1975). Probably neither are physiologically bound to a saline environment, but have adapted to thrive in spite of the salinity. In the case of lizards, we can conclude, based on habitat requirements presented in Conant (1975), that they do not inhabit the estuarine community.

Table 5. Representative reptiles and amphibians of the estuarine community, Corpus Christi Bay study area. Habitats are saltmarsh (SM), brackish to freshwater marsh (BFM), and freshwater marsh (FM) (Raun and Gehlbach 1972; Conant 1975; Gosselink et al. 1979).

Scientific name	Common name	Habitat		
		SM	BFM	FM
Kinosternon flavescens	Yellow mud turtle			x
K. subrubrum hippocrepis	Mississippi mud turtle			x
Chrysemys scripta elegans	Red-eared turtle			x
Malaclemys terrapin littoralis	Texas diamondback turtle	x	x	
Lampropeltis getulus holbrooki	Speckled kingsnake			x
Nerodia fasciata clarki	Gulf salt marsh snake	x	x	x
Storeria dekayi texana	Texas brown snake			x
Hyla cinerea	Green treefrog		x	x
Pseudacris triseriata feriarum	Upland chorus frog			x
Rana utricularia	Southern leopard frog		x	x
Bufo woodhousei woodhousei	Woodhouse's toad		x	x
Gastrophryne olivacea	Great plains narrow-mouthed toad			x
G. carolinensis	Eastern narrow-mouthed toad		x	x
Bufo valliceps	Gulf Coast toad		x	x

The National Fish and Wildlife Laboratory (1980) reported sightings of the green turtle (*Chelonia mydas*), Kemp's ridley turtle (*Lepidochelys kempi*), and leatherback turtle (*Dermochelys coriacea*) in the waters along the Corpus Christi Bay study area, but sightings are uncommon due to this endangered species' depleted numbers.

The endangered American alligator (*Alligator mississippiensis*) is found in brackish and freshwater marshes in the study area where the population appears stable but considerably smaller than that of the Galveston area (Joanen 1974, cited by National Fish and Wildlife Laboratory 1980). See Section 5.6.4 for more information on this species.

Conant (1975) reported no amphibians in the salt marsh, but four anurans may be seen in brackish to freshwater marshes in the Corpus Christi Bay study area: the green treefrog (*Hyla cinerea*), Woodhouse's toad (*Bufo woodhousei*), eastern narrow-mouthed toad (*Gastrophryne carolinensis*), and southern leopard frog (*Rana utricularia*).

Fish. During the 10-year period 1968 through 1977, mean values for the top five commercial finfish in the Corpus Christi Bay study area were black drum (Pogonias cromis), 5.71 x 10^4 kg; red drum (Sciaenops ocellatus), 4.4 x 10^4 kg; spotted seatrout (Cynoscion nebulosus), 4.1 x 10^4 kg; sheepshead (Archosargus probatocephalus), 2.0 x 10^4 kg; and all species of flounder, 9.4 x 10^3 kg (USFWS and TPWD 1968; NOAA and TPWD 1970; NOAA 1971, 1972, 1973b, 1974, 1975, 1977, 1978a, 1978b). Harvests of all these fish have shown an overall increase during the 10-year period. Although no figures on fishing pressure were available, TPWD (1975) reported that the increased harvests, at least from 1969 to 1973, resulted from both heightened effort and improved hydrologic conditions (presumably the increase in river flow).

Compared to those of Aransas-Copano and San Antonio drainage areas, the commercial harvest of these five finfish in the Corpus Christi Bay area ranks second with a 10-year average of 1.7 x 10^5 kg. Average harvests were 3.8 x 10^5kg for the Aransas-Copano area and 1.1 x 10^5 kg for San Antonio. Of the six drainage systems in the Texas Barrier Islands Region, Corpus Christi on the average is the third most commercially productive area for the five finfish previously mentioned, following Laguna Madre and Copano-Aransas. When the average yields by weight for all finfish are compared, Corpus Christi drops to fourth, behind Laguna Madre, Copano-Aransas, and Galveston. Thus, the commercial finfish industry in the Corpus Christi Bay area is a moderate one, averaging 1.1 x 10^5 dollars annually over the 10-year span 1968 through 1977 (USFWS and TPWD 1968; NOAA and TPWD 1970; NOAA 1971, 1972, 1973b, 1974, 1975, 1977, 1978a, 1978b).

Sportfishing in the Corpus Christi Bay system focuses on the spotted seatrout, black drum, sand seatrout (Cynoscion arenarius), Atlantic croaker (Micropogonias undulatus), and red drum (Breuer et al. 1977). From September to mid-November, sport fishery for the southern flounder is active (D. Meineke, USFWS Ecological Services Divison; pers. comm. 1980). From September 1975 to August 1976, spotted seatrout not only had the highest sports catch for the Corpus Christi Bay area (8.4 x 10^4 kg), but also the greatest mean harvest per man-hour fished (77.0 g/hr). Spotted seatrout was followed by black drum, with a harvest of 5.0 x 10^4 kg and a harvest rate of 45.3 g/hr (Breuer et al. 1977). In total sports harvest, Corpus Christi Bay ranks fourth by weight and fifth by hourly yield rate (Breuer et al. 1977; Heffernan et al. 1977).

Life history discussions of the spotted seatrout, red drum, and black drum are in the Laguna Madre synthesis paper (Section 5.1.2). The life history of the southern flounder (Paralichthys lethostigma), the major flatfish representative, is described in the Matagorda-Brazos synthesis (Section 5.1.2). Spawning seasons and locations for these fish are as follows: spotted seatrout spawn in the bay, preferably in vegetated areas during warm months; black drum spawn from February to May in the gulf and perhaps in some parts of Corpus Christi Bay; both gulf and southern flounder spawn in the gulf during the winter, and red drum spawn in the gulf during the fall (TPWD 1975). A discussion of larval and juvenile nursery grounds follows in the section dealing with invertebrates.

Finfish in the Corpus Christi Bay area have undergone some changes following the 1972 completion of the Mustang Island Pass. Harrington (1973) sampled the area for 1 year before and 1 year after the pass construction. The major changes were a 35.7% increase in spot (Leiostomus xanthurus) and a 95% decrease in Atlantic threadfin (Polydactylus octonemus). There were numerous other increases in finfish collected after completion of the pass, but usually they were considered normal annual fluctuations. Overall, the sample data suggest that the pass is functioning as a migratory route, but its capabilities for aiding fish movements and decreasing water salinity are limited because of its small size (Harrington 1973).

Invertebrates. White shrimp (Penaeus setiferus), and to a lesser extent, brown (P. aztecus) and pink shrimp (P. duorarum), are the major shellfish harvested commercially in the Corpus Christi Bay area. From 1968 to 1977, the average annual harvest for white shrimp was 1.9 x 10^5 kg, valued at 6.5 x 10^5 dollars, and for pink and brown shrimp the harvest was 1.0 x 10^5 kg (USFWS and TPWD 1968; NOAA and TPWD 1970; NOAA 1971, 1972, 1973b, 1974, 1975, 1977, 1978a, 1978b). These yields are low compared to those from the rest of the Texas Barrier Islands Region. Only the hypersaline Laguna Madre area has a smaller shrimp harvest. Commercial blue crab (Callinectes sapidus) yields from 1968 through 1977 averaged 4.7 x 10^4 kg, the lowest harvest of the six inshore study areas (USFWS and TPWD 1968; NOAA and TPWD 1970; NOAA 1971, 1972, 1973b, 1974, 1975, 1977, 1978a, 1978b). No data on effort or yield per hectare were available for shrimp or blue crabs. The low harvest values, compared to those of other Texas inshore areas, may partially result from the Corpus Christi Bay study area having the smallest surface area of the six drainages under consideration.

Commercial oyster (Crassostrea virginica) production in the Corpus Christi Bay area as of 1977 was virtually nonexistent (USFWS and TPWD 1968; NOAA and TPWD 1970; NOAA 1971, 1972, 1973b, 1974, 1975, 1977, 1978a, 1978b). The bay supported extensive oyster reefs until the late 1950's when devastating infections of slime mold disease (Labyrinthomyxa marina) caused massive mortalities (TPWD 1975). The infestation was accelerated by droughts in the late 1950's and early 1960's. Reduced freshwater inflow increased salinity, which, in turn, increased the spread of the disease. Oyster production could perhaps be re-established by introducing disease-resistant strains, (an unsuccessful effort so far), improving old reefs with new shell fragments, and maintaining freshwater inflow to the bay (TPWD 1975).

Corpus Christi, Oso, and Nueces Bays provide valuable nursery grounds for larval and juvenile finfish and shellfish. These critical areas are subject to extreme disruption by man-made impacts such as navigation channels and industrial-municipal pollution (TPWD 1975). Some specific nursery areas are (1) a shallow area west of Harbor Island, the only nursery ground in the study area influenced by a natural pass; (2) Ingleside Cove, an especially important red drum nursery; (3) Rincon Point Reef and Indian Point Reef, two of the few remaining live oyster reefs in the Corpus Christi Bay area; and (4) the shallow grass flats along the bay side of Mustang Island (TPWD 1975).

Many invertebrates of no commercial value constitute important links in the food web of the estuarine community. An abundant one in the Corpus Christi Bay study area is the copepod Acartia tonsa, tolerant of wide ranges in temperature and salinity. This tolerance accounts for its dominance in the area throughout the year. Other common zooplankton are copepods of the genus

Diaptomus, various gastropod and bivalve veligers, and barnacle nauplii (Henley and Rauschuber 1978). The benthic community is dominated by annelids, especially *Mediomastus californiensis* in Nueces and Corpus Christi Bays and *Streblospio benedicti* in Oso Bay. *Mulinia lateralis*, a primary food of the black drum, is the most abundant mollusk in the study area (Henley and Rauschuber 1978).

5.2 BARRIER ISLAND COMMUNITY

Mustang Island is the barrier separating the Corpus Christi Bay complex from the Gulf of Mexico. Although Mustang Island has been historically separated from Padre Island, they are presently joined and are only intermittently separated following hurricanes. Mustang Island regulates the estuarine system by absorbing high energy storm waves and surges, facilitating the longer retention of freshwater inputs into the system, and aiding in the development of hypersaline conditions during periods of low freshwater inflow. In short, the barrier indirectly increases habitat diversity by its ability to separate processes going on in the bays from processes occurring in the gulf.

Intrabarrier productivity and species diversity are not generally regarded as high. While this may be true of the beach and dune areas, diversity of the barrier island increases when the conterminous tidal flats and seagrass beds on the lee side of the island are considered. While the tidal flats and seagrass beds are included as part of the estuarine community, these habitats on the bay side of Mustang Island have developed partly as a result of the cross barrier transport of sediment by storm surges and wind. For these valuable habitats to expand, there must be a net supply of sediment to the beach. The sediment supplied to the beach is essential for dune formation. The dunes, in turn, are reworked and sand is deposited into the estuary by storm surges, resulting in shoaling of the waters bayward of the island. Where the shoals remain, subaqueous seagrass beds may develop, and where the shoals become intermittently exposed and flooded, tidal flats and emergent macrophytes may develop. Shoreline studies indicate that Mustang Island is now in an erosional phase (see Section 2.1).

Man's presence and impacts on Mustang Island are considerable in relation to many other barrier islands of the Texas Barrier Islands Region. The proximity to Corpus Christi, construction of Kennedy Causeway, building of recreational communities, past livestock grazing, closing off of natural tidal passes, dredging of artificial passes, bulkheading sections of the shoreline, construction of jetties that interrupt littoral transport of sediment, and recreational vehicle activity on the barrier have reduced the quality and number of Mustang Island habitats.

5.2.1 Vegetation

Vegetation zones on Mustang Island are determined largely by the topography and sediment characteristics of the island. According to Brown et al. (1976), the cross sectional profile of this island closely resembles that of northern Padre Island (see Laguna Madre synthesis). The gulfward margin is composed primarily of fine quartz eolian sand (Gillespie 1976) and is barren of vegetation except for sparse culms of sea oats (*Uniola paniculata*) and halophytes at the foot of the foredune ridge (Brown et al. 1976). The foredune ridge[2] is well developed and averages 4.5 m in height. Effective, natural stabilization from wind and storm surge is provided by dune vegetation such as morning glory (*Ipomea* spp.), panic grass (*Panicum* spp.), beach tea (*Croton punctatus*), marshhay cordgrass (*Spartina patens*), and sea oats (Brown et al. 1976; Gillespie 1976). Without the protective vegetation, the foredune ridge would be a shifting sand environment subject to every change in wind.

Fifty percent of Mustang Island comprises a vegetated barrier flat[3] (Brown et al. 1976). Relict beach ridges are neither on this portion of the island nor on most of the islands in southern Texas. The heightened eolian activity in the south (see Laguna Madre synthesis) has destroyed the beach ridge-and-swale topography common on barrier islands along the northern Texas coast and has formed the uniform barrier flat that typifies Mustang Island and most of the barrier complex south of the Corpus Christi Bay study area. Formerly used for cattle grazing, the barrier flat is now the site of considerable housing development. The vegetation remaining is tolerant of salt spray and occasional flooding by storm surge. Representative species, according to Brown et al. (1976) and Gillespie (1976), are coastal sacahuista (*Spartina spartinae*), windmill grass (*Chloris* spp.), seacoast bluestem (*Schizachyrium scoparium littoralis*), morning glory (*Ipomea* spp.), and Texas prickly pear (*Opuntia lindheimeri*).

Back-island dunes occur behind the vegetated barrier flat, and usually are barren of any stabilizing vegetation. Brown et al. (1976) reported that on the southern end of the island near Mustang Island Pass, small areas are undergoing vegetative colonization, but did not report species.

Back-island dunes grade into the wind-tidal flats (or sandflats) that border Corpus Christi Bay. The elevation of this topographic feature varies from 0.0 to 0.6 m mean sea level, and the extent of flooding depends on wind and astronomical tidal conditions (Brown et al. 1976). During low water stages, these flats are barren, but during, and shortly after flooding, mats of blue-green algae (i.e., *Lyngbya confervoides*) occur (Sorenson and Conover 1962, cited by Conover 1964).

Historically, large scale changes have occurred on Mustang and North Padre Islands. Investigations by White et al. (cited by Brown et al. 1976) reveal three trends in environmental changes between 1938 and 1974. First, the area of vegetated dunes and barrier flats has increased by almost 200%. The increase is attributed to widespread vegetational colonization of formerly active dunes. The approximate 2,600-ha increase in vegetated area matches closely the 2,300-ha decrease in active dunes reported by White et al. (cited by Brown et al. 1976). Grassflats have also increased in areal extent, at the expense of the wind-tidal flats and nonvegetated subaqueous shoals. This change suggests a relative rise in sea level of the north Mustang Island area (see Section 2.1). A final trend, completely man-related, is a 400% increase in the areal extent of spoil and man-made land, the result of petroleum exploration, dredging operations, and land fill for recreation and community development (Brown et al. 1976).

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[2] Foredune ridge of Brown et al. (1976) is termed foredunes and dunes by Gillespie (1976).

[3] Barrier flat of Brown et al. (1976) is termed grassland by Gillespie (1976).

5.2.2 Fauna

Mammals. The most numerous resident mammals on Mustang Island are rodents (Table 6). Preferred habitat for several species overlaps considerably. For the most part, the rodents present are adapted to the dry habitat: although with the increase in human habitation on parts of the island, water has become less of a limiting factor. It is therefore likely that the house mouse (Mus musculus) and Norway rat (Rattus norvegicus), which require reliable freshwater sources, have become well established there. In the late 1930's Baker and Lay (1938) found no sign of those two species, but Mustang Island was much less developed then.

Table 6. Representative mammals present in the barrier island community of Mustang Island, Corpus Christi Bay study area (Baker and Lay 1938; Davis 1974).

Scientific name	Common name
Sigmodon hispidus	Hispid cotton rat
Onychomys leucogaster	Short-tailed grasshopper mouse
Spermophilus spilosoma	Spotted ground squirrel
Geomys personatus	South Texas pocket gopher
Taxidea taxus	Badger

The badger (Taxidea taxus), the coyote, and the raccoon may be the only nondomestic mammals on the island that do not belong to the Order Rodentia. The highly friable soil of Mustang Island and the plentiful rodent supply make the barrier island community conducive to the growth and survival of the badger.

Birds. Gulls and terns are among the most common birds frequenting the barrier island beach. The herring gull (Larus argentatus), ring-billed gull (L. delawarensis), and laughing gull (L. atricilla) commonly are seen feeding along the beach. For the most part, gulls are scavengers, picking up floating bits of garbage or refuse from fishing boats. They rarely submerge themselves during feeding. The laughing gull, the only gull breeding in Texas, uses sand dunes, barrier flats, and salt marshes for its colonies (Oberholser et al. 1974).

Terns nest on Mustang Island, generally preferring loose, sandy areas, often without vegetation, for laying their eggs. Terns, unlike gulls, usually dive for their food. For example, the royal tern (Sterna maxima), Sandwich tern (S. sandvicensis), and Caspian tern (Hydroprogne caspia) fly above the water in search of small fish, shrimp, and other invertebrates, and plunge completely under the surface to capture their prey (Oberholser et al. 1974). Black skimmer (Rynchops nigra), while not in the tern family, is very ternlike in appearance, but its feeding habits are considerably different. The skimmer takes its food while flying low along the water with its beak open and the mandible just under the surface, scooping up small fish, shrimp, and other crustaceans. This bird is often seen reskimming a furrow it has just cut in the water. Ornithologists suggest that the initial disturbance attracts some organisms, which are then taken on the second flight (Oberholser et al. 1974).

Shorebirds, working the edge of the surf and staying just out of reach of the waves, feed primarily on small mollusks, crustaceans, and marine worms. Representative species include the sanderling (*Crocethia alba*), dunlin (*Erolina alpina*), ruddy turnstone (*Arenaria interpres*), piping plover (*Charadrius melodus*), Wilson's plover (*C. wilsonia*), and killdeer (*C. vociferus*).

See Table 4 in Section 5.1.2 for population estimates of gulls and terns common to the barrier island.

Reptiles and amphibians. According to Henley and Rauschuber (1978), the Corpus Christi-Nueces Bay area received an average of 412 x 10^6 m^3/yr of direct precipitation from 1941 to 1974, but average evaporation of bay waters amounted to 756 x 10^6 m^3/yr. This means that the reptiles and amphibians there must take advantage of intermittent wet periods and ephemeral freshwater sources. Some of the amphibians on Mustang Island are the gulf coast toad (*Bufo valliceps*), Texas toad (*Bufo speciosus*), green treefrog (*Hyla cinerea*), and Hurter's spadefoot toad (*Scaphiopus holbrooki hurteri*) (Conant 1975; Moore 1976). Just as increased human habitation increases water availability for mammals, the developed sections of the island may allow many amphibians with more stringent water requirements to be present now.

Common reptiles on Mustang Island are the ornate box turtle (*Terrapene ornata ornata*), tolerating arid conditions by burrowing down into the sand; the keeled earless lizard (*Holbrookia propinqua propinqua*), indigenous to barrier islands of south Texas and the Mexican coast; the Texas horned lizard (*Phrynosoma cornutum*), and prairie racerunner (*Cnemidophorus sexlineatus viridis*), both preferring a relatively open habitat with scattered vegetation; the western diamondback rattlesnake (*Crotalus atrox*), whose size and venom make it one of the world's most dangerous snakes; and the western coachwhip (*Masticophis flagellum testaceus*), found in grass and shrubs of the barrier flat (Conant 1975).

5.3 RIVERINE COMMUNITY

The Nueces River is the major river in the Corpus Christi study area. According to the definition of Cowardin et al. (1977), mid-depth salinities indicate that the Nueces River technically should be classified as estuarine throughout the entire study area. The choice has been made to extend the inland boundary of the study area to provide the reader with a listing of fish species found in the riverine community.

The Nueces River provides an important supply of nutrients, sediments, and freshwater to the Corpus Christi Estuary. As discussed previously, the projected magnitude of diversion projects will reduce substantially the input of the Nueces River and ultimately lead to a decreased productivity of fish species, including those of sport and commercial importance. The effects probably will be felt beyond the immediate study area as salinities in Upper Laguna Madre are affected by Nueces River streamflow.

5.3.1 Vegetation

Vascular plants grow in quiet waters bordering the Nueces River, but the vegetation dominating the riverine community is phytoplankton. The planktonic component, along with detritus, provides the basis of the riverine food web (Clapham 1973). Although no specific data on phytoplankton species or their productivity in the river were available, some of the common forms in Nueces and Corpus Christi Bays probably occur in the river. These may include the taxa *Anabaena*, *Oscillatoria*, and *Chaetoceros* (Henley and Rauschuber 1978).

The bulk of the phytoplankton dies before it can be eaten by primary consumers. Much of the dead plant material is removed from the riverine detrital food web because velocities of the Nueces River are sufficient to carry considerable amounts of detritus downstream to the estuary.

5.3.2 Fauna

Mammals. No aquatic mammals occur in the Nueces River. The semi-aquatic species are discussed in the floodplain community (Section 5.4.2).

Birds. See Section 5.4.2.

Reptiles and amphibians. Common turtles of the riverine community are the gulf coast spiny softshell turtle (*Trionyx spiniferus asperus*) and the red-eared turtle (*Chrysemys scripta elegans*), which frequents quiet ox bows of the Nueces River. The yellow mud turtle (*Kinosternon flavescens flavescens*) and Mississippi mud turtle (*K. subrubrum hippocrepis*) may be observed in the quieter waters along the river, but they are more abundant in, and typically associated with, marshy sloughs bordering the river (Carr 1952; Raun and Gehlbach 1972; Conant 1975).

See Section 5.4.2 (floodplain community) for a discussion of amphibians and other reptiles closely associated with the riverine community.

Fish. The saline influence extends at least 16.1 km upstream in the Nueces River (Hahl and Ratzlaff 1970, 1972, 1973, 1975), exerting at least a seasonal influence on the biota a considerable distance upstream in the Nueces River. Strictly freshwater fish probably are not found in the lowest reaches of the river, and marine species appear seasonally in the lower Nueces River. Those marine fish known to enter freshwater frequently may be observed along this river section throughout the year.

According to records of marine fish common in Corpus Christi and Nueces Bays, the following species, designated by Hoese and Moore (1977) as marine, but frequently entering freshwater, are likely to be in the lower reaches of the Nueces River: southern flounder (*Paralichthys lethostigma*), red drum (*Sciaenops ocellatus*), hardhead catfish (*Arius felis*), striped mullet (*Mugil cephalus*), sheepshead (*Archosargus probatocephalus*), and Atlantic croaker (*Micropogonias undulatus*).

Freshwater species, collected by Conner (1977) from the Nueces River above tidal influence but within the bounds of the Gulf Coastal Plain, are listed in Table 7. Conner (1977) collected only 35 freshwater species here, indicating that species diversity in the riverine community is low. By contrast, in the neighboring San Antonio River, with less than a quarter of the drainage area of the Nueces River, Conner (1977) found over 50 species of freshwater fish. Conner offered no explanation for the disparity.

Table 7. Freshwater fish of the lower Nueces River (Conner 1977).

Scientific name	Common name
Astyanax mexicanus	Mexican tetra
Hybopsis aestivalis	Speckled chub
Notemigonus crysoleucas	Golden shiner
Notropis buchanani	Ghost shiner
N. lutrensis	Red shiner
N. texanus	Weed shiner
Opsopoeodus emiliae	Pugnose minnow
Pimephales promelas	Fathead minnow
P. vigilax	Bullhead minnow
Carpiodes carpio	River carpsucker
Cycleptus elongatus	Blue sucker
Ictiobus bubalus	Smallmouth buffalo
Moxostoma congestum	Gray redhorse
Ictalurus furcatus	Blue catfish
I. lupus	Headwater catfish
I. melas	Black bullhead
I. natalis	Yellow bullhead
I. punctatus	Channel catfish
Noturus gyrinus	Tadpole madtom
Pylodictis olivaris	Flathead catfish
Chaenobryttus gulosus	Warmouth
Lepomis cyanellus	Green sunfish
L. macrochirus	Bluegill
L. megalotis	Longear sunfish
L. microlophus	Redear sunfish
L. punctatus	Spotted sunfish
Micropterus salmoides	Largemouth bass
Pomoxis annularis	White crappie
P. nigromaculatus	Black crappie
Etheostoma gracile	Slough darter

The Nueces River appears to represent a faunal break separating the central and southern basins of Texas. It marks the southwestern dispersal for most of the eastern lowland/Mississippi Valley ichthyofauna (Conner 1977).

Oso Creek is the only other organized flow in the Corpus Christi Bay system; no ichthyofaunal studies of the creek are available.

5.4 FLOODPLAIN (PALUSTRINE) COMMUNITY

The floodplain community in the Corpus Christi Bay study area is almost entirely contiguous to the Nueces River. Smaller floodplains, such as along Oso Creek, have been greatly modified, either by urban expansion or agricultural practices.

The diversion projects located upstream from the study area will ultimately result in a reduction in the diversity of habitats within the Nueces River floodplain. Under full operational capacity, the diversions will reduce the average historic flow by over 40% (Henley and Rauschuber 1978). Such a reduction will undoubtedly reduce the frequency and magnitude of flooding of bottomlands. Some consideration should be given to the possible pressures to cultivate these highly productive and seemingly "dry" lands.

Henley and Rauschuber (1978) assumed that the diversions would be under full operational capacity and, using the natural flow of the Nueces River from 1941 to 1974 for comparison, projected the discharge that would have occurred if the diversions had been operational during that interval. Their projections indicated that during the low flow period from 1950 through 1956 there would have been one period of only a few months when any flow would have been allowed to spill over from the dams. Thus, the discharge of the Nueces River for over 7 years would have been reduced to that generated over the drainage basin below Mathis, and the floodplain would have experienced severe drought conditions.

5.4.1 *Vegetation*

Typical floodplain vegetation along the lowest reaches of the Nueces River is an assemblage of coastal sacahuista (*Spartina spartinae*), scattered clumps of mesquite (*Prosopis glandulosa*), groundsel tree (*Baccharis halimifolia*), and retama (*Parkinsonia aculeata*) (Henley and Rauschuber 1978). Although Correll and Correll (1975) chose to exclude retama from their list of aquatic and wetland species of the Southwestern United States, they recognized that the plant is sometimes found in poorly drained or even flooded areas. Certainly in the lower Nueces River floodplain it is a common species. Brown et al. (1976) also reported rush (*Juncus* spp.), cattail (*Typha* spp.), common reed (*Phragmites communis*), and willow (*Salix* spp.) as common species.

Areas of the floodplain lying west of U.S. Highway 77 begin to show a different type of vegetation, one dominated by trees more than shrubs (Brown et al. 1976). In the lowest floodplain elevations, the most water-tolerant species are found. Included in this assemblage are canopy species such as water oak (*Quercus nigra*), ash (*Fraxinus* spp.), and elm (*Ulmus* spp.), and understory species like sweet bay (*Magnolia virginiana*), yaupon (*Ilex vomitoria*), and green-briar (*Smilax* spp.). The willows (*Salix* spp.) are part of both the canopy and understory. At slightly higher elevations, which are less subject to flooding, hickory (*Carya* spp.), pecan (*C. illinoensis*), and live oak (*Quercus virginiana*) constitute a typical canopy; the understory is composed of red haw (*Crataegus viburnifolia*), carpetgrass (*Axonopus* spp.), green-briar (*Smilax* spp.), and grape (*Vitis* spp.).

5.4.2 *Fauna*

Mammals. Some of the more common mammals in the floodplain community are considerably important as furbearers. They include the raccoon (*Procyon lotor*), bobcat (*Lynx rufus*), gray fox (*Urocyon cinereoargenteus*), and nutria (*Myocastor coypus*). No data on the number of trappers nor the annual fur harvest for the Corpus Christi Bay system were available, but Henley and Rauschuber (1978) have roughly estimated that between 1,700 and 5,600 pelts per year have been recently taken from the Corpus Christi Bay area. On a statewide basis, the number of licensed trappers between the 1972-73 and the 1977-78 seasons has increased 674%. Locally, such an increase in trappers is unlikely since the area in which the Corpus Christi system lies is not a major trapping region. Likewise, individual harvests have probably not increased as dramatically in this area as in the State as a whole, although some moderate increase likely has occurred (TPWD 1979b).

Game species of the floodplain include fox squirrel (*Sciurus niger*), eastern cottontail (*Sylvilagus floridanus*), and white-tailed deer (*Odocoileus virginianus*). Based strictly on sight and specimen records presented by Hall and Kelson (1959), the Corpus Christi Bay system is the southern coastal limit of the fox squirrel. The fox squirrel, more so than the other two species, is restricted to the floodplain community by its shelter and food requirements. Fox squirrels nest and take shelter in hollows of tree trunks, usually older hardwoods. They compete with other wildlife for these hollows; if a shortage occurs, the fox squirrel is forced to construct a leaf nest in the fork of a tree. Hardwoods also provide an important portion of the squirrel's food, e.g., hickory nuts, pecans, and most importantly, acorns (TPWD 1978c).

Rodent species are not as diverse in the floodplain as in the upland. According to Davis (1974), three of the more abundant species are the fulvous harvest mouse (*Reithrodontomys fulvescens*), deer mouse (*Peromyscus maniculatus*), and white-footed mouse (*P. leucopus*).

Birds. Many of the herons and egrets listed in Table 4 are common in the floodplain. The great blue heron (*Ardea herodias*) and green heron (*Butorides virescens*) are two of the most abundant species. Others include the black-crowned night heron (*Nycticorax nycticorax*), little blue heron (*Florida caerulea*), and great egret (*Casmerodius albus*).

Ducks found in the floodplain community include the common mallard (*Anas platyrhynchos platyrhynchos*), black-bellied tree duck (*Dendrocygna autumnalis*), common redbreasted merganser (*Mergus serrator serrator*), and shoveler (*Anas clypeata*) (Oberholser et al. 1974).

Rapacious birds are well represented in the floodplain. Included are the broad-winged hawk (*Buteo platypterus*), sharp-shinned hawk (*Accipiter striatus*), Cooper's hawk (*A. cooperi*), red-shouldered hawk (*Buteo lineatus*), and barred owl (*Strix varia*). These species prefer wooded habitats to the open grass and brushland. The swallow-tailed kite (*Elanoides forficatus*) was formerly abundant in the river bottom forests, cypress swamps, and freshwater marshes, but its numbers plummeted in the early 1900's. While no definite cause has been determined, evidence seems to point to the lumbering of tall trees required for its nesting (Oberholser et al. 1974).

Reptiles and amphibians. Lizards adapted to a relatively moist environment or to an arboreal existence thrive in the floodplain community. In the Corpus Christi Bay system, common species of the floodplain include the green anole (*Anolis carolinensis carolinensis*), five-lined skink (*Eumeces fasciatus*), spotted whiptail (*Cnemidophorus gularis gularis*), and prairie racerunner (*C. sexlineatus viridis*) (Conant 1975). The first two species are essentially arboreal, spending the majority of their time in trees, shrubs, and vines that dominate the habitat. The latter two species, common in the floodplain, are equally abundant in the drier and more sparsely vegetated coastal prairie (see Section 5.5).

Snakes exhibit considerable diversity in the floodplain community. Several species of watersnakes (*Nerodia* spp.) are common; other nonpoisonous species include the Texas rat snake (*Elaphe obsoleta lindheimeri*), mud snake (*Farancia abacura*), rough green snake (*Opheodrys aestivus*), and speckled kingsnake (*Lampropeltis getulus holbrooki*). Venomous snakes found here are the Texas coral snake (*Micrurus fulvius tenere*) and western cottonmouth (*Agkistrodon piscivorus leucostoma*). Nueces County is the southern limit of the range of the cottonmouth (Raun and Gehlback 1972). Conant (1975) notes that the cottonmouth is widely believed to be a snake whose bite has serious consequences. The coral snake, on the other hand, is often underestimated because of its small size but may be equally dangerous to man. Although the coral snake is typically associated with dry habitats, it is not uncommon in the moist floodplain; Wright and Wright (1957) even reported a sighting of the coral snake swimming.

The American alligator (*Alligator mississippiensis*) is found in the floodplain community contiguous to the Nueces River. Population levels are low but appear stable (see Section 5.6.4). Full operation of the proposed diversion projects discussed earlier will result in reduced freshwater flows that may lead to a reduction in suitable habitat for the alligator.

Turtles common to the floodplain are discussed with the riverine community (Section 5.3) because they spend the majority of their time there.

Amphibians are probably more diverse than reptiles in this community. The habitat is ideal for these species, which require more moisture than do most reptiles. Table 8 lists representative species of amphibians in the floodplain of the Corpus Christi Bay system.

