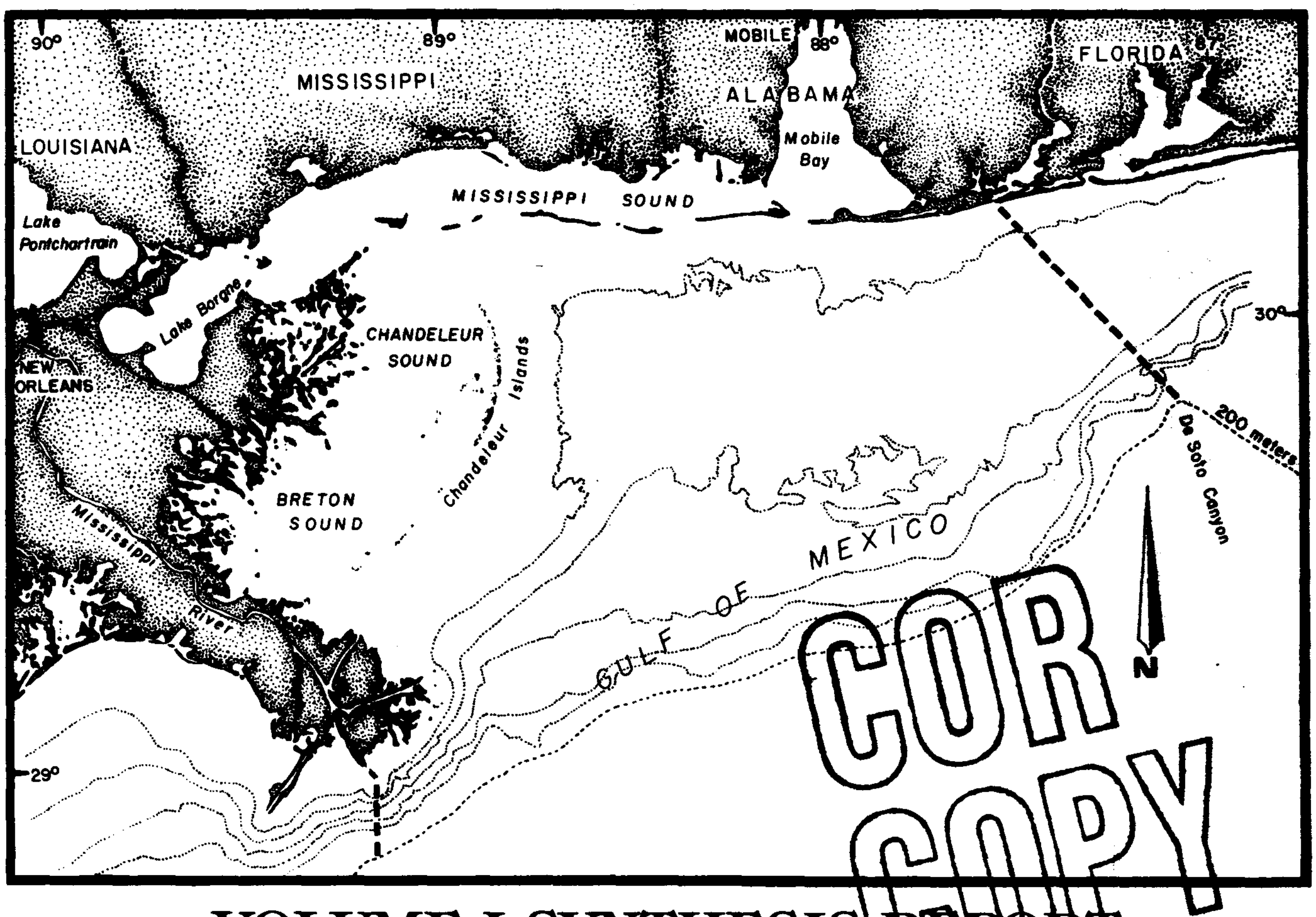
TUSCALOOSA TREND REGIONAL DATA SEARCH AND SYNTHESIS STUDY



VOLUME I SYNTHESIS REPORT

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Prepared For
U.S. Department of the Interior
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TUSCALOOSA TREND REGIONAL DATA SEARCH AND SYNTHESIS STUDY

FINAL REPORT
VOLUME I SYNTHESIS REPORT

Prepared under Contract No. 14-12-0001-30048

By

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ABSTRACT

Information on the natural resources of the Tuscaloosa Trend OCS (southeastern Louisiana-Mississippi, and Alabama), from coastal marshes to a depth of 200 m, have been collected, annotated, and synthesized. Over 1200 published and unpublished data sources were reviewed and citations computerized in the NEDRES format to provide MMS a means for retrieving, updating, and expanding the data base. A conceptual ecosystem model of the Tuscaloosa Trend shelf has been developed that represents the OCS region as an integrated system of physical and biogeochemical components, stressing functional relationships and interactions with adjoining ecosystems. Synthesis report chapters characterize the ecosystem model, physiography and geology, physical and chemical oceanographgy, ecological resources, and socioeconomic features of the region. Data gaps are identified and suggestions for additional research on the OCS are discussed.

The Tuscaloosa Trend lies primarily on the broad Mississippi-Alabama shelf and is a transitional region between the West Florida shelf and the active modern delta of the Mississippi River. The main geographic features include eastern Mississippi River Delta, Chandeleur-Breton Sounds and Islands, Mississippi Sound and adjoining barrier islands, and Mobile Bay. Water mass circulation in both coastal and shelf waters is strongly affected by open Gulf circulation (e.g., Loop Current), diurnal tides, sustained winds, and freshwater discharge from major river systems (e.g., Mississippi and Mobile Rivers). Net longshore littoral drift is generally to the west along the Mississippi-Alabama barrier islands and to the north along Chandeleur-Breton Islands as determined from island migration patterns. Transport of nutrients to the inner shelf occurs during periods of high river dishcarges, while outer shelf areas are provided with nutrients primarily during intrusions of oceanic waters. Pollutants are generally restricted to areas of localized inputs (i.e., discharges from coastal industrial and municipal centers).

Approximately 269,000 acres of coastal marshes fringe the Tuscaloosa Trend area and contribute significantly to the productivity of nearby bays and sounds, especially as primary nursery grounds for finfish and shellfish species of sport and commercial importance. Demersal fishes and benthic community patterns are defined on the basis of habitat parameters such as sediment type, depth, salinity, and seasonality. An overview of the biotic interrelationships between the OCS and adjacent coastal marshes and estuaries includes discussions on seasonal migrations and trophic interactions.

The socioeconomic resources of the Tuscaloosa Trend area include extensive international and domestic waterborne commerce, expanding tourism and recreation, a highly productive recreational and commercial fishery industry, and an increasingly active oil and gas industry.

Additional studies which couple the physical and biogeochemical processes on the shelf are needed in order to formulate effective OCS management policies for the Tuscaloosa Trend region.

EXECUTIVE SUMMARY

INTRODUCTION

The Tuscaloosa Trend Regional Data Search and Synthesis Study is designed to identify and summarize important information pertaining to the environmental and socioeconomic characteristics of this area of the Gulf of Mexico. The geographic boundaries of the Trend area are defined by South Pass on the west (i.e., the southeast corner of the Mississippi River Delta) and by a line from the head of the DeSoto Canyon and the boundary between Alabama and Florida on the east. The seaward limit of the study area is the 200 m isobath, while the landward limit is the coastal areas of eastern Louisiana, Mississippi, and Alabama.

The report characterizes the Trend area with respect to physiography, geology, physical oceanography, chemical oceanography, biology, socioeconomics, and a conceptual model of the Trend area. The Executive Summary is intended to provide an overview of the significant aspects of these topics as well as important information gaps which should be addressed in future investigations of the management of Outer Continental Shelf resources by the Minerals Management Service.

CONCEPTUAL ECOSYSTEM MODEL

Conceptual representations of physical, chemical, geological, and ecological processes were developed for the Tuscaloosa Trend ecosystem as part of the data search and synthesis effort. These representations were to provide a framework for information search and synthesis activities and for identification of data gaps that could be filled in subsequent research efforts. The conceptual model will also provide a means by which such research activities could be directed and communicaiton between researchers be enhanced. Finally, the model should provide the Minerals Management Service with a management device which clearly identifies the interrelationships and potential multiple use conflicts among the resources of the Trend study area.

The approach to development of the Tuscaloosa Trend conceptual ecosystem model involves: (1) review and evaluation of existing marine ecosystem conceptualizations; (2) selection of an appropriate existing conceptualization; and (3) adaptation of the selected model to the Tuscaloosa Trend study area. The review activities identified the conceptualization of the New York Bight ecosystem by McLaughlin et al. (1975) as being the most applicable of those studied. This model, developed for the NOAA Marine Ecosystem Analysis (MESA) Program Office, represents an ecosystem approach to marine pollution problems, and can serve as a framework for a scientific research program and as a tool for resource management. Adaptation of this conceptualization to MMS needs is consistent with the goals of the National Marine Pollution Program Plan, which requires that federally funded research be coordinated across agencies and disciplines. Consistent with the MESA approach, the conceptualization of the Tuscaloosa Trend study area is hierarchical, consisting of three levels: Level 1 - the whole ecosystem; Level 2 - individual subsystems (e.g., sedimentological, biogeochemical and ecological); and Level 3 - specific ecological applications (e.g., nekton life histories, marsh-estuarine interactions, pelagic and benthic food webs).

PHYSIOGRAPHY

The Gulf of Mexico is a small mediterranean-type sea which encompasses over 1.5 million square kilometers. Its continental shelf ranges in width from only 10 km near the Mississippi River Delta to 280 km off southern Florida. The Tuscaloosa Trend study area lies primarily in the Mississippi-Alabama Shelf subprovince of the continental shelf and in the Coastal Lowland subprovince of the East Gulf Coastal Plain. The western portion of the Trend area encompasses features associated with the subsidence of the now-abandoned St. Bernard Delta complex as well as with the active modern delta. Several clusters of islands occur in this area, including Chandeleur, Breton, and numerous smaller islands. The waters of Chandeleur and Breton Sounds extend for 96 km along the abandoned St. Bernard Delta and have an average depth of 2 m.

Lake Borgne lies north of these features. It also has an average depth of approximately 2 m and marks the west end of the Mississippi Sound. The Sound is a long, narrow, protected, brackish body of water which extends eastward along the coasts of Mississippi and Alabama. It ranges in width from 24 to 130 km and has an average depth of 3 m. Six barrier islands separate the Sound from the Gulf, while freshwater input is provided largely by discharges of the Pearl and Pascagoula Rivers. The barrier islands (Cat, West and East Ship, Horn, Petit Bois, and Dauphin) range from 4 to over 22 km in length and from 0.3 to 1.9 km in width. Dunes as high as 14.3 m occur on Dauphin Island.

Mobile Bay is a submerged river valley which is approximately 49 km long (north-south) and 37 km wide at its widest point, between Mississippi Sound and the eastern shelf of Bon Secour Bay. It averages approximately 3 m in depth. The Bay merges with Mississippi Sound at Pass aux Herons, which is 1.6 km wide. The southeastern margin of the Bay is delineated by the Fort Morgan Peninsula.

The oceanic portion of the Tuscaloosa Trend area lies on the Mississippi-Alabama Shelf, which is a triangular-shaped region extending from the Mississippi River Delta to the DeSoto Canyon. The shelf is approximately 128 km wide in the west and narrows to 56 km in the east. It has a mean declivity of approximately one meter per kilometer. The shelf slope break occurs at an average depth of 55 m.

The DeSoto Canyon marks most of the eastern boundary of the Trend study area. It is an S-shaped canyon formed by late Tertiary erosion, deposition, and structural control by diapiric activity.

The Gulf shelf from Mobile Bay westward has been influenced primarily by the St. Bernard and Balize Deltas, and by sedimentation from the Mobile and Pascagoula Rivers. Areas to the east are subject to only slight sedimentation and some features produced during the Holocene transgression are still present.

GEOLOGY

The primary geologic feature of the Tuscaloosa Trend region is the Gulf Coast geosyncline. This structure extends from Alabama to northeast Mexico and is characterized by a clastic wedge created by regional subsidence and rapid deposition. These deposits range in thickness from greater than 600 m seaward of the Mississippi River Delta to very thin or absent on the Wiggins Arch. The geosyncline exhibits salt deposits created by upward migration of Jurassic age Louann Salt.

The topography and sediment distribution of the continental shelf are products of a combination of sea level transgressive-regressive episodes and deltaic progradation and destruction. Except for peripheral deposition of sediments from the Mississippi River Delta, little active sedimentation is presently occurring on the Tuscaloosa Trend study area shelf and slope.

Changes in sedimentation patterns associated with the output of the Mississippi River result in deltaic areas of rapid progradation and accretion as well as areas characterized by subsidence and erosion. The Mississippi River Delta's modern form has been created by 7,000 years of deposition. As many as 16 separate delta lobes have been formed within five deltaic complexes, two of which (the abandoned St. Bernard Delta and Plaquemines Modern Delta complex) occur within the Tuscaloosa Trend study area. The center of deposition appears to be shifting from these areas to the Atchafalaya Basin.

Barrier islands occur along both the Alabama-Mississippi coast and along the eastern Louisiana coast. Westward littoral drift along the Alabama-Mississippi barrier islands are thought to replenish the sands which constitute the shoreface, while portions of some of the island cores may be composed of Pleistocene age material. The average annual westward transport of sands along these northern barrier islands has been estimated to be 162,180 m^3.

Mississippi Sound lies landward of the Alabama-Mississippi barrier islands. Sound sediments are predominantly estuarine silty clays, which are concentrated in its center. Sands occur in a band along the periphery of the Sound. Surficial sediments in the eastern Sound are primarily derived from the Mississippi Delta, while western Sound sediments are prodelta clays deposited from the Pearl River.

Mobile Bay derives sediments primarily from the Mobile River system. The northern part of the Bay contains prodelta silts, clayey silts, delta front sands, and silty sands transported into the estuary by the Mobile River distributaries. The Bay margins contain a band of fine to medium sand, while the central and lower Bay sediments consist of varying amounts of silty clay and clay.

The eastern Louisiana barrier islands which delineate Chandeleur and Breton Sounds are composed of residual or reworked deltaic deposits from the abandoned St. Bernard Delta. The size of these islands has been decreasing as a result of reduced sediment supply as well as by patterns of sediment dispersal. Sediment movement nearshore exhibits a southerly drift pattern.

The Chandeleur and Breton Sounds landward of these barrier islands are characterized by a thin veneer of post-St. Bernard lagoonal sediments overlying marsh and fluviatile deposits. This veneer contains sediments ranging from sands to clays and varies in thickness from a few inches to several feet.

The mainland shore along these sounds is irregular as a result of subsidence and erosion patterns. Natural land loss is exacerbated by construction and maintenance of navigation channels, levees, diversions, and flood-control reservoirs. Canal dredging and dredged material disposal are locally important factors.

Shelf surface sediments in the Trend study area are distributed in six broad sedimentologic subdivisions and are characterized by rapidly deposited organic-rich clay and silt, fine quartz sand, shelly sands, and carbonate sands. The Mississippi-Alabama sand sheet is generally heterogeneous, as a result of such factors as patterns of Holocene transgression and regression, changes in sediment transport direction, and reworking by wave action and bioturbation.

Topographic pinnacles or reefs occur at the eastern edge of the Trend area. These relict features average 9 m in height and occur in water depths from 22.5 to 28.0 m and 32.3 to 36.5 m.

Geologic processes in the Trend area include relatively rapid changes in bathymetry related to depositional patterns along the delta front, as well as long-term formation and movement of geologic structures such as salt domes and faults.

The dynamic processes assocated with the Balize Delta of the Mississippi River result from rapid deposition and accumulation of organic-rich sediments. Accretion rates average 1m annually but accumulations of 5 m may occur during high flood stages. The unstable bottom topography produced by these processes includes such features as depressions and slides, mudflow gullies, erosional furrows, faults, and diapirs. Mudflow gullies are the most numerous and extensive erosional features of the delta front. The mechanisms which drive and initiate the movement and formation of these and other features are only partially understood but probably involve oversteepening of the upper delta front followed by high amplitude storm waves which trigger sediment transport downslope.

Sediment transport on the open outer continental slope and slope is thought to be driven by broad regional oceanic currents, shelf edge slumping, and major storm activity. Bedforms appear to be related to storms, tides, density currents, and oceanic currents. Bedforms have been defined in four zones in the Tuscaloosa Trend area and include smooth sand bottoms, low relief swells, large sand waves, and irregular hummocky topography.

Geohazards in the Trend area include shallow faulting, steep and unstable slopes, gas seepage, and peripheral sediment slumping associated with diapirs. Buried stream channels may also present geohazards as a result of variable sediment texture and biogenic gas accumulation. The shelf break in the Trend area exhibits traits which suggest that it may be susceptible to mass wasting.

PHYSICAL OCEANOGRAPHY

The climatology of the Tuscaloosa Trend area is influenced primarily by the anticyclonic Bermuda High. The High intensifies during the spring and causes winds to become southerly and southeasterly. It diminishes in the fall and the region is subjected to continental pressure systems and northerly winds. Summer air temperatures over the Gulf average 29°C, while average winter temperatures range from 17 to 23°C. Temperature extremes are greater in the coastal region. The coastal areas of the Trend experience heavy rainfall as a result of coincidence of northerly cold fronts and strong maritime, tropical air masses moving in the opposite direction. Annual coastal precipitation averages range from 137 cm at New Orleans to 162.5 cm at Mobile, with maximum rainfall occurring during the summer.

Tropical cyclones include hurricanes (wind velocities above 119 $km \cdot hr^{-1}$), tropical storms (velocities between 63 and 118 $km \cdot hr^{-1}$), and tropical depressions (velocities below 63 $km \cdot hr^{-1}$). Hurricane-force winds generally develop in tropical zones between 8° and 15°N latitude, although several hurricanes originated in the Gulf of Mexico since 1901. These storms may cause a surge height of over 4.5 m above normal sea level in addition to storm waves. Hurricanes affect bottom topography through extensive sediment resuspension and transport.

Wave height patterns in the Trend study area usually correspond to wind speed trends. Wave heights of 3.6 m may occur throughout the year on the shelf, while heights of 6 m or greater have been reported. Coastal areas experience similar seasonal trends but generally lower wave heights. Nearshore wave energies along the Mississippi River Delta coast are low compared to other major river deltas. Barrier islands in the Trend study area are subjected to the highest wave energy.

Water mass circulation in both coastal and oceanic waters of the Trend area is strongly affected by riverine discharges, including the Mississippi, Pearl, Pascagoula, and Mobile Rivers. These systems drain a combined land area of greater than 3 million km^2. The Mississippi River accounts for nearly 90% of the total freshwater discharge of approximately 17,370 $m^3 \cdot sec^{-1}$, while the Mobile River represents 10% of the total. The Mississippi River discharge causes high turbidity levels and temperature / salinity regimes which contrast sharply to oceanic Gulf waters. The Mississippi River's influence on vertical patterns of salinity and temperature appear to be limited to the upper 10 to 20 m nearest the Delta and to lesser depths east of the Delta.

Gulf of Mexico tides are both diurnal and semidiurnal with an average tidal range of from 30 to 60 cm. Semidiurnal tides are found in the Tuscaloosa Trend region with an average tidal range of from 37 cm at the mouth of Mobile Bay to 47 cm in Chandeleur Sound.

Surface water temperatures in the shallow sounds and bays in the Trend area closely approximate air temperatures. These waters are better mixed and more thermally uniform than the deeper waters of the open shelf. Estuarine water temperatures reach a maximum of approximately 30°C during July-August and a low of less than 13°C from January to March. Winter offshore surface temperatures range from 12°C near the barrier islands to 16°C, while summer temperatures range from 29 to 31°C. Shelf waters exhibit definite thermoclines during the summer, with a 5 to 6°C difference between the surface and bottom. The water column is relatively homogeneous during the winter.

Trend study area salinities are strongly influenced by riverine discharge and exhibit a definite pattern of increasing salinity with distance from the mainland. In Mississippi Sound, salinities are highest in the passes and deep channels, while salinity decreases westward toward the influence of the Pearl and Mississippi Rivers. Average salinities range from 10 to 20 $^{o}/oo$ in the western Sound to 16 to 30 $^{o}/oo$ near Mobile Bay.

Salinity patterns on the continental shelf are highly variable due to river and tidal pass plumes and aperiodic Loop Current intrusions. Surface salinities may range from 19 $^{o}/oo$ near Dauphin Island to 31 $^{o}/oo$ approximately 20 km offshore. Corresponding bottom salinities are 30 and 35 $^{o}/oo$, respectively. Very steep salinity gradients from 0 to 36 $^{o}/oo$ may occur on the shelf, especially in winter. In late spring, low salinity waters extend over much of the Trend area.

Turbidity in shelf waters is a function of riverine discharge, currents, seiches, and internal waves. A nepheloid layer generally extends across the entire shelf during the summer and winter and reflects highly stratified conditions. Winter nepheloid layers can be seiche-derived, while summer occurrences can result from internal waves.

Thermal features in the Tuscaloosa Trend area conform closely to meteorological conditions. Three distinctive thermal regions are present: the cold shelf waters; the warmer deep Gulf surface waters; and the equatorial waters of the Loop Current.

Circulation patterns in the Trend area involve the surface-mixed layer and the subtropical underwater layer. The Loop Current is the dominant circulation feature of the Gulf of Mexico. Although its influence is normally focused on the West Florida Shelf, aperiodic intrusions of Loop Current waters are experienced in the Trend study area. The DeSoto Canyon may act as a conduit for these intrusions. When the Loop Current is present on the shelf, it dominates circulation; even when it is further offshore it may be the principal force behind a counterclockwise circulation pattern. Sustained winds are the dominant driving force of circulation on the inner continental shelf and coastal waters, while riverine discharge also influences circulation in shallow waters of the Mississippi Sound and Mobile Bay. Density stratification and shoreline variations in coastal geometry are significant factors in circulation patterns on the shelf. A combination of strong onshore winds and horizontal density gradients results in a transient two-layer flow across the shelf (i.e., onshore flow at the surface and offshore flow at the bottom). Bottom flow may be correlated with the Ekman spiral, resulting in a direction of flow approximately 90° to the right of sustained wind direction. Near-bottom current velocities offshore are not well documented but have been estimated to average 20 $cm \cdot sec^{-1}$ with a maximum sustained speed of 60 $cm \cdot sec^{-1}$. Bottom waters may flow shoreward toward the barrier islands due to sustained northerly winds, but are generally deflected to the west by bottom topography. The Chandeleur Islands deflect these waters southward. Sustained southerly winds also cause shoreward flow of bottom waters, but this flow is deflected to the east by bottom topography.

In Mobile Bay, a northerly current occurs during flood tide and a southwesterly current during ebb tide at the mouth of the Bay. Tidal exchange with Mississippi Sound comprises from 20 to 25% of the Bay volume flushed. Winds and riverine discharge play the major roles in circulation patterns in the Bay. Mississippi Sound circulation patterns include both a westward flow from the passes to Lake Borgne and an eastward flow to Mobile Bay, during flood tide. During ebb tide, this flow is reversed. The combination of sustained winds and tidal currents can cause surface and bottom waters at the passes to flow in opposite directions. Freshwater discharge generally has a minimal impact on wind-and-tide-induced currents, although velocities increase during high riverine discharge.

Although circulation patterns in Chandeleur and Breton Sounds are not well defined, the hydrodynamic system is generated primarily by two tidal inputs. Currents average from 10 to 15 $cm \cdot sec^{-1}$ in the passes between the Chandeleur Island components. Tidal ranges in the northern part of this area are higher than in the south, causing flow to the south. Circulation is strongly influenced by wind direction and velocity, as in the other shallow estuaries of the Trend area.

CHEMICAL OCEANOGRAPHY

The outer continental shelf of the Tuscaloosa Trend study area is poorly defined with respect to chemical oceanography. Most information on nutrients, trace metals, and hydrocarbons has been developed in coastal or nearshore waters. Most chemical wastes which are introduced directly into the Trend area are associated with material dredged from major ship channels. Other sources of chemicals in the study area are land-based industrial effluents and air emissions as well as vessel-related discharges.

Dissolved oxygen production and consumption in surface and bottom waters are dependent on seasonal variations in temperature, density stratification, and primary production on the shelf. Levels are highest during the winter months but decrease during the summer due to decomposition of waterborne and sediment organics, stratification, and higher biological respiration. Low oxygen conditions (hypoxia) which occur along the Louisiana shelf west of the Mississippi River Delta have not been well documented in the Tuscaloosa Trend area.

Nutrient levels on the shelf are thought to follow seasonal patterns observed in coastal waters. Phosphates increase in concentration during the summer and fall, while nitrite-nitrate levels are high throughout the summer, due to minimal discharge of freshwater from the Pearl, Pascagoula, and Mobile Rivers. The concentrations of these nutrients are higher in coastal waters than on the shelf, apparently as a result of industrial/municipal discharges from coastal population centers.

Sediment trace metals exhibit similar geographical patterns: concentrations are highest in the vicinity of shore-based sources of effluents and decrease with distance from shore. Trace metal levels are also correlated with sediment texture: areas of silt and clay accumulation exhibit the highest accumulations of metals.

Smectite and kaolinite are the predominant clay minerals in the Trend study area. The former is most prevalent on the shelf, while kaolinite increases in importance nearer the shore. Smectite (as montmorillonite) is the major clay mineral in Mobile Bay but kaolinite dominates sediments at the mouth of the Bay and in Mississippi Sound.

Sediment hydrocarbon distributions in the northeastern Gulf define two distinct shelf environments—the West Florida Shelf and the Mississippi-Alabama Shelf. The latter area, which includes the Tuscaloosa Trend study area, receives terrigenous biogenic and anthropogenic hydrocarbons from the Mississippi River discharge. Vegetative inputs are reflected in the abundance of high molecular weight n-alkanes of pronounced odd/even ratio and by a relatively high lipid content (up to 232 ppm). Some shelf areas are reported to contain aliphatic hydrocarbons indicative of oil, which could have been introduced by waterborne commerce, commercial fishing vessels, and oil production and transport. Sediments in Mississippi Sound contain both terrigenous and marine hydrocarbons nearer the shoreline but contain primarily marine hydrocarbons at the passes, suggesting that organic pollutants which occur outside the barrier islands are not derived from land-based sources (e.g., industries) but rather, from activities on the shelf. Chronic petroleum contamination has been reported in the Chandeleur and Breton Sounds; however, hydrocarbons released by the Chevron Main Pass Block 41C Platform spill in 1970 were fully weathered within approximately one year.

Suspended particle loads in the water column are highest near sources of riverine discharge and are higher in bottom waters than near the surface. A nepheloid layer occurs in the shelf waters of the Trend study area, with maximum suspended solids concentrations in the fall and winter. Major constituents of these suspended solids are clays and particulate organics.

The waters off Mobile Bay are generally high in barium and vanadium, apparently as a result of terrigenous sediment input from the Mobile River system. Concentrations of heavy metals in the Trend shelf area show seasonal patterns related to resuspension and riverine discharge. Constituents of suspended solids may become incorporated in zooplankton and neuston in shelf waters. However, trace metal concentrations generally do not reflect significant contamination from land-based sources.

Particulate organic carbon levels in shelf waters of the Trend area are highest during the summer and decrease with increasing distance from shore. Dissolved organic carbon concentrations are higher in the winter. Chlorophyll _a_ levels generally increase with depth in the Trend area, a pattern typical of tropical and subtropical waters.

Water column hydrocarbons on the Mississippi-Alabama Shelf have been reported to include levels of 0.12 to 1.31 $ug \cdot l^{-1}$ for total dissolved hydrocarbons and 0.06 to 3.61 $ug \cdot l^{-1}$ for particulate hydrocarbons. Concentrations are highest in the winter and lowest in the fall and reflect no petroleum contamination on the shelf. Natural sources of these hydrocarbons include both terrigenous and marine biogenic processes. No high molecular weight hydrocarbons have been reported south of Mobile Bay, while pesticide concentrations are extremely low or non-detectable. Elevated levels which occur in coastal waters are associated with sources such as major industrial complexes and drainage from areas of heavy agricultural cultivation.

The concentrations of heavy metals in biota of the Tuscaloosa Trend shelf area are generally low and reflect little contamination from anthropogenic sources. Concentrations in biota of the sounds and bays are generally higher but are also quite variable as a result of migratory behavior, sediment type, trophic level, and other factors. Blue crabs contain higher levels of barium, chromium, copper, iron, lead, nickel, strontium, and vanadium than oysters, while oysters contain higher amounts of cadmium and zinc than blue crabs. Levels in biota from the coastal waters are generally typical of estuaries throughout the Gulf of Mexico.

There is little evidence of petroleum or petrogenic hydrocarbons in zooplankton, macroepifauna, and fish of the shelf area. Oysters and blue crabs in Mobile Bay, on the other hand, have been observed to contain some traces of refined petroleum hydrocarbons, probably attributed to vessel traffic in fishing areas such as oyster reefs.

ECOSYSTEM STRUCTURE AND FUNCTION

Coastal marshes which fringe the Tuscaloosa Trend area mainland contribute large amounts of organic material to waters of the sounds, bays, and open Gulf. Approximately 269,000 acres of marshes occur within the Trend study area, including 57,000 acres of saline marsh, 168,000 acres of brackish-intermediate marsh, and 44,000 acres of fresh marsh. These marshes have primary production rates of up to 2,960 g dry $wt \cdot m^{-2}$ per year. Marsh vegetation decomposition rates range from 36% per year for *Spartina patens* to 86% per year for *Spartina alterniflora* and provide an influx of organic matter into coastal waters during January-March. Net export of organic particulates from the coastal marshes is thought to be episodic. Primary consumers in coastal marshes include insects, gastropods, crustaceans, birds, and mammals. Detritivores include meiofauna, macrofauna, and epifauna.

Marsh sediments generate large amounts of methane through anaerobic decomposition of marsh organics. Other decomposition products which are released by marshes include nitrates, nitrites, phosphorus, and carbon dioxide. Perhaps 40% of total net primary production is exported to estuarine waters through tidal exchange, stormwater runoff, and biological population migration.

Phytoplankton communities in coastal waters of the Trend study are poorly known. Primary production rates of 208 g $c \cdot m^{-2}$ per year, or 462 g dry $wt \cdot m^{-2}$ per year have been reported. Chlorophyll *a* concentrations in coastal Louisiana average 17.4 to 19.2 $ug \cdot l^{-1}$, with highest values near sources of municipal wastewater discharged by metropolitan New Orleans.

Submersed grasses represent another source of primary production in Trend area coastal waters, although production rates have not been determined. Grassbeds are abundant in Mississippi Sound as well as in the vicinity of the Chandeleur Islands.

Zooplankton of coastal waters provide a key link between phytoplankton and higher trophic levels. They include meroplankton (forms which spend only a portion of their life cycle in the zooplankton community) and holoplankton. Seasonal variations in zooplankton abundance correspond to changes in both water temperature and freshwater discharges. Abundance peaks occur in the summer, following spring peaks in nutrient discharge from rivers. Zooplankton biomass (standing crop) appears to be higher in the coastal waters (up to 0.80 $ml \cdot m^{-3}$) than on the open shelf (0.10 $ml \cdot m^{-3}$). The calanoid copepod *Acartia tonsa* is the dominant zooplankter in the coastal waters of the Tuscaloosa Trend, while the ctenophore *Mnemiopsis mccradyi* is an important grazer on zooplankton populations. Ichthyoplankton are an important component of the zooplankton, especially during the summer and fall. An average of nearly 5 $individuals \cdot m^{-3}$ was reported in the summer in Biloxi and Back Bays, Mississippi; no fish larvae were found in the winter.

Nekton of the Trend area's coastal waters include a variety of fishes, cephalopods, crustaceans, mammals, and turtles. The ichthyofauna have been relatively well-studied because of their importance to fisheries. Many exhibit seasonal migratory behavior and are dependent on the coastal marshes and shallow water habitats for protection and feeding grounds. Major species include croaker (Micropogonias undulatus), spot (Leiostomus xanthurus), menhaden (Brevoortia patronus), mullet (Mugil cephalus), and others. Nektonic cephalopods include in particular the squids Loligo pealei, Lolliguncula brevis, and Doryteuthis plei.

Coastal waters support diverse and abundant benthic communities in the Trend study area. The meiofauna have not been studied extensively, although meiofaunal communities have been identified in lower Mobile Bay to the family-level. Macroinfauna are dominated by polychaetes in terms of both number of species and abundance. Community types are correlated primarily with sediment texture and salinity. Several different types occur in the coastal waters, including a shallow, coastal margin (mud) assemblage; lower Mobile Bay (mud) assemblage; deep, open Sound (sandy mud to muddy sand) assemblage; tidal pass (sand) assemblage; and shallow Sound (sand) assemblage.

Macroepifauna include species such as penaeid shrimps, as well as oysters, crabs, and a great variety of other molluscs, crustaceans, and other invertebrates. Three species of shrimps (Penaeus setiferus, P. aztecus, P. duorarum) dominate the epifaunal community. They generally spawn in the open Gulf, while postlarvae migrate into shallow coastal waters and fringing marshes via tidal passes. Subadults and adults migrate offshore to spawn. The blue crab Callinectes sapidus mates in higher salinity waters from March through November. The female broods the eggs until they hatch, in nearshore waters. Zoea normally do not occur in coastal waters but the megalops, or pre-juvenile stage, is common in the shallow bays and sounds. Oyster (Crassostrea virginica) larvae are planktonic and dispersed by tides and currents. They settle on a variety of hard substrates throughout the coastal waters of the Trend study area. Oyster reefs are most extensive in areas exposed to brackish waters. They are vulnerable to predation by the drill Thais haemastoma when salinities exceed 15 $^{o}/oo$.

The coastal waters of the Tuscaloosa Trend area communicate with the open Gulf through tidal passes between the barrier islands. Many biota use these passes as migratory routes, while others are generally restricted to either coastal or open Gulf waters. Phytoplankton in the Trend study area have not been investigated but may include species which have been reported to occur west of the Mississippi River Delta (e.g., Thalassionema nitzochioides, Nitzschia seriata, Skeletonema costatus, and others.

Zooplankton in shelf waters of the Trend area exhibit standing crops of 0.3 to 1.0 $ml \cdot m^{-3}$ and are dominated especially by Temora stylifera, T. turbinata, and chaetognaths. Diversity has been reported to remain relatively constant with distance from land.

Ichthyoplankton are only poorly described in the outer continental shelf portion of the study area, although a recent and on-going investigation of these important biota has been initiated by the National Marine Fisheries Service. Ichthyoplankton biomass appears to average 0.17 $ml \cdot m^{-3}$ over the shelf.

Fish communities on the shelf are dominated by five species, including croaker (Micropogon undulatus), longspine porgy (Stenotomus caprinus), butterfish (Peprilus burti), spot (Leiostomus xanthurus), and seatrout (Cynoscion arenarius). Species which enter the adjacent estuaries at some time during their life cycle include warm weather spawners such as sea catfish (Arius felis) and seatrout (Cynoscion arenarius). These species are generally most abundant on the shelf in the winter. Cold weather spawners include menhaden (Brevoortia patronus), spot (Leiostomus xanthurus), mullet (Mugil cephalus), and several others. While menhaden are most abundant on the shelf in the winter, the other fish species common in OCS water are most abundant there in the summer or fall. Synthesis of nektonic community analyses identified several taxa groups associated with habitats defined on the basis of salinity, depth, and sediment characteristics (e.g., shallow, low salinity waters overlying muddy sediments; nearshore high salinity waters overlying sandy sediments; offshore high salinity waters overlying sandy sediments; high salinity waters overlying muddy sediments; etc.).

More typically marine fishes which occur in the Trend study area include several species of sharks, snappers (Lutjanus spp.), groupers (Epinephelus spp.), and others. Species assemblages are defined as inner shelf or outer shelf.

Meiofaunal assemblages in the Trend shelf area are dominated by free-living nematodes, followed by harpacticoid copepods and polychaetes. Individual abundance generally decreases with depth or distance from land.

Open shelf benthic communities show a disjunct distribution at the DeSoto Canyon, due to sedimentary and circulation differences between the eastern Gulf shelf and the western Gulf shelf (which includes the Trend region). Macroinfaunal communities in the Trend study area may be categorized as occurring in the surf zone, 2 to 12 m along the open coast, 2 to 12 m along the Mississippi River Delta, 12 to 40 m, 40 to 60 m, and 60 to 100 m. Smaller-scale variations in sediment texture and salinity may result in delineation of sub-communities within these broad categories. Macroinfaunal abundance varies with season and distance from land: a winter peak occurs in the deeper shelf, while a summer peak occurs in shallower waters. The number of species and species diversity generally decrease with increasing depth across the shelf. Polychaetes and crustaceans dominate the benthic communities with respect to species and individual abundance.

Epifaunal communities are rather well-described in the Trend shelf area. Five assemblages occur in the OCS portion of the study area, including the pro-delta fan assemblage, pro-delta sound assemblage, intermediate shelf assemblage, outer shelf assemblage, and upper slope assemblage. Except for the pro-delta fan assemblage, community distributions correspond closely to zones of water depth.

Endangered and threatened species of the shelf area are generally the same as in the coastal waters, except that brown pelicans and alligators are not present. Remaining species include manatee, six species of sea turtles, and four species of whales.

The open shelf ecosystem may be considered to have two principal food chains: a plankton-based food chain in which energy fixed by phytoplankton is transferred to zooplankton and thence to higher trophic levels; and a benthic food chain in which energy fixed in organic detritus is transferred to detritivores, to benthic consumers, and thence to consumers in the water column.

SOCIOECONOMICS

The socioeconomic resources of the Tuscaloosa Trend study area include waterborne commerce, travel and tourism, sport and commercial fisheries, and oil and gas. The Trend area provides navigational access to international and domestic commerce. The Gulf Intracoastal Waterway extends 212.8 km from New Orleans to Mobile Bay. In 1981, it was traversed by nearly 28,000 vessels, primarily barges, carrying 15.7 million metric tons of commerce. Major commodities transported are coal, crude oil, and grain. Opening of the Tennessee-Tombigbee Waterway in 1985 will extend waterborne commerce from Mobile to the Tennessee and Ohio River systems.

Deep draft vessels use the offshore fairway network to reach deep channels which lead to several harbors in the Trend coastal area (New Orleans, Mobile, Gulfport, and Pascagoula). New Orleans is the second-largest harbor in the United States and handled over 171 million metric tons of commerce in 1981.

Coastal travel, tourism, and recreation represent a significant economic resource. Nearly 12% of all travelers in Alabama in 1983, or 7.5 million people, cited visiting the beach areas as the reason for travelling in the state. Mississippi coastal cities experience year-round tourism and reported nearly $52 million in lodging income in 1983. Louisiana tourism trade is dominated by New Orleans, which accounted for $1.9 billion, or 57% of the state's total tourism receipts, in 1982.

Recreational fisheries in the Gulf of Mexico as a whole involved an estimated 3.2 million residents in 1979, and gross retail sales of $1.32 billion in 1980. This represents one-third of such sales nationwide and is the highest of any region in the United States. Approximately 204,000 persons participated in marine recreational fishing in Alabama in 1979 and caught nearly 3.9 million fish. Similar estimates exist for Mississippi for 1979 (155,000 persons, 3.2 million fish). In Louisiana, over 530,000 persons caught 22.4 million fish in 1979. In Alabama, kingfish and croaker were the most abundant fish caught; croaker and sand seatrout were most frequently caught in Mississippi; and croaker and sea catfish were most often caught in Louisiana.

Commercial fishery harvests in the Trend study area in 1983 generated nearly $42.6 million in Alabama, including $25.9 million from shelf waters. Corresponding yields for Mississippi are $48.4 million and $14.8 million, respectively. Louisiana's commercial fishery value ws $225.2 million, of which $71.5 million was produced in outer continental shelf waters. Shrimp comprise the largest component of each of two of these state fisheries values (94% in Alabama and 59% in Louisiana), and 45% of Mississippi's landings. (Finfish accounted for 46% of Mississippi landings by value in 1983.) Other major components of commercial fisheries in the Trend area are blue crab and oysters. Louisiana's oyster harvest is second only to that of Maryland, and was valued at $14.6 million in 1983.

Mineral resources in the Trend study include oyster and clam shells, which have been used for cement, chemicals, and road foundation. Dredging in Lake Pontchartrain produced clam shells valued at over $60 million annually. Dredging for buried oyster reefs in Alabama ceased in 1981.

Oil and gas production in the Gulf of Mexico accounts for nearly all of the United States outer continental shelf production. In the Tuscaloosa Trend area, production occurs only adjacent to Louisiana. No production has yet occurred off Alabama or Mississippi. Approximately 90% of the undiscovered but recoverable gas expected to occur in the Eastern Planning Area is thought to lie in the Tuscaloosa Trend study area. Alabama state waters could contain recoverable hydrocarbons worth from $7 to $21 billion in royalties, while Mississippi's hydrocarbons could be worth from $200 million to over $1 billion in royalties.

Other mineral resources, which have not been developed, include sand, gravel, heavy minerals, and geothermal energy.

Cultural resources of the Trend area include both prehistoric and historic sites. Prehistoric sites have been postulated to occur offshore where former shorelines were submerged by a rise in sea level but none have been located. Numerous terrestrial prehistoric sites have been identified throughout the Trend study area. Historic period sites (post 1519) also occur throughout the area, including many sites which are located in the coastal regions of Louisiana, Mississippi, and Alabama. These sites represent exploration and settlement by the Spanish, French, and Germans.

RECOMMENDATIONS FOR FUTURE RESEARCH

Information gaps have been identified for each of the principal components of the Tuscaloosa Trend study area. Some are related to basic environmental or socioeconomic characterization of the region, while others pertain to the processes which define the dynamics of the ecosystem. The purpose of this section is to describe the most important information needs for this area. These are presented according to major topics in the order they appear above in the summary.

Geology

Although several geological studies have been performed in the coastal and outer continental shelf (OCS) portions of the Trend area, significant data gaps are apparent, especially for the open shelf. The following investigations are recommended:

1. The Minerals Management Service's Marine Geologic Atlas Series should be extended to include the remaining areas within the Tuscaloosa Trend;

2. Efforts should be made to better define the hydrodynamic mechanisms which influence sediment transport both nearshore and in deep water;

3. Areas where there are potentially hazardous foundations for petroleum exploration and production structures and pipelines need to be well documented. Geologic features should include: (a) gas at shallow depth; (b) buried stream channels; (c) active faults; (d) surficial and shallow deformation including slumping and creep; and (e) diapirs and faulting;

4. Detailed study of the Chandeleur Sound, Breton Sound, and the adjacent continental shelf should be conducted, and should include sediment distribution mapping, bathymetric surveys, and subbottom profiles.

Physical Oceanography

Many aspects of the physical oceanography of the Trend study area remain poorly-defined. The study of this component of the Trend ecosystem is essential to our understanding of how biological systems and physico-geochemical processes are interrelated and how they may be affected by future activities in this area. Future research should address the following considerations:

1. Circulation patterns and driving forces in the DeSoto Canyon should be investigated in order to determine the movement of sediments and chemicals across the Trend shelf and up- and downslope;

2. Existing current, temperature, and salinity data should be further analyzed in order to assist in description of shelf processes and to aid in designing and directing future process-oriented investigations.

3. The occurrence and extent of the nepheloid layer on the shelf should be evaluated in support of fate and effects studies of hydrocarbon and heavy metal pollutants introduced from coastal, riverine, and shelf sources;

4. Additional studies of currents and circulation patterns across the shelf should be performed, including meteorology, hydrography, horizontal currents, sea state, bottom pressure, and freshwater discharge;

5. Development of a physical oceanographic model for the Trend area should guide future studies and predict pollutant dispersion.

Chemical Oceanography

Chemical characteristics of the waters and sediments of the Trend study area are poorly-defined. In particular, sources and fates of possible contaminants on the shelf cannot be described from existing information. The following are recommended studies to fill these data gaps:

1. Nutrient flows and distributions from the tidal passes across the shelf should be characterized in order to complement studies of biological productivity and communities;

2. Phenomena with significance to the distribution and abundance of biota on the shelf--i.e., hypoxia and the nepheloid layer--should be investigated through field sampling;

3. Processes of transport and dispersion of terrigenous pollutants should be examined in order to distinguish between effects of coastal and upstream activities vs. those which occur on the open shelf;

4. Fates of pollutants associated with shelf activities--including petroleum exploration/production, dredged material disposal, and waterborne commerce--should be studied;

5. Processes of bioaccumulation and biomagnification of chemicals introduced to the Trend shelf should be defined, in order to provide a means to assess the long-term ecological effects of pollutant influxes.

Ecosystem Structure and Function

In general, the coastal portion of the Trend study area has been well-studied with respect to benthos, demersal fish and invertebrates, and nekton. Studies of phytoplankton, zooplankton, biological production, and trophic dynamics are lacking or inadequate. Ecological resources are insufficiently known to define processes and interrelationships between open shelf and near-shore ecosystems. The following recommendations for future investigation reflect the paucity of information for the shelf:

1. Movements of biota through the tidal passes should be described to determine energy flux between coastal and OCS waters;

2. Shelf benthic communities should be defined, with emphasis on habitats (sediment types) not previously described, near major points of riverine discharge, and near-slope environments (including the DeSoto Canyon);

3. Plankton communities should be described for the shelf with emphasis on primary and secondary production, and correlated with physical and chemical processes to assess relationships between shelf/coastal waters/riverine discharge and OCS biotic potential;

4. Further analysis of trophic relationships among the biotic components of the shelf ecosystem should be conducted, with emphasis on energy transfer within and between pelagic and benthic components;

5. Processes of bioaccumulation and biomagnification of chemicals introduced to the Trend shelf should be defined, in order to provide a means to assess the long-term ecological effects of pollutant influxes.

Socioeconomics

The socioeconomic characteristics of the Tuscaloosa Trend area are generally well described. However, some aspects of the area should be examined further for specific types of information, as summarized below:

1. Patterns of navigation and vessel casualties should be examined throughout the Trend study area, in order to assess the potential for increasing likelihood of accidents due to petroleum production;

2. A model should be formulated for projecting the impacts of major oil spills on travel, tourism, and recreation in the Trend area, based on effects of the Ixtoc spill off Texas;

3. Studies of recreational fishing activities should be standardized among the three states which border the Tuscaloosa Trend area;

4. Additional studies of the extent of the clam shell resource of coastal Louisiana could be performed, assuming that exploitation of this resource is allowed to continue.

5. Areas of possible submerged prehistoric habitation should be examined through sediment coring and bathymetric profiling to determine whether such sites would be impacted by offshore petroleum exploration/production.

1.0 INTRODUCTION

1.1 OBJECTIVES

Recent advances in oil drilling technology have lead to increased oil and gas exploration in U.S. coastal waters. Much of this exploration has been concentrated in the northern Gulf of Mexico. In 1981, the Outer Continental Shelf produced 6% of our nation's oil and 24% of its natural gas, of which 94% and 99%, respectively, were produced from Gulf of Mexico fields. It is estimated that 6.6 billion barrels of oil and 71.9 trillion cubic feet of natural gas remain undiscovered in the Gulf of Mexico (USGS, 1982).

One area of historical and current interest to oil and gas exploration in the Gulf of Mexico is located off Louisiana, Mississippi, and Alabama (Figure 1.1). This area, known as the Tuscaloosa Trend, extends from southern Louisiana into the offshore waters of the Chandeleur Islands, eastward to the DeSoto Canyon, and promises to be highly productive in terms of recoverable oil and natural gas reserves. (The "Tuscaloosa Trend" is an area of active exploration for gas and oil in deeply buried Upper Cretaceous Tuscaloosa Group sediments. It is characterized by an expanded wedge of clastic sediments that strikes northwest-southeast across Louisiana and extends beyond the Chandeleur Islands.) The waters adjacent to the Chandeleur Islands and within Breton Sound and Mississippi Sound also support a significant recreational and commercial fishery. A portion of this area lies within the Breton National Wildlife Refuge and the Gulf Islands National Seashore of the National Park Service.

Information describing the physical environment, biological habitats and communities, and naturally occurring regional hazards is needed to make management decisions regarding advisability of leasing in a particular area. Similarly, information is needed to define the terms of the lease stipulation or other mitigating measures to assure their effectiveness. This information will be used by the Minerals Management Service (MMS) for development of the Programmatic Environmental Impact Statements upon which the 5-year OCS Oil and Gas Leasing Schedule is based, for development of regional environmental profiles and OCS environmental impact statements (EIS's) and other NEPA documents, and for planning other studies conducted by MMS. The information will also be used by numerous other persons in private industry, academic institutes, and other federal or state government agencies for many purposes.

The Tuscaloosa Trend study is planned as a multiyear effort. As has historically been the case with study elements of the MMS's Studies Program, marine ecosystem studies in general and the Tuscaloosa Trend study in particular begin with a characterization of the "Present Level of Knowledge," addressing the following areas:

1. What information is presently available concerning the marine ecosystem in this region to meet MMS information needs?

2. What are the precise locations of previous study efforts and the results of those studies?

3. What is our present understanding of the processes which most significantly influence the nature of the ecosystem in the region?

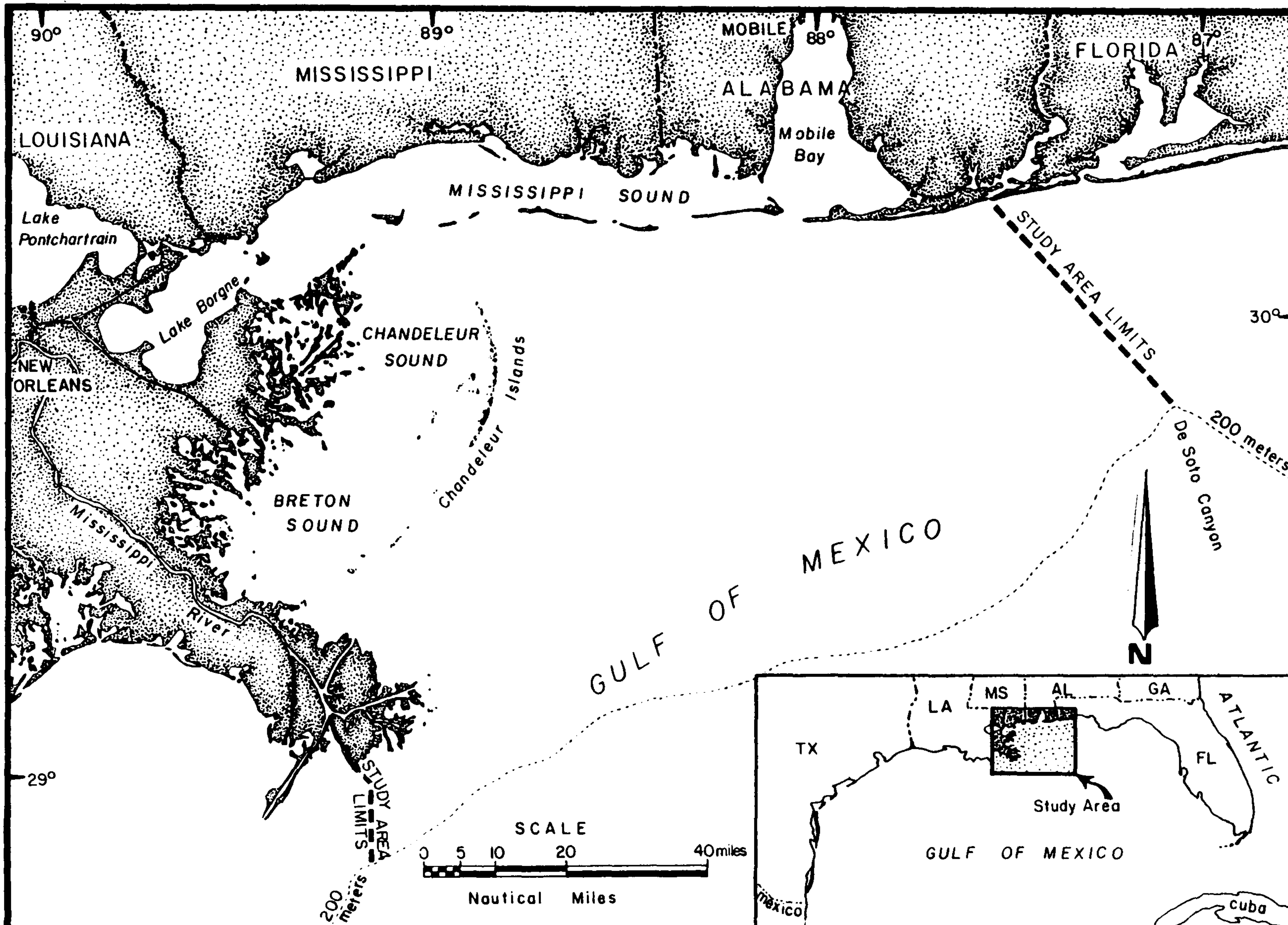

Figure 1.1 The Tuscaloosa Trend study area.

(4) What are the outstanding information gaps which should be addressed through additional studies?

The "Summary of Knowledge" phase involves the identification, review, and synthesis of all existing information contained in published and unpublished research and ongoing proposed programs. The Summary of Knowledge phase has provided the basis for subsequent activities in the MMS Environmental Studies Program. This first year effort consists of a comprehensive survey of available data and literature to describe ecological processes on the Tuscaloosa Trend OCS study area and adjacent hydrologic units, including physical, geological, chemical, biological, and socioeconomic data, through development of a conceptual ecosystem model. Additional information and data needs are also addressed.

1.2 APPROACH

(1) Identification and selective collection of published and unpublished information;

(2) Review and annotation of the published and unpublished information;

(3) Development of a separate computer manual and a computer program that accesses, cross-indexes, and stores the data base; and

(4) Interpretation and synthesis of information in a technical report with separate visuals (maps) and an executive summary.

Vittor & Associates organized a team of researchers to identify and collect the available data, to review and annotate the pertinent published and unpublished information, and to prepare this synthesis report. Quantus, Inc. was enlisted to perform the computer searches, enter the literature and data set citations, and develop the retrieval system for accessing the data base. Science Applications International was enlisted to develop a conceptual model of the Tuscaloosa Trend ecosystem.

1.2.1 LITERATURE

Relevant published literature was initially identified through searches of computerized bibliographic data bases. Table 1.1 lists the bibliographies searched during this study, together with a brief discussion of their contents. Approximately 1000 citations potentially relevant to the study area were uncovered through these searches. Computerized searches were supplemented by visits to libraries of universities and funding agencies located along the eastern Gulf of Mexico (Table 1.2). These visits were especially useful in identifying dissertations, theses, and technical reports pertinent to the study area.

Literature identified in the computerized searches and library visits was reviewed and a citation form was completed for those documents containing information relevant to the study area. In addition to the standard citation information such as author, title, year of publication and publisher, various geographical and subject descriptors were assigned to each citation. A controlled vocabulary list was used in selecting the descriptors to reduce

Table 1.1. Computerized bibliographic data bases.

Database	Temporal Coverage	Description
Biosis Previews	1969 - 1983	Comprehensive worldwide coverage of biological literature. Includes over 9000 primary journals as well as reviews, symposia, selected government and institutional reports, research communications and other secondary sources.
Coastal Information Depository, Louisiana State University		Index of the literature holdings of researchers at the Center for Wetland Resources, Louisiana State University.
DOE Energy	1974 - 1983	Comprehensive coverage of all aspects of energy and related topics.
Life Sciences Collection	1978 - 1983	Worldwide coverage of applied ecology.
National Technical Information Service	1964 - 1983	Coverage of government funded research, development and engineering reports that are publically available from approximately 250 federal agencies.
Oceanic Abstracts	1964 - 1983	Worldwide coverage of oceanography, marine biology, marine pollution, ships and shipping, geology and geophysics, meteorology, and legal and governmental aspects of marine resources.

Table 1.2 List of libraries of universities and funding agencies visited for information searches on the Tuscaloosa Trend study area.

LOUISIANA

Louisiana State University
Center for Wetland Resources Library
Baton Rouge, LA

Louisiana State University
Louisiana Sea Grant
Baton Rouge, LA

Louisiana State University
Coastal Studies Institute
Baton Rouge, LA

Louisiana State University
LSU Library
Baton Rouge, LA

Tulane University
Main Library
New Orleans, LA

University of New Orleans
Reference Library
New Orleans, LA

Southeastern Louisiana University
Main Library
Hammond, LA

MISSISSIPPI

Gulf Coast Research Library
Gunter Library
Ocean Springs, MS

University of Southern Mississippi
USM Library
Hattiesburg, MS

Mississippi-Alabama Sea Grant Consortium
Publications Office
Ocean Springs, MS

National Marine Fisheries Service
Publications Office and Reference Library
Pascagoula, MS

ALABAMA

University of South Alabama
USA Library
Mobile, AL

Marine Environmental Sciences Consortium
Dauphin Island Sea Lab
Dauphin Island, AL

synonymies and redundancy. Abstracts were prepared for selected documents especially pertinent to the study area.

1.2.2 DATA SETS

Data sets relevant to the study area were identified through a combination of computerized searches, library visits and personal contacts with researchers in the study area. Table 1.3 lists the computerized data indexes accessed and Table 1.4 lists the personal contacts made during the study.

Results of the searches and contacts were reviewed and a data documentation form was compiled for each data set relevant to the study area. This form included such information as title and abstract of the study which generated the data, the spatial and temporal extent of the data set, the parameters measured, and the availability, source, and format of the data. These forms have been submitted to the National Environmental Data Referral Service for inclusion in their data base.

1.2.3 INFORMATION DATA BASE

All of the literature and data citations compiled during the study were computerized and entered into an information data base. This data base permits a user to retrieve citations on the basis of geographical and subject descriptors, author names, and title words. Retrievals from the data base can be displayed in a variety of formats and arranged in author, title, or descriptor order.

1.2.4 VISUALS

Five visuals (maps) were developed from the synthesized published and unpublished information to graphically display: 1) faunal habitats and assemblages; 2) fishery and recreational resources; 3) vegetation and oceanographic features; 4) areas of critical concern, including spawning, nursery and feeding areas, and migration routes of commercially important fish species; and 5) oil and gas infrastructure.

1.2.5 COMPUTER PROGRAM

A computer software package was prepared to catalog all of the annotated published and unpublished information sources and to manipulate the references for recall on the basis of key words, author(s), geographic areas, and sources. This package will allow the contents of the data files to be updated in the future.

A user's manual includes a key word thesaurus to assist users in the construction of the most useful query statements.

Table 1.3. Computerized data indices.

Database	Temporal Coverage	Description
Coastal Information Depository, Louisiana State University		Index of the data holdings of researchers at the Center for Wetland Resources, Louisiana State University.
National Environmental Data Referral Service	1974 - 1983	Comprehensive index of climatological, meteorological, geological, geophysical, oceanographic, geographic, hydrologic, and limnological data.
National Marine Pollution Information System	1980 - 1982	Catalog of federally funded marine pollution research programs.
SSIE Current Research	1978 - 1982	Index of governmental and privately funded scientific research programs.

Table 1.4 Sources contacted for available published and unpublished information pertaining to the Tuscaloosa Trend regional data search and synthesis study.

SOURCES	CONTACTS	
FEDERAL AGENCY		
Gulf Coast Fisheries Commission Ocean Springs, MS	P. Thompson	
Gulf States Marine Fisheries Commission Ocean Springs, MS	L. Simpson N. Bane	
Minerals Management Service Corpus Christi, TX	D. Foote	
Minerals Management Service Gulf of Mexico OCS Office Metairie, LA	R. Rogers V. Reggio M. Stright M. Bartz	L. Handley C. Hill K. Adams M. Brown
Minerals Management Service Reston, VA	M. Davis	
NASA/Earth Resources Laboratory National Sciences Technology Lab Bay St. Louis, MS	H. Sveklak D. Brannon	
National Marine Fisheries Service Southeast Fisheries Center Miami, FL	D. Tidwell P. Pristas	
National Marine Fisheries Service New Orleans, LA	T. Dolley	
National Marine Fisheries Service Southeast Fisheries Center Panama City, FL	E. Nakamura B. Fable	
National Marine Fisheries Service Southeast Fisheries Center Pascagoula, MS	H. Hague B. Rohr A. Kemmerer	W. Stunts T. Henwood F. Diaz
National Marine Fisheries Service Southeast Fisheries Center St. Petersburg, FL	R. Schmied I. Bird	
National Marine Fisheries Service Southeast Fisheries Center Beaufort, NC	D. Hoss	

Table 1.4 (Continued)

SOURCES	CONTACTS	
National Oceanographic and Atmospheric Administration (NOAA) National Climatic Data Center Ashville, NC	V. Cinquemani	
Naval Ocean Research and Development Activity (NORDA)	H. Morris J. McCall D. Gilhouser	D. Young B. Green T. Holcombe
U.S. Army Corps of Engineers Mobile District Mobile, AL	D. Gibbons W. Burdin R. Barrineau	S. Rees D. Nester P. Bradley
U.S. Army Corps of Engineers New Orleans District New Orleans, LA	T. Ryan G. Montz J. Robertson	
U.S. Army Corps of Engineers Waterways Experiment Station (WES) Vicksburg, MS	R. Saucier J. Lunz D. Kendall	D. Clarke
U.S. Environmental Protection Agency Gulf Breeze Laboratory Gulf Breeze, FL	J. Couch T. Duke N. Rubenstein	
U.S. Environmental Protection Agency Region IV Atlanta, GA	R. Rogers	
U.S. Environmental Protection Agency Washington, D.C.	S. Hitch	
U.S. Fish & Wildlife Service National Coastal Ecosystems Team Slidell, LA	C. Cordes J. Johnston W. Kitchens	
U.S. Fish & Wildlife Service Daphne, AL	J. Carroll	
U.S. Fish & Wildlife Service Boguechitto, LA	S. Joyner	
U.S. Geological Survey Bay St. Louis, MS	R. Wallace	
U.S. Geological Survey Corpus Christi, TX	J. Kindinger	
U.S. Geological Survey Woods Hole, MA	M. Ball	

Table 1.4 (Continued)

SOURCES	CONTACTS
STATE AGENCY	
LOUISIANA	
Board of Commissioners Port of New Orleans, New Orleans, LA	G. Austin
Louisiana Dept. of Culture, Recreation, and Tourism Baton Rouge, LA	E. Navarre K. Byrd C. Montgomery
Louisiana Dept. of Highways Baton Rouge, LA	E. Letalle
Louisiana Dept. of Natural Resources Baton Rouge, LA	B. Benson-Rodenbaugh R. Hannah T. Hewey
Louisiana Dept. of Wildlife & Fisheries Seafood Division Baton Rouge, LA	C. Boudreaux J. Smith B. Ancelet S. Barthel R. Dugas B. Barrett
Louisiana Geological Survey Louisiana State University Baton Rouge, LA	T. Moslow S. Penland
New Orleans Planning Commission New Orleans, LA	A. Laska
MISSISSIPPI	
Jackson County Port Authority Gulfport, MS	C. Moore
Mississippi Bureau of Marine Resources Long Beach, MS	J. Franks
Mississippi Bureau of Marine Resources Ocean Springs, MS	T. Quinne S. Gordon
Mississippi Bureau of Pollution Control Jackson, MS	R. Sherrard
Mississippi Dept. of Archives and History Jackson, MS	K. P'Poo S. McGahey
ALABAMA	
Alabama Bureau of Tourism Montgomery, AL	L. Williams

Table 1.4 (Continued)

SOURCES	CONTACTS	
Alabama Dept. of Conservation and Natural Resources Dauphin Island, AL	M. van Hoose H. Lazauski H. Swingle W. Tatum	S. Heath
Alabama Geological Survey Tuscaloosa, AL	P. O'Neil S. Mettee	
Alabama Oil and Gas Board Tuscaloosa, AL	B. Mink	
Alabama State Docks Dept. Mobile, AL	T. Adger E. Browning	
South Alabama Regional Planning Commission Mobile, AL	L. Gudac	
UNIVERSITIES AND INSTITUTIONS		
LOUISIANA		
Louisiana State University Center for Wetland Resources Baton Rouge, LA	W. Sikora R. Shaw I. Mendelssohn	B. Thompson
Louisiana State University Coastal Studies Institute Baton Rouge, LA	W. Wiseman	
Louisiana Universities Marine Consortium (LUMCON) Chauvin, LA	D. Boesch N. Rabalais	
McNeese State University Lake Charles, LA	J. Brooks	
Nichols State University Thibodeaux, LA	J. Green	
Southeastern Louisiana University Hammond, LA	G. Childers	
Tulane University New Orleans, LA	D. Davis A. Smalley M. Batuck	
University of New Orleans New Orleans, LA	W. Dahl R. Stoessel S. Simmons	J. Laseter D. Overton M. Poirrier
University of Southwestern Louisiana Lafayette, LA	D. Felder W. Reese H. Hoese	

Table 1.4 (Continued)

SOURCES	CONTACTS	
MISSISSIPPI		
Gulf Coast Research Laboratory Ocean Springs, MS	J. LaRoche W. Waller T. Lytle R. Heard T. McIlwain B. Woodmansee	E. Otvos T. McBee J. Lytle H. House R. Overstreet
Mississippi-Alabama Sea Grant Consortium Ocean Springs, MS	J. Jones	
Mississippi State University Starkville, MS	D. Wolfe	
University of Mississippi Mississippi Minerals Resources Oxford, MS	J. Woolsey	
University of Southern Mississippi Hattiesburg, MS	S. Ross R. Wales	
ALABAMA		
Marine Environmental Sciences Consortium Dauphin Island Sea Lab Dauphin Island, AL	T. Hopkins G. Crozier W. Schroeder	J. Stout J. Dindo
University of Alabama at Birmingham Birmingham, AL	S. Brande K. Marion	
University of Alabama at Tuscaloosa Tuscaloosa, AL	D. Raney B. Benson	E. Futato
University of South Alabama Mobile, AL	R. Shipp G. Lamb R. Fuller	W. Isphording R. Stowe D. Blancher
OTHER UNIVERSITIES		
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University of South Florida Bayboro Campus St. Petersburg, FL	L. Doyle	
University of West Florida Pensacola, FL	S. Collard S. Bortone	

Table 1.4 (Continued)

SOURCES	CONTACTS
OTHER SOURCES	
Coastal Environments, Inc. Baton Rouge, LA	D. Kelly
Continental Shelf Associates, Inc. Tequesta, FL	D. Gettleson J. Thompson
Exxon Company Southeastern Division New Orleans, LA	H. Johnson
Florida Governor's Office Tallahassee, FL	D. Tucker
Louisiana Land and Exploration Co. Saraland, AL	W. Oberdeen
Mobil Oil Exploration and Producing Southeast, Inc. New Orleans, LA	J. Martin
Shell Offshore, Inc. Division of Safety and Environmental Affairs New Orleans, LA	R. Zygmunt V. Harris
Sport Fishing Institute Washington, D.C.	H. Gatewood

1.2.6 SYNTHESIS REPORT

All identified and collected information and annotations were reviewed and evaluated for summary preparation of the following topic areas:

Chapter	Subject
2.0	Conceptual Ecosystem Model
3.0	Physiography and Geology
4.0	Physical Oceanography
5.0	Chemical Oceanography
6.0	Ecological Resources
7.0	Socioeconomics

This technical report constitutes the compilation of those written subject chapter summaries. Each chapter cites and reviews where appropriate, the major studies concerning the topic area; identifies and evaluates important data gaps; and is followed by a literature citation section. A separate Executive Summary is presented which summarizes the results of this study and incorporates recommendations in response to information needs.

1.3 OVERVIEW OF THE TUSCALOOSA TREND REGION STUDY AREA

The Tuscaloosa Trend Region Study Area is located in the north central Gulf of Mexico adjacent to the states of Louisiana, Mississippi, and Alabama (Figure 1.1). The study boundaries include the Mississippi Delta on the west, the DeSoto Canyon on the east, and offshore to a depth of 200 m. This coastal region includes the Chandeleur Islands, Chandeleur Sound, Breton Sound, Mississippi Sound, Mobile Bay, the barrier islands along the coasts of Mississippi and Alabama, and the coastal marshes fringing the three states. The area is dominated by the presence of the Mississippi River, which empties freshwater into the Gulf and serves as a transition zone between oceanic and freshwater environments.

Many abiotic and biotic components contribute to this complex ecosystem. These components are described briefly below as they pertain to the study area.

1.3.1 ABIOTIC COMPONENTS

Physiography

Much of the study area is a broad, flat, alluvial plain, usually less than 1.6 m above mean sea level (MSL). Barrier islands along the Gulf coast are low, with average elevations of 1 to 1.3 m MSL; however, elevations of 8 m occur in the dune systems of some islands (e.g., Dauphin Island, Alabama).

The various bays and sounds range up to 4 to 6 m deep. The Breton, Chandeleur, and Mississippi Sounds are dissected by numerous ship channels and their associated dredged disposal area. Seaward of the barrier islands, the seafloor falls off at a moderate rate.

Meteorology

The subtropical humid climate of the Tuscaloosa Trend region can be attributed directly to the moderating influence of the Gulf of Mexico. The annual average temperature of the area is 20°C (68°F) with summer highs over 32°C (90°F) and winter lows near -7°C (20°F). Cold temperatures occur from mid-November to mid-March when Arctic air masses move into the Gulf coastal region.

Prevailing wind direction is determined by the water-land temperature differential. In late fall-early winter, Gulf waters are warmer than the land mass, so northerly winds dominate. In the summer, when the land heats up rapidly, winds switch and come out of the south, creating the characteristic humid seabreeze. The mean wind speed is about 8 mph and is characteristically higher in the winter and lower in the summer months.

The rainy season occurs from December through March, when steady rains for 2-4 days are not uncommon. Precipitation in summer months occurs as sporadic thunderstorms.

The Trend area occasionally experiences hurricanes with winds in excess of 120 mph and 14-inch rainfalls within 24 hours. On the average, a storm of this magnitude occurs once every 100 years. Smaller tropical storms with winds of 75 mph and 8- to 20-inch rains in 24 hours occur on the average of once every five years.

Circulation

The major offshore oceanic current component of this area is the Loop Current, which originates off the east coast of Yucatan and travels north across the Gulf to the Mississippi River Delta where it splits, forming a counter-clockwise circulation and westerly movement of waters west of the Delta, and and easterly movement of waters east of the Delta. Occasionally, eddies from this current bring high salinity oceanic waters onto the continental shelf.

The current patterns behind the barrier island system are dependent on a number of parameters such as freshwater output from the Mississippi and Mobile River systems, wind direction and speed, bathymetry, and shoreline configuration. Prevailing southerly and easterly winds result in a net westerly longshore current (1-3 knots) on the seaward side of the barrier islands and cause significant erosion on eastern portions of the islands and accretion on the western tips.

Tides are diurnal (one low and one high each day) in the northern Gulf, with a maximum tidal amplitude of 0.8 m. Normal tidal fluctuations along the coastal regions are between 0.3 and 0.6 m.

Sediments

The Gulf of Mexico continental shelf is a subsided portion of the Atlantic Plain and extends from Florida to the easternmost point of the Yucatan Peninsula. Shelf sediment distribution is dependent upon prevailing current patterns and sediment-bearing river systems which drain the continent. The relatively heterogeneous surficial sediments offshore eastern Mississippi, Alabama, and the western Florida peninsula cover the eastern edge of the Gulf Coast Geosyncline. Coarse and medium sands (MAFLA sand sheet) on the shelf east of Mobile Bay grade westward into fine and very fine sand which in turn give way to silts and clays of the Mississippi pro-delta. The same trend also continues from north to south across the continental shelf. Fine sediments also lie at the head of the DeSoto Canyon. Sediment dispersion on the inner shelf is affected by the Mississippi, Pearl, Pascagoula, and Mobile rivers, while transport on the open shelf is primarily due to the prevailing westerly currents.

Estuarine sediments are heterogeneous mixtures of sands, silts, and clays. Mississippi Sound and Mobile Bay are characterized as having mostly silt and clay sediments with patchy areas of fine to medium sand near shoals and inter-island passes. Sediments in the Chandeleur Island area are composed of medium sands as a result of reworking of the old St. Bernard Delta of the Mississippi River by wave action.

1.3.2 BIOTIC COMPONENTS

Flora

The shoreline of the study area is dominated by tidal marshes and submergent grassbeds which form an interface between marine and terrestrial habitats, while seagrass beds occupy a transition zone between emergent vegetation and unvegetated coastal bottoms. These habitats can occupy narrow bands or wide expanses and can consist of sharply delineated zones of different species or stands of single species.

The coastal marshes of the Gulf of Mexico comprise some 5.7 million acres with 58% located in Louisiana alone. Approximately 269,000 acres occur in the Trend region. Dominant marsh species in these coastal marshes include *Spartina patens*, *Spartina alterniflora*, *Salicornia* sp. and *Juncus roemerianus*. Mississippi and Alabama coastal marshes are dominated by *J. roemerianus* and *S. alterniflora*.

Marshes provide organic nutrients to coastal waters through decay, and provide substrate for bacteria and protozoa. The vegetation is converted into detritus which becomes the major component of the marine food bulk. Marsh grasses also provide shelter to wildlife, and their roots help bind sediments and reduce erosion of the coastline.

Nekton and Demersal Fauna

Nearly all commercially important species of fishes from the Gulf of Mexico are estuarine-dependent. Most leave the estuaries as juveniles and spawn at sea after becoming reproductively mature. The majority of eggs hatch at sea; the larvae become part of the offshore planktonic community, and with the influence of tides, currents, and winds, the larvae enter the estuarine nursery grounds. The estuaries provide shelter from predators and food for growth of juveniles prior to migration back to the Gulf to repeat the spawning process.

Shellfish, including oysters, crabs, and shrimps, are also generally estuarine-dependent. Oyster reefs occur in brackish waters protected by barrier islands or embayments. Juvenile blue crabs and penaeid shrimps enter the estuaries through the tidal passes and mature in the shallow waters and marshes of the sounds and bays.

Benthos

The continental shelf benthic habitats can be described primarily on the basis of sediment texture and depth. The North Central Gulf of Mexicc may be divided into 3 zones: Inner Shlef (0-20 m); Intermediate Shelf (20-60 m); and Outer Shelf (60-120 m). The Inner Shelf habitat contains mostly fine sand sediments in the east grading to mud sediments toward the Mississippi Delta. The Intermediate Shelf consists of medium to fine sands east of the Mississippi River with some sparse patches of muddy sand sediment. The Oyster Shelf has been sparsely sampled. Its eastern region is characterized by fine sands and foraminiferan deposits, which grade into muddy sands and muds near the western region. Characteristic species assemblages are associated with the different sediment types at different depths. For example, shallow muddy sand and silt habitats are dominated by deposit-feeding polychaetes and other opportunistic macroinfauna. Fine sand substrates are populated by a more diverse benthos, including amphipods, bivalves, and polychaetes.

1.3.3 SOCIOECONOMIC COMPONENTS

Industrial Developments

The Tuscaloosa Trend region varies substantially in socioeconomic patterns, ranging from low density areas to highly developed urban centers. The highest levels of employment are in the areas of manufacturing, wholesale/retail trade and services. Unemployment in the Louisiana-Mississippi-Alabama tri-state region was well above the national average in 1970 and 1980 but was lower for the coastal area than for the states at large during that same period.

Mineral Resources

The most important exploitation of mineral resources in the central Gulf tri-state region is oil and gas. The production of oil and gas may be considered a primary industry while processing of oil and gas (refineries, petrochemical, supply bases, construction) may be considered secondary. Increased development of tertiary industries can be expected as a result of the economic activity of the primary and secondary industries. By far, the majority of the oil and gas industry activity is concentrated along the Texas-Louisiana coastal regions.

Fishery Resources

The Gulf of Mexico is the single most important area for fisheries food production in the United States while the Gulf shrimping industry represents the single most valuable type in the United States. In 1977, shrimp production reached almost 270 million pounds worth over $296 million dockside. Louisiana ranked first in the nation in both commercial fisheries landed and value in 1979 with 1.5 billion pounds landed worth $198.5 million. In addition to shrimp, Gulf landings of blue crab averaged about 40 million pounds annually worth about $5-6 million. Oysters are the main mollusc harvested in Gulf estuaries and produce 14-15 million pounds per year with dockside values estimated at $10-13 million. Perhaps one-third of these fishery resources may be attributed to the Tuscaloosa Trend region.

2.0 CONCEPTUAL ECOSYSTEM MODELING

2.1 INTRODUCTION

This chapter discusses the ecosystem modeling effort conducted as part of the Tuscaloosa Trend Regional Data Search and Synthesis Study. An ecosystem is a real entity, consisting of at least two interacting components (e.g., organisms and their environment) and exchanging material and energy with adjacent entities. An ecological model is an abstraction that expresses our understanding of the ecosystem. Depending on the stage of development, ecosystem models can be conceptual or numerical. The Tuscaloosa Trend modeling effort is conceptual in scope.

Section 2.2 presents the objectives of the modeling effort and Section 2.3 discusses the approach employed in the study to develop a conceptual representation of the Tuscaloosa Trend regional ecosystem. This is followed in Section 2.4 by an introduction to conceptual ecosystem modeling. Once this context is established, representations of processes on the Tuscaloosa Trend are presented at several levels of detail in Section 2.5. Section 2.6 then summarizes the major ecosystem relationships on the Trend OCS in the context of the model.

2.2 OBJECTIVES OF THE TUSCALOOSA TREND CONCEPTUAL ECOSYSTEM MODELING

The objectives of the conceptual modeling effort are fourfold:

(1) Develop a simplified conceptual representation of the Tuscaloosa Trend ecosystem that stresses those ecosystem components and processes most important to the goals of the Tuscaloosa Trend ecosystem study;

(2) Provide the conceptual framework for (a) information gathering, organization and synthesis, and (b) prioritization of research and monitoring efforts in subsequent years of the program;

(3) Enhance communication and coordination of activities among researchers working on various aspects of the Trend ecosystem study; and

(4) Provide the context for intelligent planning and management of marine resources on the Trend OCS.

2.3 APPROACH TO TUSCALOOSA TREND CONCEPTUAL MODEL DEVELOPMENT

The approach to development of the Tuscaloosa Trend conceptual ecosystem model first involved reviewing and evaluating existing marine ecosystem conceptualizations in an attempt to identify one that could be adapted to the needs of this study. This approach was consistent with the available resources and with the basic rule of not "reinventing the wheel." It is predicated on the assumption that temperate continental shelf ecosystems in various geographic regions share certain basic functional similarities.

These review activities identified the conceptualization of the New York Bight ecosystem by McLaughlin et al. (1975) as being clearly the one most applicable to the goals of this study. This model, developed for the NOAA Marine Ecosystem Analysis (MESA) Program Office, represents an ecosystem approach to marine pollution problems. It can provide the framework for information gathering and synthesis, identification of data gaps, management of scientific multidisciplinary research programs, and multidisciplinary resource management (McLaughlin and Elder, 1976). Adapting this conceptualization to MMS needs is consistent with the goals of the National Marine Pollution Program Plan (COPRDM 1981) which mandates that federally funded marine pollution research activities be coordinated across agencies and disciplines.

Consistent with the MESA approach, the conceptualization of the Tuscaloosa Trend study area is hierarchical, consisting of three levels; Level 1 - a comprehensive ecosystem representation; Level 2 - major processes (e.g., sedimentary, biogeochemical and ecological); and Level 3 - specific ecological applications (e.g., nekton life histories, marsh-estuarine interactions, pelagic and benthic food webs). Each level is discussed in Section 2.5, where they are depicted in wire diagrams. The Tuscaloosa Trend ecosystem is depicted as a single unit in these models, implying that the conceptualization is functionally representative of any portion of the system. Although the Trend region includes a variety of habitats (e.g., coastal marshes, estuaries, oceanic waters), the functional relationships within and between these systems are relatively constant among the geographic areas considered.

2.4 OVERVIEW OF CONCEPTUAL ECOSYSTEM MODELING

2.4.1 INTRODUCTION

Figure 2.1 (modified from UNESCO, 1983) shows the steps in conceptual ecosystem model development. Any ecological modeling effort begins with an identification of the ecosystem of interest and a clear and unambiguous definition of goals and objectives of the study. These objectives, along with the observable behavior of the ecosystem, will determine the form (i.e., structural and functional representations) in the model. Once the objectives are defined, the development of the conceptual model itself can be initiated. Subsequent steps in conceptual ecosystem model development include: (1) definition of conceptual, spatial and temporal boundaries and scales; (2) identification of physically and ecologically homogeneous subsystems (discretization); (3) identification of inputs, outputs and external controlling factors; (4) selection of state variables (i.e., compartments); and (5) delineation of processes within the system and regulators controlling these flows.