Table 8. Representative amphibian species in the floodplain of the Corpus Christi Bay study area (Conant 1975).

Scientific name	Common name
Bufo woodhousei woodhousei	Woodhouse's toad
B. woodhousei fowerli	Fowler's toad
Hyla cinerea	Green treefrog
H. versicolor	Gray treefrog
H. chrysoscelis	Gray treefrog
Pseudacris streckeri	Strecker's chorus frog
P. triseriata feriarum	Upland chorus frog
Acris crepitans blanchardi	Blanchard's cricket frog
Rana utricularia	Southern leopard frog
R. catesbeiana	Bullfrog

5.5 UPLAND COMMUNITY

Between the floodplain and the upland community is a biologically transitional zone, the Ingleside Barrier Strand Plain Oak Motte Wetlands area discussed in Section 2.4. The area is characterized by dense thickets of live oak, red bay, and yaupon. Many small ponds and wetlands are interspersed within the brushy areas. These wetlands are generally small, less than 300 m^2

although some may be over 2 ha in size. It has been estimated that there are 16 of the small ponds per hectare in the vicinity of Ingleside. The ponds are biologically active and contribute heavily to the productivity of this dwindling ecosystem in the Corpus Christi/Rockport area (Allison and Sides 1980). This Oak Motte-Wetlands belt that parallels the western edge of the Coastal Bend Bay provides habitat for numerous indigenous vertebrate species as well as food and cover for migrating songbirds and wintering waterfowl (D. Meineke, USFWS, Ecological Services Division, Corpus Christi, Texas; pers. comm. 1980).

Uplands are those areas not subject to flooding under normal circumstances. The following descriptions include species found in natural upland habitats. Most of the area is represented by man-modified habitats; especially conspicious are urban development and cropland.

An important function of the uplands is the export of nutrients to the estuary, largely via freshwater drainage. A portion of the natural nutrient flow is interrupted by man, directly through his harvest of crops and indirectly through livestock grazing. This loss of naturally occurring nutrients is more than replaced by man's addition of fertilizers. Combined with pesticides, herbicides, and man's own wastes, the nutrient and toxin load to the estuary is greater than under conditions without man's presence. In addition to the input of nutrients by man, natural nutrients are supplied to the uplands largely through decomposition of plant and animal matter, by rainfall, and by the chemical breakdown of near-surface sediments.

5.5.1 Vegetation

Although little site-specific information is available on the upland vegetation of the Corpus Christi Bay study area, exhaustive studies on tracts of land within neighboring Copano-Aransas study area provide some relevant data.

The majority of the grassland in this area is or has been under cultivation and therefore has lost its former natural vegetative assemblages. In a few undisturbed sites, dominant vegetation was determined by using the classification system established by Mann (1975) for the Welder Wildlife Refuge. The natural vegetation in the Corpus Christi Bay study area is dominated by three grasses (Mann 1975): seacoast bluestem (Schizachyrium scoparium littoralis), fringeleaf paspalum (Paspalum setaceum), and balsamscale (Elyonurus tripsacoides). The major forbs associated with the grasses vary with the season. Dayflower (Commelia erecta), hoary milkpea (Galactia canescens), and snoutbean (Rhynchosia americana) are the most common species during summer. The above assemblage, termed a bunchgrass-annual forb community (Mann 1975), grows predominantly on fine-grained sands.

In the less permeable muds and clays, components of two assemblages occur. These assemblages, defined as mesquite-buffalograss and chaparral-bristlegrass communities (Mann 1975), are dominated by woody vegetation. According to a biological assemblage map of the Corpus Christi Bay study area (Brown et al. 1976), large expanses of these dense shrubs do not appear. Scattered throughout the grassland, woody vegetation, such as mesquite (Prosopis glandulosa), huisache (Acacia farnesiana), and blackbrush (A. rigidula), is common (Mann 1975; Brown et al. 1976).

Common cacti in the upland include several species of prickly pear (Opuntia spp.). The prickly pear-shortgrass assemblage, once common in the coastal prairie, is being replaced by woody assemblages. For a more detailed discussion of the mechanisms of change and possible successional trends in the upland community, see the Copano-Aransas synthesis.

5.5.2 Fauna

Mammals. The white-tailed deer (Odocoileus virginianus) is the principal big game animal present in the upland community. Texas Parks and Wildlife Department (1978b) provides harvest and hunting pressure data by county; those counties lying within or overlapping into the Corpus Christi Bay study area are Nueces, Live Oak, and San Patricio. These data provide only approximate values for the study area, and deer are harvested in communities other than the upland. The values are for all habitats within a county. Of the three counties in the Corpus Christi Bay system, Nueces, with 51.6 hunters per 1000 ha, averaged the greatest hunting pressure during the 5-year period 1973-77. This value is well above the average hunting pressure of 28.6 hunters per 1000 ha in the gulf prairies and marshes (the ecological area that includes most of the Texas Barrier Islands Region) during that same period. Whereas hunting pressure was greatest in Nueces County, the average harvest of antlered and antlerless deer was greatest in Live Oak County, with 2,696 deer. Hunting pressure there was 27.1 hunters per 1000 ha. Average hunting pressure and annual harvest during the 5-year period 1973-77 for the Corpus Christi Bay study area were higher than in the neighboring areas of Copano-Aransas and San Antonio (TPWD 1978b).

Furbearers in the uplands include the bobcat (Lynx rufus), raccoon (Procyon lotor), opossum (Didelphis virginiana), eastern spotted skunk (Spilogale putorius), striped skunk (Mephitis mephitis), badger (Taxidea taxus), and coyote (Canis latrans). No data are available on the value of the yearly harvests of these mammals in the Corpus Christi Bay system. However, on a per pelt basis for 1977-78, the three most valuable animals listed above are the bobcat, $55 per pelt; coyote, $20; and raccoon, $16 (TPWD 1979b).

As in the barrier island community, rodents are the most abundant mammals in the upland community. Table 9 lists the common species of the uplands.

Table 9. Representative rodents in the upland community of the Corpus Christi Bay study area (Davis 1974).

Scientific name	Common name
Spermophilus mexicanus	Mexican ground squirrel
S. spilosoma	Spotted ground squirrel
Geomys bursarius	Plains pocket gopher
G. personatus	South Texas pocket gopher
Perognathus merriami	Merriam pocket mouse
P. hispidus	Hispid pocket mouse
Onychomys leucogaster	Short-tailed grasshopper mouse
Reithrodontomys fulvescens	Fulvous harvest mouse
Baiomys taylori	Pygmy mouse
Peromyscus maniculatus	Deer mouse
P. leucopus	White-footed mouse
Dipodomys ordi	Ord's kangaroo rat
Sigmodon hispidus	Hispid cotton rat
Neotoma micropus	Gray wood rat

Other mammals of this community include the California jackrabbit (*Lepus californicus*), eastern cottontail (*Sylvilagus floridanus*), and nine-banded armadillo (*Dasypus novemcinctus*), according to Davis (1974) and Henley and Rauschuber (1978). The javelina (*Dicotyles tajacu*) is hunted mainly for sport although until recently it was considered a menance by area ranchers (Davis 1974). Domestic livestock is also present and is the primary cause of overgrazing in the uplands.

Birds. The most important game bird in Texas is the mourning dove (*Zenaida macroura*), which provides more hunter recreation than any other game bird in the State. No population estimates for the counties in this study area are available. On a statewide basis the numbers of mourning doves appear to be declining. The Corpus Christi Bay system is included in Texas Parks and Wildlife Department's Ecological Area 2, the gulf prairies and marshes. In this area from 1977 to 1978 there was a 35.3% decline in dove calls heard in call-count surveys. Of 10 Ecological Areas, only 3 exhibited declines; of those three, the gulf prairies and marshes underwent the most marked decline (TPWD 1979c). Other game birds in the upland area of the Corpus Christi Bay system include the white-winged dove (*Zenaida asiatica*), Rio Grande turkey (*Meleagris gallopavo intermedia*), and bobwhite (*Colinus virginianus*).

Among birds common to the upland community are cattle egret (*Bubulcus ibis*) and upland plover (*Bartramia longicauda*). Not as dependent upon water as some egrets, the cattle egret prefers grassy habitats where it feeds on insects associated with grazing cattle. The upland plover is similar to the cattle egret because, unlike its sandpiper relatives, it is typically found far away from shorelines. The short grasses of coastal prairies are one of its favorite habitats (Oberholser et al. 1974).

Birds of prey common to the upland community include the red-tailed hawk (*Buteo jamaicensis*), Swainson's hawk (*Buteo swainsoni*), barn owl (*Tyto alba*), and great horned owl (*Bubo virginianus*). Swainson's hawk and the barn owl are restricted to relatively open habitats. The red-tailed hawk and great-horned owl are less specific in their requirements, but avoid densely forested areas. General food items of these species include rodents, rabbits, snakes, frogs, and lizards. In addition, Swainson's hawk consumes large quantities of agricultural pest insects like grasshoppers (Oberholser et al. 1974).

Reptiles and amphibians. The ornate box turtle (*Terrapene ornata ornata*) and Texas tortoise (*Gopherus berlandieri*) are the dominant turtles in the upland community. Their feeding habits differ considerably. Whereas the box turtle is essentially insectivorous, the Texas tortoise is especially fond of the pads, flowers, and fruits of prickly pear (*Opuntia* spp.) and grasses (Conant 1975).

Lizards common to the upland community are included in Table 10. The southern spot-tailed earless lizard (*Holbrookia lacerata subcaudalis*) is found on the coast only in the vicinity of the Corpus Christi Bay, Copano-Aransas, and San Antonio Bay study areas, but its range extends westward into the Edwards Plateau (Conant 1975). In the study area, the lizard lives in close association with mesquite and prickly pear.

Snakes likely to be found in the upland community are also listed in Table 10. The western diamondback rattlesnake (*Crotalus atrox*) and Texas coral snake (Micrurus fulvius tenere) are the predominant poisonous snakes. The coral snake is seen less frequently than the rattler because of its nocturnal habits. Historically, the coral snake population was considered low, but collections by Ruick on the Chapman and King Ranches suggested the species was more common than had been believed, especially in the area around Corpus Christi (Wright and Wright 1957).

Table 10. Representative lizards and snakes of the upland community, Corpus Christi Bay study area (Conant 1975).

Scientific name	Common name
Holbrookia lacerata subcaudalis	Southern spot-tailed earless lizard
Phrynosoma cornutum	Texas horned lizard
Sceloporus olivaceus	Texas spiny lizard
Eumeces obsoletus	Great Plains skink
E. fasciatus	Five-lined skink
Cnemidophorus gularis gularis	Spotted whiptail
C. sexlineatus viridis	Prairie racerunner
Leptotyphlops dulcis dulcis	Plains blind snake
Lampropeltis calligaster calligaster	Prairie kingsnake
Masticophis flagellum testaceus	Western coachwhip
Pituophis melanoleucus sayi	Bullsnake
Rhinocheilus lecontei tessellatus	Texas long-nosed snake
Thamnophis marcianus marcianus	Checkered garter snake
Crotalus atrox	Western diamondback rattlesnake
Micrurus fulvius tenere	Texas coral snake

The relatively dry climate of the upland community places special demands on the amphibians there. Since most amphibians require water for their reproduction, they must be opportunistic in their breeding. The eastern green toad (Bufo debilis debilis) is stimulated to breed by heavy rains, and metamorphosis of the young is completed in less than 3 weeks (Wright and Wright 1949; Conant 1975). Similar adaptations are exhibited by Couch's spadefoot toad (Scaphiopus couchi) and the gulf coast toad (Bufo valliceps). Inactivity or burrowing during dry periods, typical of the spotted chorus frog (Pseudacris clarki) among others, is another adaptive behavior (Conant 1975).

5.6 RARE AND ENDANGERED VERTEBRATES AND INVERTEBRATES OF THE CORPUS CHRISTI BAY STUDY AREA[4]

5.6.1 Mammals

The endangered mammals within this study area are the same as those discussed in the Laguna Madre and San Antonio syntheses with the following

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[4] The status for each rare and endangered species is listed for three agencies: Texas Organization for Endangered Species (TOES), Texas Parks and Wildlife Department (TPWD), and the U.S. Fish and Wildlife Service (USFWS). Status designations include: Endangered (E), Threatened (T), and except for the USFWS, Peripheral (P). Additional designations of Status Undetermined (SU) and Not Considered (NC) are from Gustavson et al. (1978).

exceptions: the jaguar (Felis onca veraecrucis) and the southern yellow bat (Lasiurus ega or Dasypterus ega xanthinus of Hall and Kelson 1959) in the Laguna Madre system do not extend to the Corpus Christi Bay area; and the river otter (Lutra canadensis texensis) of the San Antonio system does not extend as far south as Corpus Christi (Hall and Kelson 1959; Davis 1974).

5.6.2 Birds

Haliaeetus leucocephalus leucocephalus - southern bald eagle. Presently there are no known southern bald eagle nests in the Corpus Christi Bay study area although the area lies within the bald eagle's historical range (TPWD 1979a). Oberholser et al. (1974) list several specimen records obtained from this area. During the winters of 1971 to 1972 through 1975 to 1976, there were five sightings of bald eagles over the Corpus Christi Bay study area (TPWD 1976). See San Antonio and Matagorda syntheses for present nesting areas. TOES = E, TPWD = E, USFWS = E.

Pandion haliaetus carolinensis - osprey or fish hawk. While no known nesting presently occurs in Texas, there are sight records of this migrant species. In the Corpus Christi Bay study area, 44 sightings were recorded between 1971 and 1976 (TPWD 1976). It is not known how many were repeat sightings. Also see Matagorda-Brazos synthesis. TOES = E, TPWD = NC, USFWS = SU.

Falco peregrinus tundrius - Arctic peregrine falcon. These winter migrants are presently sighted over the Corpus Christi area. See Matagorda-Brazos, Galveston, Laguna Madre, and San Antonio syntheses. TOES = E, TPWD = E, USFWS = E.

Pelecanus occidentalis carolinensis - brown pelican. Blacklock et al. (1978) reported that eight pairs of brown pelicans were nesting on Pelican Island in Corpus Christi Bay in 1976. Nesting occurred here in 1967, 1970 through 1972, and 1975 through at least 1977 (TPWD 1978a). Historically, breeding has also occurred on Dimmit and Dead Man Islands in Corpus Christi Bay (TPWD 1978a). The present Texas range of nesting brown pelicans extends from Corpus Christi Bay to San Antonio Bay. The species had nested all along the Texas coast during the earlier part of this century (TPWD 1978a). Pearson (1920, cited by TPWD 1978a) estimated that there were 17 colonies with a maximum population of 5,000 along the Texas coast in 1920. In 1977, the total State population was 34 (TPWD 1978a). The decline in the brown pelican population has two major causes. The first occurred in the 1920's and 1930's when fishermen and hunters, believing that the species was competing with man for fish, killed vast numbers of adults and destroyed nests. After 1939 legislation eliminated the hunting and destroying of nests, pesticides and related eggshell-thinning became the primary cause of continued depletion (National Fish and Wildlife Laboratory 1980). By 1963, only 14 pairs were reported breeding along the Texas coast (TPWD 1978a). Also see Copano-Aransas and San Antonio syntheses. TOES = E, TPWD = E, USFWS = E.

Other rare birds. For peripheral species (species rare in the study area but more abundant elsewhere) see Laguna Madre, Matagorda-Brazos and Galveston syntheses.

5.6.3 Amphibians

None of the rare, threatened, or endangered amphibians listed in USFWS (1978) or Gustavson et al. (1978) are indigenous to the area.

5.6.4 Reptiles

Alligator mississippiensis - American alligator. Both Joanen (1974, cited by National Fish and Wildlife Laboratory 1980) and TPWD (1975) reported the existence of alligators in all three counties in the Corpus Christi Bay study area. In 1974, TPWD (1975) made the following county population estimates: Live Oak, 62; Nueces, 12; and San Patricio, 121. The population level in the latter two counties are stable, but it had decreased in Live Oak County. Compared to other study areas within the Texas Barrier Islands Region, the Corpus Christi Bay study area has a relatively small alligator population. Only the Laguna Madre study area contains a lower estimated population. In general, the alligator population decreases with decreasing habitat from the Galveston study area towards the Laguna Madre study area. See other study area syntheses for estimates of the local populations within those areas. TOES = E, TPWD = E, USFWS = E.

Malaclemys terrapin littoralis - Texas diamondback terrapin. The Corpus Christi Bay study area represents this species' southernmost range along the Texas coast. While more southern populations are suspected, no specimens have been recorded (Raun and Gehlbach 1972; Conant 1975). Also see Galveston Bay synthesis. TOES = T, TPWD = NC, USFWS = NC.

Other endangered reptiles. For endangered sea turtles, see Laguna Madre and Marine syntheses.

5.6.5 Fish

There are no reported findings of any of the threatened or endangered species listed, proposed, or under review by the USFWS (USFWS 1978; Deacon et al. 1979).

5.6.6 Invertebrates

None of the invertebrates listed (USFWS 1978) are indigenous to the Texas coast. See Matagorda-Brazos synthesis for references consulted.

5.7 RARE AND ENDANGERED PLANTS OF THE CORPUS CHRISTI BAY STUDY AREA

The only species that is rare in the area and on a global basis is the slender rushpea (Hoffmanseggia tenella). This species has been recorded from Nueces and Kleberg (Laguna Madre study area) Counties (Gustavson et al. 1978). Two resident species of the sunflower family are endangered in Texas, but are more abundant elsewhere: Mustang Island sumpweed (Iva imbricata) and gray ragweed (Ambrosia cheiranthifolia), found on Mustang Island and in San Patricio County, respectively (Gustavson et al. 1978). Brush stenandrium (Stenandrium fascicularis) is a rare south Texas species but abundant outside the State. See Gustavson et al. (1978) for a more complete listing.

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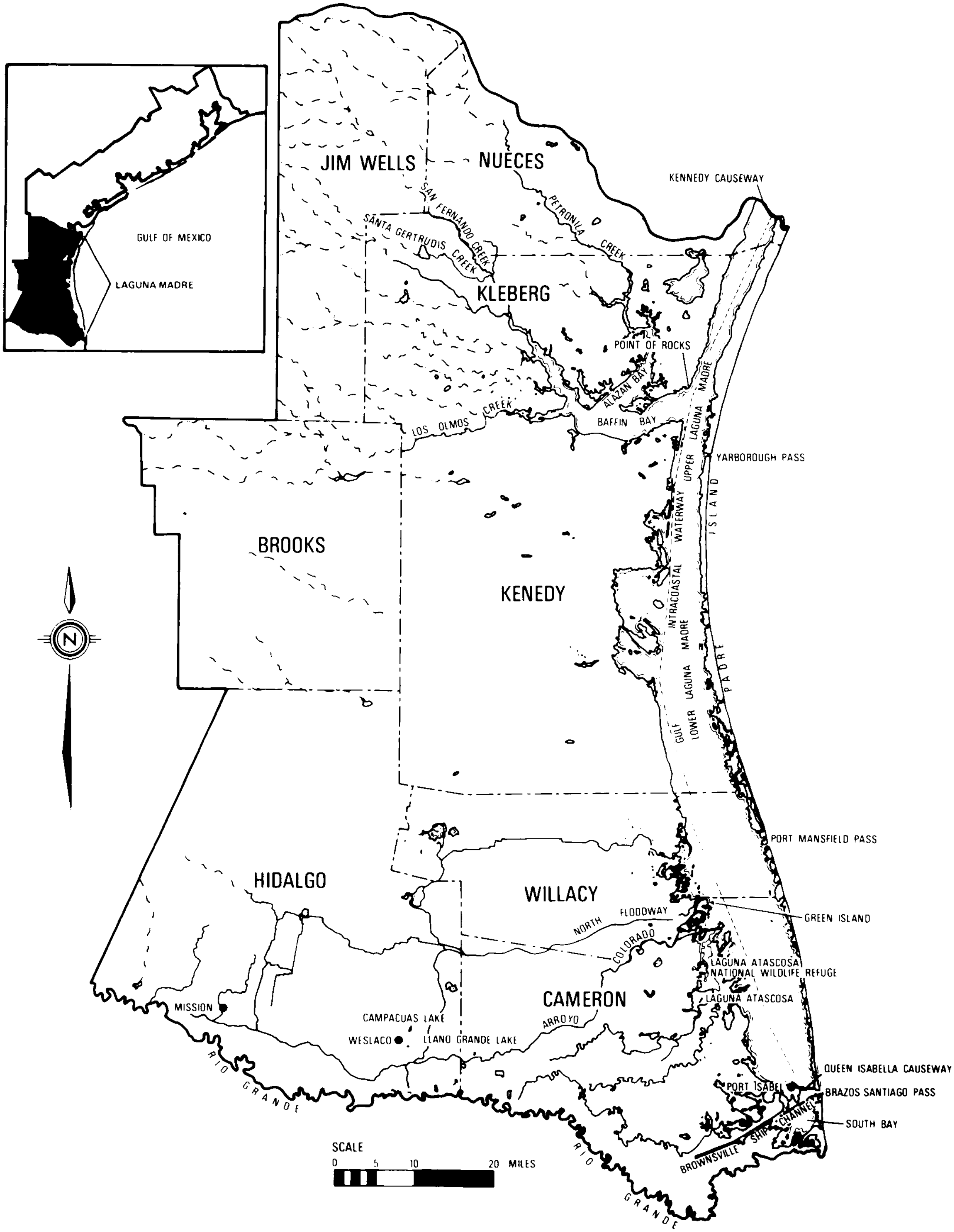
LAGUNA MADRE STUDY AREA SYNTHESIS



Map 7. Laguna Madre study area.

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1.0 INTRODUCTION

The Laguna Madre study area, while not entirely unique, is vastly different from the estuarine systems of the upper and central Texas coast. Climatic processes interact strongly with geologic and hydrologic variables, resulting in environments characterized by few resident species but often with large populations.

Hypersaline conditions are the rule rather than the exception in this estuarine system. Wind is the major driving mechanism for circulation and mitigation of hypersalinity because of the lack of local precipitation, riverine input, and tidal flux, combined with high evapotranspiration rates and shallow water depths.

There is conspicuous areal variability of biota. Aquatic fauna are concentrated near submerged grassbeds or freshwater outflows, or both, with the food chain based predominantly on benthic plants rather than phytoplankton. Within the upland areas, oak mottes, playas, and natural brushland are often associated with wildlife concentrations. The lower Rio Grande floodplain and delta historically have supported a diverse array of habitats in an otherwise low diversity region. For several neotropical species, this area is the northern limits of their range. While man has had a relatively small impact on the Laguna Madre system as a whole (in comparison with other Texas coastal basins), his impact along the lower Rio Grande Valley is nothing less than disastrous with respect to the biota and associated habitats. Agriculture and, to a lesser extent, an increasing industry-related development have led to the near decimation of floodplain habitats in this area. Recent efforts by wildlife biologists and private landowners have resulted in some progress towards multipurpose management.

Tourism is a major industry associated with the barrier island-lagoon complex. This industry, with private, State and Federal groups and agencies, have made efforts to preserve the area's natural assets. Regardless of the wants and desires of various interest groups, a study of long-term geologic processes indicates that the lagoon system is gradually being transformed into terrestrial habitat.

2.0 GEOLOGY

The few tidal passes, the long stretch of coastline with little riverine input, the sediment-filled valley of the Rio Grande, the convergence of littoral drift, and the coastal and inland migrating sand dunes are some of the more conspicuous and unusual physical features and processes characterizing the Laguna Madre system. The physiographic features represent the culmination of the interaction of the area's local climate and geology, both past and present. The variability of soil development in this area has been strongly influenced by climatic factors operating through time on various sedimentary deposits; this fact, in turn, largely has dictated man's use of the area.

2.1 GEOLOGIC ORIGIN AND PROCESSES - ESTUARINE AND RIVERINE TRANSPORT OF SEDIMENT

Much of the landscape of the Laguna Madre study area is dominated by sediments deposited during Pleistocene interglacial periods. The prairie soils between Corpus Christi and Brownsville consist largely of Pleistocene deltaic and other fluvial sediments deposited by ancestral courses of the Nueces River and the Rio Grande (Price 1958). The volume and various characteristics of these deposits and associated biotic assemblages uncovered indicate that the area's climate during the Pleistocene must have been considerably more pluvial (net moisture) than at present (Brown et al. 1977). Much of this area subsequently has been covered by a relatively thin veneer of reworked Pleistocene and Holocene loess (wind-deposited silts) and sands (Brown et al. 1977). These thin reworked sediments are currently undergoing active eolian (wind) transport, forming rather extensive dune fields in some areas (e.g., South Texas sand sheet).

During glacial episodes within the Pleistocene, when sea level was perhaps as much as 200 m lower, the Nueces River and Rio Grande carved deeply into older underlying deposits (Fisk 1959). With the termination of the Pleistocene and the beginning of sea level rise to its present position, the rivers experienced a corresponding adjustment in grade. This last major rise in sea level was rapid, in a geologic sense, and only those rivers carrying substantial sediment loads were able to fill in their previously eroded river valleys. The Rio Grande is one of three present river systems along the Texas coast which has successfully filled in its Pleistocene valley (Fisk 1959). In contrast, Baffin and contiguous bays are drowned segments of the ancient Nueces River and tributaries (Behrens 1963). Since sea level reached its approximate present level about 4,500 years ago, the Rio Grande Delta has continued to enlarge slowly, and Baffin Bay has experienced some shoaling.

Sediments in the Baffin Bay complex have three basic origins: (1) before the full development of Padre Island when the bay was open to the gulf, marine and estuarine sediments were dominant near the mouth; (2) relict serpulid (annelid worms) and oyster reefs may have been active as late as this century (Breuer 1957); and (3) as Padre Island developed and closed off the bay, riverine sediments and redistribution of eroded sediments from the river valley walls made up an increasingly larger portion of the bay bottom (Brown et al. 1977). Relative to other drowned river valley estuaries, however, the total amount of fill is small, and tidal movement of sediment from Laguna Madre is negligible (Brown et al. 1977). Table 1 shows the total riverine sediment input from the Rio Grande. Los Olmos and San Fernando Creeks contribute sediment into the Baffin Bay complex during episodic high discharge periods (Brown et al. 1977).

Table 1. Mean input of suspended sediment into Laguna Madre and Gulf of Mexico systems via the Rio Grande, October 1966-September 1976 (USGS 1967-1976b).

Month	Kgx10^3	Month	Kgx10^3	Month	Kgx10^3	Month	Kgx10^3
Oct.	189,964	Jan.	5,939	Apr.	8,730	July	73,558
Nov.	42,027	Feb.	4,289	May	10,168	Aug.	125,935
Dec.	27,140	Mar.	2,968	June	23,320	Sept.	232,987

Padre Island, which separates Laguna Madre from the Gulf of Mexico, was initially (approximately 7,000 years ago) a series of small islands gulfward of its present position (Fisk 1959). The sediment source was predominantly reworked sands from Pleistocene deltas which extend a considerable distance offshore underneath the present Gulf of Mexico. High energy, long period waves (such as those generated by hurricanes) drag along the shelf and transport the sands landward (Brown et al. 1977). Sands deposited on the foreshore and nearshore are then reworked by littoral drift during periods when energy levels are more typical. This lateral movement resulted in spit accretion, and eventually spits coalesced, cutting off tidal passes (Brown et al. 1977). While hurricane-generated waves transport sediment to the barrier island, they may also result in breaches. These cuts are ephemeral features along Padre Island since normal wave energies and sufficient sediment availability quickly close them. Recent studies indicate that Padre Island as a whole is experiencing net erosion (Brown et al. 1977). If this is indeed a reversal of the long-term accretionary trend, then Padre Island could be expected to be displaced landward, reducing the estuarine area. Given centuries of time and stable sea level conditions, the lagoon could transform into nearshore gulf habitat and the system would be drastically different from its present state.

Concomitant with Padre Island's development was Laguna Madre's formation. This 200-km long hypersaline lagoon has been slowly filling in, primarily with sand. The source of sand is Padre Island which, in turn, received its supply mainly from the gulf. Two processes deposit the sand: hurricanes, which can transport large volumes of material in a matter of hours, and the persistent southeasterly winds, which promote dune migration across Padre Island into Laguna Madre. Several areas of the lagoon have already shoaled to a near sea level elevation. These include the area east of Point of Rocks, the Middle Ground area, and the area known as the Land-Cut, which has been filled for the past 150 years (Fisk 1959). These areas are commonly referred to as wind-tidal flats. Persistent southeasterly winds usually cause prolonged flooding of these flats. Thin veneers of clay are often deposited during these periods. Algal blooms are common, but die with the ebbing of the wind tide. The sediments of these flats, therefore, are composed of sands with lenses of clay and algal mats, a substrate in which numerous mollusks and crustaceans are found.

A second type of feature known as a wind-tidal flat occurs along the western shore of Laguna Madre. While the appearance is similar to those flats just described, these areas are erosional features which have been deflated by winds and which contain a considerably greater proportion of fine-grained sediments (Hayes 1967).

The Laguna Madre study area, part of the geologic region known as the Gulf Coast Geosyncline, is experiencing long-term subsidence. Inorganic sediment supply, combined with organic production, must aggrade the surface at an equivalent or greater rate than subsidence to maintain emergent wetlands and other low-lying habitats above sea level elevation. Swanson and Thurlow (1973) estimated that the subsidence rate at Port Isabel was approximately 5 mm/yr from 1959 to 1971, a relatively low rate in comparison to that of other areas along the Texas coast. The maintenance of Padre Island and the filling of Laguna Madre provide morphological evidence that the sediment supply exceeds the subsidence rate.

2.2 SOILS

Soil types within the Laguna Madre system largely reflect Pleistocene and Holocene geological and climatological processes. The area used most intensively for agriculture is within and flanking the Rio Grande floodplain, where most of the soil types have the potential for moderate to high yields, provided an adequate water supply can be obtained. In this area, modern bottomland soils and loamy to clayey soils, which have developed on Pleistocene fluvial deposits, dominate. Much area from north of the Rio Grande floodplain to Baffin Bay is rangeland because lack of freshwater, high soil salinity, caliche deposits, and active dune complexes adversely affect crop yields (General Land Office 1975). North of Baffin Bay, soils are composed largely of clay with low permeability, typical of the natural prairie. Interspersed throughout this area are soils more suitable for cultivation which contain larger percentages of silt and sand. These latter types have developed on Holocene and Pleistocene river valleys.

Soils on Padre Island are poorly developed since eolian processes tend to disrupt soil development. Wetland soils surrounding Laguna Madre are variable, generally with a high sand content. Peat layers are meager, and emergent vegetation is sparse. During periods of depressed water levels, deflation (eolian erosion of the soil surface) is common, curbing the development of wetland soils (for further discussion on soil types in the area, see Brown et al. 1977; Brown et al. in progress; and individual county soil reports available from the U.S. Department of Agriculture, Soil Conservation Service).

2.3 TOPOGRAPHIC AND BATHYMETRIC FEATURES

Topographic relief is generally lacking throughout the system. Maximum elevations at the inland boundary of the study area seldom exceed 30 m and a gentle slope averaging approximately 0.5 m/km is typical. Similarly, water bodies are shallow with over half of Laguna Madre being less than 1 m in depth. Baffin Bay is relatively deeper in its central portions, averaging about 2 to 3 m; however, many connecting basins, containing numerous tidal flats, are generally shallower.

This lack of gradient, combined with sufficient sediment supply and climatic processes, has resulted in the formation of the broad wind tidal flats, a valuable shorebird habitat and an unusual feature along the Texas coast.

2.4 UNIQUE OR UNUSUAL STRUCTURES

The major physical process in the area is wind. This dominance which has persisted for several thousand years, and intermittently throughout the Pleistocene (Fisk 1959), has resulted in unusual landscape features. Foreshore dunes and the contiguous deflation zone along most of Padre Island potentially provide a preferred nesting habitat for several species of marine turtles and birds. Ancient stabilized dunes on the mainland are locally known as live-oak mottes, the only upland forest habitat. Similar features, known locally as "potreros" (generally associated with the Ingleside sands; see Corpus Christi geology section), have reached a climax vegetation and contain abundant upland game (see Section 5.0). Deflation zones (often called "playas") of both ancient and active dunes and dune fields provide intermittent or ephemeral freshwater marsh habitat in the upland zone (Brown et al. 1977).

The Rio Grande, which carries large volumes of sediment during the fall flood period, through time has filled its floodplain and built a prograding delta. The only relatively large expanse of emergent wetland vegetation in the study area is near the Arroyo Colorado area of the Rio Grande Delta (see Section 5.0).