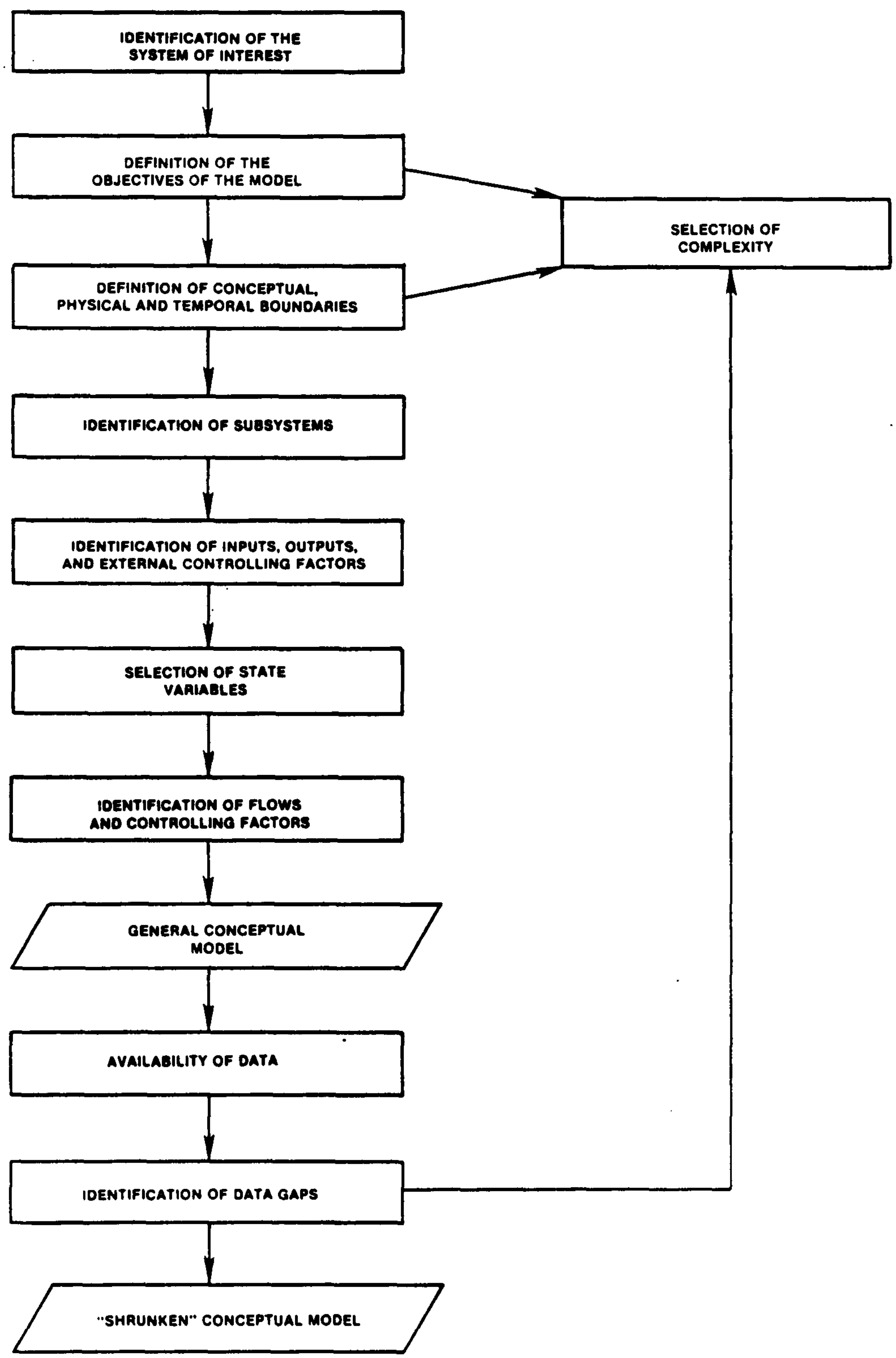


Figure 2.1. The process of conceptual ecosystem model development (modified from UNESCO, 1983).

The initial conceptual representation generally includes more detail than can be incorporated into a workable numerical model, and is usually reduced to a workable level before being developed into numerical form. Numerical model development begins with a representation of the inputs, outputs and processes by specific numerical functions (usually differential equations).

2.4.2 STRUCTURAL FORM OF THE MODEL

Two major lines of marine ecosystem modeling together demonstrate the relationships of structural form to study objectives. Considerable effort has been expended in the last quarter century in modeling the eutrophication process. Eutrophication-type models stress the interactions of primary producers (phytoplankton populations and/or communities) to inputs of nutrients. In most cases, trophic levels above herbivores (consumers of phytoplankton) are not modeled explicity, but are treated as external sinks. At the other extreme, multispecies fisheries models, which are based on the pioneering work of Andersen and Ursin (1977) in Denmark, concentrate their attention at the top of the marine food chain (i.e., at fish populations). The DYNUMES model developed by the NMFS' NWAFC (Laevastu and Larkins, 1981) is of this type. These multispecies models are directed primarily at commercial fish populations and communities and their relationship to the physical environment, and do not include those state variables or compartments (i.e., phytoplankton) that are most important to the eutrophication-type models. The DYNUMES model does not include a primary producer compartment and treats the zooplankton as an input term (outside the model and controlled).

2.4.3 SPATIAL AND TEMPORAL SCALES

One of the major concerns in ecosystem model development is reconciling the spatial and temporal sales required to address adequately the processes of importance in the ecosystem. Figure 2.2 (from NAS, 1980) demonstrates scale differences for three trophic groups, phytoplankton, herbivorous zooplankton and pelagic fish (feeding on the zooplankton). Generations of phytoplankton populations are measured on time and space scales on the order of several days and kilometers, while spatial and temporal scales for zooplankton fish population dynamics are, respectively, one and two orders of magnitude greater in both dimensions. The basic question is one of how to balance these contrasting scales so that the important questions can best be framed in a modeling context, while still retaining enough detail to represent adequately the functional dynamics of all compartments of interest.

2.4.4 DEFINING MODEL BOUNDARIES AND SUBSYSTEMS (DISCRETIZATION)

One of the first tasks in ecological modeling is defining the spatial boundaries of the ecosystem, so the relationships of the ecosystem of interst and adjacent interrelated ecosystems can be identified. This implies that the ecosystem is an open system, which exchanges energy and materials across the boundaries with adjacent ecological systems. These relationships are shown schematically in Figure 2.3. A continental shelf ecosystem such as the Tuscaloosa Trend OCS exchanges materials and energy with the atmosphere, with adjacent estuaries and terrestrial/fresh water ecosystems, with adjacent upcoast and downcoast continental shelf ecosystems, and with the deep ocean located further offshore (at the shelf/slope break or, in this case, at the 200 m depth contour). The boundaries separating the shelf ecosystem in question from adjacent shelf ecosystems is probably the least meaningful from an

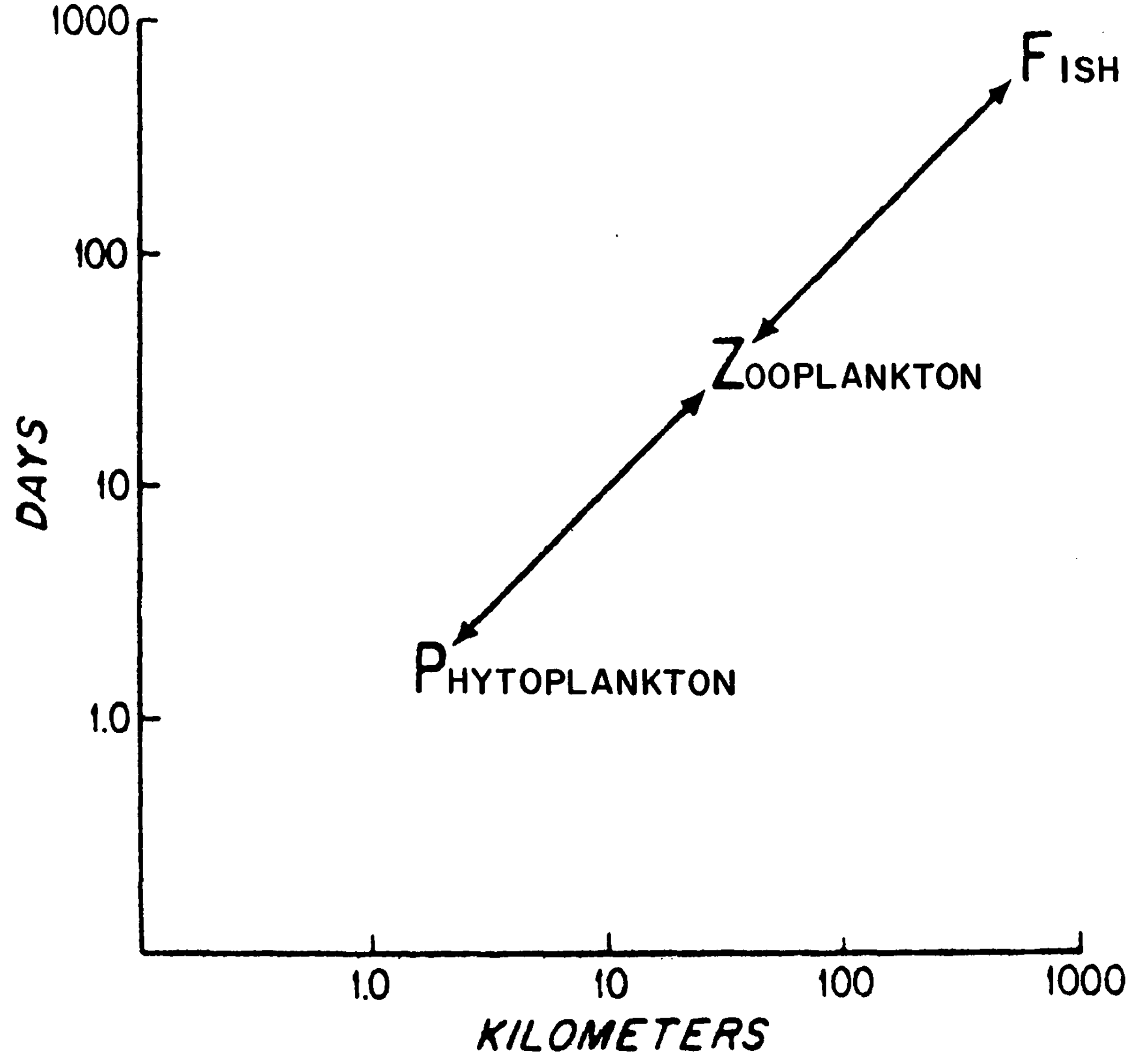


Figure 2.2. A heuristic representation of scale relations for marine food webs. (Source: NAS, 1980).

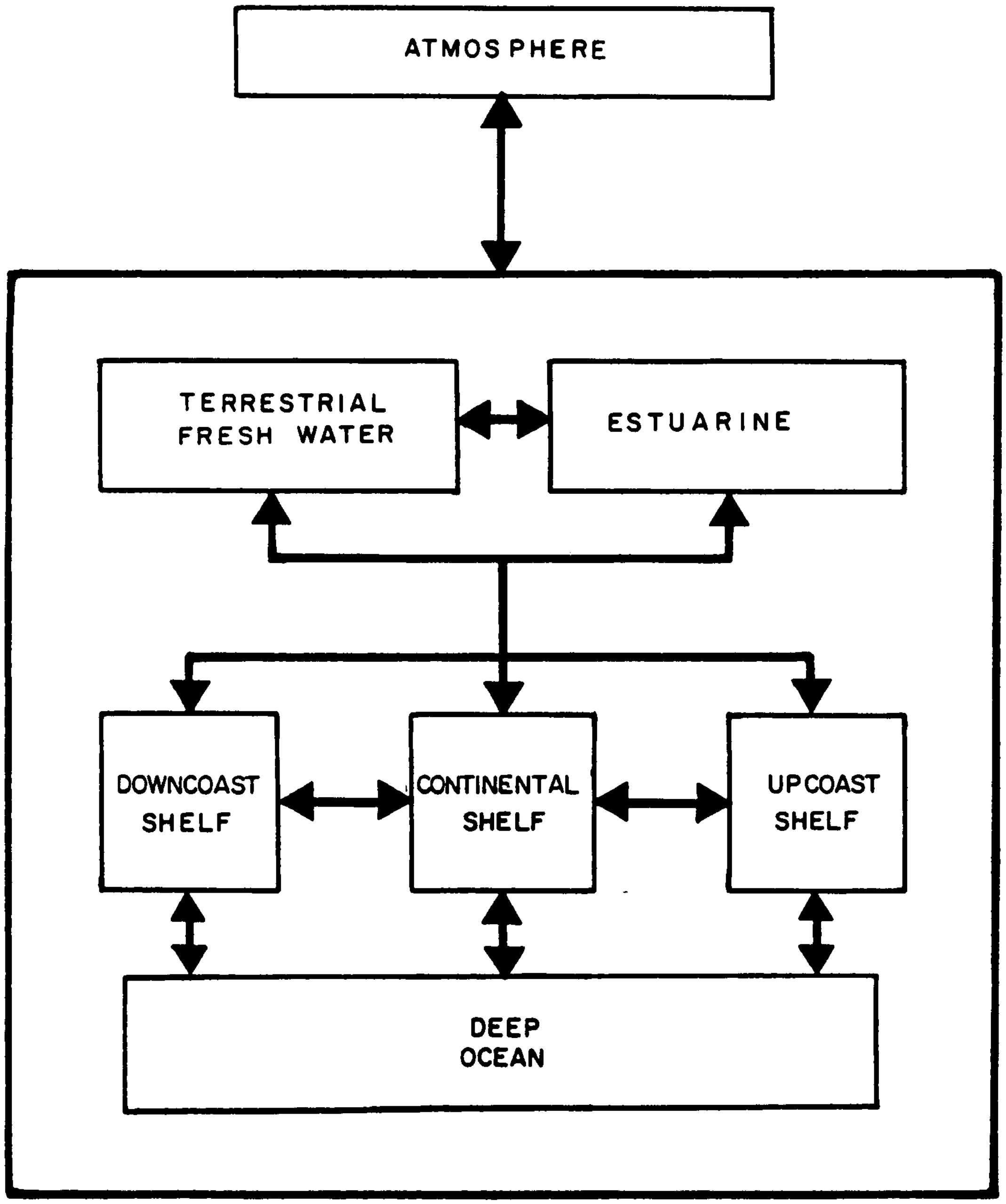


Figure 2.3. A block diagram representation of a continental shelf ecosystem.

ecological perspective; such boundaries often do not represent natural discontinuities and are often imposed to accommodate the geographic domain of some particular human use or activity where ecological impacts are being assessed.

Once the boundaries of the ecosystem have been defined, inputs and outputs can be calculated. Assuming no gradient in physical processes across the surface of the boundary, a flux of energy or biochemicals can be calculated as:

flux = current speed X boundary surface area X concentration

Input-output relationships provide the context within which ecosystem processes can be studied. Simple mass balance models can be constructed to identify those geochemicals that are accumulating in or being exported from the Trend ecosystem. Mass balance models can be used to identify the most important fluxes as well as to calculate an unknown flux when all others are known.

Discretization, the subdividing of the ecosystem into ecologically homogeneous units, is important not only in identifying ecological subsystems but also in guiding and optimizing the design of subsequent research and monitoring programs in the study area. The general rule is to discretize where interactions are weakest (e.g., at the shelf-slope break). That is, the ecosystem should be discretized where natural, ecologically meaningful, and well-defined discontinuities in ecosystem structure and functioning exist.

In some ecosystems, clear-cut boundaries do not separate well-defined subsystems. In these cases, discretization generally involves subdividing the ecosystem along major habitat gradients. For example, the Institute for Marine Environmental Research (U.K.) developed a General Ecosystem Model For Bristol Channel and Severn Estuary (GEMBASE) that subdivides the subject estuary into segments along a salinity gradient (Radford and Joint, 1980). While some modeling efforts have discretized the subject ecosystem on more of a biological community basis (e.g., Sweden's Asko Laboratory's "Energy Flow Through the Baltic Ecosystem," Jansson (1972), the emphasis in discretization is usually on physical processes (currents, pycnoclines, and hydrography) and bottom features (bathymetry, and sediment composition), for several reasons. First, data for physical characteristics are more readily available than for biological parameters. Second, if the physical characteristics are selected intelligently, those which are important in determining ecological structure and functioning (e.g., primary production and community distributions) will be included. Under these conditions, the subsystems defined on the basis of physical characteristics can be expected to represent habitats.

Perhaps the simplest example of discretization involves subdividing the ecosystem into an upper photic zone and a lower aphotic zone. In this case, a physical factor (distribution of solar radiation with depth) defines ecologically meaningful subsystems. Another similar criterion by which the water column can be discretized is the interface of two physically different water masses (the pycnocline or the shelf-slope front).

If physical processes are well-enough known and the boundaries of the system are well-enough defined, hydrodynamic models can be developed to reproduce observed hydrographic and current patterns and predict patterns under new sets of conditions. This will not only facilitate identification of subsystems within the ecosystem, but will also permit input-output relationships with adjacent and linked systems (i.e., across boundary conditions) to be defined. In order words, hydrodynamic models can be used to generate the larger (i.e., eastern Gulf of Mexico) regional context of which the Tuscaloosa Trend ecosystem is a part. This is precisely what was done in the Belgian National Program on the Environment-Sea Project in the North Sea Project (Nihoul, 1976).

Discretization is a prerequisite to development of spatial ecosystem models. Spatial models, in turn, must include transport processes linking the subsystems (through input-output relationships). Therefore, the more the system is discretized, the greater the need for a hydrodynamic model to link subsystems together.

2.4.5 DEFINING MODEL COMPLEXITY

In conceptual ecosystem modeling, complexity is usually expressed in terms of the number of compartments or state variables to be included in the model. The compartments or state variables are the actual entities in the model and include such things as biota (producers, consumers, decomposers) and abiotic features (water column, sediments). Flows in the model define how compartments are relatd to each other and to entities outside the ecosystem. Figure 2.4 (from Odum, 1972) shows how complexity can increase with increasing numbers of compartments. In this example, three levels of disaggregation or compartmentalization are identified. At each level, everything occurring at the next higher level is "blackboxed" (i.e., only addressed through its input-output relationships). Thus, at the most general level, the ecosystem is treated as a single compartment with three inputs and three outputs. The dynamics within the ecosystem are not explicitly addressed at this level, but are implied through the input-output relationships, (i.e., the ecosystem is viewed as a processor, converting inputs to outputs). Increasing the number of compartments from one to three increases the number of inputs and outputs for each compartment to four and includes five additional flows linking the three compartments (Figure 2.4). At this level, the dynamics within the three compartments are not addressed. The final level includes ten compartments, eight inputs, four outputs and about twenty intercompartmental flows (Figure 2.4).

The several levels of complexity shown in Figure 2.4 should not be interpreted as fixed entities, but instead as stages along a continuum. Detail (complexity) can be built into any part of the model to suit the specific needs of the research program by disaggregating any compartment to the level required. Each level represented in Figure 2.4 would be useful at certain stages of model development and for certain purposes. Thus, early in a modeling program, the first level can be used to quantify basic input-output relationships to determine if, for example, toxic substances are accumulating within the ecosystem. This would tell nothing about where these toxicants are accumulating (i.e., spatially and in which compartments), but would identify those which bear further investigation.

2.4.6 ECOSYSTEM MODEL COMPONENTS AND THEIR REPRESENTATION

Defining the Components

Conceptual ecosystem models are composed of four components, as indicated in Table 2.1. The inputs and outputs define relationships of the

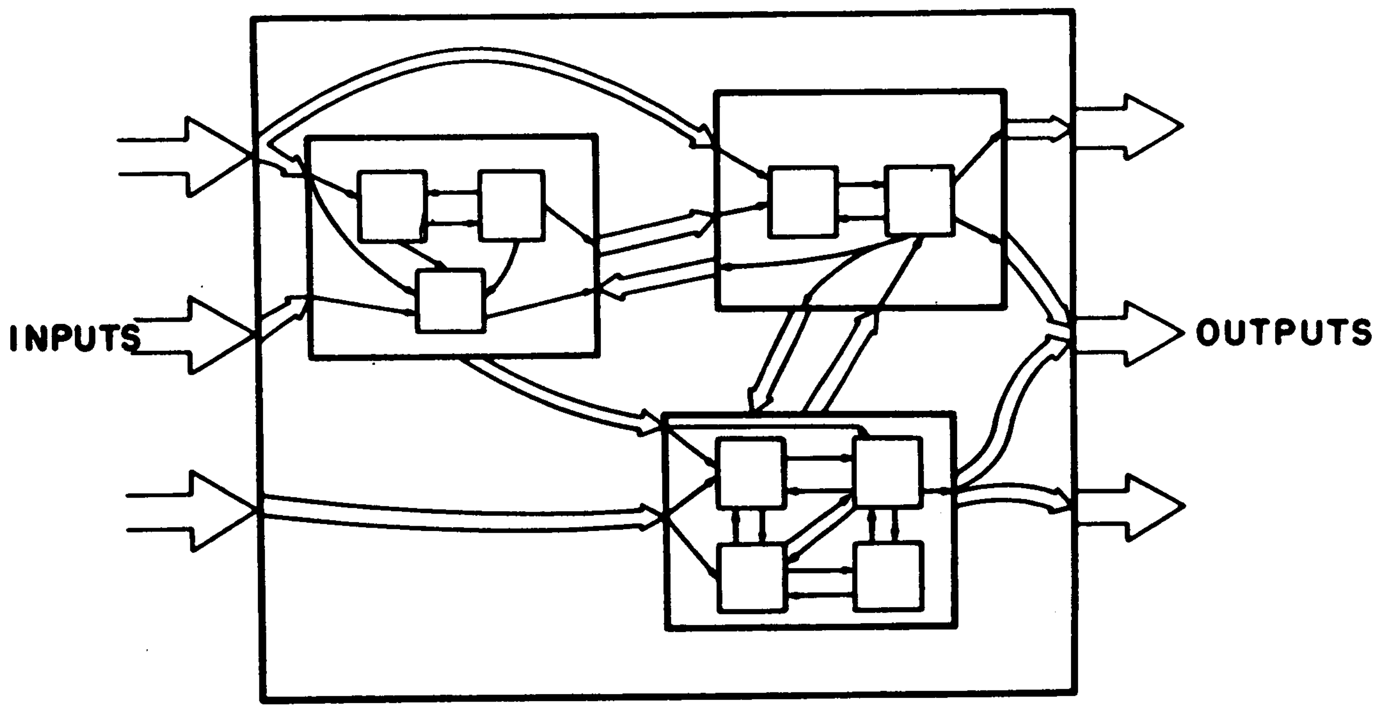


Figure 2.4. Structural detail versus "block boxes" in conceptual ecosystem representation. (Source: Odum, 1982).

Table 2.1. Components of conceptual ecosystem models.

CONCEPTUAL ECOLOGICAL MODELS

COMPONENTS

- INPUTS AND OUTPUTS

- COMPARTMENTS
  - Biotic
  - Abiotic

- PROCESSES
  - Physical
  - Chemical
  - Geological
  - Ecological

- REGULATORS
  - Salinity
  - Temperature
  - Advection
  - Turbulence
  - Others

subject ecosystem to adjacent interrelated ecosystems. The compartments or state variables are the functional entities in the model. These compartments are either biotic (living) or abiotic (non-living), and their number contributes to defining the complexity of the conceptual model. They include producers (phytoplankton), consumers (e.g., zooplankton, benthos, and nekton), decomposers (e.g., bacteria), particulate detritus, and organic and inorganic material dissolved in the water column. The functional relationships among these entities are represented by the flows connecting them, and these flows are controlled by environmental regulators.

Conceptual Model Representation

Ecosystem components must be represented in an unambiguous and consistent language so the conceptual representation is simplified and intelligible. Several such languages have been developed, but the one that has been used most consistently in marine ecosystem modeling is that of H.T. Odum (Odum, 1972). Odum's flow language is based on some elementary concepts of energy and mass flow, and provides a way to represent the basic structural and functional components of ecosystems so they can be simply and concisely related in a modeling context.

The symbols of Odum's language are shown in Figure 2.5, and are used to provide a simple representation of an ecological system in Figure 2.6. Sources of energy and materials (from outside the ecosystem) are represented by circles (o). The biotic compartments are usually defined on the basis of how they "feed" since such trophic relationships define many of the most important interactions among biological components. The most fundamental compartmentalization of the biota involves separating producers (plants ( ) that can generate organic matter from sunlight through photosynthesis) from consumers (animals and bacteria ( ) which ultimately depend on organic matter produced by plants). Passive storage compartments, such as the dissolved and particulate material in the water column and seafloor sediments are represented by storage tanks ( ). Any type of energy or mass flow path is represented by an arrow (→), defining the direction of flow. These arrows represent physical, chemical, geological, and ecological processes in the model. These flows are often controlled or regulated by physical and biological factors. These regulators are represented by unidirectional and bidirectional "hollow arrows" (and , respectively). Often more than one regulator controls a flow, and one process can regulate another type of process. Primary among these regulators, especially for those compartments with no innate mobility, are advection and turbulence. One of the main utilities of physical processes in ecological modeling is to the regulators of biogeochemical processes. The other symbol of importance in representing model components is the "ground" ( ) coming off the bottom of compartments and regulators. This symbol represents the energy loss associated with work being accomplished.

A complementary way to represent an ecosystem conceptualization is through a connectivity or adjacency matrix, which, in tabular form, identifies the same four components of the ecosystem as does the wire diagram. An example of a connectivity matrix is shown in Section 2.5.2.

2.4.7 SIMPLIFIED REPRESENTATION OF A TYPICAL CONTINENTAL SHELF ECOSYSTEM

Odum's symbols have been used in Figure 2.7 to provide a simplified conceptual representation of processes operating in a typical continental

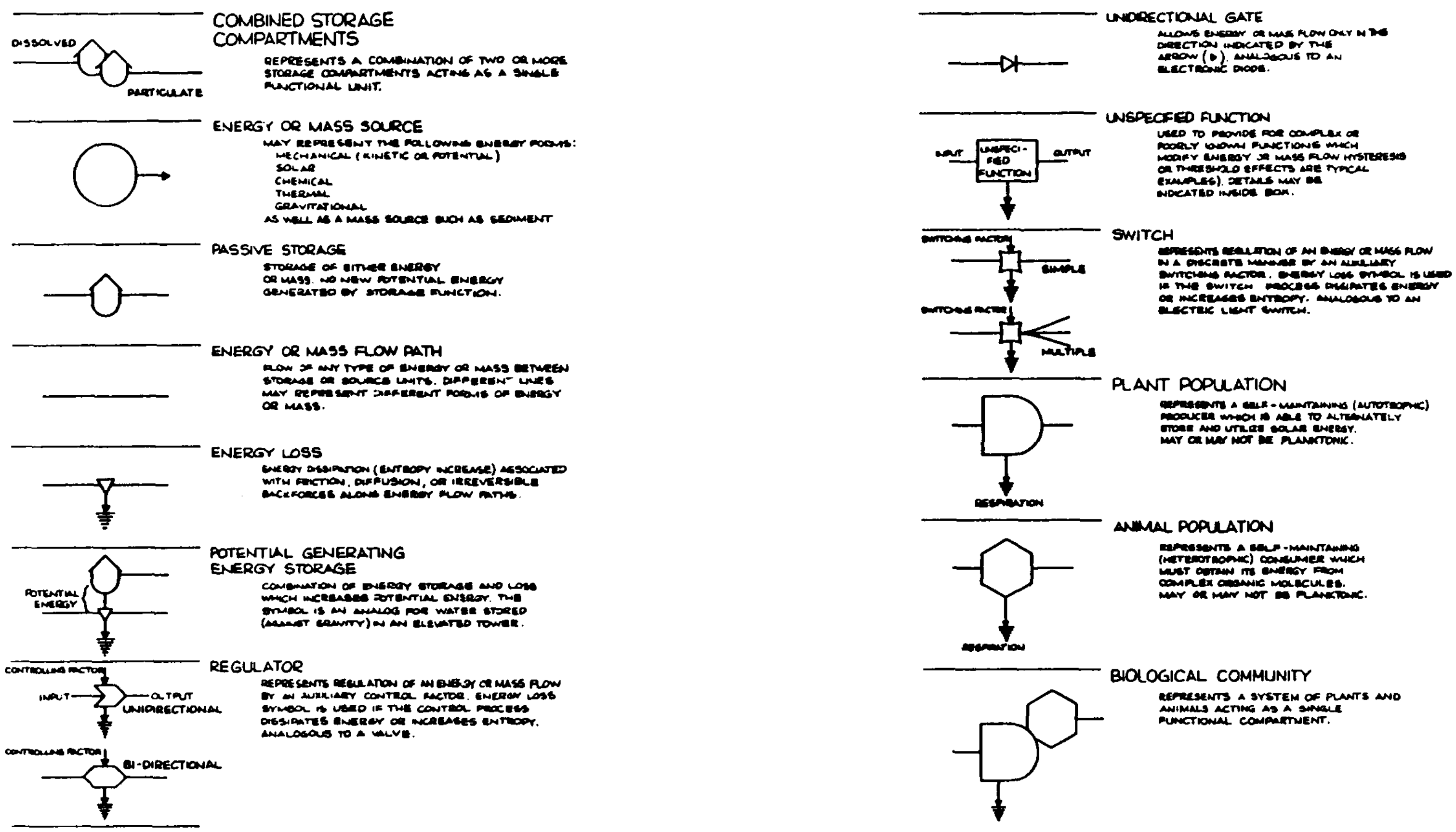


Figure 2.5. Odum energy-mass language symbols used in the Tuscaloosa Trend ecosystem conceptualization.

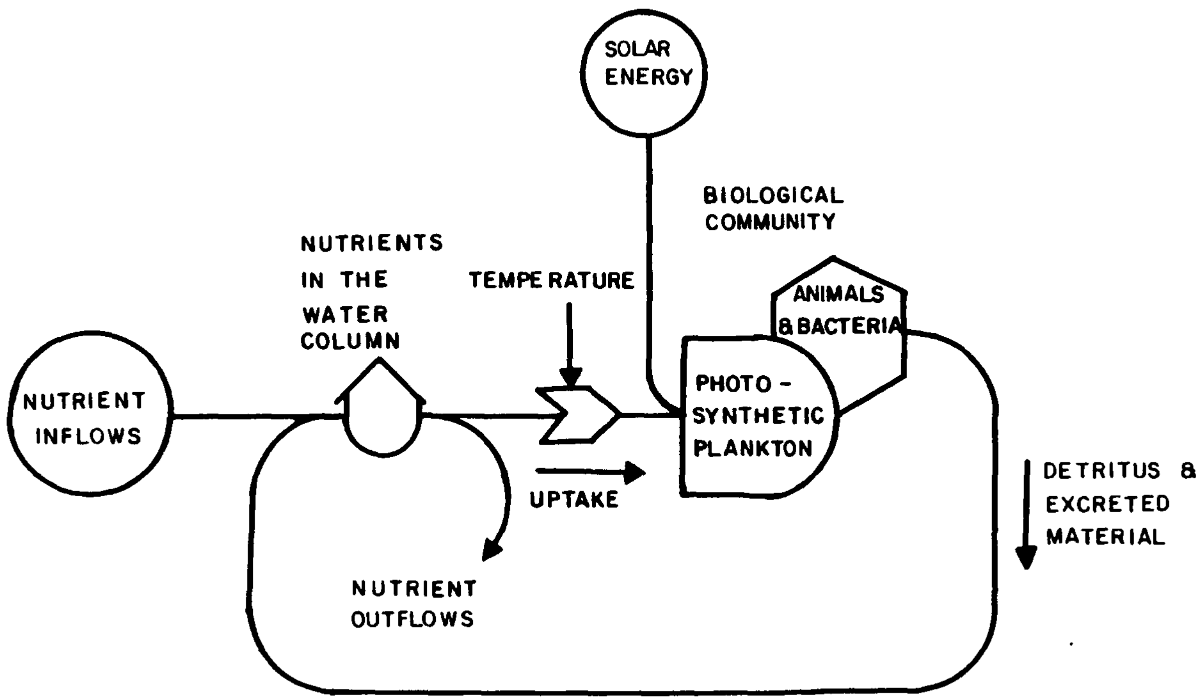


Figure 2.6. A simplified representation of an ecosystem using Odum's energy-mass language symbols. (Source: McLaughlin et al., 1975).

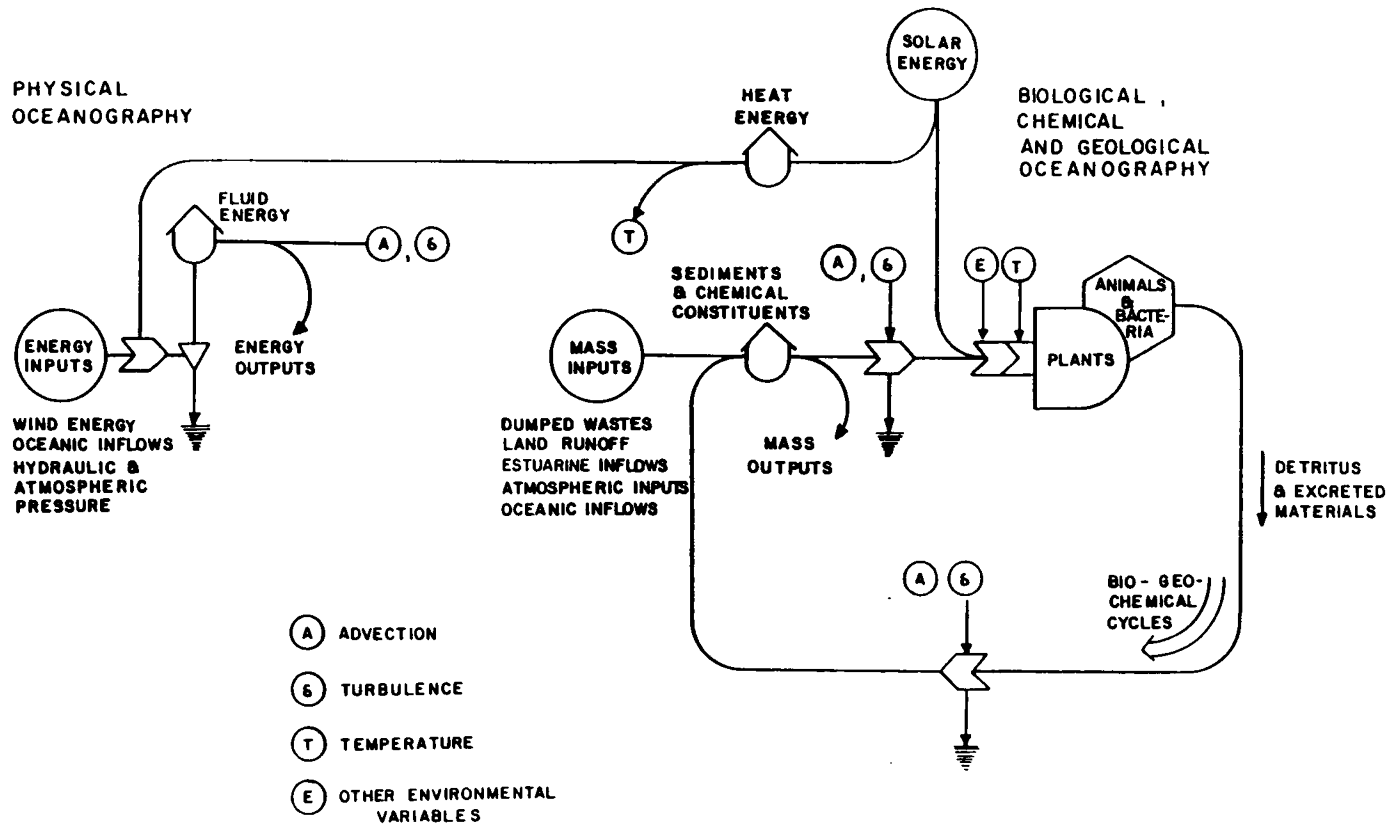


Figure 2.7. A simplified representation of processes operating in a typical continental shelf ecosystem. (Source: McLaughlin et al., 1975)

shelf ecosystem. Physical oceanographic processes (on the left), which mainly involve energy flows and water movements, are segregated from biogeochemical processes (on the right), but both categories are ultimately dependent on the sun for the energy to fuel this process. Physical processes influence chemical cycling, sediment transport and ecological structure and functioning in this conceptualization by generating regulators of these processes. Among the most important regulators are advection, turbulence, temperature, and density.

One aspect of particular note in Figure 2.7 is the lack of feedback from the biogeochemical subsystem to the physical subsystem, indicating that, on a large scale, physical processes are unaffected by the biogeochemical subsystem. In the real world, there are situations where feedbacks to the physical subsystem are obvious. For example, storm-induced disruption of the shelf floor can subsequently alter flow patterns, as can geological processes measured in thousands of years. However, under "normal" conditions and over the short-term, the assumption of independence appears to be reasonable. Accepting this assumption has considerable implications for ecological modeling, foremost of which is the freedom afforded to the researcher to model hydrodynamic processes independently of biogeochemical processes. This independence accommodates some of the most difficult problems regarding temporal and spatial sale resolution of physical and biogeochemical processes, and permits the researcher to select as input to the ecological model, outputs from hydrodynamic simulations (i.e., current and density fields) at time intervals most compatible with ecological functioning.

Solar radiation directly regulates physical and biogeochemical processes by heating of surface waters and, indirectly, by generating wind and barometric fields in the atmosphere (Figure 2.7). These energy sources combine to produce fluid energy which generates the advection and turbulence responsible for the transport of matter and energy in the ecosystem. The fluid energy generated by local winds (and other conditions) is superimposed on the energy that flows across the boundaries of the ecosystem due to large-scale air-ocean interactions. These and other regulators are shown controlling the biogeochemical processes in Figure 2.7.

The depiction of biogeochemical processes in Figure 2.7 involves a functionally integrated biological community consisting of primary producers (plants), consumers (animals), and decomposers (bacteria) and the geochemical environment (i.e., the abiotic materials in dissolved and particulate phases in the water column and sediments) with which the biological community interacts. In addition to inputs of energy, biogeochemical processes are strongly influenced by inputs and outputs of materials in the system. These input-output relationships are, to a large degree, regulated by advective and turbulent motion of the water medium.

Trophic relationships can be separated into anabolic and catabolic processes, depending on whether they involve the formation or degradation of organic materials, respectively. The formation of organic matter (reduction of carbon) in the ecosystem occurs mainly through the process of photosynthesis, while breakdown (oxidation) of organic matter is termed respiration. The energy released in respiration fuels biotic activity.

Solar radiation is utilized by the primary producers (e.g., phytoplankton) in the process of photosynthesis to convert inorganic carbon to plant biomass (Figure 2.7). In addition to sunlight and a source of inorganic carbon (the latter seldom if ever becoming a limiting factor in the sea), plants require nutrients dissolved in the water column to fuel the chlorophyll/enzyme systems responsible for photosynthesis. Dissolved nutrients are directly exchanged with the environment by the phytoplankton. Nitrogen appears to be the nutrient most often limiting to photosynthesis in the oceans, but phosphorous can be limiting under some conditions, and silica is required by coastal groups such as diatoms. A considerable fraction of the photosynthetically-fixed carbon may be excreted or secreted by the phytoplankton directly into the water column. Dissolved organic material as well as nutrients are taken up from the water column by bacteria in decomposition processes.

Consumers (herbivores) graze on phytoplankton biomass, converting some to animal tissue and the remainder (through excretion and egestion) to dissolved and particulate organic detritus. Other consumners (e.g., carnivores and omnivores) prey on the herbivores as well as each other, leading to food chains and food webs. All organisms not consumed eventually die, becoming part of the organic detritus pool.

At this stage microorganisms (e.g., free-living and particle-associated bacteria) begin their decomposition activities in earnest. Decomposition processes sustain the decomposer population, while at the same time, converting dissolved and particulate detritus to inorganic material and a refractory organic residue that is broken down very slowly, if at all. These populations of decomposers are then eaten by a number of different detrital consumers, forming the basis of a detrital food web. Some of the inorganic materials released in decomposition processes are once again absorbed by primary producers, and the cycle continues.

This representation (Figure 2.7) is highly simplified, and does not, for example, differentiate between the pelagic and benthic subsystems which can have entirely different energy and material dynamics. Distinctions of this type are rendered in the discussions of the more detailed representations that follow.

2.5 THE TUSCALOOSA TREND CONCEPTUAL MODEL

2.5.1 DEFINING ECOSYSTEM BOUNDARIES

The block diagram representation of a continental shelf ecosystem in Figure 2.3 is transformed into a pictorial depiction of the boundaries of the Tuscaloosa Trend ecosystem in Figure 2.8. For the purposes of this modeling exercise, the Tuscaloosa Trend ecosystem is defined as the entire continental shelf outward to 200 m depth. The ecosystem is bounded on the north and west by the potentially sensitive areas of the Chandeleur Islands and Chandeleur Sound, Breton Sound, Mississippi Sound, and Mobile Bay. The western and eastern boundaries dissect the continental shelf in the vicinity of the birdfoot delta and the head of DeSoto Canyon, respectively, while the deep ocean boundary runs along the 200 m isobath. Although the 200 m isobath encompasses the uppermost part of the continental slope, the boundary is close enough to the shelf break for the purposes of this modeling effort. The boundary with inland waters is very diffuse and poorly defined, especially in the western

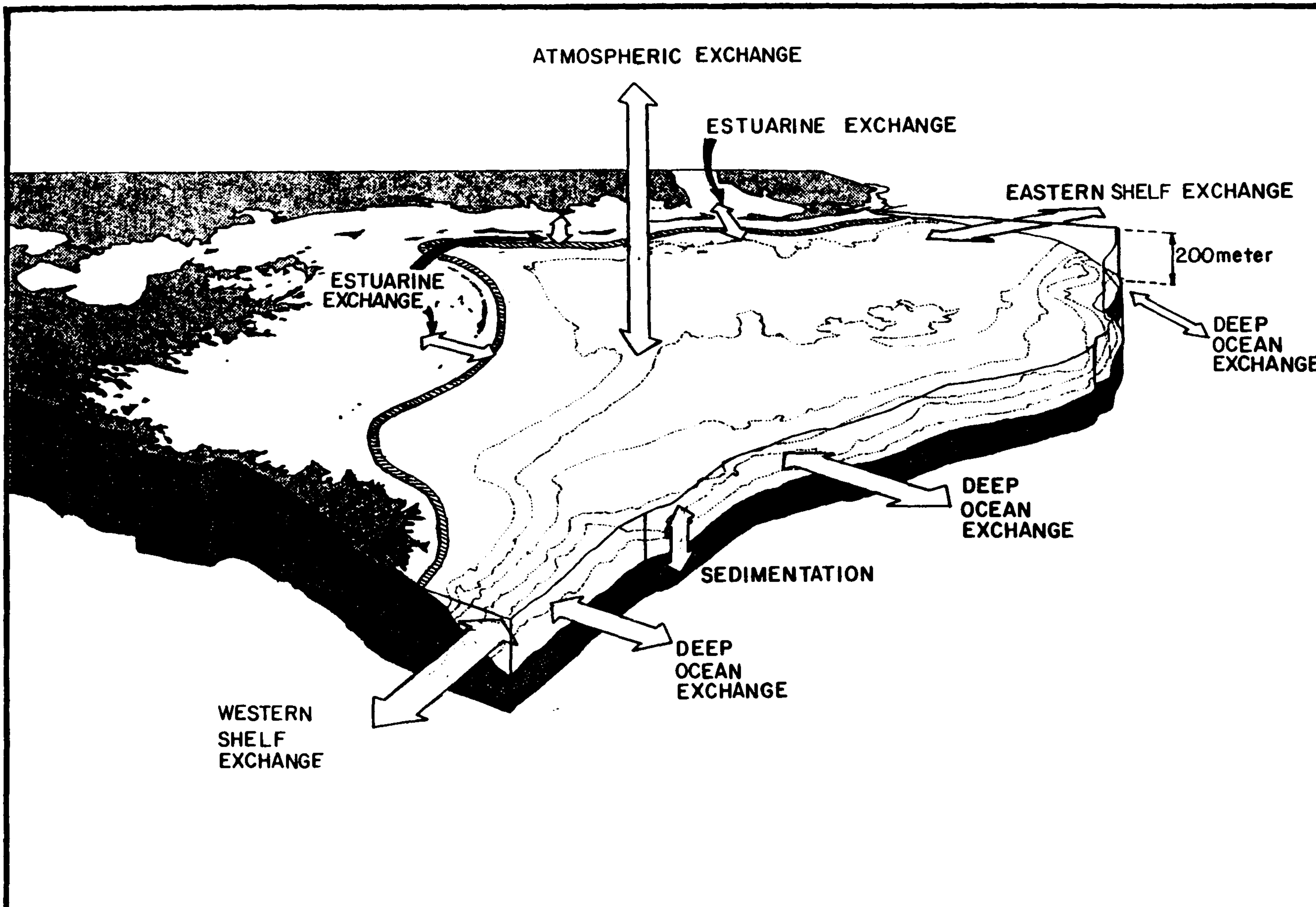


Figure 2.8. The boundaries and exchange processes used in the conceptual representation of the Tuscaloosa Trend ecosystem.

portion of the study area. Transport across the surface of this estuarine boundary could hardly be expected to be the same in different parts of the study area.

8.5.2 THE LEVEL 1 COMPREHENSIVE MODEL OF THE TUSCALOOSA TREND ECOSYSTEM

Introduction

Figure 2.9 is the Level 1 comprehensive conceptual representation of physical and biogeochemical processes in the Tuscaloosa Trend ecosystem. As in the simple conceptualization presented above (Figure 2.8), the left side of Figure 2.9 shows important physical oceanographic processes, while the right side portrays important biogeochemical processes. Table 2.2 is a connectivity matrix showing these same components of the comprehensive conceptual representation of the Tuscaloosa Trend ecosystem.

Physical Processes

In an ecosystem context, physical processes are important because they generate the regulators of biogeochemical processes. Among these are advection (mean transport) and diffusion (random component) of the water mass, which provide the primary means by which biogeochemicals are transported and dispersed in the ecosystem. Water temperature, which also results from physical phenomena, regulates the rates of many biological and geochemical processes. Temperature also influences advection and turbulence through its effect (along with salinity) on density and stratification of the water column.

Physical processes on the Tuscaloosa Trend are highly dependent on energy exchanged across the atmospheric, estuarine and oceanic boundaries. Kinetic energy, or energy of motion, flows across the estuarine and oceanic boundaries of the Trend associated with tidal forces, offshore storms (e.g., hurricanes), large-scale Gulf circulation patterns (e.g., the intrusion of the Loop Current onto the shelf), and riverine inputs. The latter are especially important in the study region, where physical oceanography is strongly influenced by discharge from the Mississippi River. Proximity to the Mississippi River outfall is perhaps the major factor that distinguishes the Tuscaloosa Trend ecosystem from a "typical" continental shelf ecosystem. These energy inputs are driven by coupled atmospheric-oceanographic processes that operate on hemispheric to global scales. In addition to these regional sources, local winds (which are also ultimately dependent on solar radiation) pass over the Trend ecosystem, transferring kinetic energy across the air-water interface to the upper layer of the water column. Potential energy is also introduced to the Trend ecosystem by way of local barometric and gravitational (i.e., hydraulic) pressure fields. The combined effect of local and regional processes determines advection and turbulence in the Trend ecosystem. Advection and turbulence in turn regulate inputs/outputs of the ecosystem, as well as distribution of materials and energy within it.

On the continental shelf, ocean boundary conditions, along with cross-shelf density gradients generate the long-term shelf circulation patterns that determine advective transport. The more transient shelf currents driven by time-varying local wind fields are superposed on this long-term mean circulation. In the open ocean, semipermanent features such as rings, eddies, upwelling, and intrusion of loop current water also contribute to advection.

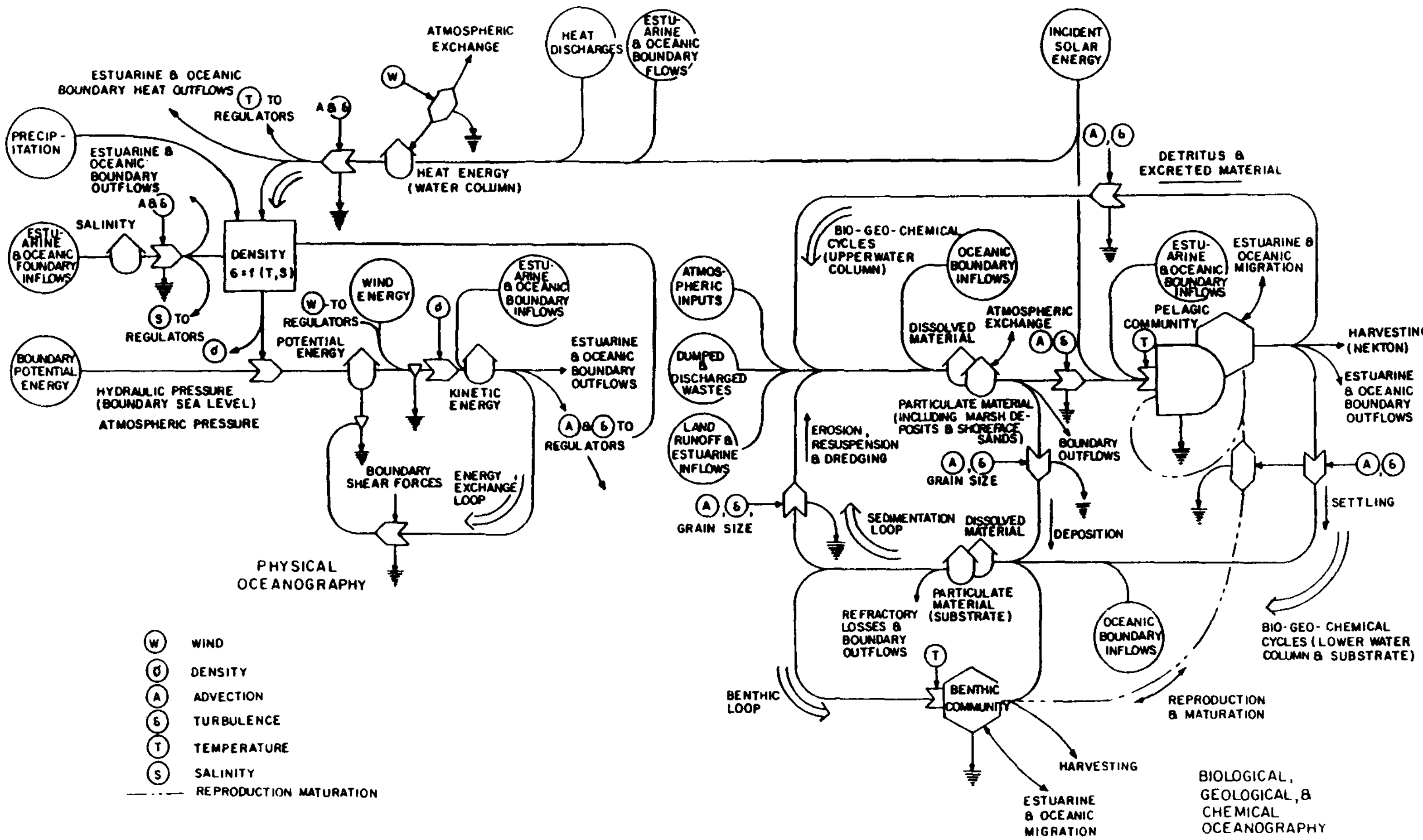


Figure 2.9. A comprehensive conceptual representation of the Tuscaloosa Trend ecosystem (modified from McLaughlin et al., 1975).

Table 2.2. A connectivity matrix showing the components of the comprehensive conceptual representation of the Tuscaloosa Trend ecosystem.

To		Compartments: Pelagic Community	Compartments: Benthic Community	Compartments: Dissolved Materials	Compartments: Particulate Material	Compartments: Sediments	Inputs: Atmospheric Inputs	Inputs: Estuarine Inputs	Inputs: Oceanic Inputs	Inputs: Man
	Pelagic Community	$\phi_1(\beta)$	$\phi_4(\tau,\alpha,\beta)$	$\phi_3(\tau,\beta)$	$\phi_2(\delta,\beta,\tau)$		$\phi_8(\sigma,\tau,\gamma,\alpha,\Theta,\beta)$	$\phi_4(\sigma,\tau,\alpha,\beta)$	$\phi_4(\alpha,\tau,\beta)$	
Compartments	Benthic Community	$\phi_4(\tau,\beta)$	$\phi_1(\beta)$	$\phi_3(\beta,\tau,\alpha)$	$\phi_2(\delta,\beta,\tau)$	$\phi_2(\gamma,\tau,\Theta)$ $\phi_6(\tau,\beta)$		$\phi_4(\sigma,\tau,\alpha,\beta)$	$\phi_4(\alpha,\tau,\beta)$	
Compartments	Dissolved Material	$\phi_7(\tau,\beta)$ $\phi_9(\tau,\beta)$	$\phi_7(\tau,\beta)$ $\phi_9(\tau,\beta)$		$\eta_9(\sigma,\tau,\Theta)$	$\eta_9(\Theta,\delta)$ $\eta_{11}(\alpha,\tau,\lambda)$	$\eta_5(\sigma,\tau,\gamma)$ $\eta_7(\lambda)$	$\eta_3(\Theta,\sigma,\rho,\lambda)$	$\eta_3(\rho,\lambda)$	η_{13}
	Particulate Material	$\phi_9(\tau,\beta)$	$\phi_9(\tau,\beta)$	$\eta_6(\sigma,\rho,\alpha,\Theta)$ $\eta_{10}(\sigma,\tau,\alpha,\Theta)$		$\eta_2(\rho,\delta,\alpha,\Theta)$	$\eta_7(\lambda)$	$\eta_2(\sigma,\rho,\delta,\Theta)$ $\eta_3(\Theta,\sigma,\rho)$	$\eta_3(\rho,\lambda)$	η_{13}
	Sediments		$\phi_5(\delta,\beta)$ $\phi_6(\tau,\beta)$ $\phi_9(\tau,\beta)$	$\eta_{10}(\sigma,\tau,\alpha,\Theta)$	$\eta_1(\rho,\delta,\alpha,\Theta)$					
	Atmosphere			$\eta_5(\sigma,\tau,\gamma)$ $\eta_8(\tau,\sigma,\rho)$						
Outputs	Estuary	$\phi_4(\sigma,\tau,\alpha,\beta)$	$\phi_4(\sigma,\tau,\alpha,\beta)$	$\eta_3(\sigma,\rho,\lambda)$	$\eta_3(\Theta,\rho,\delta)$					
Outputs	Ocean	$\phi_4(\alpha,\tau,\beta)$	$\phi_4(\alpha,\tau,\beta)$	$\eta_3(\rho,\lambda)$	$\eta_3(\Theta,\rho,\delta)$					
	Man	$\phi_{10}(\lambda,\beta,\gamma)$	$\phi_{10}(\lambda,\beta,\gamma)$							

Processes

Biotic

- ϕ_1 - biotic interactions
- ϕ_2 - ingestion
- ϕ_3 - nonfeeding uptake
- ϕ_4 - spawning, migration and passive dispersal
- ϕ_5 - bioturbation
- ϕ_6 - decomposition
- ϕ_7 - respiration
- ϕ_8 - photosynthesis
- ϕ_9 - excretion, egestion, detritus (death)
- ϕ_{10} - harvesting

Physical/Chemical

- η_1 - deposition
- η_2 - suspension
- η_3 - advection
- η_4 - turbulence
- η_5 - diffusion
- η_6 - flocculation
- η_7 - precipitation
- η_8 - volatilization
- η_9 - dissolution
- η_{10} - absorption
- η_{11} - upwelling
- η_{12} - freshwater intrusion
- η_{13} - dumping and discharging waste

Regulators

- σ - salinity
- τ - temperature
- ρ - water density
- δ - grain size
- α - advection (currents)
- Θ - turbulence
- γ - water quality
- β - population dynamics
- λ - climatic factors

Diffusion is defined as redistribution by turbulent mixing, and in the Tuscaloosa Trend ecosystem, is probably dominated by tidal-induced mixing. Mixing processes at the shelf-slope break may also contribute significantly to turbulence near the offshore boundary, especially when well-defined fronts are present. Mixing also occurs in the upper layer of the water column by differential heating and wind stress, and throughout the water column by the breaking motion of internal waves.

Advective and turbulent flows generated by inputs of kinetic and potential energy are responsible for the transport of large quantities of heat energy across the estuarine and oceanic boundaries of the Tuscaloosa Trend ecosystem. However, boundary conditions at the sea surface are also very important to the heat balance of the oceans. Short wave solar radiation passes through the air-water interface of the Trend ecosystem and into the water column, where much is converted to heat energy. A two-way exchange of long-wave radiation also occurs across this surface.

Heat energy influences the temperature of the water column, which in turn influences the density of the water mass. Density, which is also a function of salinity, is a very important regulator of flow patterns in the Trend ecosystem. Heating of surface waters by solar radiation can result in a well-mixed surface layer of warmer water separated from a cooler bottom layer by a pycnocline or density gradient.

Salinity is transported across estuarine, oceanic, and (to a negligible degree) atmospheric boundaries, and is influenced by regional transport processes, riverine discharge, precipitation and evaporation. Along with temperature, salinity determines water density, which in turn regulates advection and turbulent transport of materials and energy.

Within the Trend ecosystem, there is a continuous conversion of kinetic to potential to kinetic energy through the "energy exchange loop" shown in Figure 2.9. Kinetic energy is shown moving water masses into, around, and out of the Trend ecosystem through advection and turbulence. That energy not so utilized contributes to wave motion, s expressed in the energy exchange loop (Figure 2.9). The energy exchange loop is regulated by the distribution of density in the water mass and by bottom shear forces. Heat losses due to friction (the ground symbols in Figure 2.9) do not contribute significantly to the overall energy balance of the water mass of the Trend ecosystem.

Biogeochemical Processes

The right side of Figure 2.9 is a comprehensive representation of biological, chemical, and geological processes on the Tuscaloosa Trend ecosystem. The regulators of the various processes are provided by the physial oceanographic processes on the left of Figure 2.9.

Figure 2.9 depicts the pelagic habitat (upper water column) separately from the benthic habitat (lower water column and substrate), thereby discretizing the ecosystem into two subsystems or habitats. Whether or not two functionally distinct subsystems actually exist depends to a large degree on physical processes (e.g., presence of a pycnocline). On the nearshore shelf, where intensive mixing occurs during much of the year results in a relatively homogeneous water mass, discretization of the water column into upper and lower layers may not be appropriate. During periods of intensive mixing, pelagic and benthic functioning may be closely coupled.

Both subsystems in Figure 2.9 include an integrated biological community and the dissolved and particulate loads of various materials in the medium (i.e., water column or sediments). The benthic subsystem is shown receiving inputs of materials from oceanic boundary inflows only, while the pelagic subsystem also receives inputs from the atmosphere (wet and dry deposition), from dumping and discharging of wastes, from land runoff, and from estuaries. Both the pelagic and benthic communities utilize and contribute to the dissolved and particulate loads of the water column and substrate, both directly and indirectly. These exchanges involve organic carbon, oxygen, inorganic nutrients (nitrogen, phosphorous, silica), toxicants (trace metals, hydrocarbons, pesticides) and other trace organics.

The pelagic and benthic subsystems exchange materials by several means, including a deposition/erosion-resuspension sedimentation loop, gravitational settling of organic detritus generated by death and egestion of components of the pelagic community, and active and passive transport of living material associated with reproduction and maturation of members of the pelagic and benthic communities (Figure 2.9). The sedimentation loop is regulated by advection and turbulence, as well as the grain size of the material in question. It contributes strongly to the load of particulate material in the water column, and is enhanced by storm-induced erosion of marsh deposits and shoreface sands from the shallow bottoms along the edges of the study area.

While the benthic and pelagic communities are included as distinct state variables in this general ecosystem conceptualization (Figure 2.9), they are not further disaggregated therein. Even so, the basic differences in the functional relationships of thef pelagic and benthic communities is evident in Figure 2.9. Note that the benthic community includes no primary producer component, attributable to a lack of light near the bottom of the ocean. At the shallowest depths on the Trend OCS this representation may not be entirely appropriate. Results from the BLM South Texas Outer Continental Shelf (STOCS) study (Flint and Rabalais, 1981) indicated the presence of peak chlorophyll concentrations in a nearbottom nepheloid layer, indicating high rates of primary production near the bottom on the south Texas coast. These high rates of production may have been sustained by regeneration and release of ammonia from the sediments under anaerobic conditions. Otherwise, given the general lack of firm substrate for attachment of benthic plants and the considerable turbidity of the water column in much of the east central Gulf, the conceptualization is probably representative of the vast majority of the water surface area in the Trend ecosystem. Freshwater and estuarine influences are expected to be greatest in the muddy-bottomed western region of the Trend area, while increased water clarity to the east would increase the depth of light penetration and the importane of primary production in deeper waters.

Components of these biological communities are outputs of the ecosystem through harvesting by man, as well as by estuarine, coastal, and oceanic migrations and outflows. Dissolved and particulate organic materials in the water column are also lost to the Trend system by ocean and estuarine boundary outflows. Organic material may also be converted to refractory forms in the sediments and/or buried where sedimentation rates are high. Materials which can assume a volatile (gaseous) state (e.g., dissolved oxygen, carbon dioxide and some hydrocarbons) may be exchanged across the air-sea interface.

Wind and wave action can generate sea spray, some of which can be transported out of the Trend ecosystem as small atmospheric particles (aerosols). This provides a mode of egress of nonvolatile materials across the air-sea interface, from the Trend ecosystem, although the mass transport is not large compared to other estuarine, coastal, and oceanic outflows.

2.5.3 LEVEL 2 REPRESENTATIONS OF BIOGEOCHEMICAL PROCESSES

Introduction

In the following subsections, the biogeochemical processes in Figure 2.9 are shown in greater detail as separate sedimentation, chemical and ecological representations. If one were to attempt to depict the several important chemical cycles in one representation, the result would necessarily be complicated and not easily intelligible. This in itself would defeat the main purpose of these conceptual representations. Therefore, three chemical representations are presented. The first of these describes the cycling of both carbon and oxygen because of their obvious links through primary production, respiration and oxidation of inorganic carbon sources. The second depicts the cycling of nitrogen, one of the most important nutrients in the ocean, while the third depicts the transport and fate of a prototype toxicant.

Sedimentation Processes

The representation of sedimentation processes in the Tuscaloosa Trend ecosystem (Figure 2.10) depicts the dynamics of particulate material both in the estuaries and on the shelf, as well as the interactions between the two. As in the generalized conceptualization (Figure 2.9), the Trend ecosystem is discretized into two subsystems, but in this case the boundary between the two subsystems is the water-substrate interface (rather than the upper and lower parts of the water column). The estuarine portion is similarly subdivided. The representation includes five sediment storage compartments, the suspended and bottom sediments in the estuaries and on the shelf, as well as marsh deposits and shoreface sands located at shallow depths along the estuarine boundaries of the Trend ecosystem. This conceptualization does not address dissolved materials (i.e., there are no storage compartments for dissolved materials). Water column compartments receive inputs from land runoff and rivers, dumped and discharged wastes, ocean boundary inflows and the atmosphere. Particulate material leaves the OCS by way of estuarine and oceanic boundary outflows.

Linking the five sediment storage compartments are six feedback loops (Figure 2.10), which collectively include all significant sediment transport processes operating in the linked estuarine and shelf ecosystems. The estuarine and shelf transport loops involve erosion and deposition of sediments under non-storm conditions, and are regulated by advection and turbulence, sediment grain size, and bottom topography. In the Tuscaloosa Trend study area, strong winds blowing over the shallow shelf result in periodic disturbance of the bottom sediments. In areas of fine-textured sediments (e.g., the western half of the Tuscaloosa Trend study area), this results in resuspension of the surface sediments and development of a highly turbid nepheloid layer, which may also be high in dissolved nutrients such as ammonia. This nepheloid layer could be included as a third subsystem in Figure 2.10.

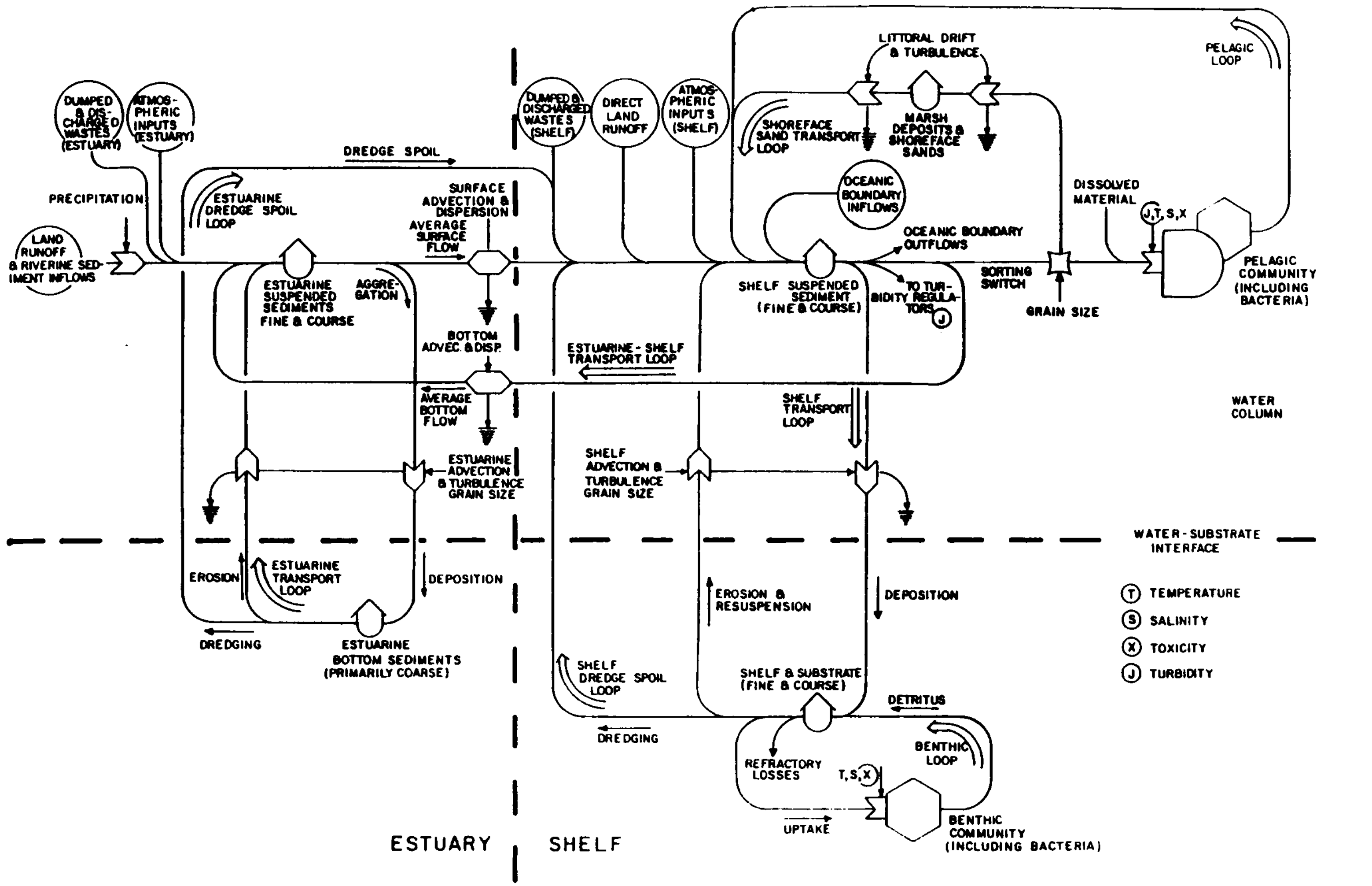


Figure 2.10. A conceptual representation of sedimentation processes in the Tuscaloosa Trend ecosystem. (Source: McLaughlin et al., 1975).

Linking the sedimentation processes in the estuaries and shelf is the estuarine-shelf transport loop, which represents the two-way transport of suspended sediments between the estuaries and the continental shelf. These flows are regulated primarily by advection and turbulence in the vicinity of the estuary-shelf boundary, which are in turn generated by tidal forces and local winds.

The estuarine and shelf dredge material loop, which describes the dredging of material in the estuaries and on the nearshore shelf and its deposition into the upper water column of the shelf ecosystem, represnts a second link in the sedimentary cycle between the estuary and shelf (Figure 2.10). Depending on the prevailing currents and depth, and grain size, dumped dredge material may fall to the lower water column and sediments, or may be carried some distance away by advection and turbulence before being deposited.

On the continental shelf, the biologically-mediated pelagic and benthic loops (Figure 2.10) represent the uptake and release of both particulate organic and inorganic material by thef biological community. Only the finest-grained particulate material is consumed by the pelagic community. The rest is transported to the shelf floor by way of the shelf transport loop, to adjacent estuaries by way of the estuarine-shelf transport loop, or across oceanic boundaries by way of the pelagic loop itself. The pelagic loop includes an inner shoreface sand and marsh deposit transport loop, representing the erosion and deposition of shoreface sands from beaches and dunes and marsh deposits from adjacent wetlands, and is especially important under storm conditions. It is regulated by littoral drift and turbulence associated with wave energy, rising sea levels, and erosion-deposition of marsh sediments, and contributes to the sediment load of the water column.

Being detritus-based, the benthic food web can process large amounts of sediments in areas of intense biological activity. This biological reworking and mixing of the sediments results in an unstable sediment surface which is more easily disturbed by strong currents (Rhoads et al. 1974), contributing to the development of a turbid nepheloid layer.

Chemical Processes

Introduction

In all three representations of chemical processes, the ecosystem is discretized into an upper water column and a lower water column and substrate, with the two layers being separated by a region of the water column where density increases sharply with depth (i.e., the pycnocline). In near-coast areas and in the vicinity of the Mississippi River outfall, water column density can be strongly influenced by estuarine and riverine inputs. Further offshore, seasonal trends in solar insolation and the resulting heating and cooling of surface waters are more important and in summer can lead to development of a warm, well-mixed layer in direct contact with the atmosphere. Formation of this upper water layer effectively seals off thef lower water column and substrate from direct contact with the atmosphere. This can have profound influences on chemical cycling.

All three representations also depict the pelagic and benthic communities at the same degree of complexity as in the general ecosystem conceptualization (Figure 2.9). No trophic relationships among components of these biological communities are explicitly shown in these conceptualizations, but are implied.

Carbon-Oxygen Cycling

In the depiction of carbon-oxygen cycling (Figure 2.11), the three storage compartments, organic carbon, oxidizable inorganic material, and dissolved oxygen, are found both above and below the pycnocline. Two major sources of dissolved oxygen are uniquely available to the upper water column. The first is the atmosphere, which is especially important in replenishing dissolved oxygen concentrations during periods when winds are strong. The other source of dissolved oxygen is photosynthesis by the primary producer component of the pelagic community. Both subsystems receive inputs across oceanic boundaries. Besides this, the only other source of dissolved oxygen to the lower water column and substrate is exchange across the pycnocline (i.e., from the upper water column).

In both upper and lower layers of the water column, dissolved oxygen is utilized in biological respiration and oxidation of inorganic materials. Organic carbon resulting from excretion, egestion, and death of members of each biological community, as well as that input to the upper water column from external sources, can be re-utilized by the same community, transported upward or downward in the water column (i.e., across the pycnocline), or transported across estuarine and ocean boundaries. The net flux across the pycnocline is downward, emphasizing the dependence of metabolic activity in the lower water column and sediments on organic material formed elsewhere. The settling of organic carbon (from the upper water column) to the lower water column and sediments in the presence or absence of a pycnocline is the source of reduced carbon that supports the detritus-based benthic food web.

If a pycnocline is particularly strong and long lasting, and biological activity in the upper water column intense (a situation that often exists in the nearshore Gulf during the late spring-early summer period), dissolved oxygen conditions in the lower water column and sediments can be affected. A tremendous amount of organic material may "rain" down to the lower water column and substrate during periods of high primary and secondary productivity in the pelagic zone. This influx of labile food material may stimulate the benthic community to metabolize at such high rates that the dissolved oxygen pool in the lower water column becomes depleted, leading to anaerobic (oxygen deficient) conditions. Anaerobic conditions also exist at some depths in most shelf sediments due also to lack of replenishment of dissolved oxygen across the lower water column-sediment interface and within the sediments themselves. Anaerobic conditions which results from oxygen depletion are not conducive to survival of aerobic (oxygen dependent) organisms (including virtually all multicellular organisms). In areas of dissolved oxygen depletion (concentrations less than 3.0 mg^{-1}), mobile organisms flee the "dead" area, while sessile or poorly mobile bottom dwelling organisms succumb and become part of the detrital organic carbon pool. All processes requiring dissolved oxygen either cease or slow appreciably under anaerobic conditions, while certain chemoautotrophic or chemosynthetic microbes which live under anaerob conditions are activated. When anaerob conditions occur, many changes in chemical state (oxidation-reduction) also occur, such as release of phosphorous from the sediments. These changes in biological functioning and chemical state can re-stimulate production once aerobic conditions return.

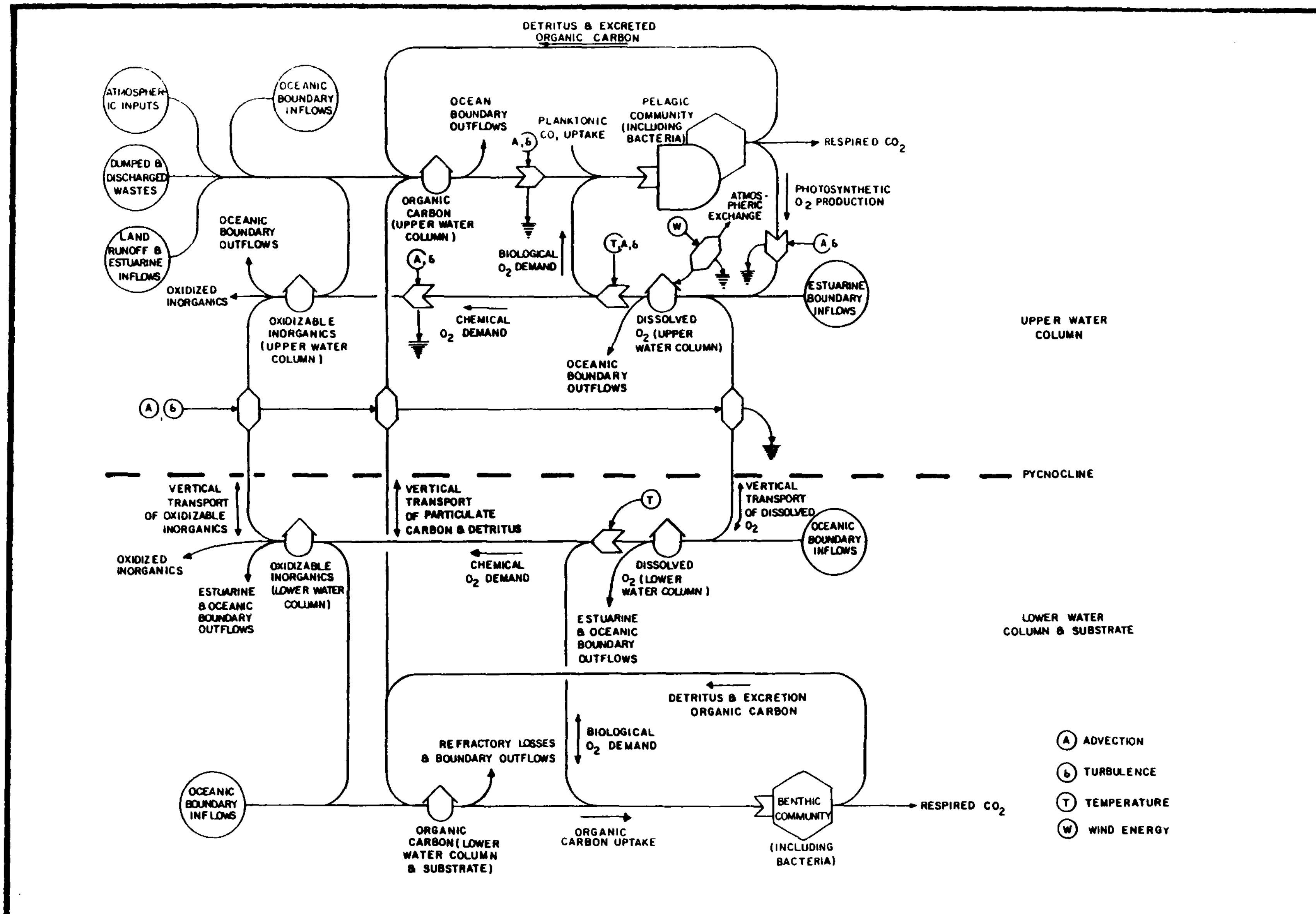


Figure 2.11. A conceptual representation of carbon-oxygen cycling in the Tuscaloosa Trend ecosystem. (Source: McLaughlin et al., 1975).

Nitrogen Cycling

The depiction of nitrogen cycling (Figure 2.12) includes two storage compartments, the particulate and dissolved nitrogen pools, as well as the biological community in both the upper and lower portions of the water column. This representation does not depict the many forms of dissolved nitrogen, such as ammonia, nitrite, nitrate and dissolved organic species. Both dissolved and particulate nitrogen are exchanged between the biological community and the water column. Primary producers and decomposers absorb dissolved nitrogen from the water column, while many detritivores filter nitrogenous organic material from the water column. All components of the biological community cycle both dissolved and particulate nitrogen back to the water column.

Toxicant Cycling

The representation of sources, transport mechanisms, and fluxes of a typical "prototype" toxicant (Figure 2.13) is the simplest and most general of the three chemical conceptualizations. This is at least partly attributable to the wide array of chemicals that can act as toxicants and the many different processes associated with each chemical species.

Since concerns regarding toxicants do not generally arise under natural conditions, modeling of toxicant cycling almost invariably emphasizes inputs to the system from man's activities. The amount and properties of chemicals and mode of delivery to the ecosystem are important in determining transport, fate and residence time of pollutants in the ecosystem. For different chemical species and environments, the relative importance of the various inputs will vary. For example, in the deep ocean, far removed from the influences of river discharge and shoreline erosion, transport of atmospheric pollutants across the air-water interface (via wet and dry deposition) represents a major flux of many trace metals, especially those in the particulate phase. In the Tuscaloosa Trend ecosystem, riverine and estuarine inputs are dominant for all these toxicants. Inputs of toxicants also occur across the ocean boundaries of the Trend ecosystem, but the contributions are probably relatively minor compared to estuarine and riverine inputs. The final category of inputs are dumped and discharged wastes, which include discharges of trace metals and hydrocarbons from OCS oil and gas exploration and development activities. Dumping of dredged materials, which may be contaminated with toxicants, occurs in the shallow portion of the Tuscaloosa Trend study area associated with various waterway maintenance and development projects in the adjacent inland waters and passes.