In consideration of the length of coastline in this study area (approximately 200 km), there are relatively few tidal passes (see Section 4.0), a result of the lack of hydraulic head (due to the micro tidal range and low riverine input). In other words, there is no physical cause for additional channels. This, in turn, has indirectly played a role in the circulation of water in Laguna Madre, with resulting hypersalinity and (ultimately) its effects on biotic assemblages within.

2.5 MAN-MADE DEVELOPMENTS

Man's role as a geologic agent in the Laguna Madre system has been generally of a lesser magnitude than in the other systems along the Texas coast, partially because the area's population density is relatively low and the climate is less than optimum for developmental growth.

The extension of the Gulf Intracoastal Waterway (GIWW) through Laguna Madre from Corpus Christi to Port Isabel in 1949 (Brown et al. 1977) has had two general effects. The channel occasionally carries fresh flood waters which temporarily reduce salinities in Laguna Madre, and the spoil deposits from dredging operations reduce east-west circulation (Simmons 1957). An important shrimp and finfish nursery area locally known as "The Hole" was becoming less accessible to these species due to the combined obstructions caused by the continued natural filling of the middle ground area and spoil deposit from the GIWW and oil access canals. The recent dredging of an additional channel into "The Hole" appears to have mitigated this problem some (E. Simmons, Texas Parks and Wildlife Department, Austin, Texas; pers. comm. 1980). To the north, construction of the Kennedy Causeway (mostly landfill) significantly has reduced circulation in the northern part of Upper Laguna Madre (Simmons 1957).

Breuer (1972) discussed several construction projects which have decreased the value of the South Bay area as a nursery ground: (1) Brownsville Ship Channel construction in 1936, (2) subsequent channel maintenance dredging and spoil disposal in South Bay, (3) the artificial deepening and placement of jetties at Brazos Santiago Pass, and (4) the building of approaches to the Queen Isabella Causeway (now a State fishing pier). Cumulatively, these projects have closed Boca Chica Pass, a valuable avenue to the South Bay area for fish. The spoil placement also has eliminated Vadia Ancha and Bahia Grande as marine nursery grounds (Breuer 1972).

Another landscape modifer in this area is agriculture. Overgrazing on the prairie has led to a long-term reduction in grassy areas and an increase in woody shrubs (Bogusch 1952; Diener 1975). Much area in the Rio Grande

Valley has been converted to citrus, cotton, sorghum, and sugarcane. In addition to the loss of natural floodplain habitats, irrigation requirements have had several indirect effects on the system. The construction of Falcon Dam and the levee system below Mission has reduced the freshwater inflow and sediment transport over the floodplain and into Lower Laguna Madre and the Gulf of Mexico. The extent of riparian habitat along the river valley and the ability of the deltaic wetlands to maintain and increase their area have been reduced drastically. Additionally, the reduced freshwater inflow affects salinities at the mouth of the Rio Grande and its distributaries.

3.0 CLIMATE

The Laguna Madre study area is perhaps the most obvious area along the Texas coast where the layman can see that climatic factors have substantially sculptured the general physiography and controlled biotic diversity and movements. The relatively meager precipitation, warm temperatures, and prevalent and predominant southeasterly winds have resulted in an eolian-dominated landscape consisting of well-developed barrier island dunes, poorly developed soils, sparse vegetation cover, and hypersaline lagoons.

3.1 PRECIPITATION

The Laguna Madre study area can be classified as semi-arid with the greatest amount of rainfall occurring in the northeastern portion, averaging 725 mm annually, according to the National Oceanic and Atmospheric Administration (NOAA 1973). Precipitation levels decrease in a southerly direction along the coast and westward in an inland direction. Rio Grande City, which lies inland of the southernmost extent of the study area, receives only 480 mm annually (NOAA 1973). The seasonality of rainfall can be examined (Figure 1) by using Port Isabel and Corpus Christi (representing the southern and northern portions of the study area) as examples. The single late summer maximum is atypical for the U.S. gulf coast, existing only along the south Texas and south Florida coasts. The seasonal peak is associated with the increased occurrence of tropical weather regimes.

3.2 TEMPERATURE

Temperatures are generally warm throughout much of the year with maximum temperatures typically lagging behind maximum solar radiation by 1 or 2 months (Figure 2). Port Isabel (south) has a mean annual temperature 1° C higher than Corpus Christi (north). By comparison, the mean annual difference in temperature between the Port Isabel (Rio Grande Delta area) and the somewhat cooler Galveston Bay vicinity is approximately 2.2° C. While the magnitude of this difference is seemingly small, one only has to examine the literature with regard to the differences in climate through geologic time. The consensus of several authors is that the mean temperature during the Pleistocene glacial periods was only a few degrees (Celsius) lower than present (National Academy of Sciences 1975), resulting in effects upon geography and biota which were indeed enormous. Thus, the temperature difference along the Texas Barrier Islands Region should partially account for the areal heterogeneity of habitats and their associated communities.

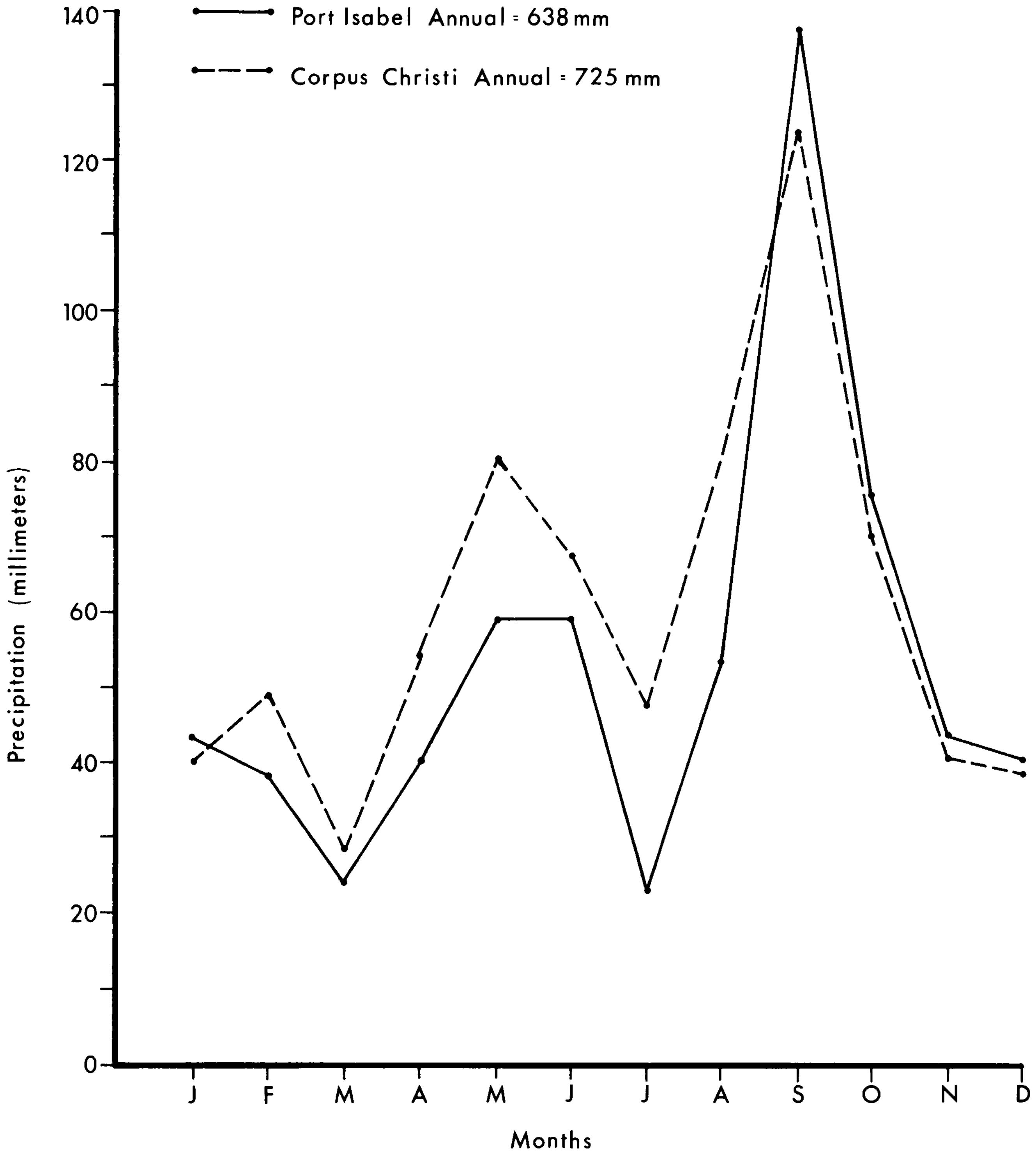

Figure 1. Mean seasonal precipitation for Port Isabel and Corpus Christi, 1941-1970 (NOAA 1973).

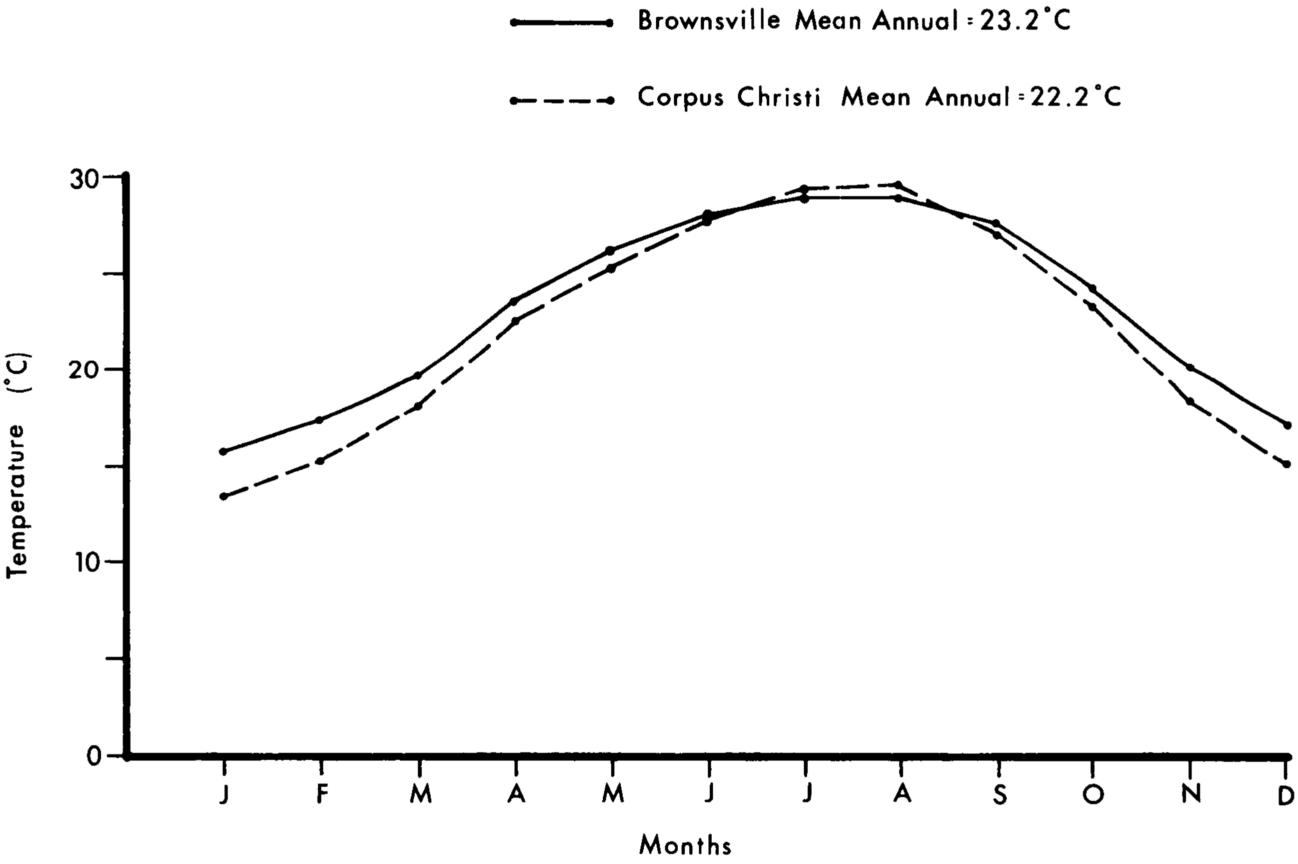

Figure 2. Mean seasonal temperature for Brownsville and Corpus Christi, 1941-1970 (NOAA 1973).

The relatively mild winter temperatures are reflected in the length of the growing season which averages 310 days in the northern part of Laguna Madre and 330 days in the Rio Grande Delta (Orton 1964), where a viable citrus industry exists.

By using rainfall and temperature data, a theoretical climatic water budget can be calculated (Thornthwaite and Mather 1955), providing a fair representation of water demand by the natural environment. Due to the warm temperatures, the potential for evaporation and plant transpiration is high. Because of the paucity of rainfall, the actual amount of evapotranspiration is much less than the potential. Under such conditions a moisture deficiency exists. Orton (1969) calculated annual moisture deficiencies for Texas and has shown that the Laguna Madre area averages 500 mm of deficit near Corpus Christi, increasing to over 700 mm in the Brownsville-Port Isabel area. On a seasonal basis, moisture deficiencies consistently appear, with not a single month showing a surplus (when the amount of precipitation exceeds the potential for evaporation and transpiration) when averaged over a 10-year period (Figure 3). This explains the arid conditions which prevail, including characteristics such as hypersaline lagoons, the absence of local streams, and the low species diversity of the vegetation.

3.3 WIND PATTERNS

The prevailing (duration) and predominant (energy) winds are from the southeast. The South Texas sand sheet with its characteristic barchan dunes (crescent-shaped dunes with arms pointing downward) provides morphological evidence of the impact of the persistent southeasterly winds. Wind frequency, strength, and aridity have led some to classify this area as a wind-dominated coast (Brown et al. 1977).

During the winter, an average of 15 to 20 cold fronts with associated northerly winds pass through the area (Brown et al. 1977). The rapid temperature decrease which often accompanies the passage of these fronts is known to result in fish kills throughout the Texas coast (Gunter and Hildebrand 1951, cited by Diener 1975). The species inhabiting the very shallow waters of the Laguna Madre study area have experienced the largest losses (E. G. Simmons, Texas Parks and Wildlife Department, Austin, Texas; pers. comm. 1980).

Laguna Madre, as most U.S. gulf coast estuaries, is dominated by the diurnal components of tidal harmonics with a mean range of only 15 cm (Brown et al. 1977). This microtidal range, combined with the lack of major freshwater discharge, emphasizes the importance of wind in controlling estuarine circulation. Southeasterly winds push water northward through Laguna Madre and northwestward into the upper reaches of Baffin and Alazan Bays. Northerly winds, often accompanied by precipitation, produce a more complex circulation pattern, but in general opposite that of southeasterly winds (Brown et al. 1977). During non-winter months when prevailing winds are southeasterly, the frequency of wind-induced water flux diminishes. During the winter, the reversal of winds during the passage of a frontal system causes abrupt changes in circulation. After a few days, the air circulation returns to its southeasterly flow until the passage of the next front (usually within several days). Thus, winds and consequently circulation are in a constant state of flux and the total movement of water is at its greatest during winter (Brown

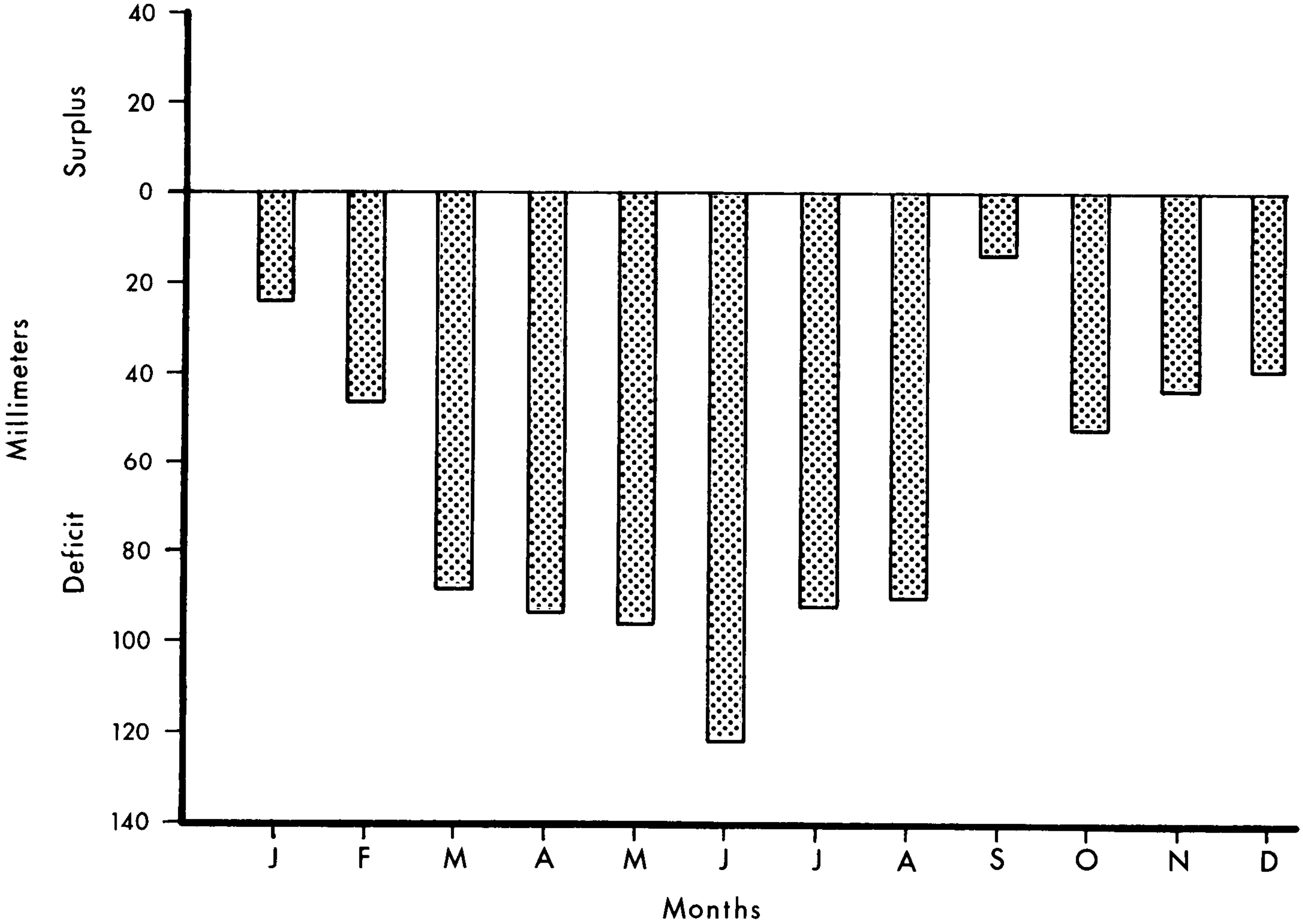

Figure 3. Mean seasonal noncontinuous water budget for Weslaco, 1969-1978, calculated by subtracting mean monthly adjusted pan evaporation from mean monthly precipitation (Environmental Science Service Administration 1970; NOAA 1971-1979).

et al. 1977). Many gulf coast shrimpers know that the passage of a cold front means that shrimp will be moving through the passes. (For a more detailed discussion on circulation see Section 4.2).

3.4 EPISODIC WEATHER EVENTS

Gulf tropical disturbances and nontropical intense rain storms are two weather types which infrequently occur but should be considered normal for the area. The latter type occurs with both diminished frequency and intensity in comparison to other areas along the Texas coast. The effects on the system of these storms are similar but usually of less magnitude than the heavy rains accompanying gulf tropical disturbances.

Gulf tropical disturbances (which include hurricanes) result in short-lived high energy levels impacting a particular area. While these energy regimes are perceived as destructive by man, the gulf coast systems have long developed within their sphere of influence. Although some effects of the hurricanes are destructive to the natural system, many can be perceived as constructive. In Laguna Madre, where tidal range and river flow are low, high water associated with tropical disturbances flushes out pollutants, reduces hypersalinities, and moves organisms into the open water systems. Intense rainfall, which often accompanies these storms, swells river valleys, and in the Laguna Madre area where vegetation is sparse, causes extensive erosion of upland areas. Much of this sediment, in turn, is deposited in the bays and over existing wetlands, providing material for maintenance of these wetlands and the development of new wetland areas. Hayes (1967) found that Hurricanes Carla and Cindy played an important role in depositing sediment over tidal flats in Laguna Madre. Many of these flats were subsequently colonized by marsh grasses.

Beach habitat can be substantially altered during the passage of hurricanes. Breaks in the barrier islands and substantial removal of foreshore sands are the immediate impacts. In a relatively short time, however, when more typical wave energies return, sand is redeposited, closing the breaks and returning the foreshore beach profile to its pre-storm state (Hayes 1967). Brown et al. (1977) stated that there is actually a net gain of sand to the barriers in this area after a hurricane, since increased energies drag on the shelf, transporting sand to the shoreface.

Several gulf coast investigators have sought to determine the effects of hurricanes on the biota. While the immediate hurricane result is a drastic reduction in animal populations, several authors concluded that there was no permanent damage. Investigators included Hubbs (1962), studying a coastal pond and ditch near Port O'Connor, Texas; Tubb and Jones (1962), studying Florida Bay; and Chabreck and Palmisano (1973), investigating the Mississippi Delta marshes. Harris and Chabreck (1958) and Chabreck and Palmisano (1973) noted that many areas actually improved as waterfowl habitat. Craighead and Gilbert (1962), however, noted that modification of hardwoods in southern Florida was extensive following Hurricane Donna. The coastal oaks mottes in the Laguna Madre system may be similarly susceptible if comparable energies affected this area. These clustered oaks on relict dunes are a valuable habitat, especially during hurricanes. With virtually no well-defined drainage in this area, flooding is extensive and prolonged following intense rainfall, causing these mottes to be extensively used for shelter by local fauna (Brown et al. 1977).

4.0 HYDROLOGY AND HYDROGRAPHY

The relatively limited stream flow and local precipitation, micro-tidal range, warm temperatures, and scarcity of tidal passes have resulted in Laguna Madre being hypersaline and wind-dependent for circulation. Water circulation is usually poor and, because the water is shallow, the area is susceptible to large fluctuations in water temperature and related water quality. Due to the area's inherent slowness in flushing, perturbations by man can be expected to impact the area for lengthy periods and have a greater chance of being cumulative.

4.1 TIDAL INFLUENCES - SALINITY REGIMES

True tides in Laguna Madre average about 15 cm in range (Collier and Hedgpeth 1950). The principal harmonic components favor diurnal tides, a situation common to the northern Gulf of Mexico (Marmer 1954). These factors, combined with the presence of few tidal passes, result in a relatively low degree of flushing due to astronomical tides. Indeed, this is a principal factor contributing to the system's hypersalinity. Smith (1978) noted that tides in Upper Laguna Madre accounted for only 5% of the total observed variation in water level. This observation supports Simmons (1957), who noted that tides were negligible in the upper lagoon, especially since the construction of the Kennedy Causeway at the north end. Both studies contradict Hedgpeth (1947), who reported a complete turnover of water during the September equinoctial tide. The Hedgpeth study, however, was completed before the causeway's construction. Even with this in mind, Hedgpeth's results conflict with those of Marmer (1954), who showed that diurnal tides are depressed during the equinox. Breuer (1962) indicated that circulation in Lower Laguna Madre is considerably greater than in Upper Laguna Madre, especially since the artificial opening of Port Mansfield Pass; however, he noted that true tides contribute little to the Lower Laguna Madre's circulation. When the flood tide and wind are in phase, hypersalinity can be reduced throughout much of the lower lagoon. The influx of seawater to reduce salinities in bays and lagoons is, of course, restricted to hypersaline situations and is of limited duration.

Another common use of the term "tide" along the gulf coast is associated with the effect of wind on water flux. Known locally as wind tides or simply tides, the resulting changes in water flux often are more important than lunar tides (Marmer 1954). Data obtained by Copeland et al. (1968) indicated that the passage of a typical cold front can result in a water flux of 30 to 45 cm. The cyclical nature of cold front passages followed by returning gulf air throughout the winter months increases circulation (Copeland et al. 1968). This factor, combined with lower temperatures and, to a lesser extent, precipitation associated with frontal passages, partially mitigates high salinities in the lagoon and bays. Data presented by Simmons (1957) for the upper lagoon indicated that, while circulation is improved during the winter, it is at best sluggish.

Seasonal water flux in the Laguna Madre area (Figure 4) is similar to that experienced throughout the northern Gulf of Mexico. It is associated with variable wind stress and seasonal heating and cooling of water (see Sturges and Blaha 1976). The magnitude of the seasonal change exceeds the average tidal range. The fall maximum is usually sufficient to flood the vast tidal flats in Laguna Madre for extended periods. Flooding during other seasons can be expected to be correspondingly less, perhaps resulting in a seasonal change in the function of the tidal flats as a habitat. The possible role of seasonal water flux as a low frequency contributor towards flushing can only be inferred.

Salinities in both Laguna Madre and the Baffin Bay complex ordinarily exceed that of seawater. During occasional wet years salinity can be expected to be depressed below average seawater values. For example, the data of Martinez (1975) showed that average salinity in the Upper Laguna Madre was 27.7 ^{o}/oo;and 27.2 ^{o}/oo in Lower Laguna Madre during 1973. A typical seasonal pattern (Figure 5) indicates that salinities are highest (up to 60 ^{o}/oo) in late summer, corresponding to high evaporation rates and low stream inflow. The abrupt decrease in salinity in October corresponds to the equally abrupt increase in rainfall and discharge. Below-average salinities persist through the winter due to lower evaporation rates and the continued effects of the fall floods.

The Baffin Bay complex experiences a wider range of salinities than does Laguna Madre, apparently true both before and after the construction of the GIWW (Hedgpeth 1967). As limited as the exchange is between the gulf and Laguna Madre during summer periods of low discharge, the lagoon has lower salinities than the bay complex (Breuer 1957; Simmons 1957; Hedgpeth 1967; Brown et al. 1977). Simmons (1957) stated that before the GIWW, salinities exceeding 100 ^{o}/oo were not uncommon in Baffin Bay. During infrequent floods, salinity in Baffin Bay has been as low as 6 ^{o}/oo, while most of Laguna Madre remained about 45 ^{o}/oo (Brown et al. 1977). Breuer (1957) noted that the torrential rains of September 1951 and August 1953 were followed by a mass migration of fish into Baffin Bay. Laguna Madre did not experience the mitigating effects of these rains to the same extent as did Baffin Bay, where low salinities persisted for at least 7 months. The slow rate of water exchange between these two bodies of water is due to the partial barrier created by the flats and serpulid reefs at the mouth of the bay and to spoil deposits form the GIWW.

Man has made several attempts to improve circulation and reduce salinity in the system. Fish kills from hypersalinity were previously common (Collier and Hedgpeth 1950) and led local fishermen to press for the creation of an artificial pass (Hedgpeth 1967). One man-made pass (known as Yarborough Pass) closed shortly after its creation. Gunter's (1945) salinity data showed that even while the pass was open, salinity in Laguna Madre was reduced only 0.5%. Repeated efforts at maintaining this pass have failed (Hedgpeth 1967; Brown et al. 1977).

The completion of the GIWW along Laguna Madre in 1949 has changed salinity and circulation. Salinities in Lower Laguna Madre have been generally lowered by the northward flow of gulf water through the waterway via Brazos Santiago Pass. The deeper GIWW is a refuge and avenue of exit for fish during periods of excessive salinities and/or temperatures. Mass mortalities due to

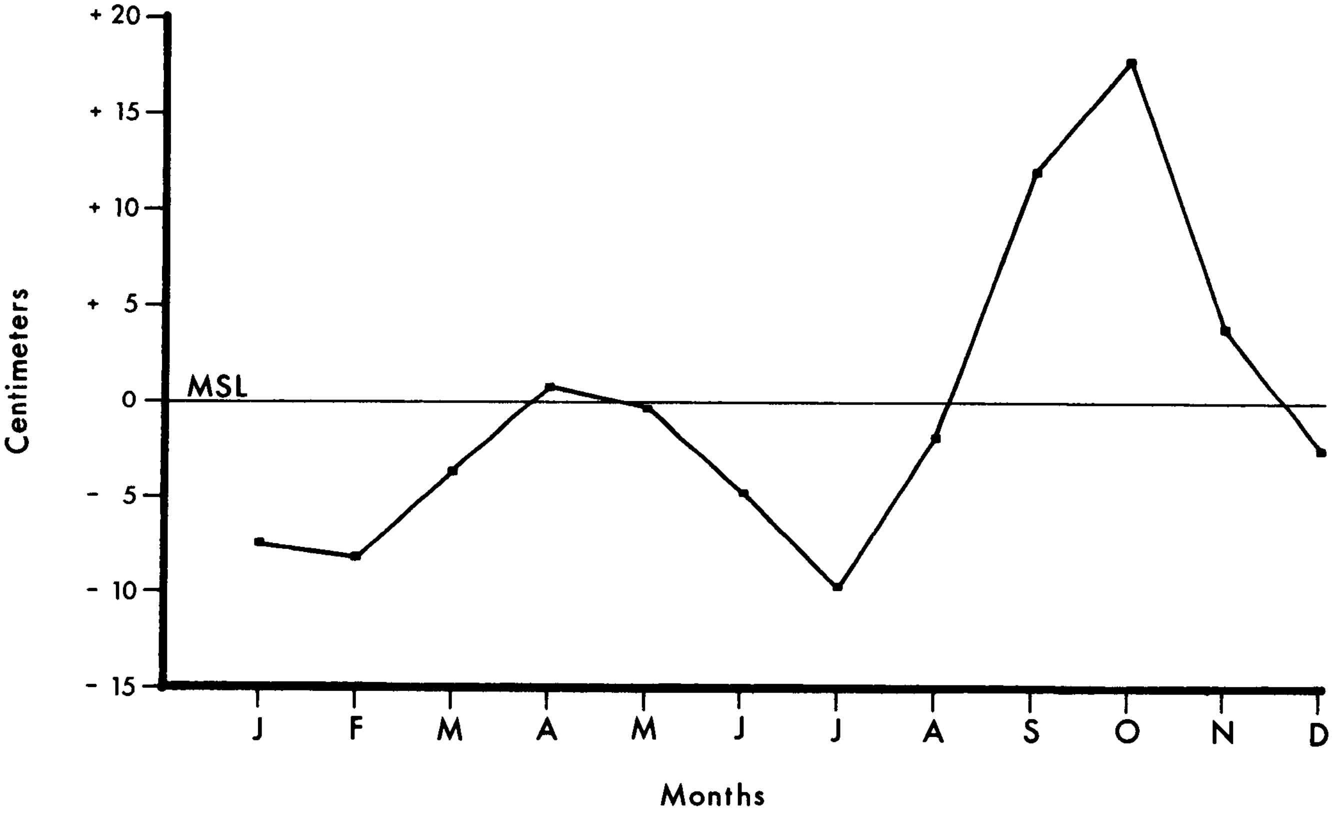

Figure 4. Seasonal variation in sea level at Port Isabel, 1945-1950 (Marmer 1954).

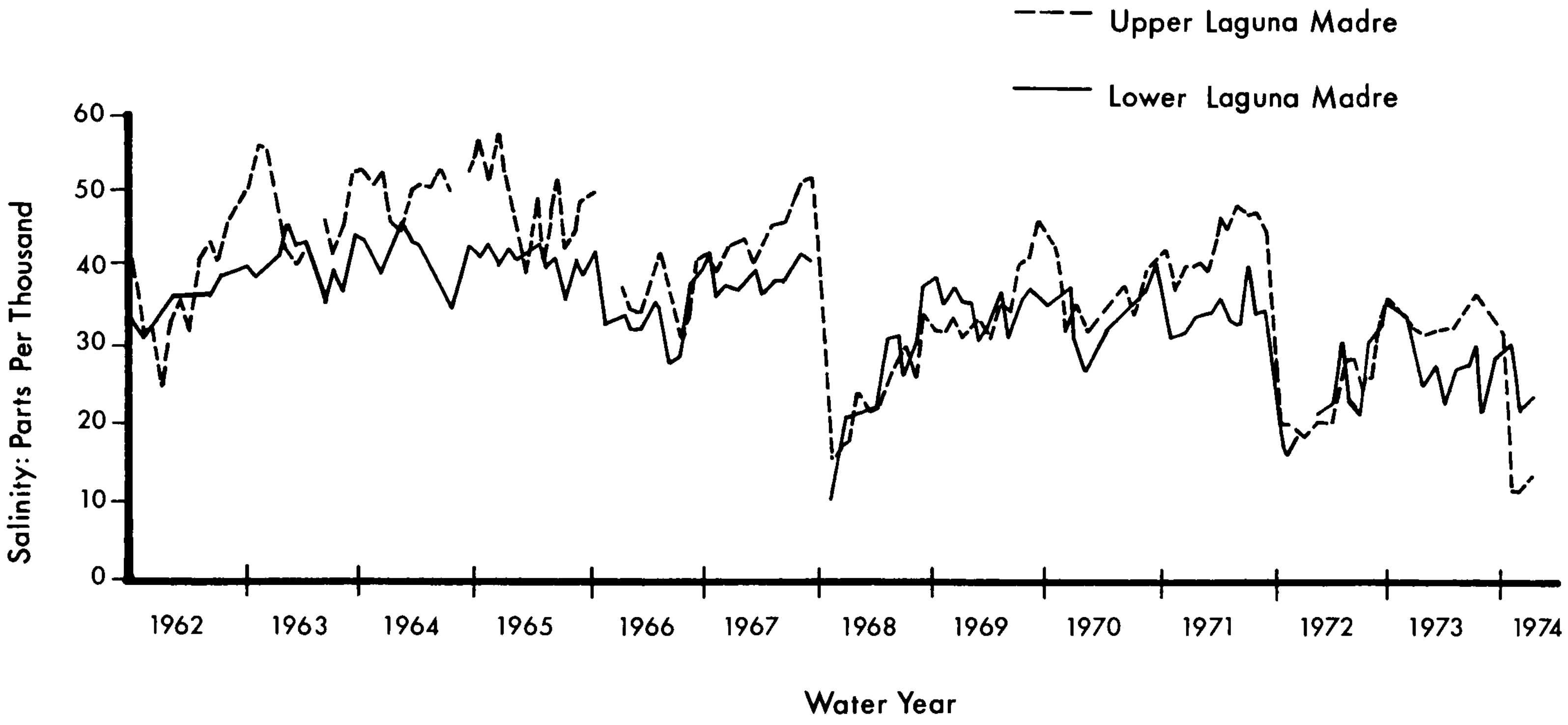

Figure 5. Monthly salinity records for Upper and Lower Laguna Madre (Warshaw 1974).

temperature and salinity conditions have been greatly reduced since the GIWW construction (Simmons 1957; Breuer 1962; Hedgpeth 1967). In the northern part of Laguna Madre, however, spoil deposits resulting from the GIWW and the Kennedy Causeway have reduced water exchange with the fresher Corpus Christi Bay waters, causing a stagnation of dense saline waters in Upper Laguna Madre (Simmons 1957). In addition, the spoil has partially segmented the lagoon into east and west components and has retarded water exchange between the two (Breuer 1962).

The construction of the Port Mansfield Pass in Lower Laguna Madre has led to a circulation pattern of water entering Brazos Santiago Pass and flowing north and out Port Mansfield Pass. Salinities in this area have stabilized at a level nearer Gulf of Mexico values, with subsequent alteration in the faunal assemblage (Hedgpeth 1967; Pulich 1980).

4.2 CURRENT AND WATER CIRCULATION PATTERNS

The lagoon and bay system is characterized by sluggish, wind-dominated circulation. Effects of tides and man's attempts to improve circulation have been previously described (see Section 4.1). Effects of stream flow are included in Section 4.3, and the effects of prevailing winds and storms are discussed in Sections 3.3 and 3.4.

The poor circulation in these water bodies has important ecological implications. Variability in salinity and water temperature is reflected in the rather large seasonal variability in biotic assemblages (Hedgpeth 1967). While pollutant levels in the area generally have been low, one can envision the dramatic effects of any increased level of toxic substances, combined with the poor mechanism for flushing them through the system. It is apparent that the southern portion of the Lower Laguna Madre has become a case in point (see Section 4.5).

Man's attempts at increasing circulation both directly (e.g., Yarborough Pass) and indirectly (e.g., GIWW) have had both positive and negative results (see Hedgpeth 1947, 1967; Breuer 1957; Simmons 1957). Although increasing circulation may be a desirable goal, long-term physical processes will decrease circulation as Laguna Madre continues to constrict and shoal (also see Section 2.1).

In the nearshore zone of the Gulf of Mexico, the recurved coastline, combined with seasonal wind regimes, results in a convergence of longshore drift in the Padre Island area (Price 1933; Lohse 1952; Hayes 1967). The nodal point of convergence shifts up and down the coast with seasonal shifts in the wind (Brown et al. 1977). For example, during the summer when the predominant winds are from the southeast, convergence is near Corpus Christi Bay. The annual average position resulting from an average predominant wind from the east is near 27° N latitude (Big Shell Beach area) (Brown et al. 1977). The geologic significance of this convergence zone is that the area receives sediment from both the north and south, and since there is no downdrift, large quantities of sediment accumulate. Once deposited on the beach, sediments are transported landward by wind, forming dunes and sand flats.

4.3 DRAINAGE PATTERNS AND FRESHWATER INFLOWS, RIVERINE FLOODING PATTERNS

One unusual characteristic of the Laguna Madre system is the lack of streams flowing into much of its area. The Rio Grande is, of course, a substantial river, draining some 466 x 10^3 km^2 of land along a distance of approximately 3,200 km (Timm 1941). However, because of arid conditions over much of its drainage area, total volume of flow is relatively low. On an annual basis, the Rio Grande averages 57.1 m^3/sec of flow over a 30-year period (modified from Diener 1975). The present main outflow of the Rio Grande is into the Gulf of Mexico, although as recently as 200 years ago the mouth was located in South Bay (Breuer 1962). During the Rio Grande's peak flows, the North Floodway and the Arroyo Colorado, which originate near Mission, Texas, carry floodwaters into Lower Laguna Madre. The Cayo Atascosa flows intermittently, but much of it is intercepted and impounded at the Laguna Atascosa National Wildlife Refuge (Bryan 1971).

Into the Baffin Bay complex flow several small streams, including Santa Gertrudis, Petronila, Los Olmos, and San Fernando Creeks; the latter two, routinely monitored, flow at a combined rate of 1.3 m^3/sec, the lowest discharge into any Texas bay.

By any relative comparison around the U.S. gulf, the total stream discharge into the Laguna Madre is meager. For example, it would take 26 months of the combined discharge of the Rio Grande and the small, monitored streams to fill an empty Laguna Madre to the mean low water (MLW) level. This calculation indicates what little influence stream flow has on turnover rates and circulation in this system. In dramatic contrast, the average Mississippi River discharge would fill the lagoon to MLW in approximately 22 hours.

A pronounced seasonal variation in rate of stream flow is apparent (Figure 6). The peak flow in local streams coincides with peak rainfall, while the Rio Grande's crest is somewhat delayed due to the large area it drains. Expectedly, salinities have a corresponding seasonal low, although they may still exceed that of normal seawater (Brown et al. 1977). During extremely heavy rainfall (e.g., tropical storms) with corresponding high stream discharge, surface salinities may be reduced to less than 6 $^{o}/oo$ at the mouths of streams in the Baffin Bay complex, and to 20 $^{o}/oo$ in "The Hole" (Brown et al. 1977).

4.4 GROUNDWATER

Because the area is semi-arid and lacks major rivers, man depends largely on groundwater for his water supply. In the southern part of the area, surface waters from the Rio Grande are a preferred source, but during low flow periods groundwater supplies may become the principal source. The slightly saline nature of most reservoirs makes them unsuitable for continued irrigation, the largest use of water in the lower Rio Grande Valley (Baker and Dale 1964). Continued groundwater use builds up salts in the soil which subsequently must be leached.

Since large-scale groundwater use is relatively recent in this area (ca. 1950), it is unknown whether withdrawal rate exceeds that of recharge. Baker and Dale (1964) reported a maximum of a 5-m piezometric (hydrostatic pressure)

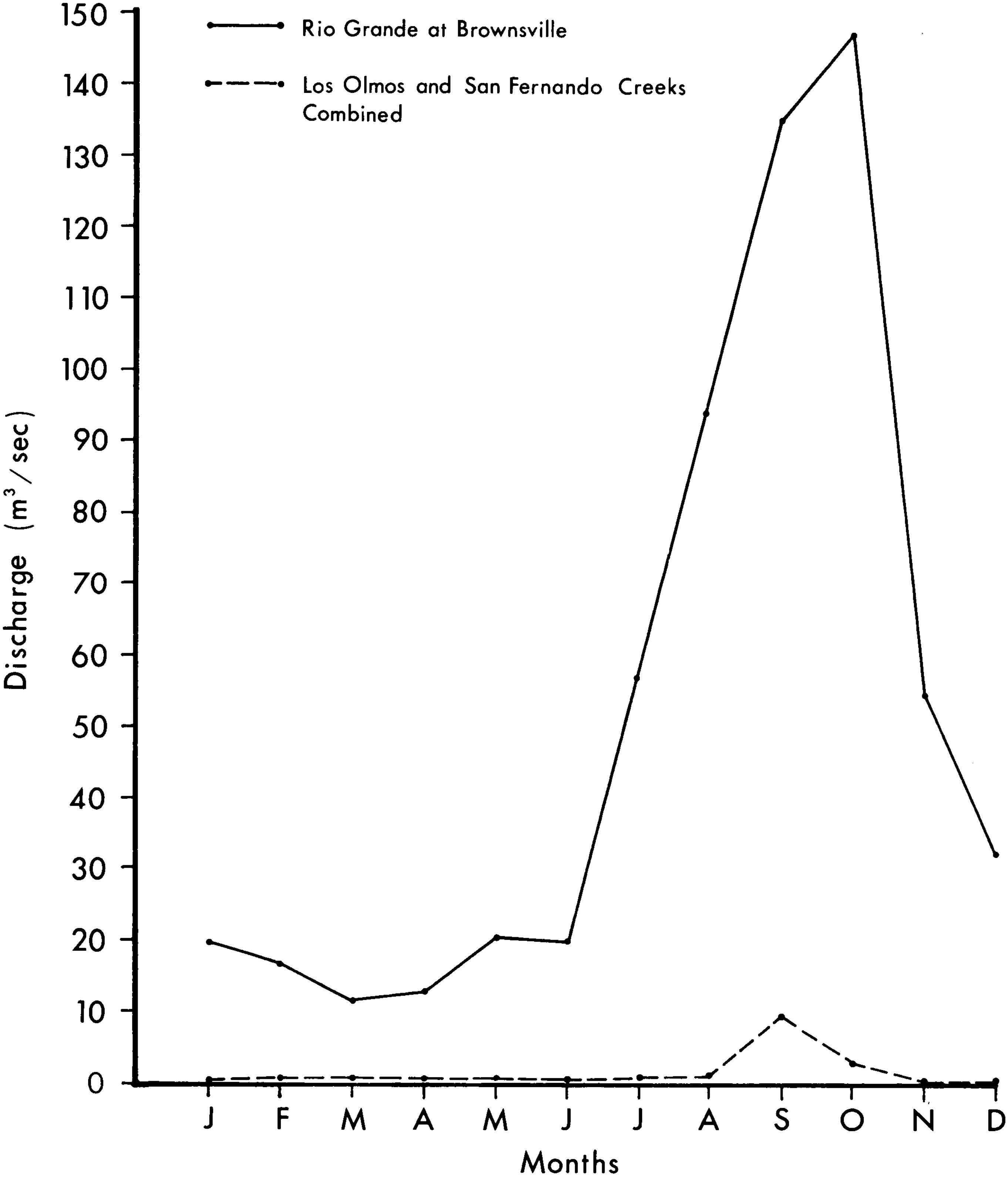

Figure 6. Mean daily discharge by months, October 1966-September 1976 (USGS 1967-1976a).

decline in some wells from 1948 to 1958, but measurements were made during a dry period when rapid conversion to groundwater was taking place.

In the northern part of the Laguna Madre study area, where no major surface flow occurs, ground reservoirs supply most of the water. Agricultural and industrial use is markedly less than in the south where these activities are more concentrated. Municipalities are the major users of groundwater in the Kingsville area (Shafer and Baker 1973). Despite the north's smaller demand for water, its dependence on groundwater has led to a maximum of a 60-m piezometric decline near Kingsville between 1932 and 1969 (Shafer and Baker 1973). Apparently, this relatively large decline has not caused measurable surface subsidence (Brown et al. 1977).

Much of the groundwater either evaporates or transpires in the agricultural fields, holding ponds, etc. A portion of the supply used for municipal and industrial purposes is returned to the system as surface flow. While the total volume of this return flow is difficult to ascertain, we must assume it is significant since the volume of natural runoff is often near zero over much of the area. Conceptually then, the quality of this return water will have a considerable impact on the quality of the total upland water input. In other words, given the same input of point source and non-point source discharges, the impact on overall surface water quality is likely to be more adverse in the Laguna Madre system than in a more humid system like Galveston Bay.

4.5 WATER QUALITY

The principal factors affecting water quality in any estuarine system are the physical and hydrologic characteristics of the watershed and man's activities in that area. The Laguna Madre system has a low population density concentrated into a few areas, with agriculture as the dominant land use. Since surface water is at a premium, man has done much to modify local drainage for his water needs.

The available water quality data are too fragmentary for a detailed temporal and areal evaluation. The U.S. Geological Survey (USGS) and the USGS in cooperation with the International Boundary and Water Commission (IBWC) monitor various parameters of major streamflow. In the Laguna Madre system, this is mainly restricted to the Rio Grande, which primarily discharges into the Gulf of Mexico. During times of flood a variable portion of the flow is diverted, some emptying into the Laguna Madre. The Texas Department of Water Resources (TDWR) monitors the coastal basins' water quality. While TDWR's spatial coverage is adequate, there is no periodicity in the sampling and the total number of samples is small. These data, combined with a few ecological surveys sponsored by the Texas Parks and Wildlife Department (TPWD), are the basis of an estimate of water quality.

Total phosporus (P) is used here as a general indicator of nutrient load. While nitrogen (N) is considered to be a critical limiting nutrient in the coastal marine environment (Ryther and Dunstan 1971), N and P are usually found in equal amounts in most pollutants (Gosselink et al. 1979). Using the data of Hahl and Ratzlaff (1970, 1972, 1973), the P loading rates into Baffin Bay and into Laguna Madre from Port Mansfield south are excessive, based on the guidelines of Shannon and Brezonik (1971). The Arroyo Colorado is consistently the worst example with concentrations of P in excess of 3 g/m^3 in areas above tidal influence, reducing to approximately 0.6 g/m^3 at its mouth. Unfortunately, nearly all measurements are taken during nonflood periods. Discharge is not routinely monitored at the Arroyo Colorado, making annual average loading rates difficult to assess. In Baffin Bay, where discharge data are more readily available, total P is estimated at 1.3 x 10^8 g/yr, with an estimated loading rate of 0.51 $g/m^3/yr$. Shannon and Brezonik (1971) considered values in excess of 0.22 $g/m^3/yr$ as dangerous and values <0.12 $g/m^3/yr$ as permissible. These guidelines do not take into account the flushing rate of the water body, volume of the water body, past history of loading rates, or the ability of the sediments to retain nutrients (i.e., estuarine systems can generally withstand higher loading rates than lacustrine systems).

The data of Hahl and Ratzlaff (1970, 1972, 1973) showed that P concentrations quickly diminish in the Laguna Madre system, with concentrations in the 0.03-0.06 g/m^3 range throughout most of the area. No data are available on the retention of P in the bottom sediments, nutrient exchange in the grassbeds, or the flow of nutrients through the passes.

In summary, while loading rates are high in terms of concentrations, the total volume of inflow is sufficiently low to result in overall low loading rates. At present, the Arroyo Colorado appears to be the only excessive loading area which may have a detrimental impact on water quality.

Dissolved oxygen (DO) concentrations in Laguna Madre and Baffin Bay average 6.5 to 7.5 mg/liter at the surface (Hahl and Ratzlaff 1970, 1972, 1973). Values are typically near or above saturation levels. Shallow depths and wind-induced mixing result in a vertical uniformity of DO concentrations. In the comparatively deep artificial channels, stratification occurs; but values tend to remain above 5 mg/liter at depths of approximately 10 m. Two notable exceptions are the upper reaches of the Brownsville Ship Channel and the entire Arroyo Colorado where concentrations frequently reach zero a few meters below the surface.

Martinez (1970) examined certain aspects of DO in Laguna Madre. As expected, DO was found to be inversely related to temperature and salinity. On a seasonal basis, DO peaked in January, with lowest values (semimonthly sampling) recorded in October. The relatively few diurnal samples show that DO levels are lowest before sunrise and then rise rapidly for a short time. Further increases or decreases depend on stage of tide, land-sea breeze effect, and change in water temperature in addition to daylight.

Water temperature is an important hydrographic variable; and because of the relative ease and accuracy of measurement, there is a considerable amount of data for the area. A seasonal pattern is evident, with a rapid response of water to changing air temperature because of the relative shallowness and poor circulation in the area. Simmons (1957), examining the 1952-55 period, and Martinez (1970), examining the 1969-70 period, found that the maximum monthly mean temperature (approximately 31° C) in Upper Laguna Madre occurred in August, and the more variable minimum monthly mean temperature (9.9° to 14° C) occurred any time from November through February. Martinez (1970) found temperatures in Lower Laguna Madre varied less seasonally, undoubtedly another effect of the Port Mansfield Pass opening and the GIWW construction (discussed previously in this chapter).

Point source discharges, mainly municipal and industrial outfalls, are concentrated in the southern part of Lower Laguna Madre. The Texas Water Quality Board routinely gathers these data. Diener (1975) reported these discharges and locations for the 1967-69 period. Some effects on the biota of the cumulative discharge from several of these sources were examined by Bryan (1971). The Arroyo Colorado receives the outfall of several of these point sources, as well as nonpoint source effluents from the intensive agricultural lands of the lower Rio Grande floodplain. The Arroyo Colorado is a natural distributary of the Rio Grande which has been straightened and deepened by man. Its use as a natural channel for carrying Rio Grande floodwaters has been greatly reduced since dam construction along the main river (Breuer 1962). As a consequence, flushing of the Arroyo occurs only sporadically when heavy rains persist over the local drainage area. The Arroyo Colorado Delta in Laguna Madre has been well documented (Breuer 1962; Simmons and Breuer 1962; Bryan 1971) as an important nursery area for red drum (Sciaenops ocellatus), menhaden (Brevoortia spp.), spotted seatrout (Cynoscion nebulosus), blue crab (Callinectes sapidus), shrimp (Penaeus spp.), and in the past tarpon (Megalops atlantica). The Texas Parks and Wildlife Department routinely samples the area for species occurrence and life stages as part of their annual coastal fisheries projects. The recent picture is clear: due to its brackish water conditions the area is a preferred habitat for estuarine-dependent species. Excessively low DO concentrations (zero in many instances) and a high level of DDT, Dieldrin, and Endrin contamination (100% of the samples contained an average of 0.294 ppm DDT) result in massive fish mortalities (Bryan 1971) and prohibition of oyster harvest (Childress 1967).

Turbidity is a water quality variable for which there are only fragmentary data from the area. Turbidity data collected by Martinez (1975) indicated that levels in Upper and Lower Laguna Madre were among the lowest along the Texas coast. Turbidity is particularly important in this system because of its effect on submerged aquatic vegetation. Dredging activities are known to result in the loss of submerged grassbeds for a considerable distance beyond the direct activity (e.g., Breuer 1962). In general, turbidity is low in the Laguna Madre study area. Data gathered in 1979 (Pulich 1980) revealed that transmittance of light in Upper Laguna Madre averaged 45% of surface light at a depth of 50 cm. This compares favorably with a 27% transmittance at the same depth in Redfish Bay (Copano-Aransas study area).

In summary, most of the Laguna Madre and Baffin Bay area have relatively good water quality. In the southern end of Lower Laguna Madre, where aquatic and terrestrial habitats are the most diverse, water quality is often poor. Still, the area probably remains the most productive finfish fishery in the Texas Barrier Islands Region.

5.0 BIOLOGY

5.1 ESTUARINE COMMUNITY

Because of hypersaline conditions combined with the unstable nature of other physical parameters, the Laguna Madre estuarine community is characterized by low species diversity, primarily pioneer or colonizing species (Carpelan 1967; Hedgpeth 1967; Pulich 1980). Competition is more with the physical environment than between species because of the overriding influence of salinity (Pulich 1980). As in many hypersaline lagoons, the few species present occur in high numbers (Pulich 1980). Creel and commercial fish catch data gathered by TPWD and National Marine Fisheries Service (NMFS) give evidence for few species with high populations (see Section 5.1.2). In a system such as this, food chains are simple and conversion of plant production to fish production is more efficient than in systems with more complex trophic relationships (Carpelan 1967). Hellier (1962) found this conversion rate to be 0.074% (on a dry weight basis) in Laguna Madre, a rate which rivals those calculated for offshore fishing banks or for coral reefs (Pulich 1980). The high conversion rate is attributed by Pulich to the low species diversity which abbreviates the food chain.

Compared with other estuaries in the Texas Barrier Islands Region, this system does not receive large quantities of nutrients from riverine inflow. The high production rates indicate efficient nutrient recycling, but the processes involved in the recycling remain largely undefined. Pulich et al. (1976, cited by Pulich 1980) postulated that the low flushing rate allows the retention of detritus within the system, with no major gain or loss of nutrients. Pulich stated that perturbations which increase flushing ultimately may actually decrease production due to a net loss of nutrients.

The estuarine community, as defined here, is composed of three basic habitats: (1) aquatic or lagoon, (2) wind-tidal flat, and (3) emergent wetland. These habitat distinctions are based on the substantial differences among the community assemblages yet their interactions are substantial, with water flux being the common denominator. The following faunal and floral descriptions within the estuarine community are organized on the basis of the distinctions between these habitats.

5.1.1 Vegetation

The most conspicuous flora of the aquatic habitat are the subaqueous spermatophytes, commonly called seagrasses (because of their grasslike appearance). The four dominant species in descending abundance are shoal grass (*Halodule beaudettei* formerly *Diplanthera wrightii*), widgeongrass (*Ruppia maritima*), manatee grass (*Cymodocea filiformis*), and turtle grass (*Thalassia testudinum*). The spatial distribution of these species is not uniform. Upper Laguna Madre is dominanted by shoal grass, although substantial widgeongrass beds appear when salinities are reduced to 45 $^0/oo$ or below (Simmons 1957). In Lower Laguna Madre, where the salinity is closer to that of normal seawater, all four species are found. Manatee grass is locally abundant near Brazos Santiago Pass (Breuer 1962) and occurs as far north as Port Mansfield (Pulich 1980). Turtle grass is restricted in its distribution to the Port Isabel area (Pulich 1980). None of the seagrasses normally covers any sizable area in the Baffin Bay complex probably because of its higher turbidity and salinity (Breuer 1957). During wet cycles extensive shoal grass beds occur in Baffin Bay (E. G. Simmons, Texas Parks and Wildlife Department, Austin, Texas; pers. comm. 1980).

New seagrass growth in the area starts generally in March; die-back begins during August and September, coinciding with high temperatures and salinity (Hellier 1962; Hedgpeth 1967). Annual standing crop of shoal grass in Laguna Madre has been estimated at 250 to 600 g dry wt/m^2 (McMahan 1968;

Merkord 1978, cited by Pulich 1980; Armstrong and Gordon 1979, cited by Ward et al. 1979). Midsummer standing crop for turtle grass and manatee grass was estimated by Merkord (1978, cited by Pulich 1980) in Lower Laguna Madre at 400-700 g dry wt/m^2, and 400-800 g dry wt/m^2, respectively. Circe (1979, cited by Pulich 1980) found that 70% of the biomass of shoal grass was roots and rhizomes in summer and 80% in winter.

Two years of data collected by Hellier (1962) and four years of data collected by Odum and Wilson (1962) indicated that gross photosynthesis of the grassbeds exceeds 4,000 g/m^2/yr (expressed as oxygen).[1] McRoy and McMillan (1977) estimated annual production of turtle grass along the south Texas coast to be 1,000 g C/m^2. Yearly variation does not appear large although the species composition varies considerably, depending primarily on salinity (Odum and Wilson 1962). Seasonal gross photosynthesis varies from approximately 0.5 g/m^2/day (expressed as oxygen) during winter to 20 g/m^2/day during summer (Odum and Wilson 1962). Odum and Wilson (1962) found that the most important factor affecting maximum summer production rates was water clarity, with Lower Laguna Madre generally having the highest rates of production and lowest turbidity. In several areas close to upland run-off, respiration often exceeded photosynthesis; Baffin Bay contained the highest percentage of stations where this happened.

Submerged grasses are an important habitat for black drum (Pogonias cromis), spotted seatrout, and several other fish species in Laguna Madre (Simmons 1957). Hellier (1962) provided some empirical evidence indicating that the seasonal production and biomass of fish in Laguna Madre coincide with seagrass production with no lag factor. The importance of these grasses as primarily an indirect food source for finfish can be inferred. Fry and Parker (1979) provided evidence that Laguna Madre trophic relationships are primarily based on benthic plants rather than phytoplankton. McMahan (1970) analyzed the importance of these grasses as a direct food source for waterfowl in the area (see Section 5.1.2).

Given the relationship between seagrasses and turbidity, dredging can substantially perturb this community. For example, in the South Bay area dredging indirectly resulted in the mortality of a large area of submerged grass beds (Breuer 1962). During dredging, high turbidity caused mortalities. After completion, the finer-grained sediments which settled out of suspension were easily resuspended, sustaining high turbidity levels and preventing recolonization. Pulich (1980) noted that change in species composition of seagrasses in Lower Laguna Madre may result from increased turbidity and nutrients. Herbicides combined with high turbidity may be responsible for the recent decline in seagrass beds on Lower Laguna Madre (D. White, U.S. Fish and Wildlife Service, Victoria, Texas; pers. comm. 1980).

Algal mats are the dominant vegetation in the wind-tidal flat habitat. Algal blooms occur frequently when favorable conditions prevail. During periods of nonflood these flats are essentially devoid of vegetation. The alternating drying and flooding of these flats result in a vertical section of numerous lenses of algae interspersed with sand and clay (Brown et al. 1977). The most common species is the blue-green alga, Lyngbya confervoides (Sorenson

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[1] 1.07 g O_2 = 1.0 g biomass dry wt; 0.5 g C = 1.0 g biomass dry wt.

and Conover 1962). Hildebrand (1958 cited by Hedgpeth 1967) found this same species dominant in the Laguna Madre de Tamaulipas along the neighboring Mexican coast. Pulich (1980) estimated that nitrogen fixation by these mats is approximately 50 kg N-fixed/ha/yr. Maximum growth occurs from early May to late June and minimum growth occurs in November to December (Conover 1964). No production estimates are available for the area.

The floating algae represent a second group of algae prevalent in the area. Species present vary seasonally. The green alga (Acetabularia crenulata) is abundant during warm months (Simmons 1957; Breuer 1962; Pulich 1980), and a red alga (Chondria sp.) is abundant during winter. Generally these species cannot withstand salinities exceeding 50 °/oo (Pulich 1980).

The seaward edge of the emergent wetland habitat borders the hypersaline open water lagoon or the wind-tidal flats. Consistent with these habitats, species diversity is low in the emergent wetlands. The area encompassed by tidal marsh is small, restricted primarily to the southwestern portion of Lower Laguna Madre. Because of the hypersaline waters and the arid climate, the species composition differs from that in the marshes of the other study areas. The most seaward community (lowest in elevation) comprises succulent halophytes with maritime saltwort (Batis maritima), Bigelow glasswort (Salicornia bigelovii), salicornia (S. perennis) and seablite (Suaeda conferta and S. linearis) being dominant (Johnston 1955). In a few areas where a higher percentage of clay is present, black mangrove (Avicennia nitida) is present in shrub form (Johnston 1955). The community is spreading in spite of freezes in the early 1950's (D. Woodard, U.S. Fish and Wildlife Service, Office of Biological Services, Washington, D.C.; pers. comm. 1980). At a slightly higher elevation is a herbaceous community with sea-oxeye (Borrichia frutescens), shoregrass (Monanthochloe littoralis), and maritime saltwort as codominants (Johnston 1955). Above this community, in sand and clayey soils, sacahuista (Spartina spartinae) is usually the sole dominant (Johnston 1955).

5.1.2 Fauna

Mammals. Mammals are uncommon in this estuarine community with the exception of the bottlenose dolphin (Tursiops truncatus). This species feeds mainly on finfish (Davis 1974). All fish common in Laguna Madre have been found in stomach contents of this dolphin, with the striped mullet (Mugil cephalus) constituting the bulk of the diet (Davis 1974).

Wetland furbearers and other mammals are absent from the emergent wetland habitat because of the lack of preferred foods, small area of preferred habitat, and hypersaline conditions (Hall and Kelson 1959; Davis 1974). No mammals are commonly associated with the wind-tidal flat habitat.

Birds. Of the approximately 650 bird species in the United States, 380 occur along the Texas coastal zone (Lay et al. 1978). Due to their habits many of these species are a part of more than one community. Table 2 provides population estimates and trends for colonial fish-eating birds in the Laguna Madre area. The cattle egret (Bubulcus ibis), although not a fish-eating species, is listed because it is a common colonial egret in the area. Birds like the Louisiana heron (Hydranassa tricolor) and the reddish egret (Dichromanassa rufescens) depend heavily on the estuarine community, whereas the terns are also part of the beach and marine community. Many egrets and herons may be found considerable distances inland.

Table 2. Pairs of colonial fish-eating birds, Laguna Madre System (adapted from Blacklock et al. 1978).

Scientific name	Common name	Year				Historical population trend for all of Texas
		1973	1974	1975	1976	
Pelecanus erythrorhynchos	White pelican	225	350	331	320	Only coastal nesting in U.S.; stable
Ardea herodias	Great blue heron	254	370	311	386	Stable
Florida caerulea	Little blue heron	1	50	150	141	Primarily inland; stable
Bubulcus ibis	Cattle egret	437	953	1,372	1,887	First arrived 1954; rapid increase
Dichromanassa rufescens	Reddish egret	270	464	717	737	Long-term decline but stable since 1960's
Casmerodius albus	Great egret	72	166	17	57	1910, near extinction; currently stable
Leucophoyx thula	Snowy egret	532	1,494	1,122	796	1910, near extinction; currently stable
Hydranassa tricolor	Louisiana heron	890	1,732	1,777	2,021	Rapid increase during past 10 years
Nycticorax nycticorax	Black-crowned night heron	52	200	14	327	Insufficient data
Nyctanassa violacea	Yellow-crowned night heron	0	0	0	10	Insufficient data
Plegadis chihi	White-faced ibis	17	428	624	643	Stable since 1974 decline

Continued

Table 2. Concluded.

Scientific name	Common name	Year 1973	1974	1975	1976	Historical population trend for all of Texas
Eudocimus albus	White ibis	110	300	16	293	Stable to increasing during last 20 years
Ajaia ajaja	Roseate spoonbill	105	208	332	161	1910 near extinction; currently stable
Larus atricilla	Laughing gull	13,114	5,512	14,252	18,185	Stable
Gelochelidon nilotica	Gull-billed tern	1,790	400	953	674	Stable to decreasing
Sterna forsteri	Forster's tern	132	105	110	50	Slow decline since 1940's
S. fuscata	Sooty tern	11	1	9	12	Always small
S. albifrons	Least tern	1,755	6	495	91	Rapid decrease
S. maxima	Royal tern	5,127	131	1,968	3,105	Always abundant
S. sandvicensis	Sandwich tern	3,907	0	3,530	5,186	Stable below San Antonio Bay
S. caspia	Caspian tern	90	97	299	133	Slow decline
Rynchops nigra	Black skimmer	4,452	1,539	2,410	1,540	Insufficient data

The Laguna Madre study area has long supported a large concentration of waterfowl. Redhead ducks (Aythya americana) particularily prefer the area; 78% of the world population winters in Laguna Madre (Weller 1964). Heit (1948) estimated the Laguna Madre population to be 280,000 in January 1948, and McMahan (1967) located some 490,000 redheads in the area during December 1966. McMahan (1970) found that seagrasses constituted 94% (by volume) of the diet of the Laguna Madre redheads. Of greatest importance was shoal grass, accounting for 84% of the total mass.

McMahan (1970) also found that seagrasses were 92% of the diet of pintail (Anas acuta) but only 22% of the diet of lesser scaup (Aythya affinis), which consumed mostly animal matter.