The chemical state of a toxicant in the water column or sediments depends on its affinity for the surface of particles as well as the redox potential (i.e., oxidation-reduction) status of the medium. Partition coefficients that determine the proportion of the toxicant in the dissolved and particulate states (i.e., the sorption-desorption relationships) have been determined for many toxicants under many environmental conditions. The chemical state will determine the path by which toxicants cycle through the ecosystem. Those with a strong affinity for absorption onparticles will more likely be transproted to and accumulated by the sediment system. For these particle-bound toxicants, transport and fate are closely tied to the major sedimentary cycles shown previously (see Figure 2.10). Those remaining in dissolved form are more likely to be transported out of the ecosystem. The redox state of

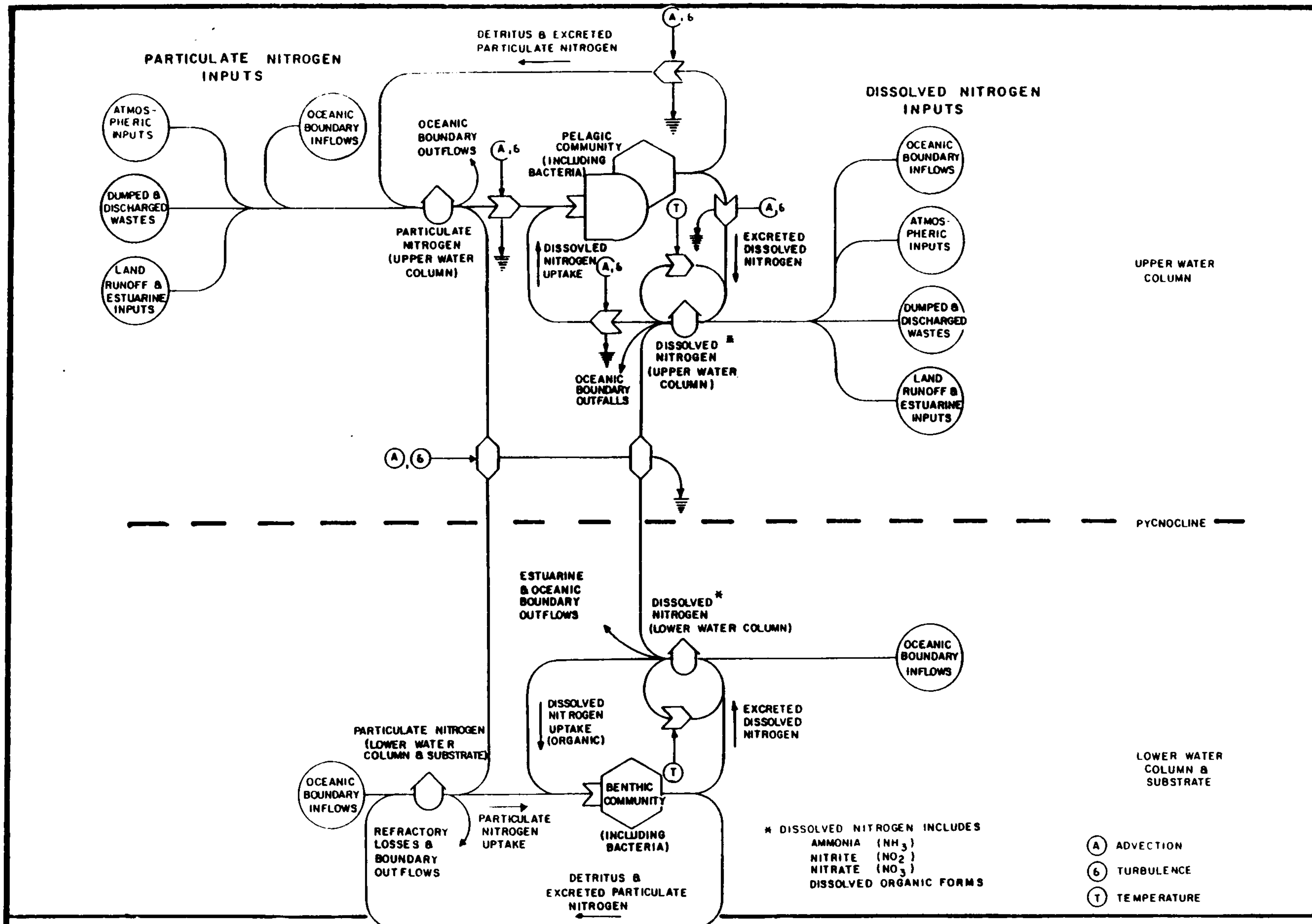


Figure 2.12. A conceptual representation of nitrogen cycling in the Tuscaloosa Trend ecosystem. (Source: McLaughlin et al., 1975).

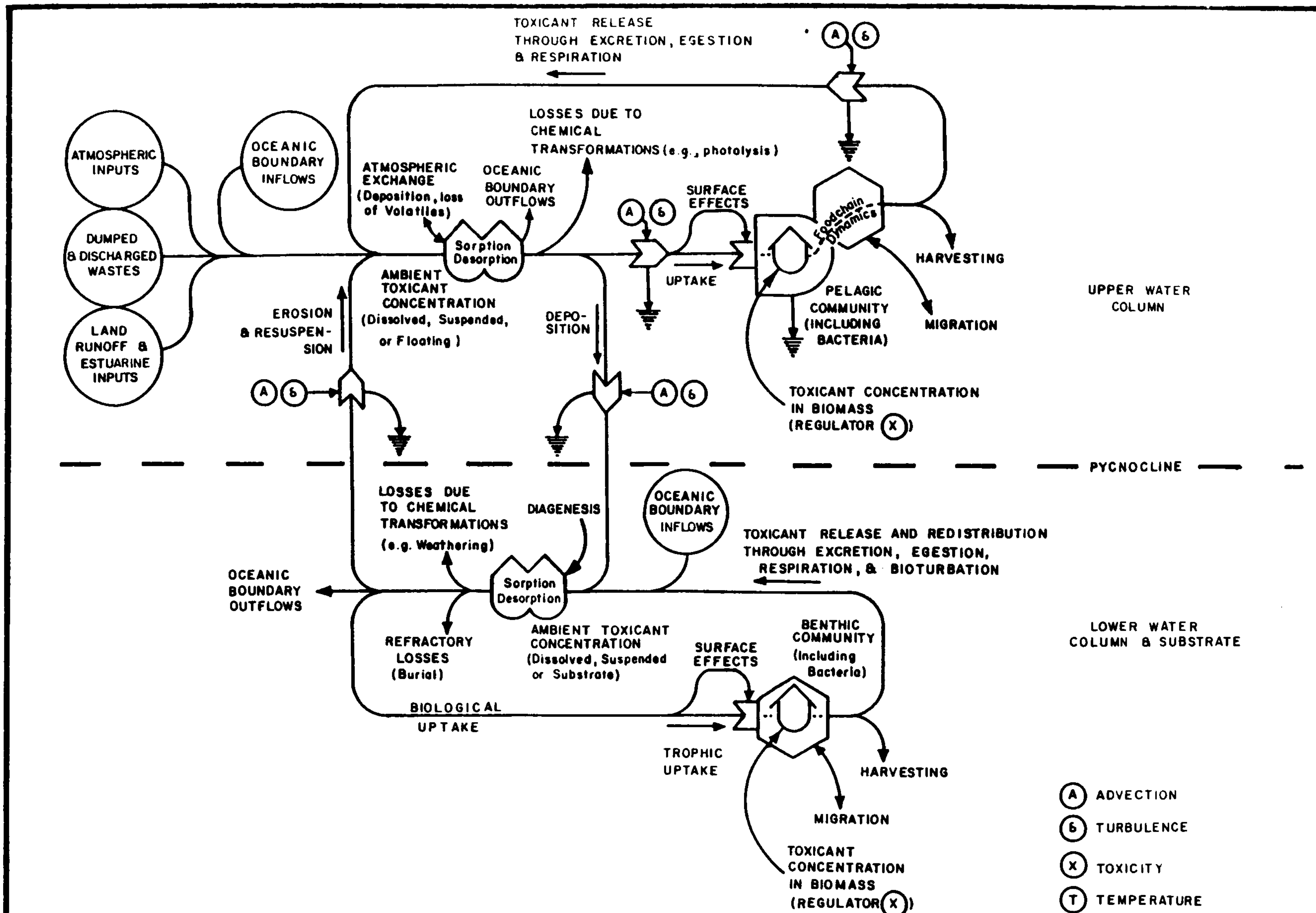


Figure 2.13. A conceptual representation of toxicant cycling in the Tuscaloosa Trend ecosystem (modified from McLaughlin et al., 1975).

the water column or sediment system is also very important in determining the chemical and physical state of the toxicant. Changes from aerobic to anoxic conditions may result in the release of toxicants previously bound to particles in the water column and sediments.

Toxicants are incorporated into living biomass by food chain processes and by direct uptake through the respiratory surfaces of many types of organisms, and are returned to the water column or sediments through metabolic processes such as excretion, egestion and death. Organisms have a considerable propensity to accumulate toxic materials, and when they die, these toxicants become part of the detrital pool. Organic detritus derived from plankton death may be quickly digested by consumers and the toxicants remineralized in the water column. Fecal pellets, resulting from zooplankton egestion, may settle through the water column at a relatively rapid rate, reaching the sediments more or less intact and providing a major source of food and toxicants to the benthic community. The concentration at which a toxicant has adverse effects on biota is difficult to predict, varying substantially under different environmental conditions and for different taxa. However, Figure 2.13 does show that at some undefined accumulation level, further biological uptake is regulated because of debilitating effects of the toxicant on the biota.

Among the processes that determine the fate of particle-bound toxicants once they reach the sediment surface, physical disturbance, diagenic reactions, and redox state are most important. Storms may disrupt the sediments on the shelf, leading to cycles of erosion-resuspension and deposition. This disturbance would tend to homogenize the distribution of toxicants over the depth of the disturbed surface layer. In biologically active sediments, benthic community feeding activities involve a reworking and mixing of the upper 10-20 cm of sediment. This would again result in the redistribution of toxicants over the biologically active layer of the sediment profile. This reprocessing mechanism would tend to keep toxicants near the sediment surface after the source of a pollutant has been eliminated. Bioturbed sediments are also more prone to resuspension by current shear, increasing the amount of particulate material and bound toxicants resuspended in the water column.

On the other hand, in the vicinity of the Mississippi River outfall, where deposition processes are intense, toxicants can be buried relatively quickly and removed from the zone of biological activity. Toxicants are also lost from the ecosystem by transport across oceanic boundaries, and for volatile compounds, across the air-water interface. Within the ecosystem, toxicants may also degrade to non-toxic states through chemical transformations in the water column and sediments that are both biologically and non-biologically mediated.

Ecological Processes

Like the models for chemical cycling, the ecological conceptualization (Figure 2.14) includes a pycnocline which discretizes the ecosystem into two layers or subsystems. Density stratification of the water column is extremely important in determining the distribution and amount of primary production. Fluxes between the two subsystems (i.e., across the pycnocline) are accomplished through the shelf sediment loop, settling of organic material produced in the upper water layer, dispersal of eggs and larvae stages of nekton and macrobenthos species (i.e., ichthyoplankton and meroplankton,

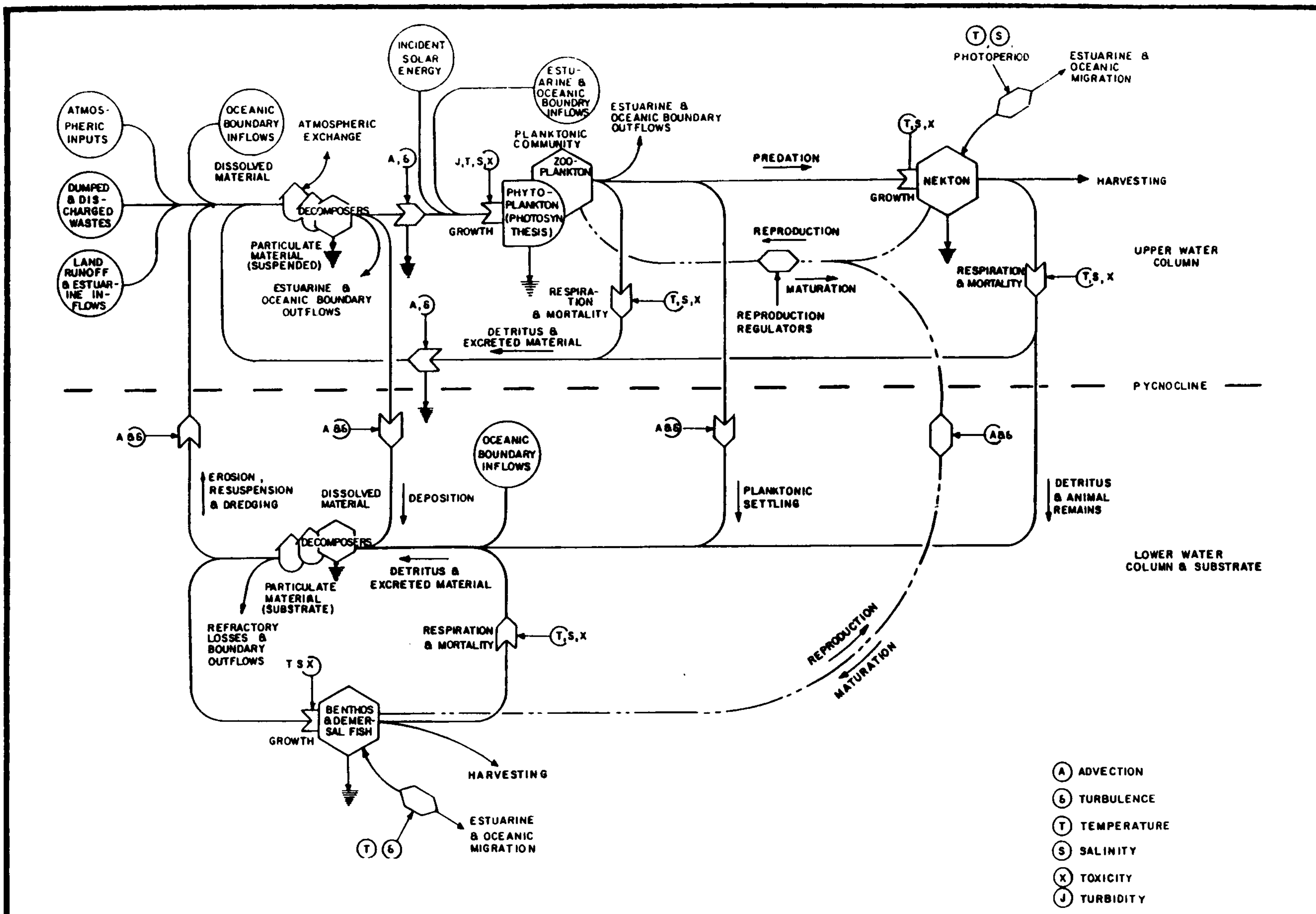


Figure 2.14. A conceptual representation of ecological processes in the Tuscaloosa Trend ecosystem. (Source: McLaughlin et al., 1975).

respectively), and migration of juveniles to their adult habitats. In the following section, this generalized ecosystem representation is developed into several Level III representations to portray major ecological patterns and processes on the Tuscaloosa Trend OCS.

2.5.4 LEVEL 3 ECOLOGICAL PROCESS REPRESENTATION

Introduction

The generalized representation of ecological processes (Figure 2.14) disaggregated only the nekton compartment from the rest of the pelagic community and included no detail concerning the components of the benthic community. Detailed conceptualizations of trophic processes of the pelagic and benthic subsystems in the Tuscaloosa Trend ecosystem are shown and discussed in Chapter 6.0, Ecosystem Structure and Function. In both of these conceptualizations, the biological communities have been disaggregated into a number of functional entities. In these representations, a species may occupy several trophic compartments during its life cycle as its feeding relationships change with size and stage of development. Similarly, individuals of the same size and age could also be allocated to two or more feeding compartments depending on the proportions of their feeding which can be allocated to each mode. This is especially applicable to members of the benthic community which appear to exhibit considerable plasticity in their feeding habits. These conceptual representations depict processes such as growth and predation on the same path or flux, even though they are obviously different processes. Also presented in this section are the Level III representations of life cycles of demersal nekton in the study area and marsh estuarine dynamics, especially as it relates to these life cycles.

Pelagic Trophic Dynamics

The pelagic food chain is based on primary production which occurs within the Tuscaloosa Trend ecosystem itself. In the pelagic trophic conceptualization (Figure 2.15), the primary producer component has been disaggregated into nanno and net phytoplankton, a distinction that is largely based on size but which has considerable functional meaning. Nannophytoplankton are those photosynthetic plankton smaller than 20 um, and include yellow-green algae, dinoflagellates and coccolithophores. Net phytoplankton include all photosynthetic plankton larger than 20 um, and are dominated by diatoms and large dinoflagellates.

These two size groups of phytoplankton are functionally quite different. Nannoplankton exhibit both higher rates of primary production and turnover. However, only mucus net feeders and microzooplankton can graze on these small phytoplankton (Figure 2.15). As a result, a nannoplankton-based food web contains more steps and involves greater energy loss. Net phytoplankton are larger and provide food for grazing zooplankton as well as herbivorous fishes such as menhaden (Brevoortia patronus). The total food chain is shorter as a result. Distributions of those few planktivorous nekton that can feed directly on net phytoplankton should coincide spatially and temporally with distributions of the food resource.

A third difference in functional relations of net and nannophytoplankton involves their habitat distributions. Data from a number of continental shelf areas worldwide, including the STOCS study area (Kamykowski,

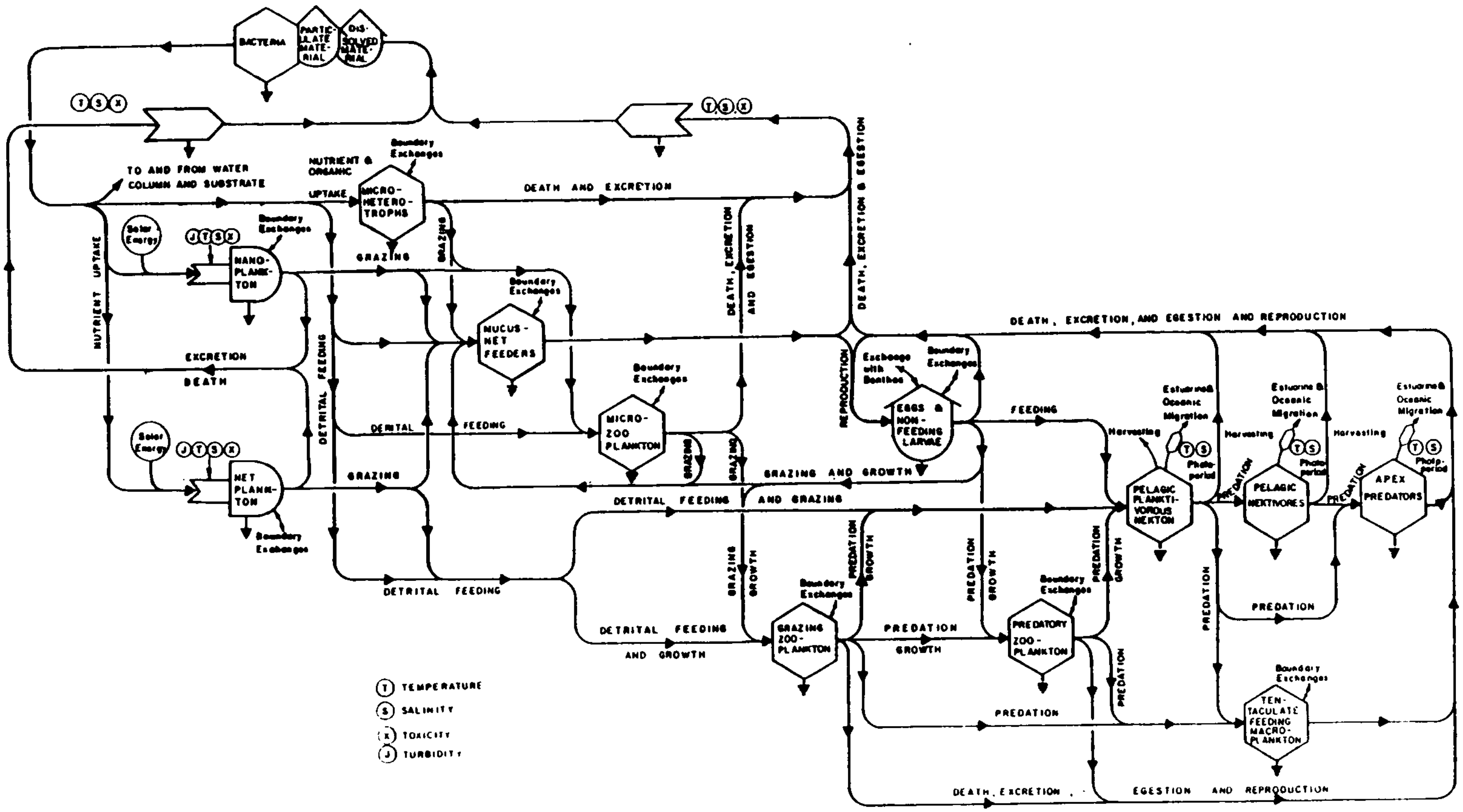


Figure 2.15. A conceptual representation of trophic processes in the pelagic subsystem of the Tuscaloosa Trend ecosystem.

Pulich, and Van Baalen, 1977; Flint and Rabalais, 1981) indicate that close to the coast, in that portion of the shelf influenced by land runoff, net phytoplankton constitute a greater fraction of the primary producer component than further offshore.

Nutrients are generally more concentrated seasonally in coastal waters and phytoplankton communities contain larger species as well as greater peaks of population growth. Net phytoplankton in the Gulf of Mexico typically experience a major spring bloom and a smaller population increase in the fall. Although offshore communities would be expected to contain smaller (e.g., nanno-) phytoplankton, insufficient data are available in the Tuscaloosa Trend region to determine whether this is the case.

The pelagic food chain includes free-living and attached microbes (bacteria and fungi). Free-living forms occupy the microheterotroph compartment in Figure 2.15. These small organisms are fed upon by microzooplankton and mucus net feeders. The former include mainly ciliated protozoans. This group represents an important trophic link between phytoplankton and zooplankton because they feed upon nannoplankton which are unavailable to larger zooplankton, and are themselves prey for these larger species, which include especially copepods.

Similarly, these grazing zooplankton (herbivorous and omnivorous holozooplankton, or true plankton) are prey for predaceous zooplankton, planktivorous nekton, and tentaculate-feeding macroplankton. Predatory plankton include true plankton such as chaetognaths and copepods as well as temporary plankton such as meroplankton (benthic forms) and ichthyoplankton (nektonic forms). As seen in Figure 2.15, two groups--mucus net feeders and tentaculate-feeding macroplankton--do not generally represent prey for other organisms and are important primarily in detritus production and microbial decomposition.

Pelagic planktivores feed upon eggs, grazing and predatory zooplankton, and detrital matter. They are in turn eaten by apex predators such as sharks.

As in other oceanic and estuarine areas, Tuscaloosa Trend phytoplankton production is controlled primarily by light, temperature, nutrients, density stratification, and turbulence. Figure 2.16 depicts the relationship between light intensity and water depth. If nutrients are not limiting, photosynthesis will decrease in proportion to decreased light intensity. The compensation depth is that depth where photosynthesis equals respiration, and defines the bottom of the uphotic zone. In Figure 2.15, the correspondence between the upper water column and the euphotic zone depends upon the relative positions of the pycnocline and compensation depth.

Benthic Trophic Dynamics and Related Processes

The detailed representation of benthic trophic processes on the Tuscaloosa Trend OCS is shown in Figure 2.17. This representation resulted from the disaggregation of the single benthic community compartment in the general ecological process conceptualization (Figure 2.14) into a number of functionally-related entities.

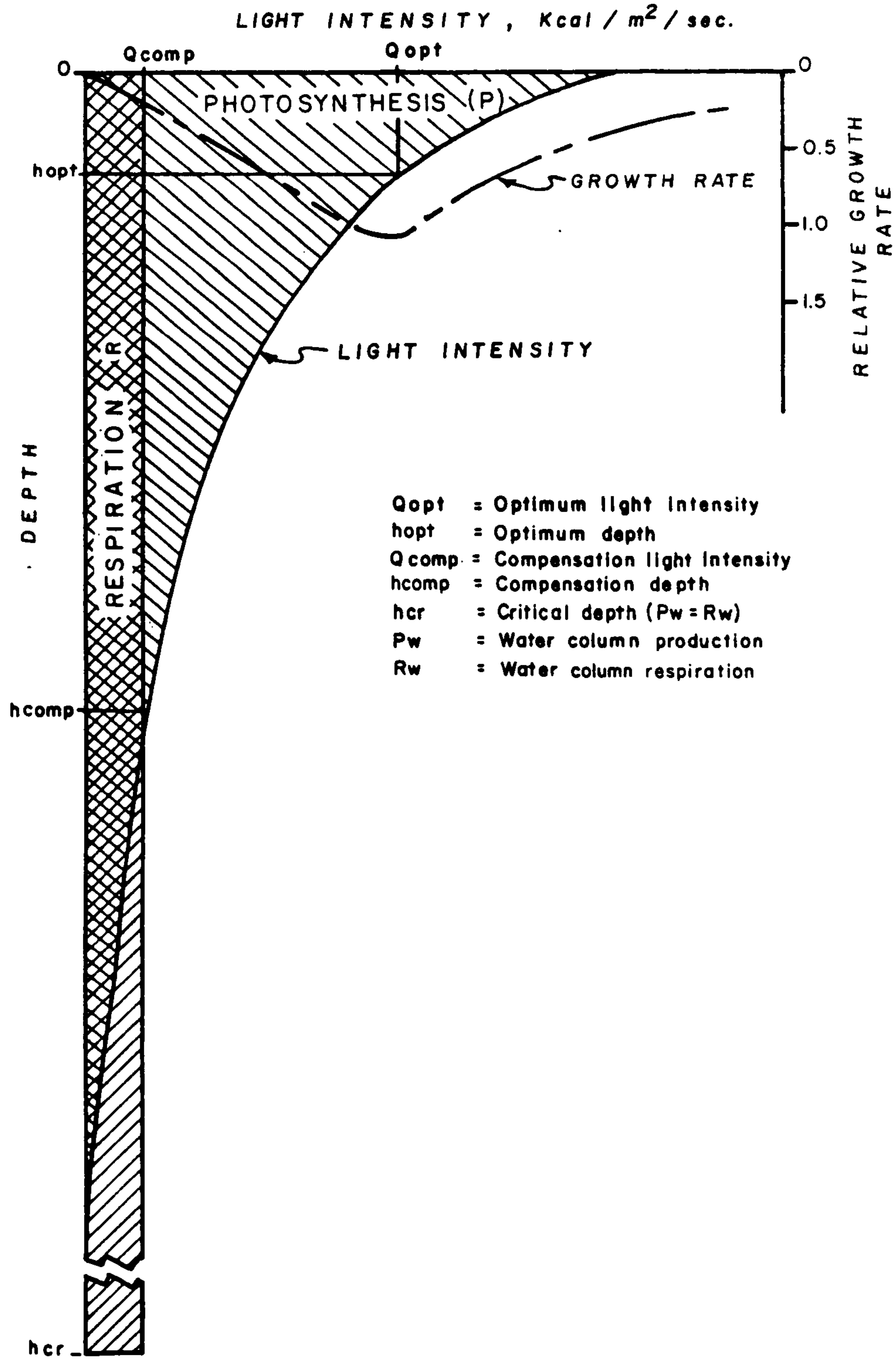


Figure 2.16. A conceptual representation of the relationships between depth, light intensity, and relative growth rate of phytoplankton in the Tuscaloosa Trend ecosystem. (Source: Sverdrup, 1953).

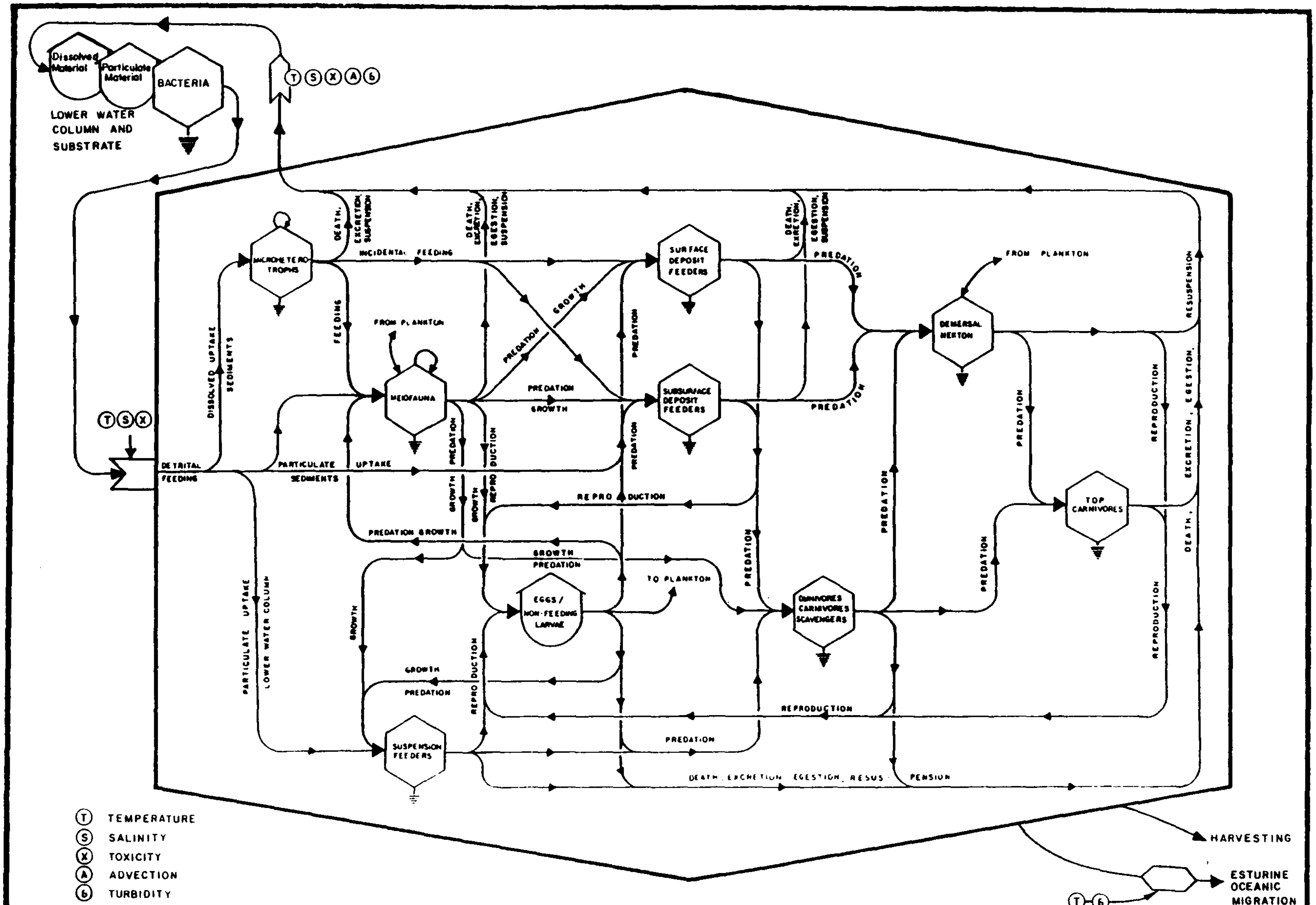


Figure 2.17. A conceptual representation of trophic processes in the benthic subsystem of the Tuscaloosa Trend ecosystem.

The benthic community food web is primarily detritus-based. However, the benthos may rely more upon consumption of bacteria which decompose detritus than on the detritus itself (Flint and Rabalais, 1981). Much of the detritus which enters the Tuscaloosa Trend area is transported across the pycnocline by gravitational settling. In general, allochthonous detritus (derived mainly from terrigenous soures) decreases in importance with increased distance from shore. As distance offshore increases, the benthic community becomes more dependent on production in the upper layers of the water column. On most continental shelves, benthic standing stock, productivity, and species richness all decrease with distance offshore, presumably due to decreased food resource availability. Due to the hydrography characteristic of the Tuscaloosa Trend ecosystem, these patterns may be altered to some degree.

In recent years, it has become apparent that organisms that consume detritus (detritivores) receive a considerable portion of their nutritional intake by digesting the microorganisms that decompose the detritus, rather than the detritus itself. Detritivores contribute to the decomposition process by reducing detritus to smaller sizes with greater overall surface area. Figure 2.18 is a schematic diagram of a model for decomposition in the Trend area ecosystem. Decomposers (bacteria and fungi) occur freely in the water column or attached to detrital particles. Other components of a detrital particle include the organic matrix itself and dissolved organic material that originated in the water column and was subsequently sorbed on the surface of the organic matrix. Free-living decomposers digest labile and refractory organic matter dissolved in the water column, while attached decomposers digest similar material absorbed on the surface of the detrial particle, as well as the organic matrix itself. Both free-living and attached decomposers absorb dissolved nutrients (nitrogen, phosphorus) directly from the water colum. When a detrital particle is ingested by a benthic organism, the decomposers and sorbed labile dissolved organic matter are digested, along with some amount of the detrital particle itself. The organism then egests the particle and the process of microbial colonization and organic sorption begins again.

Microheterotrohic organisms such as protozoa and diatoms consume attached bacteria which grow in detritus as well as free-living bacteria in the water column (Figure 2.17). Many of these microheterotrophs show a high degree of feeding specificity and may be restricted to feeding on only one or several species of bacteria. Microheterotrophs are in turn consumed with the associated detrital particles by meiofauna and macrofauna. Note that the microheterotroph compartment in the bednthic community is not equivalent to the compartment of the same name in the pelagic conceptualization (Figure 2.15).

Meiofauna consume smaller detrital particles and associated bacteria than do macroinfauna but may also be highly selective in feeding. They appear to be effective at conditioning detritus for microbial decomposition by mechanically breaking down the particles and increasing the surface-to-volume ratio. They also consume eggs and larvae of all trophic groups, as well as each other. Meiofauna include permanent meiofaunal groups such as nematodes and rotifers and temporary forms such as larval stages of macroinfauna. Meiofauna are prey for a variety of surface and subsurface deposit feeders as well as some predators/omnivores (Figure 2.17).

Subsurface deposit feeders consume meiofauna, eggs, and larvae, and may be very selective on the basis of particle size. Another factor in food resource utilization by deposit feeders is vertical location in the sediment.

Surface deposit feeders include infaunal species of polychaetes, sipunculids, bivalve molluscs, and holothuroideans. Epifaunal forms include polychaetes, ophiuroids, crabs, gastropod molluscs, and some shrimps. Because surface deposit feeders are readily available as prey for epibenthic and nektonic animals, their populations may be predator-limited in more biologically-accommodated environments. Suspension feeders (e.g., bivalve molluscs, amphipods, some polychaetes) include many tube-dwelling forms of infauna as well as those which extend filtering apparatus (tentacles or siphons) above the sediment surface. Epifaunal suspension feeders are generally preyed upon by benthic and nektonic carnivores.

The carnivore/omnivore/scavenger macrobenthos feed on meiofauna and each other, as well as on animal detritus. They are prey for demersal nekton and top carnivores and include motile taxa such as flatworms, polychaetes, asteroid echinoderms, and decapod crustaceans.

Mention was made earlier of the importance of dissolved oxygen to the functioning of Tuscaloosa Trend ecological systems and the potential for seasonal development of oxygen-depleted conditions below the pycnocline. Oxygen depletion is expected to occur when benthic respiratory activity is intense and there is little or no replenishment of the oxygen (i.e., while the water column remains stratified). A change from aerobic to anaerobic conditions affects many aspects of ecological functioning and biogeochemical cycling. Figure 2.19 is a conceptual representation of nitrogen and sulfur cycling in the sediment subsystem as influenced by the dissolved oxygen content of the sediment water. The left side shows the gradient from aerobic to anaerobic conditions as measured by Eh, the oxidizing or redox potential (measured in millivolts). The anaerobic zone represents a storehouse of chemical energy that can become part of the food chain under certain conditions. In anaerobic environments, different groups of microbes exist that can decompose organic material using sulfate and nitrate as sources of oxygen, in the process forming reduced substances, such as methane, hydrogen sulfide and ammonia. These reduced compounds can then be utilized by chemoautotrophic bacteria along with carbon dioxide as a carbon source and inorganic compounds as sources of energy to produce microbial biomass under anaerobic conditions.

Representation of Nekton Life Cycles

The importance of the commercial fisheries of the Tuscaloosa Trend study area suggest the appropriateness of conceptually representing typical life cycles for these nekton (finfish and crustaceans). For the purposes of this representation, distinctions between pelagic and demersal modes of life history are not addressed. Four general types of life cycles are apparent in the study area, based on the degree of dependence of the particular taxon on the estuarine environment. These are (in order of decreasing estuarine dependence) estuarine, estuarine-dependent, estuarine-related and estuarine-independent life cycles.

Estuarine taxa spend their entire life cycles in the estuaries, as shown by the left side of Figure 2.20. The postlarvae drift and swim to the marshes fringing the open water, where they spend their first months. The

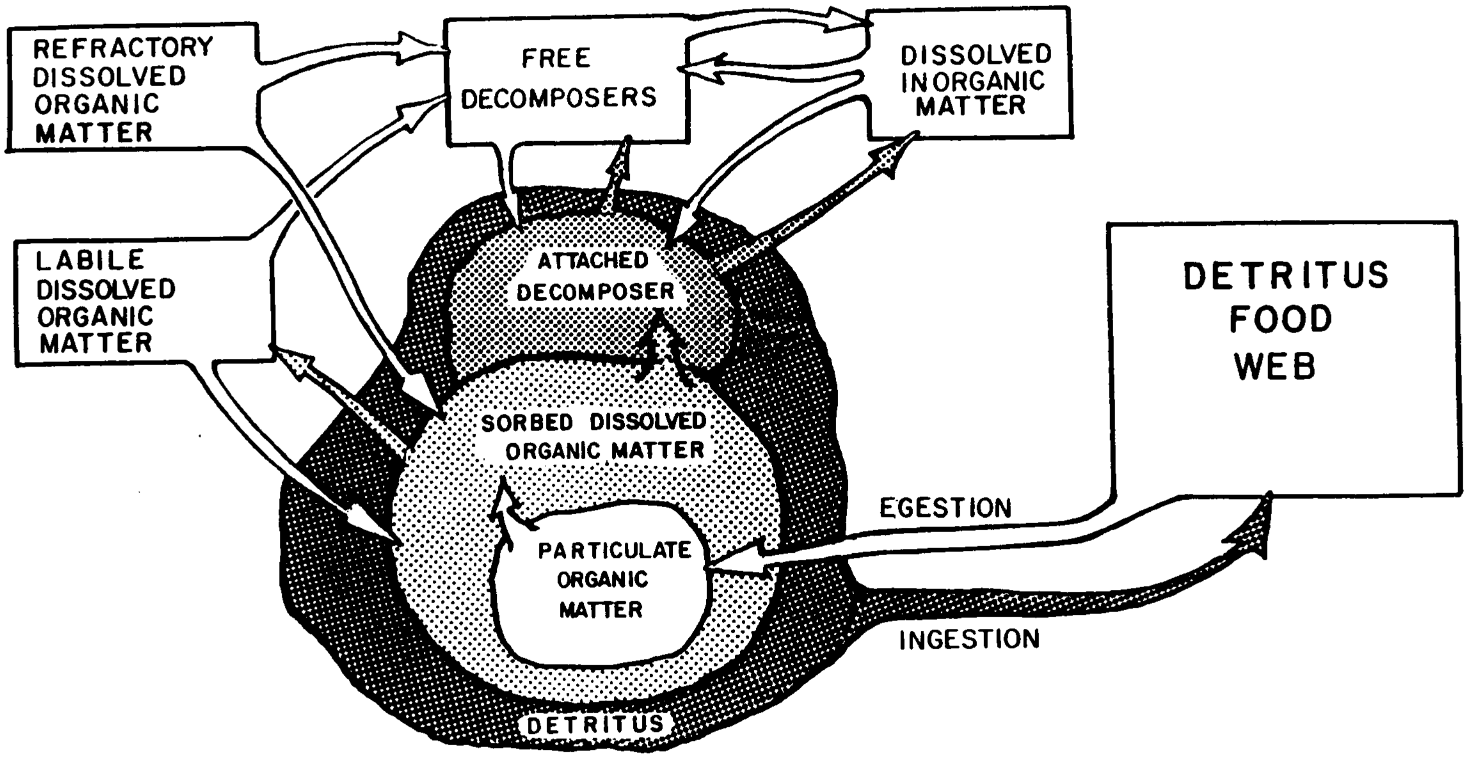


Figure 2.18. A schematic representation of detrital processing in the Tuscaloosa Trend ecosystem (modified from Cleseri et al., 1977).

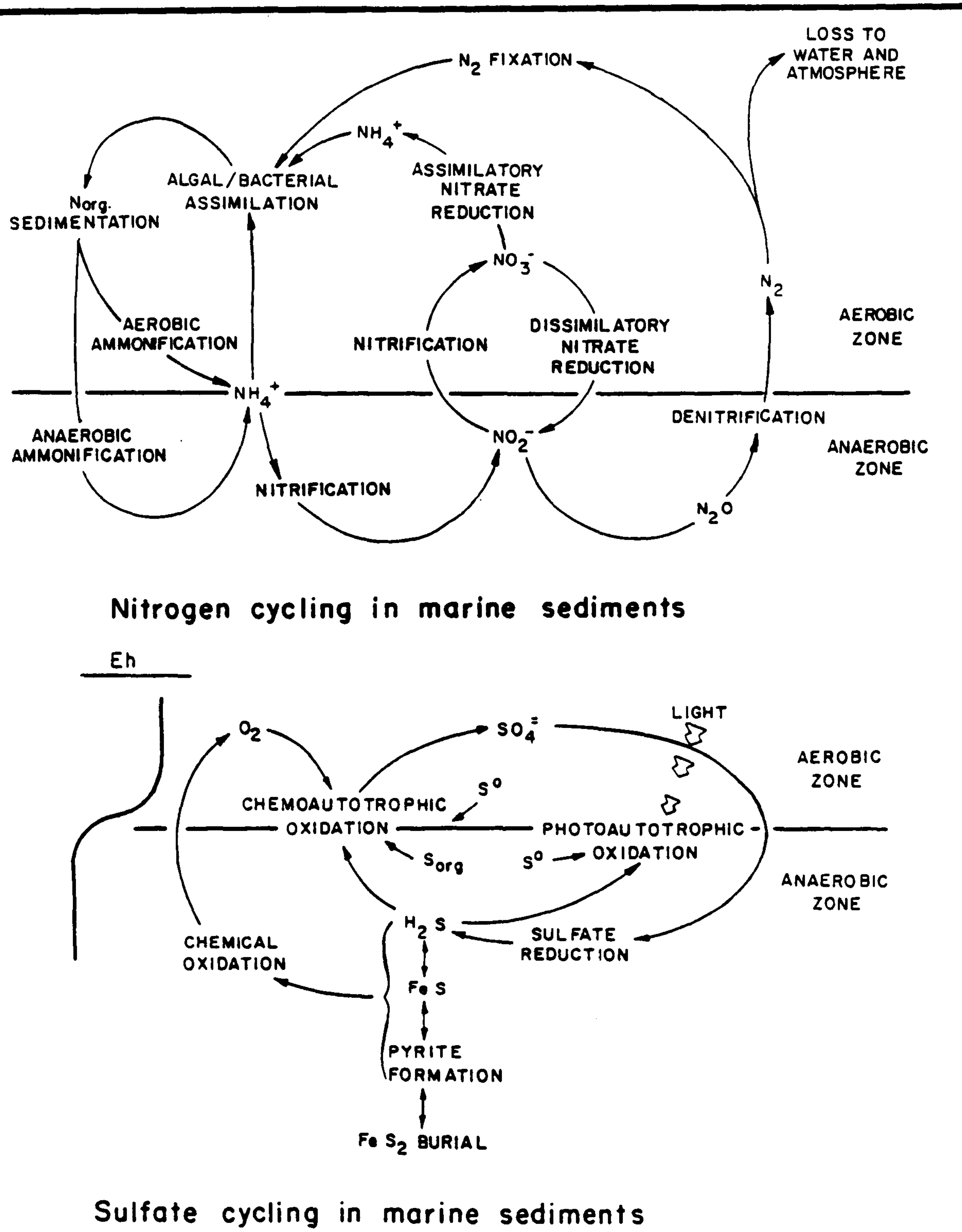


Figure 2.19. A schematic representation of the importance of dissolved oxygen to biologically-mediated cycling of sulfur and nitrogen.

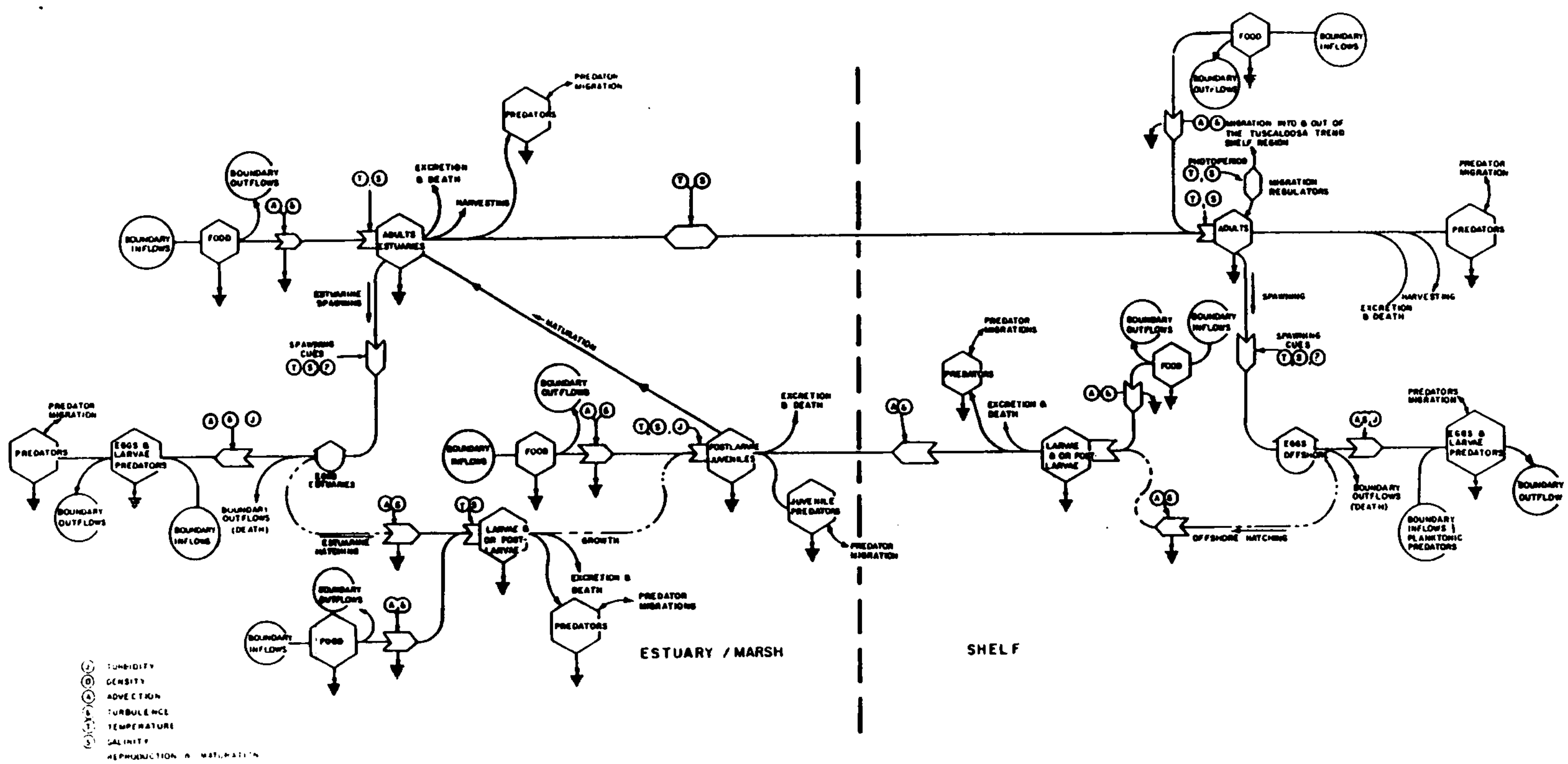


Figure 2.20. A conceptual representation of the life cycles of estuarine and estuarine-dependent nekton in the Tuscaloosa Trend study area.

amount of marsh/estuarine habitat available to the postlarvae and juveniles of the various nekton taxa depends on the salinity and temperature regimes in the estuaries and the response of the taxa to these regulators. A large number of the commercially important taxa in the Tuscaloosa Trend study area, including all three shrimp species of the genus Penaeus, the menhaden, and several species of sciaenids (seatrouts and drums), are estuarine dependent as postlarvae and/or juveniles. Their life cycle is represented by the entirety of Figure 2.20. Spawning generally occurs in the nearshore Gulf, although menhaden may spawn considerably further offshore. The eggs hatch at sea and the larvae are transported toward the estuaries by advection and turbulence, associated with the atmospheric processes, with local wind-driven currents becoming important in the nearshore area. Considering the predominantly longshore current drift in the northern Gulf of Mexico, transport processes appear to be ideal for dispersal of larvae and postlarvae across suitable estuarine systems. Once in the estuaries, the early life is similar to that of the estuarine species. As they grow they migrate from the marshes into the estuaries and ultimately to the nearshore to middle continental shelf.

Figure 2.21 depicts the life histories of estuarine-related and estuarine independent nekton taxa. The estuarine independent taxa have no relationship with the estuaries at any stage in their life cycle. The entire life cycle is spent offshore (i.e., on the right side of Figure 2.21). They include such taxonomic groups as the groupers, snappers, tilefish and billfish. Estuarine-related taxa do not require estuarine conditions, but juveniles and occasionally adults of these species enter estuaries to feed. Since these taxa are less tolerant of salinity changes (i.e., more stenohaline) than the euryhaline estuarine and estuarine-dependent taxa, their entry into the estuaries may be restricted to periods of low river discharge and high salinities. They include such taxa as bluefish and mackerel. The life cycle of these estuarine-related taxa are represented by the entirety of Figure 2.21.

Marsh-Estuarine Dynamics as Related to Ecological Processes

Figure 2.22 shows some of the more important features of marsh-estuarine dynamics as related to life cycles of estuarine and estuarine-independent taxa. Two main links exist btween the marsh and estuary subsystems. The first involves two-way transport of dissolved and suspended particulate materials by advection and turbulence associated primarily with energy generated by the tidal cycle. Incoming tides flood the marsh with large quantities of higher salinity estuarine water. Outgoing tides crain the marsh, removing detritus that ws produced or mobilized on the preceding flood cycle. The net result of these cyclic exchanges is output of organic material from the marsh to the estuary.

The other link between the marsh and estuary involves the migration/transport of postlarvae and early juveniles of a number of species of finfish and shellfish into the marshes and their subsequent movement into open bays as advanced juvniles. The marshes surrounding the estuary appear to be the true nursery area. Juveniles feed principally on detritus while in the marshes, and become more predaceous as they grow. Also productive are the seagrass beds found in manyh of the estuarine areas surrounding the Tuscaloosa Trend OCS (e.g., Chandeleur Sound). Functionally, they differ from marshes in that seagrasses are submerged, while marsh plants are emergent. Thus, marsh plants do not become part of the aquatic ecosystem until the plants or parts thereof die and fall to the marsh soil as detritus. This detritus forms the

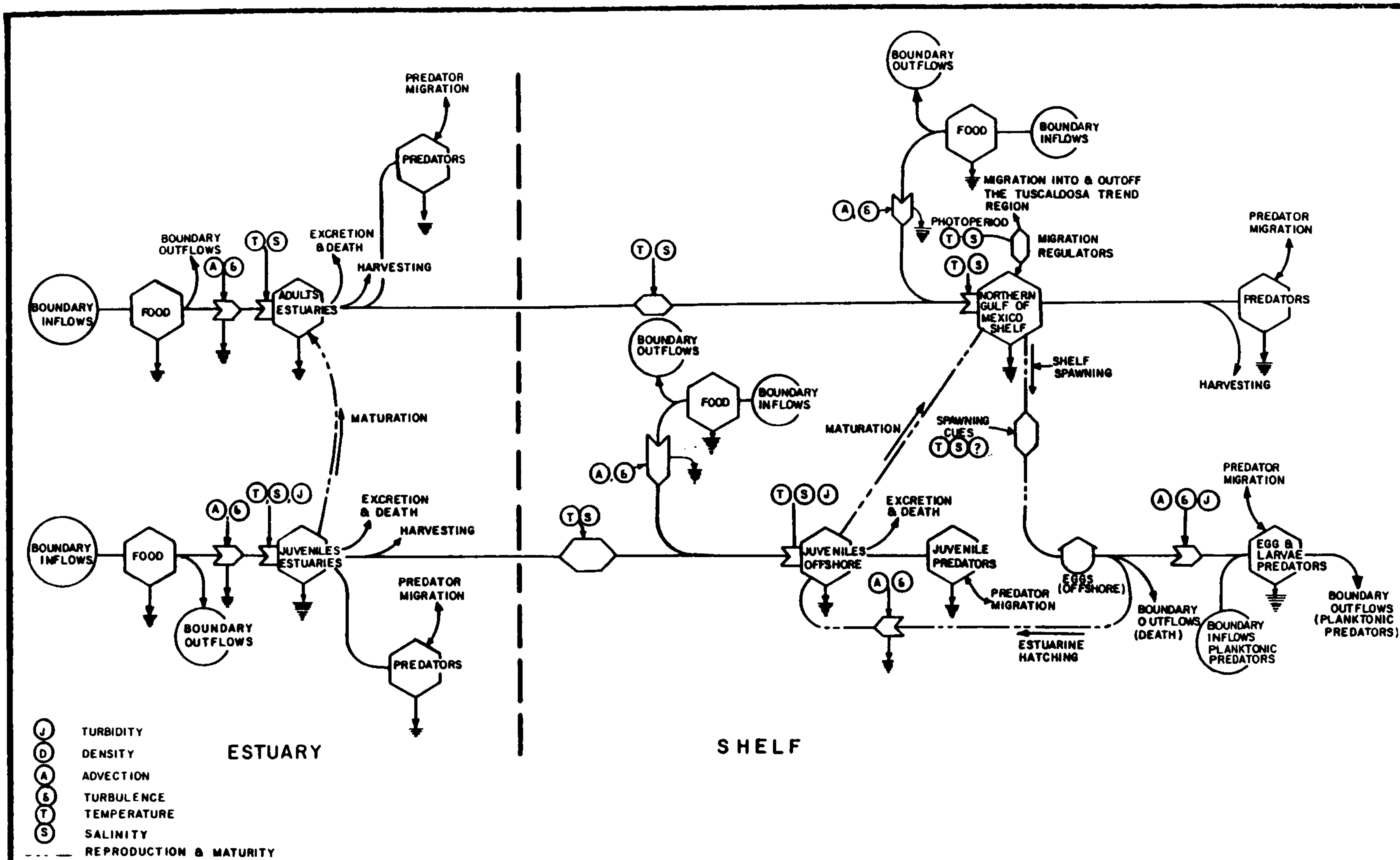


Figure 2.21. A conceptual representation of the life cycles of estuarine-related and estuarine-dependent nekton in the Tuscaloosa Trend study area.

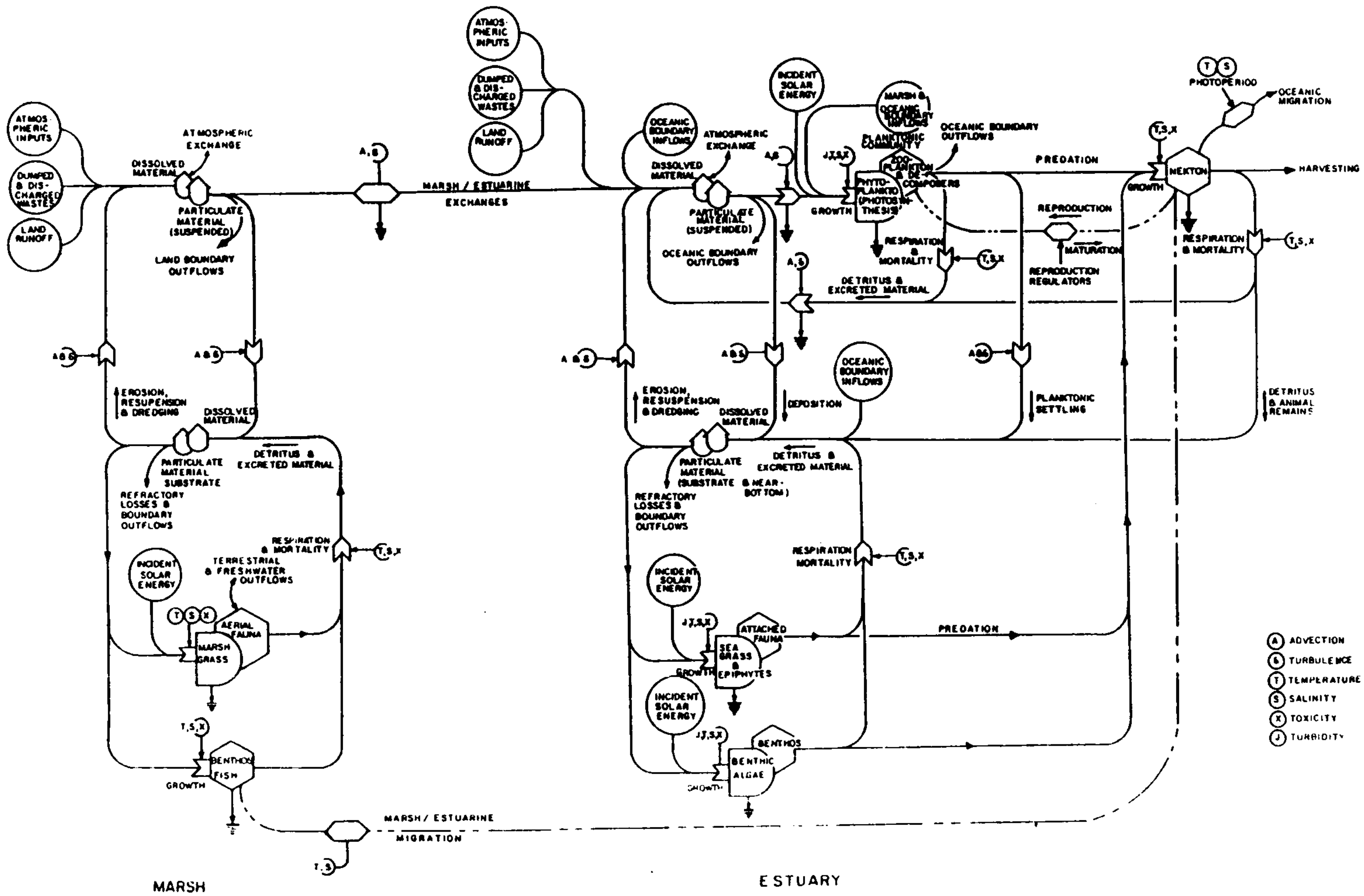


Figure 2.22. A conceptual representation of the important ecological features of marsh-estuarine dynamics in the Tuscaloosa Trend study area. (Source: McLaughlin et al., 1975).

food base of the linked marsh/estuarine subsystems. Although somewhat less speciose and including more representatives of freshwater or oligohaline (low salinity) environments, the detrital food chain in the marshes and estuaries is functionally similar to that shown in Figure 2.17 for the continental shelf.

2.5 SUMMARY

Results of this modeling effort, in conjunction with results of information synthesis indicate that the Tuscaloosa Trend OCS may differ substantially from a typical continental shelf (e.g., off south Texas or southwest Florida). On a typical continental shelf ecosystem, major changes in ecosystem structure and functioning occur in an onshore-offshore direction due to decreasing influences of the land mass going away from the coast and increasing water depth. In these systems, hydrographic variability, tidal influences, nutrient concentrations, detrital inputs, community standing stocks, species richness, net/nannophytoplankton ratios, estuarine dependence and relationships, and benthic-pelagic coupling would all be expected to decrease with distance offshore. On the other hand, fineness of sediment texture, depth to bottom, depth of the euphotic zone, length of pelagic food chains, importance of biological interactions, and biological accommodation of the communities all generally increase with distance offshore. Longshore variability is usually minor compared to changes observed in an onshore-offshore direction. Classification analyses conducted on biological community data and sediment data collected in the STOCS study area consistently showed station or habitat groupings based on distance offshore and depth, with most groups extending along the entire south Texas shelf (Flint and Rabalais, 1981). These groupings conform well with the predominant alongshore transport processes on the South Texas shelf. On the basis of this evidence, it would seem appropriate to discretize such typical shelf ecosystems on the basis of depth or distance offshore. In other words, subsystems would occur in bands of specific depth intervals along the shelf.

Such a relatively simple situation does not exist in the Tuscaloosa Trend study area. The physical oceanography of the Tuscaloosa Trend system appears to be much more complex than that of a typical shelf system, due primarily to its proximity to the Mississippi River delta, the poorly defined and diffuse boundaries with adjacent terrestrial/estuarine systems, and the periodic influence of the Loop Current on the hydrography of the Trend area. Since the birdfoot delta and adjacent estuaries occupy most of the western boundary of the study area, the dominant longshore currents prevalent over the western and central Gulf continental shelf are undoubtedly obscured, and eddy and gyre formation is likely. The shelf at the western boundary of the study area is very narrow and steep (see Figure 2.8), probably impeding both passive transport of materials and active migration of organisms across the boundary. The Mississippi River discharges from the mouth of the birdfoot delta at a latitude close to that of the offshore boundary of the Tuscaloosa Trend ecosystem. Although much of this water is transported to the west, a considerable portion, with its suspended sediment load, is discharged to the offshore reaches of the study area. This situation probably results in surface waters of the offshore and western portions of the Trend ecosystem that are less saline, higher in nutrients, and seasonably more variable than those of a typical shelf ecosystem. It also probably indicates that primary production is higher at the outer reaches of the Trend ecosystem, with higher productivity, higher standing stocks and numbers of species of both phytoplankton and zooplankton, and a higher ratio of net to nannophytoplankton compared to waters over similar depths off Texas or Florida. This riverine discharge, with its substantial organic and inorganic detrital load, probably also leads to substantial deposition of materials on the sediments at relatively great depths on the Trend ecosystem. This would tend to alter the typical pattern of lower food resources in the benthic habitat at greater depths (i.e., further offshore).

Perhaps the most obvious manifestations of this deposition pattern are the decreasing organic and fine particulate fractions of the sediments moving eastward in the study area. The major shift in sediment composition on the northeastern Gulf OCS occurs in the study area, approximatelyh in the vicinity of Mobile Bay. In the western and central regions, sediments are predominantly muddy. To the east, sediments are much sandier; however, most of the sand is terrigenous in origin and fine in texture as compared to the authochthonous sands of the western Florida shelf.

From the analyses and synthesis activities conducted for this study, it appears that sediment composition may be highly representative of the several major habitats on the Trend OCS. Since benthos are highly dependent on sediment texture, distributions of organisms are expected to conform closely to sediment distribution. However, the analyses of the SEAMAP and Fisheries Independent data conducted for this study (see Appendix C) clearly indicated that demersal nekton community distributions on the Trend OCS are most closely tied to sediment distributions. They display mainly longshore trends,just the opposite of what would be expected on a typical shelf. Finally, analysis of Gulf Coast Shrimp Data conducted for this study (see Appendix C) also indicated that populations of all Penaeus species as well as the seabob, declined dramatically in the statistical reporting units east of Mobile Bay. While this might be expected for white and brown shrimp, it was not expected for pink shrimp, which are supposed to prefer sandy sediments. The OCS area from Mobile Bay to Pensacola appears to represent a gap in the distribution of pink shrimp, which occur in largest numbers on the west Florida shelf.

Primary production in the Tuscaloosa Trend study area is very high, attributable to the vast quantities of nutrients, such as input to the study area from riverine and estuarine sources. The portion of primary production directed to zooplankton biomass is not well documented, but Flint and Rabalais (1981) found relatively low zooplankton productivity compared to primary production in the STOCS area. They concluded that low zooplankton production would lead to low nekton production in the pelagic zone compared to other ecosystems. They concluded that up to 80% of the primary production in the STOCS area was directed to benthos, compared to 30% for the North Sea, where pelagic nekton (herrings) dominated nekton production (Steele, 1974). In contrast to the North Sea, the Scotian shelf appears to be more similar to the Tuscaloosa Trend, with most primary production being diverted to the demersal fishes (Mills and Fournier, 1979).

One of the questions that remains unresolved is the relative importance of detritus and living animal biomass (meio and macrofauna) to demersal nekton production. In general, macrobenthos standing stocks and productivity in the northern Gulf of Mexico are lower than those for other continental shelf ecosystems, despite the substantial inputs of allochthonous organic material to the system, high rates of primary production, inputs of large fractions of the production was insufficient to support the fishery on the south Texas OCS, and that many demersal nekton must consume detritus (and associated microorganisms) directly. This is another case where a shorter food chain contributes to greater production at the top of the chain. Demersal nekton production in the Tuscaloosa Trend study area is dominated by penaeid shrimp, which are known to feed directly on detritus. Thus, it appears that demersal nekton production may be based primarily on detritus, with benthic production providing a supplemental resource. The extremely high densities of shrimp and other nekton on the shelf may contribute to the low densities and small sizes of the benthos in the Gulf of Mexico in general.

If the situation in the Tuscaloosa Trend study area is similar to that in the STOCS region, high rates of demersal nekton production may result from a comnbination of factors, including (1) low rates of zooplankton grazing, leading to deposition of phytoplankton biomass directly to the sediment system; (2) high primary productivity in the nepheloid layer due to adequate light and abundant nutrients; and (3) direct utilization of detritus by demersal nekton.

3.0 PHYSIOGRAPHY AND GEOLOGY

3.1 INTRODUCTION

The Gulf of Mexico (Figure 3.1) is a small mediterranean-type sea encompassing more than 1.5 million square kilometers. The continental shelf skirts the margins of the Gulf from the southern tip of Florida to the easternmost point on the Yucatan Peninsula, extending seaward to depths of generally 100 to 200 m. The shelf width varies from the broad 280 km wide platform off southern Florida to merely ten kilometers in front of the Mississippi River Delta. Local relief on the Gulf shelf has resulted from the many sea level changes during the last glacial epoch, from reef growth, from the near-suface movement of diapiric salt, and by small-scale faulting.

The Gulf of Mexico continental shelf may be divided into five subprovinces based on the geomorphic features unique to each region (Martin and Bouma, 1978): (1) the West Florida Shelf; (2) the Mississippi-Alabama Shelf; (3) the Texas-Louisiana Shelf; (4) the East Mexico Shelf; and (5) the Yucatan Shelf. Similarly, the Gulf continental shelf may be categorized by the broad sediment types present. The northern, western and southwestern shelves consist of terrigenous clastic sediment, while the broad platforms off west Florida and the Yucatan are primarily carbonates. This sediment pattern has persisted since Late Cretaceous times.

The Tuscaloosa Trend study area lies primarily in three major physiographic provinces: The Deltaic Plain; the Coastal Plain; and the Continental Shelf (Figure 3.2). Those portions of the study area within the Coastal Lowland subprovince of the East Gulf Coastal Plain encompass the land bounded on the interior by the Southern Pine Hills subprovince and extending seaward out to and including the barrier islands of the Mississippi-Alabama coast (O'Neil and Mettee, 1982), and the Plaquemines, St. Bernard, Balize, and Modern Birdfoot delta lobes of the Mississippi River Deltaic Plain. The submerged regions within the Tuscaloosa Trend study area seaward of the coastal barrier islands include the Mississippi-Alabama continental shelf, the shelf break, and the upper continental slope to the 200 m isobath. An eastern boundary is

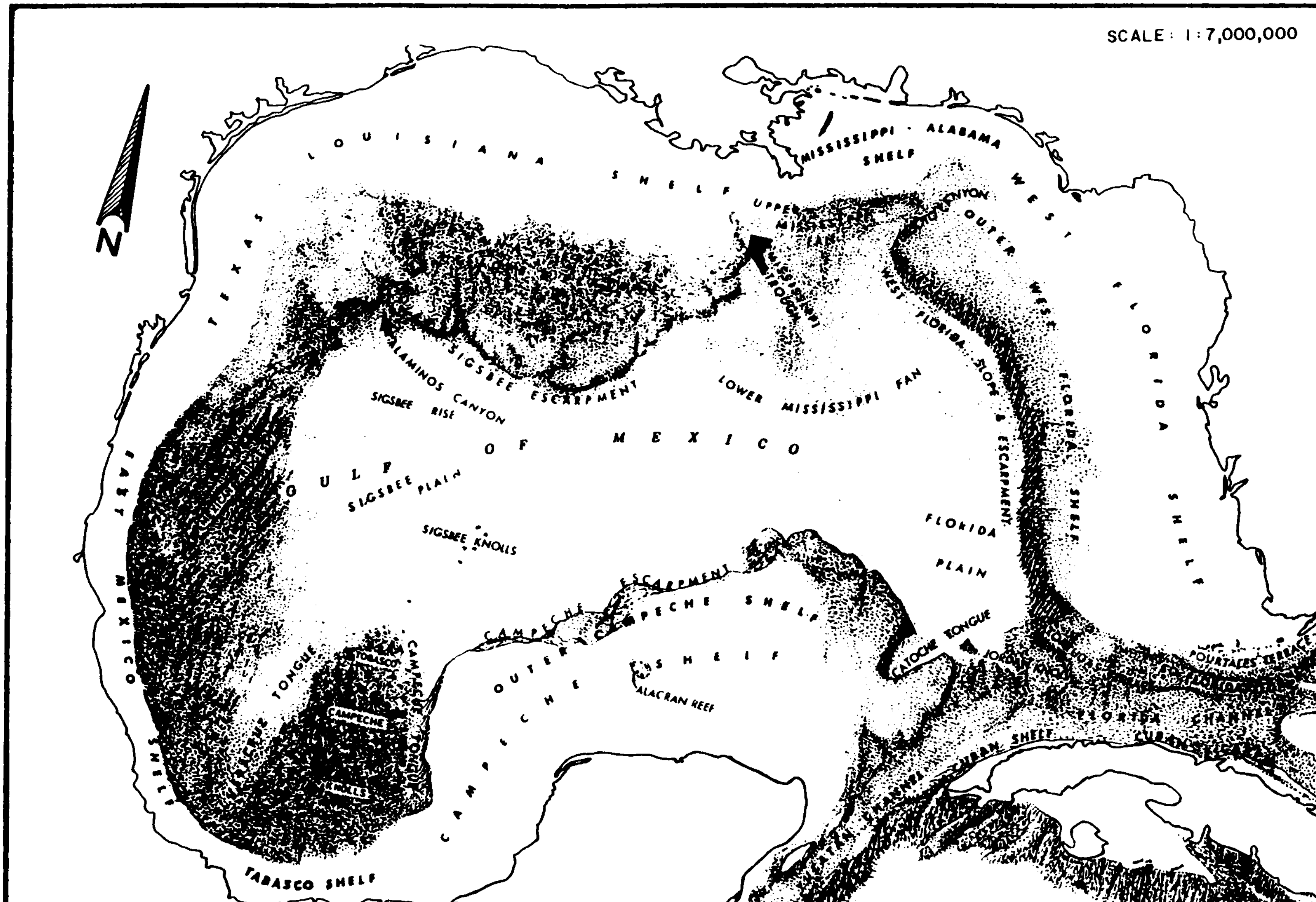


Figure 3.1 Seafloor topography of the Gulf of Mexico. Source: Modified from U.S. Department of the Interior (MMS, 1983).

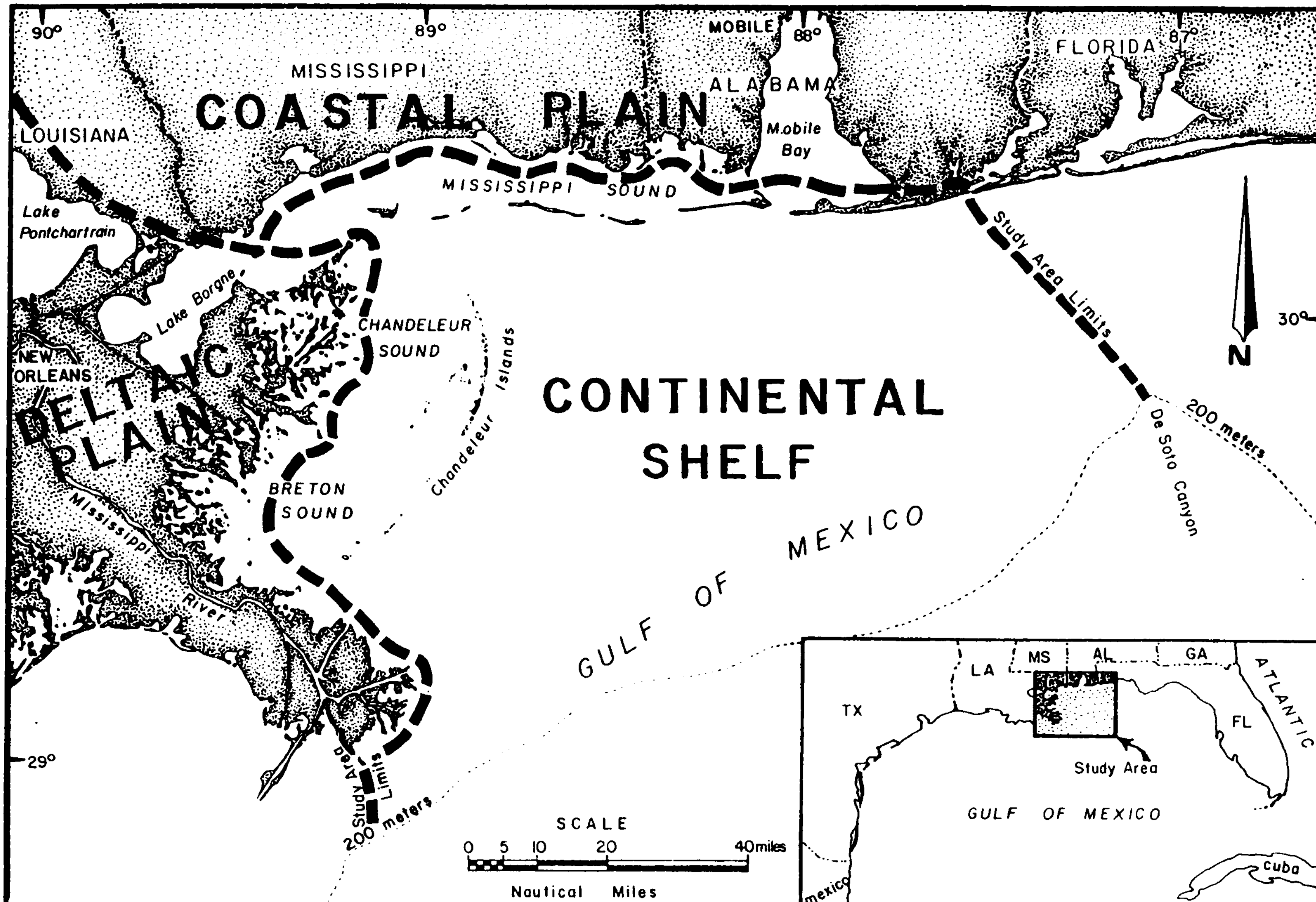


Figure 3.2 Major physiographic provinces of the Tuscaloosa Trend study area.

set as a line from the head of DeSoto Canyon at the 200 m isobath extending northwestward to the Alabama-Florida state line. The western boundary of the study area is delineated by a line running southward from South Pass of the Mississippi River Delta to the 200 m isobath.

3.2 PHYSIOGRAPHY OF MAJOR REGIONS OF THE STUDY AREA

3.2.1 THE TUSCALOOSA TREND ADJACENT TO THE MISSISSIPPI RIVER DELTA

The portion of the Tuscaloosa Trend adjacent to the Mississippi River Delta encompasses features that resulted from the subsidence of the now abandoned St. Bernard Delta complex and, farther south, the eastern flank of the presently active modern or birdfoot delta (Figure 3.3). This nearshore zone is roughly delineated on the eastern, seaward margin by the Chandeleur Island chain that encloses Breton and Chandeleur Sounds. The island chain is an arcuate tract approximately 37 km south of Biloxi, Mississippi. It ranges south-southwestward and lies between 32 and 40 km east of the Bayou A Loutre mainland. The northern portion of the arc, which is about 40 km long, is a relatively continuous island belt. The next, less continuous section is chiefly shoal with islands interspersed. These include Curlew Islands, Errol Island, Grand Gossier, and the largest and most stable island, Breton Island. In the lee of the main Chandeleur Island is an expanse of shoal extending about 13 km into the Sound and marked by several small clusters of islands. These are the North Islands, New Harbor Islands, Free Mason Island, and Old Harbor Island.

Beach material varies somewhat on the main Chandeleur Island and from island to island (Russell, 1936). The beach on the northern end of the main island is much sandier than further south, and is the only area with any significant foredune relief (Nummedal et al., 1980). Thick shells compose the outer beach on the northeast section of the North Islands. Slabs of well-indurated sandstone are evident on Chandeleur Island and on the northern tips of North Islands. On the lee shores of the Chandeleur arc there are extensive stands of low mangrove trees. Breton Island at the southwest tip of the arc displays a small, relict strandplain as evidence of prior island growth, probably associated with some previously active Mississippi River subdelta which provided sand for island progradation (Otvos, 1984). The main Chandeleur Island retains many scars from encounters with hurricanes. Following the passage of Hurricane Frederic in 1979, Kahn (1980) recorded 21 major reopened channels 150 to 300 m wide within a 16 km stretch. The southern section of the main island is rapidly migrating soundward leaving behind large areas of exhumed peat and mangrove roots on the Gulf shore (Nummedal et al., 1980).

The inland waters enclosed by these retrograding barriers--Chandeleur and Breton Sounds--are gently sloping and shallow. They average a depth of approximately two meters and extend for 96 km along the flank of the subaerial portion of the abandoned St. Bernard Delta. The northern edge of Breton Sound is cut by the Mississippi River-Gulf Outlet which is 10.9 m deep and 152.4 m wide extending southeastward 121 km across the Mississippi River Delta out to the 12 m isobath in the open Gulf (Briggs, 1968).

Submergence has produced the "form" of the region north of the actively prograding delta (Russell, 1936). Shoreforms exhibit the rapidity of subsidence. Double islands (e.g., Isle Au Pitre) are remnants of natural

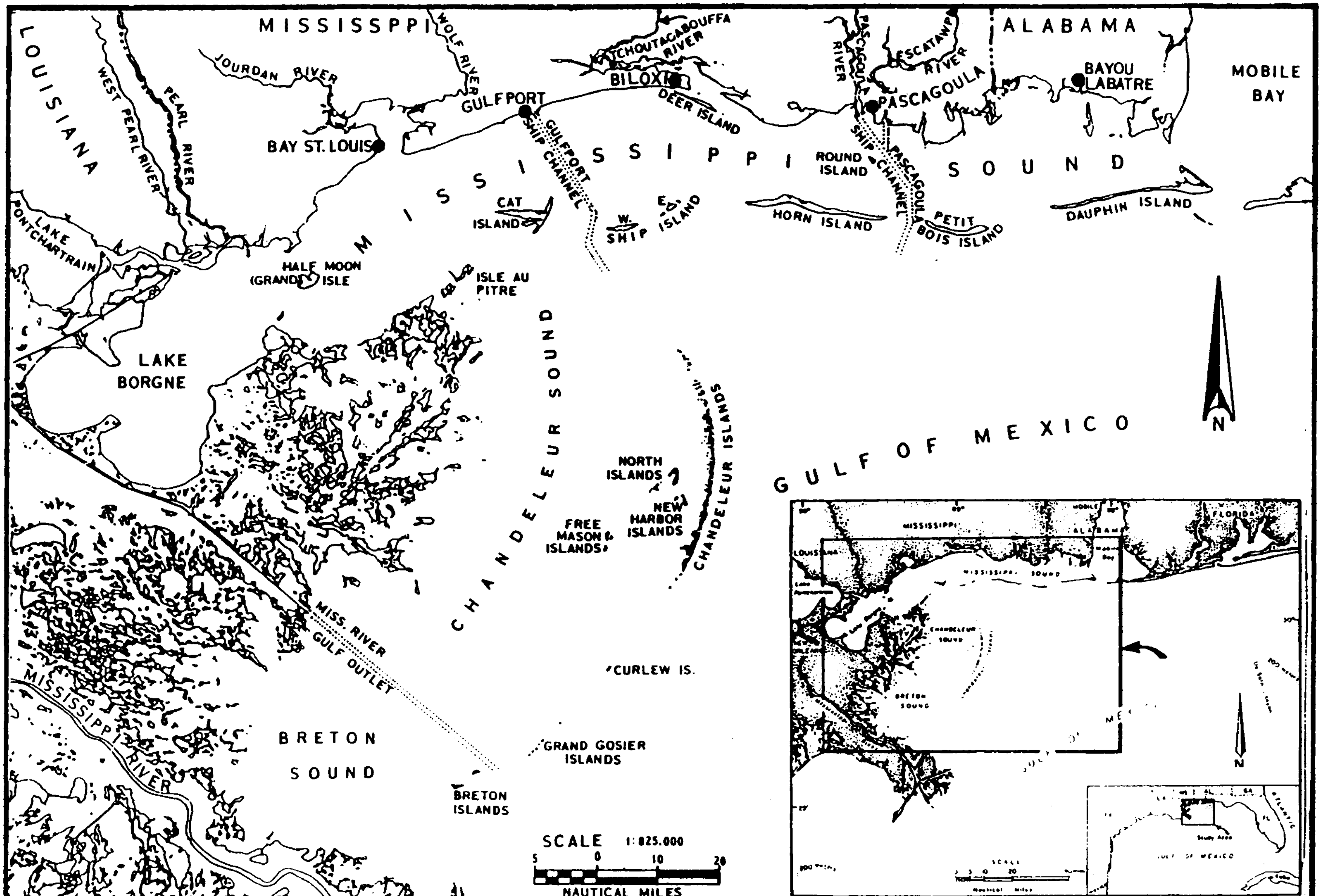


Figure 3.3 Nearshore areas within the Tuscaloosa Trend study area.

levees of old distributary patterns. The relict channels between the levees are straight and usually sediment-filled. Shallow open water covers most of the area between the levees and are connected by winding tidal channels. Most of the inland waters are 0.9 to 1.2 m deep with flat bottoms. Lake Borgne, which is generally two meters deep, marks the end of the east-west trending Mississippi Sound. The Lake is a delta flank depression that is essentially an arm of the Gulf which was partially cut off by deltaic progradation (Otvos, 1982). The area of Lake Borgne has increased in recent times as a result of relative sea level rise, shoreline erosion, general land subsidence, and wetland deterioration.