Reptiles and amphibians. No reptiles or amphibians are common in the estuarine community. Several sea turtle species have been reported foraging in the area (see Section 5.6.4).

Fish and shellfish. The most important sport and commercial species in the inshore area are the red drum, spotted seatrout, and black drum. Breuer (1975) reported that of the total monitored commercial catch in Lower Laguna Madre 43.3% were red drum, 39.7% spotted seatrout, and 11.6% black drum.

The black drum feeds mainly on bivalves (e.g., Anomalocardia cuneimeris), which are concentrated in seagrass beds (Simmons and Breuer 1962). The black drum's feeding uproots vegetation and damages grassbeds. Mulinia lateralis, another pelecypod, formerly the preferred food of the black drum (Parker 1959; Hedgpeth 1967), no longer prevails in the area except in Lower Laguna Madre's southern end (Simmons and Breuer 1962).

Spawning of the black drum occurs in the bays, passes, and less frequently, in the gulf, with 90% of the known spawning taking place in February or March (Simmons and Breuer 1962). Simmons and Breuer (1962) estimated that black drum reach a length of 400-430 mm in 3 years; growth rate beyond that length is approximately 50 mm/yr in Laguna Madre.

The euryhaline black drum is found in salinities as high as 80 ^{o}/oo and as low as 6 ^{o}/oo in Laguna Madre, with a preferred 25-50 ^{o}/oo range (Simmons and Breuer 1962). The species is in the area year round with minimal emigration except during times of adverse conditions such as cold temperatures and lack of food (Simmons and Breuer 1962).

The Texas catch data demonstrate that Laguna Madre is a preferred habitat for the black drum. Before a concerted effort by TPWD to depress local populations (because of their effect on seagrass beds), 53% of the total State catch of black drum for a 22-year period came from Laguna Madre (Simmons and Breuer 1962). More recent reports (e.g., Breuer 1975) indicated that the area remains the largest black drum producer in the State although the local catch has declined. Due to the continued downward trend, TPWD no longer encourages over exploitation of the black drum (E. G. Simmons, Texas Parks and Wildlife Department, Austin, Texas; pers. comm. 1980).

Red drum (also known as redfish or channel bass) is prized by sport and commercial fishermen. The Laguna Madre area consistently produces over 60% of the total annual Texas inshore catch (Simmons and Breuer 1962; Diener 1975; NMFS, no date). More red drum are taken in the area by commercial fisherman than sport anglers. In Lower Laguna Madre the commercial catch was 3.7 X 10^5kg and the sport harvest was 9.4 X 10^3kg from September 1975 through August 1976 (Breuer et al. 1977). In Upper Laguna Madre sportsmen harvested 3.5 X 10^4kg, and commercial fishermen took in 1.7 X 10^5kg from September 1974 through August 1975. In terms of the percentage of total area catch, red drum accounted for only 7.2% of the Upper Laguna Madre sport harvest, but accounted for 34.8% of the commercial harvest (Heffernan et al. 1977). The same pattern was evident in Lower Laguna Madre where red drum accounted for 2.4% and 42.3% of the sport and commercial harvest, respectively (Breuer et al. 1977).

Red drum usually spawn in the nearshore open gulf and near the tidal passes from late summer through early fall although winter spawning is also suspected for this area (Simmons and Breuer 1962). The juveniles are aided by currents as they move into Laguna Madre in late winter (Figure 7) when they aggregate in grassy bottoms with little wave action and current movement (Pearson 1928; Simmons and Breuer 1962; Breuer 1975). Growth is rapid. Tag returns for the area (Simmons and Breuer 1962) indicated that mean growth is 325 mm at the end of the first year, a total length of 540 mm at the end of the second, and 760 mm at the end of the third year. These values are in general agreement with other studies in neighboring areas (Pearson 1928; Gunter 1945; Miles 1950).

Young red drum subsist primarily on copepods, amphipods, and palaemonetid shrimp. Adults' diets vary more (Simmons and Breuer 1962). In Laguna Madre, the adult diet consists mainly of small crabs, with the mud crab (*Neopanope texana*) and the blue crab being the most common. Other organisms, however, like small mullet, sheepshead minnows (*Cyprinodon variegatus*), and shrimp (*Penaeus* spp.) constitute a significant part of the diet (Simmons and Breuer 1962). This analysis agrees with stomach analysis studies conducted in neighboring estuaries by Miles (1949, cited by Simmons and Breuer 1962), Knapp (1949, cited by Simmons and Breuer 1962), and Gunter (1945).

Red drum movements, more pronounced than those of black drum, are largely associated with spawning (Pearson 1928). Pearson (1928) discussed the rapid return of red drum to the lagoon and bays in the spring and the less noticeable migration through the passes to the gulf in the fall. Simmons and Breuer (1962) generally agreed although they believed the movements occur over a relatively short period and do not involve the population en masse. Within the lagoon, movements are generally restricted, approaching that in a closed system (Simmons and Breuer 1962). While red drum are euryhaline (Pearson 1928), movements out of Upper Laguna Madre have been documented when salinities exceed 50 ^{o}/oo (Simmons 1957). Extremes and sudden changes in temperatures cause movements to deeper waters within the lagoon and towards the passes (Simmons and Breuer 1962) and can lead to mass mortalities (Gunter and Hildebrand 1951, cited by Diener 1975). The recovery of depleted populations appears to be much slower for red drum than black drum (Simmons and Breuer 1962).

One might conclude that Lower Laguna Madre provides a suitable habitat for red dum within this estuarine community because hypersalinity and temperature extremes are mitigated, producing conditions favorable to red drum and

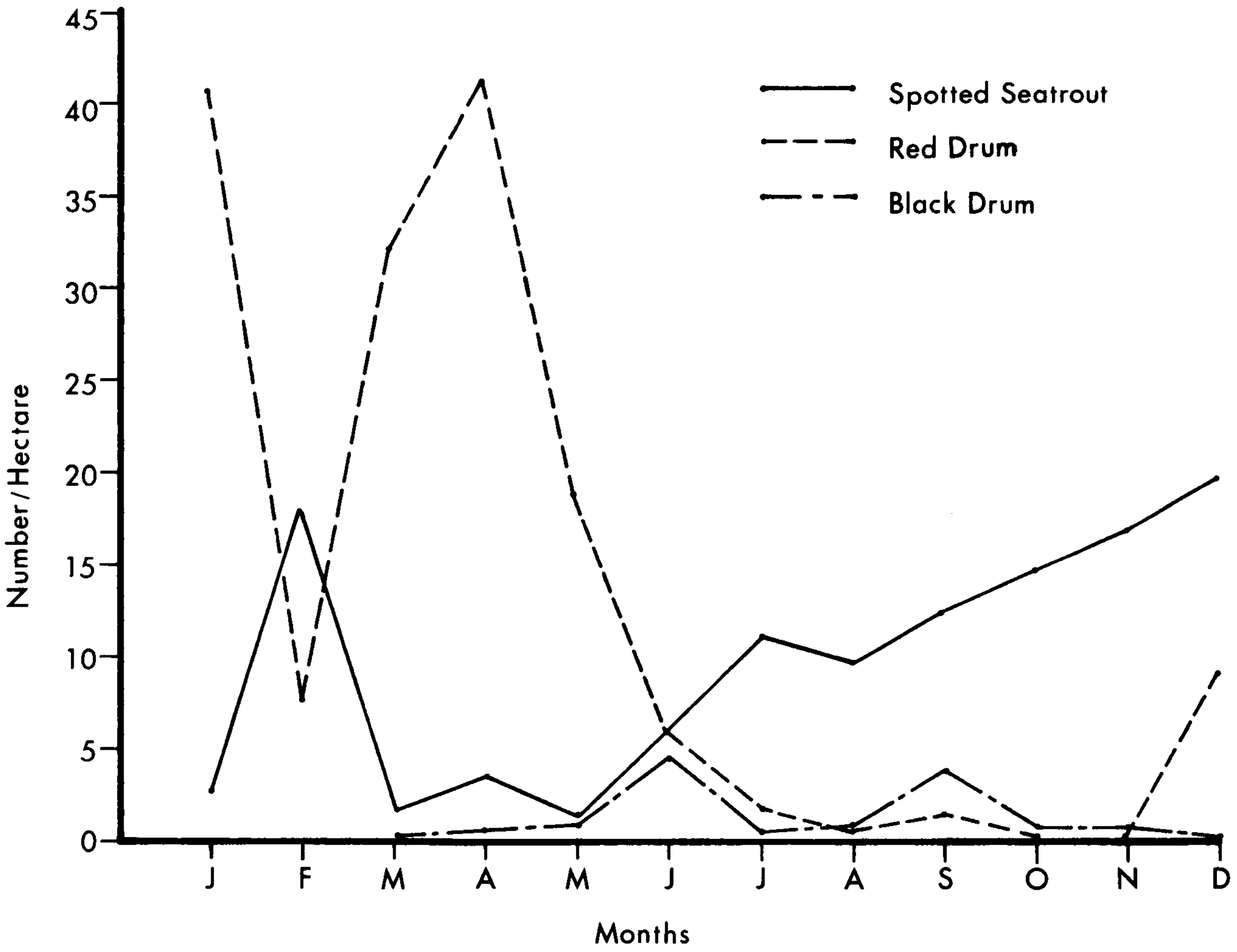

Figure 7. Mean seasonal density of juvenile spotted seatrout, red drum, and black drum in Upper Laguna Madre, 1970-1975 (Breuer 1975).

its primary food. Both Upper Laguna Madre and Baffin Bay, however, support a large and perhaps a greater population (Breuer 1975). Obviously, information voids exist concerning the ecology of this locally important and abundant commercial and sport species.

The spotted seatrout is important commercially and as a sport fish. In 1968 some 38% of the Texas inshore commercial catch of this species was harvested from Laguna Madre (Diener 1975). Breuer (1975), however, reported a general decline in juvenile and adult populations in the lagoon from the late 1960's through the mid-1970's. The reasons for the decline and whether or not a trend has been established were not analyzed.

In Laguna Madre the spotted seatrout's migration behavior is similar to that documented throughout its range (Breuer 1957, 1962; Simmons 1957). Typically, the species leaves the lagoon for deeper gulf waters with the approach of cold weather and returns to spawn within the lagoon in the spring (Pearson 1928). The spawning season typically extends throughout the period the trout is within the inshore waters (Pearson 1928), and the juveniles are present throughout much of the year (Breuer 1975) (Figure 7).

The spotted seatrout prefers the seagrass habitat in the lagoon for spawning and feeding (Pearson 1928; Breuer 1962). While shrimp (mainly *Penaeus* spp.) are considered the most important food for young trout by Pearson (1928), some changes in feeding habits have apparently occurred in Lower Laguna Madre. Breuer (1962) stated that since 1955 small trout have shifted from feeding on brown shrimp (*P. aztecus*) to a nocturnal polychaete (*Nereis pelagica occidentalis*). Thus, the shift also represents a change from day to night feeding. No explanation for this shift is provided by Breuer (1962) although apparently it was not due to a shortage of brown shrimp. In Baffin Bay Breuer (1957) found that brown shrimp are abundant only for a short time in spring and early summer, when young trout feed mainly on tidewater silverside (*Menidia beryllina*). In the Port Isabel area, larger trout (1.5 kg) feed on a variety of fish, with striped mullet, sheepshead minnow, pigfish (*Orthopristis chrysoptera*), and smaller trout being representative prey items.

Warm temperatures and high salinity do not appear to adversely affect adult seatrout (Simmons 1957). In fact, Gunter (1961a, cited by Hedgpeth 1967; Gunter 1961b) reported a positive correlation between seatrout size and salinity. Simmons (1957) found that specimens weighing 4-5 kg were relatively common in Upper Laguna Madre, and Breuer (1962) obtained numerous specimens between 4 and 6 kg in Lower Laguna Madre. With these sizes, it is easy to understand the area's popularity with sport fishermen.

The commercial oyster, *Crassostrea virginica*, spawns and grows in harvestable quantities in South Bay and near the Queen Isabella Causeway (Breuer 1962). This species' presence in Lower Laguna Madre is something of an anomaly because turbidity, salinity, and temperature values frequently exceed generally accepted tolerance levels (Breuer 1962). This situation led Breuer (1962) to postulate the possibility of a new physiological race of *C. virginica* in Texas. Harvest occurs year round but is greatest during the summer when waters in other Texas bays are closed. Several experimental plantings to increase production have had disappointing results (Breuer 1962; Diener 1975; Brown et al. 1977). Only some 1,200 kg of oysters were harvested in 1968, less than 0.1% of the State total (Diener 1975).

Several other species are taken commercially in Laguna Madre and Baffin Bay, but generally represent a minor portion of the State catch. Shellfish include the following species: blue crabs and brown, pink (*P. duorarum*), and white shrimp (*P. setiferus*). Relatively common blue crabs, brown shrimp, and white shrimp do not generally reach commercial size but are an important food source to larger finfish (Breuer 1962). Among the finfish, sheepshead (*Archosargus probatocephalus*), flounder (undifferentiated), pompano (*Trachinotus* sp.), and Atlantic croaker (*Micropogonias undulatus*) are taken commercially (Diener 1975). Breuer (1957, 1962) and Simmons (1957) provided a more complete listing of species and comments on relative abundance.

While we have emphasized the commercial and sport species, it should be noted that most of the fish biomass is concentrated in forage species. Hellier (1962) found that five species: pinfish (*Lagodon rhomboides*), striped mullet, spot (*Leiostomus xanthurus*), bay anchovy (*Anchoa mitchilli*), and tidewater silverside - represented 70% of the total sampled biomass and made up a major part of the diet of the commercially important species.

In summary, the number of species in the estuarine community in the Laguna Madre complex is low, but populations are generally large. This trend is reflected in the catch data, which for several species represent a disproportionately large number of the total State landings. Correspondingly, several species commercially important in Texas are rare in Laguna Madre. The bulk of the producers is turbidity-limited, and there is good reason to consider turbidity as a limiting factor for the entire community.

5.2 BARRIER ISLAND COMMUNITY

One outstanding feature of the Laguna Madre system is the nearly continuous barrier island known as Padre Island. The processes which have led to its formation are discussed elsewhere (see Section 2.1 and the Corpus Christi synthesis). In brief, the island is highly dynamic, its form controlled by processes which move the offshore sand supply to the island, and then by eolian transport, across the island and into the lagoon. Anchored vegetation inhibits saltation (the primary mechanism of eolian sand transport) and promotes dune formation. The increasing aridity as one moves south on the island is considered by Brown et al. (1977) as a major reason for decreasing vegetative cover and hence, dune formation along the island's lower end. Hurricane perturbations and animal overgrazing may also be important factors (D. Woodard, U.S. Fish and Wildlife Service, Office of Biological Services, Washington, D.C.; pers. comm. 1980).

Padre Island's biological importance lies more in its function as a controlling influence on surroundings areas rather than its intrinsic productivity and species diversity. The island controls the exchange of water between Laguna Madre and the gulf, absorbs much of the energy from storm waves (which provide nutrients), and is perceived by many as desirable for man's habitation (the subject of much concern and debate).

5.2.1 Vegetation

Vegetation exists in well-defined zones determined in general by topography (Judd et al. 1977). A horizontal transect across Padre Island (Figure 8)

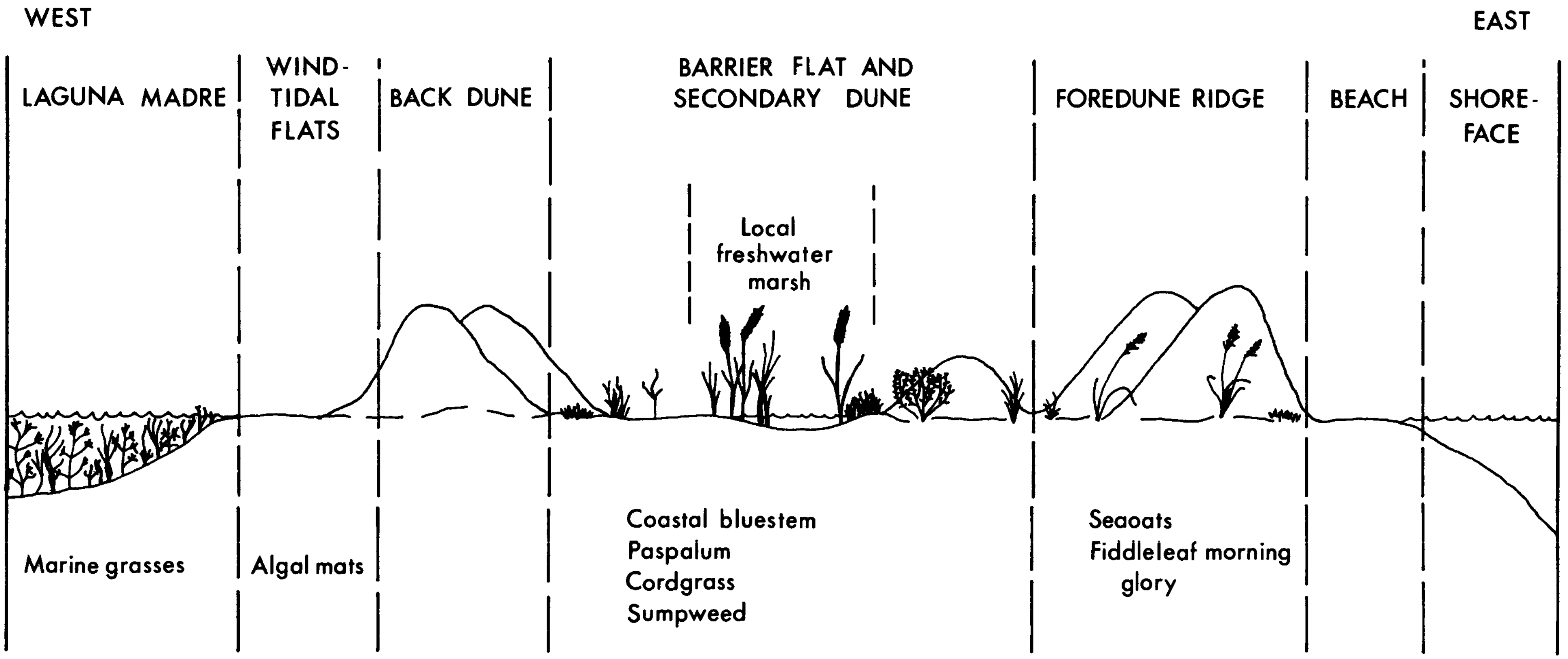

Figure 8. Schematic profile of Padre Island (after Brown et al. 1977; Judd et al. 1977).

passes through four major zones: (1) beach, (2) foredunes, (3) secondary dunes and barrier flats, and (4) back dunes (Brown et al. 1977; Judd et al. 1977). The beach is barren of vegetation although on its landward border it grades into embryonic dunes with sparse cover of sea oats (Uniola paniculata) and sea purslane (Sesuvium portulacastrum).

Foredunes, the largest dunes, are stabilized by sea oats and fiddleleaf morning glory (Ipomoea stolonifera). Dune formation on the southern end of the island is poor, making it highly susceptible to hurricane surge, which further diminishes protective vegetative cover. By 1968 this destructive cycle spurred the Gulf Universities Research Consortium to make experimental vegetative plantings to aid natural dune formation through sand trappings (Dahl and Woodard 1977). Bitter panicum (Panicum amarum), a native grass, was the main plant used because of its high survival rate and ease in handling. Bitter panicum, once common on Padre Island, declined because it is a preferred food of cattle and sheep. Since the removal of livestock in 1971, this grass has reappeared. The test plots of bitter panicum were well established and beginning to spread by 1973 (Dahl and Woodard 1977). Programs like this offer new hope for maintaining fragile dune systems.

Secondary dunes and barrier flats constitute an extensive environment on Padre Island. Throughout the length of the island, the composition of this zone varies from entirely dune to entirely flat. Because secondary dunes are smaller than their primary counterparts, they receive considerable protection from winds. Consequently, these dunes are often completely stabilized. Seacoast bluestem (Schizachyrium scoparium littoralis) is the dominant species in the secondary dune zone (Judd et al. 1977). Other common vegetative cover includes paspalum (Paspalum sp.), milkpea (Galactia sp.), cordgrass (Spartina sp.), and sumpweed (Iva sp.). Locally, ephemeral freshwater marsh assemblages may occur in swales; cattails (Typha spp.), rush (Juncus spp.), and bulrush (Scirpus sp.) are dominant in these marshes (Brown et al. 1977).

Along some sections of Padre Island, the barrier flats are bounded by back dunes, barren and shifting features that migrate when subjected to high, sustained winds. These dunes may be dispersed over the wind-tidal flats bordering Laguna Madre or may be deposited into the lagoon itself (Brown et al. 1977).

5.2.2 Fauna

Mammals. By far the most common mammals on the island are rodents. Ord's kangaroo rat (Dipodomys ordi) inhabits the shifting sands of Padre Island. The pioneer species establishes itself in disturbed areas along with pioneer vegetation. A burrower, the species spends daylight underground, protected from heat or cold. It ventures out only at night to feed on seeds, which supply its nutrient and water requirements (Davis 1974).

Other burrowers are the south Texas pocket gopher (Geomys personatus) and spotted ground squirrel (Spermophilus spilosoma), according to Davis (1974) and Selander et al. (1962). Both species feed primarily on green vegetation, with the gopher doing most of its foraging underground, seizing plants by the roots and pulling them into its burrow (Davis 1974).

The raccoon (Procyon lotor), white-tailed deer (Odocoileus virginianus) eastern cottontail (Sylvilagus floridanus), and coyote (Canis latrans) also inhabit Padre Island. In addition Selander et al. (1962) reported the California jackrabbit (Lepus californicus) on the island. Weathered remains of the nine-banded armadillo (Dasypus novemcinctus), and a skull, burrow, and tracks of the badger (Taxidea taxus) have been discovered by the same workers on a barrier island off Tamaulipas, Mexico, not more than 60 miles to the south. These mammals could probably inhabit the more northerly Padre Island as well.

Birds. See Section 5.1.2.

Reptiles and amphibians. The number of reptile species on Padre Island is low. The keeled earless lizard (Holbrookia propinqua propinqua) frequents the beach and foredunes whereas the Texas horned lizard (Phrynosoma cornutum) and prairie racerunner (Cnemidophorus sexlineatus viridis) are present on firmer soils (Conant 1975). Arboreal species are precluded from Padre Island due to the lack of trees.

According to Wright and Wright (1957), two common snakes on the island are the western diamondback rattlesnake (Crotalus atrox) and the western coachwhip (Masticophis flagellum testaceus). Diamondbacks, because of their size, toxicity, and pugnacious nature, are dangerous (see Section 5.5.2), and signs are posted on the beaches of Padre Island warning visitors of their presence in the dunes and barrier flats. Rodents are the main food items of the rattlesnake, but coachwhips feed primarily on lizards, insects, young birds, and snakes. The large size of the diamondback allows it to include rabbits in its diet.

The beaches of Padre Island have reportedly been sporadic nesting sites for the endangered Kemp's ridley turtle (Lepidochelys kempi) (Ogren 1977). Some nestings have occurred subsequent to attempts at stocking the island with eggs and young turtles from clutches in Tamaulipas, Mexico (Lund 1974, cited by National Fish and Wildlife Laboratory 1980). At present an international project, representing a concerted effort, is augmenting the faltering population of Kemp's ridley turtle.

Padre Island is also inhabited by at least one terrestrial turtle, the ornate box turtle (Terrapene ornata ornata). The habitat is ideal for the Texas tortoise (Copherus berlandieri), but its burrowing habits and the relative scarcity of its preferred food, prickly pear (Lonard et al. 1978), may be responsible for its absence; no information is available concerning the occurrence of Texas tortoise on Padre Island.

Amphibian species fare worse than reptiles on Padre Island, probably because of a shortage of freshwater and saline conditions. Other than intermittent freshwater ponds, amphibians have no breeding sites. The gulf coast toad (Bufo valliceps), Texas toad (B. speciosus), and Rio Grande leopard frog (Rana berlandieri) occur on Padre Island, but no data on their abundance are available (Conant 1975).

5.3 RIVERINE AND LACUSTRINE COMMUNITIES

Estuaries, by definition, are maintained in part by freshwater inflow. In many areas, such as in Louisiana, estuaries have been constructed by rivers and associated processes. The Texas Barrier Islands Region, however, has been primarily formed by other processes (see Section 2.1). In Laguna Madre, the Rio Grande and lesser streams can be regarded as having the role of a modifier in estuarine formation.

Site specific information pertaining to the riverine community in this area is sparse. The impacts of the riverine system are large and complex. We have presented the following material from other regions which is applicable to this portion of the study area.

5.3.1 Vegetation

Little of the primary production of phytoplankton is directly consumed in the riverine community and most of it dies (Reid 1961). In quiet waters most would settle to the bottom and become a food source for benthic consumers. Along the Rio Grande and lesser streams with sufficient velocities, organic matter remains suspended, flowing out into the estuary and gulf. Although solar energy is the key factor controlling the primary productivity, turbidity is also important here (Williams 1973). Nutrients (e.g., phosphates and nitrates) necessary for primary production are adsorbed onto suspended particles (Williams 1973; Gosselink et al. 1979). Sklar (1976) found that primary productivity is greater in turbid waters than in neighboring clear waters along the coast of Louisiana. Conceptually, there must be an optimum turbidity range because additional increases in turbidity reduce the zone of light penetration (Gosselink et al. 1979). Along the lower Rio Grande, dams are effective barriers to waterborne suspended solids, with the resulting reduction of nutrients downstream. Upstream of the dam, particles tend to fall out of suspension. One indirect effect of this reduction in turbidity has been increased numbers of the ringed kingfisher (Megaceryle torquata) in the Falcon Dam area. Oberholser et al. (1974) attributed this increase to the fact that the bird is able to see its prey in the water. Overall, however, productivity probably decreases downstream as the available nutrients are reduced, ultimately affecting the marshes along the delta of the estuarine community (Williams 1973; Rowe et al. 1975).

5.3.2 Fauna

Mammals. No aquatic mammals regularly inhabit the rivers of the Laguna Madre area. Rare sightings of the West Indian manatee (Trichechus manatus) have been reported (Davis 1974; Husar 1977). A few semi-aquatic mammals occur in the floodplain community. The distinction between the floodplain and riverine communities is a subject of some debate (see Cowardin et al. 1979) as these habitats are closely linked.

Birds. See Section 5.4.2.

Reptiles and amphibians. Reptiles and amphibians are discussed as part of the floodplain community. Four primarily aquatic turtles are included here. The pond slider (Chrysemys scripta) is a common turtle usually inhabiting the quieter waters like the oxbows along the lower Rio Grande. The pond slider has several color variations; some herpetologists give these forms individual subspecies status and others believe the variation is due only to age and sex difference. Carr (1952) listed this species as omnivorous although it may be more carnivorous when young. Brimley (1943, cited by Carr 1952) found that the species not only tolerated high pollution levels in North Carolina but also actually increased in abundance with increased organic nutrients in the water. The spiny softshell (*Trionyx spiniferus*) has a wide geographic range but is common in this area only near the Rio Grande (Carr 1952). This species is primarily omnivorous, with a preference for invertebrates (Carr 1952). The probable subspecies in the area is *T. s. emoryi* (Raun and Gehlbach 1972). The yellow mud turtle (*Kinosternon flavescens*) is also common in the Rio Grande and other freshwater streams of the area.

Neck (1978) discussed the possibility of marine turtles entering the Rio Grande and breeding on adjacent sand bars. His comments were based upon letters written by R. A. F. Penrose, a noted local geologist of the 1880's. Neck concluded that these were probably green turtles (*Chelonia mydas*), but the descriptions also resemble Kemp's ridley, a more likely candidate in light of migrations and nesting habits reported by Pritchard and Marquez (1973).

Fish. Bryan (1971) provided a species list as well as relative abundance data for the fish of the Arroyo Colorado. Formerly a distributary of the Rio Grande, the flow of the Arroyo Colorado has since been greatly reduced by man. In the past the most abundant fish were all of marine origin, many of them juveniles. Before the 1967 flood, surface salinity was approximately 19 ^{o}/oo with bottom salinity near 33 ^{o}/oo 40 km upstream from the mouth. One year after the flood, salinity was 2.8 ^{o}/oo and 27.8 ^{o}/oo at surface and bottom, respectively. At present, freshwater species are relatively uncommon at least as far as 40 km upstream, and the overall community is estuarine rather than riverine.

Detailed lists and distribution maps of fish species of the lower Rio Grande have been provided by Trevino (1955). While several marine specimens were reported, freshwater species were overwhelmingly dominant. Consistent with other biota of the area, several neotropical species were also present. Any changes occurring as a result of levee and dam construction (e.g., IBWC 1971, 1973) since 1955 are unknown.

Breuer (1970) examined the lower 45 km of the Rio Grande and found that the area was an important nursery for white shrimp and Atlantic croaker, indicating this section of the Rio Grande is primarily estuarine.

Fish species composition and population trends are unknown for the lesser streams flowing into the Baffin Bay complex. Breuer (1957) reported saltwater intrusion upstream for considerable distances during nonflood periods, and overall salinity is probably greater now than in the past.

A sampling of the fish (based on Knapp 1953; Trevino 1955; Hubbs 1972; E. G. Simmons, Texas Parks and Wildlife Department, Austin, Texas; pers. comm. 1980) includes primarily marine species that invade freshwater, like the river herring (*Alosa chrysochloris*), bay anchovy, tidewater silverside, spotted seatrout, red drum, southern flounder (*Paralichthys lethostigma*), and occasionally young tarpon. The alligator gar (*Lepisosteus spatula*) is a freshwater species that tolerates saline waters, and the gizzard shad (*Dorosoma cepedianum*) thrives in both environments. Among the suckers, the slender carpsucker (*Carpiodes carpio elongatus*) and the smallmouth buffalo (*Ictiobus bubalus*) are common. The gray redhorse (*Moxostoma congestum*) is a more locally distributed species. Several of the numerous species of minnows have localized distributions. While most are upriver from the study area, the Mexican roundnose minnow (Dionda episcopa conchi) inhabits several small tributaries of the lower Rio Grande.

The Texas Parks and Wildlife Department conducted a survey of Llano Grande and Campacuas Lakes in 1964 (IBWC 1973). In Llano Grande Lake, sport species constituted only 5.2% of the number and 4.5% of the weight of all fish sampled. Sport species included channel catfish (Ictalurus punctatus), white bass (Morone chrysops), largemouth bass (Micropterus salmoides), warmouth (Chaenobryttus gulosus), and white and black crappie (Pomoxis annularis and P. nigromaculatus). The bulk of the fish sampled was Rio Grande perch (Cichlasoma cyanoguttatum), gizzard shad, and carp (Cyprinus carpio). In nearby Campacuas Lake, 18.8% of the number and 13.6% of the weight of the samples were sport species. No bass were obtained, but the blue catfish (Ictalurus furcatus) was present in addition to the other species. Spotted gar (Lepisosteus oculatus) was the most abundant species (IBWC 1973).

5.4 FLOODPLAIN (PALUSTRINE) COMMUNITY

The lack of abundant precipitation in this area and the prevailing high evapotranspiration rates have precluded the development of extensive riparian habitat. Even before man's presence, this habitat existed only along the Rio Grande (Johnston 1955).

Due to the floodplain's inherent variability and proximity to other habitats, its number of species is relatively high compared to surrounding communities. Because of the flood plain's small size, however, populations are limited. Man's practices have significantly reduced the areal extent and quality of this habitat; this reduction has led to reduced species diversity. Dam building has changed the natural water flux (Johnston 1955); artificial levee construction has removed much natural vegetation and permanently decreased the floodplain's width. The clearing for agriculture, inevitably following levee building, has affected further the floodplain habitats. The combination of the reduction in the quality and quantity of floodplain habitats and the area's geographical position as the northern limit for several neotropical species has resulted in a disproportionately large number of locally endangered and threatened species in this area.

In addition to the Rio Grande floodplain, Johnston (1955) included in this community: (1) discontinuous areas in Cameron County associated with former distributaries of the Rio Grande, (2) sections of San Fernando and Santa Gertrudis Creeks in Kleberg County, and (3) edges of many of the playas scattered over the sand sheet area.

5.4.1 Vegetation

The following is largely taken from Johnston (1955), who provides a more complete flora listing and discussion. Except for the oak mottes, the floodplains contain the only large trees in the study area. These are confined to the Rio Grande. The trees of smaller floodplains are largely stunted forms in communities with lower species diversity. The forested floodplain is divided into the upper and lower Rio Grande regions, the latter restricted to a small area below Brownsville. The division is based primarily on the presence of the native palm (*Sabal texana*) in the lower section (Table 3), which according to Johnston (1955), was first mapped as the boscaje de palma (palm grove) by Clover (1937) and was the subject of an extensive work by Davis (1942). Johnston (1955) listed an additional 22 species occurring in this area which are at the northern limit of their range.

Table 3. Representative canopy vegetation along the floodplains of the Laguna Madre system (Johnston 1955). Common names from Vines (1960).

Upper Rio Grande - below Falcon Dam to Brownsville

Leucaena pulverulenta - Great lead-tree
Fraxinus berlandieriana - Berlandier ash
Celtis laevigata - Hackberry or sugar hackberry
Ehretia anacua - Anaqua
Pithecellobium flexicaule - Ebano (ebony)
Sapindus drummondii - Western soapberry
Prosopis juliflora - Mesquite

Lower Rio Grande - below Brownsville

Sabal texana - Texas palm
Sapindus drummondii - Western soapberry
Celtis laevigata - Hackberry
Fraxinus berlandieriana - Berlandier ash
Colubrina texensis - Texas colubrina or hog-plum

Resacas - Cameron County

Pisonia aculeata - Devils-claw pisonia
Esenbeckia runyoni - Runyon esenbeckia
Solanum verbascifolium - Mullein nightshade or potato-tree

San Fernando and Santa Gertrudis Creeks - Kleberg County

Celtis laevigata - Hackberry
Ehretia anacua - Anaqua
Ulmus crassifolia - Texas elm or cedar elm

Along the upper portion of the Rio Grande, a conspicuous horizontal zonation of vegetative types exists. Large trees are located closest to the river in the looser sandy soils. Away from the river, trees decrease in abundance and vigor and merge with shrubs.

The canopy along the resacas (ponds) is generally devoid of trees and is dominated by brush (Table 3). Along San Fernando and Santa Gertrudis Creeks the width of the hardwood zone is often restricted to a few trees, usually stunted and discontinuous.

Many species constitute the understory. Dominance is less pronounced than in the overstory, and many species there are also associated with other communities. *Urtica chamaedryoides* exists solely within the floodplain community and is listed as endangered (see Section 5.7). Johnston (1955) provided a detailed checklist of understory species.

No estimates of primary productivity or changes in production resulting from land use practices and changes in water flow regime are known for this area.

5.4.2 Fauna

Mammals. Mammals are well represented in the floodplain community. The floodplain's heterogenous nature results in a diverse array of habitats which is associated with great species diversity. Many large carnivores and sport species either depend on, or demonstrate a preference for, these floodplain habitats. The demise of floodplain habitats has had a parallel effect on these species. The jaguar (*Felis onca*) and the cougar (*F. concolor*) have been virtually eliminated due to habitat loss (see Section 5.6.1). Ocelot (*F. pardalis*) and jaguarundi (*F. yagouaroundi*) are still seen in the area although populations have been reduced as a result of brush clearing (National Fish and Wildlife Laboratory 1980). The taking of ocelot pelts has been a contributing factor, and both species are now protected (see Section 5.6.1). The bobcat (*Lynx rufus*) is also found in the thickets of the floodplain, probably because of its abilities to adapt to a wide variety of habitats and to cope with human populations (Davis 1974).

Several bat species (Order Chiroptera) are part of this community. Most are migrants, roosting in trees and feeding on insects (Davis 1974). These include the evening bat (*Nycticeius humeralis*), red bat (*Lasiurus borealis*), and hoary bat (*L. cinereus*). The greater yellow bat (*L. intermedius*) is an infrequent summer visitor which forages in the citrus orchards, and the lesser or southern yellow bat (*L. ega*) is a permanent resident which inhabits the *Sabal texana* groves below Brownsville (Davis 1974).

Carnivores like the raccoon and its rare southern relative, the coati (*Nasua narica*), depend more on floodplain habitats than do the badger, gray fox (*Urocyon cinereoargenteus*), coyote, and several skunk species.

On the Laguna Madre area's floodplain are numerous grazers, including the white-tailed deer, cottontail, and the collared peccary or javelina (*Dicotyles tajacu*), all also found in other habitats. Several species of mice and rats provide a food source for the carnivorous mammals and birds. The Mexican spiny pocket mouse (*Liomys irroratus*), which prefers the seeds of hackberry (*Celtis laevigata*) and mesquite (*Prosopis juliflora*), does not range farther north than the Rio Grande floodplain (Davis 1974). Tree squirrels are absent from this area, but ground squirrels are present. While not common in the floodplain, the spotted ground squirrel and the Mexican ground squirrel (*Spermophilus mexicanus*) occasionally are encountered along sections of higher elevation (Hall and Kelson 1959).

Furbearers, such as the Mexican beaver (*Castor canadensis mexicanus*) and nutria (*Myocastor coypus*), are relatively uncommon. Swepston (1976) estimated the lower Rio Grande Valley population of Mexican beaver at 900 individuals. Present populations appear stable and are concentrated in reservoirs. Other mammals in the floodplains of the Laguna Madre study area include the opossum (*Didelphis virginiana*), nine-banded armadillo, and the eastern mole (*Scalopus aquaticus*).

Birds. The white-winged dove (*Zenaida asiatica*) is one of the most heavily hunted birds in Texas. This species has long been associated by sportsmen with the lower Rio Grande Valley although it extends inland to the Edwards Plateau and up to the central Texas coast (Oberholser et al. 1974). The clearing of much brushland has reduced the preferred habitat, and presently most of the dove population has adapted to mature citrus groves. Survey data (TPWD 1977) indicated that the 1976 local population was 516,000 with an additional 296,000 white-winged doves nesting outside the Laguna Madre study area. While most doves in the Laguna Madre study area live in citrus groves (327,000 in 1976), TPWD (1977) data clearly showed that their density is considerably higher in natural brushland areas than in the citrus groves.

A negative aspect of the citrus groves as dove habitat is their susceptibility to freezes. In 1950 approximately 1,000,000 white-winged doves were nesting in citrus groves. Following a hard freeze in January 1951, which destroyed many mature trees, only 110,000 doves nested in the area (Oberholser et al. 1974).

Other important game species of the Rio Grande floodplain as well as upland brush areas are the mourning dove (*Zenaida macroura*) and the Rio Grande turkey (*Meleagris gallopavo intermedia*).

Species which may be observed along the Rio Grande, resacas, and other freshwater areas include the following: least grebe (*Podiceps dominicus*), pied-billed grebe (*Podilymbus podiceps*), chachalaca (*Ortalis vetula*), green kingfisher (*Chloroceryle americana*), ringed kingfisher, and jacana (*Jacana spinosa*). The latter two are relatively scarce.

Birds found in floodplain brush or wooded areas and in the uplands include these species: Mexican turkey vulture (*Cathartes aura aura*), Harris' hawk (*Parabuteo unicinctus harrisi*), roadrunner (*Geococcyx californianus*), pauraque (*Nyctidromus albicollis*), and olive sparrow (*Arremonops rufivirgata*). See Oberholser et al. (1974) for a complete listing of Texas birds.

Reptiles and amphibians. Some reptiles use the palm groves along the floodplain for shelter. The four-linked skink (*Eumeces tetragrammus tetragrammus*) frequently hides under dried frond husks at the base of palm trees (Conant 1975). Other lizards common not only to the floodplain, but also to the dry upland areas, include the spotted whiptail (*Cnemidophorus gularis gularis*) and the prairie racerunner (Conant 1975). The diamonback watersnake (*Nerodia rhombifera rhombifera*) is common in the area and like several water snakes can be easily mistaken for the cottonmouth. The Texas coral snake (*Micrurus fulvius tenere*) is one of the few poisonous snakes in the floodplain (Conant 1975).

Floodplain vegetation, especially palm groves along the Rio Grande, provides a suitable habitat for such amphibians as the Rio Grande frog (*Syrrhophus cystignathoides*) and Mexican tree frog (*Smilisca baudini*) (Conant 1975). Both are Mexican species whose northern range limit is the lower Rio Grande Valley. The giant toad (*Bufo marinus*), another Mexican species whose range extends into southern Texas, frequents pools and arroyos in the Rio Grande Valley (Wright and Wright 1949). The giant toad is infamous for its large size and strong parotid secretions which are poisonous to predators.

5.5 UPLAND COMMUNITY

The term upland is used here to designate areas not normally flooded by any recurring event (i.e., tides, seasonal floods, etc.).

The uplands as a habitat interact with wetland habitats largely through the hydrologic cycle. The runoff from uplands supplies organic and inorganic sediment to the estuaries via streamflow. Nutrients are recycled to the uplands primarily through atmospheric processes.

The upland habitat is the most extensive in the study area. The landward boundary of the study area is defined as 64 km (40 mi) inland from the coast.

5.5.1 Vegetation

From a regional perspective (the Gulf Coastal Plain), the primary influence on upland vegetation is climate. Within the Laguna Madre upland habitat, vegetation is heterogeneous, and the primary controlling factor is edaphic (relating to soil). Thus, the vegetational variability reflects pedogenetic (soil-forming) factors. Of these, slope, parent material, groundwater table, and coastal proximity (eolian transport of minerals) appear the most important (Johnston 1955). Johnston (1955) recognized six plant communities within what we have defined as the upland community: brush (chaparral), live oak mottes, *Spartina spartinae* community, and three prairie grass communities.

The brush community is dominated by mesquite. Spiny hackberry (*Celtis pallida*), white thorn (*Zizyphus obtusifolia*), and lime pricklyash (*Xanthoxylum fagara*) are also common (Johnston 1955). The brush community was extensive along the higher elevations of the Rio Grande floodplain before large-scale clearing (Bogusch 1952; Johnston 1955). In shorter brush communities, sacaton (*Sporobolus wrightii*), several types of prickly pear (*Opuntia* spp.), bee brush (*Aloysia ligustrina*), and yucca (*Yucca treculeana*) are common (Bogusch 1952; Johnston 1955). Both Bogusch (1952) and Johnston (1955) discussed the expansion of the brush community, which they attributed to overgrazing and the spread of mesquite disseminules through the digestive tract of cattle.

The live oak mottes and scrub are considered by Johnston (1955) to be the climax community of the sandy ridges. Virtually all old sand dunes in the sand sheet area are dominated by live oak (*Quercus virginiana*). Where live oaks are well developed, shading effectively prevents growth of understory prairie grasses. Where growth of live oaks are in a savannah distribution, such as in parts of Nueces and Kleberg Counties, an understory of prairie grasses and shrubs may be found (Johnston 1955).

The Spartina spartinae community (known locally as sacahuista; otherwise known as gulf cordgrass) is predominantly a wetland community of the coast (Correll and Correll 1975). Johnston (1955), however, found sufficient upland stands to include its discussion here. The upland location of this species is restricted to swales, usually deflation areas. Johnston (1955) found sacahuista at 60-m elevations and knew of its presence at higher elevations. This phenomenon is probably related to perched water tables (groundwater separated from an underlying main body of groundwater by an unsaturated zone), especially where a caliche layer is present. This water table reaches the surface in the swales and frequently contains moderate concentrations of salts (Johnston 1955; Brown et al. 1977). While this community is not extensive, it may be heavily used by the fauna because of the presence of water in an otherwise arid area. Sacahuista has been extensively burned in the past, as only the young shoots provide adequate forage for cattle and horses (Correll and Correll 1975).

Johnston (1955) differentiated three prairie types based on the soil-vegetation relationships. He further divided these by degree of grazing. In loose sandy soils, the seacoast bluestem is dominant in undisturbed areas. At least 40 other perennial grasses and forbs, along with annuals, may be locally abundant. In grazed areas there is no consistency in dominance, and seasonal variability of the species present is greater (Johnston 1955). In sandy soils the equivalent of the Spartina spartinae community is the buttonbush (Cephalanthus occidentalis) and stiffleaf chloris (Chloris petraea) community (Johnston 1955).

The sandy loam prairie is the first to be invaded by brush (Johnston 1955). There is no distinct dominance; the most distinguishing characteristic is the lack of bluestem.

The clay prairie has been almost entirely disturbed by grazing (Johnston 1955). Mesquite is prevalent, and buffalograss (Buchloe dactyloides) as well as slimspike windmill grass (Chloris andropogonoides) are normally present, but there is no clear dominance (Johnston 1955).

5.5.2 Fauna

Mammals. Many mammals inhabiting the upland also inhabit the floodplain, especially those species preferring dense brush (e.g., Felis sp.). The following descriptions are from Davis (1974) and Hall and Kelson (1959).

The most numerous in terms of populations and species are rodents (Table 4), which are the major part of the diet of coyote, badger, long-tailed weasel (Mustela frenata), bobcat, and larger cats, as well as birds of prey and some snakes. The California jackrabbit is also an important part of the diet of these carnivorous species. The jackrabbit prefers sparsely vegetated sites and is often associated with overgrazing areas. The eastern cottontail is another common rabbit in the upland.

Table 4. Common rodents in the upland habitat of the Laguna Madre system. Most of the rodents are primarily herbivores. Habitat preference within the upland zone is variable. Several species occur in brush areas while others prefer prairie grasses. Differentiation of species based on soil types and density of cover is also noteworthy.

Scientific name	Common name
Spermophilus mexicanus	Mexican ground squirrel
S. spilosoma	Spotted ground squirrel
Geomys personatus	South Texas pocket gopher
Perognathus merriami	Merriam pocket mouse
P. hispidus	Hispid pocket mouse
Dipodomys ordi	Ord's kangaroo rat
Onychomys leucogaster	Short-tailed grasshopper mouse
Reithrodontomys fulvescens	Fulvous harvest mouse
Baiomys taylori	Pygmy mouse
Peromyscus maniculatus	Deer mouse
Sigmodon hispidus	Hispid cotton rat
Neotoma micropus	Gray wood rat

Among the hoofed mammals, the white-tailed deer and the collared peccary or javelina are important sport species. The latter was hunted commercially for its hide until 1939 when it received status as a game animal. Its preference for prickly pear as part of its diet has changed some ranchers' attitudes about the peccary, and the species is now considered by many to be a valuable asset for range management.

The nine-banded armadillo, the only U.S. species of the order Edentata, is found where soils are loose and near a water source.

Birds. Upland birds inhabiting the brushland are discussed in Section 5.4.2. The bobwhite (Colinus virginianus) and the relatively rare Botteri's sparrow (Aimophilia botterii) are species which prefer the grassy prairie. Also see Section 5.6.2.

Reptiles and amphibians. For so harsh an environment, the upland area supports a large number of reptiles and amphibians.

Some of the same turtle species in the riverine community are also found in upland areas, where they inhabit prairie ponds and cattle tanks. In addition there are several terrestrial species like the western box turtle and the Texas tortoise (Thomas 1976). Insects are the preferred food of the box turtle; the Texas tortoise is predominantly herbivorous.

Lizards limited to drier habitats in the upland include the Texas horned lizard, the mesquite lizard (Sceloporus grammicus disparilis), and the Great Plains skink (Eumeces obsoletus). Texas horned lizards (also called horned toads) are frequently captured for pets, only to be released later outside their natural range, or to die as captives during cold weather when they refuse food. In Texas this species is protected by law from commercial exploitation (Conant 1975; Thomas 1976).

Most noteworthy of the snakes in the dry uplands is the western diamondback rattlesnake, responsible for more serious snakebites and deaths than any other North American snake. Not only is this rattler large, sometimes exceeding 200 cm in length, but it also has a tendency to stand its ground (Conant 1975). Other poisonous snakes include the Texas coral snake and the desert massasauga (Sistrurus catenatus edwardsi). Rodents are preferred food for the rattlesnake whereas the coral snake preys upon lizards and young snakes. Common nonpoisonous species include the desert kingsnake (Lampropeltis getulus splendida), blotched watersnake (Nerodia erythrogaster transversa), and checkered garter snake (Thamnophis marcianus marcianus), all of which seldom stray from their water source (irrigation ditch, cattle tank, etc.). Preferred food for the kingsnake is rodents; the latter two species feed mainly on amphibians and fish (Wright and Wright 1957).

Common resident amphibians such as the Rio Grande leopard frog, Couch's spadefoot toad (Scaphiopus couchi), and the green toad (Bufo debilis) are able to persist in the semi-arid climate because of their opportunistic breeding habits. The latter species, for example, with the stimulus of heavy rains, can breed any time of the year (Conant 1975). Breeding sites are temporary bodies of water, including ditches, rain pools, intermittent streams, and cattle tanks. The numerous poorly drained deflation swales are probably an important amphibian habitat during rainy periods. Metamorphosis is rapid and completed less than 3 weeks following breeding (Wright and Wright 1949).

5.6 RARE AND ENDANGERED VERTEBRATES AND INVERTEBRATES OF THE LAGUNA MADRE STUDY AREA[2]

5.6.1 Mammals

The following descriptions of mammals were compiled from National Fish and Wildlife Laboratory (1980), USFWS (1978), Custavson et al. (1978), and Davis (1974).

Felis pardalis albescens - ocelot. The ocelot is increasingly rare in the continental United States; the Laguna Madre system is near the northern limit of its natural range. In this area, it inhabits dense thickets and possibly oak mottes. Locally, numbers have decreased because of sport hunting, predator control (killing or live trapping of a species to protect livestock, poultry, or other wildlife species), and destruction of habitat

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[2] The status for each rare and endangered species is listed below for three agencies: Texas Organization for Endangered Species (TOES), Texas Parks and Wildlife Department (TPWD), and the U.S. Fish and Wildlife Service (USFWS). Status designations include Endangered (E), Threatened (T), and except for the USFWS, Peripheral (P). Additional designations of Status Undetermined (SU) and Not Considered (NC) are from Gustavson et al. (1978).

via agriculture. The ocelot's food habits are not well known. It hunts primarily at night, preying upon nesting birds including domestic fowl, rabbits, mice, snakes, and lizards. There are several population estimates for the area (75 individuals maximum). The Laguna Atascosa National Wildlife Refuge (NWR) contains suitable protected habitat and has a population of 12-24 (two separate estimates). The Santa Ana NWR (west of the study area) may contain a small population. TOES = P, TPWD = E, USFWS = E.

Felis yagouaroundi cacomitli - jaguarundi. The diminishing population is due to the loss of thicket and oak motte habitats. The lower Rio Grande Valley is the northern limit of its preferred range, but the spread of mesquite may offer suitable habitat and a range extension. Individuals are occasionally reported in other Texas Barrier Island study areas. Primarily active at night, it feeds mainly on birds but will also take small mammals and some fish. Estimated populations include 8 on Laguna Atascosa NWR, 12 on Santa Ana NWR, and 2 on Aransas NWR (see Copano-Aransas synthesis). TOES = P, TPWD = NC, USFWS = E.

Felis onca veraecrucis - jaguar. This species once occurred as far north as Louisiana but now is virtually absent from Texas, with no recent reported findings. Occasional individuals wander into the Laguna Madre system from Mexico. Due to habitat loss (chaparral and timber for northern areas of its range) it is unlikely that the jaguar will re-establish in the area. TPWD = E, USFWS = E.

Trichechus manatus latirostris - West Indian manatee. Sighting records exist for Laguna Madre and the Rio Grande mouth. This species' extreme sensitivity to cold probably excludes the manatee from consideration as a possible year round resident (Husar 1977). Hypersalinity may also be a limiting factor. TOES = E, TPWD = E, USFWS = E.

Other endangered mammals. The gray wolf (*Canis lupus monstrabilis*) is no longer in the area. The black bear (*Ursus americanus*) and cougar (*Felis concolor stanleyana*) are listed as endangered by TOES, but are not considered by TPWD or USFWS. Although TOES considers the southern yellow bat (*Lasiurus ega* or *Dasypterus ega xanthinus* of Hall and Kelson 1959) peripheral, the area is near its range limit and the species is common elsewhere. The bobcat (*Lynx rufus texensis*) is under review by the USFWS and is not considered by TPWD (see San Antonio synthesis). (For endangered marine mammals, see the Texas Barrier Islands Marine synthesis.)

5.6.2 Birds

Information on rare and endangered birds is from USFWS (1978), Gustavson et al. (1978), and Oberholser et al. (1974).

Dichromanassa rufescens - reddish egret. The largest known colony in Texas is on Green Island in Laguna Madre near the Cameron-Willacy County border. In 1976, 411 pairs were reported there; a total of 1,620 pairs occurred along the entire Texas coast (Blacklock et al. 1978). Populations have been increasing steadily since the 1960's low, for which high pesticide levels were partially responsible. TOES = E, TPWD = NC, USFWS = NC.

Plegadis chihi - white-faced ibis. This species is considered by many as conspecific with the glossy ibis (*P. falcinellus*). It nests sporadically in the area and along all of the Texas coast. The white-faced ibis prefers artificial holding ponds or natural deflation-zone ephemeral ponds where cattail is present. The species is usually found in large colonies along with other species. Pesticides are blamed for the decline of this ibis with almost no young raised in 1970. Population estimates are 9,200 pairs in 1969; 2,100 pairs, 1974; and 5,380 pairs, 1976, with most in the central and upper coast. TOES = T, TPWD = NC, USFWS = SU.

Dendrocygna bicolor - fulvous whistling duck. For a detailed account of this bird, see Oberholser et al. (1974). Recent sightings are restricted to the area from the Rio Grande River to Corpus Christi Bay. Formerly, this duck was abundant in rice fields to the north. It is still a common species in neighboring Mexico. TOES = E, TPWD = NC, USFWS = NC.

Pandion haliaetus carolinensis - osprey. One breeding pair was sighted in the Laguna Madre system along the Rio Grande in the early 1900's. TPWD (1979) reported no nests from 1971 (first year of investigation) to the present. TPWD (1976) reported 75 sightings of transients in counties within and overlapping the Laguna Madre study area during the 1971-76 period. It is unknown how many of the 75 are repeat sightings. Pesticides ingested via fish are generally blamed for the decline. (See Matagorda-Brazos synthesis.) TOES = E, TPWD = NC, USFWS = SU.

Numenius borealis - Eskimo curlew. An abundant migrant during the last century, this species has been on the verge of extinction for some time. Although usually confined to inland prairies, two coastal specimens from the Laguna Madre area have been recorded. TOES = E, TPWD = E, USFWS = E.

Other endangered birds. Numerous species are known or have been known to migrate through or inhabit the area. Several sightings or specimens taken have been in the lower Rio Grande and Laguna Madre area. These species are mostly common to abundant tropical and neotropical birds whose maximum range borders the area. Local population decline primarily results from pesticides, hunting, and the basic habitat change of the lower Rio Grande River due to land clearing.

These birds include the masked duck (*Oxyura dominica*); roseate spoonbill (*Ajaia ajaja*); white-tailed kite (*Elanus leucurus*), increasing due to agricultural habitat preference; zone-tailed hawk (*Buteo albonotatus*); gray hawk (*B. nitidus*); white-tailed hawk (*B. albicaudatus*); black hawk (*Buteogallus anthracinus*); jacana (*Jacana spinosa*); sooty tern (*Sterna fuscata*); ferruginous owl, sometimes locally known as four eyes owl, (*Glaucidium brasilianum*); ringed kingfisher (*Megaceryle torquata*), increasing along the Rio Grande River below Falcon Dam; beardless flycatcher (*Camptostoma imberbe*); rose-throated becard (*Platypsaris aglaiae*); yellow-green vireo (*Vireo flavoviridis*); tropical or olive-backed warbler (*Parula pitiayumi*); Sharpe's or white-collared seedeater (*Sporophila torqueola*); and Botteri's sparrow (*Aimophila botterii*).

Occasional visitors from the north include the merlin or pigeon hawk (*Falco columbarius*) and Arctic peregrine falcon (*Falco peregrinus tundrius*), the latter known to be illegally trapped on Padre Island. According to TPWD

(1978), 169 falcons were observed on Padre Island in 1973 and 135 were observed in 1976 (also see Galveston, Matagorda-Brazos, and San Antonio syntheses).

The other rare or endangered species, formerly known in the area but now found elsewhere along the Texas coast, include the southern bald eagle (Haliaeetus leucocephalus leucocephalus); Ross' goose (Chen rossi), brown pelican (Pelecanus occidentalis carolinensis); American oyster catcher (Haematopus palliatus); and whooping crane (Grus americana). Numerous other species have been recorded, but their preferred habitat is not within the area. Among the more notable are the golden eagle (Aquila chrysaetos) and prairie falcon (Falco mexicanus).

5.6.3 Amphibians

No known endangered amphibians are in the Laguna Madre area although the giant toad (Bufo marinus), Mexican white-lipped frog (Leptodactylus labialis), and the Mexican tree frog (Smilisca baudini) are considered peripheral by TOES (not under consideration by either USFWS or TPWD).

5.6.4 Reptiles

Information on endangered reptiles in the Laguna Madre area is from National Fish and Wildlife Laboratory (1980), USFWS (1978), Gustavson et al. (1978), and Raun and Gehlbach (1972).

Alligator mississippiensis - American alligator. The alligator, rare in the Laguna Madre system, probably never existed in large numbers in this area due to little adequate habitat. TPWD (1975) reported 52 alligators in counties within and bordering the Laguna Madre study area. In comparison, the estimated statewide population was 36,558. (See Galveston Bay synthesis.) TOES = E, TPWD = E, USFWS = E.

Chelonia mydas - green turtle. No nesting sites have been recently reported although there is suitable nesting habitat along the Laguna Madre coast. Records exist from Nueces and Kenedy Counties. Adequate forage is available as adults feed primarily on seagrasses. Green turtles are presently known to feed in Lower Laguna Madre. Beach development, large numbers taken as incidental catch by trawlers, and commercial exploitation have contributed to this species' declining numbers. TOES = E, TPWD = NC, USFWS = T.

Lepidochelys kempi - Kemp's ridley turtle. Nesting is known to have occurred on Padre Island; the only nesting site at present is south of Laguna Madre along the Mexican coast. Several recent attempts to transfer eggs to Padre Island to establish a population have had inconclusive results. The decline of this species has been for the same reasons as Chelonia. TOES = E, TPWD = E, USFWS = E.

Other endangered reptiles. The leatherback turtle (Dermochelys coriacea) is listed as endangered by all three agencies; no nesting has been recorded on Padre Island since 1930. No records exist for the hawksbill turtle (Eretmochelys imbricata). Additional discussion of sea turtles is in the marine synthesis. The black-striped snake (Coniophanes imperialis) is found only in the extreme lower Rio Grande Valley for Texas but is more common elsewhere. TOES = P, TPWD and USFWS = NC.

5.6.5 Fish

There are no reported findings of any of the endangered species listed in USFWS (1978) or Deacon et al. (1979) in the Laguna Madre area. Many endangered freshwater species inhabit the Rio Grande system although none have been reported from the extreme lower reaches. The numerous dams along the river system are effective barriers in restricting the range of these species.

5.6.6 Invertebrates

None of the invertebrates listed by USFWS (1978) are indigenous to the Texas coast. (See Matagorda-Brazos synthesis.)

5.7 RARE AND ENDANGERED PLANTS OF THE LAGUNA MADRE STUDY AREA

Table 5 includes those species found in the immediate and bordering areas of the Laguna Madre system. Numerous other species are rare in the area, but have a more widespread distribution elsewhere. For a more complete listing, see Gustavson et al. (1978).

Table 5. Rare and endangered plants native to Laguna Madre (Gustavson et al 1978; USFWS 1979).

Scientific name	Common name	Rareness[a]	Distribution (including neighboring counties)
Atriplex klebergorum (Goosefoot fam.)	Kleberg saltbush	6	Kleberg and Webb Counties
Hoffmanseggia tenella (Legume fam.)	Slender rushpea	6/7	Nueces and Kleberg Counties
Grindelia oolepis (Sunflower fam.)	Plains gumweed	5	?
Nephropetalum pringlei (Cacao fam.)	Pringle kidneypetal	7	Hidalgo County, 1888
Polygonum striatulum (Knotweed fam.)	Kleberg knotweed	6	Brooks and Kleberg Counties
Urtica chamaedryoides var. *runyonni* (Nettle fam.)	Southmost nettle	6	Cameron County
Willkommia texana (Grass fam.)	Willkommia	5/6	Coastal Bend counties
Echinocereus reichenbachii var. *albertii*	Black lace cactus	?	Jim Wells and Kleberg Counties

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[a] Rareness:
5 = scarce, endangered in Texas
6 = very rare, acutely endangered in Texas
7 = presumed extinct, with no record since 1930 in Texas.

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MARINE STUDY AREA SYNTHESIS

CONTENTS

TABLES

1.0 INTRODUCTION

The marine synthesis considers the gulf waters off the Texas coast from mean high water to the 3-league (4.83-km) line. For the purpose of this paper, this narrow strip of the gulf has arbitrarily been divided into two broad communities: (1) the upper shoreface community, which extends from mean high water to the 5-m contour and (2) the nearshore community, which comprises the remainder of the area. A third area, the offshore community, while not within the established boundaries of the study site, exerts a physical influence on the nearshore and upper shoreface and is therefore considered here. In addition, fauna considered deep water species, such as whales and marine turtles, irregularly occur in nearshore waters. The physical environment of the gulf forms a continuum of habitats through which the fauna (within the limits of their physiological requirements) can move at will.

Geologically the marine study area is an extension of the Texas coast, which during Pleistocene glacial times was at least partially subaerial. Since the last rise in sea level (following the Wisconsin glacial stage), the shelf has been below water level; and alluvial sediments of Recent age have constituted the primary deposition (Uchupi and Emery 1968).

Although this narrow band of gulf along the coast is now under water, it is still influenced by the adjacent shore. Air and water temperatures are more variable than in the deeper, more stable open gulf. Temperature fluctuation directly results from the poorer insulating capacity of the coast. Salinity in waters adjacent to the land is also frequently affected. Freshwater inflow from the Mississippi River and, to a lesser extent, the rivers of Texas effectively lowers water salinity, especially during periods of peak discharge (Berryhill 1977). Other terrestrial influences are runoff, sediments, artificial nutrients, and pollutants dumped into the inshore waters primarily through freshwater inflow.

Just as man's activity on the land affects the gulf, so does such human intervention directly in gulf waters, e.g., recovery of petroleum resources. With continuing exploitation of petroleum reserves in the Gulf of Mexico, drilling rigs and pipelines provide hard substrates for numerous species of invertebrates, that themselves are food sources for fish. Above-water portions of the rigs provide perching sites for seabirds. The major hazard of the petroleum industry is the risk of oil spills. Chronic, low-level spills typically have no significant direct effects on animal population levels according to the U.S. Department of Interior (USDOI 1974), but their cumulative effect requires study. Massive spills have received more attention and have been shown to cause at least short-term perturbations to faunal populations. On the community level, effects are potentially serious because oil tends to enter the food web and become concentrated in the upper trophic levels (USDOI 1974).

This paper will present an overview of Texas nearshore and marine waters, their biological attributes, and their physical characteristics. Such information will provide baseline data helpful in determining what parameters are subject to man's coastal and marine activities.

2.0 GEOLOGY

2.1 SEDIMENTS AND THEIR GEOLOGIC ORIGIN

The submarine portion of the Texas gulf coast belongs to the clastic-terrigenous province of Bergantino (1969, cited in USDOI 1976) and is characterized by progradation and upbuilding of fluvial, deltaic, and interdeltaic sediments of Tertiary to Recent age contributed by the Mississippi, Rio Grande, and other rivers (Bernard and LeBlanc 1965, cited in Bernard et al. 1978; Uchupi and Emery 1968; Davies 1972). To a lesser extent, marine erosion of coastal deposits is also a sediment source (Van Andel and Poole 1960).

Deposits of Recent alluvial material are not thick because Texas rivers typically are not heavily laden with sediment. Also, some rivers such as the Trinity, whose flow could not keep pace with the last sea level rise, are presently forming deltas in drowned river valleys (Bernard and LeBlanc 1965, cited in Bernard et al. 1978). As a result of this delta formation, sediment that would otherwise be deposited on the Continental Shelf instead remains in the bays.

As the Texas rivers flow over the flat coastal plain, their velocities diminish to a point where only relatively fine-grained sediment remains suspended (Lynch 1954). Sand-sized sediments are the largest entering the gulf by way of the rivers. Storm (1945, cited in Lynch 1954) reported grain sizes in the gulf approximately 19 km off Corpus Christi averaging 0.21 mm in diameter. The average grain size of sediments collected 32 km offshore decreased to 0.03 mm. Forty-eight kilometers offshore the average grain size increased to 0.18 mm. Beyond 64 km the grain size decreased again. According to Storm, this variability correlates closely with dominant gulf currents. Uchupi and Emery (1968) suggested the same overall fining trend with increasing distance from shore. Within the 3-league line, only terrigenous sediments of the larger grain sizes (i.e., sand, silty sand, sandy silt) described by Uchupi and Emery (1968) are evident. On the outer shelf, sediments are typically sandy, silty clays (Bright and Rezak 1976).