The active Balize deltaic lobe (Figure 3.4), the birdfoot delta, is a network of bifurcating distributaries and crevasse splays advancing onto the continental shelf and slope. Between the advancing passes there are shallow embayments called distributary bays. The distributary bays take two general forms (Shepard, 1960). There are open bays such as East Bay and Garden Island Bay adjacent to South Pass; and others, such as Blind Bay, south of Pass a Loutre, that are protected from the open sea waves by merging distributaries. Further seaward there are numerous erosional and depositional features such as mudflow gullies, slides, and faults which modify the bottom topography. These features will be discussed in greater detail in Chapter 3: Geology.

3.2.2 MISSISSIPPI SOUND AND BAYS

Mississippi Sound (Figure 3.3) is a long, narrow, protected coastal lagoon which extends along the coasts of Alabama, Mississippi, and abutts Louisiana at Lake Borgne. Fresh water is supplied primarily from the Pascagoula and Pearl rivers, supplemented by the Wolf, Jourdan, and Tchoutacabouffa rivers, with some additional influence from Lake Pontchartrain through Lake Borgne and from Mobile Bay on the east (Isphording and Lamb, 1980; Otvos, 1982). The Sound has a length of 130 km, an average width of 15 km, and an average depth of three meters (Kjerfve, 1983). It is protected from direct Gulf influences by six barrier islands and on the southwest between Half Moon (Grand) Island and Isle au Pitre by marshy island remnants of the St. Bernard subdelta. Two ship channels cut the Sound. Gulfport channel trends south-southeasterly with a projected depth of 9.1 m. Pascagoula ship channel trends southerly and runs between Horn and Petit Bois islands with a design depth of 12.2 m.

Six barrier islands, 5 to 19 km seaward of the mainland, effectively protect the Sound from direct Gulf influences. These are Cat, West and East Ship, Horn, Petit Bois, and Dauphin Islands. East Ship Island is four kilometers long, and is the smallest of the chain. The longest island is Dauphin, which is about 22.4 km long. The islands are separated by tidal passes ranging in depth from 7.6 to 16.4 m, except for East and West Ship Island, which was dissected by Hurricane Camille in 1969 and is separated by tidal passes only six meters deep. Island width ranges from between 0.3 to 1.9 km. The highest elevations on the barriers are on the coastal foredunes behind the Gulf beaches. The dunes generally attain an elevation of around four meters, but the highest dunes are 14.3 m on the southeast portion of Dauphin Island. Petit Bois and Horn Islands exhibit clear, parallel recurved beach-ridge sets marking their westward progradation. The intervening swales support small ponds and marshes (Otvos, 1982). Cat Island, west of Ship Island, has stopped

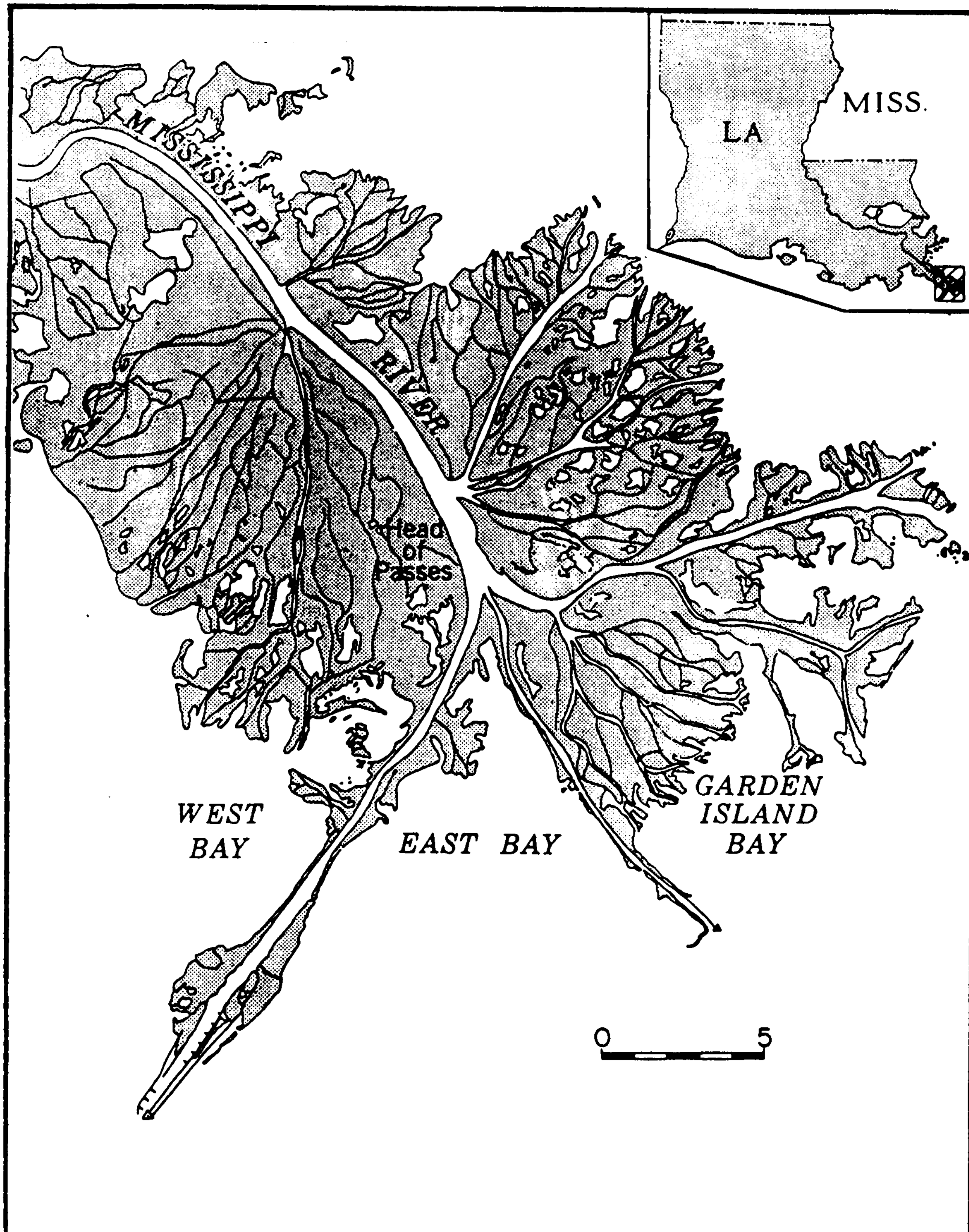


Figure 3.4 The active Balize deltaic lobe. Source: Gagliano and Van Beek (1970).

prograding and exhibits three separate sets of beach ridges (Figure 3.5). The intervening swales between the ridges have subsided producing shallow embayments.

There are other islands within Mississippi Sound which are not technically barrier islands. These are Deer Island, south of Biloxi, and Round Island, south of Pascagoula, both of which are remnant features with Pleistocene cores. At the Mississippi-Alabama state line, the remnants of the ancient Escatawpa River delta are evident as a small cluster of marshy islands and embayments, e.g., Grand Batture Islands, Isle aux Herbes, Marsh Island, Cat Island (Otvos, 1982).

The intertidal areas along the barrier islands are almost entirely clean quartz sand with fairly steep berms, bare of vegetation, along the foreshores of most of the barrier beaches. The mainland beaches of the Mississippi sections of Mississippi Sound have been extensively modified. Over one-third of the Mississippi mainland coast has had wide sand beaches created in front of seawalls by pumping material from the shallow nearshore waters (Larson et al., 1980).

3.2.3 MOBILE BAY AND ENVIRONS

Mobile Bay (Figure 3.6) is a submerged river valley about 49 km long stretching from the Mobile River Delta to Main Pass at the south. The bell-shaped estuary is approximately 37 km across at its widest between Mississippi Sound and the eastern shore of Bon Secour Bay, though the average width is 17.4 km. The Bay is relatively shallow, averaging three meters in areas outside the Ship Channel, which is 12.2 m deep. Main Pass, where Mobile Bay opens to the Gulf of Mexico, is approximately 4.8 km wide. Seaward of Main Pass, along the southeastern shore of Dauphin Island, is an arcuate ebb-tidal delta consisting of a number of shoals and ephemeral islands enclosing Pelican Bay. The most noteworthy island is the northwest-southeast trending Sand Island. Mobile Bay merges with Mississippi Sound at Pass aux Herons, which is approximately 1.6 km wide.

Mobile Bay is partially enclosed by the Mobile Point-Fort Morgan Peninsula. The Peninsula is a large spit attached to the mainland on the east and formed by aggrading beach ridges. The western section of the spit consists of broad, well-developed beaches backed by discontinuous dunes that reach six meters. Several large lagoons and marshy areas lie between the Gulf beaches and the mainland.

Perdido Key, which lies immediately east of the Fort Morgan Peninsula, is a narrow peninsula connected near its midpoint to the mainland. As on the Fort Morgan peninsula, the secondary dunes reach heights near six meters. Hurricane Frederic, in 1979, demolished much of the primary dune line. The dunes are gradually rebuilding (George Lamb, Dept. of Geology and Geography, University of South Alabma, personal communication).

3.2.4 THE MISSISSIPPI-ALABAMA SHELF

The Mississippi-Alabama Shelf (Figure 3.7) is a triangular-shaped region extending from the Mississippi River delta eastward to the DeSoto Canyon. The shelf is approximately 128 km wide on the west and narrows to 56 km

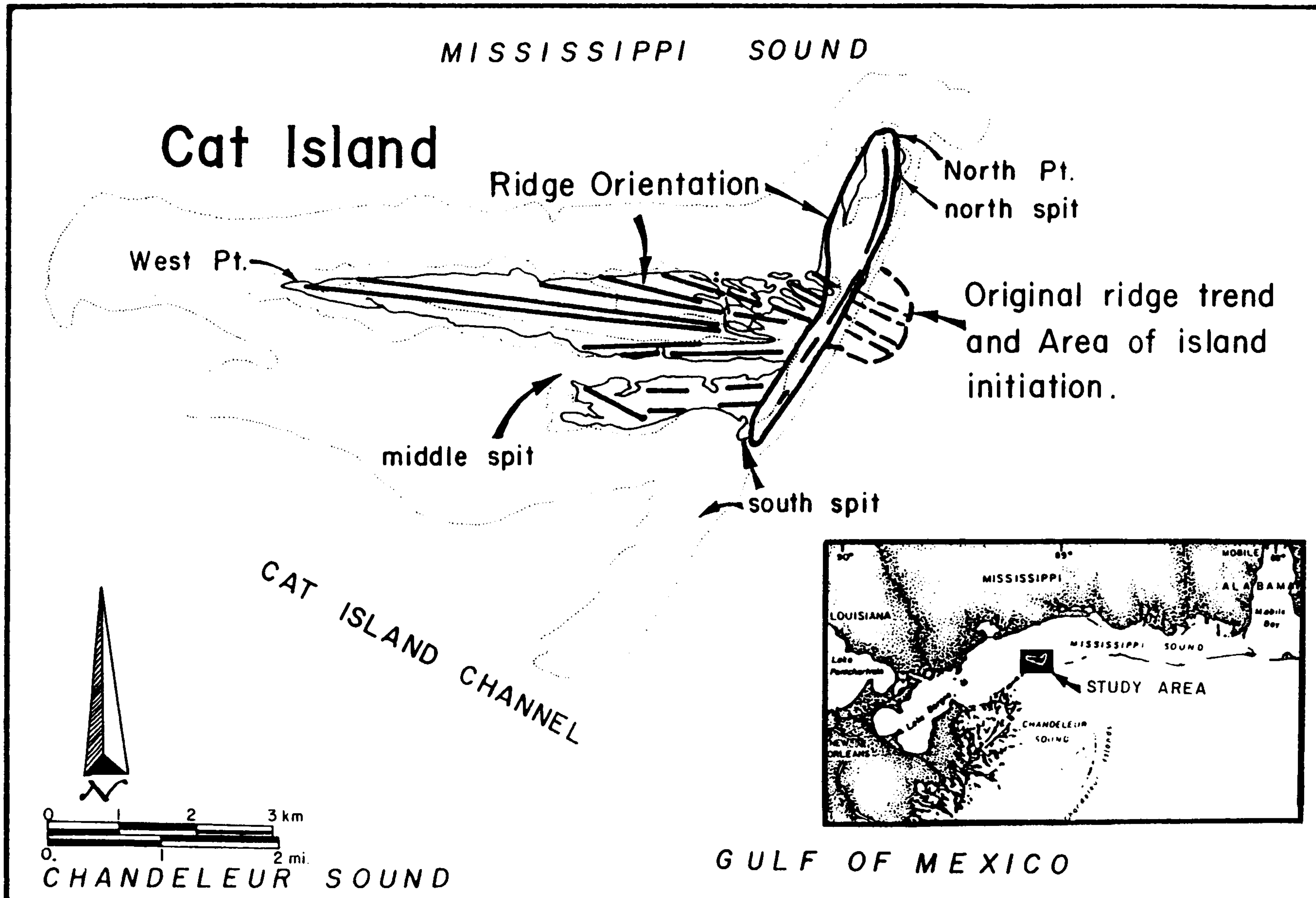


Figure 3.5 Beach ridge evolution on Cat Island, Mississippi. Source: Otvos (1982).

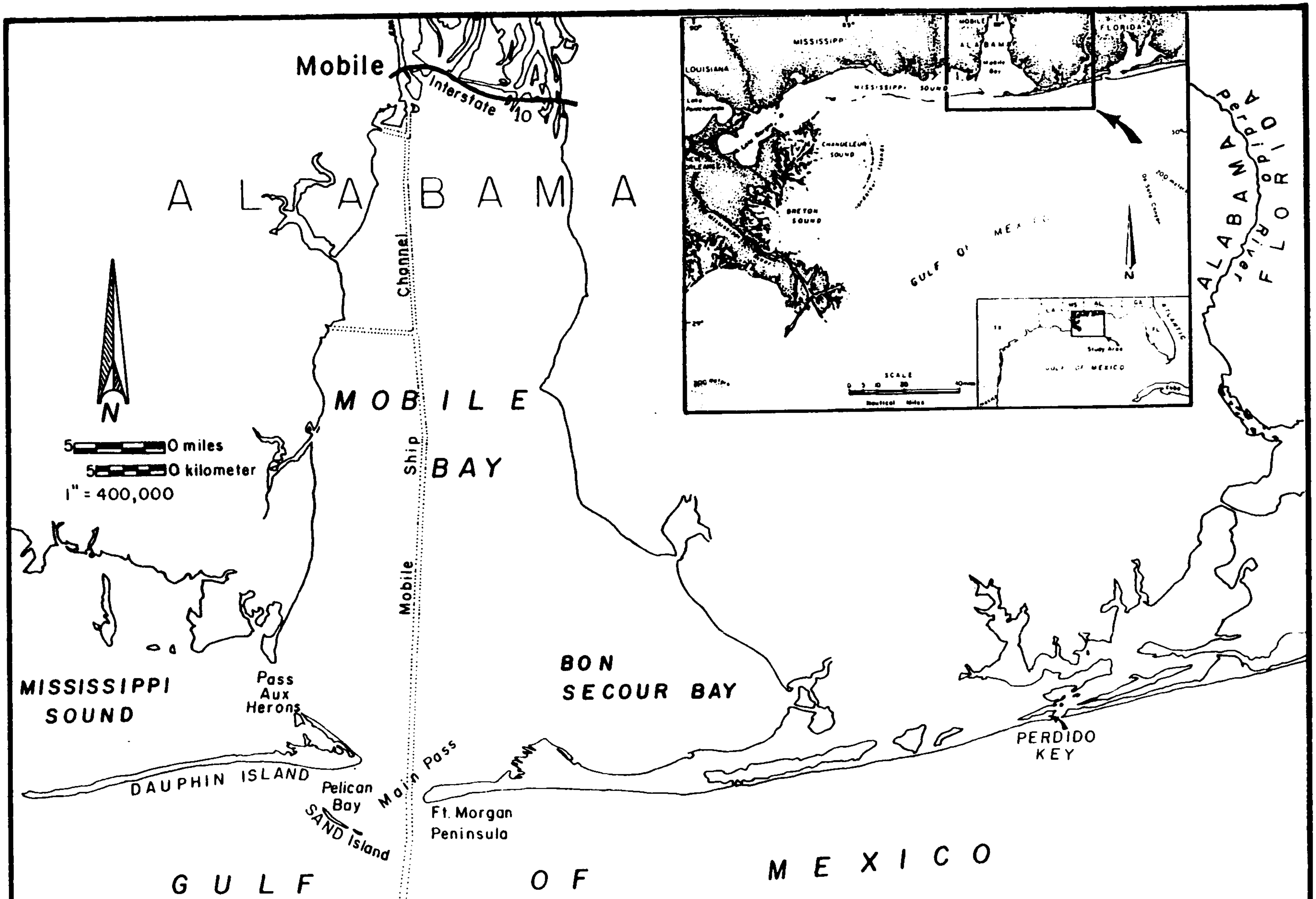


Figure 3.6 Mobile Bay and environs.

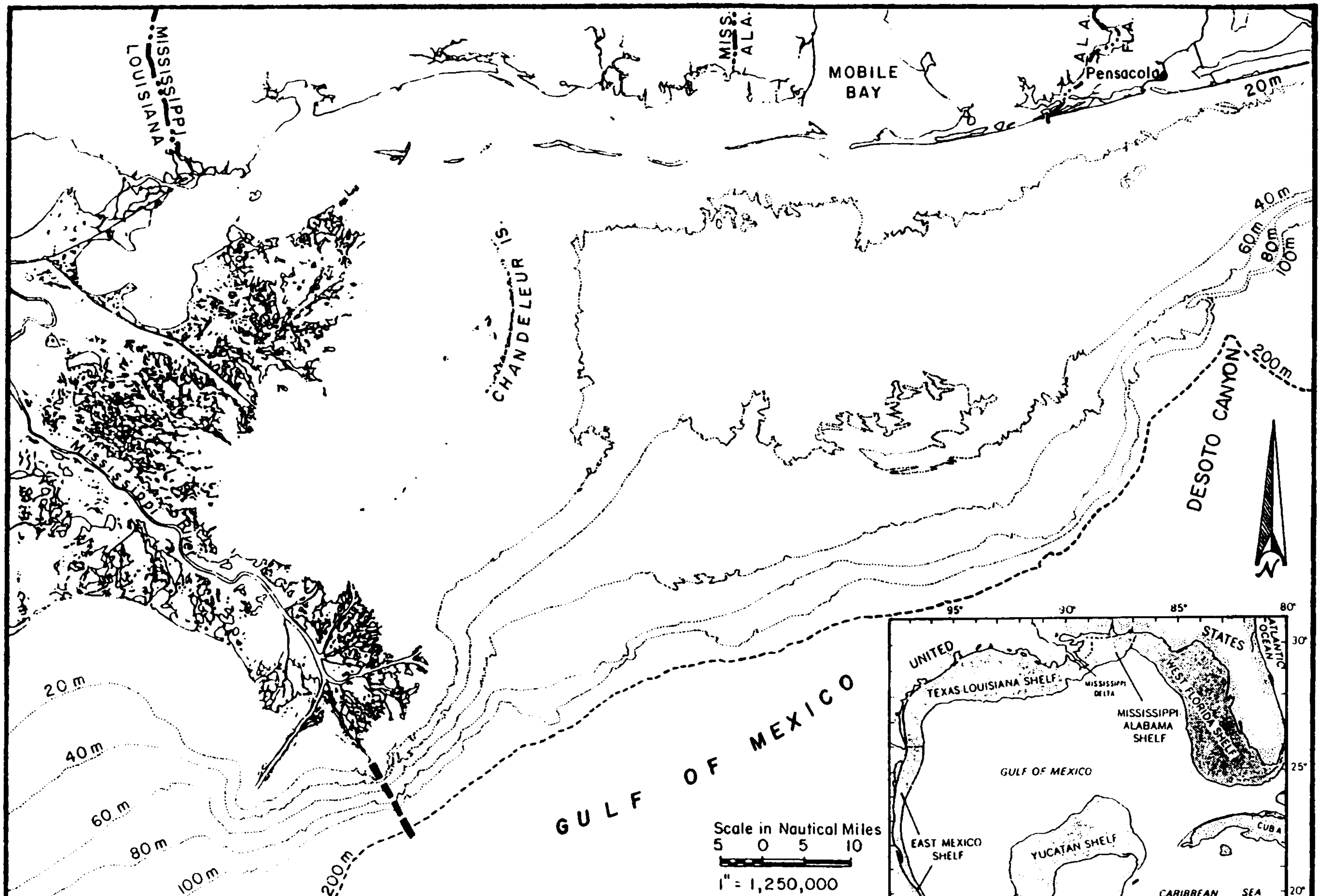


Figure 3.7 The Mississippi-Alabama Shelf.

on the east. It has an average width of 58 km and a mean seaward declivity of one meter per kilometer. The shelf is an almost flat plain delineated on the north by the abrupt shoreface seaward of the barrier chain at Mississippi Sound where the break in slope occurs at approximately the six meter isobath. The shoreface generally slopes seaward at up to 9 to 11 $m \cdot km^{-1}$. Off Dauphin Island the slope is a more gentle 06 $m \cdot km^{-1}$ (Upshaw et al., 1966). At approximately the 55 m isobath the slope increases to 4 to 6 $m \cdot km^{-1}$ and marks the shelf-break transition down to approximately the 183 m isobath. The shelf-break exhibits more complex topography than the upper shelf due primarily to tectonic activity related to salt diapirism, Pleistocene reef growth and mass wasting (Pyle et al., 1975).

The DeSoto Canyon, which marks most of the eastern boundary of the Tuscaloosa Trend study area, is an S-shaped canyon whose origin has been attributed to a combination of late Tertiary erosion, deposition and structural control by diapiric activity (Harbison, 1966). Its continued existence may be the result of lack of significant sedimentation rather than active scouring by currents (Pyle et al., 1975). Nonetheless, the clastic wedge from the Gulf Coast geosyncline is impinging on the western fringes of the canyon.

The events of the Holocene transgression from 14,000 to 8,000 B.P. left a significant impression on the morphology of the middle and outer shelf of the Gulf of Mexico. However, the portions of the shelf from Mobile Bay westward have been subject to the influence of the St. Bernard delta, the Balize delta, and Mobile and Pascagoula river sedimentation, which has produced a relatively flat seafloor. East of Mobile Point, sedimentation rates have been slight and some features that survived the Holocene transgression are still present. Southeast of Mobile Point a group of features along the 32 m isobath resembling an ancient bay, barrier island and lagoon were identified by Ballard and Uchupi (1970).

Elsewhere, lower on the shelf, there is still evidence of lower sea level stillstands. Deltaic bulges are prominent features between the 40 and 70 m isobaths (Figure 3.8). The rising sea level during the Holocene transgression, with pauses, allowed a series of sand spits to form, and is manifested by continuous, diagonal trends, generally oriented northwest-southeast between the 40 and 70 m isobaths (Ballard and Uchupi, 1970). Frazier (1974) identified features southeast of the Chandeleur Islands which he described as relict barrier beaches. Some of the sand bodies located by Kindinger et al. (1982) are as much as five meters thick. Mazzullo (Jim Mazzullo, Dept. of Geology, Texas A&M University, personal communication) has generated a paleogeographic reconstruction of the continental shelf from the Mississippi River Delta eastward to approximately Panama City, Florida. The reconstruction, which is based on the distribution of quartz sands grouped by grain shape characteristics and correlated to source areas, reveals the locations and influences of seven river systems on the shelf during the Late Pleistocene and early Holocene.

Along the shelf break ancient biogenic and tectonic features exert a strong influence on the bottom topography. Coral reefs and isolated coral pinnacles which flourished when sea level was some 160 m lower than present stand nine to nearly 17 m above the seafloor in the Mississippi-Alabama reef and interreef zones (Ludwick, 1964). Salt domes which are present in all depth zones within the Gulf are especially evident along the continental slope and shelf edge.

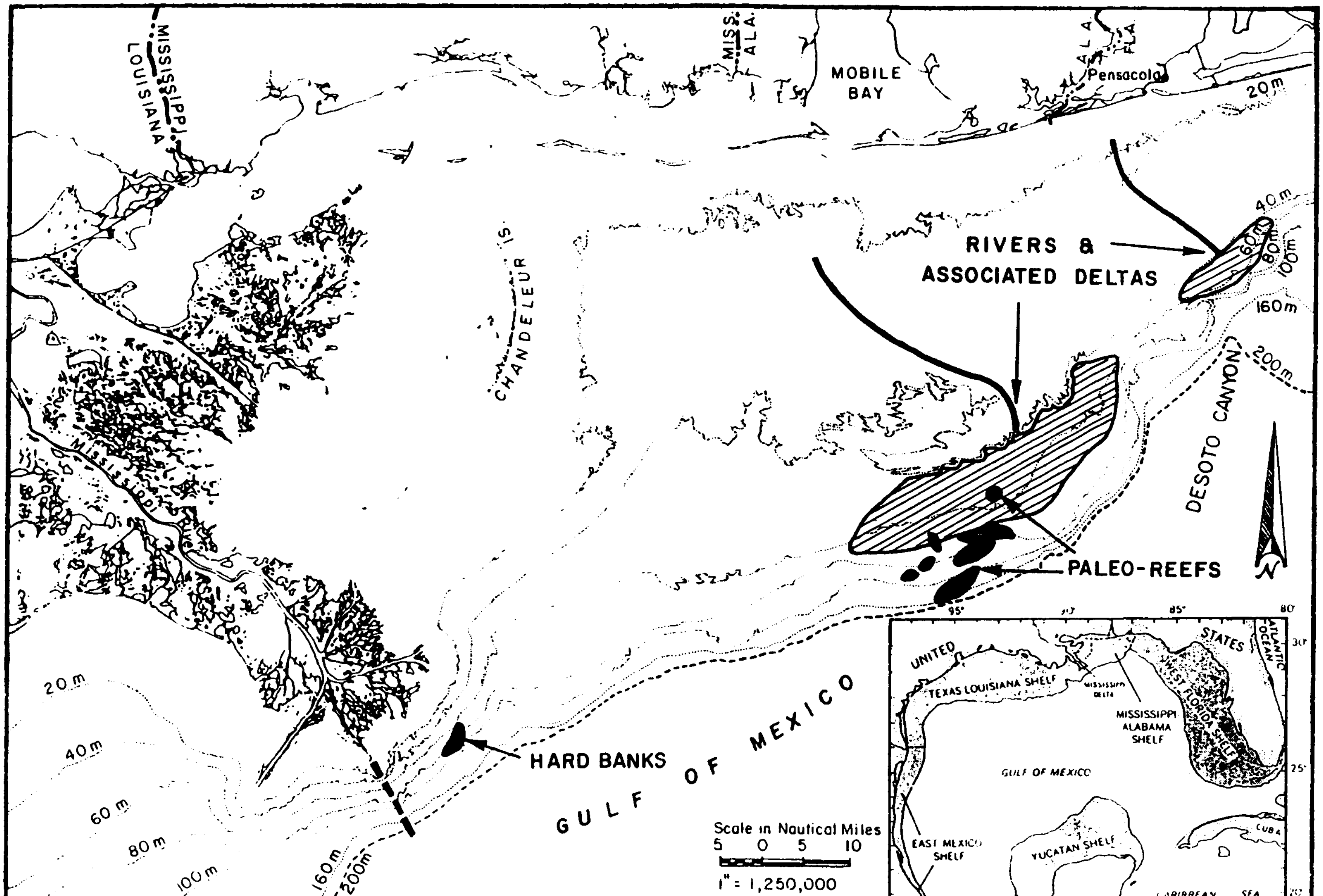


Figure 3.8 Geomorphic features associated with the 60 m and 160 m shorelines and paleo-reefs and hard banks. Source: Ballard and Uchupi (1970); MMS (1983).

3.3 GEOLOGY

The Gulf of Mexico is a geologically old sedimentary basin that has been accumulating material in a nearly unbroken sequence of thick strata since Middle Mesozoic times (Van Siclen, 1984). These deposits have achieved thicknesses greater than 15,240 m in the Gulf Coast geosyncline, and outpacing regional subsidence has prograded the shoreline approximately 400 km since its formation (Antoine et al., 1974).

Numerous papers have discussed the history and possible origins of the Gulf basin (Murray, 1960; Hardin, 1962; Rainwater, 1968; Lehner, 1969; Antoine et al., 1974; Pilger, 1981; and Van Siclen, 1984). Four basic theories have been presented to explain the Gulf's origin. These are: (1) that the Gulf represents foundered continental crust; (2) that it is a downwarp initiated by thermally controlled phase change in the crust and mantle; (3) that it is a tensional rift formed during the Mesozoic opening of the Atlantic Ocean; and (4) that it is a Paleozoic or older ocean. Pilger (1981) outlines the most recent-working hypothesis relating the Gulf's formation to complex tensional rifting associated with the early Mesozoic opening at the Atlantic Ocean.

3.3.1 THE GULF COAST GEOSYNCLINE

The primary geologic feature within the Tuscaloosa Trend study area is the Gulf Coast geosyncline. The geosyncline is a broad regional structure which dominates the geology of the northern Gulf Coast and extends from Alabama to northeast Mexico. Principally a Cenozoic basin, the geosyncline's stratigraphic sequence consists of a massive wedge of transgressive and regressive episodes from the Tertiary and Quaternary overlying Cretaceous carbonate beds. These carbonates rest on Jurassic evaporites which formed in block-faulted rift basins at the end of the Paleozoic (Figure 3.9). The rapid influx of sediments from the north and northeast has steadily prograded the shelf edge 400 km into the Gulf basin. Massive layers thicken and dip seaward, forming a clastic wedge which has been penetrated by numerous diapiric structures (salt and shale domes) and modified by broad regional folds and contemporaneous faults. From south Texas to Louisiana, the depositional centers have migrated seaward through the Tertiary, responding to the lateral shifting of the river systems.

The upward migration of the Jurassic age Louann Salt represents a significant geologic process in the geosyncline. The movement uplifted and pierced the overlying younger beds, resulting in the complex stratigraphy evident in the Gulf Coast geosyncline. The Gulf basin salt deposits extend across three broad belts delineated by fields of piercement and nonpiercement structures (Martin, 1978) (Figure 3.10). The innermost belt consists of the Mississippi, North Louisiana, East Texas, and South Texas salt basins, while the middle belt contains the Louisiana-Texas coastal and inner shelf. The third, broad expanse of salt includes nearly all of the continental shelf and slope from the DeSoto Canyon westward to northern Mexico. The study area exhibits salt deposit thicknesses ranging from greater than 600 m seaward of the Mississippi River Delta to very thin or completely absent on the Wiggins Arch (Figure 3.10). Thinner accumulations of salt deposits result in fewer diapirs than in areas where the deposits are thicker. Salt diapirs are thought to form when thick salt layers are squeezed laterally under the tremendous weight of the overlying sediments. When the salt encounters faulted areas, it rises along the faults, which are weakened zones, forming

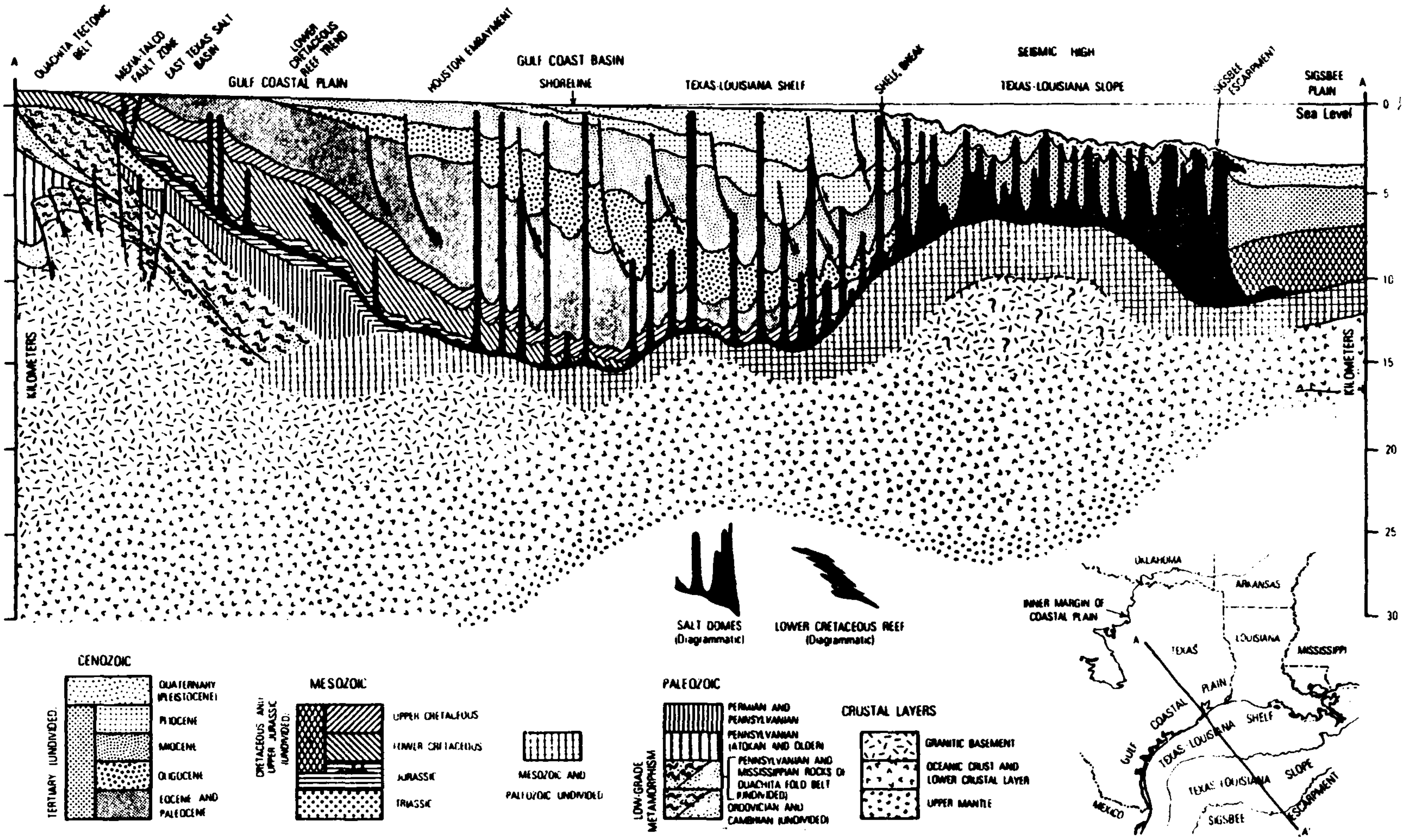


Figure 3.9 Generalized cross-section of northern Gulf of Mexico margin. Source: Martin (1978).

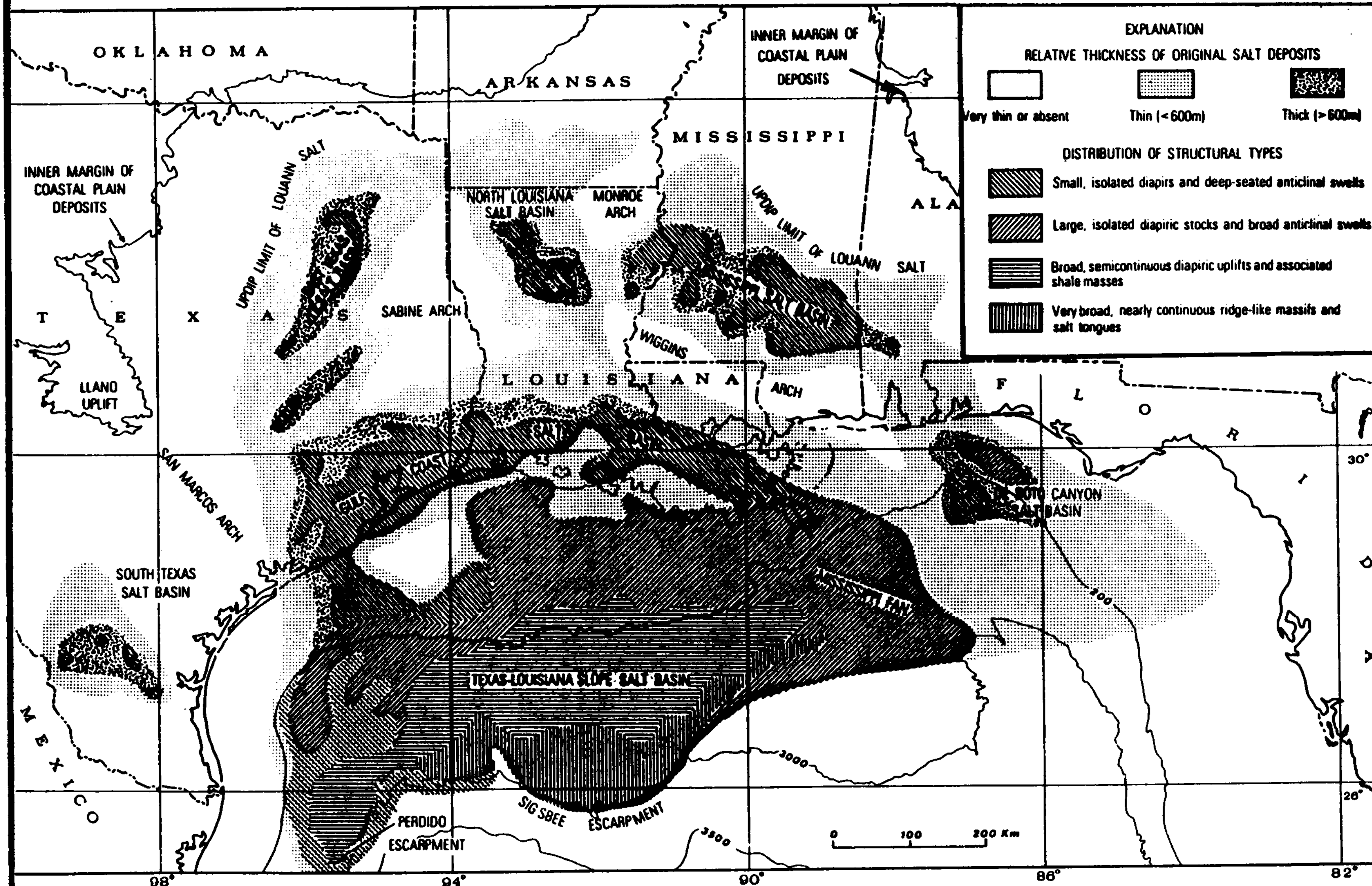


Figure 3.10 Distribution of Jurassic salt deposits and diapiric structures in northern Gulf of Mexico region. Source: Martin (1978).

structural domes and ridges (Antoine et al., 1974). These diapirs or piercement structures have been objects of hydrocarbon exploration due to their petroleum-trapping characteristics.

3.3.2 LATE QUATERNARY SEA LEVEL FLUCTUATIONS AND BOTTOM TOPOGRAPHY

The seafloor topography and sediment distribution on the continental shelf of the Tuscaloosa Trend study area are products of a combination of sea level transgressive-regressive episodes and deltaic progradation and destruction (Kindinger et al., 1982). The ocean floor across the continental shelf of Louisiana and Mississippi is characterized by low relief features and a gentle seaward slope (§1°). Local relief on the shelf is due to low fault offsets, Holocene sedimentary deposits, and further seaward at the shelf break, diapiric structures (Figure 3.11). On the shelf, the Holocene sedimentary deposits represent the most prevalent features. Sand bodies have been described as relict barrier beaches from lower sea levels (Curray, 1960; Ludwick, 1964; Frazier, 1974; and Kindinger et al., 1982), while a possible bay, barrier island and lagoon complex were noted south of Mobile by Ballard and Uchupi (1970). Deltaic bulges and associated river systems have also been identified across the shelf (Ballard and Uchupi, 1970; Mazzullo, personal communication, 1984; Texas A&M University, Dept. of Geology). On the shelf break and slope fault offsets, diapiric structures, slumps, and relict reef pinnacles contribute to the topographic relief.

Kindinger et al. (1982) have constructed an idealized north-south cross-section of the continental shelf and slope off Louisiana and Mississippi, depicting the Wisconsinan sea level fluctuations and their impacts on shelf morphology (Figure 3.12). The earliest stage illustrated occurred approximately 70,000 years ago with the erosion of the Sangamonian sediments during the early Wisconsin glacial advance (Figure 3.12). The ensuing transgressive-regressive episodes have been recorded in the stratigraphic sequence as periods of deltaic progradation, transgressive sedimentation followed by retreating seas and dissection of the exposed shelf by ancient river systems.

The latest stage (Figure 3.13) brought the sea to approximately its present level. The transgressing seas reworked and redistributed the terrigenous sediments through wave action and coastal currents, partially or completely destroying or masking river channels, lagoons, and coastal features. The reefs along the shelf break adjacent to DeSoto Canyon attempted to keep pace with the sea level rise through upward growth (Ludwick, 1964). The shallower reef complex in the Mississippi-Alabama reef facies developed during a temporary standstill. However, when sea level rise recommenced the reefs were unable to maintain growth (Ludwick, 1964). The outward growth of the St. Bernard Delta began about 4,800 years ago (Frazier, 1967) and progradated seaward until approximately 650 years ago when it was abandoned. Except for the peripheral deposition resulting from the Mississippi River Delta, little active sedimentation is presently occurring on the Tuscaloosa Trend study area shelf and slope (Pyle et al., 1975; Kindinger et al., 1982).

3.3.3 EVOLUTION OF THE MISSISSIPPI RIVER DELTA WITHIN THE TUSCALOOSA TREND STUDY AREA

The Mississippi River Delta represents the geomorphic manifestation

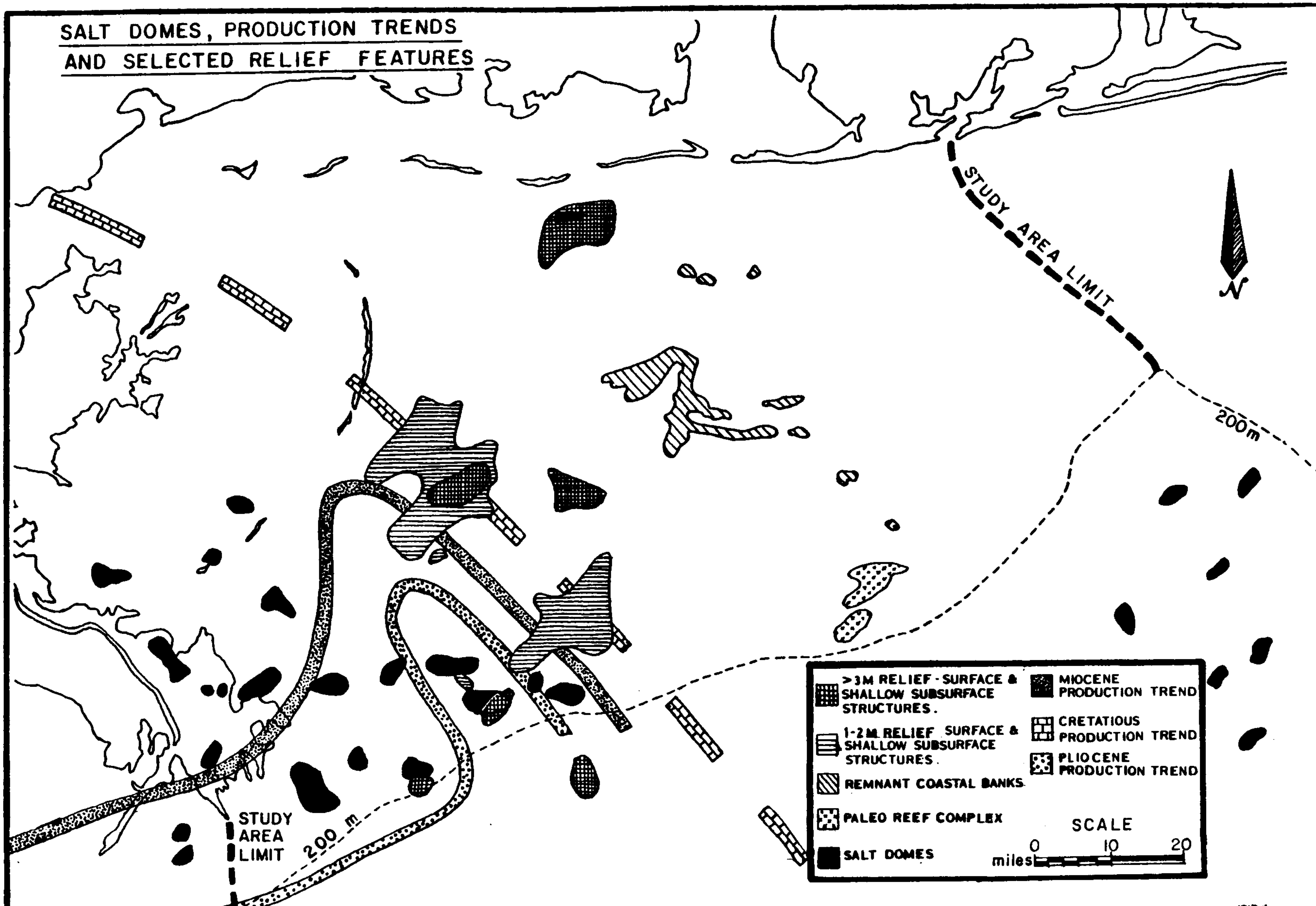


Figure 3.11 Salt Domes, Production Trends, and Selected Relief Features in the Tuscaloosa Trend study area. Sources: Hewitt et al., 1984; MMS, 1983; and Kindinger et al., 1982.

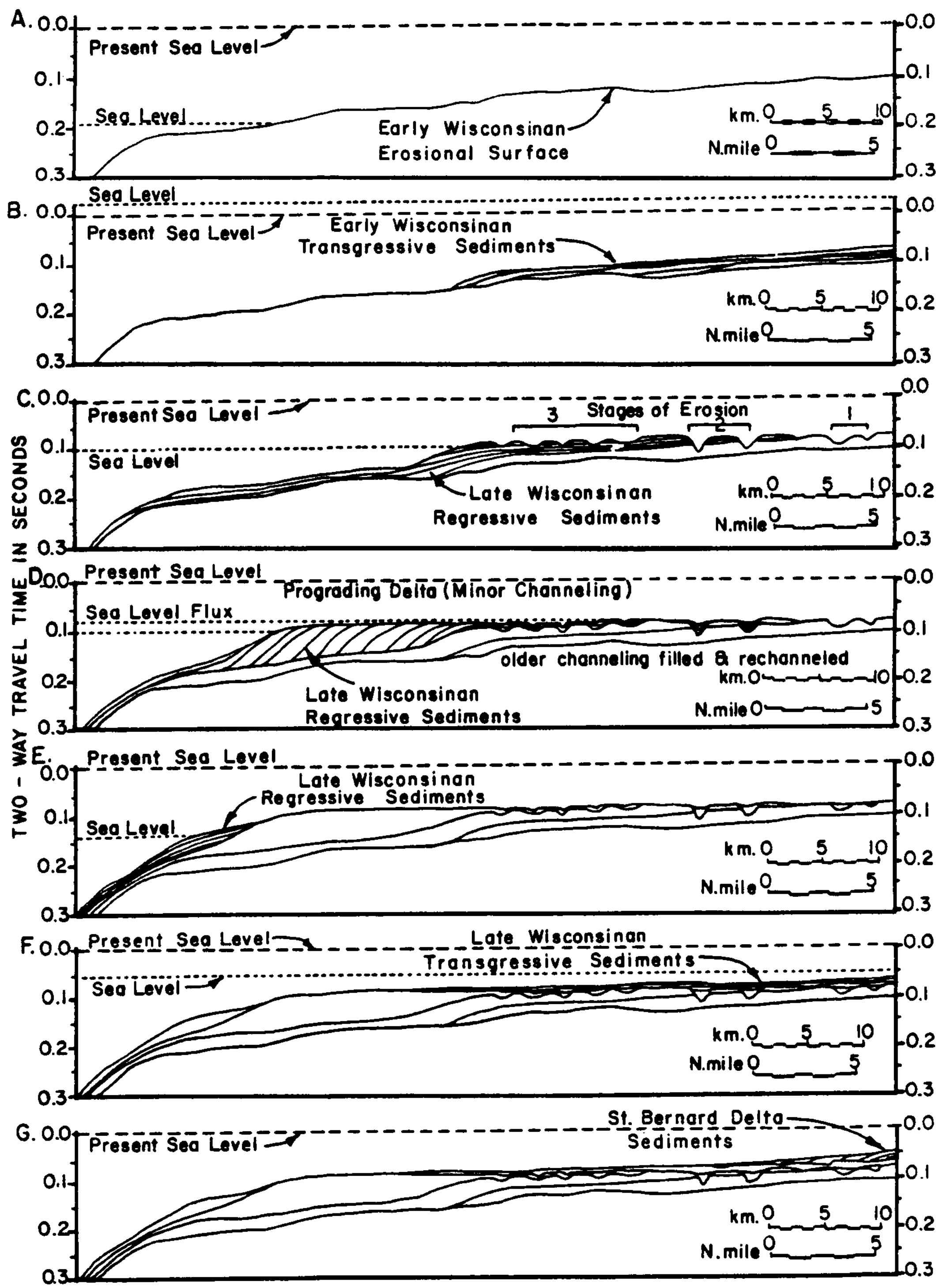


Figure 3.12 Composite cross-section of the Louisiana-Mississippi continental shelf. Source: Kindinger et al., 1982.

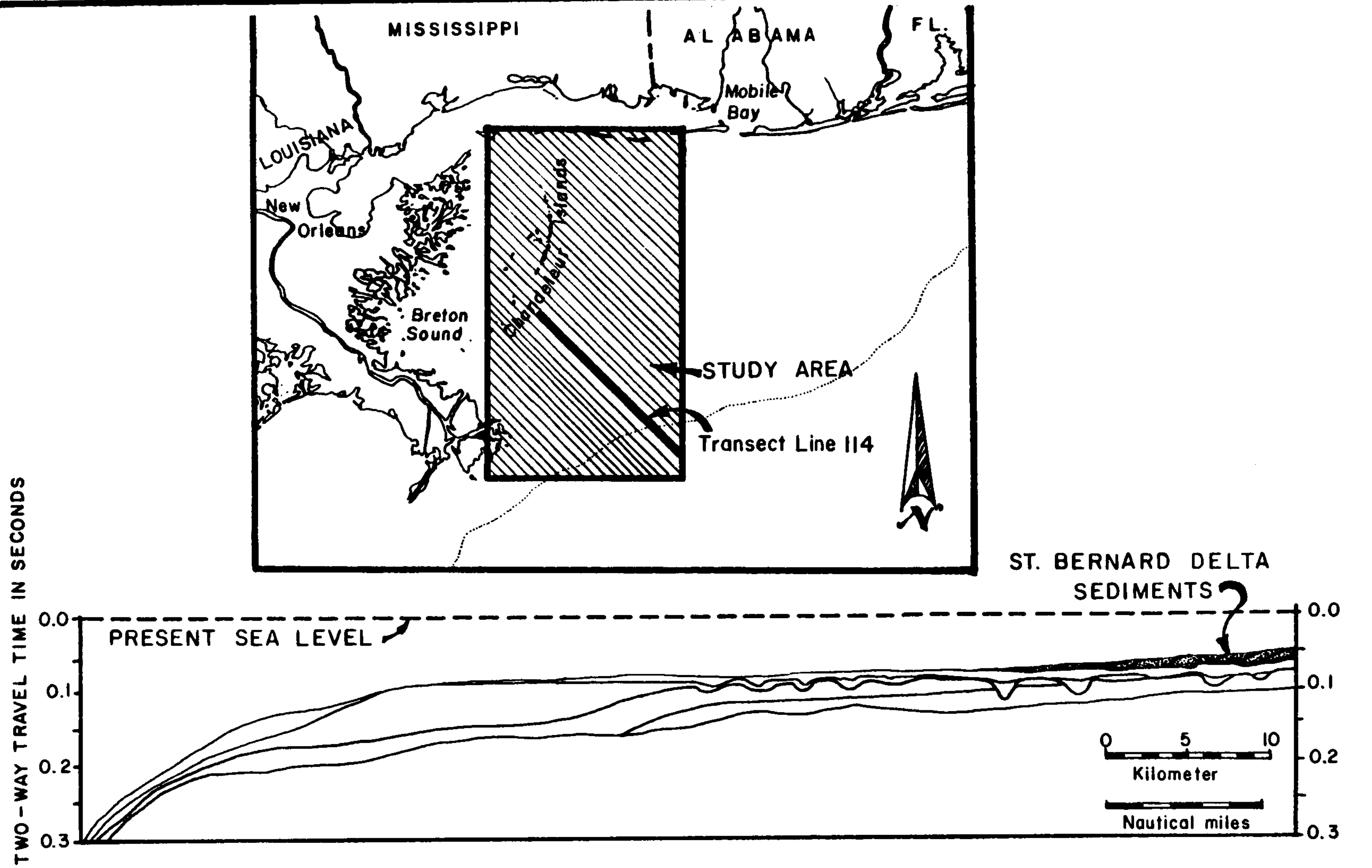


Figure 3.13 Cross-section of the Louisiana-Mississippi continental shelf during the growth of the St. Bernard Delta. Source: Kindinger et al., 1982.

of the deposition from the largest river in the United States. Draining over 40% of the contiguous United States, the Mississippi River discharges 497 billion kilograms of sediment (Rezak et al., 1983) annually into the Gulf of Mexico. The Delta is a complex, geologically dynamic feature. One section of the Delta will be rapidly prograding, accreting and laterally shifting, while another portion, lacking continuous sediment input, is characterized by subsidence and erosion.

The evolution of the Mississippi River Delta's modern form is a result of 7,000 years of Holocene deposition. Frazier (1967) has identified 16 separate delta lobes within five deltaic complexes that developed from the periodic shifting of the main channels (Figure 3.14). Two of these deltaic complexes fall within the Tuscaloosa Trend study area. These are the now abandoned St. Bernard Delta and Plaquemines-Modern Delta complex within the currently active Balize deltaic lobe. The St. Bernard Delta began prograding onto the shallow shelf about 4800 years ago, coinciding with the decline and subsequent abandonment of the Teche Delta complex. The St. Bernard Delta complex extended seaward beyond the present Chandeleur Islands before the prograding LaFourche complex began receiving the bulk of flow and sediment load. The St. Bernard complex was finally completely abandoned approximately 650 years ago. Once abandoned, the delta complex sediments began to compact and subside. Deltaic Plain subsidence allowed the sea to transgress onto, erode and rework the sediments, forming Chandeleur and Breton Sounds and an enlarged Lake Borgne. The distributary-mouth-bar deposits and headlands were reworked by waves and redistributed to form the transgressive barrier island arc consisting of the Chandeleur, Grand Gossier, and Breton Islands (Otvos, 1984). The Plaquemines-Modern delta complex began its growth onto the continental shelf and slope about 1000 years ago (Frazier, 1967). However, the period of active growth appears to be ending for the Balize Delta and the center of deposition is attempting to shift westward to the Atchafalaya Basin (Van Beek et al., 1979).

Published literature on the Mississippi River Delta is extensive. Major comprehensive papers dealing with the Delta's evolution and sediments include those by Russell (1936), Scruton (1960), Shepard (1960), Coleman and Gagliano (1964), Frazier (1967, 1974), Gagliano and Van Beek (1970), Morgan (1976), Frazier et al. (1978), and Penland and Suter (1983, 1984).

3.3.4 NEARSHORE GEOLOGY

Barrier Islands within the Tuscaloosa Trend

The barrier island system within the Tuscaloosa Trend study area can be divided into two sections, the northern barriers of the Alabama-Mississippi coast and the islands fronting Chandeleur and Breton Sounds (Figure 3.3). The Mississippi-Alabama barriers are thought to have emerged through shoal aggradation about 3,000 years ago (Otvos, 1982). Dauphin Island, the easternmost island of the chain, has a Pleistocene core at its eastern end which served as a platform for subsequent growth (Figure 3.15) (Otvos, 1984). Shepard (1960) suggests that the sand constituting the barriers originated on the continental shelf. Otvos (1973) suggests that the ebb tidal delta at the mouth of Mobile Bay is a source area for littoral flow moving westward along the island's face, and that the ebb tidal delta sands are probably eroded from the Fort Morgan peninsula immediately east of the pass and supplemented by sediments

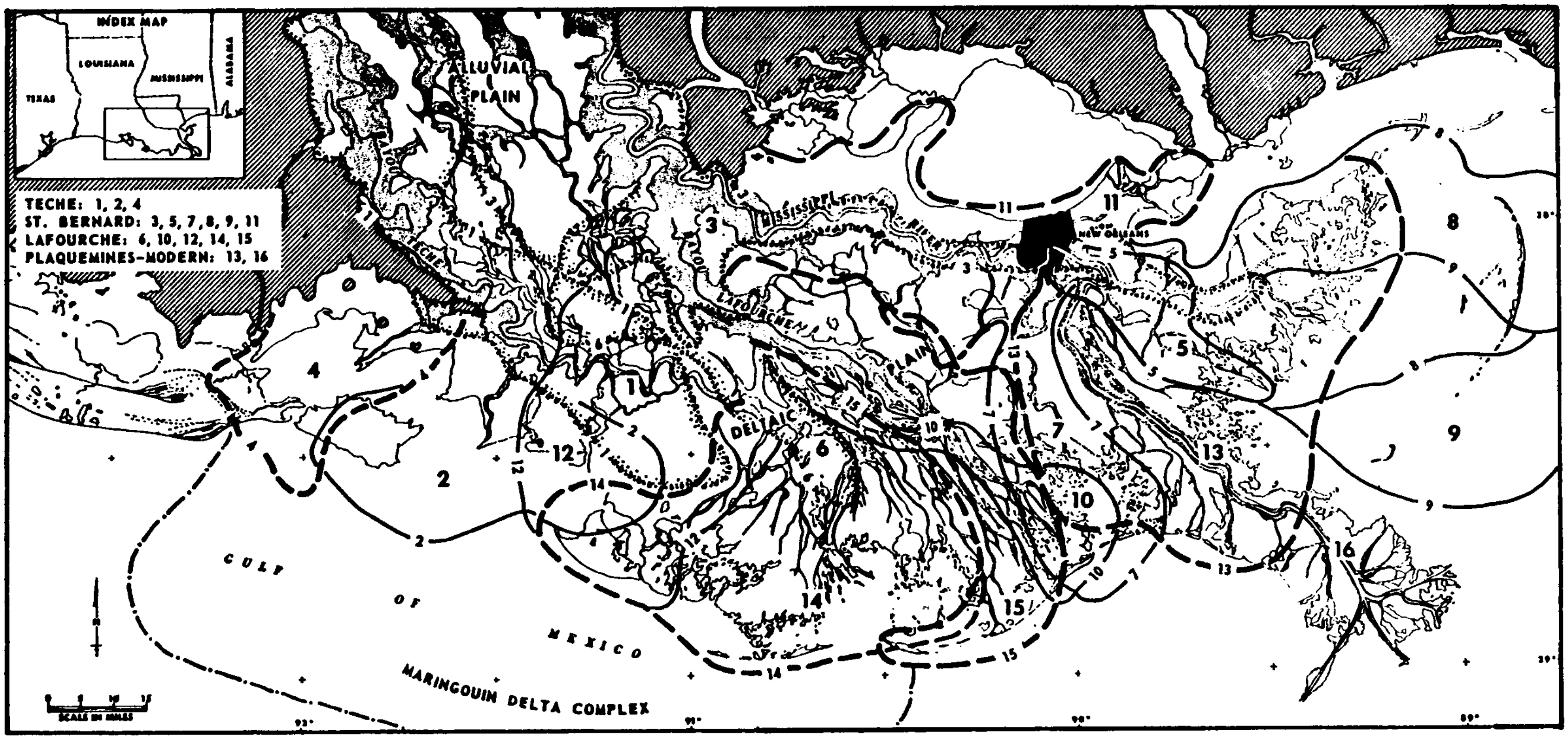


Figure 3.14 Delta lobes formed by Mississippi River. Source: Frazier (1967).

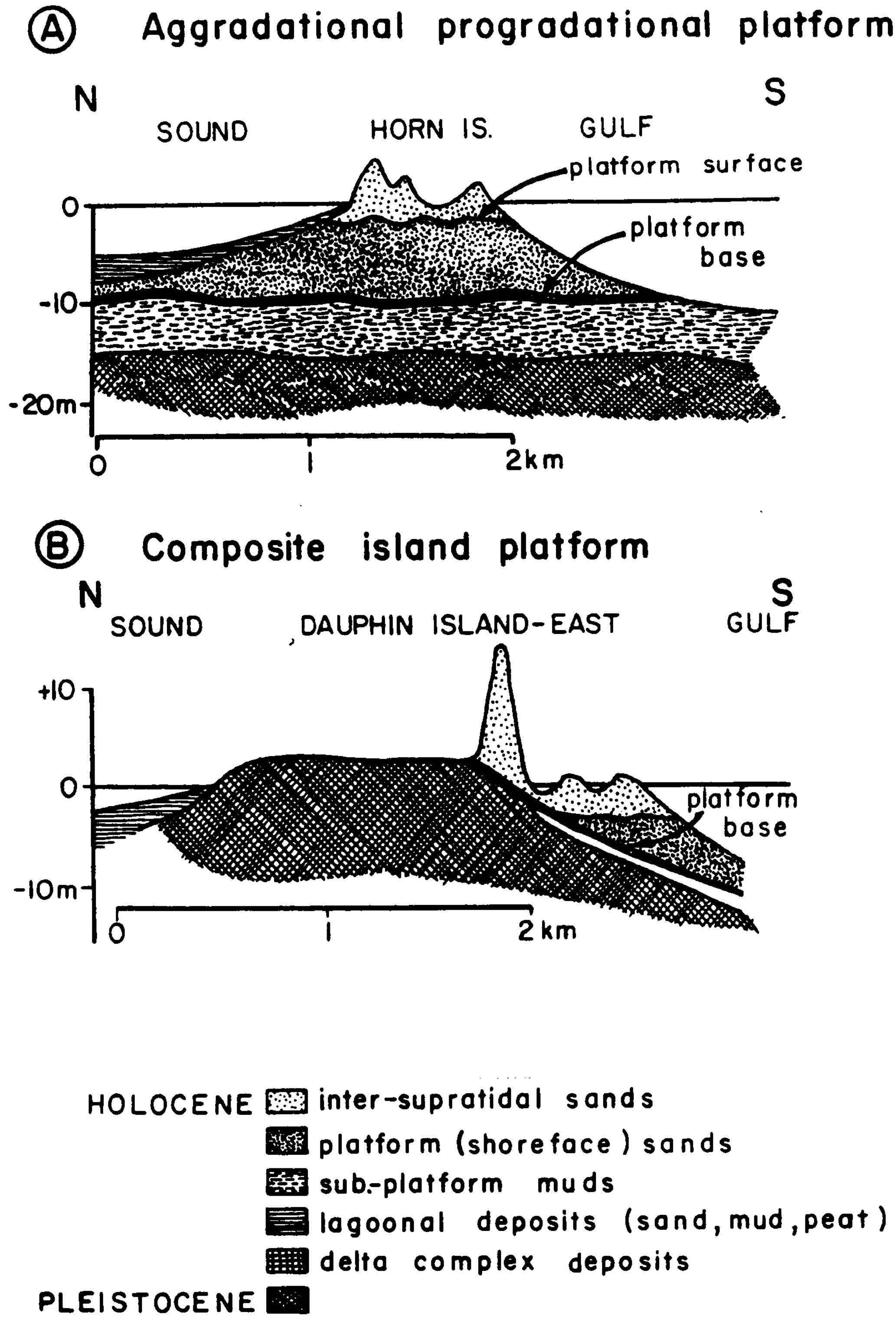


Figure 3.15 Generalized cross-sections through two types of northern Gulf barrier islands. Source: Otvos (1984).

emerging from the Bay. However, the erosion required to supply the suggested material is not readily apparent on the peninsula (George Lamb, Dept. of Geology and Geography, University of South Alabama, personal communication). The sands on the shoreface of the barriers are transported westward due to the littoral drift generated by the predominant southerly and southeasterly wave approach orientations. This westerly drift results in erosion on the eastern ends of the islands and accretion on the western tips. Malbrough and Waller (1977) measured long-term trends on Mississippi's barriers (Petit Bois, Horn, Ship, and Cat) over a 125-year period and determined maximum accretion rates ranging from 5 m to 38 m per year recorded on the western ends, while the eastern tips eroded from 13 m to 98 m. The rate of westward littoral drift has been calculated by the U.S. Army Corps of Engineers (1955) at Perdido Pass near the Alabama-Florida state line in a similar fashion. Using charts and topographic maps from 1934, 1948, and 1953, the Corps estimated an average annual westward transport of 153,000 m^3. More recently, the Corps of Engineers (1974) developed a semi-empirical technique based on wave energy and angle to calculate sand transport rates for specific points on the Gulf beaches of the Mississippi-Alabama barrier islands. Utilizing this technique yields an average westward drift of 162,180 m^3 for a point on the most seaward extremity of Petit Bois Island.

The islands fronting Chandeleur and Breton Sounds in Louisiana (Figure 3.16) are composed of residual or reworked deltaic deposits, primarily sands, from the abandoned St. Bernard Delta of the Mississippi River. The Chandeleur Islands make up the longest segment on the northern end of the arc with the Grand Gossier Islands and Breton Island comprising the southern extension. The Chandeleurs are a barrier island arc system that represents the final stage in the evolution of the St. Bernard delta lobe. The Chandeleur Island arc system has been transgressing across fine-grained, subsided delta plain and lagoonal facies (Figures 3.17 and 3.18). The combination of a limited sediment supply and a sediment dispersal system that transports sediment seaward onto a broad inner shelf and landward as backbarrier washover fans have progressively reduced the island's size and surface area. The erosion rates in the southern portions of the Chandeleur chain exceed 15 m per year, while erosion rates northward decrease to about 5 m per year due to less direct wave approach. The total island area diminished from 29.7 km^2 in 1950 to 21 km^2 in 1967 (Penland and Boyd, 1982).

Limited barrier accretion reflects the southerly longshore drift pattern. The arcuate form is derived from the regional wave refraction pattern which has shifted the chain south and westward. These low profile islands have evidenced little subaerial accretion since the first surveys were conducted in the mid-19th century (Otvos, 1984; Penland and Suter, 1983). Migration occurs when storm-generated waves wash over the low profile islands, transporting the sediments landward onto the lagoon and marsh deposits behind the islands. Though overwash processes and longshore drift are significant processes involved in barrier island morphology and growth, hurricanes and major storms function as the primary mechanism of major morphologic changes (Nummedal et al., 1980; Kahn, 1980). Kahn (1980) estimated that 50% to 90% of the net shoreline erosion on the Chandeleur Islands in this century resulted from the impact of 23 hurricanes.

There are numerous published reports which deal with the barrier islands within the Tuscaloosa Trend study area. Significant amongst these are

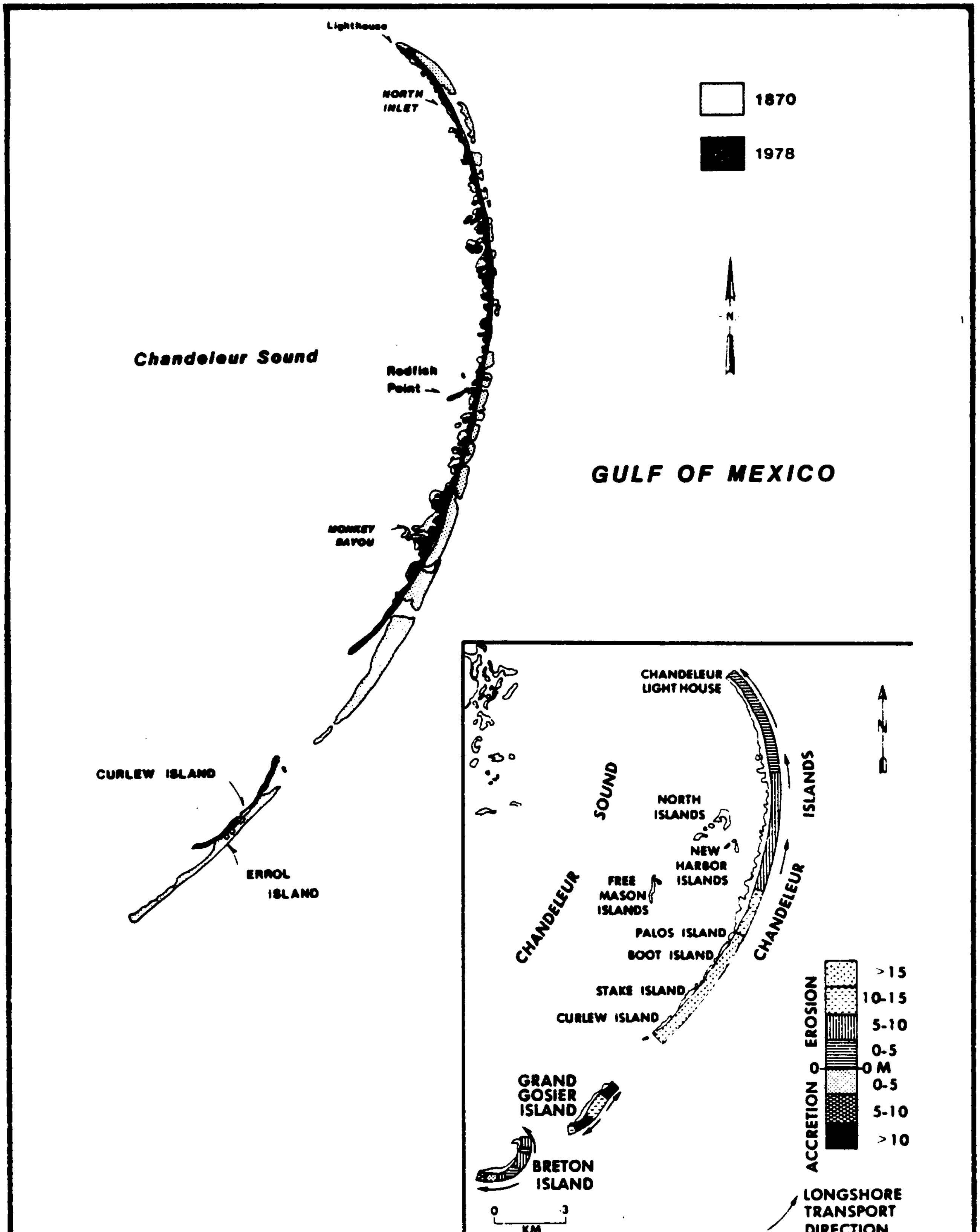


Figure 3.16 Historical map comparison of the Chandeleur Island arc showing its landward transgression into Chandeleur Sound, and average annual erosion-accretion along the Chandeleur Islands. Source: Penland and Boyd, 1982.

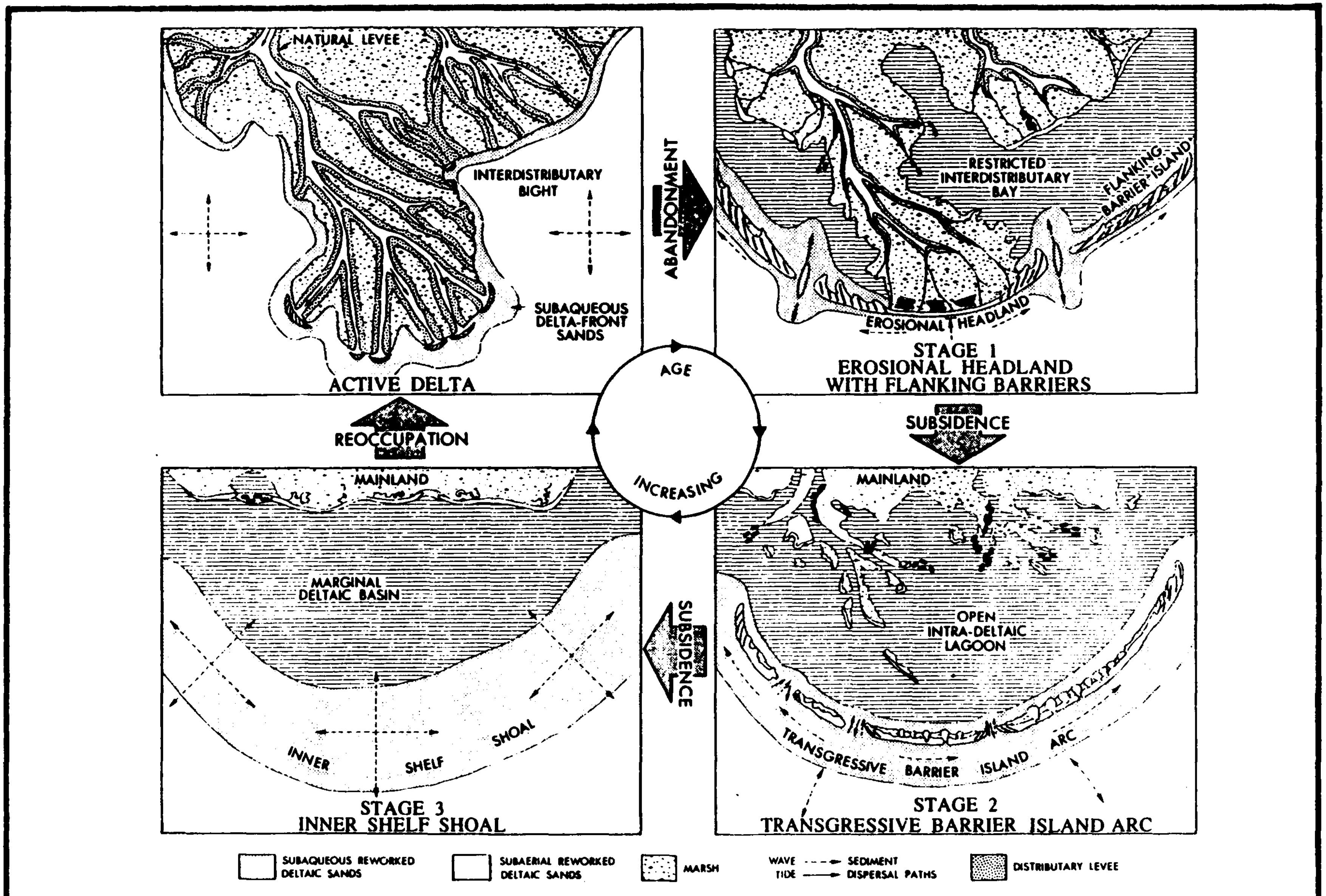


Figure 3.17 A model for the evolution of abandoned Mississippi River deltas and the development of transgressive coastal barrier systems. Source: Penland and Boyd (1982).

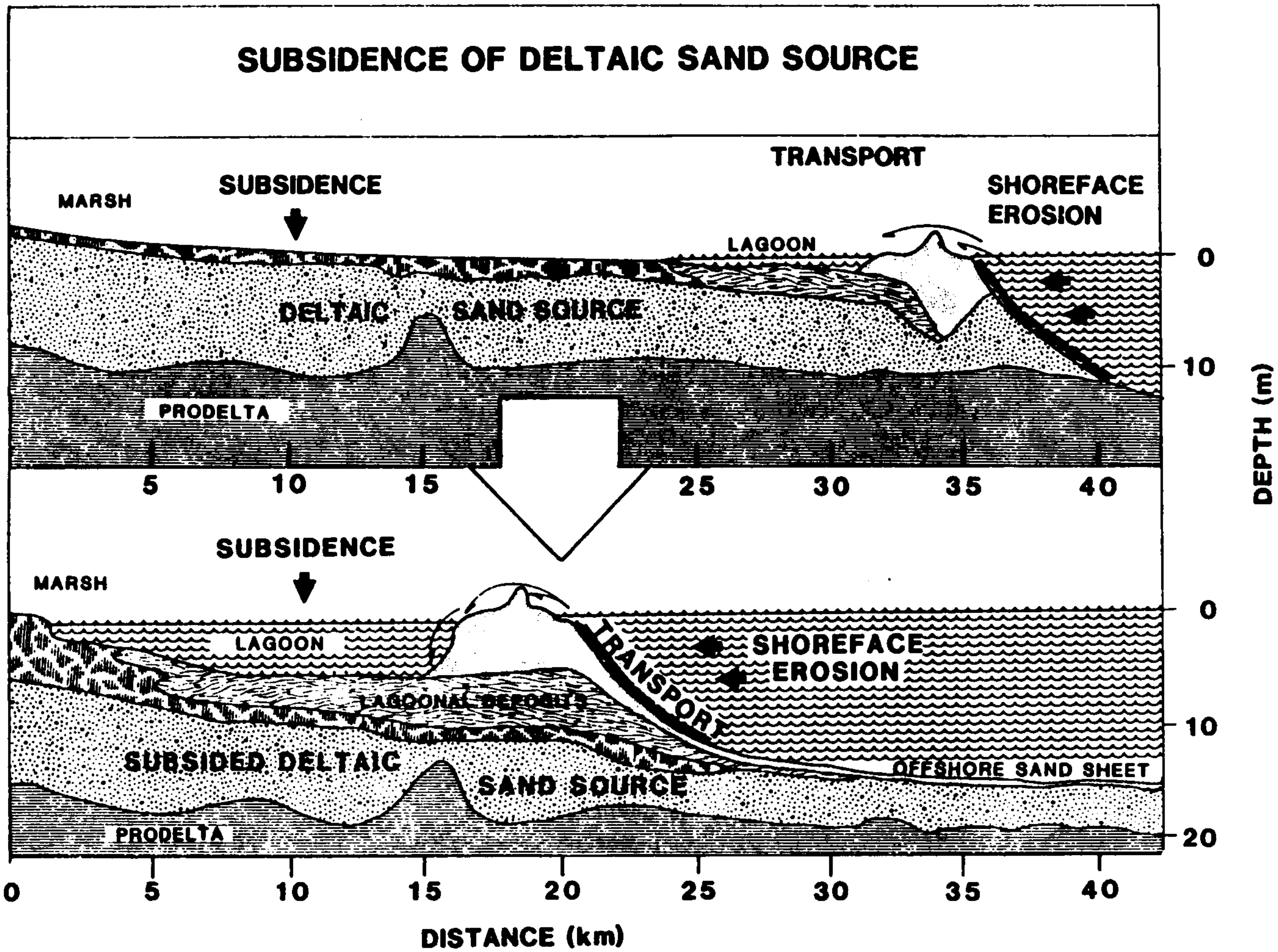


Figure 3.18 Subsidence of distributary sand sources in the major mechanism-driving coastal barrier transgression and deltaic land loss. Source: Penland and Boyd (1982).

Otvos (1976, 1982, 1984), Penland and Suter (1983, 1984), Penland and Boyd (1982), Kahn (1980), and Nummedal et al. (1980).