2.2 TOPOGRAPHY AND BATHYMETRY

On the Texas coast, the innermost section of the Continental Shelf from mean high water out to a distance of approximately 305 m (1,000 ft) typically has a series of two to three offshore bars alined parallel to the beach. The inner bar(s) are closer to shore than to the outer bar. The outermost bar is the largest, with the crest an average of 1.8 to 2.4 m below mean low water and the trough 3.7 to 4.6 m deep (Hedgpeth 1953). Offshore bars are best developed on coasts with gradual slopes and narrow tidal ranges such as those off Texas. Bars here are frequently up to a mile in length (Hedgpeth 1953).

The Continental Shelf off the Texas coast is as wide as 200 km off Galveston, narrowing to approximately 80 km off south Texas (Uchupi and Emery 1968), with an average width of 96 km (Williams 1951). According to USDOI (1976), the shelf exhibits a gradual slope averaging less than 32.3 m per nautical mile (<1°) extending to the 135-m (75-fm) contour. At this point, the continental slope begins. Other estimates place the shelf break approximately at the 183-m (100-fm) depth (Bernard and LeBlanc 1965, cited in Bernard et al. 1978; Woodbury et al. 1973). According to Bernard and LeBlanc, the slope of the shelf from the northeastern Texas shore to the 91.4-m (50-fm) contour exhibits a gradient of 1 m per nautical mile. Off central and south Texas, the gradient increases to 1.8 m per nautical mile gulfward of the Brazos and Colorado Deltas and 3.0 m per nautical mile off the coastal interdeltaic plains between those rivers. Between the 75-fm contour and the shelf edge, the slope averages 9.1 m per nautical mile off the Louisiana-Texas boundary (Bernard and LeBlanc 1965, cited in Bernard et al. 1978). As the shelf grades into the continental slope, the gradient increases to approximately 162 m per nautical mile (5°) (USDOI 1976).

Topographic features are not as common on the Continental Shelf within the 3-league line as they are farther out on the shelf and on the slope, where the topography is hummocky or hilly. Much topographic relief results from mud or salt diapirs (domes formed by a plastic core intruding through brittle overlying rock) (Uchupi and Emery 1968; Woodbury et al. 1973). From seismic studies along the continental margin of Texas, the U.S. Department of Interior (1974) suggested that all topographic highs represent salt intrusions. A primary reason for extensive oil and gas reserves in the waters off Texas is that many salt domes on the shelf and slope provide sites of hydrocarbon entrapment (USDOI 1974).

2.3 UNIQUE OR UNUSUAL FEATURES

The East and West Flower Garden Banks should be mentioned although they are located well outside the confines of this marine survey (approximately 176 km SSE of Galveston) because they represent the northernmost occurrence of coral reefs in the Gulf of Mexico (Tresslar and Poag 1972). These reefs probably originally formed on sedimentary rock forced upward by a salt dome. They now support a unique biological community that in some respects is an ecologically closed environment (Cannon and Alexander 1977).

A second reef of interest because it is within the study area is the Seven and One-Half Fathom Reef. Located 3.2 km offshore from northern Padre Island, the reef is of terrigenous sedimentary origin, indicated by the presence of land mammal bones and teeth (Tunnell and Causey 1969, cited in Tunnell and Chaney 1970) and freshwater snails (Tunnell and Chaney 1970). The reef is comprised of silty quartz sandstone partially cemented with calcium carbonate and affords a hard substrate for numerous algae and invertebrate species (Tunnell and Chaney 1970).

3.0 CLIMATE

3.1 PRECIPITATION

Data on precipitation in the open Gulf of Mexico are scarce (USDOI 1974), so coastal land stations are the primary source of such data. On land, precipitation decreases southward along the Texas coast. Land stations for

Galveston, Corpus Christi, and Brownsville have an average annual precipitation of 106.2, 71.9, and 68.3 cm, respectively (USDOI 1976; Berryhill 1977), and this same general trend may be expected in the marine study area off the Texas coast. Coastal stations report largest amounts of precipitation in the warmer months. For most stations July has maximum rainfall although the most southerly areas (i.e., Brownsville) report greatest rainfall in September (USDOI 1976).

3.2 TEMPERATURE

Average air temperature over the gulf is daily and seasonally less variable than temperatures over land masses. In July, air temperature over the center of the gulf averages 30° C and increases landward to within 5.5° C of coastal air temperatures. January air temperatures over the open gulf at the latitude of Brownsville are approximately 19° C and, at the latitude of Galveston, are about 16° C (USDOI 1976). During the winter air temperature does not differ significantly with varying longitudinal position (Leipper 1954a).

3.3 WIND PATTERNS

Air circulation over the gulf is dominated by the clockwise Azores-Bermuda atmospheric high pressure cell, particularly during spring and summer. The Bermuda high is relatively constant in the southern portion of the gulf during summer, resulting in predominantly southeasterly winds (Leipper 1954a; USDOI 1976).

By August, tropical storms exert considerable influence on gulf weather patterns. These storms usually originate in tropical waters and move northwest across the Straits of Florida or the Yucatan Channel. If wind speeds exceed 120 km per hour, the storms are classified as hurricanes; most hurricanes form in August and September. In the open gulf in water depths of at least 100 m, hurricane waves frequently reach heights of 12 to 15 m. As the waves move toward land, they are attenuated by the increasingly shallow water (Berryhill 1977). Since few man-made structures are found in the gulf, hurricane effects concentrate on the coast.

By October, few tropical storms occur in the gulf. In general, easterly systems are weakened and westerly systems are not yet strong enough to be regularly felt. The midfall is typically a time of good weather, but in November frontal fog reduces visibility to less than 9.3 km (5 nautical miles) approximately 5% of the time, increasing to about 10% during winter (USDOI 1974).

During the winter, both tropical and Arctic circulations influence weather patterns (USDOI 1976). Arctic air masses, known as northers, entering the gulf are some of the most dramatic winter circulations. Northers occur perhaps 15 to 20 times per year and cause rapid temperature drops. Associated wave build-up in the gulf often seriously hampers shipping operations. These cold fronts typically last 1 to 4 days and have wind speeds of approximately 37 km per hour (20 knots) (Leipper 1954a). As the cold air masses hit the warm gulf air, the fronts often become stalled, which explains their extended life (USDOI 1976).

4.0 HYDROLOGY AND HYDROGRAPHY

4.1 CURRENTS

Unlike the eastern half of the Gulf of Mexico, whose circulation is dominated by the Loop Current, the western half of the gulf has no semipermanent currents (USDOI 1976). It is instead characterized by a well-developed winter circulation and a highly variable summer pattern (Nowlin 1971, cited in USDOI 1976). The most distinctive portion of this circulation is the seasonal nearshore water movement known as the longshore drift.

Longshore drift, primarily a wind-driven current, is important because seasonally it transports large amounts of sediments along the inner shelf. In the course of this transport, beaches are usually replenished with new sand entering from local rivers (e.g., the Mississippi River). When rivers are dammed or otherwise diverted, new sands are denied the beach and inner shelf areas. In such cases, the longshore current may strip the region for progressively greater distances, turning sandy coastlines into gravelly or rocky ones (McConnaughey 1974).

During the winter, the longshore current off the coast of upper and central Texas generally follows the coast in a west-southwesterly direction, transporting large amounts of sediments. In summer, the currents alternate between north-northwesterly (or northeasterly) and south-southwesterly, with relatively little net transport (Smith 1975). Off the coast of Mexico and southernmost Texas, the longshore current typically follows the coast in a northerly direction. The dominant southward longshore drift off the upper and central Texas coast converges with the dominant northward drift off the lower Texas coast. The point of convergence varies but is in the vicinity of central Padre Island (see Laguna Madre synthesis, Section 4.2).

Longshore current velocities are considerably greater in the winter than in summer. For example, Smith (1975, 1978) reported average velocities in the gulf off Port Aransas to be 21.5 cm/sec and 10.0 cm/sec for the winter and summer, respectively. The low velocity of summer currents, combined with their more highly variable nature, helps explain the limited net sediment transport during this season.

Bottom circulation in the Gulf of Mexico is largely unstudied. Reports from divers suggest bottom currents are often strong enough to render diving hazardous. Bottom circulation is also reported to have dispersed drill cuttings for offshore oil rigs (USDOI 1976).

4.2 WATER TEMPERATURE AND SALINITY

Summer surface water temperatures are essentially uniform at approximately 29° C throughout the gulf (Leipper 1954b). In winter, temperatures in the southern portions of the gulf average 24° C and gradually drop to approximately 18.5° C in the northern gulf. These seasonal isotherms may vary considerably yearly (Leipper 1954b). More recent, detailed data on nearshore water temperatures reported by USDOI (1976) indicate that isotherms occur off the Texas coast and, except during summer, run parallel to the coastline rather than perpendicular as suggested by Leipper (1954b).

Thermal stratification occurs in nearshore waters, such as off Port Aransas, at least 50% of the time. North winds during the winter may disrupt vertical thermal stratification, either rendering the water column an isotherm or reversing the thermocline when colder bay waters are forced over the warmer gulf waters (Jones et al. 1965). Water temperature has biological importance because it is an important limiting factor in the distribution of flora and fauna. Thermal stratification, on the other hand, may place significant limits on productivity. The spring and fall productivity peaks are probably made possible by the primarily spring and fall mixing of waters and the contained nutrients (Jones et al. 1965).

Salinity in the open gulf is generally 36 ^{o}/oo or greater within the top 125 m (Parr 1935, cited in Leipper 1954b). Berryhill (1977) reported the 36.4 ^{o}/oo surface isohaline over the outer edge of the Continental Shelf between October 1974 and April 1975. During this period all isohalines were essentially parallel to the coast. Their position changed in a clockwise direction beginning in May, and, by July, was perpendicular to the coast.

Jones et al. (1965) studied gulf waters to a distance of 25 nautical miles out on the shelf. They reported the same trend, with waters close to shore tending to be more variable in their physical regimes due to the terrestrial influence.

4.3 RIVERINE INFLOW

Throughout this paper there have been numerous references to the influence rivers exert on the northwestern Gulf of Mexico. The two major areas of riverine influence are sediment supply to the gulf and salinity modification of nearshore gulf waters. Discussions of sediment supply appear in Sections 2.1 and 4.1. Salinity modification was mentioned in Section 4.2. Berryhill (1977) suggested that seasonally (in spring during peak river discharge) the flow from the Mississippi and Atchafalaya Rivers is the dominant factor effecting salinity in the northwestern Gulf of Mexico. Based on a 20 year mean (1950 to 1970), the discharge of each of these rivers is far greater than the combined flow of all Texas rivers, especially during spring when the Mississippi and Atchafalaya discharge rates are over 19,800 m^3/sec and 8,490 m^3/sec, respectively. The peak flow of Texas rivers is later in the spring and averages a total of only approximately 1,415 m^3/sec (Angelovic et al. 1976, cited in Berryhill 1977). Berryhill (1977) reported that 1974 and 1975 baseline data suggested that Mississippi and Atchafalaya River water may influence salinity on the Continental Shelf as far down the coast as south Texas.

4.4 WATER CHEMISTRY

4.4.1 Dissolved Organic Carbon (DOC)

Fredericks and Sackett (1970) reported that dissolved (DOC) and particulate (POC) organic carbon in the Gulf of Mexico are higher in shelf waters than in either surface or deep waters of the open gulf. They found three main sources of DOC in the gulf waters: (1) freshwater runoff, (2) nearshore contributions perhaps resulting from human activities, and (3) *in situ* generation in open gulf surface waters. Values of DOC for the entire gulf range from 0.58 to 2.35 mgC/liter, with a mean of 1.08 mgC/liter. Values for POC range from 0.022 to 1.911 mgC/liter and average 0.214 mgC/liter (Fredericks and Sackett 1970).

More recently, Maurer and Parker (1972), investigating DOC off the Texas coast from the Colorado River to Upper Laguna Madre, found the average DOC value at the 18.3-m (10-fm) contour, 36.6-m (20-fm) contour, and 54.8-m (30-fm) contour to be 1.96, 2.18, and 2.66 mgC/liter, respectively. In comparison with the gulf as a whole, these values are considerably greater, reinforcing Fredericks and Sackett's earlier contention that shelf waters contain greater amounts of DOC than do waters of the open gulf.

Based on transects perpendicular to the coasts, Maurer and Parker (1972) reported that shelf waters exhibit erratic variation in DOC levels rather than smooth decreases with increasing distance from shore. Maurer and Parker (1972) further suggested that, based on this spatial variability, nearshore DOC, in contrast with open gulf DOC, is closely associated with the biological carbon cycle.

4.4.2 Nutrients

Phytoplankton form the basis of the marine food web; and, in order to provide the primary production necessary to sustain all higher trophic levels, phytoplankton require adequate nutrients. Nitrogen, phosphorus, and silica, the three major nutrients necessary for marine plant growth, are supplied by upwelling of deep waters, advection (horizontal water movements), and outflow from land sources (e.g., rivers, industrial waste, and domestic waste). Frequently these nutrients are depleted in the surface waters due to rapid uptake by phytoplankton and a subsequent removal of phytoplankton by herbivores or by sinking (USDOI 1976, 1979). In the nearshore gulf, nitrogen is considered the limiting nutrient for phytoplankton growth because it is the first depleted during a phytoplankton bloom (Sackett and Brooks 1979, cited in Brogden and James 1979a).

Studies by Berryhill (1977) on the Continental Shelf off south Texas showed low nitrate nitrogen during 1975. Although the bottom waters on the outer shelf consistently had highest concentrations of nitrate, this nutrient was more evenly distributed than phosphate, which exhibited considerable geographic and seasonal variability. Silicate, during the entire sampling period from winter to summer, decreased seaward.

4.4.3 Chlorophyll a

Values for chlorophyll a, a photosynthetic pigment in all green plants, are frequently used to estimate standing crop of phytoplankton. Investigations in the gulf have suggested varying levels of seasonal standing crop. El Sayed (1972, cited in USDOI 1976) reported highest phytoplankton standing crops in the gulf during winter, with a drop in spring and a gradual increase into summer and fall. Berryhill (1977), however, investigating the gulf off south Texas, found greatest standing crops in spring and much lower crops in winter and summer. He also found chlorophyll a levels to decrease markedly seaward across the shelf. Through the vertical gradient, amounts tended to be greatest near the surface and approximately half way into the photic zone.

4.4.4 Dissolved Oxygen (DO)

Definitive data on dissolved oxygen (DO) values for the gulf are not available. However, vertical distribution in the upper waters at a typical western gulf station off south Texas (deep water area) was as follows: 4.8 ml O_2/liter at the surface, 4.9 ml/liter at 25 m, 2.35 ml/liter at 300 m, and 5.0 ml/liter at and below 2,400 m (Dietrich 1939, cited in Williams 1954). Dietrich also reported lowest DO values (2.5 ml/liter) of the gulf from the northwestern section. Investigations in nearshore shelf areas off Texas indicated a range from 4.51 to 6.95 mg/liter. These values represent 100% to 112% saturation. Highest DO levels are usually recorded during winter (Brogden and James 1979a). These supersaturated conditions may occur when dissolved oxygen bubbles are forced under water by waves (especially on the upper shoreface) and are under greater pressure (Brogden and James 1979b). Dissolved oxygen levels are also partly controlled by salinity and temperature (Brogden and James 1979a).

4.4.5 Trace Metals

Trace metals cadmium, chromium, cobalt, copper, lead, manganese, nickel, iron, uranium, and zinc, commonly suspended in the water column, usually occur in concentrations less than 1 ppm. These metals enter the gulf through natural weathering of rocks and from pollution associated with human populations (USDOI 1976). A study by Corcoran (1972, cited in USDOI 1976) reported common trace metal concentrations in the gulf 10 times those in the open ocean. These findings suggest that high concentrations of trace metals enter the gulf from the Mississippi River and highly developed bays of the northern gulf.

Trace metals can be separated into two groups based on their regional distribution. One group consists of cadmium, chromium, copper, nickel, and zinc. These metals exhibit a range in concentration in surface and middepth waters and minimal concentrations in the bottom water. The second group consists of manganese, vanadium, and iron; maximum concentrations are in bottom waters (Berryhill 1977). The segregation of metals into two spatial groups is an interesting phenomenon, suggesting at least two sources for trace metals. The vertical location of these metals may relate to the nature of the material (i.e., organic or inorganic) in which the metals are suspended. The first group of metals appears more abundant in plankton than in detritus of terrestrial origin, while group two metals seem to occur equally in both types of material (Berryhill 1977). This interrelationship of physical and biological aspects of the gulf is a reminder that the marine system is a highly integrated unit in which any one factor influences and is influenced by others.

5.0 BIOLOGY

The marine study area cannot be separated into its component communities as readily as can the bay systems of the Texas Barrier Islands Region. Only the intertidal zone can be separated from other portions of the marine system on the basis of physical parameters (Cowardin et al. 1979). Cowardin et al. consider the marine system to consist of intertidal and subtidal subsystems. This classification is not sufficiently detailed for the Texas coast: the area encompassed by the subtidal subsystem is enormous compared with the narrow band comprising the intertidal subsystem, and the biotic communities within the subtidal subsystem are not easily dealt with as a unit.

This marine synthesis has, therefore, divided the marine system into three general communities: (1) upper shoreface, (2) nearshore, and (3) offshore. The upper shoreface, as defined by Brogden and James (1979b), extends from the highest wash of the waves under normal conditions out to a water depth of approximately 5 m (just inshore of the outermost sand bar). The upper shoreface encompasses the intertidal zone which is intermittently exposed to air, the swash zone where waves run up onto the beach, the surf zone where waves break, and the outer bar area where wave energy begins to disturb the bottom (Brogden and James 1979b). The nearshore community consists of the rest of the marine study area from waters of approximately 5 m depth out to the 3-league line (4.83 km from shore), where the depth ranges from about 11 to 26 m (about 6 to 16 fm) (National Oceanic and Atmospheric Administration 1979). The offshore community, extending from the 3-league line seaward, is technically outside the boundary of the Texas Barrier Islands Region, but included in this synthesis because many organisms that occur offshore are also in the nearshore and upper shoreface areas.

5.1 UPPER SHOREFACE COMMUNITY

Members of the upper shoreface community must cope with daily changes in this dynamic ecosystem. The unstable, sandy shore extending along most of the Texas coastline (Taylor 1954) undergoes continuous erosion, transport, and deposition of sediments due to the high turbulence of waves (Brogden and James 1979b). Salinity and temperature may also vary daily. McFarland (1963b) recorded some abrupt fluctuations in salinity during his weekly studies of the beach along Mustang Island, and Gunter (1945, 1958) noted that water temperatures lag closely behind air temperatures during periods of abrupt weather changes.

5.1.1 Flora

The fine, unconsolidated sand of the beach effectively discourages growth of those benthic marine algae requiring solid substrate for their attachment (Taylor 1954; Edwards 1976). The numerous jetties and breakwaters constructed along the coast provide a rocky substrate; although wave action produces a harsh environment, the slopes of these man-made structures are covered with algae (Edwards 1976; Andrews 1977). Edwards and Kapraun (1973) collected 48 species of benthic marine algae from the southwest jetty at Port Aransas, Texas. They noted that *Bangia fuscopurpurea*, *Petalonia fascia*, and *Porphyra leucosticta* were dominant on the jetty during the cooler part of the year. More species were apparent during the summer months: *Enteromorpha clathrata*, *Chaetomorpha linum*, *Ulva fasciata*, *Gelidium crinale*, *Centroceras clavulatum*, *Bryocladia cuspidata*, *Padina vickersiae*, *Agardhiella tenera*, and *Rhodymenia pseudopalmata*. Little has been published on the macrophytic flora of other areas along the Texas coast, but Edwards (1976) provided an illustrated guide, helpful in identifying many marine and estuarine algal species of Texas.

Microscopic plants live in the waters and sediments of the upper shoreface community (Brogden and James 1979b). McFarland (1963b) reported large concentrations of the blue-green alga, *Trichodesmium* sp., in his samples from the surf zone waters of the beach at Mustang Island and suggested that phytoplankton constitute a major source of organic matter for higher organisms in the community during late summer and fall. Oppenheimer and Jannasch (1962) recorded averages of 1.6 x 10^6 and 9.0 x 10^5 bacteria per milliliter in their samples from the gulf beach near Padre Island Park, and Hedgpeth (1953) reported an abundant bacterial flora living in the sand of Texas beaches.

5.1.2 Fauna

Invertebrates. McFarland (1963b) discussed the zooplankton in his samples from the upper shoreface of Mustang Island. He noted that the dominant zooplankton shift from decapod larvae in spring to copepods, with a relative abundance of mysids and chaetognaths in late summer and early fall.

A limited fauna exists in or on the sediment in the upper shoreface community of the Texas coast. Where wave action is strongest (e.g., the swash zone), burrowing forms predominate. Only donax (*Donax texasianus*) and the coquina shell (*D. variabilis roemeri*) commonly occur in large numbers. These infaunal bivalves dig into the sand of the intertidal zone after exposure by retreating waves (Ladd 1951; Hedgpeth 1953). An infaunal gastropod, the shark's eye (*Polinices duplicatus*), feeds on *Donax* spp. and other small mollusks, and may be seen in the intertidal zone occasionally (Andrews 1977; Brogden and James 1979b). Other burrowing forms inhabiting the upper shoreface community include the sand dollar or keyhole urchin (*Mellita quinquiesperforata*), crustaceans like the mole crab (*Emerita portoricensis*), and marine worms like *Diopatra cuprea*, *Lumbrineris alata*, and *Arenicola cristata* (Hartman 1951; Hedgpeth 1953; Brogden and James 1979b).

Nonburrowing invertebrates of the upper shoreface community are mostly restricted to an epifaunal or pelagic existence (i.e., "subtidal," according to Cowardin et al. 1979) and are seldom seen in the intertidal zone unless they have been washed up on the beach by waves. Mollusks and crustaceans constitue the majority of the epifaunal invertebrates (those that live on the surface of the sediments). The common sundial (*Architectonica nobilis*), common Atlantic slipper shell (*Crepidula fornicata*), and eastern white slipper shell (*C. plana*) are common mollusks in this community (Ladd 1951; Andrews 1977; Brogden and James 1979b). Epifaunal crustaceans occuring in the upper shoreface community (see Gunter 1950, Felder 1973, Brogden and James 1979b) include hermit crabs (*Isocheles wurdemanni*, *Pagurus longicarpus*, and *P. pollicaris*) and the calico crab (*Hepatus epheliticus*).

The sea bob (*Xiphopeneus kryeri*), blue crab (*Callinectes sapidus*), and speckled crab (*Arenaeus cribarius*) are also common crustaceans in the upper shoreface community (Reid 1955) but can be referred to as epifaunal only in the broadest sense. The sea bob is a penaeid shrimp and probably swims intermittently; the blue crab and speckled crab are portunid crabs, described as the most powerful and agile swimmers of all crustaceans (Barnes 1974).

The commercially important shrimp of the genus *Penaeus* occur in the upper shoreface community (Gunter 1950; Hildebrand 1954; Hoese 1960), but they more typically inhabit deeper waters of the Gulf of Mexico and will be discussed later in this paper. Another species of commercial importance in Texas waters, the blue crab, is found more often in the upper shoreface community (Gunter 1950; Brogden and James 1979b). Like many invertebrates common to this community, the blue crab also occurs in deeper waters (Gunter 1950; Hedgpeth 1953; Hildebrand 1954) but occurs in greater numbers within the bay systems along the Texas coast. In fact, the lowest commercial catch of blue crabs for any Texas bay system during 1975 was more than nine times greater than that for Texas gulf waters as a whole (NOAA 1977). Life history information for this species appears in the Matagorda-Brazos study area synthesis (Section 5.1.2).

The most conspicuous pelagic invertebrates of the upper shoreface community (those that drift, float, or swim in the upper water layers) are coelenterates. Representative species include the Portuguese man-of-war (Physalia pelagica), cabbagehead jellyfish (Stomolophus meleagris), moon jelly (Aurelia aurita), sea nettle (Dactylmetra quinquecirrha) and the by-the-wind sailor (Velella mutica). The Portuguese man-of-war and sea nettle are especially noted for their long tentacles which inflict serious stings. Most of these "jellyfish" are carnivorous, feeding on small crustaceans and various other small organisms, although the moon jelly is a filter feeder living off plankton suspended in the water (Barnes 1974; Crowder 1975; Andrews 1977).

The various man-made jetties and breakwaters provide the most extensive rocky habitat along the Texas gulf coast, and the invertebrate fauna associated with these structures is quite different from that on or in the sandy or muddy substrate typical of the upper shoreface community. In considering the jetty community of the entire Texas coast, Whitten et al. (1950) stated that the invertebrate fauna is composed principally of three barnacles (Balanus eburneus, B. improvisus, and Chthamalus fragilis), a slipper limpet (Crepidula fornicata), a littorine (Littorina ziczac), a mussel (Mytilus recurvus), a Thais (T. floridana), an anemone (Bunodosoma cavernata), an isopod (Ligyda exotica), and a hermit crab (Clibinarius vittatus). For more detailed information concerning invertebrates on the jetties of the Texas coast, the reader is referred to Whitten et al. (1950) and Hedgpeth (1953).

Fish. Reid (1955) and McFarland (1963a) studied the fish of the upper shoreface community. Table 1 lists the fish they sampled most frequently. Their data indicated that gulf menhaden (Brevoortia patronus) and Atlantic threadfin (Polydactylus octonemus) are dominant in this community. Like most fish in the upper shoreface community, these fish also occur within the various bays and estuaries along the Texas coast (Reid 1955; Hoese and Moore 1977).

Of the fish in this community, the gulf menhaden is of special interest. According to Kroger and Pristas (1975), this species supports the largest United States fishery in tonnage landed. In Texas, a large menhaden fishery existed in 1951 (Simmons and Breuer 1967). The one menhaden processing plant in Texas closed in 1971, and landings for this species dropped after that year. Menhaden are currently processed in Louisiana and Mississippi (C.E. Bryan, Texas Parks and Wildlife Department; pers. comm. 1980). Menhaden have never been popular for human consumption, but menhaden fish meal is an essential addition to poultry and livestock feeds. The fish solubles are used as high protein additives in poultry feeds and in the manufacture of liquid plant food, and more than 165 uses have been developed for menhaden oil (Simmons and Breuer 1967).

Table 1. Fish inhabiting the upper shoreface community along the coast of Texas. Fish listed include only those species comprising 5% or more of the catches (Reid 1955; McFarland 1963a).

		Percent of catch (by numbers)	
Scientific name	Common name	Reid	McFarland
Brevoortia patronus	Gulf menhaden	58.67	
Polydactylus octonemus	Atlantic threadfin	8.45	44.53
Anchoa mitchilli diaphana	Bay anchovy	13.23	
Menidia beryllina	Tidewater silverside		11.51
Mugil cephalus	Striped mullet		10.16
Menticirrhus littoralis	Gulf kingfish		7.12
Arius felis	Hardhead catfish	5.22	
Chloroscombrus chrysurus	Atlantic bumper		5.21

Life history information on the gulf menhaden is scattered in the literature. The following summary is drawn from Christmas and Gunter (1960), Gunter (1963), Simmons and Breuer (1967), Houde and Fore (1973), and Hoese and Moore (1977). Adult gulf menhaden commonly occur in large, dense schools, close to shore where they feed on plankton near the water surface. They spawn in the open gulf during fall and winter. Egg diameters range from 1.04 to 1.30 mm, and larvae are approximately 3.0 mm in total length upon hatching. Three to five weeks after spawning occurs, larvae arrive in the nursery areas. Although many of the young fish use bays as nursery grounds, dense larval populations have been reported along the gulf beach at Mustang Island. Those that move into the bays remain at least through their first summer. Young menhaden are always found in the shallower waters close to shore, venturing into deeper waters only after they have passed the larval stage. Young fish resemble adults by the time they are 50 mm long and by the end of their first year may reach a length of 135 to 144 mm. Their life span is relatively short: few fish appear to live more than 4 years.

Gulf menhaden have a wide salinity tolerance. They have been recorded in Laguna Madre under hypersaline conditions, and small fish have been noted in fresh water. In rare instances gulf menhaden have been found in waters as deep as 36.6 m (20 fm), and as far as 46.3 km (25 nautical miles) from shore.

5.2 NEARSHORE COMMUNITY

5.2.1 Flora

Phytoplankton form the base of the food web in the nearshore community (Brogden and James 1979a). The major primary producers in the sea are diatoms and dinoflagellates (USDOI 1974). The neritic waters of the world's oceans all contain populations of Skeletonema spp., Biddulphia spp., Chaetoceros spp., Rhizosolenia spp., Ceratium spp., Gonyaulax spp., as well as others; and the waters of the Gulf of Mexico along the Texas coast are no exception (USDOI 1974). Phytoplankton from the nearshore community are exchanged with the estuarine system (e.g., the bays), the upper shoreface community, and the offshore community via water currents. Although many of the species occur in all three areas, phytoplankton density is higher in the estuaries and lower in offshore waters (Brogden and James 1979a).

The most widely known species of phytoplankton are those that produce red tides. In the gulf, red tide refers to discolored patches of sea water usually accompanied by fish kills (USDOI 1974). The water may be colored red by the "blooms" (i.e., sudden increases in population) of these phytoplankton but often is yellow or brown. Dinoflagellates of the genera Gymnodinium and Gonyaulax are known to cause red tides (Barnes 1974). They do so by producing a neurotoxin, capable in high concentrations of paralyzing and killing a variety of fish but relatively few invertebrates (USDOI 1974). Red tides are natural phenomena that are fairly common throughout the world. They are associated with areas of heavy land runoff or upwelling and appear to coincide with the increased amounts of iron or other trace metals in these areas. Of the four species known to bloom and produce red tides, a coastal species, Gymnodinium breve, causes the most widespread damage (USDOI 1974).

5.2.2 Fauna

Invertebrates. The invertebrate fauna of the nearshore community is quite similar to that of the upper shoreface community. Nearshore fauna consists of planktonic and pelagic forms that float or drift in the upper water layers, and various marine worms, mollusks, crustaceans, and other benthic organisms (i.e., epifaunal or infaunal).

The most notable invertebrates of the nearshore community are the penaeid shrimp. White (Penaeus setiferus), brown (P. aztecus), and pink shrimp (P. duorarum) support the most valuable commercial fishery in the Gulf of Mexico (Chittenden and McEachran 1976). From 1973 through 1977, approximately 3.38 x 10^8 penaeid shrimp were caught by Texas shrimpers in gulf waters; this amounted to an average revenue of $97.63 million per year (NOAA 1974, 1975, 1977, 1978a, 1978b). These shrimp are also harvested commercially in Texas bays. From 1973 to 1977, 85.9% of the total Texas catch was captured in gulf waters, and only 14.1% came from the bays.

The dominant penaeid of the nearshore community along the Texas coast is the white shrimp (Brogden and James 1979a). According to Chittenden and McEachran (1976), the commercial fishing grounds for white shrimp encompass gulf waters ranging from about 3.5 to 22 m (2 to 12 fm) in depth; Hildebrand (1954) reported that commercial quantities of white shrimp are not found off the Texas coast at depths greater than 31 m (17 fm). Although brown shrimp may account for the largest commercial shrimp yields in the Gulf of Mexico (NOAA 1974, 1975, 1977, 1978a, 1978b), they are apparently the second most numerous penaeid of the nearshore community (see below). The commercial fishing grounds for brown shrimp are in waters of about 22- to 91-m (12- to 50-fm) depths (Chittenden and McEachran 1976). This indicates that brown shrimp are probably more numerous outside the marine study area except during May, June, and July when they are emigrating from the bays. Pink shrimp are reportedly the least numerous penaeid in the nearshore community. However, pink shrimp are bought and sold in Texas as brown shrimp, and this practice may seriously bias data on landings of both species (Kutkuhn 1962). Large numbers of pink shrimp are sometimes captured in the nearshore community along the Texas coast, but the only pink shrimp fishing grounds of commercial importance in the western gulf are off the coast of Campeche, Mexico (Hildebrand 1954).

White, brown, and pink shrimp are biologically similar. The adults spend most of their time either buried in the sediment for protection or searching the bottom for food (Brogden and James 1979a). Their anatomical features differ little and, except for possible differences in reproductive potential and in timing of events, their life histories are practically identical (Kutkuhn 1962). For information on their life histories, see the Matagorda-Brazos synthesis (Section 5.1.2).

Fish. Many fish of recreational and/or commercial value inhabit the nearshore community along the coast of the Texas Barrier Islands Region study area. In fact, sport and commercially important species in the area are too numerous to discuss in detail here. Walls (1975) and Hoese and Moore (1977) described the marine fish of the Texas coast, and a Texas Parks and Wildlife Department bulletin (TPWD 1971) contains information on 70 marine fish important for food and sport in Texas.

Most fish inhabiting the nearshore community also occur within the various bays and estuaries along the Texas coast (e.g., TPWD 1971; Chittenden and McEachran 1976; Brogden and James 1979a). Although most of the life stages of these fish have been found in both the gulf and the bays, Brogden and James (1979a) stated that many species migrate into the estuaries as larvae or juveniles and return to the gulf as adults. Table 2 lists some fish that occur in the nearshore waters of the gulf. All these fish inhabit the bays during at least part of their life cycles (Hoese and Moore 1977).

Table 2. Fish inhabiting the nearshore community along the Texas coast. Fish listed include only those species comprising 5% or more of the catch by Chittenden and McEachran (1976).

Scientific name	Common name	Percent of catch (by numbers)
Micropogonias undulatus	Atlantic croaker	30
Trichiurus lepturus	Atlantic cutlassfish	14
Cynoscion nothus	Silver seatrout	13
Stellifer lanceolatus	Star drum	10
Cynoscion arenarius	Sand seatrout	8
Polydactylus octonemus	Atlantic threadfin	5
Arius felis	Hardhead catfish	5

Generally, the sport and commercial fishermen along the Texas coast fish for the same species, but a few species are not common to both fisheries (Hoese and Moore 1977). Fish important to commercial and sport interests include red drum (*Sciaenops ocellatus*), trout (*Cynoscion* spp.), and black drum (*Pogonias cromis*) (TPWD 1971).

A large commercial fishery has existed along the Texas coast for many years. Table 3 lists data compiled for the 7 years 1971 through 1977 on the commercial catch of fish in the Gulf of Mexico along the Texas coast. The commercial value of this catch ranged from $1.7 million in 1971 to $0.6 million in 1977 (NOAA 1972-1975, 1977, 1978a, 1978b).

Table 3. Commercial fish catches from the Gulf of Mexico along the Texas coast, 1971-1977. Values listed are in thousands of kilograms (NOAA 1972-1975, 1977, 1978a, 1978b).

Fish	1971	1972	1973	1974	1975	1976	1977
Cabio (ling)	6.7	10.2	7.2	0.1	12.2	12.1	9.1
Croaker	8.8	10.2	13.6	0.6	14.7	3.9	1.3
Black drum	34.3	20.4	29.3	82.9	28.4	41.8	28.1
Red drum	89.2	44.3	73.4	101.1	42.8	35.7	22.4
Flounder	85.6	150.4	112.9	11.3	114.7	83.2	45.4
Grouper	62.3	44.2	45.4	2.0	32.4	31.3	10.0
King whiting	32.4	42.0	32.3	4.2	113.5	22.2	12.1
Mullet	15.4	8.3	23.7	7.6	5.4	9.8	0.5
Pompano	0.6	0.5	0.1	0.4	0.7	1.5	0.2
Hardhead catfish	12.0	2.7	5.7	1.4	9.4	9.8	6.1
Spotted sea trout	125.8	118.6	240.6	68.3	113.5	92.4	50.1
White sea trout	-	0.2	0.3	0.1	2.5	0.6	-
Sheepshead	7.7	36.9	28.4	19.0	20.9	24.4	15.0
Red snapper	490.3	560.8	354.0	30.7	284.2	224.3	199.3
Unclassified	28,542.0	37.6	101.7	104.1	162.1	108.3	49.0
Total	29,517.5	1,087.5	1,068.5	1,035.6	912.3	701.3	448.6

Although the sport fishing industry is prevalent along the Texas coast and many sport fishermen frequent gulf waters, surprisingly little has been published regarding the numbers or species of fish caught by sportsmen in these waters. Fedler (1978, cited in Brogden and James 1979b) summarized the sport fish in the upper shoreface community. All other available literature either does not distinguish fish as sport species or does not differentiate between sport species caught in the gulf along the Texas coast and those caught in bays or in other areas of the gulf. The National Marine Fisheries Service is preparing a publication surveying marine recreational fishing in the Gulf of Mexico (D. G. Deuel, National Marine Fisheries Service, Washington, D.C.; pers. comm. 1980). This publication will provide much needed data regarding which gulf species are important to the sport industry but will deal with the catch of sport fish in the entire gulf rather than the various State catches from gulf waters.

5.3 OFFSHORE COMMUNITY

5.3.1 Fish

Fish of the offshore community have been studied by Moore et al. (1970), Chittenden and McEachran (1976) and Chittenden and Moore (1976), using trawls, which unfortunately miss many species. The dominant species of this community is the longspine porgy (*Stenotomus caprinus*). Other fish found here include the inshore lizardfish (*Synodus foetens*), rock sea bass (*Centropristis philadelphica*), wenchman (*Pristopomoides aquilonaris*), sand seatrout (*Cynoscion arenarius*), Atlantic croaker (*Micropogonias undulatus*), gulf butterfish (*Peprilus burti*), and Mexican searobin (*Prionotus paralatus*).

Fish of this community, in contrast to those of the nearshore and upper shoreface communities, are often independent of estuaries. Of the fish listed above, only the inshore lizard fish, sand seatrout, and Atlantic croaker frequently occur in the bays (Hoese and Moore 1977).

The offshore reefs along the Texas coast support another, more tropical community of fish. Groupers (*Epinephelus* spp.), red snappers (*Lutjanus campechanus*), butterflyfish and angelfish (family Chaetodontidae), damselfish (family Pomacentridae), wrasses (family Labridae), and parrotfish (family Scaridae) are characteristic fish found near reefs (TPWD 1971; Hoese and Moore 1977). Many of these fish also occur near oil platforms in the gulf (Sonnier et al. 1976; Hoese and Moore 1977).

5.3.2 Marine Turtles

The five marine turtle species in the Gulf of Mexico are the leatherback (*Dermochelys coriacea*), loggerhead (*Caretta caretta*), green turtle (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), and Kemp's ridley (*Lepidochelys kempi*). Loggerheads and green turtles along the Texas gulf coast are now considered threatened under federal law; the other three sea turtle species are listed as endangered.

Due to the pelagic nature of marine turtles, many aspects of their biology remain unknown. Only fragmentary data are available on factors such as reproduction, feeding, activity, migration habits, growth, seasonality, distribution, and critical habitats.

Leatherbacks are the most easily distinguished marine turtles because the carapace (dorsal shell) lacks horny scutes (scales) and instead is covered with a ridged, leathery skin. The smooth shell is elongate and triangular and has seven prominent ridges on the carapace and five on the plastron (ventral shell). The structure and color of the leatherback are described in detail by Deraniyagala (1939).

Leatherbacks are the largest living turtles. Pritchard (1971) found that the carapace length of 192 mature female leatherbacks from French Guiana ranged from 137.3 to 180.3 cm. According to Pritchard (1971), most published weights that are actual measurements and not estimates fall within 295 to 590 kg. (650 to 1,300 lb).

Leatherbacks, often found far out in the open sea, are the most powerful swimmers and most pelagic of marine turtles. Leary (1957) reported a group of about 100 leatherbacks in the gulf surf along a 48-km transect line extending up the coast north from Port Aransas, Texas. The turtles appeared to be associated with a dense school of cabbagehead jellyfish (Stomolophus meleagris).

Leatherbacks very rarely nest in the United States (Caldwell et al. 1955a). Hildebrand, according to Pritchard (1971), was informed of a few nesting individuals on Padre Island, Texas, in the 1930's, but none have been seen since.

The limited information available on the food habits of the leatherback indicates that it is primarily carnivorous with a predilection for jellyfish and tunicates (Brongersma 1969). In addition, stomachs of wild specimens contained sea urchins, squid, crustaceans, fish, and blue-green and floating algae (Ernst and Barbour 1972). Algae is thought to occur through accidental ingestion while the turtles feed on something else (Pritchard 1971).

The Atlantic loggerhead is a large (71 to 213 cm) sea turtle with a broad head and a reddish brown heart-shaped carapace. Ernst and Barbour (1972) stated that Caretta is probably the largest hard-shelled turtle living. Adults average about 136 kg (300 lb), but vastly larger individuals have been recorded. Pritchard (1967) reported recorded weights up to 454 kg (1,000 lb).

Loggerheads occur throughout the Gulf of Mexico but are more abundant in the eastern gulf than along the Texas coast. They are considered confirmed wanderers (Caldwell et al. 1955b) and may occur anywhere within their range.

Loggerheads are omnivorous but primarily carnivorous, feeding on crabs, barnacles, conchs, mussels, clams, oysters, sponges, jellyfish, squid, amphipods, sea urchins, tunicates, borers, and various fish (Carr 1952; Brongersma 1972; Ernst and Barbour 1972; Rebel 1974). Vegetation consumed includes sea grasses (Zostera, Thalassia) and various algae, including Sargassum (Ernst and Barbour 1972). Ernst and Barbour (1972) stated that Caretta commonly searches coral reefs, rocky places, and old boat wrecks for food.

Loggerheads' accidental capture by shrimp trawls and their subsequent death occur primarily along the Atlantic and Gulf of Mexico coasts of the

United States (Ogren et al. 1977). The magnitude of accidental catches and associated mortality is unknown, but the incidence of loggerhead captures by Georgia shrimp fishermen was once frequent enough to be considered a nuisance (Caldwell et al. 1959). Caldwell (1963) guessed that less than half of the turtles caught in shrimp trawls survived. Efforts are in progress to modify trawls to prevent turtle capture (Ogren et al. 1977; Bullis and Brummond 1978).

The green turtle is a medium-sized sea turtle (72 to 141 cm) with an oval carapace. Despite its common name, which probably refers to the color of the body fat, the green turtle's color varies (Deraniyagala 1939; Frazier 1971).

Hildebrand (1979) found green turtles feeding in coastal lagoons of south Texas. They are primarily herbivorous and feed on marine grasses such as Zostera, Thalassia, and Halophila and on marine algae (Ingle and Smith 1949). Hirth (1971) included invertebrates such as crustaceans, coelenterate medusae, mollusks, and sponges as occasional food items. Young turtles are assumed to be largely carnivorous (Ingle and Smith 1949; Hirth 1971). Mortality of young green turtles caused by eating balls of tar and oil in the ocean was reported by Witham (1978).

The Gulf of Mexico is not an important breeding area for the green turtle. The rookeries (breeding beaches) closest to the Gulf of Mexico are on the east coast of Florida (Lund 1974) and Quintana Roo, Mexico (Marquez 1976).

Green turtles, primarily diurnal, may spend the night on the bottom or on submerged rock ledges (Carr and Ogren 1960). They probably only rarely live deeper than 21 m (12 fm) (Carr 1967).

The hawksbill resembles the green turtle in several ways: it has an oval carapace, a small to medium-sized head, and a carapace predominantly brown with extremely variable light streaks or flecks (Deraniyagala 1939; Carr 1952).

Despite commercial exploitation of this species for tortoise shell, populations persist in many areas within continental U.S. waters (Mack et al. 1979). Reports exist for recent sightings of this species near Aransas Pass on the coast of Texas. The actual abundance and movements of this species are poorly known.

Hawksbills are omnivorous, feeding on a wide range of animals and, occasionally, plants. They are most often associated with coral reefs and rocky shorelines where they graze on the abundant invertebrate fauna. The hawksbill is probably a diurnal species. According to Ingle and Smith (1949), hawksbills only feed in daylight in captivity. Frazier (1973) reported diurnal nesting by hawksbills in the Indian Ocean. Commerce in and harrassment of this endangered species are prohibited in the United States, Mexico, and many other countries. However, international traffic in tortoise shell products and in stuffed juvenile hawksbills is common (Mack et al. 1979).

Kemp's ridley is the smallest of the marine turtles. Nesting females studied by Chavez (1967) ranged from 59.5 to 75.0 cm ($\bar{x}$ = 64.6 cm) in the straight-line carapace length. Adult males and females are of similar size (Pritchard and Marquez 1973).

The ridley carapace is relatively round in dorsal profile. The head and neck are proportionately wide relative to the carapace. Dorsal surfaces of the head, limbs, and carapace are light gray, but individuals with an olive-green to brownish carapace also occur (Pritchard and Marquez 1973).

The ridley has one of the most restricted distributions of marine turtles. Adults are restricted primarily to the waters of the Gulf of Mexico.

Pritchard and Marquez (1973) provided the most significant data compilation on the abundance and movements of ridleys. The northern Gulf of Mexico and Bay of Campeche are of primary importance to this species. Adults tagged on nesting beaches in Tamaulipas, Mexico, subsequently were recovered from the shrimp-rich areas of the gulf, including the coast of Texas. Carr (1961) interviewed shrimpers from Port Isabel, Texas, who reported ridleys common in inshore waters of the area in spring and early summer. The turtles caught in shrimp trawls off Texas often had shelled eggs in the oviducts and thus were close to a nesting beach. Since nesting is known to occur in the western Gulf of Mexico from Padre Island, Texas, south to southern Veracruz, Mexico, concentrations of adult ridleys can be expected in these waters from May through August.

Aggregations of hatchling ridleys are virtually unknown after they leave the nesting beaches in midsummer. Pritchard and Marquez (1973) assumed that the young swim offshore until they reach sargassum mats and the major clockwise current of the western gulf. This current presumably carries the young turtles progressively north and east along the Texas coast and adjacent coastal areas.

The ridley population has experienced a drastic decline since 1947 when an estimated 40,000 female ridleys nested at Rancho Nuevo, north of Tampico, Mexico (Pritchard and Marquez 1973). The latest estimate of the total world population of mature females is 2,500 to 5,000 (Pritchard and Marquez 1973).

Nesting is known to occur infrequently on the beaches of Padre Island, Texas (Werler 1951; Carr 1961). Ridley nests were found on Padre Island in 1948 and 1950 (Carr 1961) and in 1968, 1974, and 1976 (Ogren 1977).

This species has been conspicuous in the incidental catch of shrimp trawlers. On the basis of interviews with shrimp fishermen (Carr 1961), ridleys were commonly caught in trawls off the Texas coast. The ridley is known predominantly from shallow water areas (Carr and Caldwell 1956; Pritchard and Marquez 1973). Ridleys were also captured by shrimpers in the heavily trawled areas of the Louisiana coast and offshore from Campeche, Mexico (Pritchard and Marquez 1973).

The feeding habits of the ridley are poorly known. The species appears to prefer crustaceans and is often associated with areas of maximal crustacean density, especially inshore areas. Crabs of the following types have been recorded as ridley food items: Callinectes sapidus, C. ornatus, Palynichus spp., Portunus spp., Hepatus spp., and Panopeus spp. (Pritchard and Marquez 1973; Zwinenberg 1977). Dobie et al. (1961) characterized the ridley diet as resembling one from inshore areas with mud substrates. Many food items recorded for the ridley are organisms living in estuarine and inshore areas with silt substrates. This suggests that inshore areas of the Gulf of Mexico are important habitats for this species (Zwinenberg 1977).

A joint conservation program between Mexico and the United States to reintroduce the ridley to Padre Island, Texas, has been underway since 1978. Ridley eggs and young are raised to be released later off Padre Island. It is hoped the young turtles mature and return to Padre Island to nest.

5.3.3 Birds

Approximately 63 species of birds have been reported from the waters of the Gulf of Mexico off the Texas Barrier Islands Region (Oberholser et al. 1974). This figure does not include the many land birds and shore birds that migrate across the area.

The 63 or so species can be grouped into three main categories: (1) those common in lagoons and estuaries, but rare in the gulf, (2) regular users of inshore gulf waters, and (3) those common offshore, but rare inshore. The first category includes about 14 species, common in lagoons and estuaries, that use gulf waters only sporadically. The white pelican (*Pelecanus erythrorhynchos*), the pied-billed grebe (*Podilymbus podiceps*), several species of waterfowl, and some small terns are in this category.

The second category comprises about 21 species that are regular users of the inshore gulf waters, seaward of the barrier islands. The brown pelican (*Pelecanus occidentalis*), black skimmer (*Rynchops nigra*), royal and Sandwich terns (*Sterna maxima* and *S. sandvicensis*), laughing gull (*Larus atricilla*), and double-crested and olivaceous cormorants (*Phalacrocorax auritus* and *P. olivaceus*) breed on the Texas coast; others are primarily winter residents. The brown pelican is discussed in detail in the Corpus Christi Bay synthesis (Section 5.6.2).

The second category also includes coastal gulls that feed extensively on shore and in lagoons but also feed on schooling fishes and fishing boat refuse in the gulf. The ring-billed gull (*Larus delawarensis*) seldom ventures far from the shore, but the herring gull (*L. argentatus*), Bonaparte's gull (*L. philadelphia*), and the laughing gull (*L. atricilla*) may be found in season throughout the study area. Four duck species, the oldsqaw (*Clangula hyemalis*), and the surf, white-winged, and common scoters (*Melanitta perspicillata*, *M. deglandi*, and *Oidemia nigra*) are primarily occupants of inshore waters, but all are northern species that are quite rare as far south as Texas. They feed by diving for benthic plants and invertebrates (Palmer 1976).

Also in the second category are common and red-throated loons (*Gavia immer* and *G. stellata*) that winter both in lagoons and off barrier islands. They seldom move more than a few kilometers from shore and are probably more common off passes than elsewhere (McIntyre 1978). These species feed by diving for midwater and benthic fish and crabs.

In the third category are about 17 species of birds that occur regularly offshore but rarely inshore. These oceanic species include the gannet (*Morus bassanus*), white-tailed tropicbird (*Phaethon lepturus*), magnificent frigatebird (*Fregata magnificens*), two shearwaters, two storm petrels, two boobies, phalaropes, jaegers, and several gulls and terns. Small numbers of sooty terns (*Sterna fuscata*) breed on the Texas coast (Blacklock et al. 1978) but most are migrants.

Another bird in the third category is Cory's shearwater (*Calinectris diomedea*), which breeds in the Azores and other eastern Atlantic islands. This species was unknown in Texas before 1974 (Oberholser et al. 1974), but numbers of individuals have since been reported during the summer off the south Texas coast (Fritts and Reynolds 1981). Cory's shearwaters appear to be more common off Florida coasts in recent years, possibly because of the better protection of their nesting islands in recent decades (W. Hoffman, Denver Wildlife Research Center, Belle Chasse, Louisiana; pers. comm. 1980). Audubon's shearwaters (*Puffinus lherminieri*) breed in scattered colonies throughout the Bahamas and small islets off the greater and lesser Antilles and are rare off Texas during the summer (Oberholser et al. 1974; Fritts and Reynolds 1981). Cory's shearwaters feed on fish, squid, and crustaceans at the sea surface; Audubon's shearwaters dive for similar food items.

Also in the third category are phalaropes and storm petrels that feed on fish larvae, macroplankton, and other organisms at the sea surface (Bent 1927; Palmer 1962). Phalaropes are migrants from farther north, Harcourt's petrel (*Oceanodroma castro*) comes from the tropical Atlantic, and Wilson's petrel (*Oceanites oceanicus*) comes from subantarctic islands.

Other oceanic birds are magnificent frigatebirds (*Fregata magnificens*) and the jaegers (*Stercorarius pomarinus*, *S. parasiticus*, and *S. longicaudus*). They obtain some food by robbing other seabirds, but they also fish on their own. Jaegers are also highly predatory, possibly attacking migrating land birds and shorebirds.

The boobies (*Sula dactylatra* and *S. leucogaster*) and gannet (*Morus bassanus*) are oceanic birds that feed on fish by spectacular aerial plunges. The boobies are summer migrants from Caribbean and Central American colonies; the gannets are winter visitors from the colder waters of the North Atlantic.

At least 11 other seabirds are accidental or very rare in gulf waters off the Texas Barrier Islands Region. All three groups are represented although about half of these are oceanic species.

Seabirds using the gulf waters off Texas may be affected both positively and negatively by human use of the area. Gulls and terns associate with shrimp boats and other fishing boats off the coast. The waste fish and offal they obtain from the boats may be an important source of food, and this association may allow the region to support larger bird populations in some seasons than would otherwise be possible.

The structures erected or floating offshore, such as oil rigs and navigation markers, may be important perching sites for seabirds and may allow coastal species like brown pelicans, royal terns, and cormorants to exploit otherwise unavailable offshore areas. In August, masked boobies were seen flying from two drilling rigs east of Corpus Christi (Fritts and Reynolds 1981).

In terms of negative effects, floating oil is a major hazard for seabirds. Those birds that normally spend their nights on the water are most vulnerable since oil can float in among them unnoticed. Loons, grebes, and ducks are probably most vulnerable to floating oil in Texas waters.

Although cormorants normally roost on land, they are also susceptible to oiling. In August 1979, the most prominent avian victims of the Ixtoc I oil spill were masked boobies, considered rare in Texas waters (National Oceanic and Atmospheric Administration briefing, November 1979, National Wildlife Federation, Washington, D.C.).

5.3.4 Mammals

The marine mammal fauna of the Gulf of Mexico consists almost entirely of cetaceans: whales and dolphins (porpoises). In addition, two other groups are represented: the pinnipeds (seals and sea lions) and the sirenians (manatees). Of these three groups, approximately 31 species occur regularly in the gulf, have occurred there some time in the historical past, or have been reported so close to the gulf that occasional strays may be expected. Many of these species are common in gulf waters while others are rare throughout their entire range. Because of the wandering behavior of these animals, arbitrary boundaries for their distribution are unreasonable, and this report will cover the Gulf of Mexico in general. All marine mammals are afforded protection under the Marine Mammal Protection Act of 1972.

The right whale (*Eubalaena glacialis*) is the only member of the family Balaenidae known from the gulf. Based on historical evidence, the right whale was once common, but overhunting until 1953 reduced the species to near extinction. On 30 January 1972, one washed ashore near Freeport, Brazoria County, Texas (Schmidly et al. 1972). Only one other record exists for the right whale in the gulf (Moore and Clark 1963), but increased sighting reports over the past 25 years in the Atlantic may be cause for some optimism regarding the recovery of the population.

Right whales approach close to the coast; pairs and females with calves are often sighted just a few hundred meters offshore. Because of these habits, right whales are threatened by pollution, habitat destruction, and ship traffic (Winn et al. 1979). This species is not easily startled and is readily approached by vessels (Prescott et al. 1979).

Six species of whales in the family Balaenopteridae are known from gulf waters, including the blue whale (*Balaenoptera musculus*), sei whale (*B. borealis*), fin whale (*B. physalus*), Bryde's whale (*B. edeni*), minke whale (*B. acutorostrata*), and the humpback whale (*Megaptera novaeangliae*). These are all pelagic, large-bodied species. The blue whale, the largest living mammal, reaches lengths of 25.9 m. Members of this family and the family Balaenidae are unusual in that baleen plates in adult animals replace embryonic teeth. The baleen plates are thin, arranged one behind the other, and are suspended from each side of the palate into the mouth cavity. This efficient straining mechanism filters their favored food, krill (planktonic crustaceans). Past excessive commercial exploitation has decreased the populations of fin and blue whales (Vaughan 1972).

The family Physeteridae consists of two recent genera: *Physeter*, with the single species *P. catodon*, the sperm whale; and *Kogia* species *K. breviceps* and *K. simus*, the pygmy and dwarf sperm whales. The sperm whale is large, with males sometimes over 19.8 m long, and is bluish black overall. The habits of *Physeter* are fairly well known, probably because man persistently has hunted it, but little information has been published on *Kogia*.

Physeter is social, usually traveling in groups of 15 to 20 individuals, but groups of as many as 1,000 individuals have been recorded (Vaughan 1972). *Physeter* feeds primarily in deep water on squid, including giant squid, and a variety of bony fish, sharks, and skates. Sperm whales are considered uncommon in the Gulf of Mexico but were once abundant enough there to support full-scale whaling operations.

Three beaked whales of the family Ziphiidae are known from the gulf: Blainville's beaked whale (*Mesoplodon densirostris*), Antillean beaked whale (*M. europaeus*), and the goosebeaked whale (*Ziphius cavirostris*). These medium-sized whales range in lengths from 4.3 to 7.9 m. According to stranding records, no beaked whales are common in the gulf, but *Ziphius* is the most commonly stranded of the three (Schmidly 1981).

Eleven genera and fifteen species of the family Delphinidae (dolphins and porpoises) occur in the Gulf of Mexico. This diverse group contains small- to medium-sized species and the most agile and speedy of all the cetaceans; these animals swim together in groups with precision and regularity of movement (Walker 1975).

The bottlenose dolphin (*Tursiops truncatus*) is the most commonly observed cetacean in the Gulf of Mexico. Considered an inhabitant primarily of inshore waters, this dolphin occurs in greatest numbers in the vicinity of passes connecting the larger bays with the gulf; but it also occurs in back bays where water salinity is lower (Lowery 1974). These habits may make *Tursiops* even more susceptible to harm from human activities than is the right whale.

No estimates of *Tursiops* population size for the gulf alone exist, but Prescott et al. (1979) estimated 10,000 ± 3,700 for all of Florida and the Gulf of Mexico. Orr (1977) included offshore populations and estimated about 20,000 animals for the same area. Using boat and land observations, Shane and Schmidly (1979) estimated the number of *Tursiops* in Aransas Bay to vary from 48 to 104 individuals in October and 164 to 281 individuals in January.

Information from the western gulf suggests that *Tursiops* populations have been reduced. Their number in Louisiana waters appears reduced from former abundance (Lowery 1974). The decline is attributable to various factors, including the explosion of seismographic charges in offshore waters and the shooting of dolphins by commercial and sport fishermen (Lowery 1974). *Tursiops* abundance in Texas has declined drastically during the 20th century (Gunter 1942).

In contrast to the abundant *Tursiops*, other members of its family are exceedingly rare in the gulf. The pygmy killer whale (*Feresa attenuata*) is one of the rarest of all mammals on the basis of the number of specimens in museum collections (Lowery 1974). All six records from the gulf are from the southern coastal regions of Texas and Florida, consistent with the apparent tropical distribution of this species in other oceans (Schmidly 1981).

The largest delphinid is the killer whale (*Orcinus orca*), with males sometimes reaching a length of 9.1 m (Lowery 1974). This species is easily distinguished from other delphinids by its distinctive black and white pattern and its high (up to 1.8 m in males) sharply erect, hooked dorsal fin.

The killer whale is rare off the Texas coast. A single sighting was reported by Gunter (1954) 56.3 km southeast of Port Aransas, Texas, in 1935.

Only two members of the order Pinnipedia have ever been reported from the Gulf of Mexico; one is extinct and the other introduced. The only seal native to the Gulf of Mexico was the West Indian monk seal (Monachus tropicalis), now considered extinct (Rice 1977). This seal formerly occurred along the Texas coast from Brownsville to as far north as Galveston (Schmidly 1981). The most recent sight records for the Texas coast were one in 1932 and one in 1957 (Gunter 1968). The California sea lion usually occurs only on the Pacific coast, from British Columbia south to the Tres Marias Islands off Nyarit, Mexico (Lowery 1974). Its presence in the Gulf of Mexico is presumed an accidental introduction by man, possibly from a sea aquarium, and it has never been recorded near the Texas coast.

Extermination of the West Indian seal, from overexploitation for its valuable oil, has been reviewed by Allen (1942), Kellogg (1943), Moore (1953), and Gunter (1954).

Members of the order Sirenia (the dugongs, sea cows, and manatees) are the only completely herbivorous aquatic mammals (Vaughan 1972). Only the West Indian manatee (Trichechus manatus) occurs in the Gulf of Mexico. It occurs along the coast and coastal rivers of the Southeastern United States, from North Carolina southward to southern Florida, westward in the Gulf of Mexico to southern Texas and Veracruz, and through most of the West Indies and Caribbean waters of Central America to northern South America (Lowery 1974).

The general appearance of these animals is unusual. They have a rounded body, small head, forelimbs modified as flippers, no hind limbs, and a distinctly spatulate tail. They are dull gray to blackish, and their skin may be as much as 5.1 cm thick (Walker 1975). Adult manatees range in length from 2.6 to 3.5 m and may weigh as much as 890 kg. (Odell et al. 1978).

Manatees from coastal Texas, especially in the lower Laguna Madre, are somewhat more numerous than in the northern gulf, but the species is casual even there (Lowery 1974). Manatees on the Texas coast probably come from Mexico since they are known from Veracruz and Tamaulipas (Moore 1951). The manatee is intolerant of low temperatures, and even in Florida its numbers often seriously decline during occasional cold spells (Lowery 1974). Manatees that migrate northward along the gulf coast are probably affected by freezing weather associated with cold fronts that move into the Texas coastal region.

Manatees feed on marine, brackish, and freshwater plants, and on some terrestrial plants that hang over the water. Their flippers direct vegetation into the mouth, the protractile lip picks up food, and the upper lip's snout bristles work food into the mouth (Walker 1975).

To date, no documentation of predation upon manatees exists although sharks and piranhas have been suggested as potential predators (Husar 1978). Manatee habitat requirements (i.e., shallow bays, estuaries, and rivers) make them susceptible to motorboat propellers. Motorboat propellers and keels strike submerged manatees before they can react to the noise, resulting in deep lacerations that may prove fatal (Husar 1978). The greatest threat to manatees is probably a night or two of freezing weather that can result in pneumonia and death (Cahn 1940).

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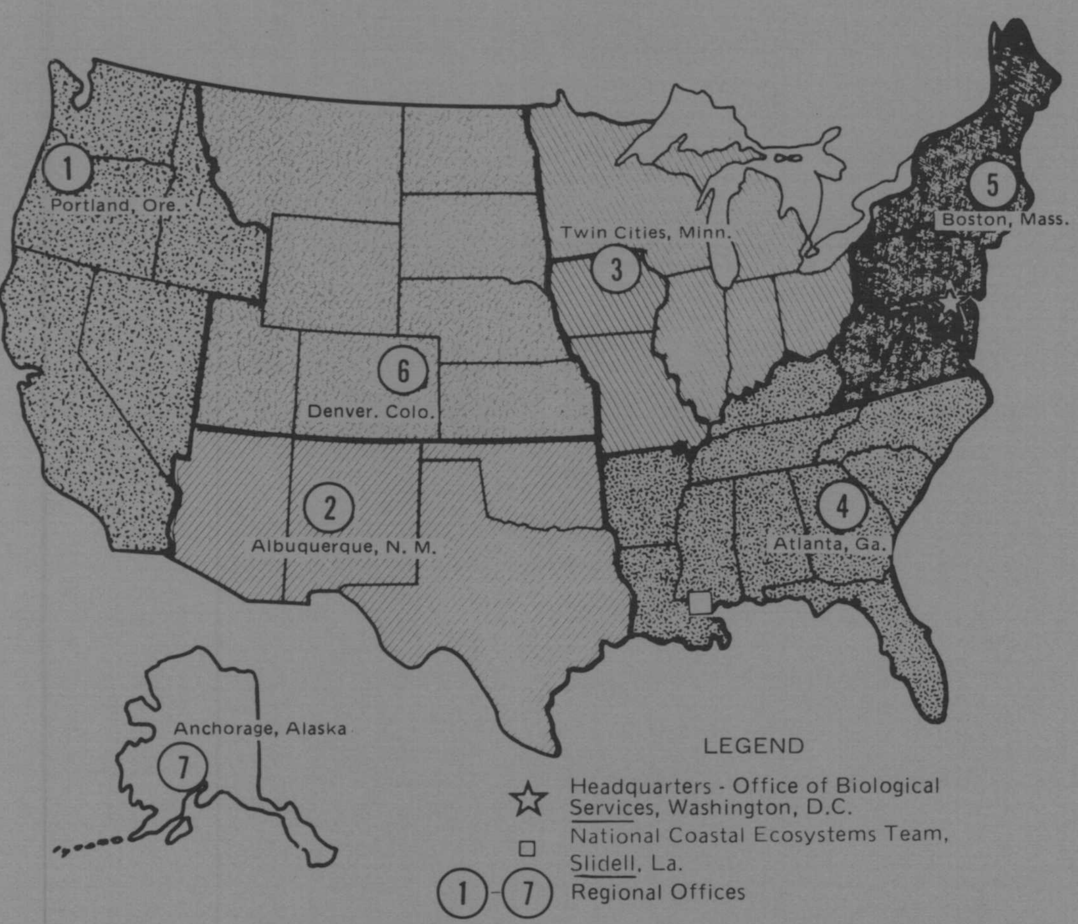

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