Chandeleur and Breton Sounds

Chandeleur and Breton Sounds (Figure 3-16) were formed through subsidence of the ancient St. Bernard Delta (Gagliano and Van Beek, 1970). These inter-connected sounds have no direct natural river accesses and constitute what Shepard (1960) refers to as an "open lagoonal" system due to the rather large inlets between the various islands. Breton and Chandeleur Sounds also differ from most bays along the Gulf coast by being more open to Gulf influences. The irregular shoreline formed by the partially drowned subsiding remnant of the St. Bernard Delta marks the Sounds' western boundary. Deposition rates are very low in the absence of active delta building. Sediments are introduced through the inlet between the active combination of tidal and storm-driven currents and barrier island overwash transporting sediments from the transgressing barrier islands and shoals. To a minor degree, sediment may be introduced from the subaerial delta on the west through wave-induced erosion (Shepard, 1960).

Chandeleur and Breton Sounds are floored with a thin veneer of post-St. Bernard lagoonal sediments overlying marsh and fluviatile deposits. The surface sediments range from sands and silty sands in the open water to silty clays and clayey coquinas in protected waters. The veneer's thickness varies from a few inches to several feet. Evidence of the ancient distributaries is still present on the sound floor (Figure 3.19). The firm bottom conditions associated with the buried natural levees influence the distribution pattern of oyster reefs (Gagliano and Van Beek, 1970). This submerged network of channels and other riverine features is periodically reworked by waves and tidal surge (Briggs, 1968). When the sediment is resuspended, bottom irregularities are smoothed and fine-grained clays and silty clays are either redeposited in the inland marshes or carried out to sea. The coarser silts, sands, and shell fragments remain behind, and form a heterogeneous layer which is generally coarser than the silts and clays of the inland wetlands, but finer than the barrier island sands and nearshore Gulf sediments to the southeast (Briggs, 1968). The southern margin of Breton Sound is essentially a broad inlet between the advancing delta and Breton Island. These inlet deposits vary between sands and mud and are the result of the mixing of the fine sediments exiting the distributaries and the winnowing action of the tidal currents moving through the inlet (Shepard, 1960). Cores taken throughout the Sounds exhibit mottled structures and sand or coarse silt inclusions (Shepard, 1960). The prominent mottling is a result of the slow deposition rates which allow burrowing organisms to thoroughly rework the sediments through bioturbation (Scruton, 1960).

The irregular mainland shore is a product of the subsidence and erosion of a complex pattern of depositional environments following the cessation of active deltaic sedimentation. The natural land loss is exacerbated by man-made alterations of depositional processes. Chief among these are federally maintained navigation channels, levees, upstream diversions, and flood-control reservoirs, all of which prohibit overbank deposition. Canal dredging and spoil disposal are additional and locally significant factors (Johnson and Gosselink, 1982). Gagliano et al. (1981) constructed maps illustrating annual erosion rates and the projected "life expectancy" for areas within the

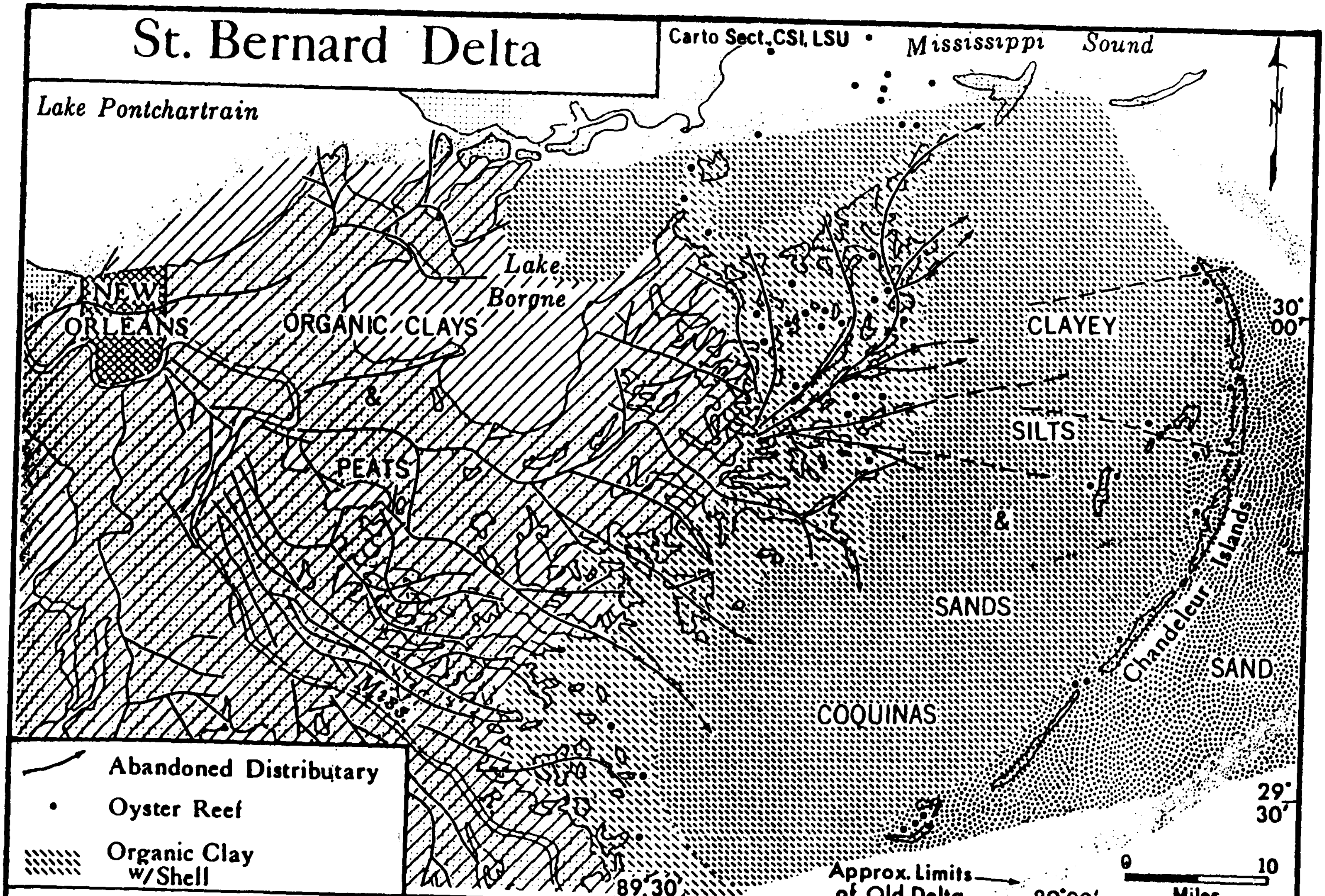


Figure 3.19 The subsided St. Bernard Delta showing positions of ancient distributaries. Source: Gagliano and Van Beek (1970).

Louisiana portion of the Mississippi Deltaic Plain. Four parishes in particular appear to be severely impacted by land loss: Lafourche; St. Bernard; Terrebonne; and Plaquemines (Table 3.1). If action is not taken to reverse the subsidence and erosion, these parishes may totally erode away within a relatively short time.

Since Breton Sound and Chandeleur Sound are products of the destructional phase of an abandoned delta of the Mississippi River, research directed at the delta and deltaic processes has often included these areas. Outstanding amongst these are: Scruton (1956, 1960), Shepard (1960), Briggs (1968), and Gagliano and Van Beek (1970).

Mississippi Sound and Bays

Mississippi Sound formed as a result of the barrier island emergence which occurred around 3000 years ago (Otvos, 1982). The islands effectively isolated the Sound, transforming it from an open Gulf system to a brackish water system. Generally, the Holocene sediments increase in thickness from north to south in the Sound. The average Holocene thickness is about 5 m in the northern portions (Otvos, 1982) as opposed to 12.2-18.3 m at the barrier islands (Ludwick, 1964).

Sediments in Mississippi Sound are predominantly estuarine silt and clays (Figure 3.20). The silty clays are concentrated in the center of the Sound, while the sands form a band along the periphery (Isphording, 1985 (in press); Isphording and Lamb, 1980). Oyster reefs comprise locally significant sedimentary features. The coarsest sands occur along the low energy northern shores of the barrier islands. The apparently paradoxical relationship is probably due to the relative inavailability of the finer sand fractions (Otvos, 1982). Montmorillonites and illite constitute 80% of the clay minerals (Isphording and Lamb, 1980). These minerals can adsorb metal and organic pollutants and release them at a later date (Isphording et al., 1983). Isphording and Lamb (1980) suggest that because the eastern Sound exhibits a greater proportion of silt size material and montmorillonite, much of the sediment must be derived from the Mississippi Delta. This sediment enters the Sound through Petit Bois Pass, and is transported eastward on a flood tide. Further west, adjacent to the Pearl River, Snowden and Forsthoff (1976) noted that prodelta clays from the Pearl River are being deposited out to the submerged northern edge of the abandoned St. Bernard Delta of the Mississippi River and can be differentiated from the underlying sediments by their clay mineral assemblage.

The heavy mineral assemblage in Mississippi Sound and the adjacent waters reflects the transition between the Mississippi River provenance and an eastern, Appalachian provenance. The heavy minerals in the Appalachian suite are primarily metamorphic, consisting of abundant ilmenite, kyanite, staurolite, zircon, and tourmaline. The western, Mississippi River heavy mineral suite is igneous, and includes pyroxenes, amphiboles, epidote, ilmenite, and biotite. Concentrations of heavy minerals occur in laminae along the storm berms and in the dunes of the barrier beaches. Van Andel (1960) identified a zone between Petit Bois and Dauphin Island with concentrations of greater than four percent heavy minerals. Another slightly less concentrated area containing between one and three percent heavy minerals lies seaward of Horn Island. Some of these heavy minerals may have commercial potential if they are found

Table 3.1. Land loss rates in the Mississippi River Delta. Source: Gagliano et al., 1981.

Parish	Remaining Land (in acres)	1980 Projected Loss Rate (in acres)	Life Expectancy (in years)
Lafourche	650,541	3,179	205
St. Bernard	257,816	1,695	152
Terrebonne	699,782	6,851	102
Plaquemines	457,523	8,831	52

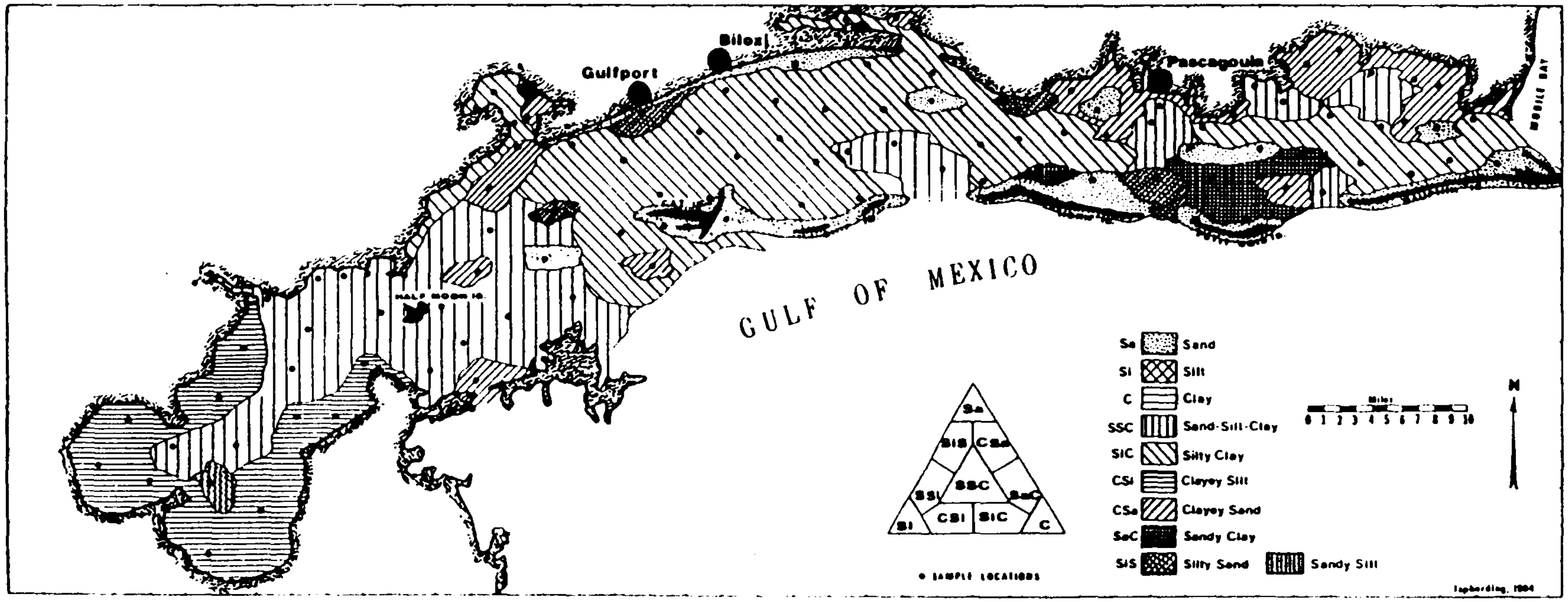


Figure 3.20 Bottom sediments: Mississippi Sound and adjacent areas. Source: Isphording, 1985 (in press).

in sufficient concentrations. These are ilmenite, rutile, kyanite, staurolite, zircon, monazite, and xenotite (Woolsey, 1984).

Most of the published sources related to the sediments of Mississippi Sound focus on portions of the Sound rather than the whole region. Significant amongst these are Otvos (1973), Reynolds and Thompson (1974), Snowden and Forsthoff (1976), and Isphording and Lamb (1980), Isphording et al. (1983). Comprehensive reports dealing with the Sound's sediments include Upshaw et al. (1966), Shaw et al. (1982), and Isphording (1985).

Mobile Bay

An average of 4.7 million metric tons of suspended sediment and an unknown amount of bedload is deposited annually into the Mobile Bay by the Mobile River system annually (U.S. Army Corps of Engineers, 1983). Ryan (1969) estimated that 1.4 million metric tons of the suspended portion bypass the Bay and mix with the shelf sediments seaward of the barrier islands. Minor sediment sources to the Bay are Dog River and Fowl River on the western Bay shore and Fish River and Magnolia River on the east.

The sediments in the northern portions of Mobile Bay are characterized as prodelta silts, clayey silts, delta front sands, and silty sands transported into the estuary by the Mobile River system distributaries (Figure 3.21). The Bay's periphery is a band of fine- to medium-grained quartzose sand with local concentrations of shell fragment, clay clasts, and heavy minerals. The central and southern portions of the Bay consist of varying amounts of silty clay and clay. The band of sand around the Bay margins results from sorting and winnowing of the fine fraction by wave action. Oyster reefs form significant features on the Bay bottom, with the largest live reefs located in the southwest. The clay minerals found in the Bay, in order of relative percentages, are approximately 60 percent smectite (montmorillonite), 27 percent kaolinite, and 13 percent clay mica (illite) (Isphording and Lamb, 1979).

Sedimentation rates average approximately 0.5 m per 100 years, but vary considerably within the Bay (Otvos, 1982). Rates in the upper Bay appear to be decreasing, probably due to the construction of impoundments (Otvos, 1982). An area north of Point Clear on the eastern shore and another east and south of Dauphin Island are subject to the greatest deposition (U.S. Army Corps of Engineers, 1983). There are several comprehensive studies available on the sediments of Mobile Bay, including Ryan (1969), May (1976), Isphording and Lamb (1979), Lamb (1979), and Isphording (1983).

3.3.5 DISTRIBUTION OF SURFACE SEDIMENTS ON THE SHELF AND SLOPE

The sediment types and distributions within the Tuscaloosa Trend study area are products of the Late Quaternary transgressive episode, relict features from lower sea level standstills, and Mississippi River deltaic growth and destruction. Figures 3.22 and 3.23 illustrate the broad sedimentologic subdivisions. Six broad sediment zones can be discerned: (1) the Mississippi prodelta facies; (2) the Chandeleur facies; (3) the St. Bernard prodelta facies; (4) the nearshore fine-grained facies; (5) the Mississippi-Alabama sand facies; and (6) the Mississippi-Alabama reef and interreef facies (Ludwick, 1964).

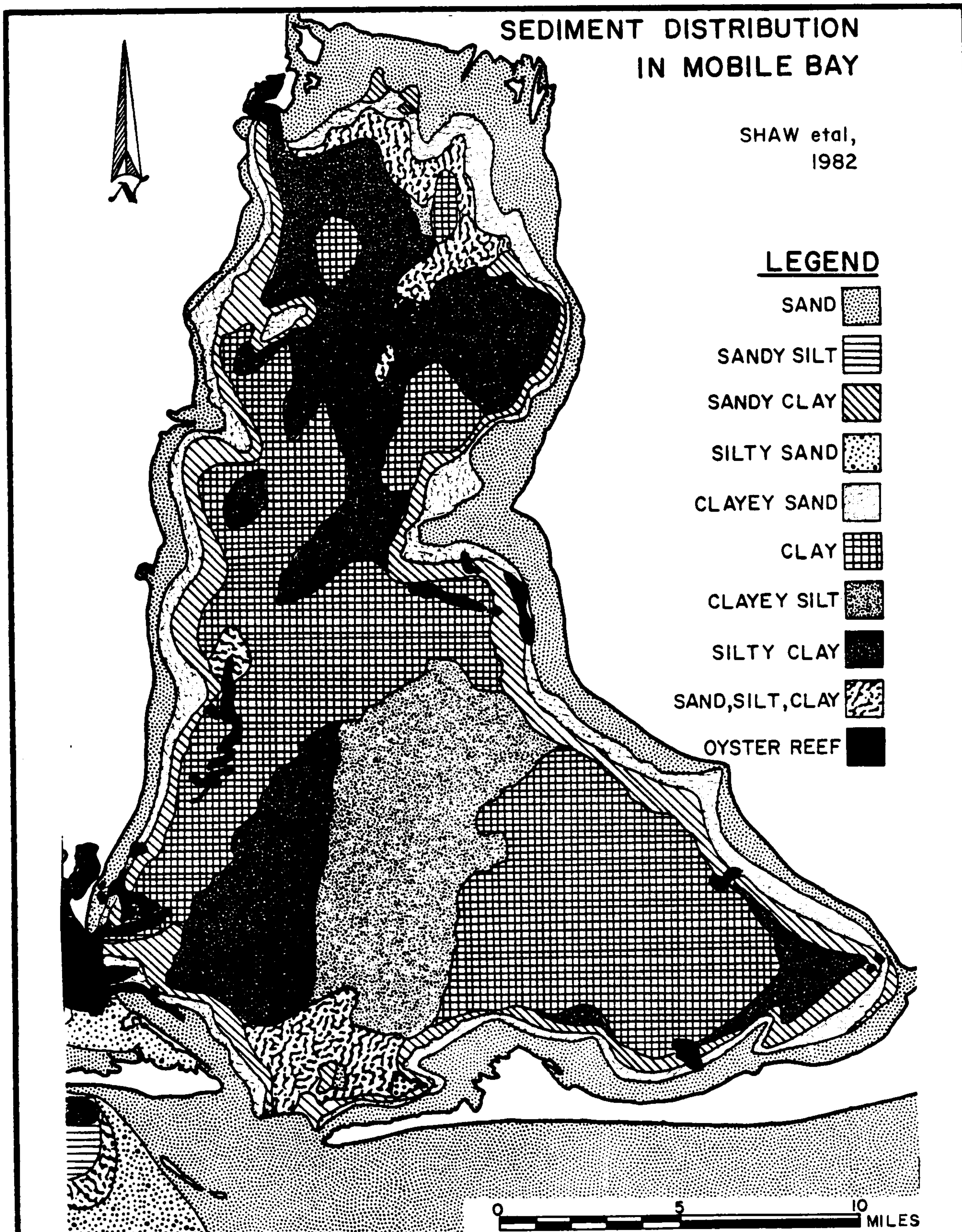


Figure 3.21 Sediment distribution in Mobile Bay. Source: Shaw et al., 1982; modified from Isphording and Lamb, 1979.

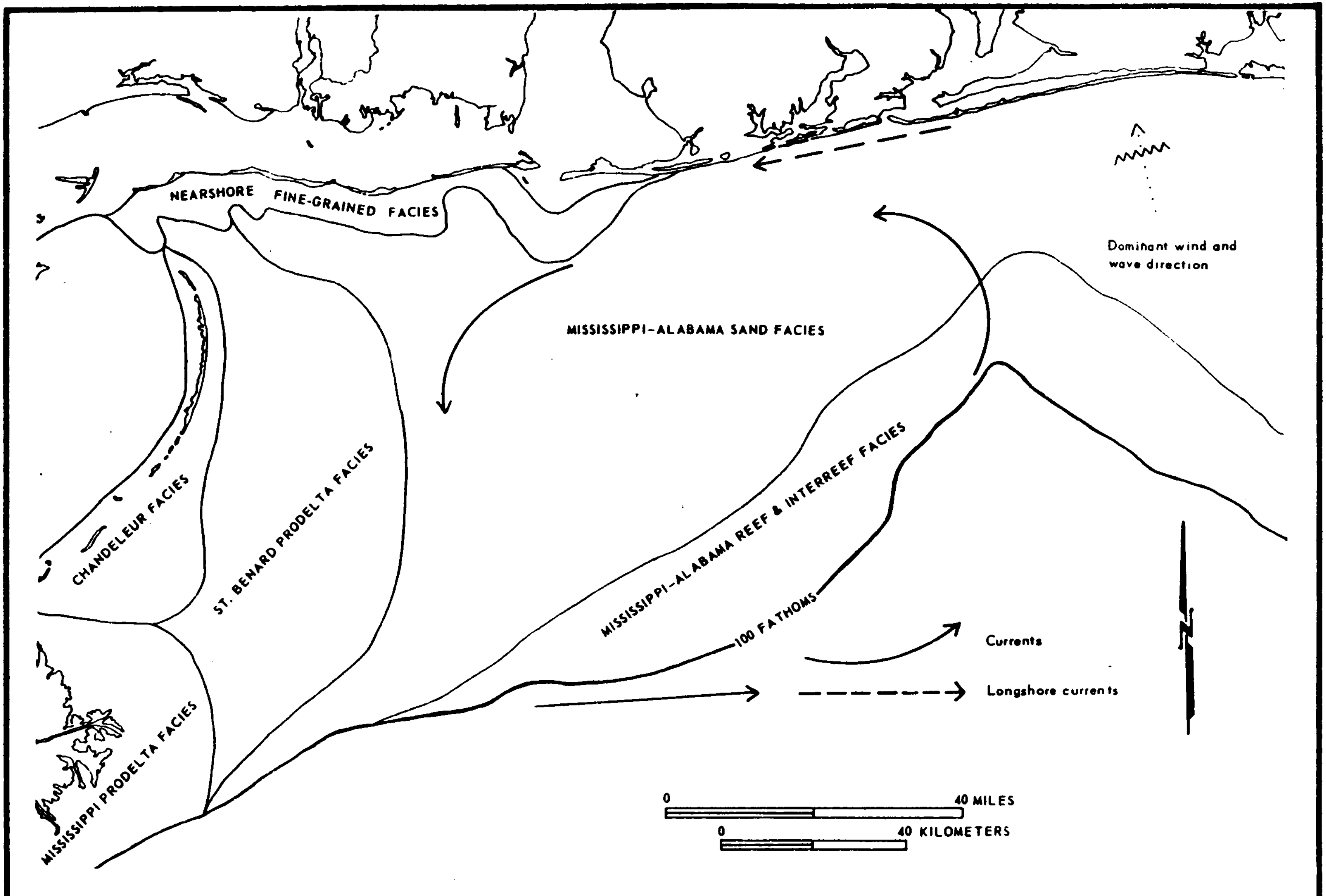


Figure 3.22 Mississippi-Alabama shelf sediment facies. Source: Boone (1973).

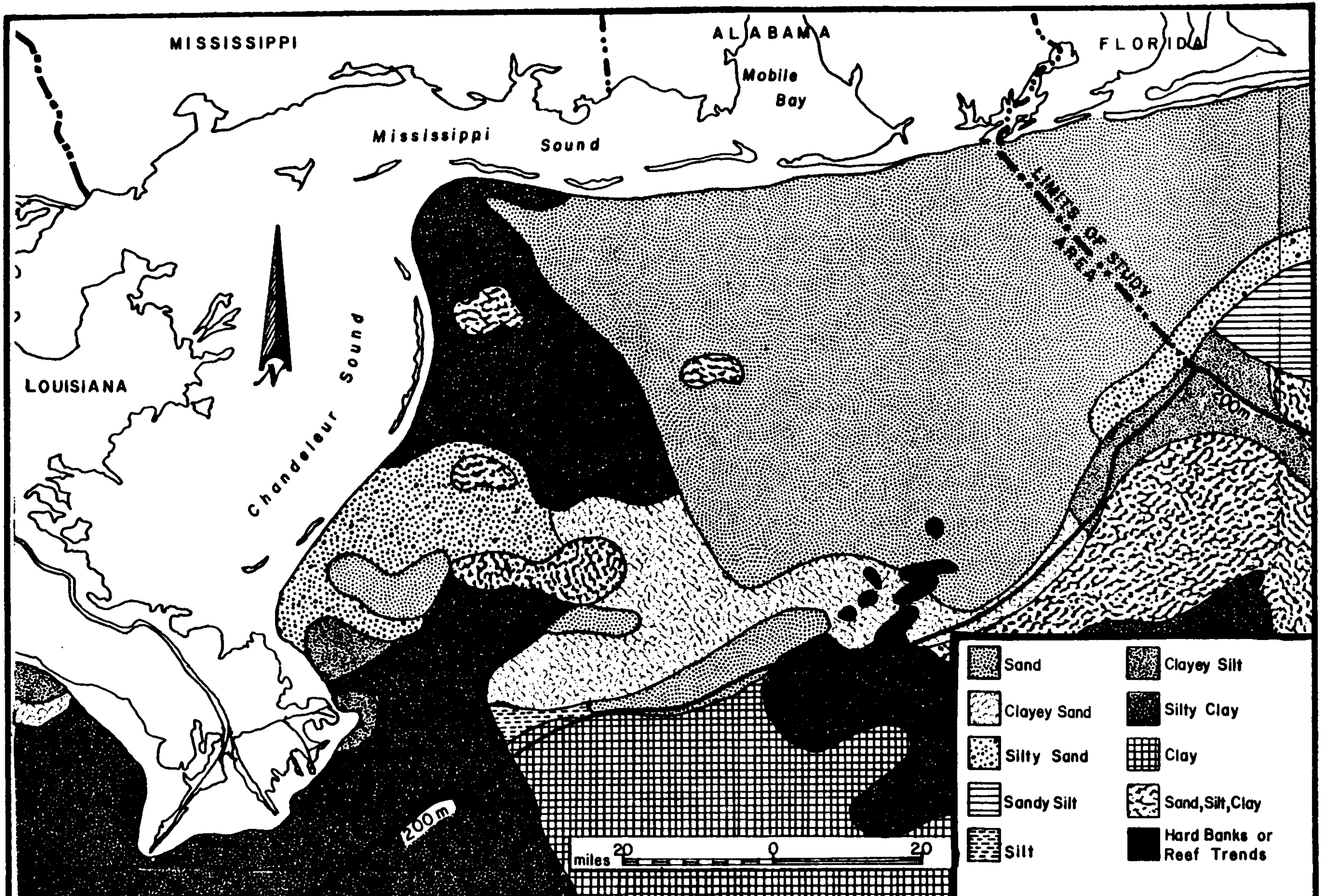


Figure 3.23 Bottom sediments within the Tuscaloosa Trend study area. Source: U.S. Department of the Interior, 1983.

Sediments within the Mississippi prodelta facies are rapidly deposited clay (predominantly smectite) and silt-size material rich in biologically derived organics. Most of this material is delivered directly to the shelf edge or is carried westward by a combination of the Coriolis effect, the longshore current system and the prevailing surface currents (Pyle et al., 1975). The sediment that is not transported seaward and westward forms a clastic wedge which projects onto the older sediments of the Chandeleur and St. Bernard prodelta facies.

The Chandeleur facies is located immediately north of the Mississippi prodelta facies and consists of well-sorted, fine-grained quartz sands. These sands are residuals from St. Bernard delta distributary mouth bar deposits that have been reworked by waves. The Chandeleur Islands represent the subaerial manifestations of these deposits.

The St. Bernard prodelta facies appears as a broad fan extending eastward from Breton Sound and overlying the older Mississippi-Alabama Sand Sheet (Shepard, 1956). Composed predominantly of clay and silt-size material, these facies represent the eastern limits of the now subsided St. Bernard delta complex. The St. Bernard facies is delineated on the east by a transition zone approximately four kilometers to six kilometers wide where it intermixes with the sands of the Mississippi-Alabama sand facies. Farther to the north the fine sands and silts emerging from Mobile Bay and Mississippi Sound that are transported westward by longshore currents intermingle with and mask the sediments of the St. Bernard facies.

The oldest clastic sediments blanketing the seafloor are the relict Late Quaternary sediments of the Mississippi-Alabama sand facies. The Mississippi-Alabama sand facies is characterized by well-sorted, fine-grained quartz sands, and locally shelly sands. Very little erosion and deposition is occurring in this area and thus some relict features and forms such as barrier beaches may be present. Ballard and Uchupi (1970) identified features southeast of Mobile Bay, Alabama along the 32 m isobath that resemble an ancient bay, barrier island and lagoon system. Elsewhere, south and east of Mobile Bay, the irregular, hummocky seafloor suggests very little deposition.

Sediment texture within the Mississippi-Alabama sand facies varies over short distances with variation in local bathymetry (Pyle et al., 1975). Consequently, the facies may be reasonably characterized by a range of grain sizes, but it is difficult or impossible to predict the sediment texture at a specific location. The heterogeneity of the sand sheet has been attributed to the complexities of the Holocene transgression with brief periods of regression, changes in transport direction, and the landward migration of a diverse system of coastal environments across the shelf (Swift et al., 1971). Products of these environments range from lagoonal shelly muds to clean, well-sorted beach sands and silty clays of the nearshore zone. Subsequent reworking of these sediments by waves aided by the burrowing activities of benthic organisms (bioturbation) has produced the heterogeneous qualities of the sand facies.

Generally, surface sediments of the Mississippi-Alabama sand facies are quartz sands with less than 25% carbonates. Van Andel (1960) and Fairbank (1962) identified the source area for the heavy minerals suite in the northeastern Gulf as the southern Appalachians. Diagnostic minerals in the suite are kyanite and staurolite with lesser amounts of zircon and tourmaline.

Doyle and Sparks (1980) also identified hematite, pyroxenes and amphiboles, which dominate the Mississippi River heavy mineral assemblage, and therefore suggest some contribution from the Mississippi River to the Mississippi-Alabama sand facies.

Southeast of the Mississippi-Alabama sand facies lies the Mississippi-Alabama reef and interreef facies (Figure 3.23). Adjacent to DeSoto Canyon, running along the shelf edge, the reef and interreef facies is a relict feature from when sea level was some 91 m lower than today. The reefs are topographic pinnacles averaging nine meters of relief, though the highest pinnacle rises 16.5 m above the seafloor. Ludwick (1964) separates the reefs into two complexes based on the range of depths where they formed. One zone occurs in depths from 22.5 to 28.0 m, while the other, deeper zone ranges from 32.3 to 36.5 m. Those reefs in the shallower zone are less continuous than the deeper reefs, though neither complex presents a continuous reef line. Gaps between the pinnacles are as much as 32 km wide. The reef area sediments are predominantly carbonate sands, while the interreef zones are composed of a more balanced mixture of sand, silt, and clay.

No truly comprehensive studies have been undertaken to characterize the relationships between the bottom sediments, hydrodynamic, and topographic features over the shelf and slope of the Tuscaloosa Trend study area. Ludwick (1964), Grady (1970), Pyle et al. (1975), and Dames & Moore (1979) offer the best overall view of the region.

3.3.6 GEOLOGIC PROCESSES ON THE OUTER CONTINENTAL SHELF AND SLOPE OF THE TUSCALOOSA TREND AREA

Geologic processes in the Tuscaloosa Trend occur on two broad time-scales. The longer scale involves the formation and movement of geologic structures such as salt domes and faults. The regional fault pattern is thought to be derived from the slow gravity creep of the thick accumulation of shelf sediments into the Gulf basin. Similarly, salt domes or diapirs are formed when thick salt layers are squeezed laterally under the tremendous weight of the overlying sediments. When the salt encounters faulted areas it rises along the faults, which are weakened zones, forming the domes and ridges evident today (Figure 3.24) (Antoine et al., 1974).

The second time-scale of geologic processes within the Tuscaloosa Trend occurs much more rapidly than those mentioned above. Geologic processes occurring on the delta front involve rapid changes in the bottom topography that have broken pipelines and toppled oil platforms (Handley, 1980). Identification of these geohazardous areas has been an important facet of research on the delta front and elsewhere on the outer continental shelf (Kindinger et al., 1982; Coleman et al., 1980).

Geological Processes Adjacent to the Mississippi River Delta

Dynamic geologic processes on the continental shelf adjacent to the active Mississippi River Delta (Balize Delta) result from the rapid deposition and vast accumulation of organic-rich sediments. As previously mentioned, the Mississippi River discharges 497 billion kilograms of sediment annually into the Gulf of Mexico (Rezak et al., 1983). The coarser material is deposited near the distributary mouths while the finer sediments are held in suspension

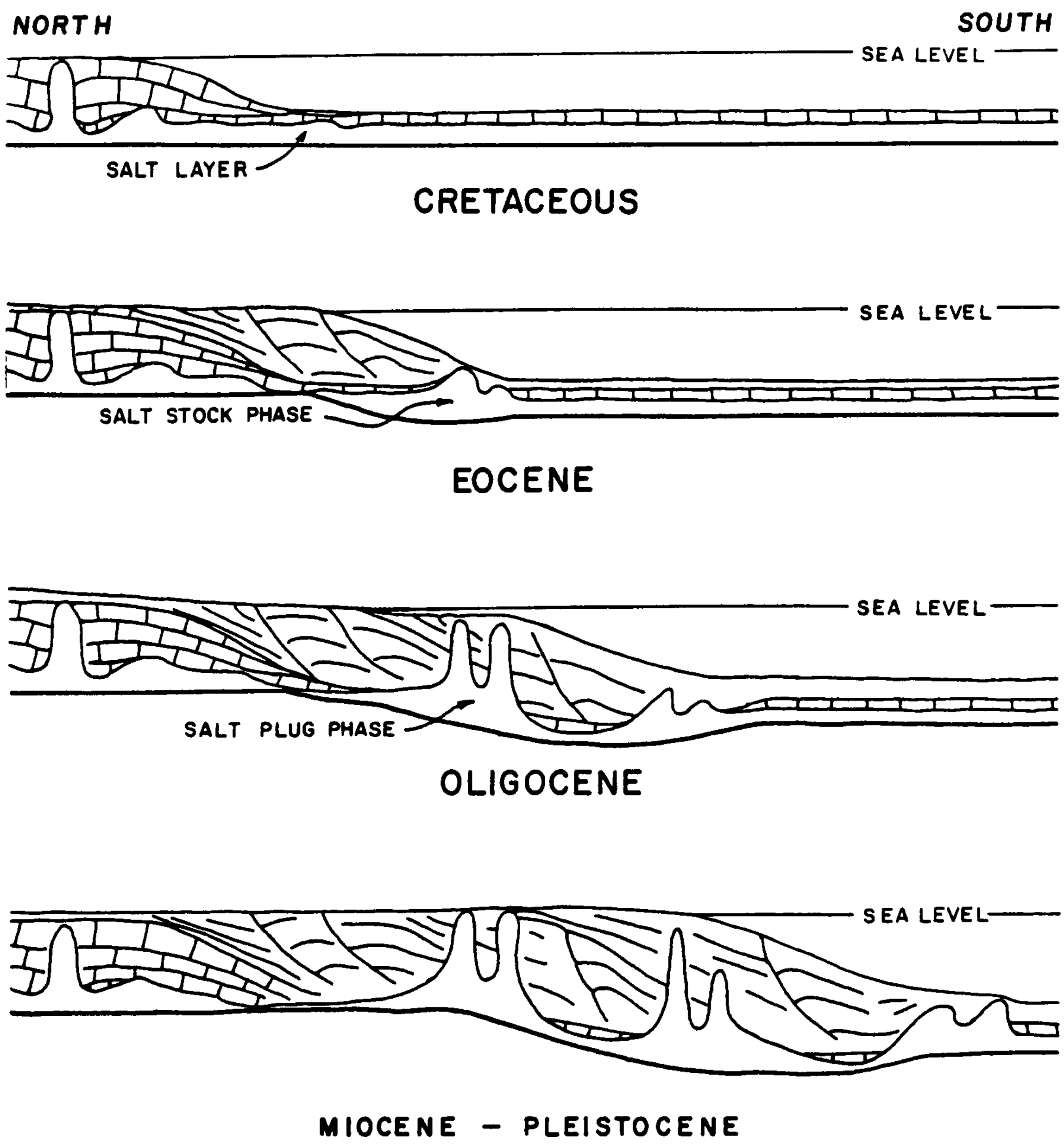


Figure 3.24 Hypothetical evolution of salt domes within the Gulf coast geosyncline. Source: Wilhelm and Ewing, 1972.

and spread laterally over a broad front. These finer, rapidly deposited materials have extremely high water contents and large amounts of fine-grained organics. Sedimentation rates vary seasonally at the delta front: they average one meter a year but accrete vertically as much as five meters during high flood stages. Delta progradation also varies, and has been recorded at greater than 100 m in a year and as little as 50 m (Coleman et al., 1980). The rapid accumulation and growth on the shelf has resulted in the formation of a complex and unstable bottom topography. As early as 1955, Shepard identified the dense network of submarine valleys radiating from the distributary mouths, and suggested the possible mass movement of sediment at the delta front.

One feature that has received considerable attention due to their sometimes dramatic appearances is the mudlump. The history and origins of mudlumps at South Pass have been extensively reviewed by Morgan et al. (1963), though mudlumps are features associated with Pass A Loutre, Northeast Pass, Southeast Pass, and Southwest Pass as well. The process of their formation relates to the prograding of the coarse-grained, heavier distributary mouth bar, channel and natural levee sediments over the fine-grained prodelta silts and clays. The added load of the heavier sediments results in lateral and vertical migration and squeezing of the clays. Vertical displacements have been known to reach 137 m (Gagliano and Van Beek, 1970). Most mudlumps exist as submarine features for a year or more before being uplifted as islands. Some never pierce the surface waters primarily because of erosion. Comparison of historic charts has revealed that several mudlump islands have persisted for more than fifty-five years at South Pass (Morgan et al., 1963). Eventually, wave attack or major storms reduce or obliterate the islands.

Coleman et al. (1980) identified six major types of mass movement and erosional features. These are: (1) collapse depressions and bottleneck slides; (2) peripheral rotational slides; (3) mudflow gullies; (4) erosional furrows; (5) faults; and (6) diapirs. Figure 3.25 illustrates schematically the relative positions of these features on the delta front.

Collapse depressions and bottleneck slides (Figure 3.26) form primarily in the shallow water areas (9-15 m) in front of interdistributary bays on bottom slopes varying from 0.1° to 0.4° (Coleman et al., 1980). Though the processes involved in their formation are the same, variation in morphology appears to be a function of slope. The features are more numerous in the low slope range; however, as the slope progressively steepens, bottleneck slides become more prevalent. Individually, collapse depressions are small features on the seafloor (36.5 to 152.4 m) with a 1.0 to 1.5 length-to-width ratio), but they tend to cluster in dense fields. Bottleneck slides exhibit narrow openings on their downslope sides through which the sediment debouches as a debris flow onto the adjacent, intact slope. Much more elongated than the collapse depressions, bottleneck slides range from 152.4 to 609.6 m from the headscarp to the base of the lobate depositional toe, and exhibit length-to-width ratios of 1.5 to 3.0. Total relief for both features can be as much as 2.7 m (Coleman et al., 1980).

Peripheral slides (Figure 3.19) are also located near distributary mouths though in shallower water than collapse depressions and on slopes ranging from 0.2° to 1.0°. Headscarps produced by these sediment movements may be one to two meters high, and often present a "stairstep" profile when there are multiple scarps. The shear planes typically penetrate 24.0 m to 33.5 m

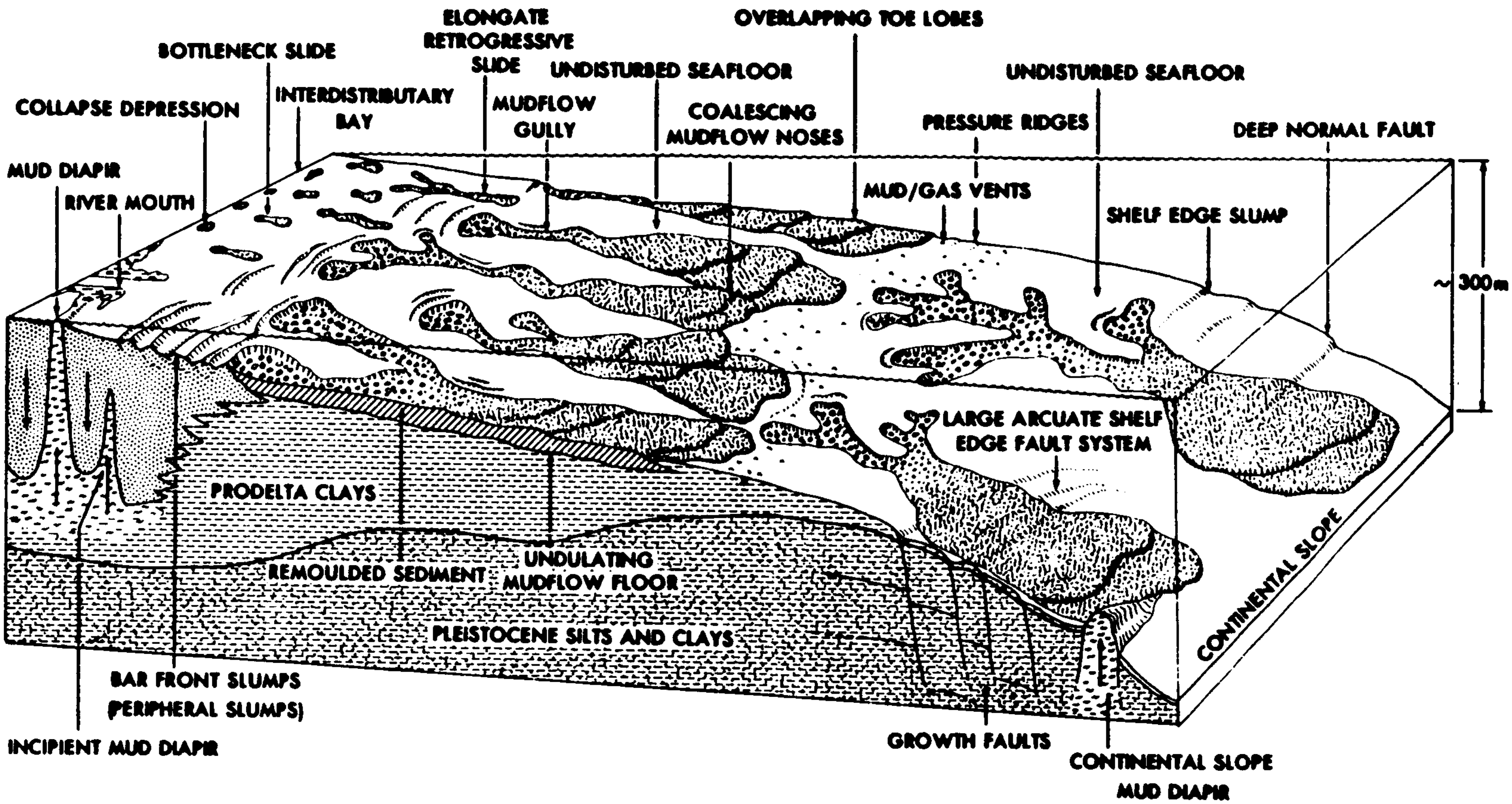
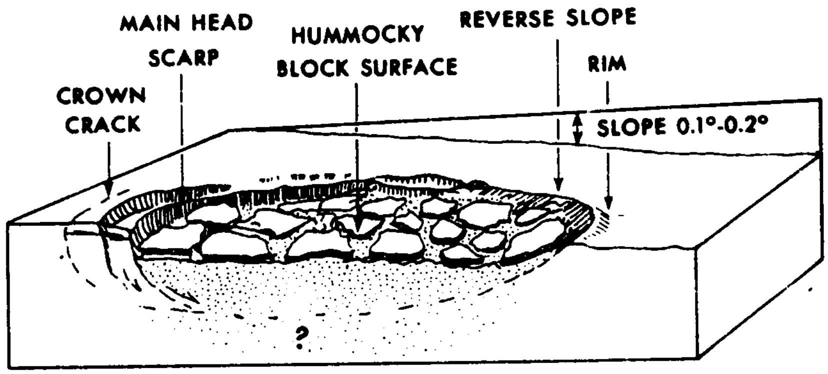
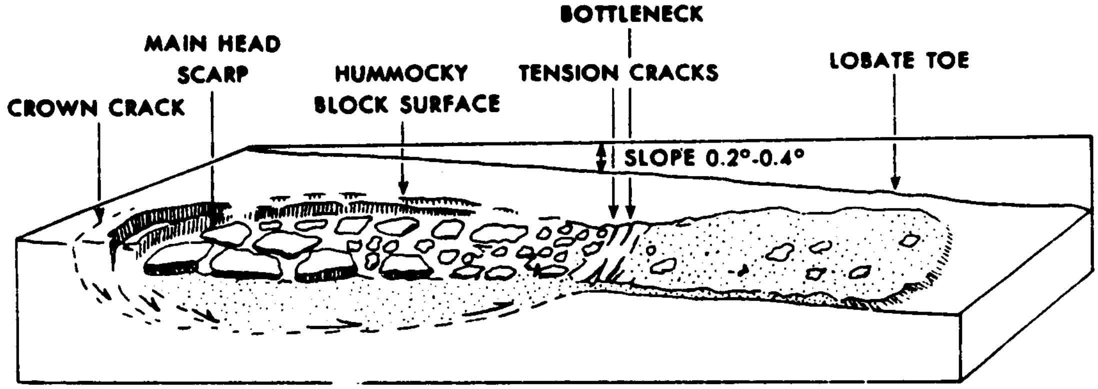


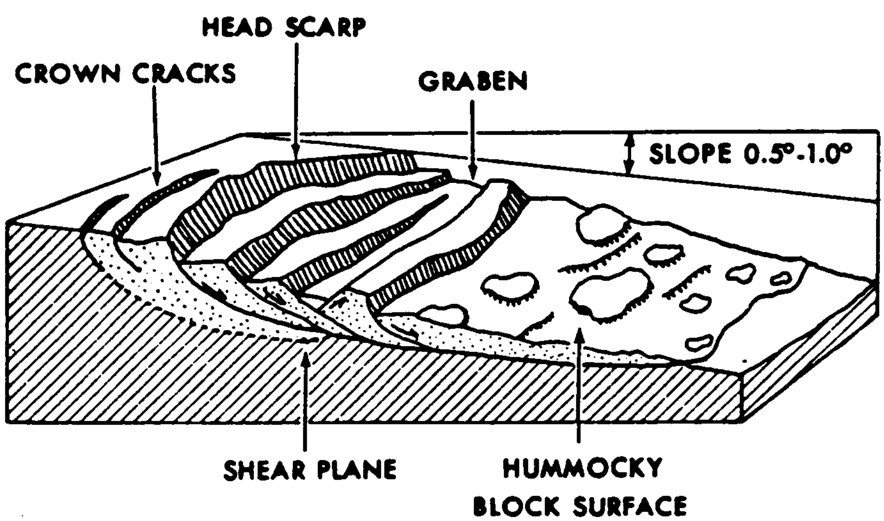
Figure 3.25 Schematic block diagram showing the relationship of the various types of subaqueous sediment instabilities. Source: Coleman et al. (1980).



Schematic diagram illustrating the morphology of collapse depressions. Stippled area represents disturbed sediments whose depth is unknown.



Schematic diagram illustrating the morphology of bottleneck slides. Stippled areas represent disturbed sediment.



Schematic diagram illustrating the morphology of rotational peripheral slides. Stippled areas represent disturbed sediment.

Figure 3.26 Morphology of selected delta front features. Source: Coleman et al. (1980).

beneath the seafloor. Downslope movements are episodic, but return surveys indicate that sliding may be at rates greater than 1.6 km in a year (Coleman et al., 1980).

The most numerous and aerially extensive instability features recognized along the delta front are the mudflow or delta front gullies (Figure 3.27). Identified by Shepard (1955), they form in water depths from 6 to 91 m. Mudflow gullies are somewhat sinuous, generally trend downslope perpendicular to the bottom contours, and may extend for more than 9.6 km down the shelf. Regionally, a set of mudflow gullies presents a radial pattern. Complex tributary systems will often form in shallow water when adjacent gullies coalesce. Both relief and sideslope angles in the gullies vary; relief ranges from 3 to 18 m and sideslope angles are found to vary from 1° to 19° (Coleman et al., 1980).

Material is transported through the gully system as a slurry, sometimes overflowing its banks to form levees, and is finally deposited as a toe or fan at the seaward mouth of the valley. The depositional lobes appear as broad, flat (<0.50°), overlapping fans with steep distal scarps (7° to 10°). Scarps thus formed may be only a meter high; however, scarps greater than 23 m high have been recorded (Coleman et al., 1980). Mudflow gullies are so numerous along sections of the delta front that the depositional fans of adjacent gullies sometimes join, producing a continuous escarpment skirting the contours.

Mudflow movement rates and sideslope growth have not been well documented, but activity is episodic. Gullies widen by sideslope slumping, producing slump blocks that are then transported through the system in a laminarly flowing slurry. Each active episode deposits material onto previously deposited lobes. These accumulated lobes will at times over-steepen and slide further down the shelf until the sediment degasses, releases internally held water, and encounters low slope angles on stable shelf material. Return surveys performed by the U.S. Geological Survey recorded that seaward advances approach 914 m in one year (Coleman et al., 1980).

Erosional furrows are deep-water features which have been detected seaward of South Pass and Pass A Loutre, radiating into topographic lows and large valley reentrants (Coleman et al., 1980). These features, up to 4.8 km long, trend perpendicular to the bottom contours in depths ranging from 122 m to greater than 396 m. Widths range from 9 to 24 m and they may be 9.0 to 2.7 m deep. Erosional furrows are probably scoured by bottom currents, but their origins are still uncertain.

Escarpments are present that are surface expressions of growth faults. Growth faults (also called contemporaneous faults) are common features on the upper continental slope (Watkins and Kraft, 1978). They are characterized by progressively greater offset with depth, which is indicative of continual movement. Shear surfaces are well-defined and linear to concave upward at angles from 20° to 45°. Geophysical surveys reveal that in most instances faulting began during the late Pleistocene and has continued to the present. When scarps are absent, sedimentation rates have kept pace with fault movement. Folded strata are often found in the vicinity of contemporaneous faults and are sometimes evident as swells on bathymetric profiles.

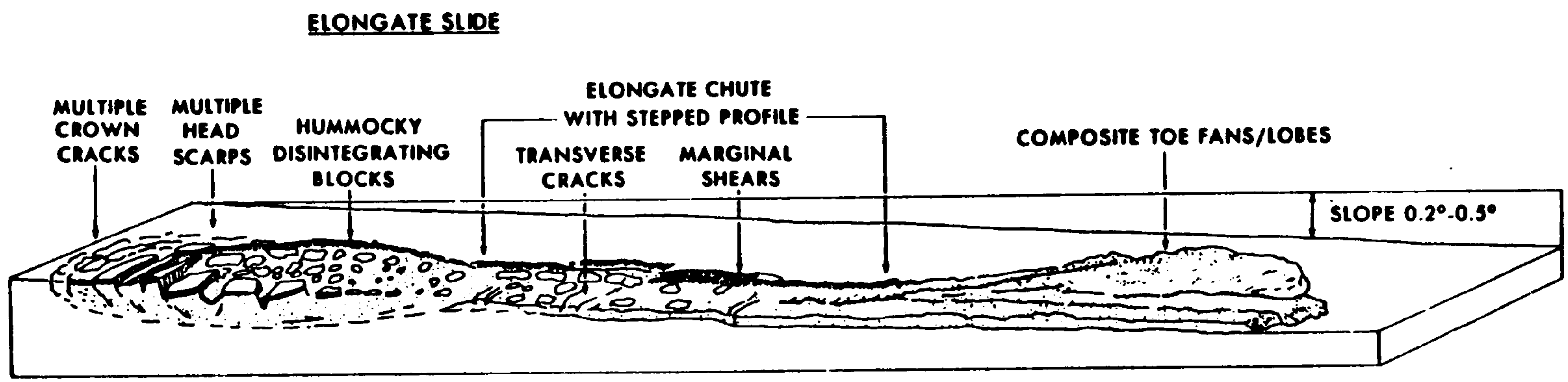


Figure 3.27 Schematic diagram illustrating the morphology of mudflow gullies and depositional mudflow lobes. Stippled areas represent disturbed sediment. Source: Coleman et al. (1980).

The mechanisms which drive and initiate the movement and formation of these features are only partially understood. The sediments involved are intrinsically unstable fine-grained sands, silts and clays, with high water content and large quantitites of interstitial gas. The gasses, primarily methane and carbon dioxide, result from the degradation of organic material. As the delta has prograded out onto the continental slope, more sediment is deposited to compensate for the increased gradient and water depth. These circumstances create a general oversteepening of the upper delta front which makes the slope highly susceptible to overloading mechanisms such as are generated by the high amplitude waves associated with the passage of major storms and internal waves (Watkins and Kraft, 1978). However, faulting, excessive local accumulations of sediment, and the over-extension of slopes are also potential mechanisms for the initiation of sediment motion. Once initiated, gravity is the force that transports the material to lower gradients on more stable seafloors.

There have been numerous excellent papers published describing subaqueous features and processes associated with the Mississippi River Delta. Significant amongst these are Morgan et al. (1963), Gagliano and Van Beek (1970), Whelan et al. (1975), Watkins and Kraft (1978), Prior and Coleman (1978, 1980, 1982), Prior and Suhayda (1979), and Coleman et al. (1980).

Evidence of Geologic Processes on the Outer Continental Shelf and Slope of Mississippi and Alabama

Moving away from the highly dynamic deltaic region, the driving geologic processes become less apparent. Sediment transport on the open outer continental shelf and slope is driven by broad regional oceanic currents, shelf edge slumping, and perhaps most importantly, by storm events such as hurricanes (Swift et al., 1971). Evidence of bottom sediment transport is found in the bedforms identified on the shelf (Pyle et al., 1975). The unconsolidated sediments on the ocean floor respond to hydrodynamic forces by forming features such as ripples, dunes, and sand waves. Under ideal laboratory conditions the types and magnitudes of the features can be quantitatively related to the forces that formed them. The seafloor does not present ideal conditions of interpreting ongoing hydrodynamic forces. Nonetheless, the presence, orientation, and magnitude of bottom features does provide clues to the types of forces active on the continental shelf (Pyle et al., 1975).

Hydrodynamic forces active on the shelf are derived from meteorological disturbances, tides, density currents, and the intrusion of regional oceanic currents (Figure 3.28) (Swift et al., 1971). These forces may act singularly or in combination to generate sufficient energy to produce bedforms. Strong frontal storms and hurricanes can generate waves of such magnitude to impact the shelf floor. Curray (1960) calculated that fine sands on the shelf edge of the northwestern Gulf are disturbed by hurricane-generated waves approximately once every five years. The intrusion of the eastern Gulf of Mexico Loop current may also influence the formation of bedforms, but the degree of influence is still speculative. Currents ranging from 50 to 100 $cm \cdot sec^{-1}$ are required to form the majority of bedforms on the shelf (Pyle et al., 1975).

The Bureau of Land Management MAFLA (Mississippi-Alabama-Florida) baseline monitoring studies (Pyle et al., 1975) recorded bedforms within the Tuscaloosa Trend area along several transects (Figure 3.29), and constructed a

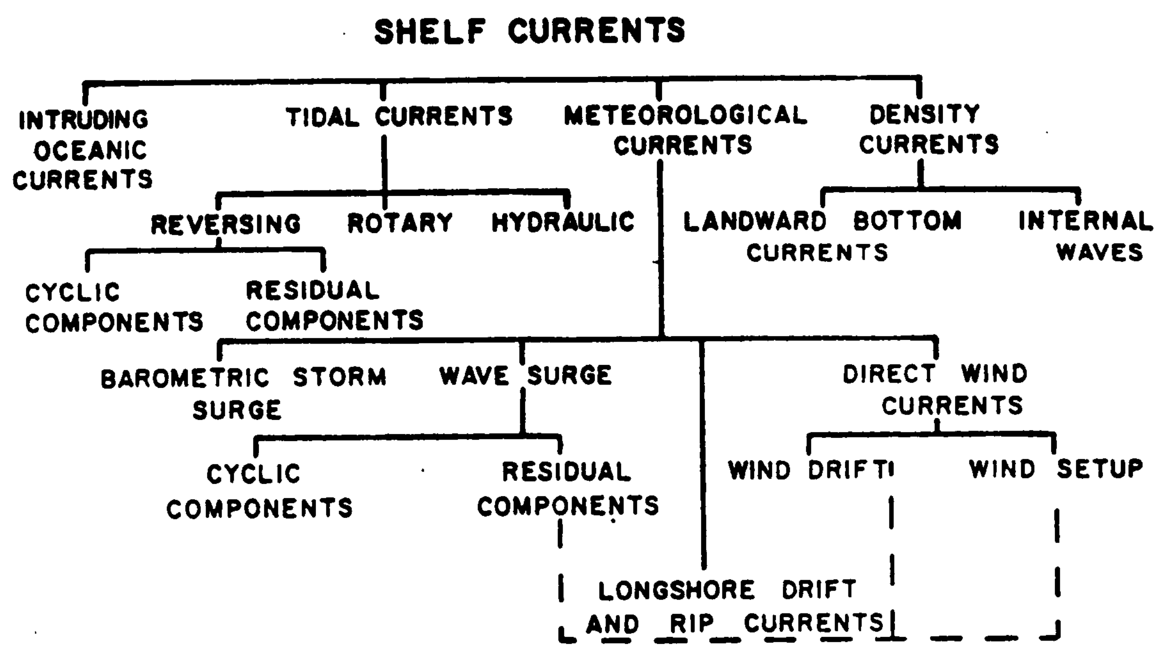


Figure 3.28 Components of the shelf velocity field.
Source: Swift et al., 1971.

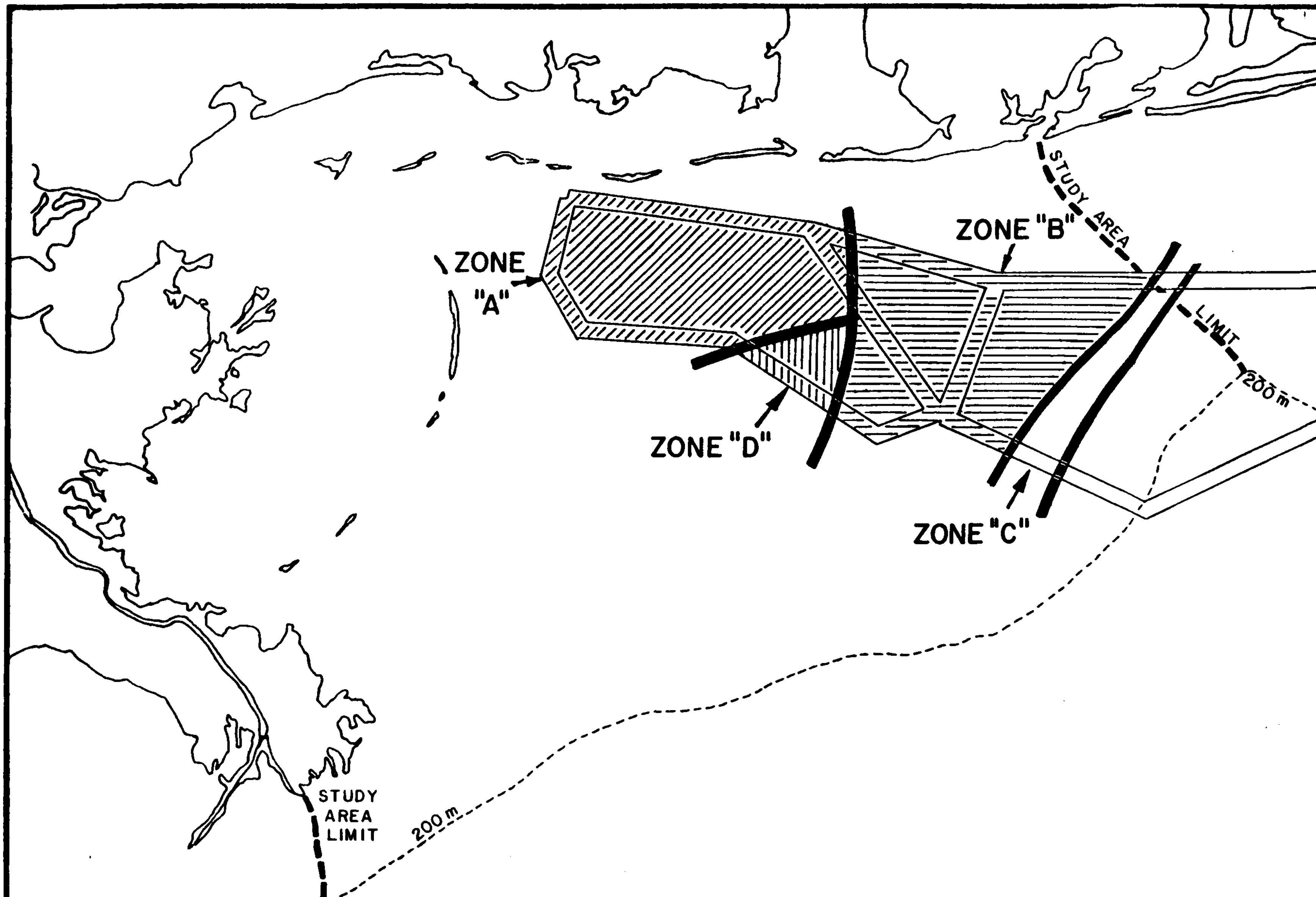


Figure 3.29 Bedform distribution identified during the MAFLA study. Source: Modified from Pyle et al., 1975.

general description of the bedform distribution. Four zones were identified based on the occurrence and distribution of bedforms. Zone A is an area south of Mobile Bay which extends westward to the Chandeleur Islands. The seafloor in the southern portions registered as an essentially flat surface lacking bedforms except for some low relief swells. Bioturbation may be responsible for destroying any smaller scale bedforms that may have formed on the swells. Further north, however, large sand waves and areas of low relief swells, giant sand waves, and irregular hummocky topography were recorded. Zone B encompasses a broad area between Pensacola, Florida and Mobile, Alabama and exhibits irregular hummocky topography with numerous patches of smooth seafloor. The frequency of the smooth bottom areas increases northward. However, scattered areas of reticulated bottom occur in topographic lows. Zone C is a transitional area consisting of combinations of bedforms: low relief swells characterize the southern portions and small sand waves dominate in the north. Zone D is south of Mobile Bay and is characterized by areas of smooth seafloor, low relief swells and irregular hummocky topography (Pyle et al., 1975).

3.3.7 AREAS EXHIBITING POTENTIALLY HAZARDOUS FOUNDATION CONDITIONS

Generally, the Tuscaloosa Trend study area outside the immediate vicinity of the recent Mississippi River deltaic deposits and the region along the shelf break shows little evidence of features associated with unstable foundation conditions. Nonetheless, certain geologic features and conditions which have been identified as presenting operational constraints related to seafloor stability are present in the study area. Diapirism, which has been briefly reviewed earlier, is associated with shallow faulting, steep, unstable slopes, gas seepage, and peripheral sediment slumping. The deep accumulations of sediment along the shelf break and the gradual downslope movement produces sediment overloading, differential compaction and resulting growth faults (down-to-the-basin faults), and local subsidence. The rapid sedimentation rates such as those presently occurring in front of the Mississippi River delta create a seafloor characterized by fine-grained, unconsolidated sediments with high water and gas contents that are inherently unstable. Coleman et al. (1980) have provided an excellent regional overview with maps of the delta front areas subject to unstable foundation conditions and mass wasting. Some of the conditions found on the delta front are, to a lesser degree, evident elsewhere in the study area. Kindinger et al. (1982) identified a large area seaward of the Chandeleur Islands where shallow interstitial gas has formed in prodelta sediments of the abandoned St. Bernard delta (Figure 3.30). Brande (1983) identified shallow gas deposits in Mobile Bay but these sediments have not been evaluated for geohazardous potential.

Buried stream channels have also been cited as presenting potential technical problems in establishing exploration platforms (Kindinger et al., 1982). Buried stream channels are characterized by highly variable sediment textures over short distances, and thus may present similarly varying load-bearing properties. Channel fill may also act as reservoirs for biogenic gas accumulations. Several buried stream channels have been located southeast of Mobile Bay (Pyle et al., 1975). Kindinger et al. (1982) identified a set of stream channel deposits dating from the break between the Pleistocene and the Holocene in the vicinity of the abandoned St. Bernard Delta. Ballard and Uchupi (1970), and Mazzullo (Jim Mazzullo, Texas A&M University, Dept. of

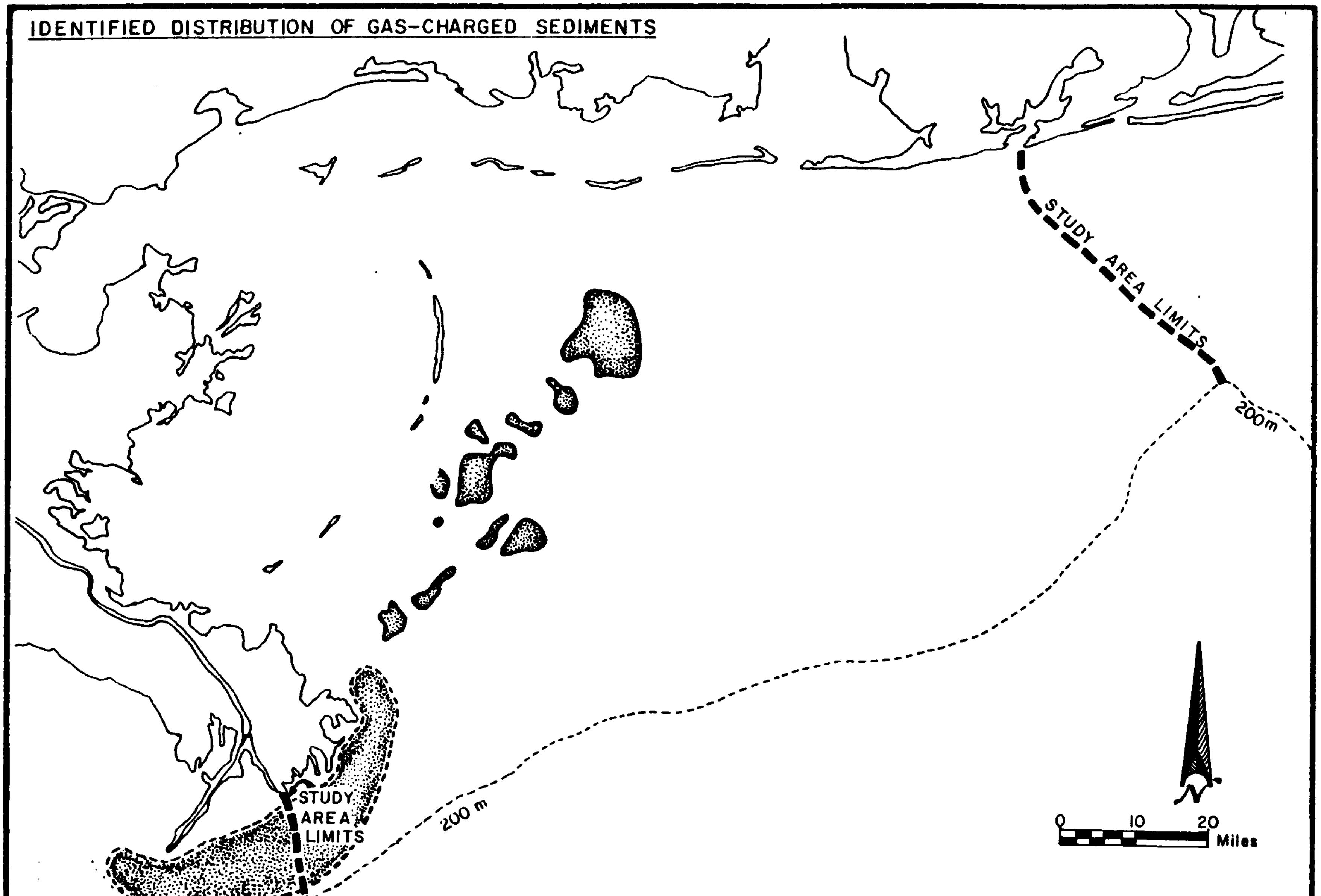


Figure 3.30 Identified distribution of gas-charged sediments, OCS, within the Tuscaloosa Trend study area. Source: Modified from Kindinger et al. (1982) and Coleman et al. (1980).

Geology, personal communication) have identified ancient river systems on the Mississippi-Alabama Shelf.

The shelf break between the Mississippi River Delta and DeSoto Canyon exhibits traits that indicate that it may be susceptible to mass wasting. Seismic reflection data collected during the Mississippi-Alabama-Florida baseline monitoring studies (Pyle et al., 1975) revealed a highly faulted area with disturbed bedding south of Mobile Bay on the shelf break and slope. Well-developed slump structures were identified further east adjacent to DeSoto Canyon, as well. Kindinger et al. (1982) identified numerous faults, complex graben systems, and six diapiric structures along the shelf break and slope east of the Mississippi River Delta. The topographic relief of the diapiric features ranges from 15 m to around 100 m.

3.3.8 DATA GAPS

Reviewing the numbers and types of studies that have been conducted within the Tuscaloosa Trend area, research gaps become readily apparent. The great amount of research within the deltaic and nearshore zones far outweighs in both number and intensity any efforts on the outer shelf. In order to alleviate this situation we suggest initiating studies in the following areas:

(1) The Minerals Management Service's Marine Geologic Atlas Series should be extended to include the remaining areas within the Tuscaloosa Trend.

(2) Efforts should be made to better define the hydrodynamic mechanisms within the Tuscaloosa Trend which influence sediment transport both nearshore and in deep water.

(3) Areas where there are potentially hazardous foundations for petroleum exploration and production, structures and pipelines need to be well documented. Geologic features meriting special attention include: (1) gas at shallow depth; (2) buried stream channels; (3) active faults; (4) surficial and shallow deformation including slumping and creep; and (5) diapirs and faulting.

(4) Detailed study of the Chandeleur Souhd, Breton Sound, and the adjacent continental shelf should be conducted, and should include sediment distribution mapping, bathymetric surveys, and subbottom profiles.

4.0 PHYSICAL OCEANOGRAPHY

4.1 INTRODUCTION

The mass circulation characteristics of the inshore and continental shelf waters which occupy the Tuscaloosa Trend study area are determined by a combination of meteorological, continental, and oceanographic factors that operate within the constraints of the local topography and basin configuration. The following account of the physical oceanographic conditions within the study area is based on available information that presents a general understanding of this dynamic system

The physical oceanographic information is presented in two categories -- meteorological/hydrographic conditions and circulation patterns. The meteorological and hydrographic conditions represent the basic driving forces for the circulation process. They include climatic features (e.g., atmospheric pressure, air temperature, winds), astronomic tides, waves, freshwater discharge, water temperature, salinity, and density distribution. Discussions of circulation or water movement include Gulf and continental shelf circulation, shelf and inshore (Mississippi and Breton-Chandeleur Sounds) currents.

4.2 METEOROLOGICAL CONDITIONS

4.2.1 CLIMATIC CYCLE

The climatic regimes that affect the northern Gulf of Mexico are shown in Figure 4.1. The subtropical anticyclonic Bermuda High exerts the greatest influence on the climate of the Tuscaloosa Trend region. The Bermuda High intensifies during spring and extends its boundaries into the Gulf of Mexico region. This extension into the Gulf results in a shift in the source direction of the winds to the southeast and south. The wind speeds are much less and more persistent than those of the winter and fall.

The Bermuda High diminishes in strength in early fall, and its boundary of influence retreats from the Gulf region. Simultaneously with this southeastward withdrawal of the Bermuda High is a southward advance of the continental pressure systems over the Gulf. As a result, the predominant winds become northerlies.

Westerly systems during winter influence the study areas as cold fronts from the northwest move southward over the Gulf of Mexico. When these cold fronts, modified by the relatively warm Gulf and coastal waters, oppose strong maritime tropical air moving in the opposite direction, the front may become stationary. Under these conditions, the coastal area becomes subject to cyclogenesis resulting in low cloud ceilings and precipitation. Because of the large heat storage capacity of water and the size of the Gulf of Mexico, the Gulf greatly influences the predominant year-round maritime tropical climate of the northern Gulf coast.

4.2.2 BAROMETRIC PRESSURE

During the summer, the average monthly barometric pressure ranges from 1014 hPa (millibars) in the western Gulf to 1016 hPa in the eastern portions of the Gulf. Maximum winter pressures average 1021 hPa. The lower

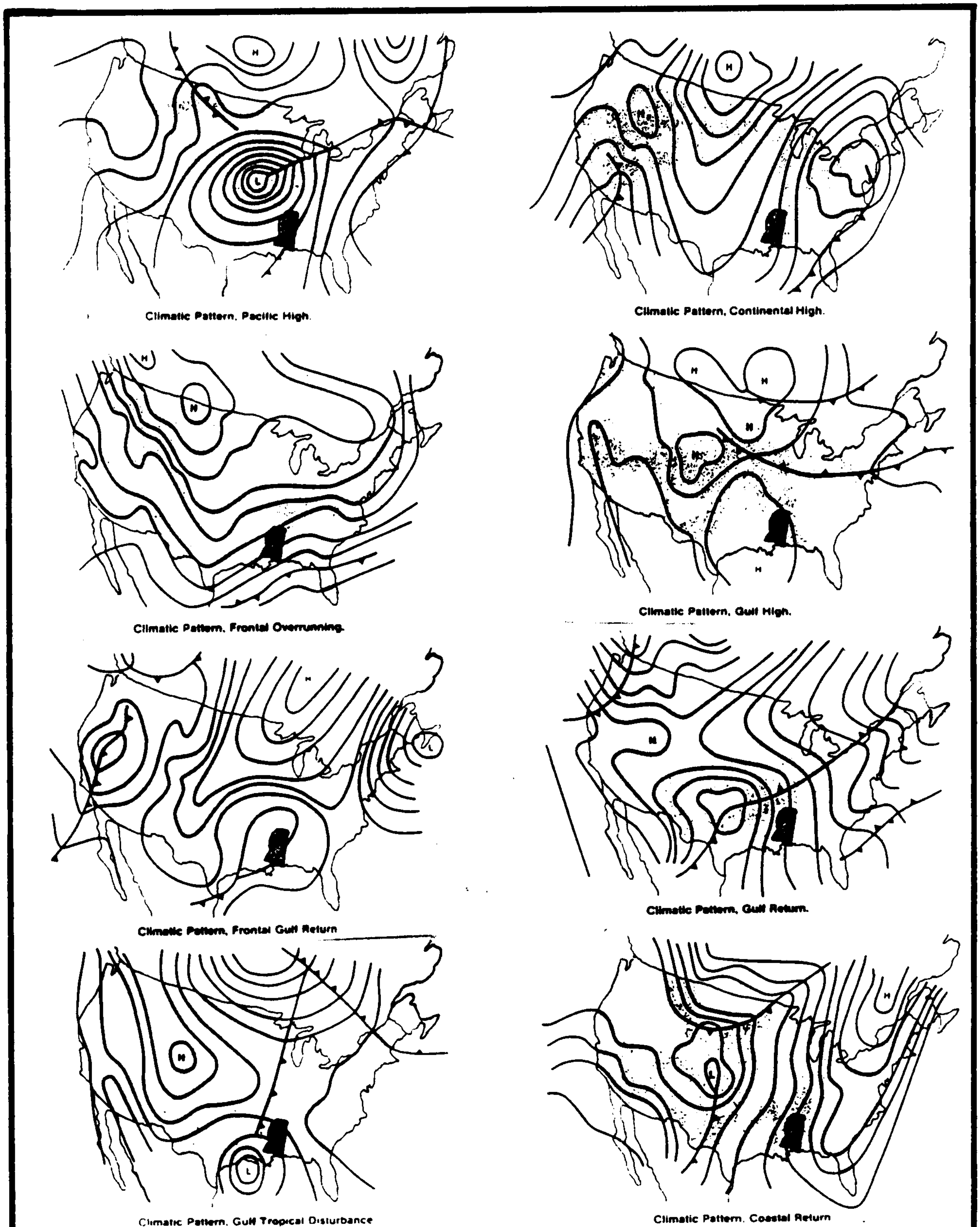


Figure 4.1 General climatic patterns for the continental United States (Source: Eleuterius and Beaugez, 1979).

summer pressure reflects the northward migration of the equatorial trough (Eleuterius and Beaugez, 1979). Based on the results of data from meteorological stations located along the Mississippi Sound barrier islands in 1980-81 (Kjerfve and Sneed, 1984), winter atmospheric pressures showed a mean of 1019 hPa, while in spring and summer mean pressures decreased to 1013-1014 hPa and 1011-1013 hPa, respectively.

4.2.3 AIR TEMPERATURE

Air temperature variations along the Gulf of Mexico are related to latitude and proximity to the Gulf. The average summer temperature over the center of the Gulf is about 29°C, compared with winter averages ranging from 17° to 23°C. Summer temperatures are moderated by seabreezes, while winter temperatures are dependent on the frequency and intensity of penetration by polar air masses, which may occur 15-20 times between November and March. The open Gulf experiences less temperature variation than the coastal areas.

4.2.4 HUMIDITY AND PRECIPITATION

The relative humidity over the northern Gulf of Mexico remains high throughout the year. Lowest relative humidities occur in the late fall and winter, responding to the incursions of cold, dry continental air masses. Maximum humidities persist during the spring and summer months when the Bermuda High dominates the air circulation.

Annual coastal precipitation within the study area averages 137 cm at New Orleans, 148.8 cm at Biloxi, and about 162.5 cm at Mobile. Rainfall throughout the northern Gulf is fairly evenly distributed, exhibiting summertime peaks, with the least precipitation occurring in the fall. The summer rainfall is characterized by convective, mainly afternoon thundershowers and occasional tropical influences. Maximum rainfall rates for the northern Gulf coast occur in July. Wintertime rainfall is generally associated with frontal passages and is usually slow, steady, and nearly continuous events, sometimes persisting for several days. Frozen precipitation is rare, but when it does occur it usually melts upon ground contact.

Widespread fog is produced when warm, moist, Gulf air overrides cooler water and land areas. Fog generally forms at the land-water interface margin, but offshore fog may restrict visibility to less than one-half mile. Coastal fog lasts three or four hours generally, but dense sea fogs may persist for several days. These widespread fog conditions develop with greatest frequency in the winter and spring when the land-sea temperature contrasts are greatest (Eleuterius and Beaugez, 1979).

4.2.5 WIND

Wind is a primary force in non-tidal circulation of estuarine and continental shelf waters. The influence of high winds on the physical environment of the study area includes circulation patterns (wind-stress), modification of water levels, shoreline erosion, disruption of vertical and horizontal gradients, and transport of suspended material.

The prevailing surface winds offshore are southerly for March through August, easterly for September through December, and northerly for January and February (National Data Buoy Center, 1973). Representative distributions of wind direction and velocity are presented in Figure 4-2 from data collected at offshore hydrographic stations between 88° and 89°W longitude (Thompson and Leming, 1978). Highest winds occur from June through November with the passing of hurricanes. Although subtropical air dominates the study area during most of the year, approximately 15-20 frontal systems penetrate the Gulf from October to March, bringing cold air and strong predominantly northerly winds with velocities that may exceed 25 to 30 knots.

4.2.6 TROPICAL STORMS

Hurricanes are the most dramatic and are generally perceived as the most dangerous weather phenomena associated with the Gulf of Mexico. A hurricane is a tropical cyclone with winds attaining 300 $km \cdot hr^{-1}$. A tropical cyclone with winds below this value may be classified a tropical storm (63 to 117 $km \cdot hr^{-1}$) or a tropical depression (61 $km \cdot hr^{-1}$ or less). The storm's energy is generated from the latent heat of water vapor condensation over the warm Gulf, Caribbean, or Atlantic waters. The feature thus generated is, in essence, a large-scale, non-frontal, low pressure weather system that may be hundreds of miles in diameter. Several patterns of hurricane routes have been identified with early season storms generally approaching from the southeast while later in the year they tend to approach from the south. Most hurricanes form in tropical zones between 8° and 15°N latitude. Sea surface temperatures in these regions are high, barometric pressures are low, and the Coriolis force is sufficient to initiate a vortex around the low pressure center. The hurricane season in the Gulf of Mexico runs from June through October, though they are most frequent in September (Figure 4.3). The late summer storms tend to form in the eastern Atlantic near the Cape Verde Islands, as opposed to the June and July storms which tend to develop in the western Atlantic and Caribbean. However, from 1901-1971, seven hurricanes and an additional seven tropical storms developed in the Gulf of Mexico north of 25°N and east of 85°W (MMS, 1983).

The tremendous destruction caused by hurricanes and the presence of hurricane-spawned tornadoes is derived from three storm components: wind, flood, and storm surge. The surge may attain heights of greater than 4.5 m above normal sea level and is further enhanced by storm waves. Greatest storm surge heights develop in the right front quadrant of hurricanes. Several factors contribute to the magnitude of the storm surge, including the angle of incidence of the landfall. A direct 90° approach angle generates greater surges than a more oblique angle. Additional factors include seafloor topography near the shore, the normal tide phase, and the coastline shape (Dewald, 1980). Figure 4.4 depicts the effects of high winds and storm surge on the water level in Mississippi Sound (Eleuterius and Beaugez, 1979).

The destruction caused by hurricanes is devastating. The most recent significant hurricanes occurring within the study area were Hurricanes Camille and Frederic. Hurricane Camille, one of the most powerful storms that has entered the Gulf, made landfall on the Mississippi coast in 1969, hurling at least a 7.2 m (24 ft.) storm surge and killing 262 people. Hurricane Allen in 1980 is rated more powerful because of 898 hPa central pressure. Hurricane Frederic, which hit Mobile, Alabama in 1979, was one of the most financially destructive storms, causing $2.3 billion in damages.

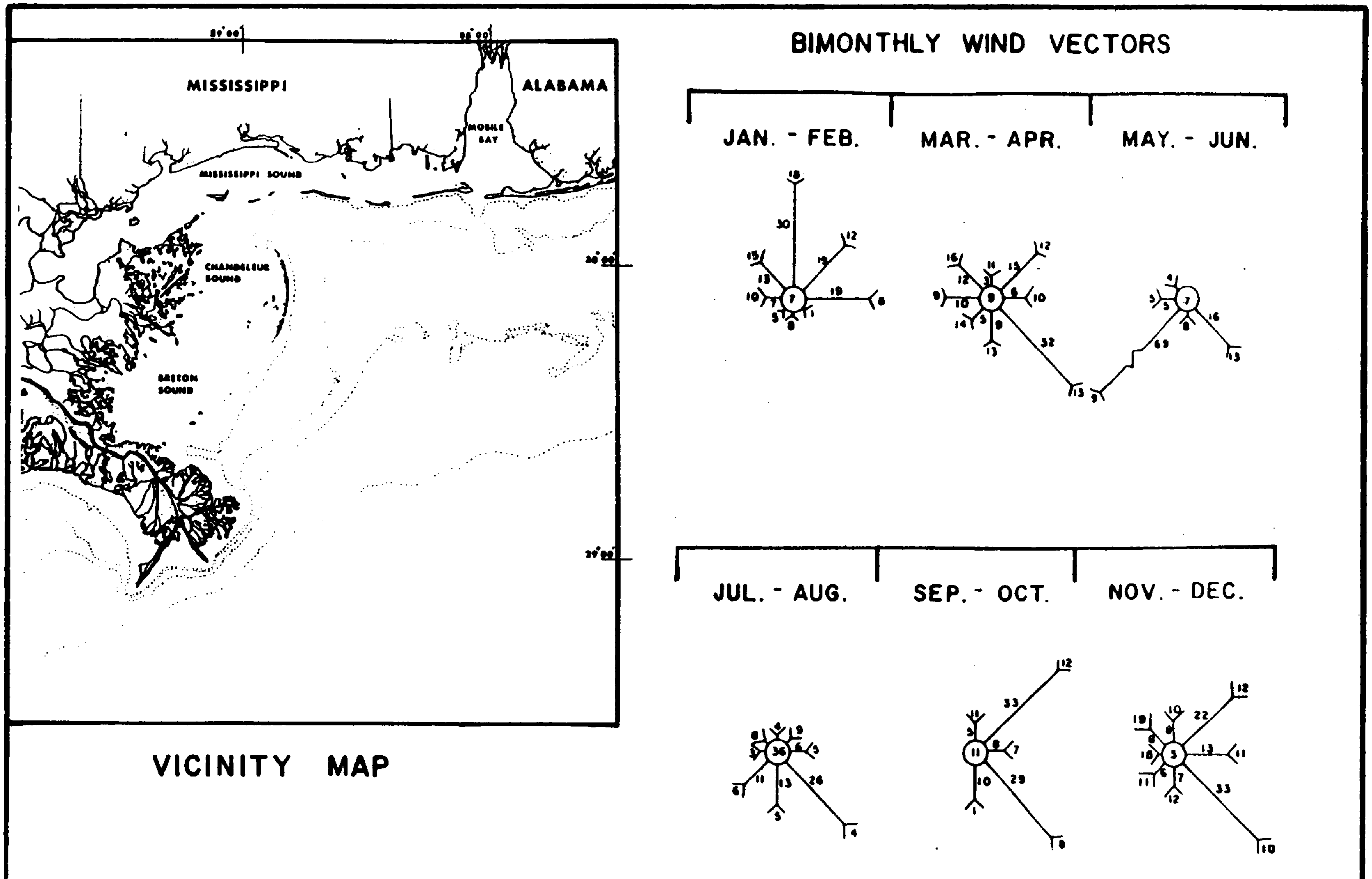


Figure 4.2 Bimonthly wind vectors of average wind speed and direction in the Tuscaloosa Trend study area. Wind rose indicates average wind speed at the end of the arrow, percent frequency at center of arrow, direction from which wind occurs, and percentage of calm winds encircled. (Source: Thompson and Leming, 1978)

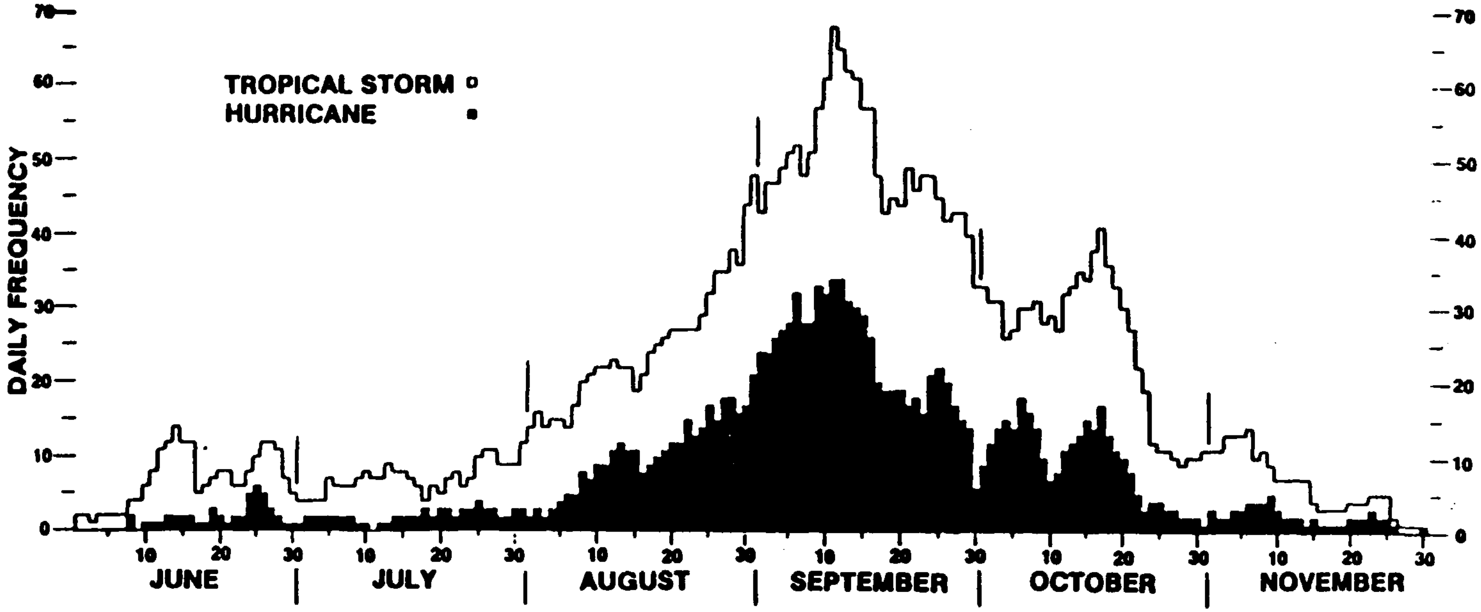


Figure 4.3 Incidences of tropical cyclones in the North Atlantic region from 1901-1963. (Source: Eleuterius and Beaugez, 1979)

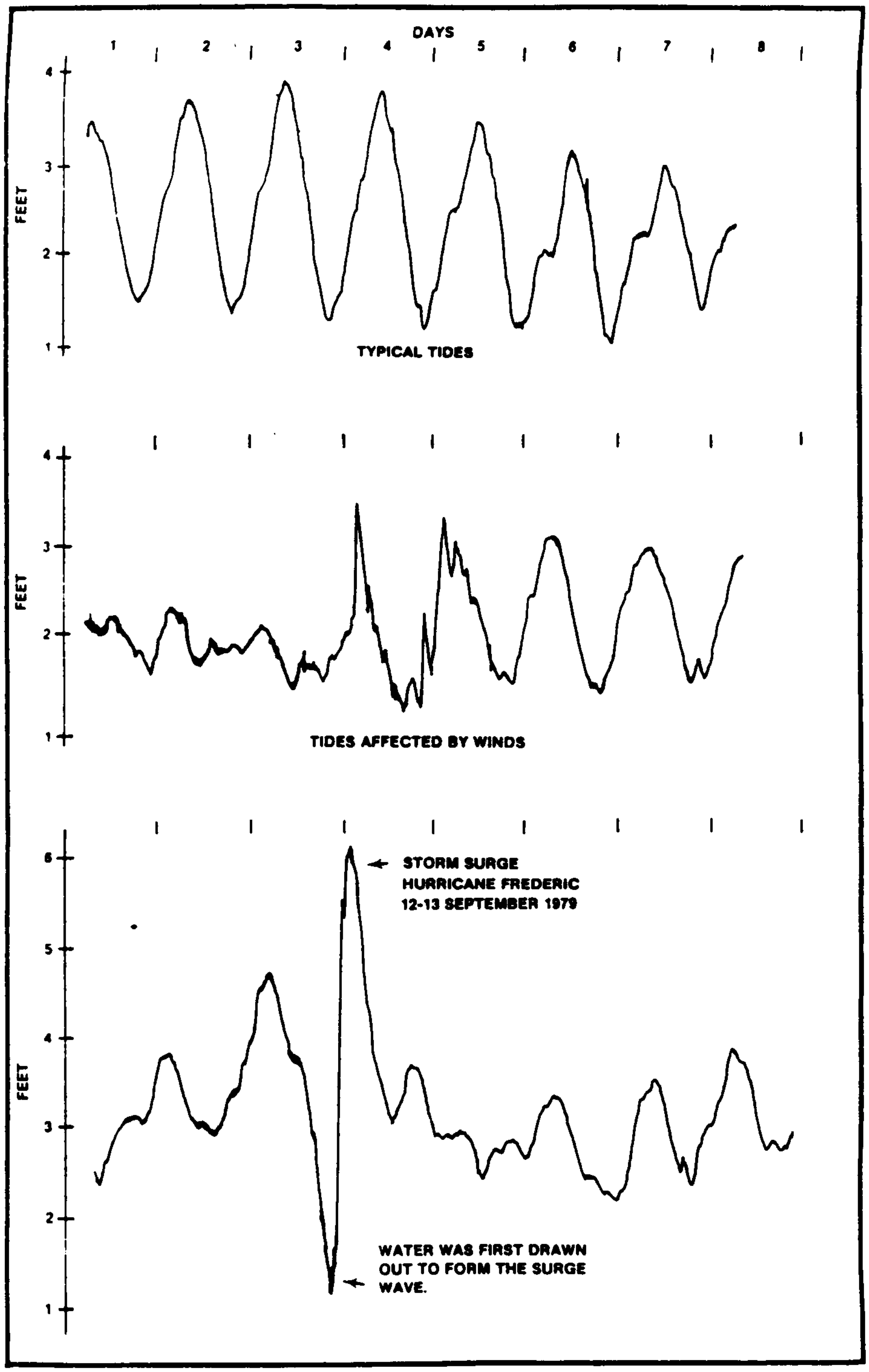


Figure 4.4 Effects of water level variations on Mississippi Sound tides. (Source: Eleuterius and Beaugez, 1979)

4.2.7 WAVES

Wave height distributions usually follow those of wind speeds, with mean wave heights being at a minimum during summer and maximum during winter. Wave heights of 3.6m or greater have been observed throughout the year on the shelf, but heights of 6m or greater have been reported primarily in the winter months (TerEco, 1979). Wave statistics compiled from the study area are presented in Figure 4.5 as wave height histograms (Eleuterius and Beaugez, 1979).

While the wave climate within Chandeleur-Breton Sound, Mississippi Sound, and Mobile Bay are not the same as that described for the offshore shelf area, similar distribution patterns would be found, but with the inshore areas showing generally smaller wave heights.

Wave energy along the coastline of the study area is variable, with areas closest to the continental shelf (i.e., barrier islands) receiving the highest wave energy. At the Mississippi River Delta, however, the riverine processes overshadow the marine processes. The nearshore wave power along this coast is minimal (0.034 ergs$\cdot$s^{-1} x 10^7) compared to other large deltas (e.g., Amazon, 0.193 x 10^7 ergs$\cdot$s^{-1}; Nile, 10.250 x 10^7 ergs$\cdot$s^{-1}). The attenuation ratio, a measure of the amount of wave energy that is dissipated offshore by the slope of the bottom, for the Mississippi delta is much higher than other deltas (Wright et al., 1974).

4.3 FRESHWATER DISCHARGE

Freshwater discharge from local rivers is one of the major factors which influence the circulation and mass characterization of inshore and continental shelf waters. The Tuscaloosa Trend study area receives freshwater runoff from a drainage basin area greater than 3 million km^2 from five primary sources along its northern and western borders, the Mississippi River, the Lake Pontchartrain drainage basin, the Pearl River, the Pascagoula River, and the Mobile River system (Figure 4.6). The drainage basin area and mean annual discharge estimates of each source are presented in Table 4.1. The monthly average discharges for these rivers are shown in Figure 4.6. The Mississippi River reaches a maximum discharge in April, while the Pascagoula and Mobile Delta system peak in March and the Amite-Pearl in February-March. Minimum discharges occur during the August to October period for all rivers.

The Alabama and Tombigbee rivers are the main components of the Mobile River system, which enters into the upper reaches of Mobile Bay. Portions of this discharge reach the continental shelf region via the Mobile Ship Channel; however, up to one-fifth of the Mobile River discharge enters Mississippi Sound via Pass aux Herons, later entering the study area through tidal passes further to the west (Austin, 1954).

The Pascagoula River is the largest river entering directly into Mississippi Sound, followed by the Jordan, Wolf, and Biloxi rivers. The Pearl River discharges into the coastal and lagoon waters of Lake Borgne and at the western extreme of Mississippi Sound.

There is additional freshwater discharge contributed by numerous rivers and streams entering Lake Pontchartrain. The freshwater discharge eventually enters the study area via Lake Borgne. Under most conditions the

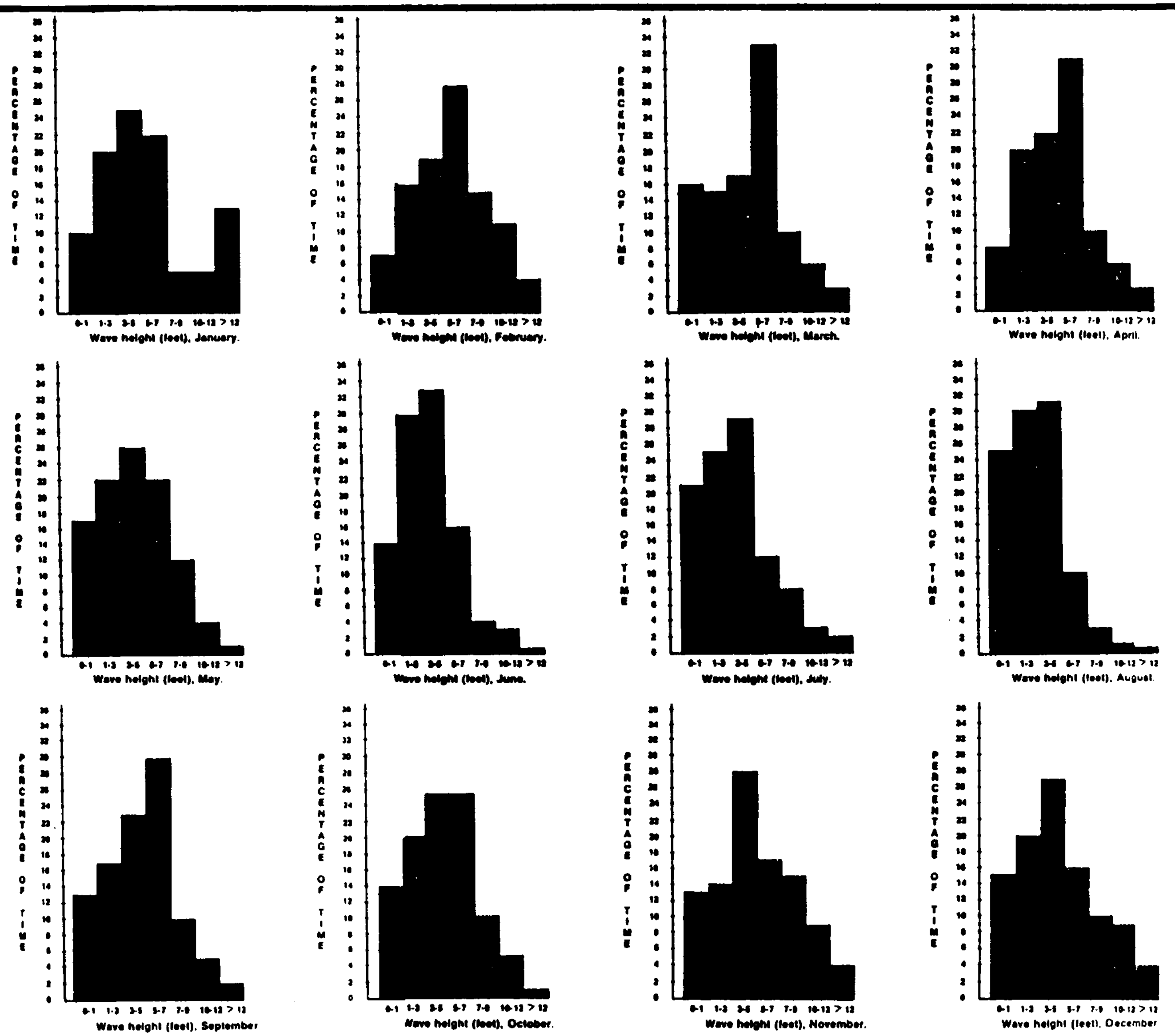


Figure 4.5 Wave heights compiled for an area 40km south of Mississippi-Alabama coast (Source: Eleuterius and Beaugez, 1979).

Table 4.1 Estimated drainage basin areas and mean annual discharge from five primary sources of freshwater runoff in the Tuscaloosa Trend study area (after Schroeder, 1978; Kjerfve and Sneed, 1984).

Source	Drainage Basin Area (km^2)	Mean Discharge Rate ($m^3 \cdot s^{-1}$)
Mobile River	114,290	1,750
Pascagoula River	24,340	417
(Mississippi Sound)	(28,000)	(490)
Pearl River	18,400	305
Lake Pontchartrain	10,700	186
Mississippi River	2,927,000	22,200
(Lower Mississippi River only)		(14,640)

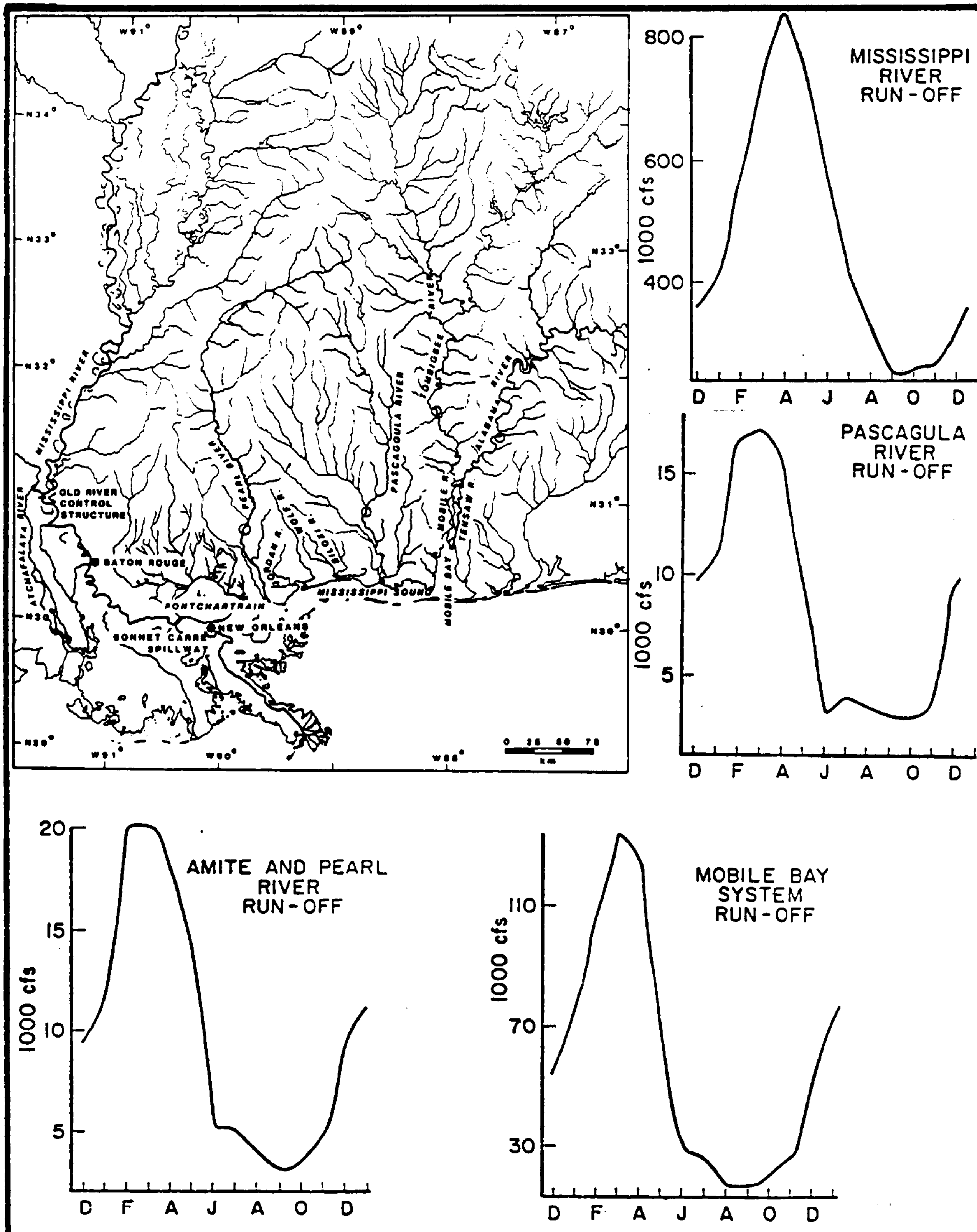


Figure 4.6 Drainage network and annual cycle of river discharge for the main rivers in the Tuscaloosa Trend study area (Source: Kjerfve and Sneed, 1984; SUSIO, 1975).

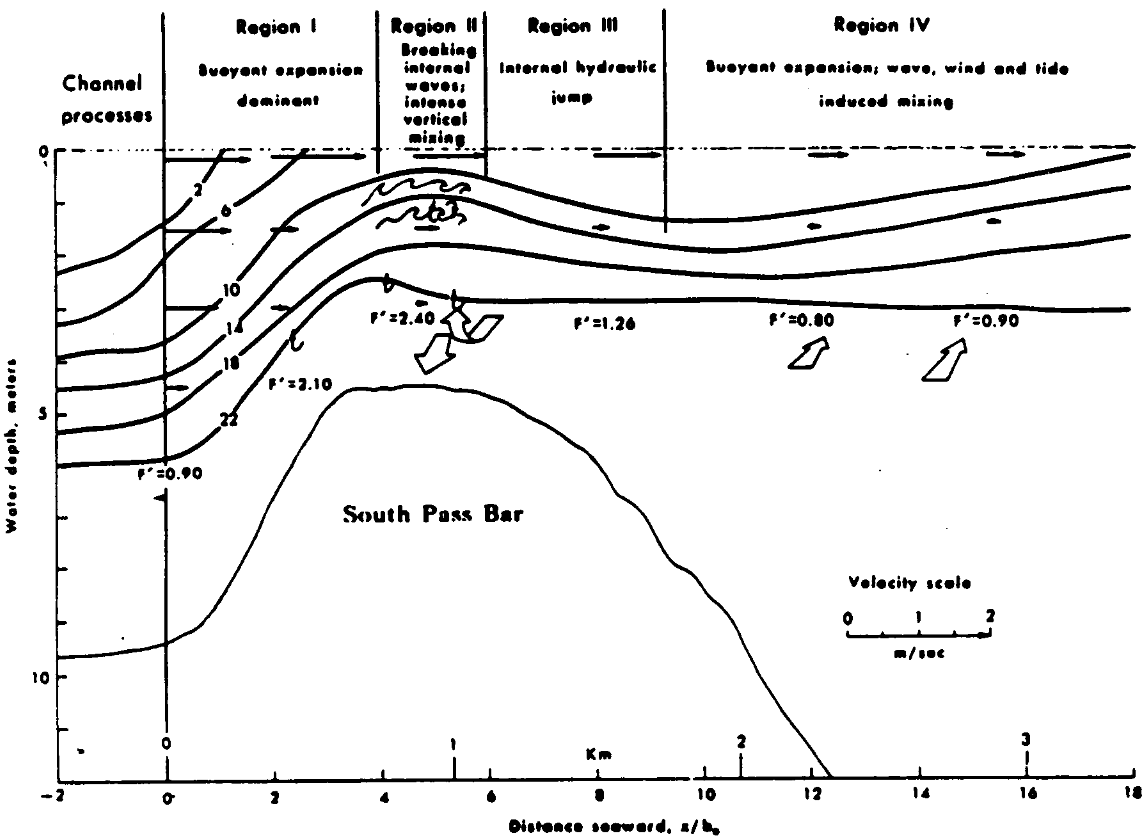
discharges of the Pearl River and Lake Pontchartrain basin occur in phase and with a combined discharge approximately 1.62 times the Pearl River discharge (Sikora and Kjerfve, in press). The freshwater input from Lake Pontchartrain is significantly enhanced during times of discharge of floodwaters from the Mississippi River via the Bonnet Carre Spillway. The Bonnet Carre Spillway structure has been opened seven times (in 1937, 1945, 1950, 1973, 1975, 1979, and 1983), releasing an average of 4,000 $m^3 \cdot s^{-1}$ via the Floodway into Lake Pontchartrain (U.S. Corps of Engineers, 1983).

Although the Mississippi River drains a total basin area of 2,927,000 km^2, only two-thirds of the river discharge reaches the sea through the river delta. The remaining third is diverted through the Atchafalaya River and basin at the Old River Control Structure. Thus, the lower Mississippi River is characterized by an annual average discharge of 14,640 $m^3 \cdot s^{-1}$, much of which flows into the Gulf of Mexico via the Southwest Pass (29%). However, an appreciable fraction of the discharge reaches the Gulf via the other two major delta distributaries: South Pass (15%) and Pass a Loutre (37%). The remainder is carried through secondary outlets (Rouse and Coleman, 1976). The discharge from Pass a Loutre can periodically impact salinity and flow dynamics in Chandeleur-Breton Sound and the offshore study area (Kjerfve and Sneed, 1984). In addition to the freshwater, the Mississippi River transports approximately 4.5 x 10^9 kg (500 million tons) of sediment to the Gulf annually. Bedload accounts for 10-20% of this total; the remainder is suspended in the effluent and can be observed from satellite imagery (Rouse and Coleman, 1976).

4.3.1 THE EFFECTS OF MISSISSIPPI RIVER DISCHARGE

One of the most dominant influences on Louisiana coastal waters is the discharge of the Mississippi River, the effects of which are seen in high levels of turbidity, temperature and salinity contrasts to normal Gulf waters. The geographical point of discharge for the Mississippi River is only 20 km from the 200 m isobath and 45 km from the 1000 m isobath. Despite the high volume of flow from the Mississippi, weakly dilute Gulf water actually flows upstream along the bottom of the channels in a classic example of a salt wedge. River water in the upper half of the channel flows Gulfward at speeds in excess of 90 $cm \cdot s^{-1}$ (Murray, 1976). The greater density of the Gulf seawater sets up the horizontal pressure gradient for the intrusion of Gulf water up the river channel. Low tides generally inhibit the intense mixing between the river and seawater, but salt does apparently move vertically up into the upper layer. Flooding tides increase the upstream flow of the salt wedge and at times can even halt temporarily the river flow in the upper layer.

Several definitive investigations on the Mississippi River mouth processes have been published (Wright, 1970, 1971; Wright and Coleman, 1971, 1974; Wright et al., 1973). Wright's work shows that buoyancy forces are usually more important than turbulence at natural stratified river mouths. In response to vertical thinning of the surface freshwater layer, such as found across a sand bar, the isopycnals rise sharply towards the surface and intense vertical mixing occurs due to breaking of interfacial (internal) waves (Figure 4.7). Further seaward, the buoyant lateral expansion mechanism maintains the stratification, but wind, wave, and tide-induced mixing of the river effluent causes the formation of the low salinity coastal water (Wright and Coleman, 1974).



$$F' = \frac{\bar{u}}{(\gamma g h')^{1/2}}$$

where

$\bar{u}$ is the average speed in the upper layer

$\gamma = 1 - (\rho_f/\rho_s)$

where

ρ_f is the density of the effluent water and

ρ_s is the density of the lower intruding water,

g is the acceleration of gravity, and

h' is the depth to the density interface

Figure 4.7 Cross-section of density and velocity fields along South Pass effluent plume on an ebbing tide. F' is the densimetric Froude number. (Source: Murray,1976)

Drennan (1968) notes that the effects of the river water on the vertical salinity and temperature structure is confined to the upper 10 to 20 meters in the immediate vicinity of the Delta and to lesser depths east of the river. Its effects on the circulation in the northeast Gulf is in the creation of sloping pressure surfaces which result from changes in density and the hydraulic head. The speed of any current established should vary in direct proportion to the amount of freshwater discharged (Drennan, 1968).

4.4 TIDES

The influence of tides on oceanographic variability is significant, particularly along the coastline and continental shelf. Astronomical tides assist in the disruption of vertical stratification through mixing action, develop residual circulation through differences in ebb and flow currents, and aid in the suspension and transport of material in the water column (Kjerfve and Sneed, 1984).

The tide in portions of the Gulf of Mexico is considered diurnal (i.e., one high and one low per lunar day), with tidal ranges that average 30 to 60 cm (Jones, 1973). Zetler and Hansen (1972) have shown that the diurnal tide in the Gulf is co-oscillatory with the tide in the nearby Atlantic Ocean with amphidromic points (i.e., where the tide range is near zero) in the Florida Straits near Miami and in the Yucatan Channel. They suggest that the semidiurnal tide amphidromic point is located in the Gulf roughly midway between the Mississippi Delta and Yucatan Peninsula.

Kjerfve and Sneed (1984) present a large-scale pattern of tidal type for the Gulf of Mexico and Caribbean Sea (Figure 4.8) based on spatial distribution of computed form numbers. The form number (F), defined as the amplitude ratio:

$$F = (K_1 + O_1)/(M_2 + S_2); \text{ where}$$

K_1 = luni-solar diurnal tide component

O_1 = principal lunar diurnal tide component

M_2 = principal lunar semidiurnal tide component

S_2 = principal solar semidiurnal tide component

is the most common characteristic used to classify tidal type (Defant, 1960). Where F is less than 0.25 the tide is termed semidiurnal; within the range $0.25 < F < 1.5$ the tide is a mixed, predominantly semidiurnal tide; within the range $1.5 < F < 3.0$ the tide is a mixed, predominantly diurnal tide; and when F exceeds 3.0 the tide is classified as diurnal.

The average tidal range for the study area measures 40 cm (1.3 ft.) in Chandeleur Sound, 47 cm (1.6 ft.) in Mississippi Sound, and 43 cm (1.4 ft.) 20 miles south and east of the barrier islands, with a tropic or maximum normal range of 53 cm (1.8 ft.), 62 cm (2.1 ft.), and 57 cm (1.9 ft.) at each of the respective sites (Kjerfve, 1983). The average tidal range for Mobile Bay is 46 cm (1.5 ft.) in the upper bay, 49 cm (1.6 ft.) in Bon Secour Bay, and 37 cm (1.2 ft.) at the mouth of the Bay (O'Neil and Mettee, 1982). The average

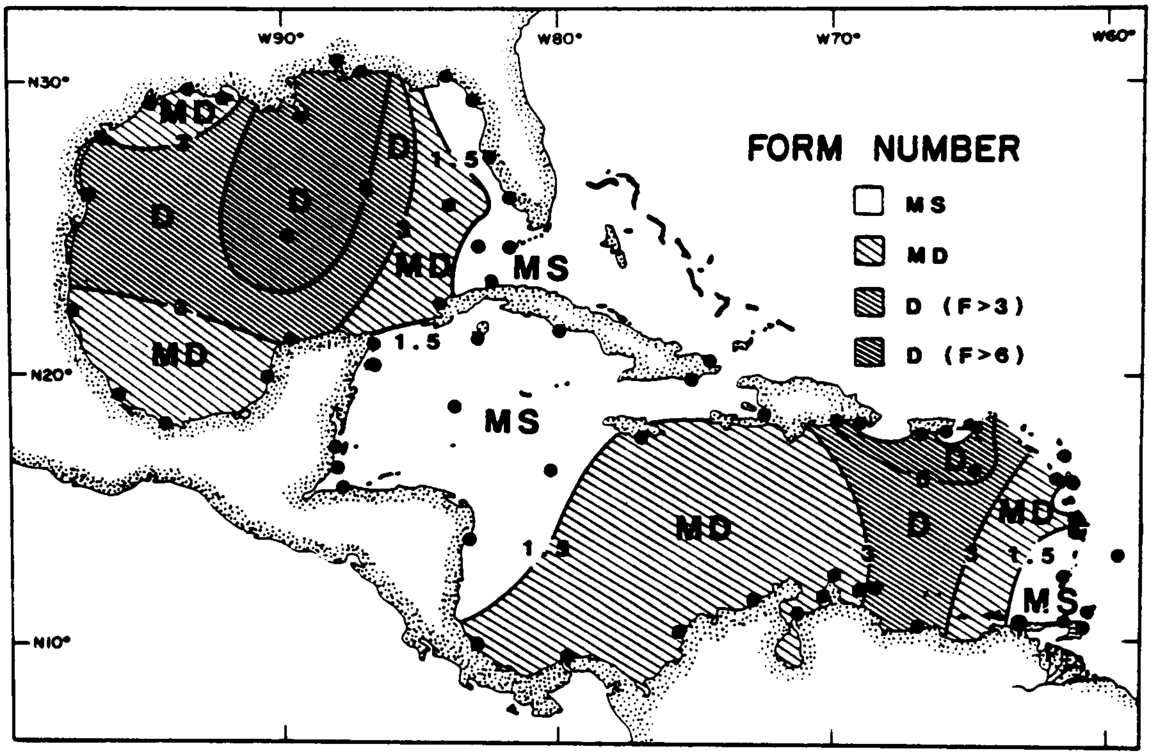


Figure 4.8 Spatial distribution of form number for the Gulf of Mexico and Caribbean, where MS is mixed semidiurnal tide, MD is mixed diurnal tide, and D is diurnal tide. (Source: Kjerfve and Sneed, 1984)

period of the diurnal tide is 24.8 hours (Kjerfve, 1983). A summary of the average tidal characteristics for the Tuscaloosa Trend study area based on harmonic analysis of data from the Mississippi Sound and adjacent areas oceanographic study (Kjerfve, 1983; Kjerfve and Sneed, 1984) is presented in Table 4.2.

The nature of the tide is diurnal throughout the study area resulting from greatly enhanced differential damping of the semidiurnal component tides as represented by the high form numbers in lower Mobile Bay and near Breton Island (Figure 4.9). Of particular interest is the small mean equatorial range which indicates the almost complete absence of diurnal tides each fortnight (Table 4.2).

The offshore tide pattern (constituent tide component O_1) represented in Figure 4.10 depicts the rapid advance of the tidal wave as it approaches the coastline from the south. The interaction of the regional bathymetry and the tides divides the northern coast into two distinct tidal regions in the vicinity of Petit Bois Island. One wave front moves north northwest which results in a slight counterclockwise rotation, while the other portion of the wave front turns east to northeast which results in strong clockwise rotations of tidal currents (Kjerfve and Sneed, 1984). The eastward progression of high water reaches Pass aux Herons (entering Mobile Bay) approximately one hour after entering Mississippi Sound (Figure 4.10). High water reaches Lake Borgne in the west approximately two hours after entering the Sound. Tidal wave propagation into Chandeleur-Breton Sounds moves east to west as modeled by Hart (1976) and depicted by Kjerfve (1983).

4.5 HYDROGRAPHY

The temperature and salinity regimes of coastal and offshore waters have a direct effect on biological processes (e.g., distribution, growth, migration, reproduction), chemical reactions, and physical aspects (e.g., density, specific heat, viscosity) of the marine ecosystem. Temperature and salinity data are useful not only for determining density gradients and analyzing stratification, but also for tracing movement of water on the continental shelf. Also, dissolved oxygen content of water affects the chemical and biological processes of the ecosystem.

4.5.1 TEMPERATURE

The temperature of nearshore surface waters of the northern Gulf coast closely approximates the air temperature. The shallow waters of Chandeleur-Breton and Mississippi Sounds and Mobile Bay are fairly well mixed and more thermally uniform than the deeper offshore waters of the shelf (Eleuterius, 1976a; Schroeder, 1976). Water temperature is determined primarily by direct solar radiation, but may be altered by mixing with intruding oceanic and/or riverine water, as in the case of nearshore coastal areas. Intrusion without mixing may cause local and temporary stratification of the water column. Also, differences in the heating and cooling of sea surface waters cause density differences that result in horizontal pressure gradients that, in turn, result in currents.

Table 4.2 Summary of average tidal characteristics for Mississippi Sound, Chandeleur Sound, and offshore study sites, based on harmonic analysis (Source: Kjerfve, 1983).

Parameter	Formula (Marmer, 1954)	Value	Interpretation
Form Number	$(K_1 + O_1)/(M_2 + S_2)$	7.0	Diurnal
Mean Range	$1.5(K_1 + O_1)$	45.2 cm	Mean diurnal range
Tropic Range	$2.0(K_1 + O_1)$	60.2 cm	Average range during tropic tide; moon near maximum northern or southern declination
Equatorial Range	$2.0(K_1 - O_1)$	0.0 cm	No tide during equatorial tide; moon approximately semimonthly declination
Diurnal Age	$0.91(K_1^o - O_1^o)$	9.1 hrs	Tropic tide occurs 9 hours after the moon's maximum semimonthly declination
Spring Range	$2.0(M_2 + S_2)$	8.6 cm	Average semidiurnal range during spring tide
Neap Range	$2.0(M_2 - S_2)$	2.2 cm	Average semidiurnal range during neap tide
Phase Age	$0.98(S_2^o - M_2^o)$	9.8 hrs	Spring Tide occurs on the average 9.8 hours after new or full moon
Inequality Phase	$\|M_2 - (K_1^o + O_1^o)\|$	80°	Diurnal inequalities occur in both high and low waters

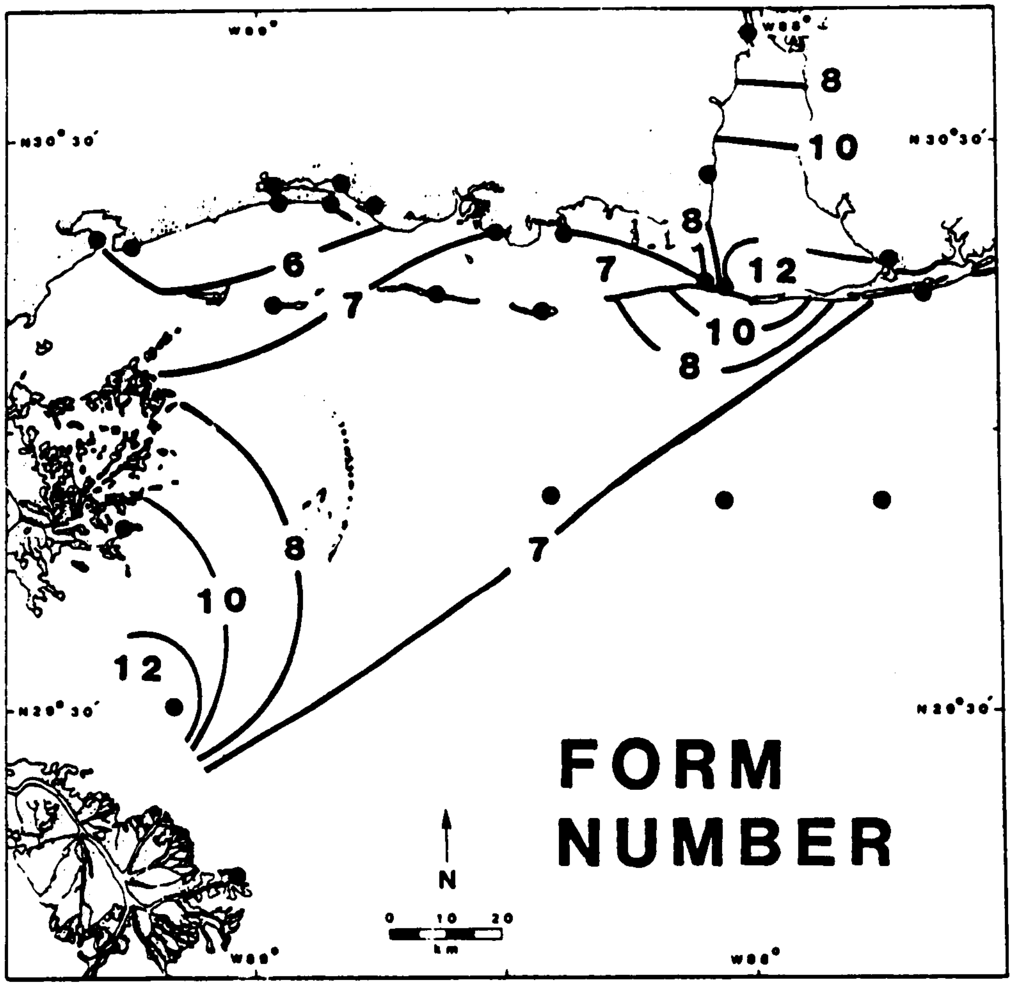


Figure 4.9 Spatial distribution of the form number, F, in the Tuscaloosa Trend study area (Source: Kjerfve, 1983).

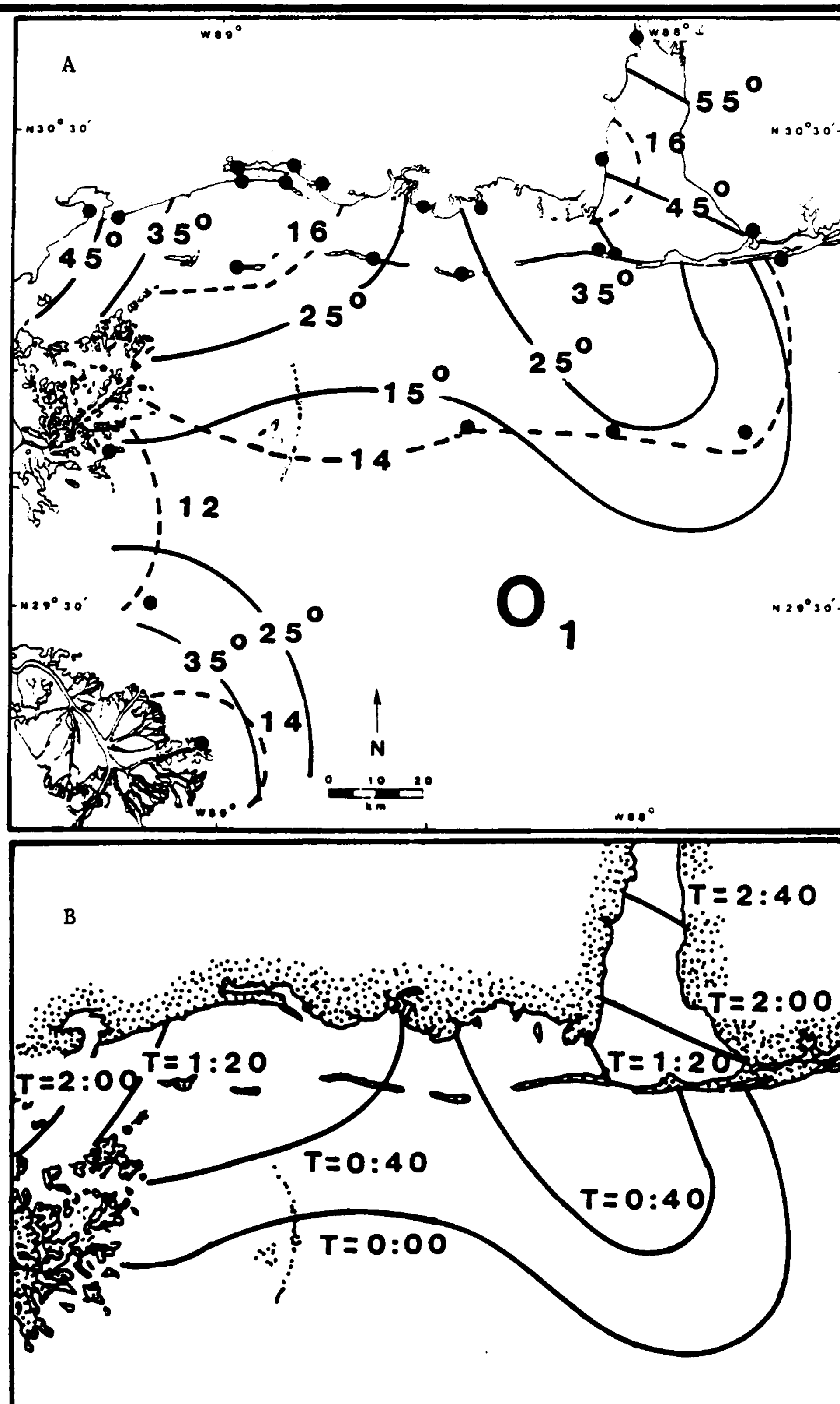


Figure 4.10 A) Cotidal chart of constituent tide O_1. Solid lines are isopleths of Greenwich phase, G^0; dashed lines are amplitude, H. B) Progression of diurnal tide wave through Mississippi Sound; lines indicate position of tidal crest (Source: Kjerfve, 1983).

The estuarine waters in the study area reach their maximum temperature (approximately 30°C) during July and August with temperatures nearly uniform throughout the water column. Minimum temperatures occur from January to March (lower than 13°C) with temperature inversions (i.e., where cooler water overlies warmer water) occurring in the winter (Eleuterius, 1976).

Surface temperatures of waters seaward of the barrier islands to about 20 km offshore reflect fluctuations in air temperatures, but to a lesser degree than do the surface waters of Mississippi Sound (Allen and Turner, 1977). Data for January and February show surface temperatures ranging from 12°C at stations near the barrier islands to approximately 15°C at a station 20 km offshore. According to their temperature profiles, warmer waters ranging from 13 to 17°C often underlie these cool surface waters. Sample collections during March, April, May, and July 1975 show a gradual warming of surface waters leading to highly stratified water columns by July. July temperatures recorded at various stations ranged from 30°C at the surface to 22°C near the bottom. Temperature profiles recorded between October and November, 1975 show uniform water column temperatures near 24°C.

Water temperature conforms less to air temperature with greater distance from shore and greater depth of the water column. As described by Drennan (1968), Franks et al. (1972), Allen and Turner (1977), and Ragan et al. (1978), winter temperatures of the shelf waters tend to be higher than those of the estuaries, and tend to increase with distance offshore (Table 4.3). Along a transect proceeding southeasterly from Horn Island to the edge of the shelf, little stratification of the water column is apparent during January; however, stratification is well defined during late summer (September) with temperatures at 200 m depth (17°C) some 12 degrees cooler than at the surface (Alexander et al., 1977).

4.5.2 SALINITY

Major sources for information on salinity distribution in the study area include Allen and Turner (1977), Christmas (1973), Drennan (1963, 1968), Eleuterius (1976a), Eleuterius and Beaugez (1979), Kjerfve (1983), Kjerfve and Sneed (1984), McPhearson (1970), Rinkel and Jones (1973), Alexander et al. (1977), Dames & Moore (1979), and Schroeder (1976, 1978, 1979).

General salinity distribution patterns of the coastal bays and sounds are greatly influenced by river flow, as depicted by the inverse relationship between river freshets and salinity. Seasonal salinity is generally lowest in late winter through spring and highest during late summer and fall. Based on existing hydrographic information on Chandeleur-Breton Sound (Barrett et al., 1971), it appears that salinities are lowest in areas along the coast (western part of the Sound) and highest along the barrier islands and passes.

Eleuterius (1976, 1977) presented a voluminous amount of salinity data for the Mississippi Sound which has been incorporated in an atlas (Eleuterius and Beaugez, 1979). Salinities in the Mississippi Sound are highest near the barrier island passes and deep channels and lowest near the water surface and next to the coast proper. Generally, salinities are highest in summer-fall, during low river outflow, and lowest in winter-spring, during high river outflow. Table 4.4 shows the salinity ranges in the three regions of the Sound. There is a noticeable westward decrease in salinity in the

Table 4.3 Monthly distribution of water temperature (°C) at selected localities within Mississippi Sound and adjacent offshore areas. Mississippi Sound values were taken in shallow water (Christmas, 1973). Shelf data are from a transect proceeding southeast from the Horn/Ship Island Pass (Franks et al., 1972). (Source: TerEco, 1979)

	Miss. Sound (Surface Means)		Shelf								
	Mainland	Barrier Islands	5-fm contour			10-fm contour			20-fm contour		
			S*	M-D*	B*	S*	M-D*	B*	S*	M-D*	B*
JAN.	12.4	9.4	12.3	12.6	14.9	13.9	14.2	16.0	15.7	17.5	18.5
FEB.	14.5	13.0	13.5	11.7	14.5	16.6	16.8	17.1	16.5	16.5	17.0
MAR.	18.4	16.8	15.9	15.4	15.5	22.4	22.2	20.2	20.9	19.0	18.5
APR.	25.3	25.8	23.2	25.0	21.7	25.1	24.3	20.6	24.2	23.5	22.0
MAY	18.0	26.9	25.5	25.0	24.7	29.5	29.5	24.0	29.4	25.0	25.0
JUNE	30.3	30.8	29.9	31.0	29.5	29.9	26.9	27.0	30.4	30.4	27.3
JULY	29.1	30.4	30.3	29.7	29.0	29.6	30.0	29.0	30.8	31.0	29.0
AUG.	30.7	30.3	29.0	29.0	29.0	28.9	28.0	27.6	28.2	27.9	28.0
SEPT.	29.5	30.2	26.5	26.0	26.4	25.1	25.4	24.9	27.0	28.1	27.1
OCT.	22.6	21.6	23.7	22.7	20.4	19.5	17.5	22.2	19.0	18.7	17.0
NOV.	19.0	18.5	17.2	17.3	17.6	16.2	16.2	16.2	16.8	17.2	17.8
DEC.	12.9	14.9	14.0	14.2	14.5	22.7	22.0	21.8	22.8	22.7	22.2

S* - Surface

M-D* - Mid-depth

B* - Bottom

Table 4.4 High and low salinities during seasonal river flow periods for 1974-1975, irrespective of collection depth. Values in parts per thousand.

	West Sound		Central Sound		East Sound	
	Coast	Passes	Coast	Passes	Coast	Passes
Low River Outflow	16	30	20	30	30	34
High River Outflow	2	8	4	20	4	18
Average	10	20	18	26	16	30

(Source: Eleuterius, 1977)

Sound which is caused by greater river outflow in the western sound. In addition, when the Bonnet-Carre Spillway is opened, waters of the Mississippi River deluge the area as far east as Ship Island. However, during any given period, the salinity may be extremely variable.

A basic pattern of lateral, vertical, and longitudinal salinity distribution is present for Mobile Bay, although variations in the discharge of the Mobile River system can cause abrupt temporary changes (Austin, 1954; McPhearson, 1970; Schroeder, 1978). Throughout most of the year, salinities in Mobile Bay are higher to the east of the ship channel than to the west and gradually increase from the head of the Bay to the mouth (Figure 4.11). A lateral distribution occurs during periods of high river discharge when the river floods down the center and eastern sides of the Bay rather than being restricted to the western side (Figure 4.12). At any given time, portions of the Bay can be highly stratified while other areas are vertically homogeneous. For example, during low river discharges a stratified system can exist in the upper bay while the high salinity lower bay waters can approach vertical homogeneity. Also, during high river discharges the upper bay can be vertically uniform with river waters while the lower bay becomes a stratified system (Schroeder, 1978).

McPhearson (1970), Eleuterius (1978), Schroeder (1979), and Kjerfve (1983) discuss vertical salinity stratification in the sounds and bays of the coastal study area. Based on the estuarine classification system according to Pritchard (1955), these bodies of water fluctuate between well-mixed and partially-mixed estuaries. However, vertical salinity stratification is variable seasonally, becoming more pronounced in late summer and fall.

The salinity structure of the continental shelf off the barrier islands is highly variable due to river and tidal inlet plumes and aperiodic Loop Current intrusions. During certain wind events, freshwater discharge from the Mississippi River water flows eastward across the shelf, and plumes of Mississippi River water have been detected as far as 75 km east of the nearest delta (Allen and Turner, 1977). However, high salinity waters are continually being brought to the outer shelf by dynamic movement of deeper waters of the Gulf. The salinity patterns of the shelf result largely from mixture of Mississippi River water; low salinity outflows from Chandeleur-Breton Sound, Mississippi Sound, and Mobile Bay; and high salinity Gulf water.

Waters less than 20 km seaward of the barrier islands and out to approximately 30 m depth display variations in seasonal patterns of salinity distribution. Surface salinities recorded at various stations during the winter of 1976 (Allen and Turner, 1977) ranged from 19 ppt near the east end of Dauphin Island to 31 ppt 20 km offshore. Bottom salinities appeared less variable, ranging from 30 ppt inshore to 35 ppt offshore. Spring freshwater runoff apparently reduced surface salinities to as low as 21 ppt (Allen and Turner, 1977) near the Mississippi River outflow. Surface salinities increased eastward to 35 ppt at a station southeast of Mobile Bay. Although near-bottom salinities may be as low as 28 ppt during this period in waters near the Mississippi River outflow, they were generally near 35 ppt elsewhere. Salinity profile patterns recorded by Allen and Turner (1977) during the summer of 1975 appear slightly higher than those recorded in March. The distribution patterns, however, seem to persist. Bottom waters were almost uniform with salinities greater than 36 ppt. Surface salinities recorded in late fall were apparently also affected by freshwater runoff. Surface salinities near

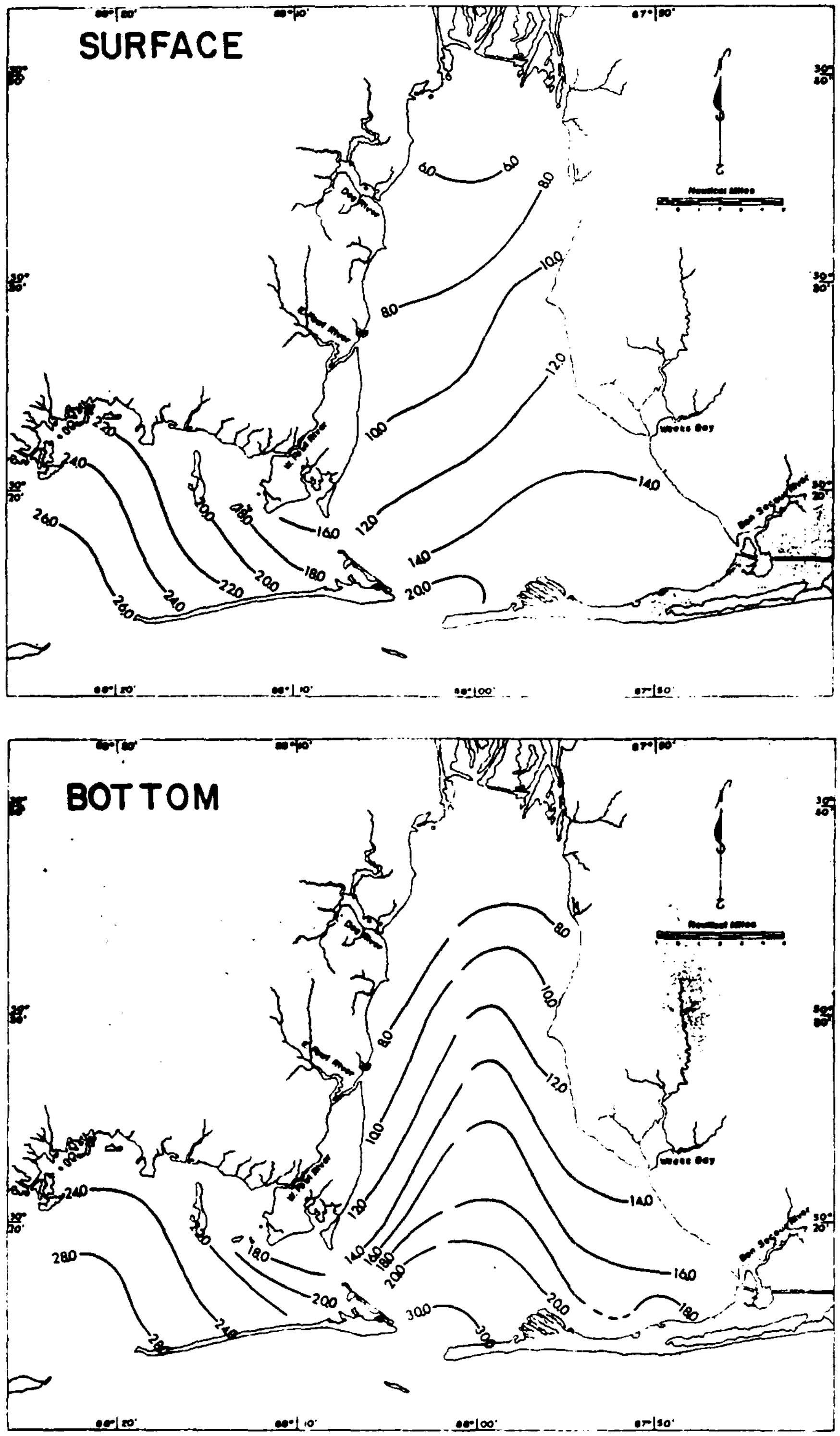


Figure 4.11 Average surface and bottom salinity, June 1963 through May 1964; November 1965 through October 1966. (Source: McPhearson, 1970)

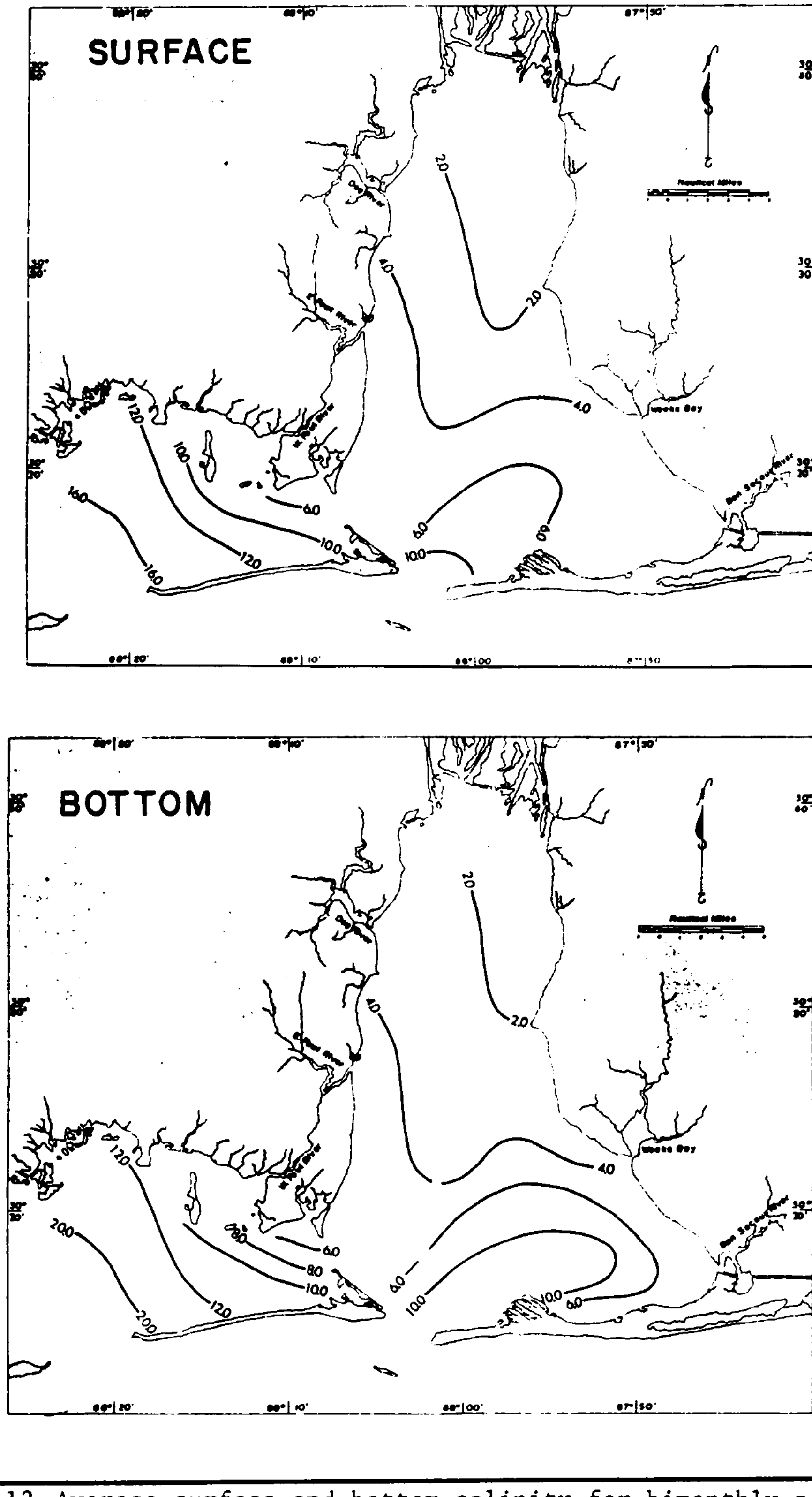


Figure 4.12 Average surface and bottom salinity for bimonthly period of highest river discharge into Mobile Bay (March-April), 1963-1966 (Source: McPhearson, 1970).

the Mississippi River and Dauphin Island measured between 27 and 28 ppt while those farther offshore were between 34 and 35 ppt. Bottom salinities were less variable and measured between 33 and 25 ppt.

Although the salinity patterns of the shelf are constantly changing, certain significant points are noted: remarkably steep salinity gradients (e.g., 0-36 ppt) are sometimes observed within a short distance; marked variations occur in the seasonal patterns of salinity distribution; during late spring and early summer, low salinity surface water may spread over much of the area's shelf; and high salinity water tends to remain at the southern edge of the area year-round (Drennan, 1968). These fronts are illustrated in Figure 4.13. Intrusion of low salinity waters onto the shelf is seen in Figure 4.13a (for the month of January) which also shows very high surface salinities off the Delta and nearshore to the north and west. A period of high freshwater outflow is illustrated in Figure 4.13b (for the month of May). Low salinity water extends over most of the study area. As in the case of temperature, salinity variation seems to be greatest nearshore and in the surface layers offshore. A cross-section of the water column of the shelf northeast of the Delta during a high freshwater outflow period is given in Figure 4.14a (Drennan, 1968). The low salinity surface water overriding high salinity bottom water produces a density gradient sufficient to create, in effect, two distinct water masses between which little mixing can take place.

4.5.3 DENSITY

Density of shelf water is a function of temperature and salinity. The distribution of density is characterized by two features, horizontal and vertical gradients, which are closely related to currents. Density-driven currents are discussed in Section 4, Non-tidal Currents.

Differences in the density of seawater cause horizontal pressure gradients that result in currents (Murray, 1972, 1976; Eleuterius and Beaugez, 1979). An increase in the density of the surface water during the passage of a cold front causes the surface water to sink while formerly lighter subsurface water is forced to the surface. Depending upon the degree of change in density, the entire water column can be overturned.

In contrast, if there is a strong increase in density with depth, vertical mixing of the water column is reduced. A strong pycnocline (density interface) present in the water column retards the mixing of waters above and below the interface. The vertical stratification which results becomes important in discussions of sediment transport and exchange of gases across the interface. Figure 4.14 depicts a vertical profile of salinity and sigma-t along a transect east of the Mississippi River Delta in May, 1964 (Drennan, 1968).

Drennan (1968) noted that major circulation features of the study area could be deduced from the spatial distributions of density; that the currents are nearly geostrophic, except in inshore regions where river discharge momentum and tides are dominant. The most significant features presented by Drennan (1968) are: the effect and extent of the Mississippi River discharge on the surface density field during the months of May, June, and July (Figure 4.15); an orientation of the isopycnals roughly parallel to the

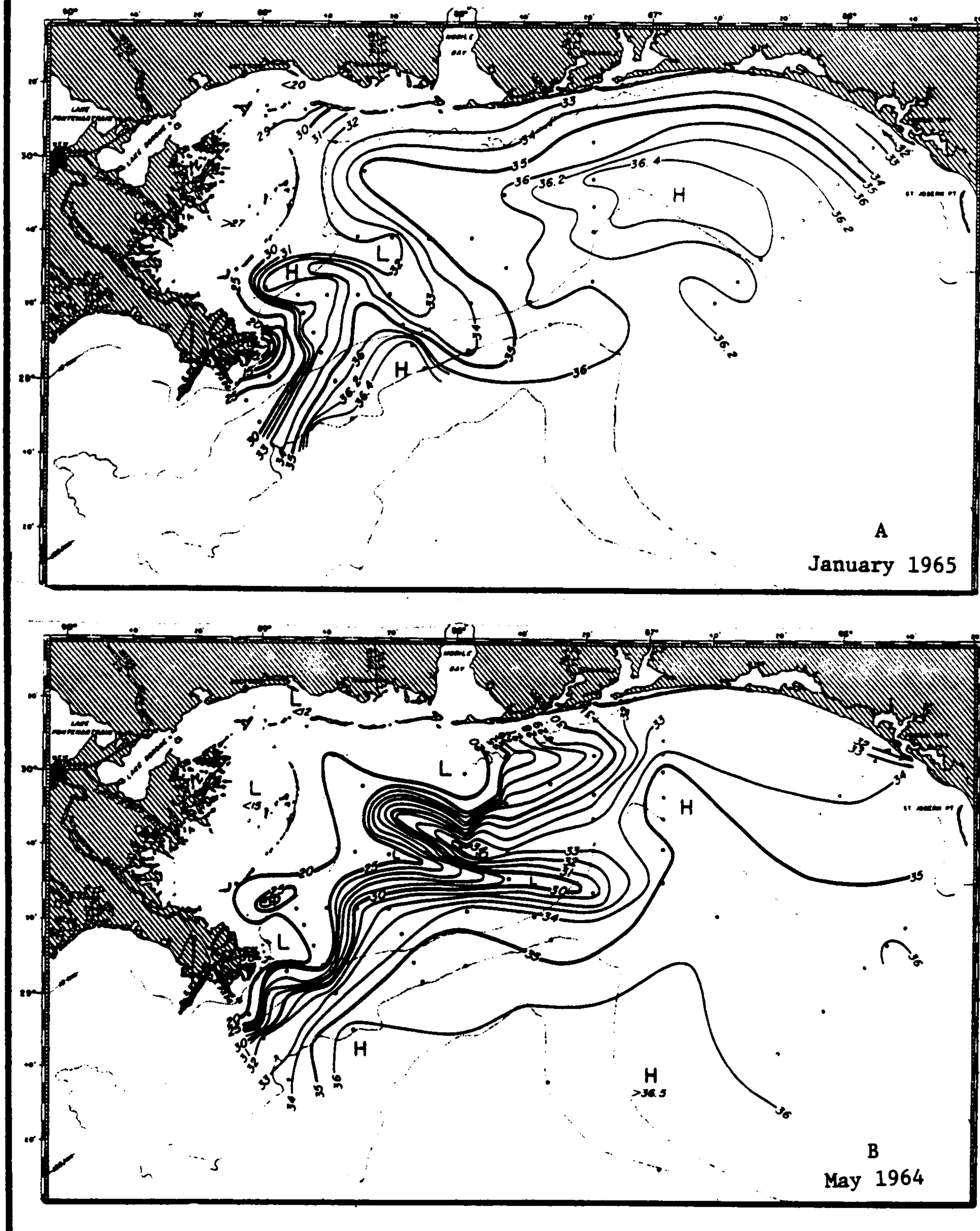


Figure 4.13 Surface salinities for January,1965 and May 1964. Verbal description of near-shore area in text. (Source: Drennan, 1968)

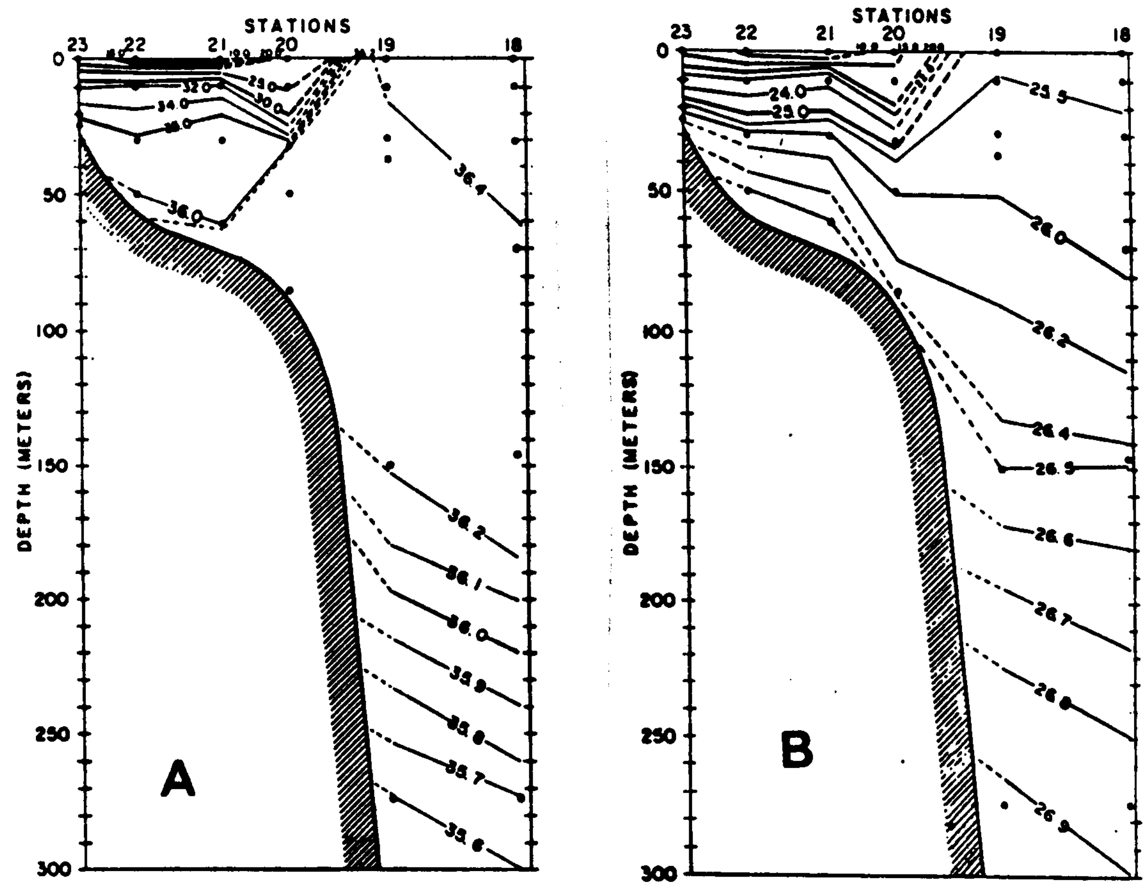


Figure 4.14 Salinity in parts per thousand (A) and density as Sigma t (B), east of Mississippi Delta, April 1965. Station 23 is located at 29° 24'N, 89° 49'W. (Source: Drennan, 1968)

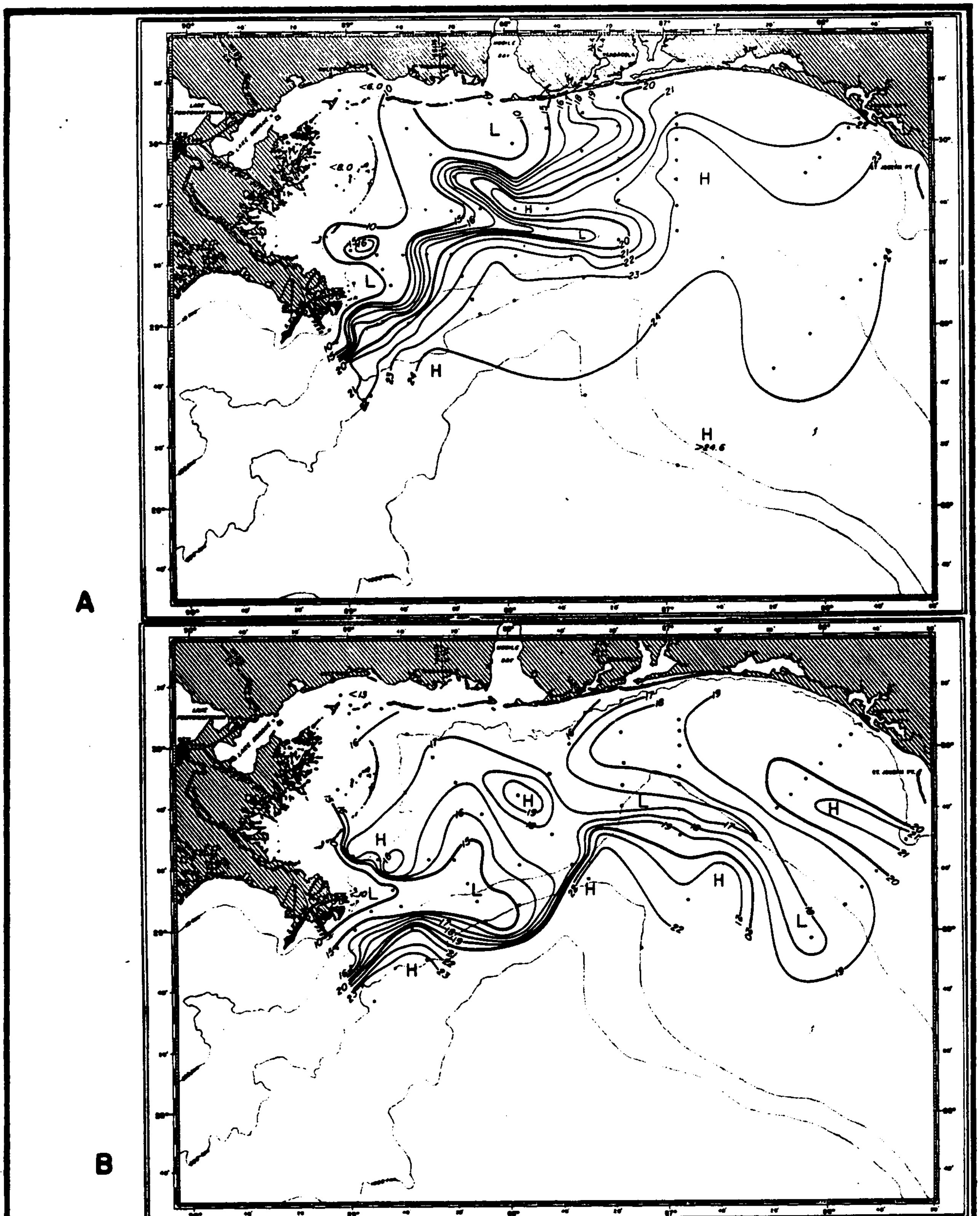


Figure 4.15 Distribution of surface density (σ_T) in the northeastern Gulf of Mexico; A) May 24-31, 1964, B) June 29- July 3, 1964. (Source: Drennan, 1968).

isobaths along the continental slope; and the large cells of high density water (σ_T † 25.2) south of Mobile Bay during winter and early spring (Figure 4.16).

4.5.4 TURBIDITY

Water clarity in the northern Gulf of Mexico is directly related to the turbulent energy (e.g., currents, internal waves seiches) on the benthic boundary layer and to the turbidity of riverine waters, primarily the Mississippi River, and biological productivity (e.g., phytoplankton blooms). Organic and inorganic input from coastal marshes and sediment loading from riverine discharge and runoff contribute significantly to the turbidity of nearshore coastal waters (McPhearson, 1970; Schroeder, 1979).

Results of a turbidity study conducted south of Mobile Bay during the summer of 1976 (Carder and Haddad, 1979) indicate that a nepheloid layer extends along the shelf (30 to 40 m depth) near the bottom (Figure 4.17). A highly turbid lens of brackish water from the Mississippi River (C_p values = 1.0 m^{-1}) occupied the water column during a 120-hour time series study (Figure 4.18). A similar lens was found inshore near Mobile Bay. Farther offshore, clear water was found between the surface and bottom turbidity regimes, providing a horizontally stratified turbidity regime. Attenuation coefficients (C_p) as high as 2.3 m^{-1} were found in the nepheloid layer along the inshore stations, and values in excess of 0.9 m^{-1} were found in the Mississippi River plume. The turbid conditions found in the winter (1978) nepheloid layer (C_p values = 0.37 - 3.m^{-1}) were seiche-derived, whereas in the summer (1976) nepheloid layer (C_p values = 0.07 - 1.29 m^{-1}) turbidity was derived from internal waves (Carder and Haddad, 1979). Evidence of open Gulf waters, possibly the Loop Current, was seen along the shelf break off Mobile and Panama City during the summer of 1976 and fall of 1977 as a very sharp contrast between the usually turbid inshore waters.

Light penetration measurements collected during the MAFLA 1977-1978 program revealed that the inner shelf station off Mobile Bay contained waters with the least penetration of all stations sampled. During winter 1978, relative illuminance values with approximate depths were: 50% at 1m, 25% at 3m, 10% at 3-6 m, and 1% at 10-15 m. The depths of penetration were half those at 25-50% illuminance and one-third at 1-10% illuminance when compared with stations sampled on the West Florida Shelf (Fausak, 1979).

4.5.5 THERMAL FEATURES

The recent use of surface temperature data from remote sensing (satellite imagery) provides a prominent surface expression of important oceanographic processes. River and estuarine discharges, coastal and shelf waters, offshore Gulf water, and the Loop Current appear as thermally differentiated water masses.

Huh et al. (1978) describe a seasonal cycle that exists in the horizontal surface temperature structure in the northern Gulf of Mexico. The surface and subsurface temperatures of the coastal bays, shelf waters, and deep water Gulf are uniform horizontally during the warm summer season (Etter and Cochrane, 1975). Major cold fronts begin to move through across the Gulf during the fall, which results in the lowering of the surface temperature of coastal lakes and bays. The maximum thermal contrasts of winter occur where

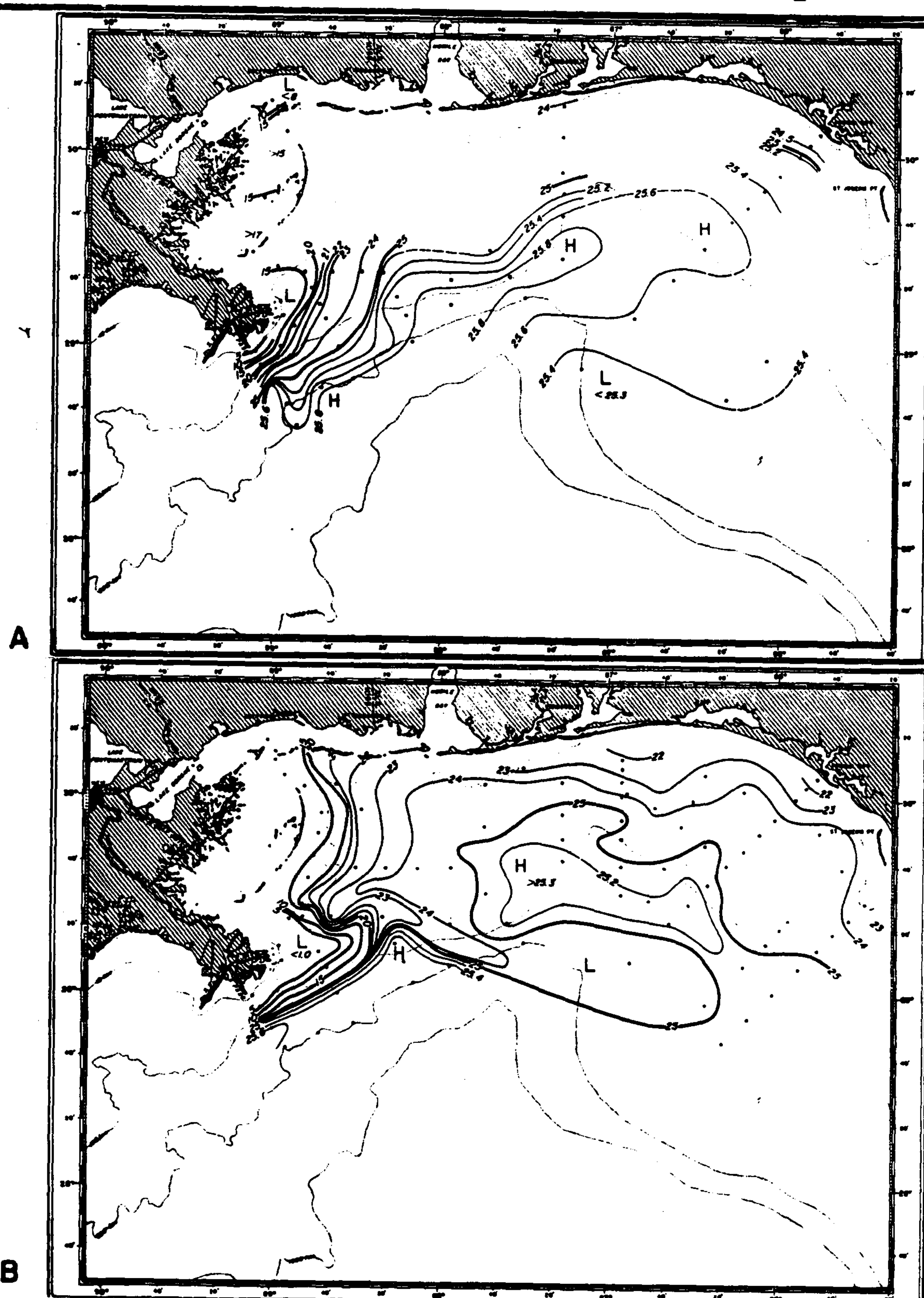


Figure 4.16 Distribution of surface density (σ_T) in the notheastern Gulf of Mexico; A) April 10-12, 1964, B) March 31-April 9, 1965. (Source: Drennan, 1968).

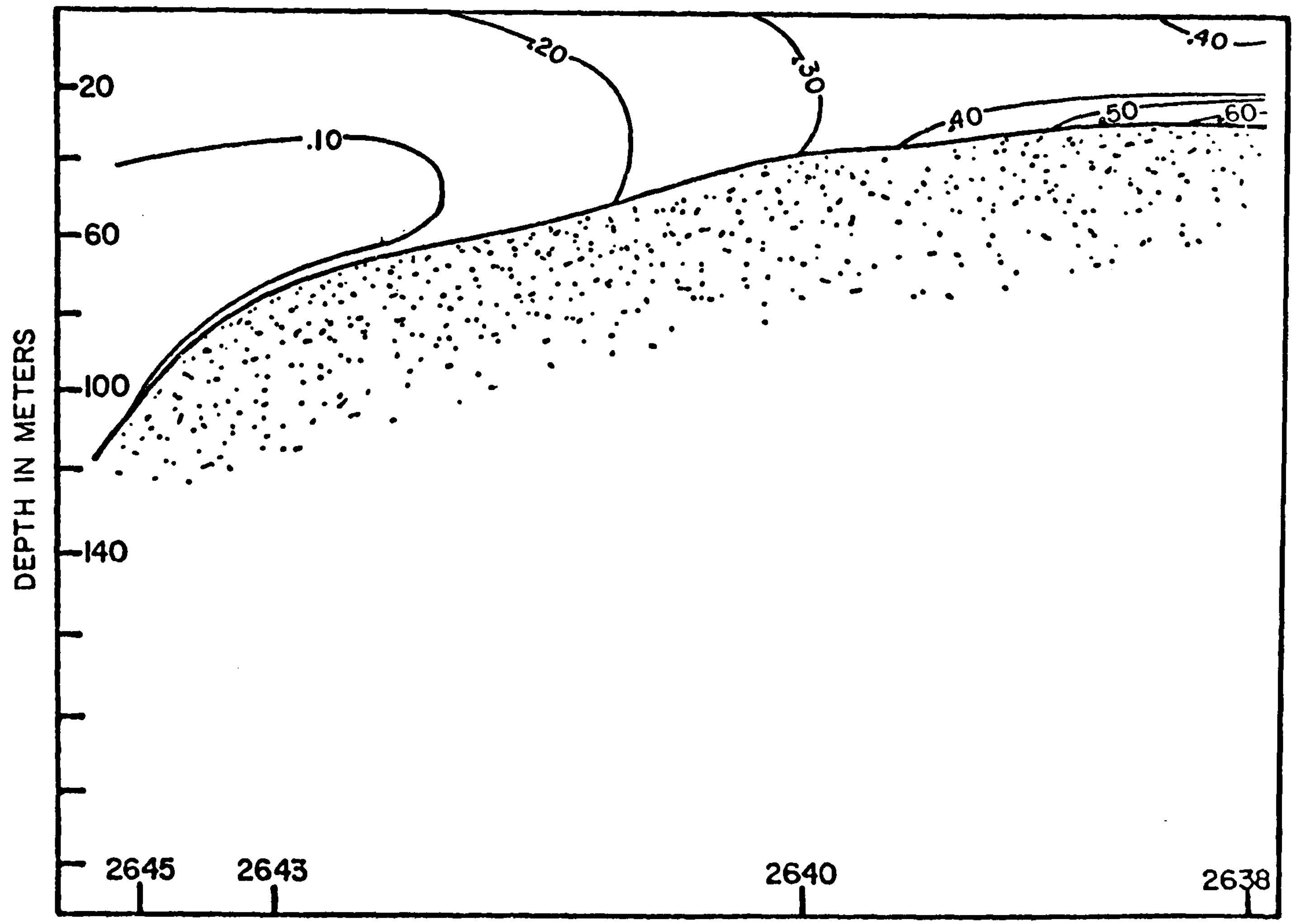


Figure 4.17 Turbidity values (c_p = attenuation coefficient) along a transect on the Mississippi-Alabama shelf beginning south of Mobile Bay, 1976. (Source: Carder and Haddad, 1979)

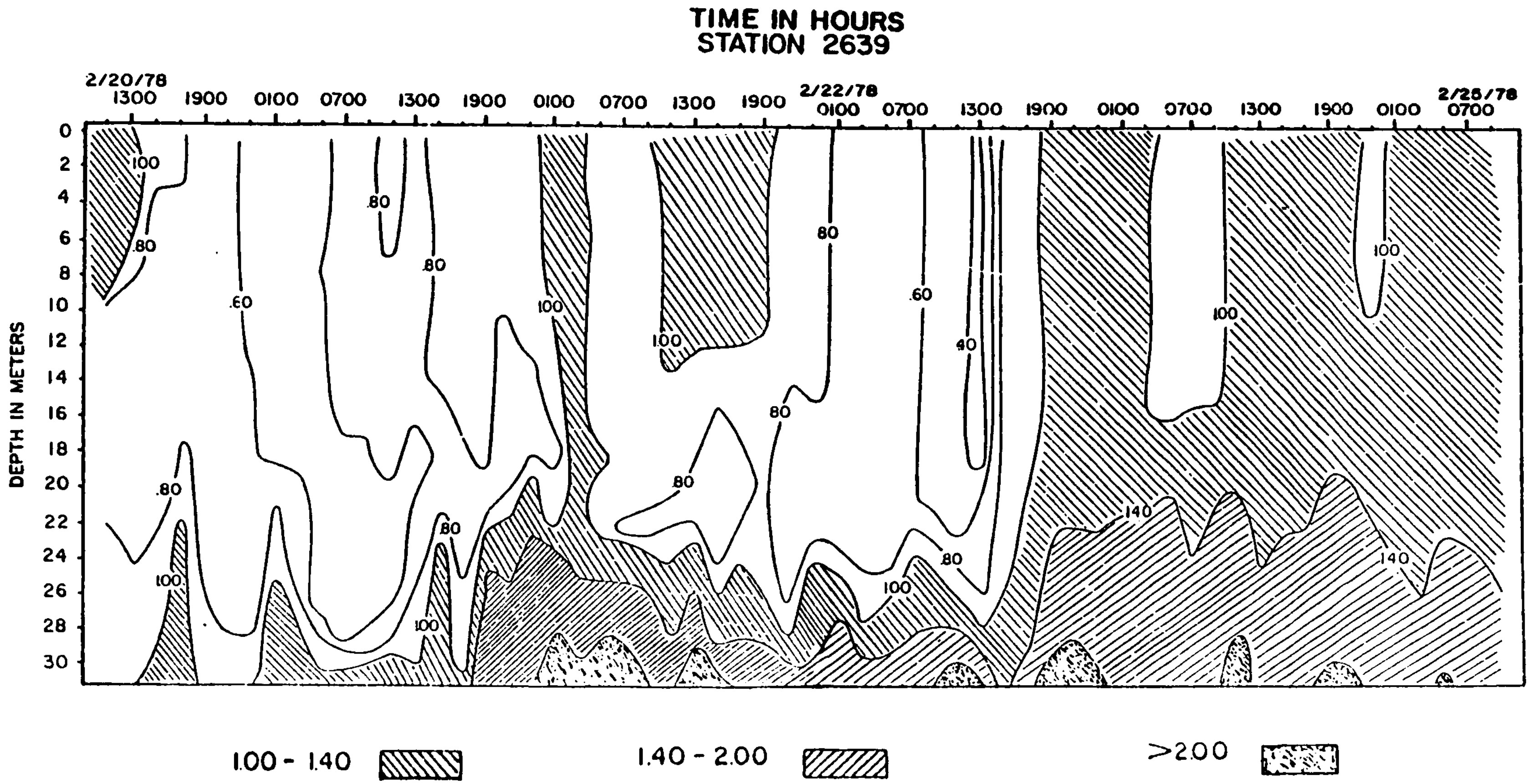


Figure 4.18 Results of time series plots of turbidity (c_p) for a station located south of Mobile Bay (30 m depth), winter 1978. (Source: Carder and Haddad, 1979)

the cool estuarine discharge of plumes overrun the still warmer inner shelf waters. The horizontal temperature gradients remain weak within the yet uncooled offshore waters. The locations of thermal oceanic fronts are controlled by bathymetry, with the shallow shelf areas (e.g., east of the Mississippi River) cooling quickest.

As the cold, dry winter air masses pass over the Gulf waters, the increase in density of surface waters which results from heat loss and evaporation (and thereby increases salinity) initiates penetrative convective mixing which dissipates stratification. The surface temperatures become more representative of the resulting isothermal water column. With the passage of successive cold fronts, inner shelf waters along the coast cool until an oceanic thermal front develops between the cold shelf waters and the warmer deep Gulf waters approximately along the 100 m isobath. Thus, three distinctive regions are present: the cold shelf waters, the warmer deep Gulf waters, and the equatorial waters of the Loop Current (Huh et al., 1978).

Mesoscale irregularities that develop along the oceanic thermal fronts between the shelf waters and those of the Open Gulf are poorly understood. Possible mechanisms include horizontal eddy motion, intrusions of surface water driven by strong winds, overrunning of strong offshore currents, and internal density cascading (i.e., downslope flow of colder, denser water from the shelf with a compensating landward flow of warmer offshore surface water) (Huh et al., 1978).

The Gulf water begins to warm as the strength of the polar air masses decreases during spring. Again, the shallow waters in the coastal lakes and bays and along the shoreline respond first to the general warming trend. As the length of days increases and the air temperatures rise, the waters of the Gulf return to the warm season conditions of summer. However, the warming process in the spring may be modified by occasional inputs of very cold fresh water resulting from seasonal snow melts in the Mississippi drainage basin.

In an evaluation of heat and freshwater budgets for the Gulf of Mexico, Etter (1983) reviewed vertical temperature data (bathythermographs) to depths of 200 m in order to calculate monthly mean oceanic heat storage rates (Q_T). Spatial distributions of Q_T contoured on maps for February, May, August, and November elucidate climatic features of air-sea interactions occurring over the Loop Current and near the shelf edges of the northern Gulf (Figure 4.19). The area on the outer Mississippi-Alabama shelf is characterized by relatively intense heat gain in May and August (Figures 4.19b,c) and intense heat loss is significant in that it coincides with the occurrence of episodic cold air outbreaks over this area of the Gulf as described by Nowlin and Parker (1974), Henry and Thompson (1976), and Huh et al. (1978).

4.6 CURRENTS AND CIRCULATION

4.6.1 GULF CIRCULATION

The Gulf of Mexico is a restricted basin with connections to the Caribbean Sea through the Yucatan Strait and the Atlantic Ocean through the Straits of Florida. The restricted channels and broad shelf areas (i.e., Campeche, Texas-Louisiana, and West Florida) profoundly affect water mass characteristics and circulation patterns through channelization and friction

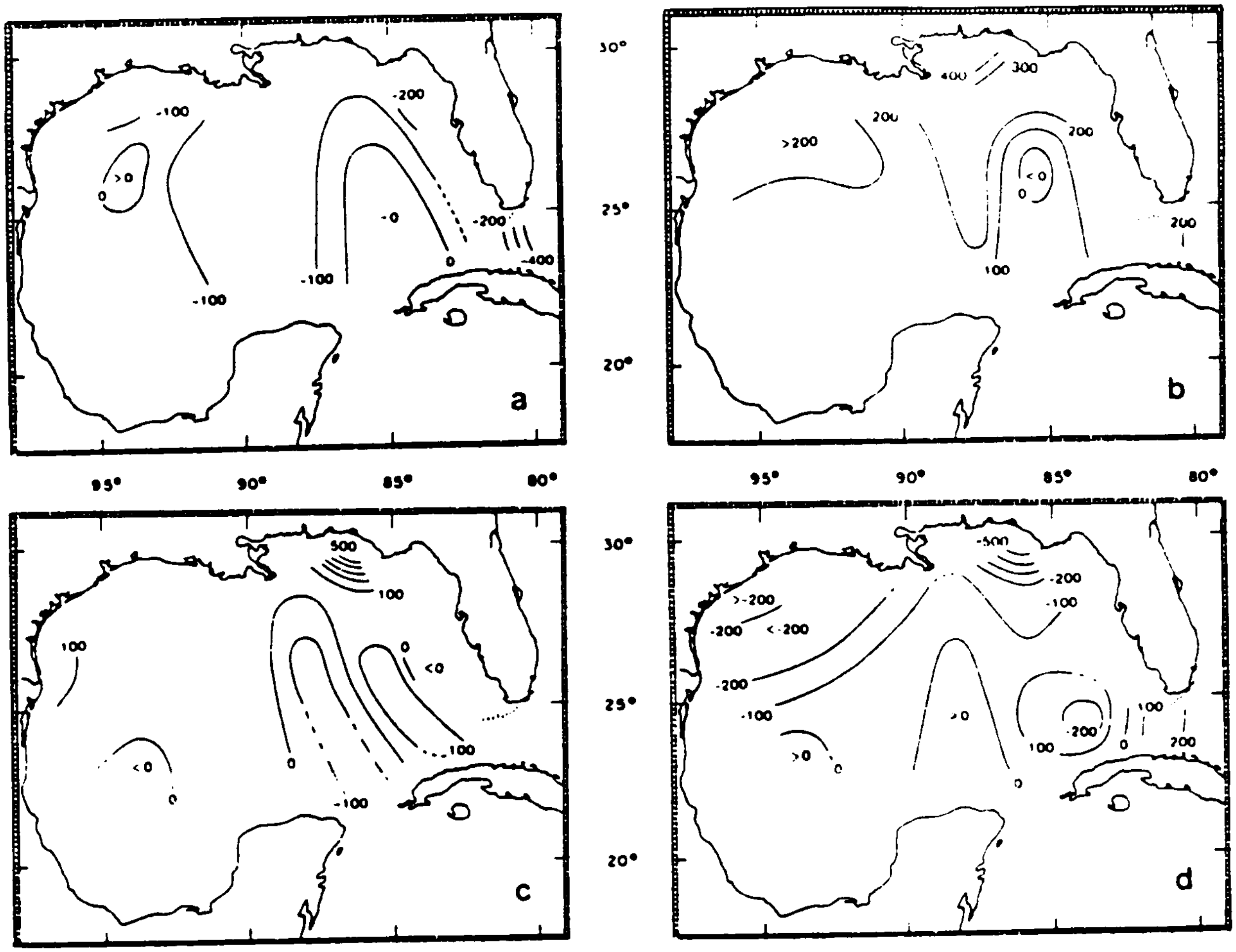


Figure 4.19 Contours of the rate of oceanic heat storage (Q_T) in the Gulf of Mexico; a) February, b) May, c) August, d) November. Units are W m^{-2}. (Source: Etter, 1983).

with the seafloor. Descriptions of water mass characteristics for the Gulf of Mexico are found in Nowlin (1971, 1972), Jones et al. (1973), SUSIO (1975), Caruthers (1972), and Ichiye (1962). Vertical profiles of temperature, salinity, and oxygen concentrations which are representative of the Gulf waters are presented in Figure 4.20. Since the Tuscaloosa Trend study area lies inshore of the 200 m isobath, the only water masses expected to be encountered are the surface-mixed layer and the subtropical underwater (Nowlin, 1971).

The dominant circulation feature of the Gulf of Mexico is the anticyclonic Gulf Loop Current. This current is formed as the Caribbean Current enters the eastern Gulf through the Yucatan Channel, intrudes northward and becomes the eastern Gulf Loop Current which subsequently progresses into the Straits of Florida to form a segment of the Gulf Stream (Figure 4.21). This current occupies a band 90 to 150 km wide and travels at 0.5 to $2m^{-1}$ transporting 25 to 30 million cubic meters of water per second. This transport is one-third that of the Gulf Stream in the Atlantic (Leipper, 1970). The existence of this current has been known for years and intensively studied since the late 1960's. Leipper (1967) noted that the clockwise current dominates the circulation pattern in the eastern Gulf and probably generates the more or less permanent eddy centered over the western Gulf, as well as many minor migratory loops to at least the depth of the Subantarctic Intermediate Water. Leipper's (1970) use of the depth of the 22° isotherm between 150 and 200 m to locate the Loop Current indicated that seasonal changes occurred in the current patterns. He found a progressive northward intrusion of the Loop Current in spring and early summer that extended up to the continental shelf off the Mississippi River, and the subsequent formation, detachment, and westward migration of a separate eddy. These general findings have been supported by later investigations (Morrison and Nowlin, 1977; Maul, 1977; Molinari et al., 1977). Molinari et al. (1975) defined the Loop Current as waters within the eastern Gulf of Mexico having salinities greater than 36 $^{o}/oo$. The existence and position of the Loop Current has also been shown through studies of plankton (i.e., plankton are concentrated along the interface of the Loop Current) and suspended partical concentrations in surface waters (Jones et al., 1973; Carder and Schlemmer, 1973). Recent investigations have used satellite and other remote-sensing data of sea surface temperatures to delineate Loop Current positions (Vukovich et al., 1979; Huh et al., 1981; Molinari and Mayer, 1982). Sturges and Evans (1983) found that the north-south fluctuations in Loop Current position are correlated with sea level at the coast and presumably with coastal currents.

Although the Loop Current most directly affects the water mass characteristics of the West Florida Shelf, there are periods when the northern intrusion of the current affects oceanographic conditions on the continental shelf within the Tuscaloosa Trend study area (Gaul, 1967; Ichiye et al., 1973, Huh et al., 1981; Molinari and Mayer, 1982). Such an intrusion would be a major mechanism for sudden modification of coastal and shelf waters and development of oceanic fronts in the northern Gulf. It is suggested that the DeSoto Canyon acts as a conduit for these northward intrusions (Huh et al., 1981).

Huh et al. (1981) present evidence of an intrusion of the Loop Current into the study area during February 1977. Based on satellite imagery data, the northern edge of the Loop Current (16.5°C isotherm) was 200 km offshore on February 1 (Figure 4.22a), but a shelfward intrusion was apparent by February 5 (Figure 4.22b). By February 11 it had spread along the continental

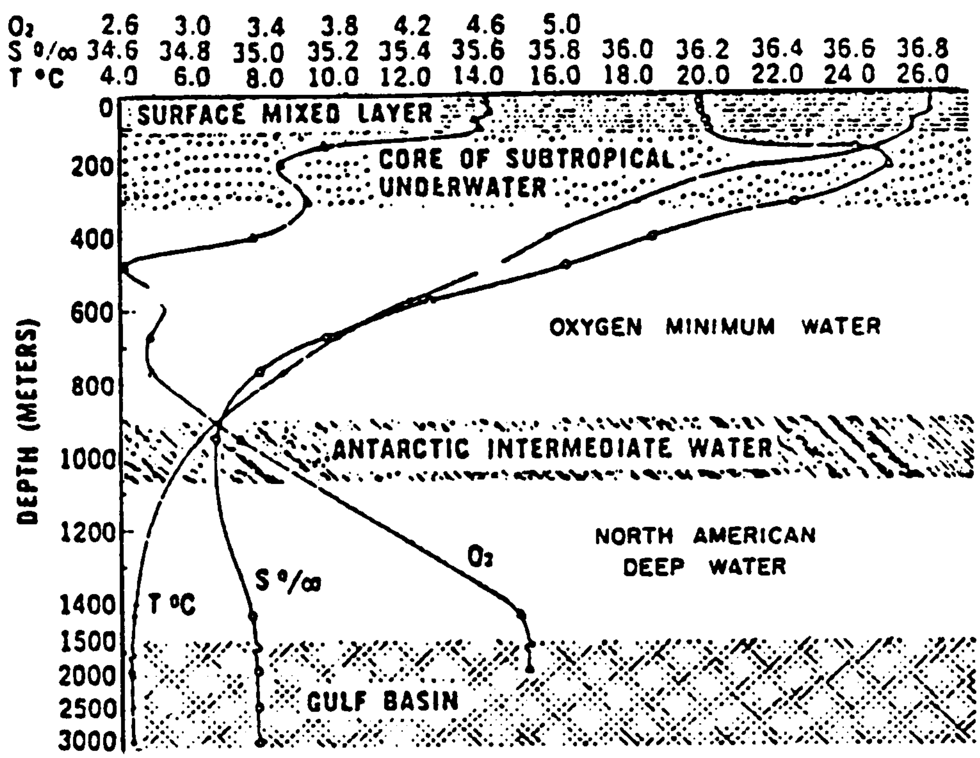


Figure 4.20 Water mass identification in the Gulf of Mexico through temperature, salinity, and oxygen profiles (Source: Nowlin, 1971).

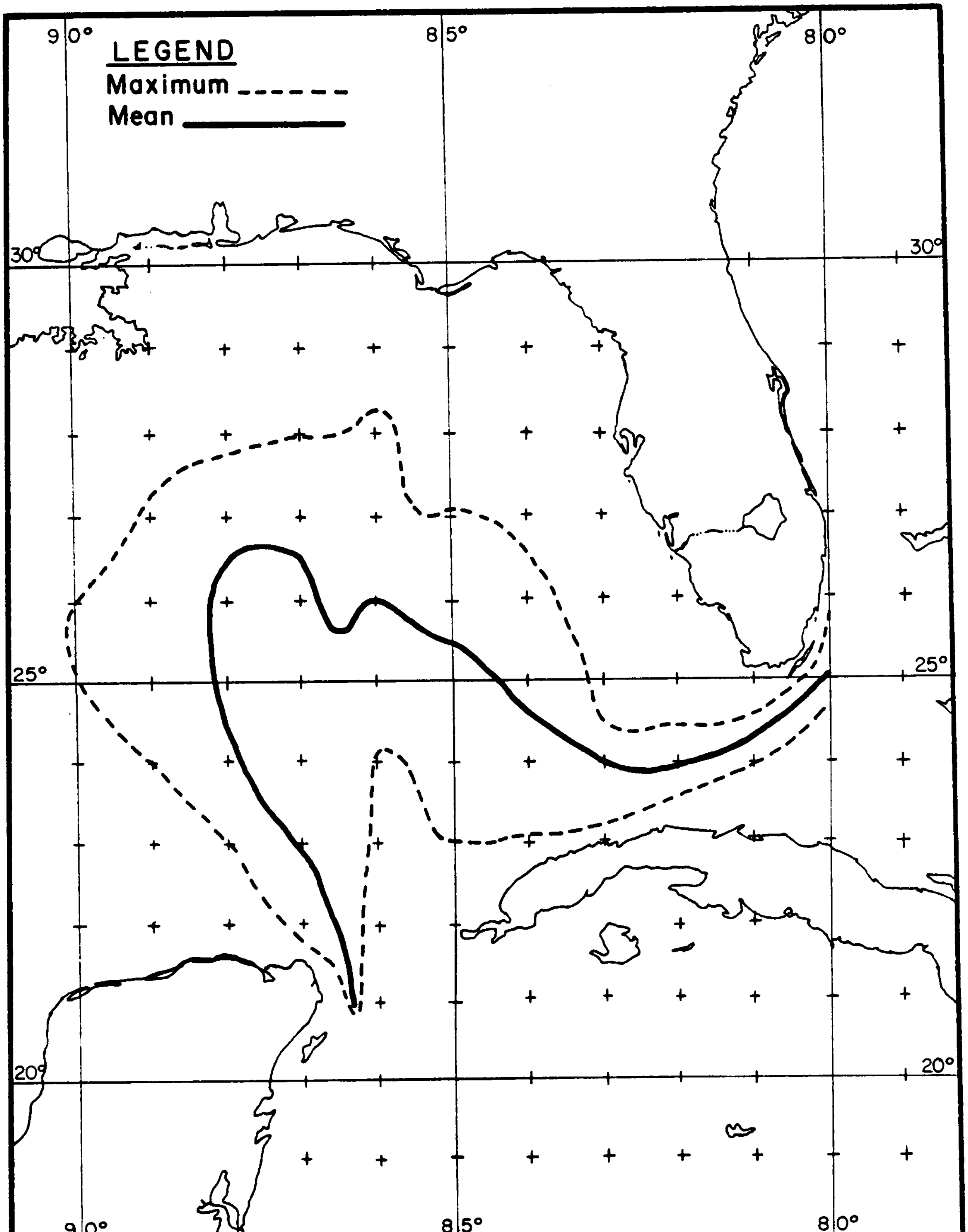


Figure 4.21 Gulf Stream landward surface edge statistical curves. Mean and maximum observations of the Loop Current during 1980-1981. (Source: Auer, 1983)

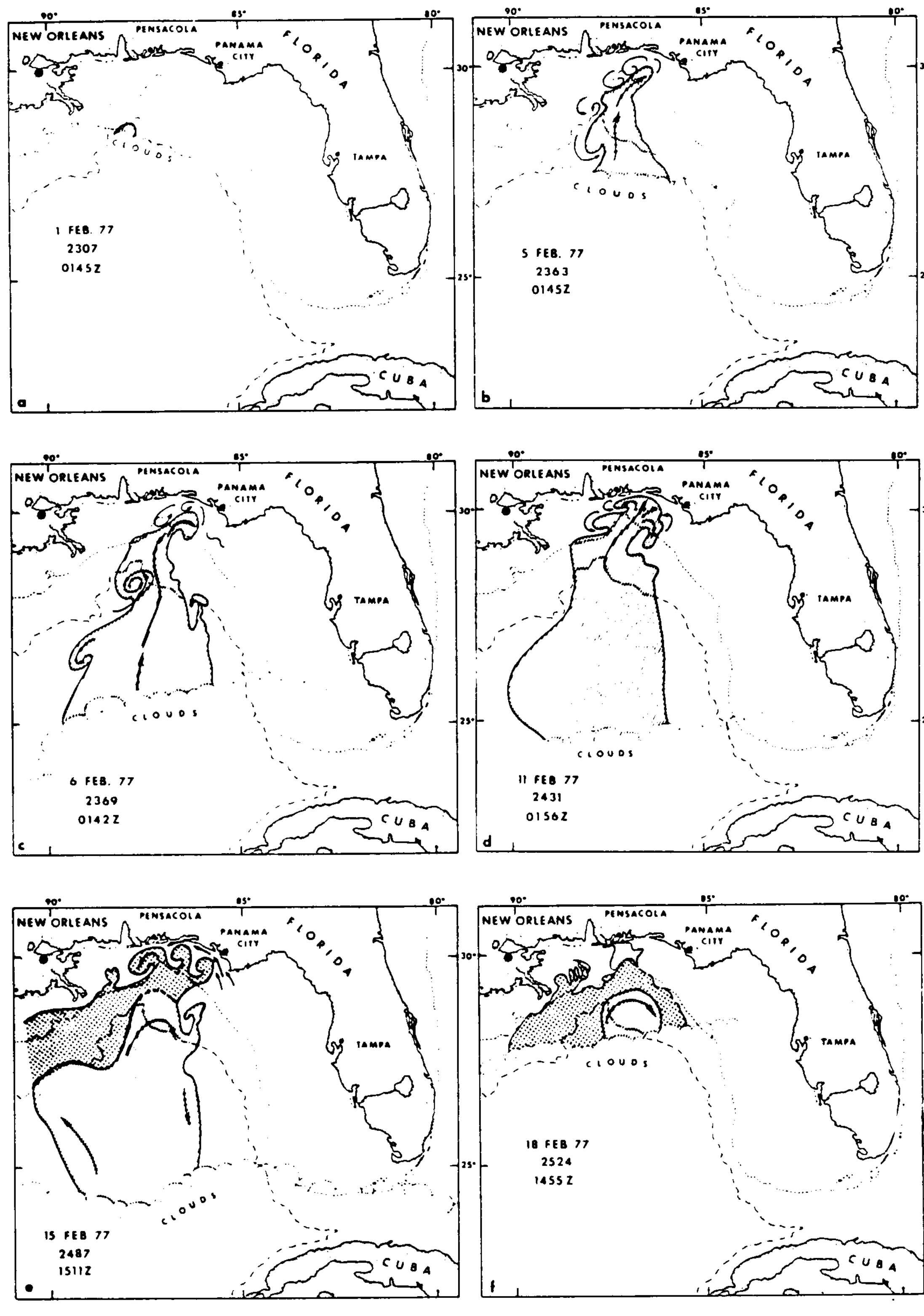


Figure 4.22 Interpretation of satellite infrared imagery: a) before intrusion; b) onset of intrusion; c) & d) shelfward extension of intrusion; e) westward advance of shelf waters; and f) fading of plume (Source: Huh et al., 1981).

shelf near the head of the DeSoto Canyon, with a 90 km wide arcuate front that came within 8 km of the northwest Florida coast (Figure 4.22d). It reached as far north as 30°14'N latitude, into water depths of 18 m, and covered 6650 km^2 of the shelf. By February 15 the eastern part appeared to be forced from the shelf by westward advection of the adjacent shelf waters (Figure 4.22e). And by February 18 the remaining section of the intrusion seemed to have been cooled *in situ* through vertical mixing or heat loss to the atmosphere (Figure 4.22f).

The effect of upwelling, the vertical motion of bringing subsurface water toward the surface, can exert a significant influence on meteorological conditions along a coast, as well as introduce quantities of nutrients (i.e., phosphates, nitrates, etc.) to the euphotic zone, thereby enhancing productivity of the surrounding waters. Areas of upwelling in the Gulf of Mexico are generally along the outer margins of the Loop Current (Bogdanov et al., 1968). It is suggested that upwelling associated with the Loop Current also occurs in the DeSoto Canyon area (Jones, 1973).

4.6.2 CONTINENTAL SHELF CIRCULATION

Outer Shelf

Circulation on the continental shelf in the northern Gulf of Mexico is strongly influenced by four factors: open Gulf circulation (e.g., the Loop Current), winds, tides, and freshwater discharge from rivers. When the Loop Current is present on the shelf it will dominate circulation. In addition, when the Loop Current is further offshore it may be the driving force of a counterclockwise circulation.

Sustained winds tend to be the dominant driving force of the circulation on the inner continental shelf. Wind-driven circulation is caused by frictional drag of the air as it passes over the surface of the water. In deep water far from coasts, surface currents in the Northern Hemisphere are deflected 45° to the right of the wind direction; this deflection continues to rotate clockwise as depth increases, forming the logarithmic Ekman spiral. In shallow waters far from coasts, the same balance of forces produces a deflection to the right, but the angle between wind and surface current is less than 45°. In water depths of 5 to 10 m the maximum deflection with depth is 5-10°.

In the case of an onshore wind in shallow water, the surface waters will tend to flow with the wind direction while bottom waters tend to flow offshore following a seaward-directed pressure gradient induced by an elevation of the water level near the coast. The presence of other forces can alter this scheme dramatically. If a horizontal density gradient is present in the bottom waters, such that lighter water lies near the coastline, the density current will oppose and perhaps reverse the effect of an onshore wind on the current field. Similarly, offshore winds will drive light (and/or low salinity) surface waters away from the coast, resulting in the upwelling of heavier bottom water. The horizontal density gradient which results is confined to the surface layer and directed offshore as a density current.

Due to their complexity and seasonal variability, currents on the continental shelf in the Tuscaloosa Trend study region are not well described. However, general understanding of the overall patterns can be derived from the works of Chew et al. (1962), Drennan (1963, 1968), Gaul (1967), Ichiye et al. (1973), Schroeder (1976), Kjerfve and Sneed (1984), Murray (1972, 1975), Molinari and Mayer (1982), and Chuang et al. (1982).

Drift-bottle studies conducted in the 1960's in the north and eastern Gulf of Mexico not only indicated the prevailing surface circulation pattern and its seasonal variation, but also provided evidence for the existence of subsurface water movements toward the northern Gulf. From a release of 11,088 bottles off the Mississippi Delta passes, 1514 bottles were recovered; 69 percent were found west of the Delta (Chew et al., 1962). The majority of the bottles that drifted west were released from Pass A Loutre, and most bottles released farther offshore (56 km) went east, indicating the existence of a narrow westbound current close to the Delta and, farther from shore, an eastbound current, perhaps the Loop Current. Drift bottles released during late spring and early summer from Stage I platform located 20 km offshore from Panama City, Florida were found primarily along local northwest Florida beaches (Tolbert and Salsman, 1964). However, the recovery zone shifted westward toward Alabama and Mississippi coasts during late summer and early fall, coinciding with the peak frequency in the westward-flowing wind component.

Later, oceanographic investigations were conducted on the continental slope south of Mobile near the head of the DeSoto Canyon (Figure 4.23) as part of NOAA's Atlantic Oceanographic and Meteorological Laboratories (AOML) Ocean Thermal Energy Conversion (OTEC) study (Molinari et al., 1979a). Current meter observations at depths of 90, 190, and 980 m from July 1977 through August 1978 provide data of oceanic water movement onto the continental shelf (Molinari et al., 1979b; Thomas et al., 1979). At 90 and 190 m, the flow was, on the average, to the east; however, sustained periods of flow to the west were observed during the summer of 1977 and spring of 1978. During periods of eastward flow, the wind was generally out of the north, while during periods of westward flow, the wind was from the east (Molinari and Mayer, 1982).

The seasonal cycle of mean flow is perturbed by events associated with the Loop Current. The northern boundary of the Loop intrusion in 1978 was responsible for the reversal of westward flow established during the spring (Molinari and Mayer, 1982). In addition, little energy was associated with barotropic tides. Maximum diurnal energy occurred near the local inertial frequency at the upper levels, probably induced by either cold front passages or other atmospheric events (Molinari and Mayer, 1982).

Inner Shelf

Examples of current profiles from a site in shallow (15.6 m) waters of the western Tuscaloosa Trend study area east of Main Pass of the Mississippi River Delta are presented in Figure 4.23 (Murray, 1972). After removal of the tidal current of approximately 15 $cm \cdot s^{-1}$, the influence of wind and horizontal density gradients are of great importance to current structure on the shelf. A strong onshore wind (i.e., from the southeast) results in a transient two-layer flow in the cross-shelf direction (i.e., vertical circulation patterns with onshore flow in the surface waters and offshore flow in the bottom waters). Subsequent to this onshore wind, strong south to southwesterly setting currents persist, establishing a relatively stable flow pattern.

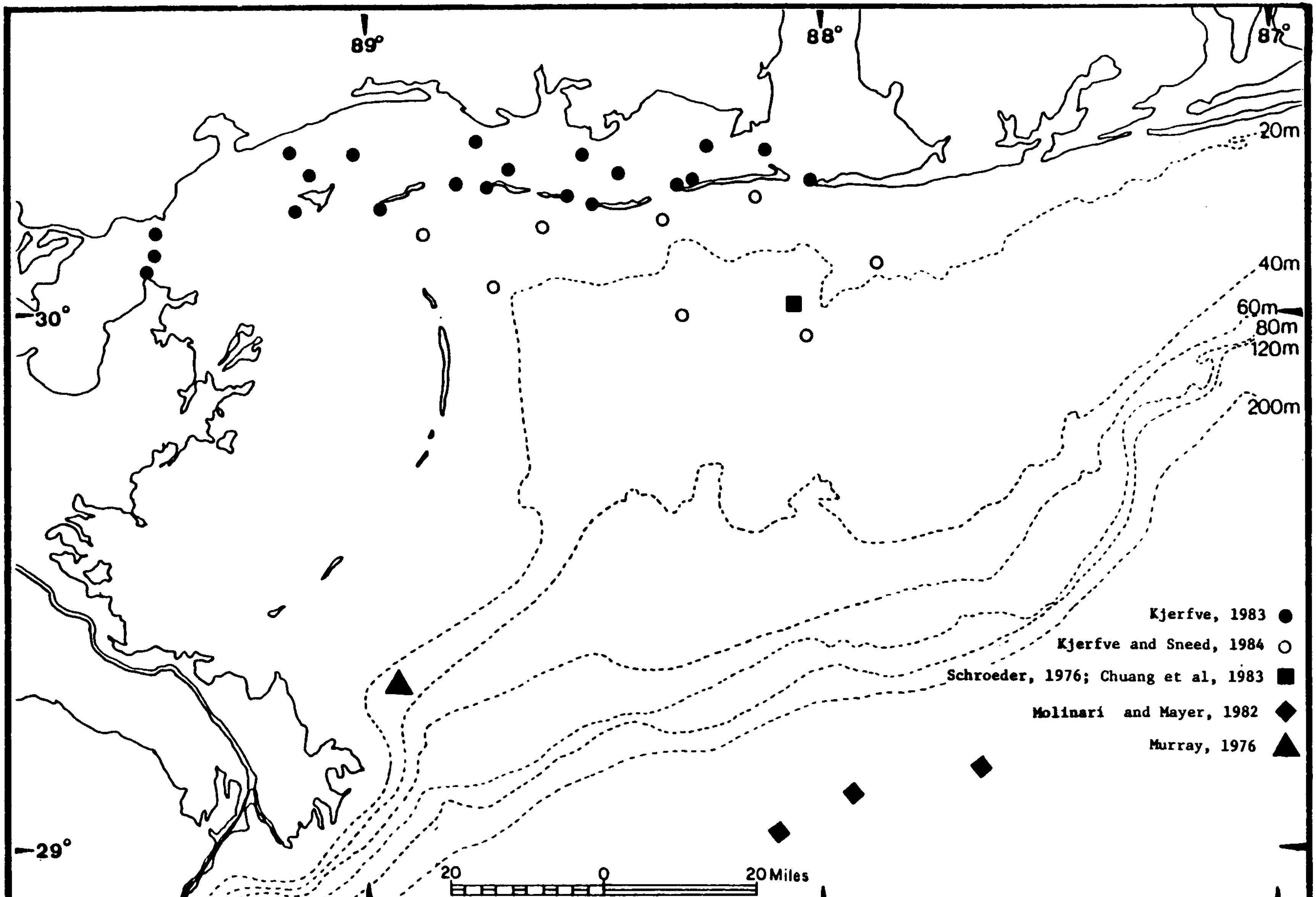


Figure 4.23 Locations of current meter moorings for the significant studies conducted in the Tuscaloosa Trend study area.

The shoreline variation in coastal geometry plays a large role in controlling circulation patterns on the shelf (Murray, 1976 and Chuang et al., 1982). The 90° angle of the coastline and broad shallow shelf of the Tuscaloosa Trend region are found nowhere else in the northern Gulf of Mexico, excepting perehaps the Big Bend are of Florida. This introduces a possible deflection variable for discussion of alongshore current variation and enhancement of localized eddy formation.

Variations in frequency response indicate that circulation is strongly affected by the wind duration, density stratification, and coastal geometry (Chuang et al., 1982). The shelf water response to local wind forcing is frequency dependent, whereby alongshore current and sea level are driven by alongshore wind at time scales longer than a week. Chuang et al. (1982) found that since the mean wind varied between the three summer seasons studies (1976, 1978, and 1979), a permanent summer circulation pattern would not be determined. They concluded that a net flow in either longshore direction is possible. In addition, the cross-shelf motion is generally negligible when the alongshore flow is to the west. However, a persistent offshore motion is associated with an eastward flow, as observed during the occurrence of a mean easterly directed summer wind and an apparent strong northward intrusion of the Loop Current in 1976 (Vukovich et al., 1979). This aperiodic reversal of flow along the shelf break has been inferred from drift bottle returns (Ichiye et al., 1973).

In his studies of the influence of wind on shelf circulation, Schroeder (1976, 1977a) shows a very close correlation of bottom flow with the Ekman spiral. Analysis of current data collected 26 km south of Mobile Bay shows the tendency of near-bottom waters to be transported about 90 degrees to the right of sustained wind direction. During July 1976, prevailing winds were to the north and northeast (Figure 4.24a) with near-bottom currents to the east and southeast. During November 1976, prevailing winds were to the south with a prevailing near-bottom current direction to the west (Figure 4.24b). Poor correlation between wind and near-bottom current was also noted, which may occur when winds are not of consistent direction or duration to produce a sustained current direction, or when Ekman transport of bottom waters is directed toward a barrier (i.e., shoals or barrier island). This may occur in the study area when northeast, east, or southeast winds tend to move bottom waters shoreward. This shoreward movement is hindered by barrier islands and thus the bottom water will be turned and will flow along the isobaths. Similarly, when westward-flowing water approaches the Chandeleur Islands it is diverted southward along the curve of the isobaths.

The vertical structure and overall current pattern along the nearshore area of Mississippi and Alabama is considered a two season event with transitional periods (Kjerfve and Sneed, 1984). Winter, with frequent energetic storms and low freshwater inputs, is characterized by a well-mixed water column. The regional winter current pattern is dominated by alongshore currents flowing to the west in response to the strong offshore-directed mean winds. In spring, increased freshwater runoff, coupled with a reduction in mixing energy as a result of fewer and less intense storms, results in the development of a partially stratified water column. Once initiated, stratification is maintained through the summer by solar heating of the surface waters and a further reduction of storm-derived mixing. With the reversal and reduction in strength of the prevailing winds to onshore conditions, the regional circulation can reverse to exhibit alongshore movement towards the east.

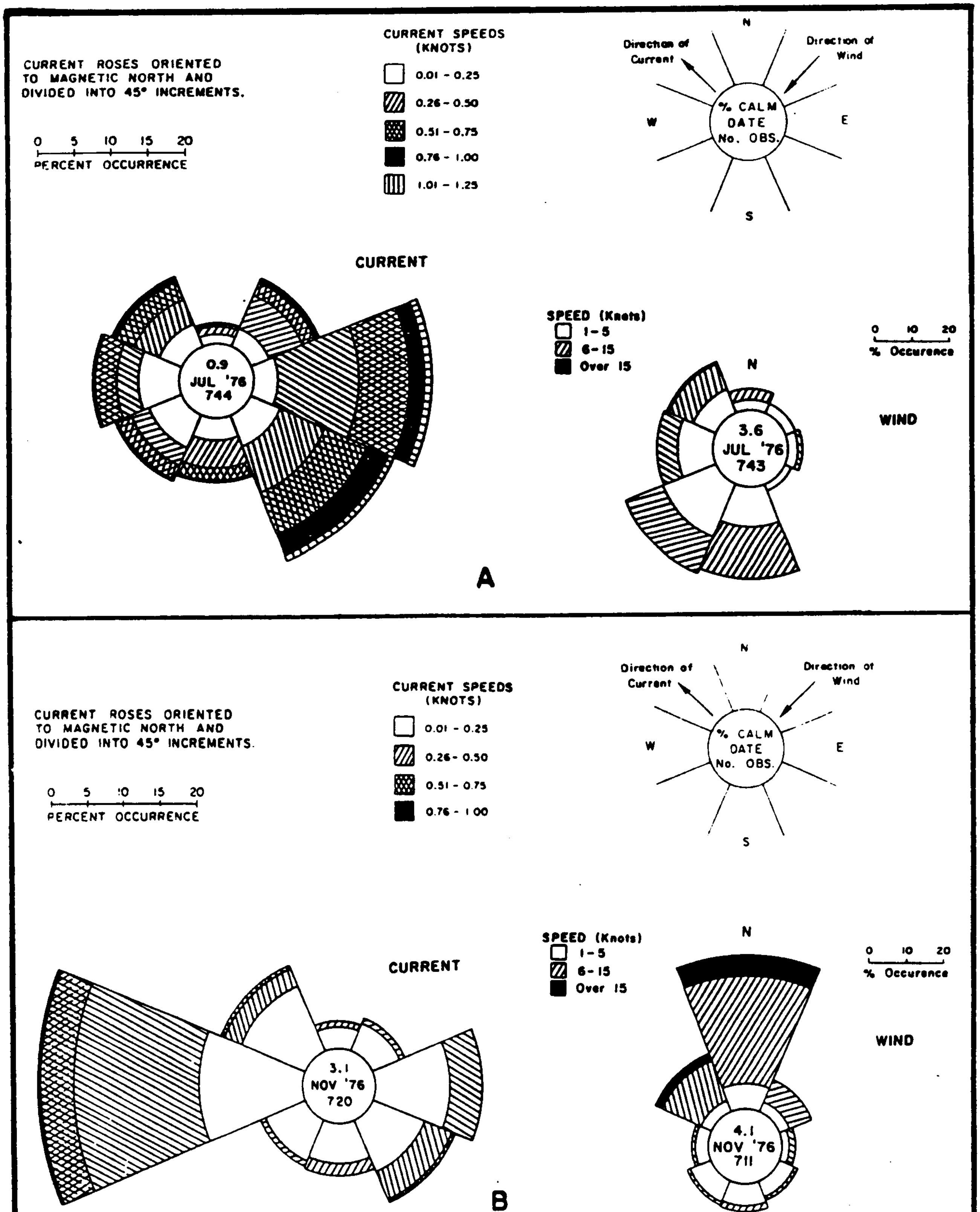


Figure 4.24 Wind and near-bottom current roses for July and November, 1976 (adapted from Schroeder, 1976).

Kjerfve and Sneed (1984) further document the seasonal differences in oceanographic conditions in the study area during a one year investigation (1980-81) offshore of coastal Mississippi and Alabama, based on three 45-day deployment periods at eight current meter stations (surface and bottom) (Figure 4.23). The mean currents for each of the three current meter deployments, indicated in Figure 4.25 as mean vectors, have different overall current characteristics. During the November 1980 - January 1981 deployment (A), mean surface flow was towards the west with bottom currents flowing north and west away from the barrier islands. During the March-May 1981 deployment (B), surface currents were largely to the east with bottom currents to the north at six of the eight stations. During the July-September 1981 deployment (C), both surface and bottom currents were largely directed towards the west.

Although tidal currents are considered the most energetic currents observed on the shallow shelf, Kjerfve and Sneed (1984) concur that non-tidal wind-induced circulation is the principal driving force of low frequency circulation. In an attempt to generalize predictions of surface and bottom flow directions based on meteorological and current data of Schroeder (1976, 1977a, unpublished data), TerEco (1978) constructed probable current regimes on the shallow Mississippi-Alabama shelf during specified sustained wind conditions. The circulation patterns as shown do not take into account open Gulf influence, density currents, or storm conditions.

With sustained winds from the west, northwest, north, or northeast, the estimated average near-bottom current speed as measured at Anderson Reef in 20 m water depth is 20 $cm \cdot s^{-1}$ and the maximum sustained hourly speed is 46 $cm \cdot s^{-1}$ (TerEco, 1978). During northeast winds there is a tendency for bottom water to move shoreward; however, bottom topography causes this portion of the flow to turn westerly along the shelf. When the westward-moving bottom flow approaches the shoal area off the Chandeleur Islands, the flow is probably diverted southward.

When winds are sustained from the southeast, south, southwest, or west, the estimated average near-bottom current speed is 26 $cm \cdot s^{-1}$ and the maximum sustained hourly speed is 60 $cm \cdot s^{-1}$. During periods of sustained southeast winds, bottom water tends to move shoreward; however, bottom topography probably causes that portion of the flow to turn eastward.

Sustained winds from the northeast, east, or southeast yield an estimated average near-bottom current speed of 26 $cm \cdot s^{-1}$ and a maximum sustained hourly speed of 60 $cm \cdot s^{-1}$. Under these wind conditions there may be a tendency for bottom and surface waters to flow shoreward, resulting in an accumulation of water along the coast. The accumulated water will generally inhibit further shoreward movement and may result in bottom transport parallel to shore in the direction of the wind. If winds are sufficiently strong, this accumulated water along the coast may force bottom water away from shore.

4.6.3 NEARSHORE PROCESSES

During an investigation of the well-known Chevron oil spill off Main Pass east of the Mississippi Delta in 1970, Murray (1972), 1975) and Murray et al. (1970) found density stratification to be common along the southeastern Louisiana coast. As noted in Figure 4.26a, sharply plunging isopycnals (noon until about 0300 March 17) indicate that fresher, less dense water has moved across the profile. Later, a sharp rise in the isopycnals reflect increased

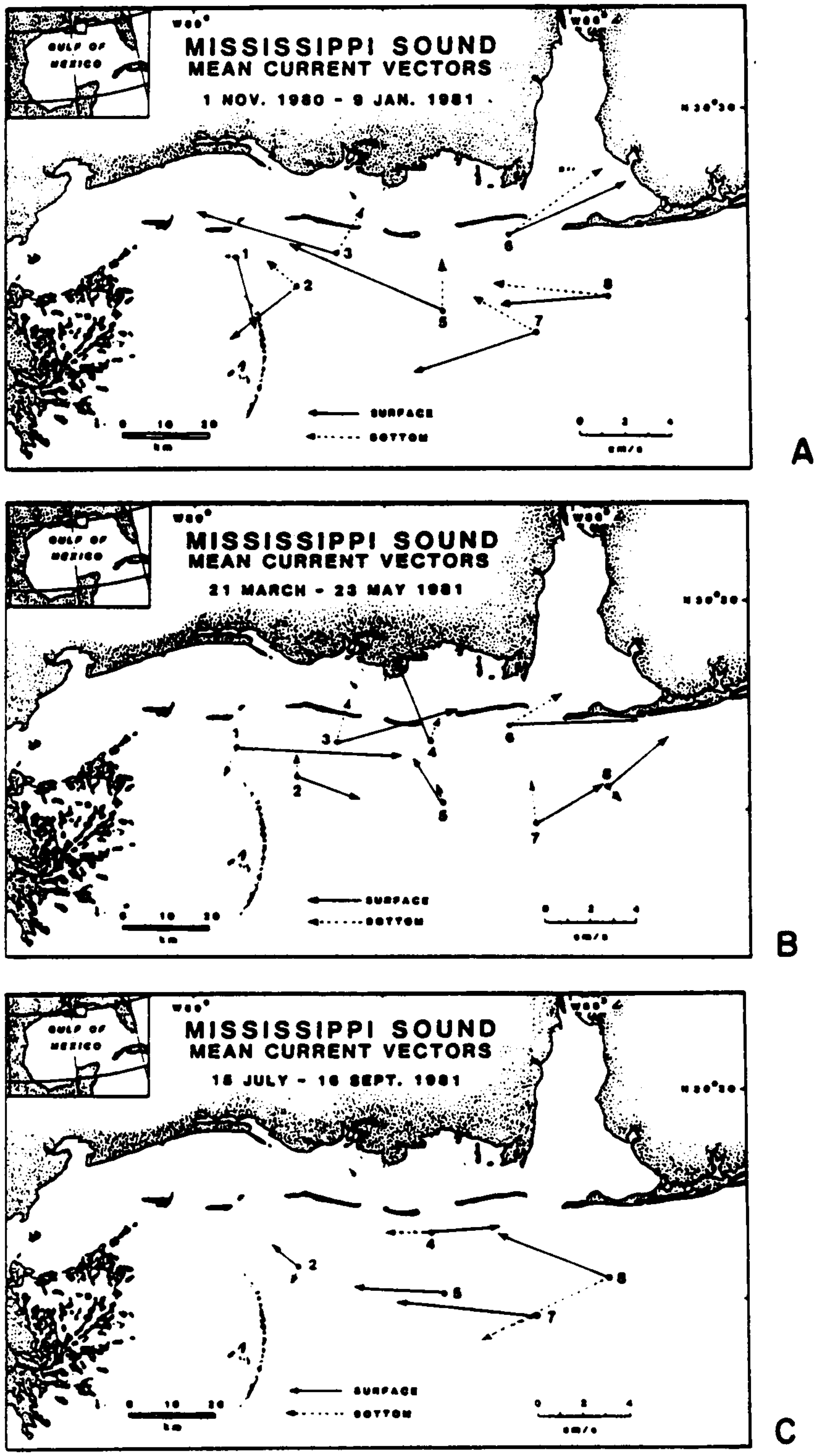


Figure 4.25 Resultant surface and bottom current vectors for moorings in the Mississippi Sound Offshore study area for deployments A,B,and C (Source: Kjerfve and Sneed, 1984).

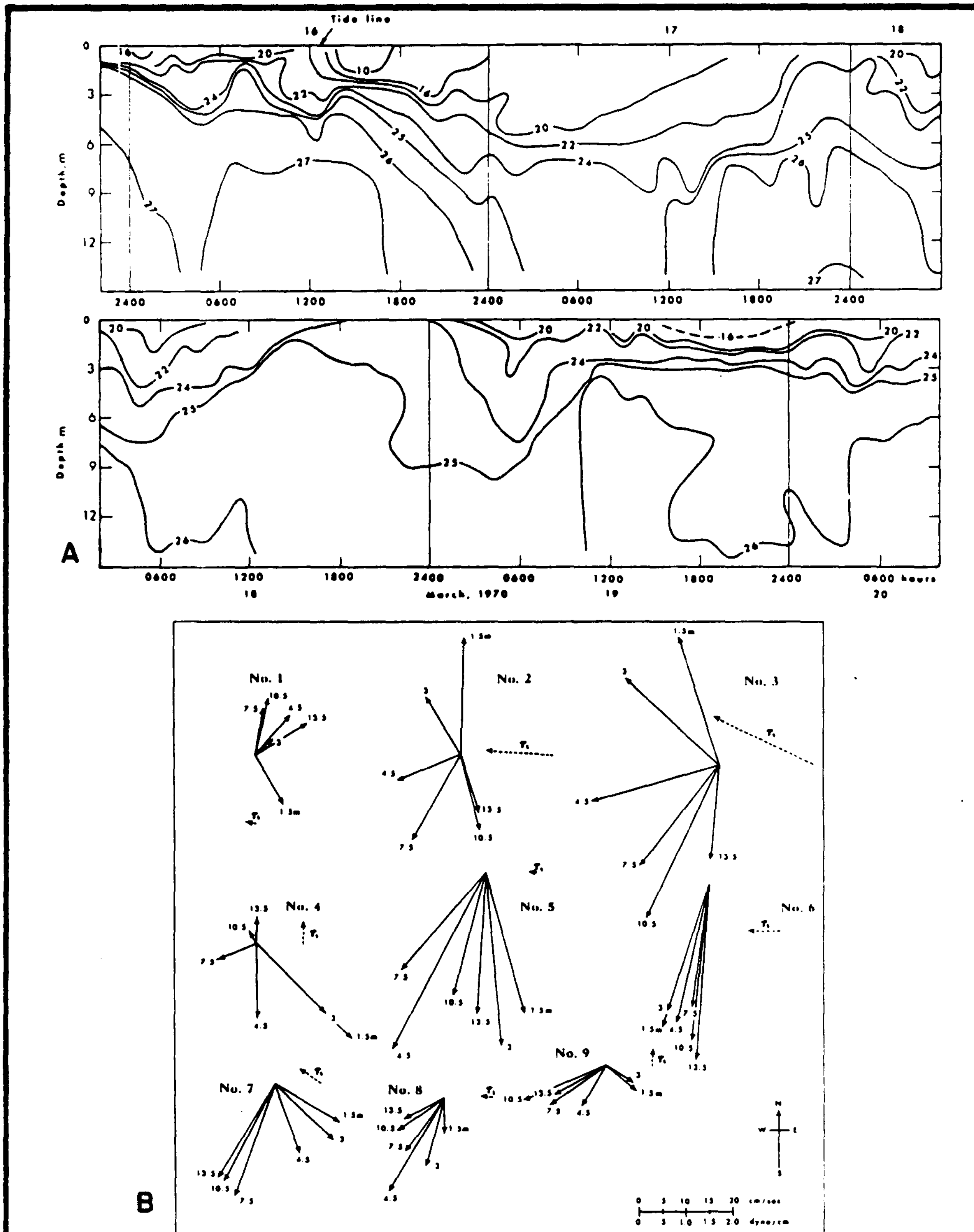


Figure 4.26 A) Time series plot of isopycnals (σ_t) 15 km east of the Mississippi Delta; B) Vertical profiles of currents and wind stress (T_S) during (A). (Source: Murray, 1976)

salinity. Simultaneous vertical profiles of currents and surface wind stress (Figure 4.26b) indicate that when isopycnals plunged, there was a corresponding strong easterly and southeasterly wind blowing the brackish surface water toward the coast and driving the higher salinity water offshore. A sudden drop in wind stress (Figure 4.26b, episode No. 4) reflects an unbalanced pressure gradient which reverses the process and causes surface currents to stream offshore and bottom currents to move inshore. This redistribution of mass by strong onshore winds, associated with migrating atmospheric pressure systems and its sudden readjustment when wind stress drops, appears to be a fundamental process in stratified coastal waters (Murray, 1976).

An example of a meteorological system that influences the nearshore currents in the study area is presented by Hsu (1970). Varying horizontal pressure gradients, because of relative heating and cooling of the land and sea surfaces, generate inshore winds in the day and offshore winds in the early morning hours. Currents near the Mississippi-Alabama coast are influenced strongly by this sea breeze wind system where currents of 25 $cm \cdot s^{-1}$ are driven along the coast by a southwesterly sea breeze (Sonu, et al., 1973). Murray (1975) observed a subtle three-dimensional structure in wind-driven currents close to the coastline that involved wind stress, wind angle to the coast, and eddy viscosity. In addition, he showed the effect of density stratification in damping out the wind-induced vertical (downward) transfer of momentum that was necessary to generate currents below 6 m (Figure 4.27). The sea breeze wind system also can have a modest effect on the nearshore wave field (Sonu et al., 1973). Inside the wave-breaking zone momentum is transferred from the shoaling and breaking waves to longshore or littoral currents. This type of wave-driven current is important in beach erosion and nourishment. Currents move inshore on the flanks of a trough-like depression referred to as a rip channel. In the channel, seaward flow extends through the wave-breaking zone and reaches speeds of 1 $m \cdot s^{-1}$ or more (Murray, 1976).

4.6.4 CIRCULATION PATTERNS IN MOBILE BAY

In a recent review of the Mobile Bay estuary, Schroeder (1979) states that no definitive studies on the circulation of Mobile Bay have been conducted, but that several small-scale investigations have approached a generalized understanding of the patterns. The tidal exchange with Mississippi Sound through Pass aux Herons approximates 20-25% of the Bay volume flushed. range from 81.6 to 102 $cm \cdot s^{-1}$ at the mouth of the Bay and 35.7 to 96.9 $cm \cdot s^{-1}$ at Pass aux Herons (Schroeder 1976, 1977a).

Historically, circulation patterns for Mobile Bay have been inferred from water levels and from salinity distribution patterns (Austin, 1954; McPhearson, 1970; Bault, 1972). However, Schroeder (1977b, 1978) has shown that the influence of the Mobile River system, which can range from a minor source of freshwater at low discharges to near total dominance during high discharges and flooding, contributes significantly to the circulation patterns of Mobile Bay. Consistent with the Coriolis effect in northern hemisphere estuaries, river waters flow along the western shore as they move south, while oceanic waters follow the eastern shore as they move north. During low river discharges, river water (<1.0 ppt) and transitional water (1.0 to 7.9 ppt) in the upper and middle bay form a surface lens over the more saline waters and move to the south favoring the western shore. At higher river discharges the

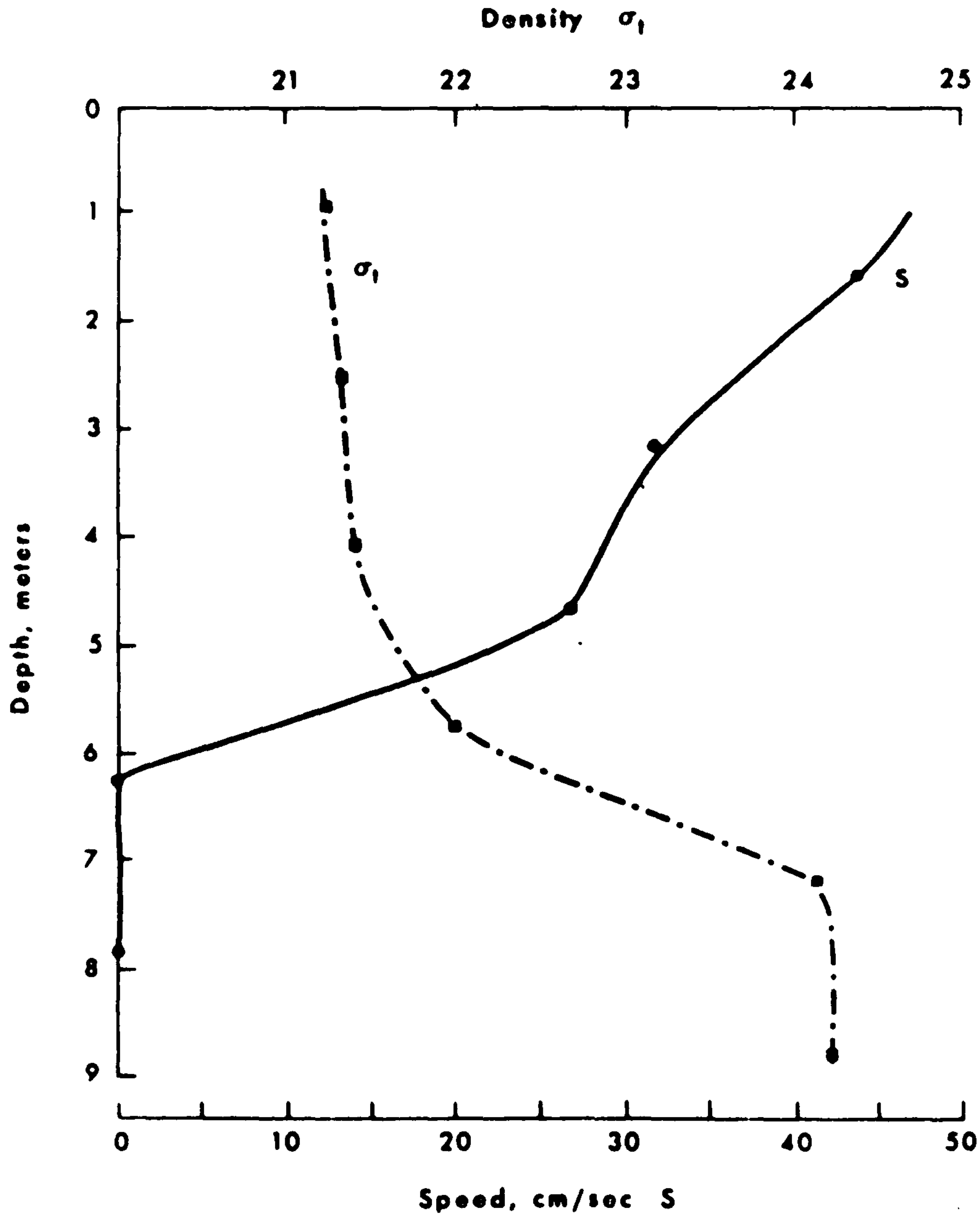


Figure 4.27 **Profile of alongshore current speed illustrating the effect of a density gradient in damping out the downward transfer of momentum necessary to generate currents in lower levels (Source: Murray,1975).**

down-Bay patterns of the river and transitional water at the surface and bottom follow the ship channel and even favor the eastern side of the Bay (see Figure 4.12).

Because of the Bay's large surface area and shallow depth, the wind can modify circulation patterns. North winds complement river flow and move river influence toward the lower bay. South winds move offshore waters up the Bay, and during low river discharges high salinity waters may extend 20 km up the Bay within a tidal cycle. The Mobile Ship Channel is 12 m in depth, as compared to the adjacent Bay bottom (3 m) and provides an avenue for high salinity waters to move up the Bay. Winds with east or west components tend to push the surface waters to the opposite side of the Bay and consequently there is often a complementary shift of the bottom waters to the windward side of the Bay.

Mathematical models of Mobile Bay have been used in the description of hydrodynamic and material transport behavior in Mobile Bay (April and Raney, 1979). The primary importance of the modeling efforts were to relate, calibrate, and verify the known hydrologic and meteorologic parameters with field and remote-sensing data collection programs for model-predictive capabilities in water resource planning. Hydrodynamic and salinity models for Mobile Bay and East Mississippi Sound (Raney and Youngblood, 1982) produced velocity vector diagrams comparable to those for Mississippi Sound (see Section 4.6.6).

4.6.5 CIRCULATION PATTERNS IN MISSISSIPPI SOUND

The general circulation patterns in Mississippi Sound are variable and are greatly influenced by tides, wind conditions, and freshwater discharge. In a review of the hydrodynamic characteristics of the Sound, Boone (1973) showed generalized net current movement and longshore drift towards the west. However, Eleuterius (1976a, 1978) identified three hydrologic regimes that characterize the Mississippi Sound system. His results indicate that the eastern sound extends from Pass aux Herons (accessing Mobile Bay) to a dredge spoil ridge off the east mouth of the Pascagoula River, dominated by water inflow from Mobile Bay and Petit Bois Pass. The central sound, which extends from the Pascagoula Ship Channel to the shoals off Cat Island, receives little freshwater inflow, but is characterized by the flux through the central tidal passes. The western sound extends from Cat Island shoals through Lake Borgne and has freshwater inputs from Lake Pontchartrain, Pearl River, and St. Louis Bay. It is connected with the Gulf through the channels off the Chandeleur and Cat Islands and by the numerous shallow passes through the marshes.

Based on the analysis of data collected from an extensive hydrographic program conducted in Mississippi Sound for the U.S. Army Corps of Engineers, Mobile District, (Raytheon, 1981), Kjerfve (1983) classifies Mississippi Sound as a lagoon with only weak gravitational circulation and weak to moderate stratification. He indicates that the general circulation pattern in the Sound is induced primarily by the tides, and that wind has a significant effect on these tidal currents. As the diurnal tide enters the Sound at Horn Island Pass, it bifurcates and divides the Sound into two distinct areas. During flood tide, currents enter through the passes and flow westward to Lake Borgne and eastward to Mobile Bay (Figure 4.28a). Conversely, during ebb tide, current flow is reversed and exits out through the passes (Figure 4.28b).

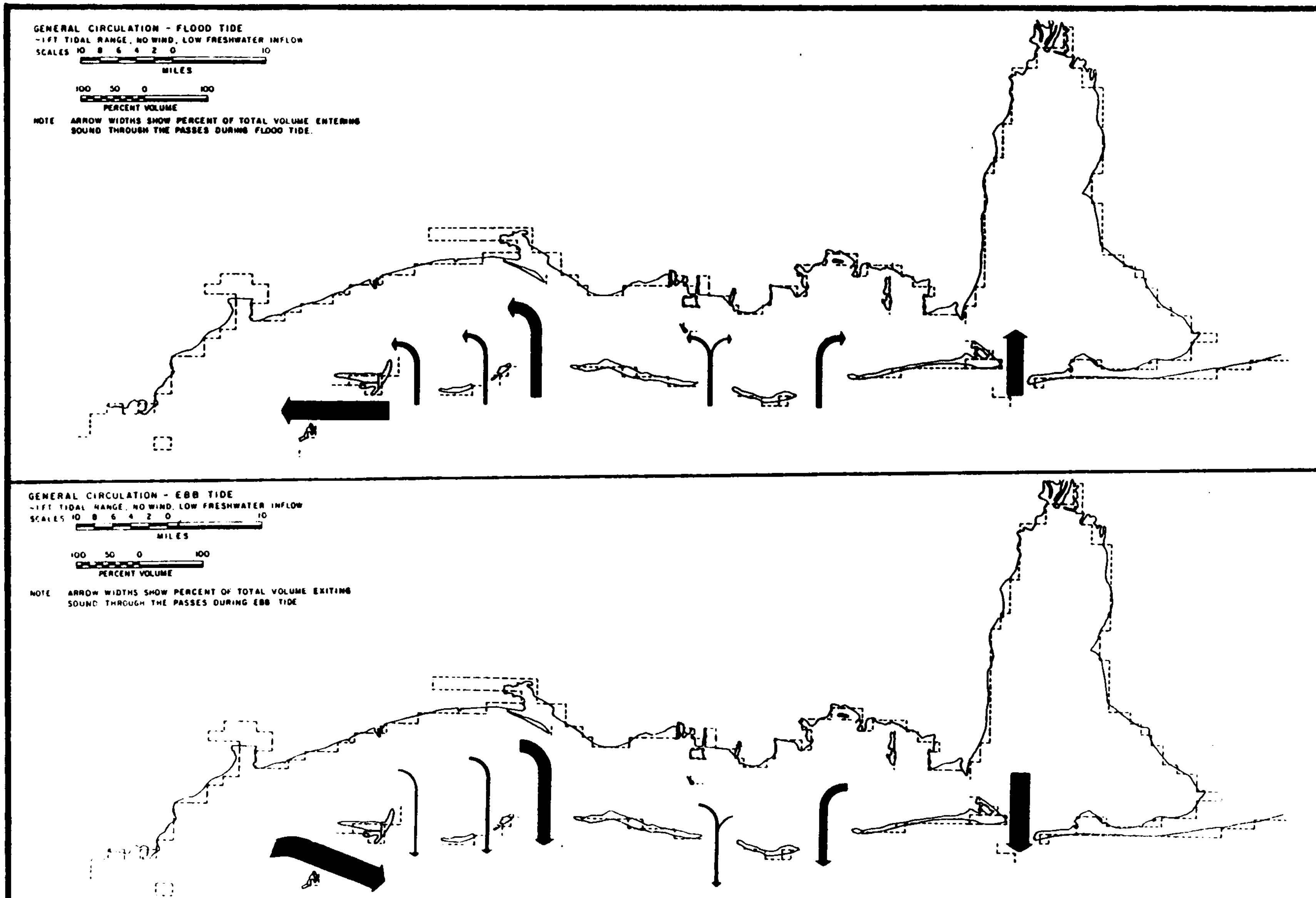


Figure 4.28 General circulation patterns during flood and ebb tides in Mississippi Sound and Mobile Bay (Source: US Army Corps of Engineers, 1983).

Further analysis of tidal currents supports the findings of Eleuterius (1976a) that Mississippi Sound has several distinct hydrodynamic regimes. Tidal currents are quite coherent in both the eastern and western portions of the Sound and show an east-west orientation (Figure 4.29). However, tidal currents in the vicinity of Pascagoula are weak and less directionally defined, indicating a different dynamic region (Kjerfve, 1983). The passes from Main Pass to Dog Keys Pass all experience strong bidirectional tidal currents along the north-south axis.

Kjerfve (1983) adds that low frequency current distribution, which relates tidal current and water level fluctuations with meteorological forcing (i.e., long period variations of 5-7 days are related to east-west winds), are good measures of circulation in Mississippi Sound. The low frequency motions are important in this system since they can cause large water displacements, whereas tidal currents yield essentially zero net displacement. Also, the long-term averages of surface and bottom currents are indicators of circulation (Figure 4.30). The mean surface flow at the tidal passes is directed towards the Gulf (Figure 4.30), while mean bottom currents are either much weaker or directed into Mississippi Sound, implying some vertical stratification.

4.6.6 MODELING OF CIRCULATION PATTERNS IN MISSISSIPPI SOUND AND MOBILE BAY

The tidal data collected for Mississippi Sound (Raytheon, 1981) were incorporated into the Waterways Experimental Station (WES) "Implicit Flooding Model" (WIFMS) as part of their modeling effort to define the current patterns and salinity distribution in the Mississippi Sound and Mobile Bay area (U.S. Army Corps of Engineers, 1983). This model was run with various wind components as variables to detect changes in circulation patterns. Results of the model indicate that the effect of the wind on circulation patterns is significant. The superimposed wind-induced current on the Sound shifts the birfurcation area at Horn Island Pass either toward the east or west, depending on the east/west wind component and an ebb or flood tide. A wind with an eastern component induces a general westward current in the Sound, causing the bifurcation area to shift eastward (Petit Bois Pass) during the flood tide and westward (Dog Keys Pass) on the ebb tide. This condition is shown in Figure 4.31 showing the flood and ebb tides induced by a 9-mile per hour (mph) wind blowing from the southeast (150°). Figure 4.32 shows the velocity vectors during a tidal cycle with this wind condition. Winds with a western component set up a general eastward circulation pattern in the Sound, thus forcing a bifurcation westward at Ship Island Pass on flood tide and eastward at Petit Bois Pass on the ebb tide (Figure 4.33). Reinforcement of this flow pattern is shown in Figure 4.34 via velocity vectors during a tidal cycle induced by a 9 mph wind from the northwest (330°).

North and south wind components have minimal effects on the general tide-induced current patterns. These wind components develop current vortices in the shallow areas of the Sound between Dog Keys Pass and Mobile Bay that tend to disrupt and reduce tidal currents. In addition, freshwater inflows were found to have a negligible effect on the general current patterns induced by the tide and winds; however, there is an increase in ebb and flood velocities during high freshwater inflow. One exception is the waters discharged from the Bonnet Carre Spillway during Mississippi River flooding. These flood waters via Lake Pontchartrain and Lake Borgne can influence the area as far

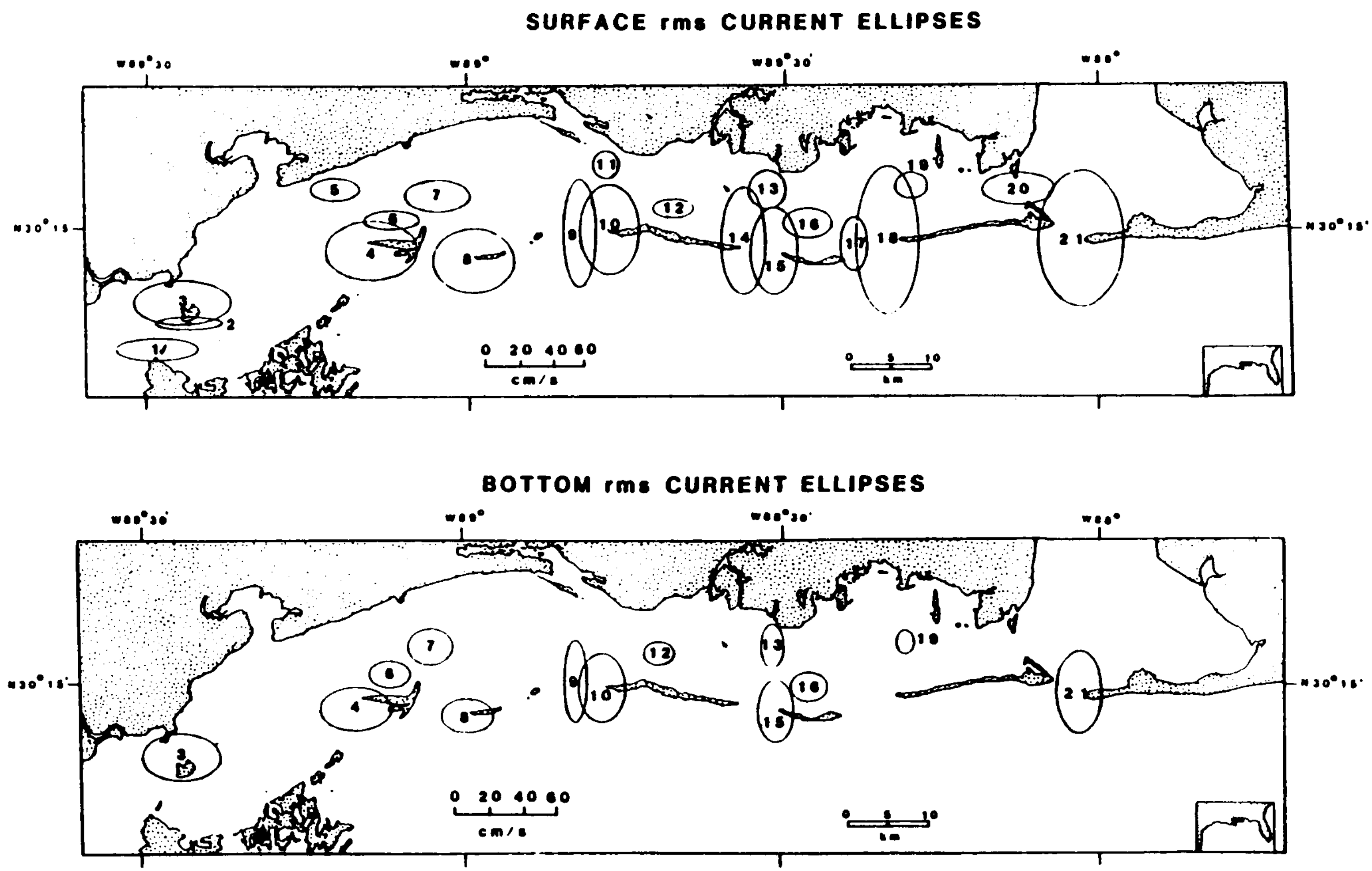


Figure 4.29 Surface and bottom root mean square velocity (rms) ellipses for the 1980-81 measurement period in Mississippi Sound. Ellipses indicate average variation of current in an east-west and north-south direction. (Source: Kjerfve, 1983)

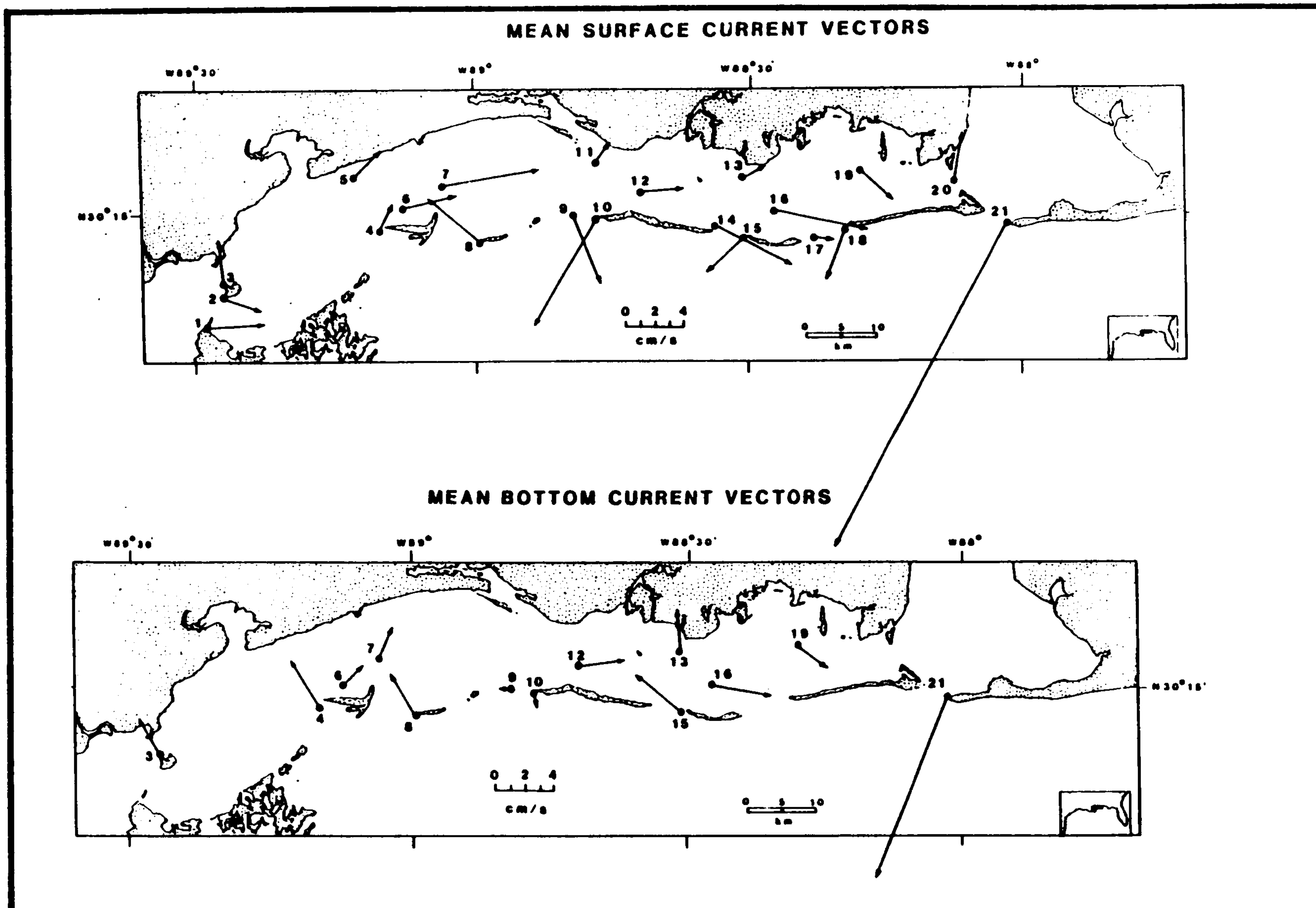


Figure 4.30 Mean surface and bottom current vectors for current moorings in Mississippi Sound during 1980-81 (Source: Kjerfve, 1983).

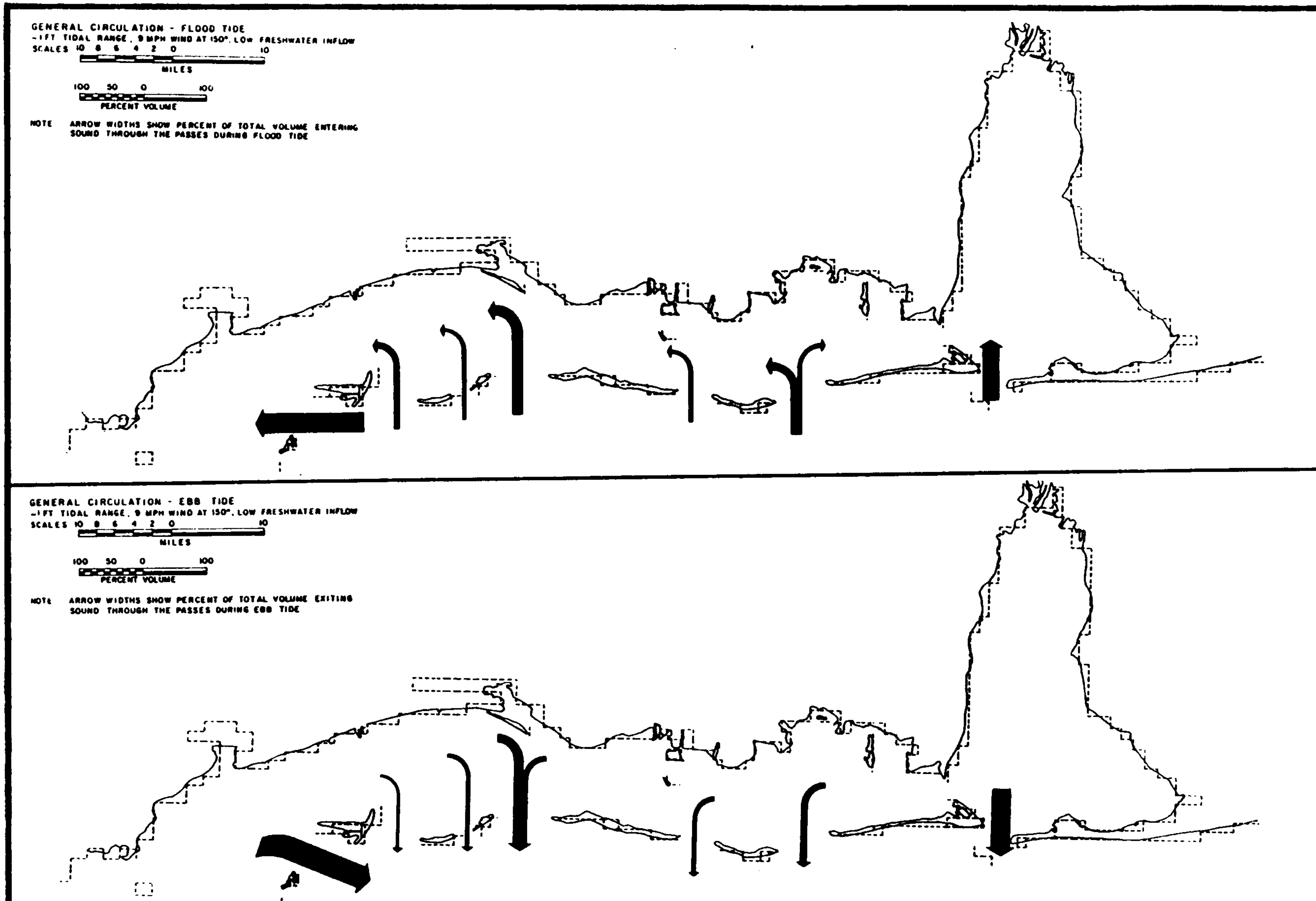


Figure 4.31 General circulation patterns during flood and ebb tides in Mississippi Sound and Mobile Bay based on a 9 mph wind from 150^{o} (south-southeast) (Source: US Army Corps Engineers, 1983).

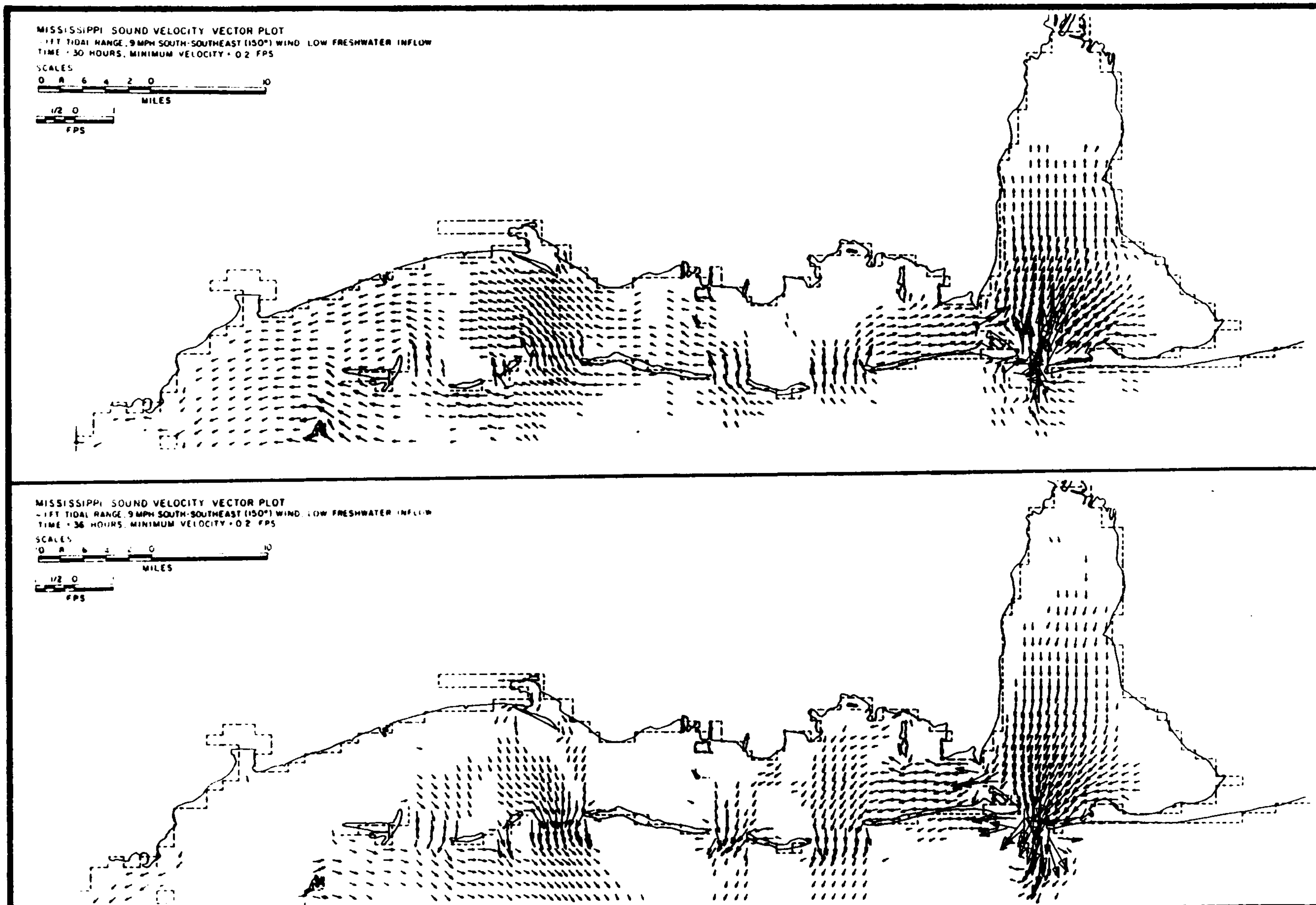


Figure 4.32 Velocity vector plots for flood and ebb tides for Mississippi Sound and Mobile Bay based on a 9 mph wind from 150° (south-southeast) (Source: US Army Corps Engineers, 1983).

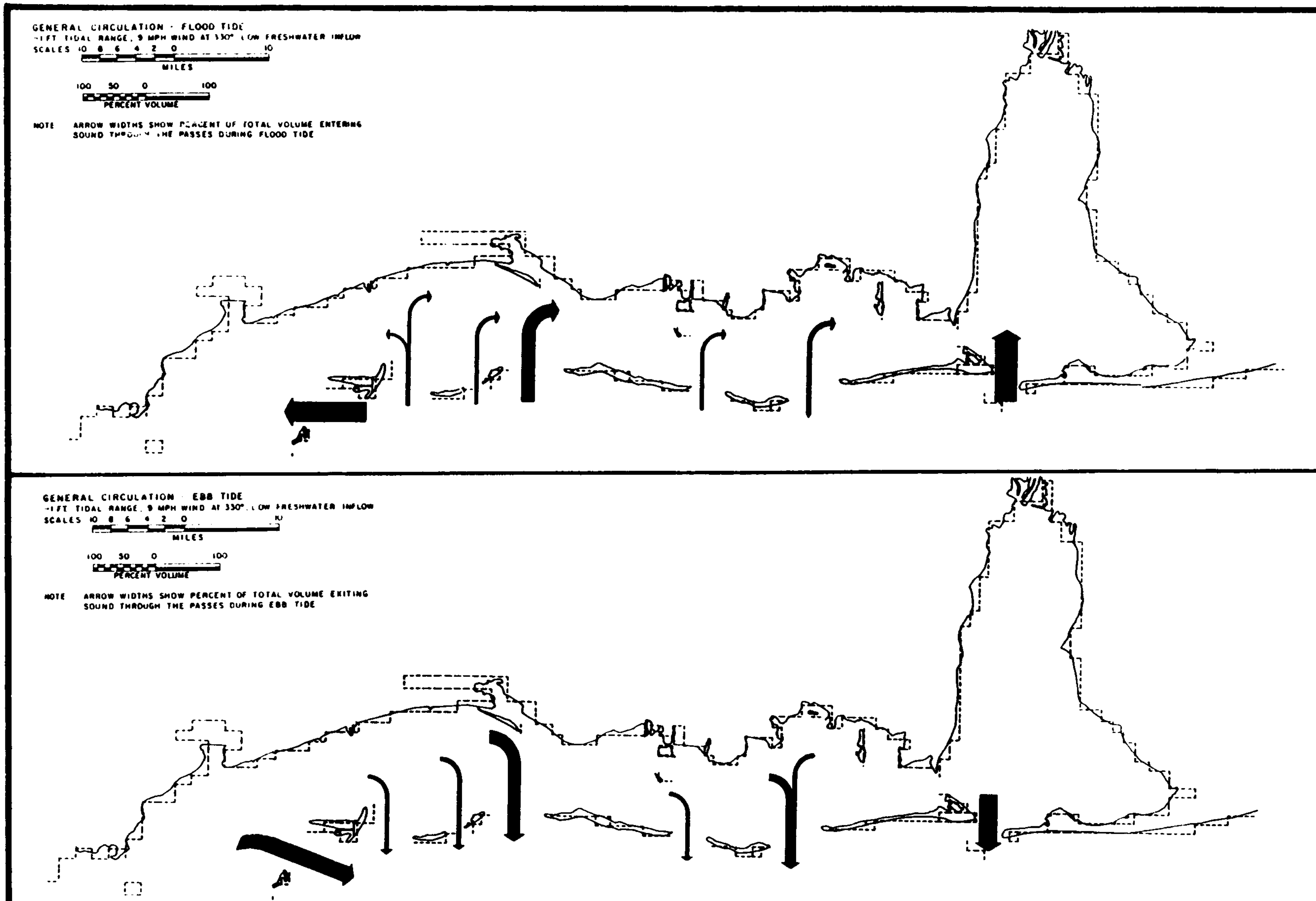


Figure 4.33 General circulation patterns during flood and ebb tides in Mississippi Sound and Mobile Bay based on a 9 mph wind from 330° (north-northwest) (Source: US Army corps Engineers,1983).

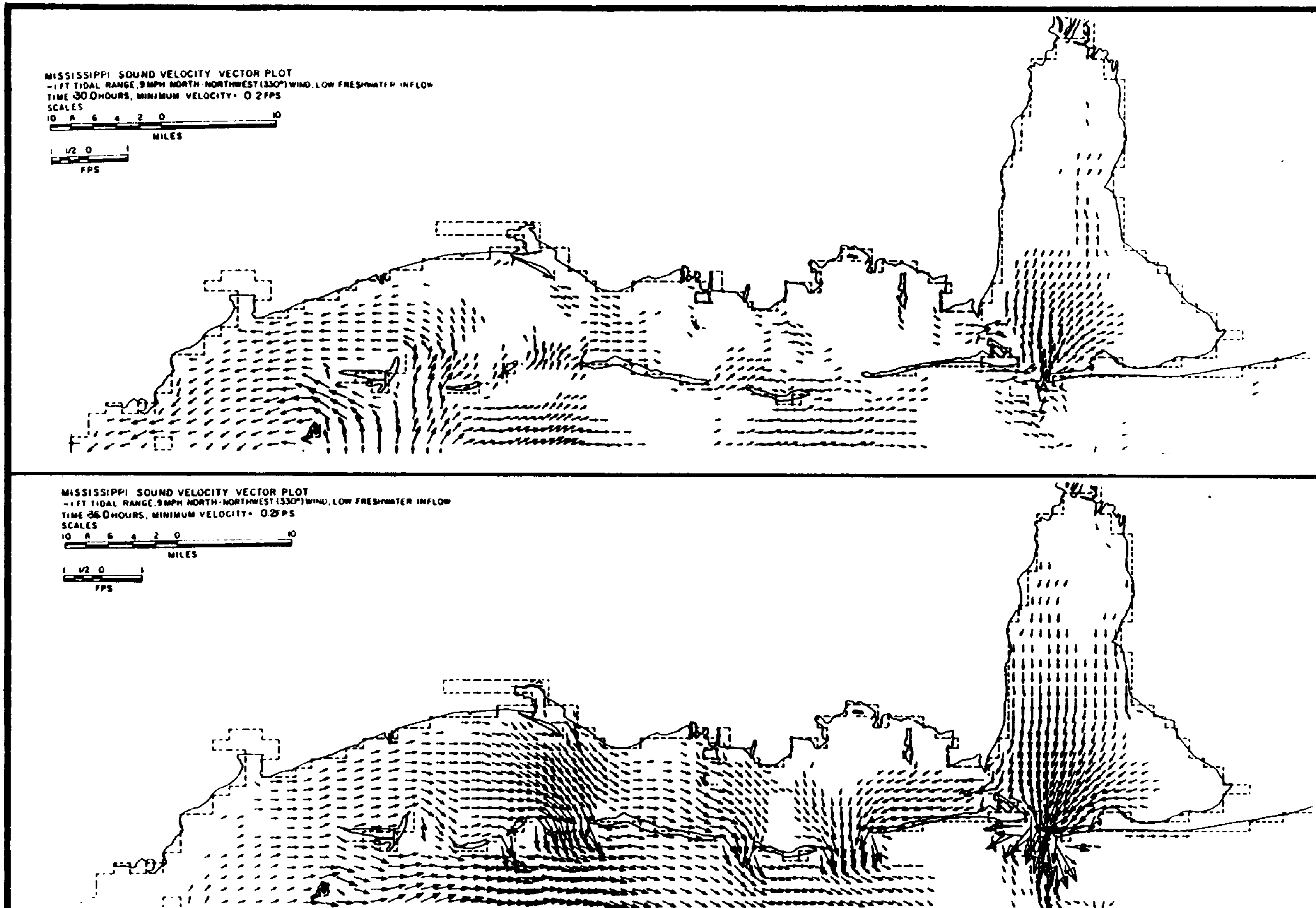


Figure 4.34 Velocity vector plots for flood and ebb tides for Mississippi Sound and Mobile Bay based on a 9 mph wind from 330° (north-northwest) (Source: US Army Corps Engineers, 1983).

east as the east end of Ship Island and can alter normal circulation patterns to an eastward flow.

4.6.7 CIRCULATION PATTERNS IN CHANDELEUR-BRETON SOUND

In 1968 a tide and current survey was conducted in Chandeleur-Breton Sound along the Mississippi River Gulf Outlet Channel by the U.S. Coast and Geodetic Survey (Figure 4.23). However, the time-dependent circulation pattern could not be deciphered (Murray, 1976). A two-dimentional numerical model of the area was conducted by Hart (1978) based on the usable survey data. The study showed that the hydrodynamic system is generated primarily by two tidal inputs, one entering from the north between Chandeleur Island and the St. Bernard delta lobe, and the other entering from the southeast around both sides of Breton Island. Currents average 10-15 $cm \cdot s^{-1}$ in the narrow, shallow entrances through the Chandeleur Island chain. As high water enters through both entrances during a flood tide, currents converge in mid-sound and veer westward to the marsh areas (Figure 4.35). As the tide turns, the currents begin to diverge from the zone, but within a few hours after high tide the major flow through the Sound is to the south.

Tidal ranges in the northern part of the estuary are 10-15 cm greater than in the south, hence, this difference drives net circulation through the Sound (Hart and Murray, 1978). This flow exists under average and tropic tidal conditions but is dominated by response to wind (i.e., as the wind direction increasingly opposes the direction of flow, the net volume flow will decrease). A directly opposing wind of sufficient strength (e.g., a 7 $m \cdot sec^{-1}$ wind heading 040°) will reverse the net flow to the north.

The results of Kjerfve and Sneed (1984) indicate a tidal progression from south to north along the inner shelf, with a divergence at Petit Bois Island (see Figure 4.10). While water may enter the northern entrance of the Chandeleur Sound as a separate tidal wave, it appears that it may lag the southern wave. Additional studies are needed to verify the current patterns modeled for Chandeleur-Breton Sound.

4.7 DATA GAPS

There are few data concerning the circulation in the DeSoto Canyon. The head of the canyon may be subject to upwelling events in conjunction with Loop Current penetration and frontal passages, with implications for sediment and pollutant transport across the shelf and slope.

There exists data sets on currents, temperature, and salinity collected in the Tuscaloosa Trend region that could be further synthesized to describe the main features of shelf processes here in comparison with processes on other continental shelves. The synthesis of data from current meter moorings over the outer shelf (Figure 4.28) should provide information on outer shelf dynamics that would intrude upon the shelf. This could be coupled with synthesis of remote-sensing data collected during the current meter deployment periods.

Additional information on the presence and extent of a nepheloid layer on the shelf would be useful in determining possible fates of organic and trace metal pollutants, and mechanisms which influence their transport across the

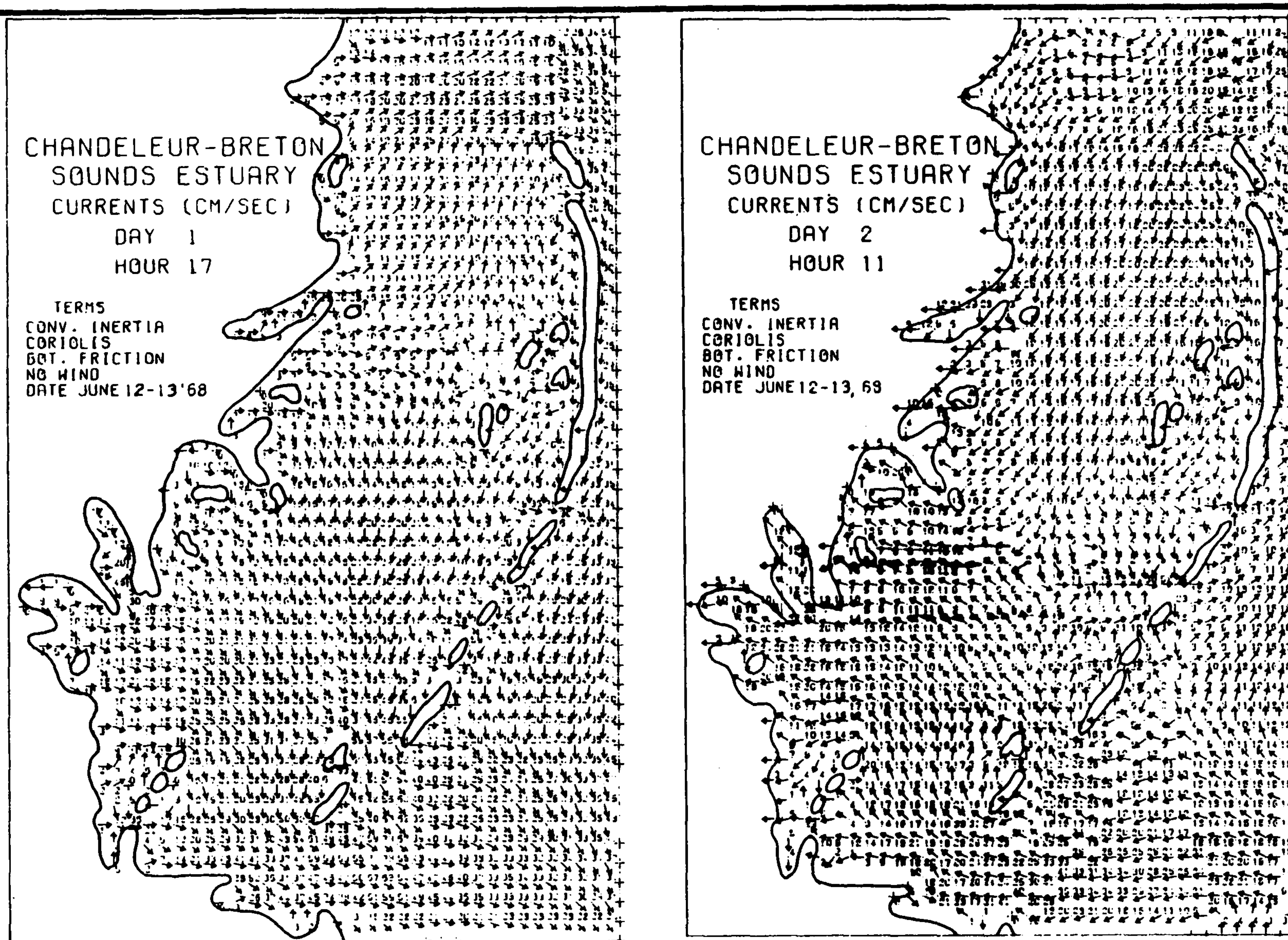


Figure 4.35 Example of ebb and flood tide currents in Chandeleur-Breton Sound, one hour after high water and three hours after low water, respectively (Source: Hart, 1978).

shelf, and ultimately, their fate in the ecosystem (i.e., bound in the sediments, residing in the nepheloid layer, dispersed throughout the water column, accumulated in fish/shellfish tissue).

In the design of future studies, preliminary modeling based on synthesized data would best predict the shelf processes most important for investigation. Of particular interest is the extent to which Loop Current intrusion influences shelf processes in the Tuscaloosa Trend region.

Synoptic measurements across the shelf are limited to areas within 20-30 km of the barrier islands. Current meter moorings extending the width of the shelf out to the slope would provide full coverage of tidal and wind stress events for implementing a circulation structure model. During the study, several components should be addressed: meteorology, hydrography, horizontal currents, sea level, bottom pressure, and river discharge. Remote sensing via satellite and high altitude fly-over would assist in documenting frontal features and Loop Current intrusion into the shelf.

5.0 CHEMICAL OCEANOGRAPHY

5.1 INTRODUCTION

The description of marine chemistry of the Tuscaloosa Trend region includes an emphasis on the chemical constituents and processes which are subject to modification by man's activities. Some of these include trace metal contamination of commercial or sport fish and shellfish; influx of hydrocarbons, pesticides, and organic toxins to biotic systems; and nutrient eutrophication associated with regional industrialization. However, before biological impacts of man's activities can be properly evaluated, a review of existing information on the chemistry of the Tuscaloosa Trend region will identify major data gaps of sources, fates, transport and cycling mechanisms, and potential toxicants.

Information on the coastal and nearshore areas is more extensive than that available for the open continental shelf. In general, data on nutrients, oxygen, trace metals, and hydrocarbon chemistry are restricted to water and sediment quality evaluations of coastal municipalities and industrial complexes, and of commercially important shellfish (e.g., oysters) harvest areas within Chandeleur-Breton Sound, Mississippi Sound, and Mobile Bay. Most data on estuarine pollutant loadings for the study area have been synthesized by the NOAA-Strategic Assessment Branch as part of their National Coastal Pollutant Discharge Inventory (NOAA, 1984). Data on concentrations of nitrate, nitrite, phosphate, silicate, oxygen, total organic carbon, trace metals, pesticides, etc. are also available from county and state resource and pollution control agencies, the Federal Food and Drug Administration laboratories, the U.S. Geological Survey, Louisiana and Mississippi-Alabama Sea Grant Programs, and the U.S. Army Corps of Engineers. However, water and sediment quality information for areas offshore of the barrier islands is usually collected only in conjunction with Federally funded multidisciplinary programs such as the Bureau of Land Management MAFLA Programs (Alexander et al., 1977; Dames and Moore, 1979) and ocean dredged material disposal surveys (U.S. EPA, 1982a,b; Harmon Engineering, 1984). Few measurements of nutrients and water column, sediment, and tissue trace metals, pesticides, and hydrocarbons are available from shelf waters deeper than 20-30 m (Dames and Moore, 1979); however, these chemical constituents are fairly well documented in waters less than 30 m (Eleuterius and Beaugez, 1979; TechCon, 1980; U.S. EPA, 1982a,b; Harmon Engineering, 1984).

The following information on the Tuscaloosa Trend is presented in overview form addressing carbon, oxygen, and nutrient components followed by trace metal and hydrocarbon constituents of the water column, sediments, and tissues. Processes and mechanisms are discussed as relevant to the presentation of respiration, nutrient cycling, toxicity, etc.

5.2 CARBON-OXYGEN

Organic carbon and oxygen in marine ecosystems are interdependent of biological photosynthesis and respiration, and on various chemical processes in the water column and sediments. Regionally, carbon is dependent on inputs of organic materials (dissolved or particulate) via riverine inflows and discharges. Oxygen is dependent on atmospheric input and respiration and chemical oxidation.

The mechanisms of oxygen production and consumption in the Tuscaloosa Trend area are complex phenomena which depend strongly on seasonal variations in temperature, density stratification, and primary production on the shelf. During the winter months, the water column becomes well-mixed, oxygen saturation concentrations increase, and reaeration improves due to increased surface turbulence. Generally, overall biological productivity decreases slightly as a result of temperature decreases and declining phytoplankton growth. Organic material is usually added to the system during spring river discharges. During the summer months, the water column stratifies, oxygen saturation concentrations decrease, and reaeration diminishes. Increased biological productivity results in higher respiration demands for oxygen, particularly in the lower water column and sediments.

The processes of biological respiration and decomposition change significantly when oxygen levels are depleted and anaerobic oxidation occurs. Productivity generally declines and nutrients are recycled more slowly. When oxygen concentration is generally less than 3 mg $O_2 \cdot l^{-1}$, the condition is referred to as hypoxia. Hypoxic zones are caused by stratification and isolation of the bottom waters from surface waters, local imbalance of oxygen sources and sinks, turbidity, and organic loading (Turner and Allen, 1982a). Mobile aerobic organisms such as crabs, shrimp, and demersal fish move out of areas when oxygen levels decline, while sessile benthic organisms may suffer high mortalities.

In a recent review of oxygen depletion and eutrophication in estuarine and coastal waters, Rabalais et al. (1985) noted that hypoxia occurs seasonally along tidal reaches and deep channels in Mobile Bay and Mississippi Sound during the warmer months. However, oxygen depletion is unlikely in Chandeleur and Breton Sounds. The sounds are much shallower than Mississippi Sound, are open and exposed to wind mixing, and experience no large freshwater discharges which may induce stratification. There may be a localized influence of the Mississippi River Gulf Outlet but probably no widespread problems. Based on SEAMAP data for 1983, hypoxia on the Mississippi-Alabama shelf is not a widespread or seasonally defineable or recurring event (Rabalais et al., 1985).

Large areas of hypoxia occur periodically along the Louisiana shelf west of the Mississippi Delta (Figure 5.1). Large freshwater discharge and related, enhanced stratification, followed by calm weather conditions, appear to influence the extent, intensity, and persistence of hypoxia. Boesch (1983) speculates that phytoplankton production stimulated by riverine nutrients is responsible for the oxygen demand. This phenomenon has not been reported for the offshore Tuscaloosa Trend region, although large cells of low oxygen freshwater can be entrained periodically on the shelf (SUSIO, 1975). Similar phenomena occur frequently during the summer on the eastern shore of Mobile Bay, as small pockets of low oxygenated riverine waters move eastward forcing shrimp, crabs, and fish (commonly, flounder) to the waters surface along the coastline. This is known locally as a "Jubilee" and occurs in early morning hours during times of peak respiration (May, 1973; Schroeder, 1979).

Dissolved oxygen values of selected water column investigations in the Tuscaloosa Trend study area (Table 5.1) reflect seasonal variability within both estuarine and shelf waters. Low dissolved oxygen values are prevalent during late summer months within nearshore (Barrett et al., 1971; Bault, 1972; Christmas, 1973) and offshore (Ragan et al., 1978; Turner and Allen, 1982a; U.S. EPA, 1982a; Harmon Engineering, 1984) coastal waters. However, mean annual DO concentrations range 6-9 ppm throughout the region.

Turner and Allen (1982a) report the presence of a narrow band of hypoxic water (less than 4 mg $O_2 \cdot l^{-1}$ a few meters thick along the bottom from Lake Borgne to 30 m depth south of Petit Bois Island (Figure 5.2a,b) during the summer 1978. By contrast, there was no such zone present along the shelf south of Mobile Bay in waters 15 to 85 m depth (Figure 5.2c,d). Shelf bottom water DO values are significantly lower than surface values at depths greater than 18 m, but do not approach hypoxic levels (Ragan et al., 1978).

5.3 NUTRIENTS

Among the inorganic chemical constituents of the marine and estuarine waters most involved in the biological processes are phosphate, nitrite, nitrate, and sometimes ammonia. Depleted levels of these nutrients are deterrents to productivity, while excessive levels may bring about eutrophication of a system. Phosphates are essential to the process of photosynthesis and may trigger phytoplankton blooms, as seen periodically off the Delta as a result of heavy discharge by the Mississippi River (Turner and Allen, 1982b). Phosphorus is present in dissolved inorganic, dissolved and particulate organic, and via adsorption, particulate inorganic forms. The predominant form of phosphorus in marine waters is orthophosphate; however, the percentage constituency of the various phosphorus forms varies seasonally. Nitrogen is a product of the decomposition of organic material primarily through the production of ammonia. Ammonia is then oxidized, first to nitrite, and finally to nitrate. The nutrient cycle within coastal and shelf marine waters is effectively summarized by McLaughlin et al. (1975) and can be modified to incorporate the existing information from the Tuscaloosa Trend study area.

Nutrient data in the Tuscaloosa Trend region are limited to coastal waters, with few investigations on the shelf. Barrett et al. (1971), Eleuterius (1976b), Lytle (1980a), and Bault (1972) present monthly nitrogen and phosphorus distribution data for Chandeleur-Breton Sound, Mississippi Sound, St. Louis Bay, and Mobile Bay, respectively. Results of these investigations are

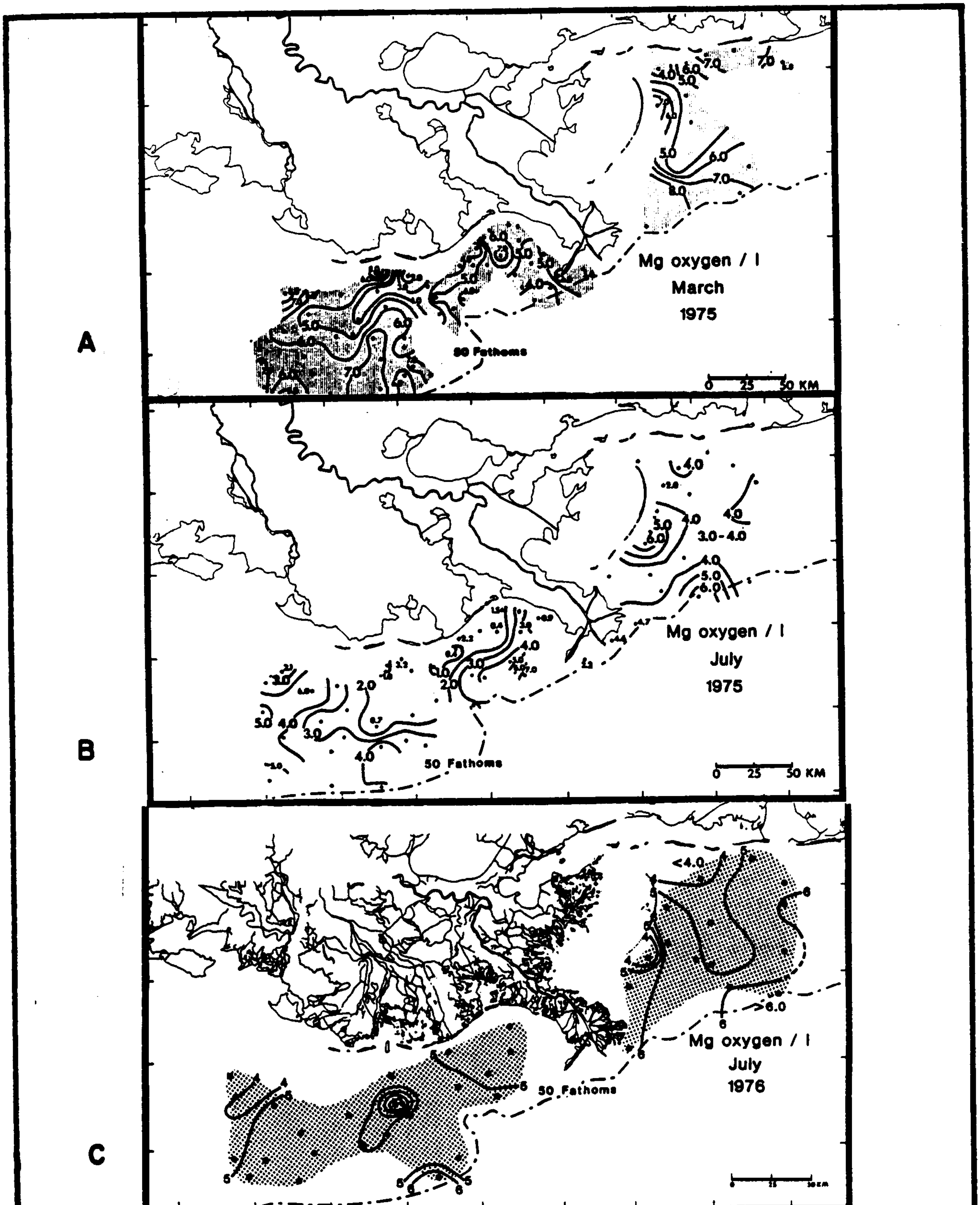


Figure 5.1. Bottom oxygen concentrations across the Mississippi River Delta Bight during (A) March 1975, (B) July 1975, and (C) July 1976. (Source: Turner and Allen, 1982a).

Table 5.1 Dissolved oxygen values of selected water column investigations in the Tuscaloosa Trend study area. Mean and (minimum-maximum) values reported as $mg \cdot \ell^{-1}$.

Chandeleur-Breton Sound	Dissolved Oxygen
Lake Borgne	7.5 (4.4-8.4)
Mississippi River Delta	7.2 (6.0-8.5)
(Barrett et al., 1971)	
Mississippi River-Gulf Outlet	(6.1-9.75)
(U.S. EPA, 1982b)	
Mississippi Sound	
East Mississippi Sound	6.7 (2.4-11.1)
(Bault, 1972)	
Pascagoula-Petit Bois	6.9 (1.0-16.21)
Biloxi Bay - Horn Island	8.8 (1.5-14.1)
St. Louis Bay - Cat Island	9.1 (1.2-14.2)
Pearl River (mouth)	9.8 (6.0-14.0)
(Christmas, 1973)	
Mobile Bay	
Mobile Delta	6.0 (1.7-10.4)
Mobile Bay	7.4 (4.8-10.9)
(Bault, 1972)	

Offshore Mississippi Delta

Depths	Surface	Bottom
mean	9.8 (7.3-14.2)	6.0 (3.8-9.8)
6 m	9.3 (7.7-10.4)	8.6 (7.2-9.8)
12 m	9.8 (7.3-11.8)	7.7 (5.0-9.7)
18 m	10.4 (8.7-14.2)	6.5 (4.4-8.0)
24 m	9.9 (8.4-13.2)	6.0 (4.2-7.5)
31 m	10.6 (8.7-13.8)	6.1 (4.6-7.5)
37 m	9.5 (7.5-12.2)	5.8 (4.4-7.8)
55 m	9.9 (8.7-11.8)	5.4 (4.1-7.4)
73 m	9.8 (8.1-11.2)	4.7 (4.5-6.0)
91 m	9.7 (9.0-10.4)	4.7 (4.3-5.1)
110 m	9.5 (8.7-10.4)	4.0 (3.8-4.2)
(Ragan et al., 1978)		

Offshore Mississippi-Alabama

Fall	(4.0-7.2)
Spring	(5.8-7.7)
(Shaw et al., 1982)	
Spring	(6.9-9.8)
Summer	(4.6-8.8)
(Harmon Engineering, 1984)	

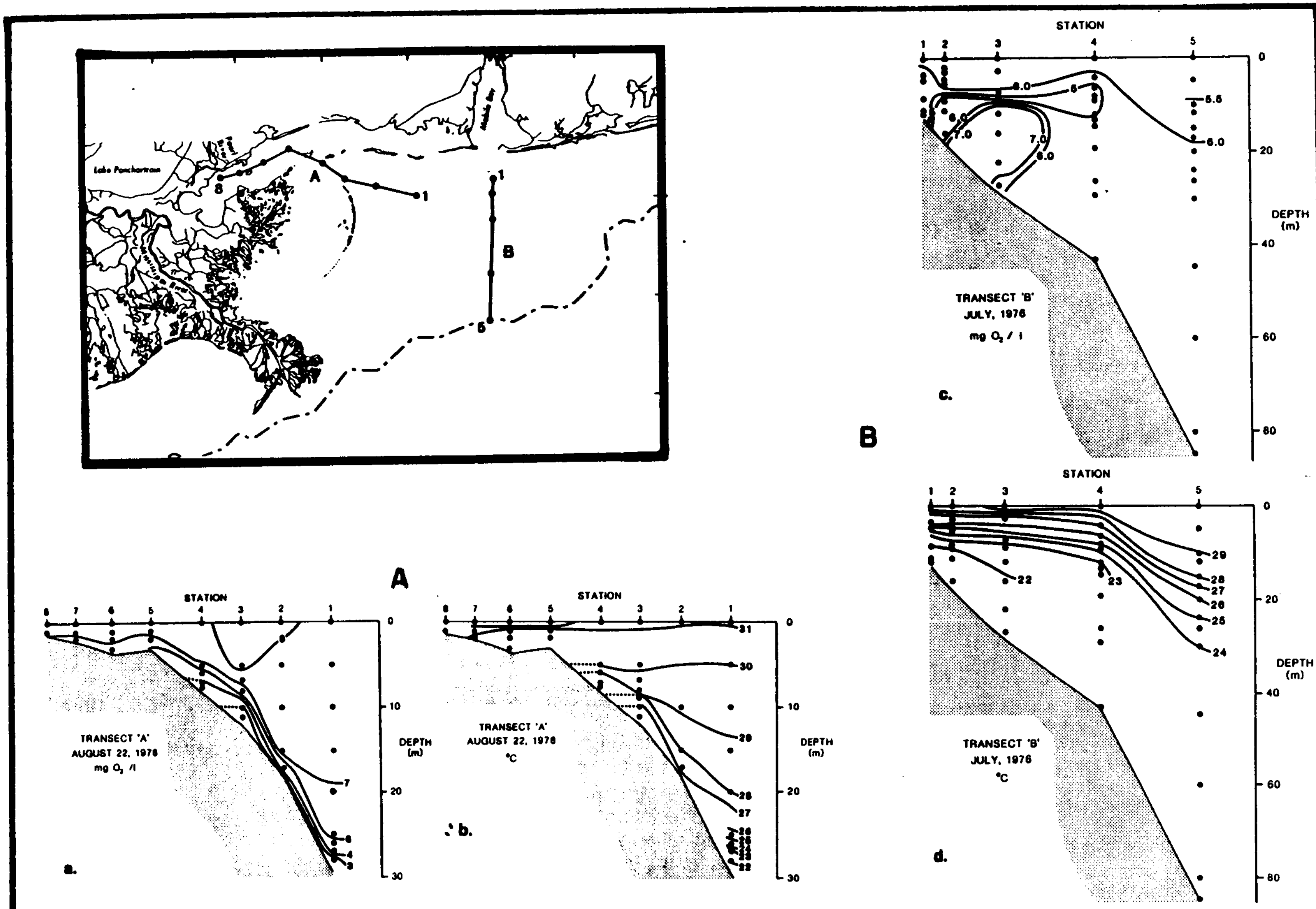


Figure 5.2. Isopleths of (a) oxygen and (b) temperature along two respective transects A and B sampled in July 1976 and August 1978. (Source: Turner and Allen, 1982a).

found in Table 5.2. In Lake Borgne and northern Chandeleur Sound, phosphorus and nitrogen levels increase during the summer, during lowest discharge of the Pearl River. Within Breton Sound, phosphates increase in the fall while nitrite-nitrate levels are high throughout the summer (Barrett et al. 1971).

In Mississippi Sound, an apparent inverse relationship between levels of nitrate and phosphorus appears limited to lower Pascagoula River. The levels of all nutrients generally decline seaward to the island passes. Seaward of the passes, nitrate was found to attain levels exceeding those of the Sound waters (Eleuterius, 1976b). Highest levels of phosphorus and nitrate are associated with the Pascagoula, Mississippi industrial complex (Eleuterius and Beaugez, 1979).

Seasonal variability in levels of phosphorus and nitrogen in Mobile Bay follows the discharge of the Mobile River--significantly higher concentrations in spring during high fresh water influx than in fall during low river flow (Bault, 1972). Nutrient values are higher in the Mobile Delta than in Mobile Bay (Table 5.2).

Monthly nutrient data collected at depths of 10-91 m on the shelf between Chandeleur Sound and Mississippi Sound barrier islands are presented in Figure 5.3 (Franks et al., 1972). Nutrient levels offshore were typically lower than in estuarine waters. Seasonal peaks in total phosphate concentration generally occurred when nitrates were low. Two seasonal peaks of nitrate concentration were evident throughout the water column; the highest in January with secondary peaks evident in May (surface and midwater) and July (bottom).

5.4 SEDIMENT CHEMISTRY

5.4.1 SEDIMENT TRACE METALS

Trace metal concentrations in the shelf and estuarine sediments are variable, primarily in response to differences in clay mineralogy, grain size, calcium carbonate, organic matter, salinity, redox potential, etc. Anthropogenic sources of trace metals are generally coastal industrial sites and major riverine drainage systems, such as the Mississippi and Mobile River systems. Redistribution of trace metals can occur from dredging and disposal practices, flood and storm events, and from site-specific drilling activities. However, the resuspension, geographic distribution patterns, and concentration of trace metals in the ecosystem are dependent on the partitioning behavior of the metal ions with the clay fractions, which will be presented later.

Of the metals selected for analysis in most shelf studies (e.g., barium, cadmium, chromium, copper, iron, nickel, lead, vanadium, zinc), only barium, chromium, nickel, and vanadium are considered significant possibilities of association with oil and gas operations. Barium and chromium, for example, are common in drilling muds, whereas nickel and vanadium, occurring as tetrapyrrole complexes, are very common in oils (Dr. Tom Lytle, Gulf Coast Research Laboratory, Ocean Springs, MS, personal communication). Lead, zinc, and cadmium are potentially toxic metals that have been observed in above natural levels near industrial and population centers along the Gulf of Mexico (Trefry and Presley, 1976a,b; Windom, 1973; Brannon et al., 1977).

Table 5.2. Results of selected water column nutrient investigations in the Tuscaloosa Trend study area. Mean and (minimum-maximum) values are reported in ug·atoms per liter.

	Nitrate N mean (range)	Nitrite N mean (range)	Orthophosphate mean (range)	Total Phosphate mean (range)
Chandeleur-Breton Sound				
Lake Borgne	2.06 (0.01-10.75)	0.27 (0.17-0.52)	0.71 (0.41-1.23)	2.97 (1.91-4.09)
Mississippi River Delta (Barrett et al., 1971)	5.00 (2.14-13.55)	0.60 (0.30-0.98)	1.20 (0.45-1.93)	4.00 (2.83-5.78)
Mississippi Sound				
Mississippi Sound (Eleuterius, 1976)	1.69 (0.00-57.21)	0.13 (0.00-8.00)	1.19 (0.00-65.60)	2.85 (0.00-91.38)
E. Mississippi Sound (Bault, 1972)	2.92 (0.00-13.81)	0.09 (0.00-0.73)		2.25 (0.14-7.88)
Pascagoula - Petit Bois	0.93 (0.29-16.00)	ND	1.76 (0.00-20.16)	3.89 (0.50-43.64)
Biloxi Bay - Horn Island	0.79 (0.19-22.9)	ND	1.66 (0.00-35.00)	3.68 (0.75-75.00)
St. Louis Bay - Cat Island	0.78 (0.22-4.15)	ND	1.42 (0.09-35.33)	2.83 (0.12-43.80)
Pearl River (mouth) (Christmas, 1973)	0.72 (0.16-2.16)	ND	1.47 (0.50-6.82)	2.73 (1.24-4.32)
St. Louis Bay (Lytle, 1980)	2.51 (1.50-4.06)	0.15 (0.08-0.51)	ND	1.19 (0.64-4.06)
Mobile Bay				
Mobile Delta	5.02 (0.00-16.86)	0.17 (0.00-1.11)	--	3.16 (0.36-9.90)
Mobile Bay (Bault, 1973)	4.38 (0.00-16.54)	0.08 (0.00-0.36)	--	2.54 (0.27-2.54)
Offshore Shelf				
<18 m depth	0.47 (0.17-3.20)	ND	0.66 (0.37-1.30)	1.79 (1.00-3.25)
18-37 m depth	0.66 (0.18-2.56)	ND	0.64 (0.37-1.33)	1.78 (1.00-3.00)
37-91 m depth (Franks et al., 1972)	0.69 (0.12-11.48)	ND	0.69 (0.50-1.96)	2.04 (1.00-3.25)

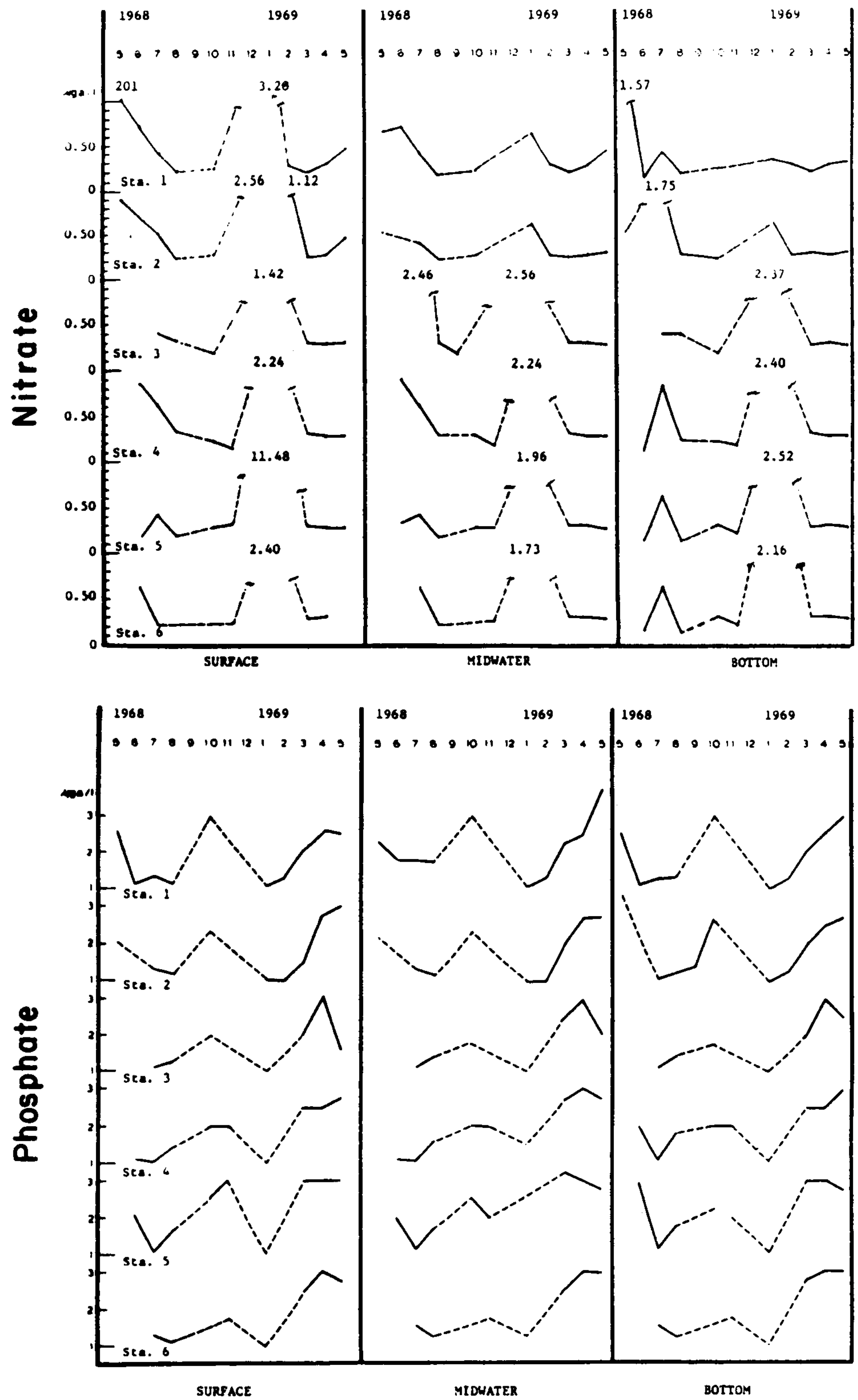


Figure 5.3. Total phosphate and nitrate concentrations (µg.ℓ-1) for six stations collected monthly (May 1968-May 1969) on the Mississippi-Alabama shelf. (Source: Franks et al., 1972).

Results of selected trace metal investigations in the Tuscaloosa Trend region are presented in Tables 5.3 and 5.4. Both mean and minimum-maximum values are tabulated where given; values for total and/or partial digestion of trace metals are noted. It was speculated that sediment analysis using the leachate from a 1N HNO_3 treatment, analyzed as "partial digestion," would be best to assess the "biological availability" of the various metals relative to total metal content (Trefry, 1979). However, it is thought now that the potential availability of trace metals to biotic communities is reflected in the partitioning of metal ions (Isphording, 1983).

Sediment trace metal concentrations are generally higher along the coast near sources of pollutants, but decrease significantly offshore to non-critical background levels (Harmon Engineering, 1984). Values for concentrations of vanadium, zinc, iron, copper, cadmium, and aluminum all averaged highest in the central Mississippi Sound, reflecting the heavy industrialization near Pascagoula, Mississippi (Isphording, 1985). Barium values increased from east to west from Mobile Bay (49 ppm) to Lake Borgne (720 ppm). Mean concentrations of nickel, vanadium, cobalt, and zinc were considerably greater in Mobile Bay sediments than all other sediments sampled (Figure 5.4).

Throughout the BLM MAFLA program (Alexander et al., 1977; Trefry, 1979; Shokes, 1979a), no instances of metal pollution were reported. Generally, the fine-grained sediments within the Mississippi-Alabama shelf have the highest trace metal values in the northeastern Gulf of Mexico. This is related to the deltaic sediments. Coarse-grained sediments within the eastern portion of the Trend area are expected to contain lower trace metal concentrations than those reported in Table 5.3.

5.4.2 SEDIMENT CLAY MINERALOGY

Composition

Clay mineralogy provides information on the composition of clay species, and thereby the origin of the minerals within water masses and/or deposited in sediments. More importantly though, the geochemistry of clay fractions, such as the characteristics of lattice structures, can indicate how certain trace (or heavy) metals may be "partitioned" in the marine environment. The importance of determining how metals are partitioned lies in the fact that clay minerals, oxides and hydroxides, and sulfides not only act under certain conditions to remove metals from solution, but may also hold the metals in a manner that will permit their release back into the water column (Gambrell et al., 1980; Isphording, 1983). In addition, the lattice structure of certain suites of clay minerals may totally bind a metal and make it functionally unavailable for biotic assimilation.

In conjunction with investigations of trace metal concentrations in estuarine sediments, in Mobile Bay and Mississippi Sound specifically, Isphording and Elliot (1979), Gambrell et al. (1980), and Isphording (1983, 1985), evaluate how environmental conditions (e.g., pH and redox potential, salinity/conductivity, organics, etc.) can cause changes in the chemical availability of metals in the water column and sediment. Isphording (1983, 1985) presents data on the potential availability of metals by determining the percentage of metals held: (1) in pore waters; (2) in exchangeable ion sites in clays; (3) as reducible ions associated with disseminated iron and

Table 5.3. Results of sediment trace metal investigations in the Tuscaloosa Trend nearshore areas. Mean and (minimum-maximum) values are reported in ppm for total and/or partial (*) digestion techniques.

Metal	Chandeleur-Breton Sound: Mississippi River-Gulf Outlet (EPA, 1982b)*	Mississippi Sound: Biloxi (Reynolds and Thompson, 1976)*	Mississippi Sound: St. Louis Bay (Lytle, 1980b)	Mississippi Sound: Mississippi Sound (Isphording, 1985)	Mobile Bay: Mobile Bay (Isphording, 1983)	Mobile Bay: Mobile Bay (Malatino, 1980)*	Mobile Bay: Lower Bay (TechCon, 1980)*
Aluminum				47,193(780-96,234)		(10-50)	
Arsenic	1.2(0.47-2.5)					(1-14)	
Barium				381(16-1390)	49(20-640)	(10-640)	
Cadmium	(<0.038-<0.078)	<50				(<10-10)	<0.05
Chromium	0.48(0.23-0.99)	120	10	57(24-85)	63(2-214)	(ND-90)	(24-72)
Cobalt		<50	8	13(0.2-44)	29(6-38)	(5-30)	
Copper	1.2 (0.22-4.1)		10	10(7-50)	32(8-49)	(5-120)	(0.4-18)
Iron		41,500	21,000	31,352(179-50,525)	35,650(2,230-57,830)	(2,000-42,000)	180-51,000
Lead	3.6 (1.3-7.0)	<50			(7-20)*	<10	(<0.2-19.5)
Manganese	93 (24-180)			409(26-961)	(519-1522)*	(12-1600)	
Mercury	0.014(0.003-0.050)				(0.10-0.47)*	(<0.2-1.1)	(0.08-2.1)
Nickel	2.0 (1.0-3.4)	<50	8	24(2-61)	57(17-100)		(<0.2-32)
Silver					8(3-17)	<10	
Strontium					44(1-156)	(10-390)	(2.0-160)
Titanium			278		4,945(112-7,134)	<10	
Vanadium			6.4	80(1-157)	163(31-250)		(0.8-110)
Zinc	8(4.7-16.0)	130	73	74(12-149)	360(13-2,689)	(40-1200)	(2-160)

Table 5.4. Results of sediment trace metal investigations in the Tuscaloosa Trend offshore areas. Mean and (minimum-maximum) values are reported in ppm for total and/or partial (*) digestion techniques.

Metal	OFFSHORE BARRIER ISLANDS: Ship Island (EPA, 1982a)*	Dauphin Island (EPA, 1982a)*	Dauphin Island (Harmon Engineering, 1984)*: N(9-17m)	S(17-24m)	MAFLA-OCS (TRANSECT VI): Trefry (1979) Partial*	Trefry (1979) Total	(Alexander et al., 1977)
Arsenic			(2.3-30)	(0.9-22)			
Barium			(1-69)	(<0.5-140)	(1.8-12)	(4-285)	(<59-321)
Cadmium	(0.002-0.042)	(<0.001-0.150)	(<0.005-0.66)	(<0.005-2.1)	(<0.01-0.16)	(0.01-17)	(0.04-0.7)
Chromium			(5.3-45)	(1.8-32)	(1.6-13.0)	(2.4-38.5)	(10-48.3)
Copper			(2.1-21)	(<0.05-4.9)	(0.27-5.5)	(0.33-7.4)	(1.7-10.1)
Iron			(5,900-26,000)	(1900-9,500)	(860-9670)	(420-72,700)	(7800-28,700)
Lead	(<0.004-1.32)	(<0.001-0.150)	(2.4-120)	(0.9-12)	(1.4-11.4)	(1.1-16.2)	(5.4-18)
Mercury	(0.002-0.038)	(0.012-19.14)	(0.04-0.62)	(<0.005-0.27)			
Nickel			(2.1-36)	(<0.05-7.2)	(<0.1-5.2)	(0.5-13.3)	(4-22)
Vanadium					(1-8)	(8-42)	(18-101)
Zinc			(21-81)	(4-25)	(4.4-34.6)	(11.3-65.8)	

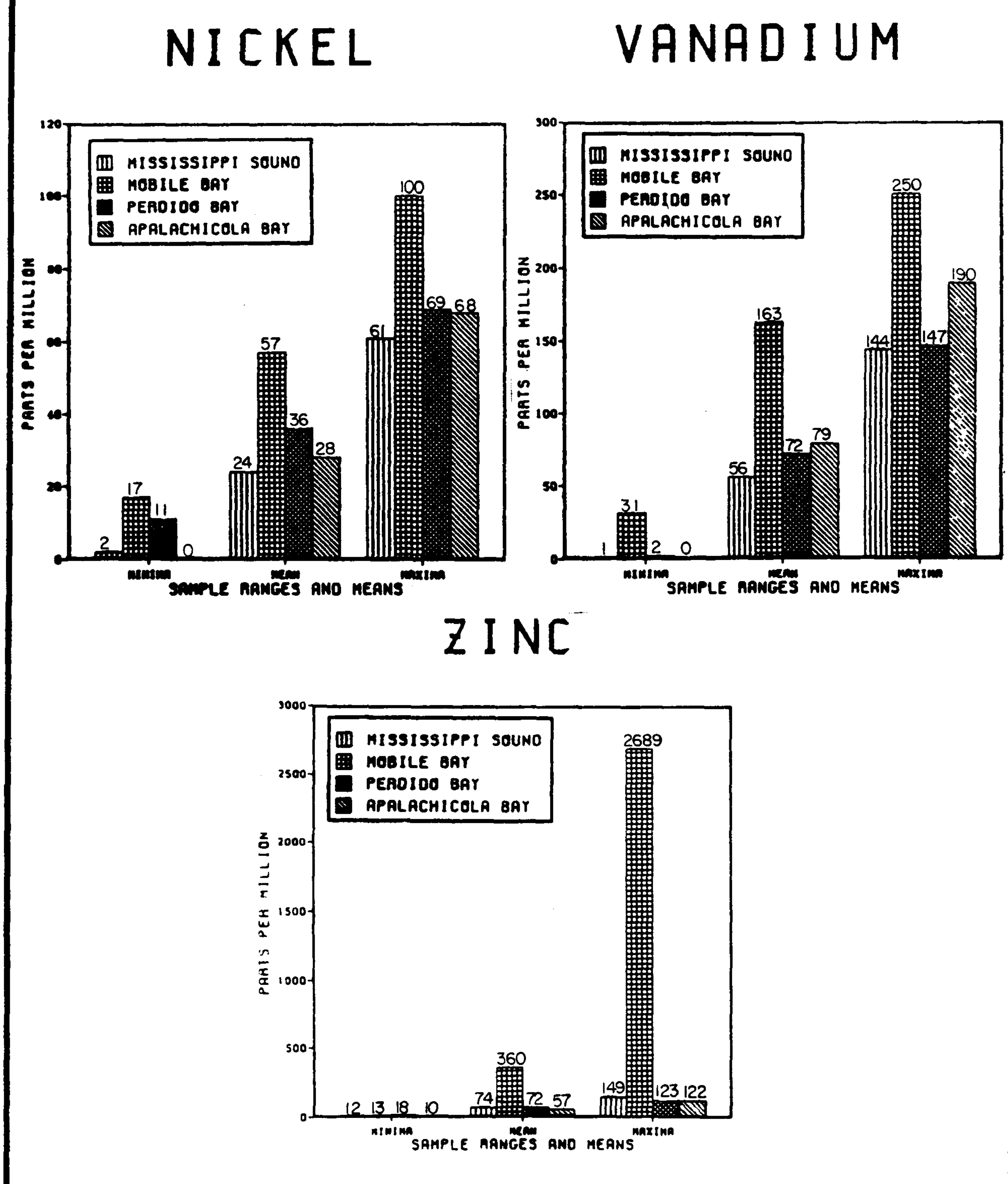


Figure 5.4. Distribution, sample ranges, and means of nickel, vanadium, and zinc in sediments from Mobile Bay and adjacent estuaries of the northern Gulf of Mexico. (Source: Isphording, 1985).

manganese compounds; (4) as organo-metallically chelated compounds adsorbed on clay mineral surfaces; and (5) as structurally-bound ions occurring in the octahedral and tetrahedral sites in clay mineral lattices. Partitioned results for copper, zinc, iron, chromium, nickel, barium, and manganese from sediments in Mobile Bay are presented in Table 5.5. The percentage of structurally coordinated ions is generally less than 50%; thus, with the exception of nickel, a significant portion of the metals in Mobile Bay sediments are potentially available for release to the water column (Figure 5.5) although the evidence for any effective release from the reducible or organically-bound phases is very slight. The low values for metals held in exchangeable ion sites probably reflect the unusually low cation exchange capacity observed for the montmorillonite clays (Isphording, 1985). Organically-bound metals comprise a significant portion of the metals in sediment; such compounds are perhaps the greatest threat to contamination during resuspension into the water column because of their general instability and sensitivity to changes in the redox potential (Isphording, 1983). However, results of sediment elutriate analyses conducted for the U.S. Army Corps of Engineers' Dredged Material Research Program (DMRP) indicate that the only significant release of metals is from exchangeable ions (Brannon et al., 1977).

Distribution

Smectite and kaolinite are the predominant clay minerals in the northern Gulf of Mexico shelf sediments (Doyle and Sparks, 1979), as well as in the coastal estuaries (Isphording and Lamb, 1979; Isphording, 1985). Illite is present in smaller concentrations. Smectite, which is characteristic of the Mississippi River and Mobile River drainage systems, is predominant in the Tuscaloosa Trend area. Doyle and Sparks (1979) found that over most of the shelf smectite decreased toward shore, while kaolinite increased in relative amounts toward shore (Figure 5.6a). Variations in smectite/kaolinite ratios were reported in the water column (surface and bottom), resulting from seiching or pulsing of smectite-laden shelf water from west to east (Figure 5.6b).

Isphording and Lamb (1979) described the sediment mineral distribution patterns in Mobile Bay with smectite (as montmorillonite) in greater concentration in the Bay, while kaolinite increased towards the mouth of the Bay. The clay mineral distribution in Mississippi Sound described by Isphording (1985) indicates that smectite is in greater concentration in the east, giving way to kaolinite in the west.

5.4.3 SEDIMENT HYDROCARBONS

Recent major hydrocarbon investigations within the Tuscaloosa Trend region are depicted in Figure 5.7. This area is dominated by inputs of terrigenous biogenic and anthropogenic materials from the Mississippi River and Delta area (Gearing et al., 1976; Boehm, 1979). The oil indicating characteristics of the land plant contribution is noted in the predominance of high molecular weight n-alkanes of pronounced odd/even preference in the lipid fraction, and in the low stable carbon isotope ratios of total organic carbon. Other characteristics of these sediments include: (1) a relatively high lipid content (up to 232 ppm) of which hydrocarbons form a significant fraction (up to 11.7 ppm) (Table 5.6a); (2) a moderate to large aliphatic fraction of

Table 5.5. Partitioned analyses for heavy metals from Mobile Bay bottom sediments. (Source: Isphording et al., 1983)

	PERCENT TOTAL METAL CONTENT			
	Pore Water & Exchangeable Ions	Reducible Phase	Organically Bound	Structural Ions
Copper	0.5	4.1	48.5	46.9
Zinc	0.9	15.1	49.8	34.2
Iron	1.5	73.8	16.1	8.6
Chromium	0.2	51.2	3.5	45.1
Nickel	0.4	30.3	2.6	66.7
Barium	2.1	53.9	30.9	13.1
Manganese	9.9	29.0	43.4	17.1

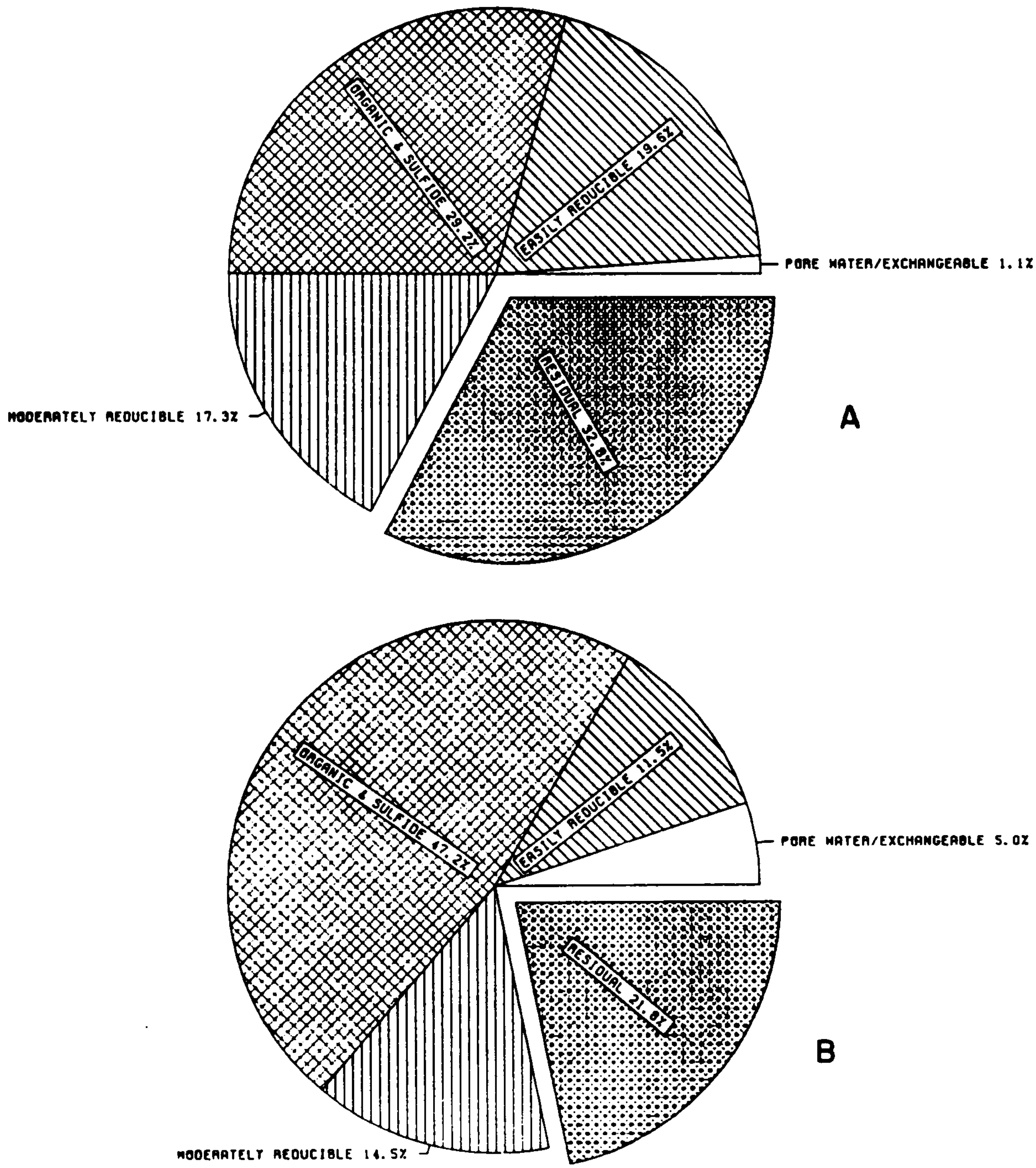


Figure 5.5. Selective ion-partitioning of zinc for samples from (A) Mobile Bay and (B) Mississippi Sound. (Source: Isphording et al., 1984).

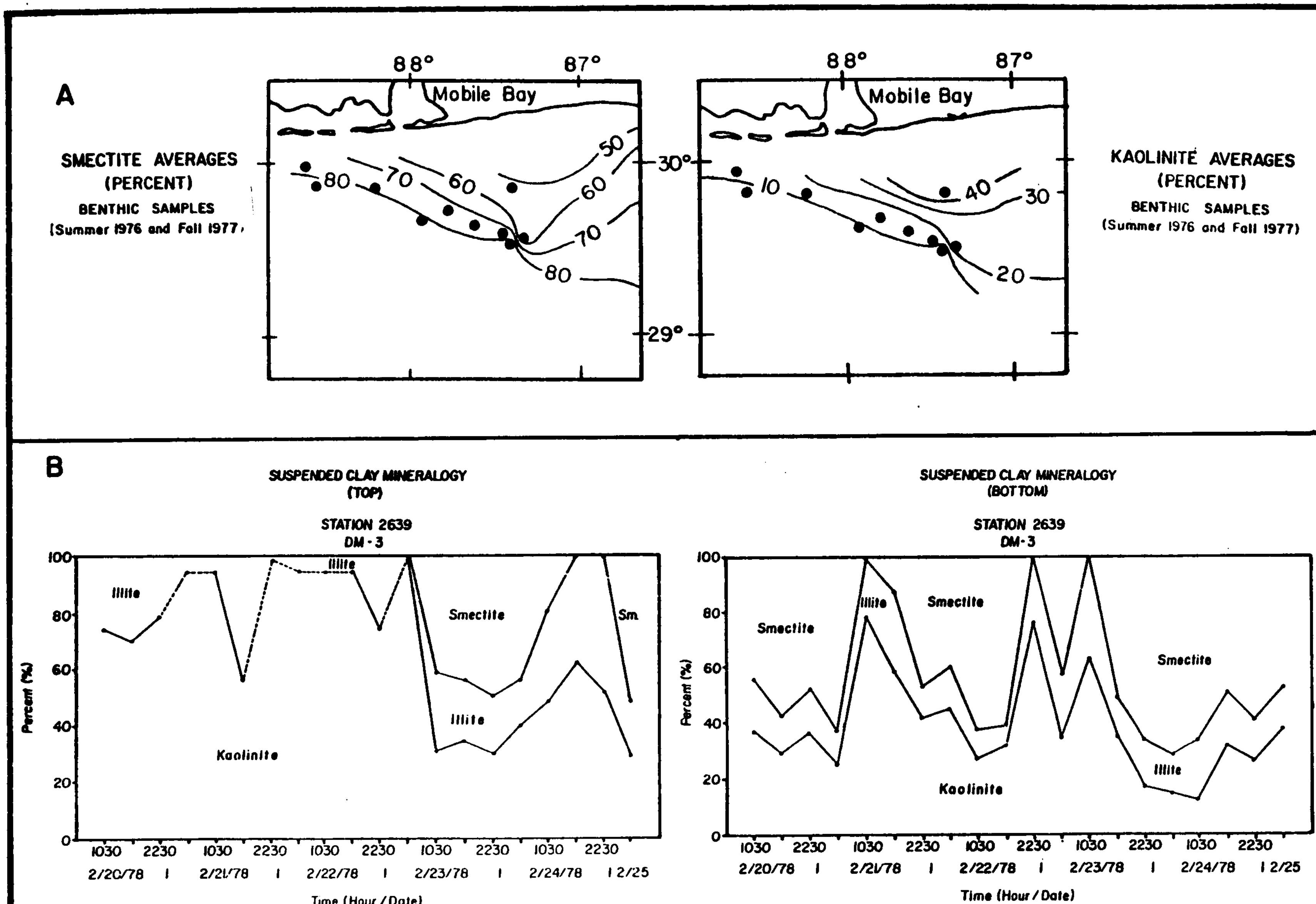


Figure 5.6. Clay mineralogy in the Tuscaloosa Trend area: (A) Distribution of Smectite and Kaolinite in sediments; (B) Composition of suspended clays in surface and near bottom waters at times series station south of Mobile Bay. (Source: Doyle and Sparks, 1979).

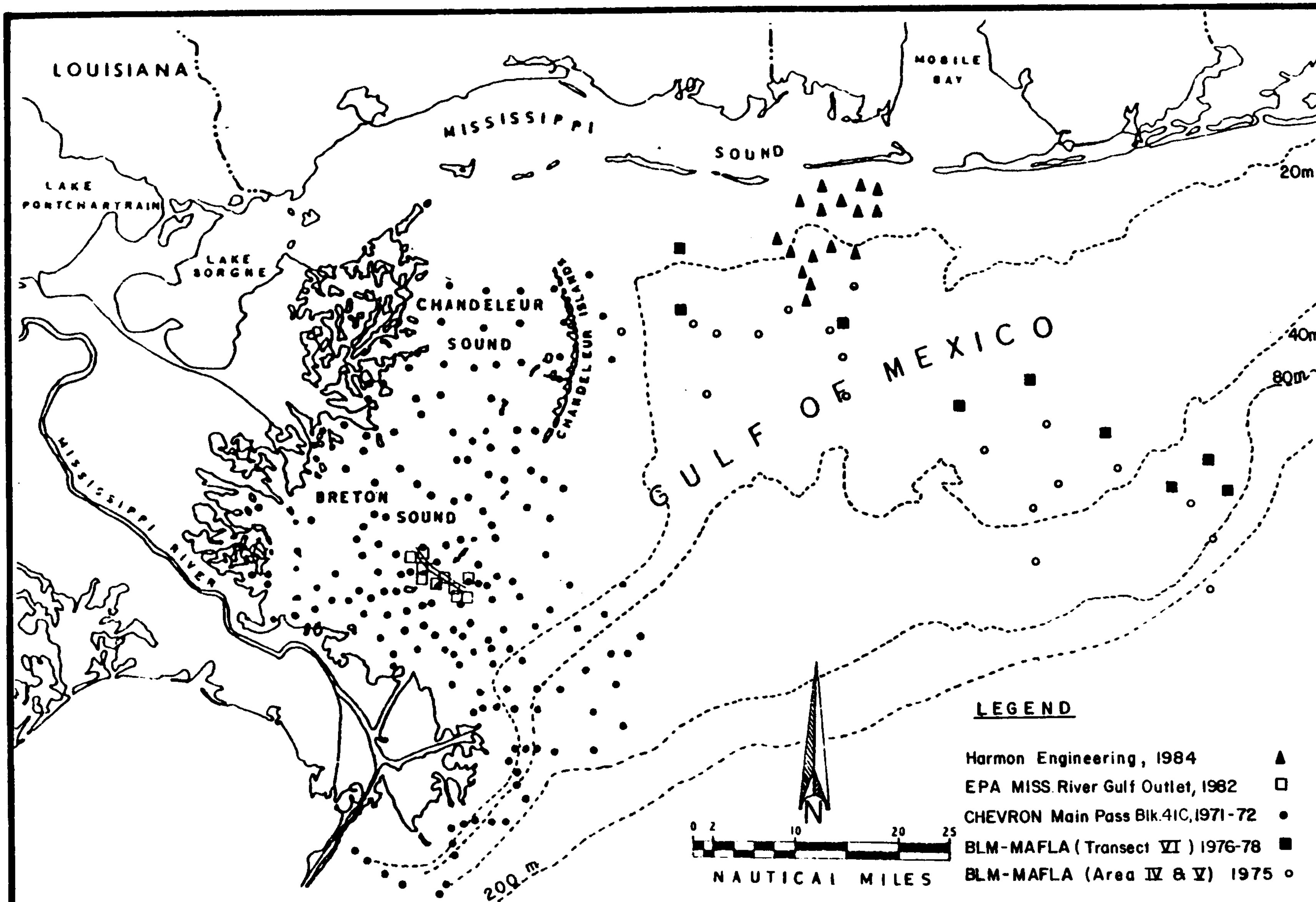


Figure 5.7. Locations of benthic sediment hydrocarbon sampling stations in the Tuscaloosa Trend region (less Mississippi Sound).

Table 5.6. Hydrocarbon results of sediment samples collected on the Mississippi-Alabama shelf: (A) Gravimetric data and (B) Gas chromatography. (Source: Gearing et al. (1976).

A

Parameter	Area IV 10 samples	Area V 10 samples
Average Water Depth, m	60	30
Percent Carbonate	44.2	15.8
Percent Organic Carbon (Total Sediment)	0.12 (0.06)	0.49 (0.14)
Percent Organic Carbon (Carbonate-free Basis)	0.77 (0.92)	0.58 (0.20)
Lipid/Total Sediment, ppm	44. (39.)	232. (122.)
Lipid/Organic Carbon x 100	5.44 (3.77)	4.76 (2.68)
Hydrocarbons/Total Sediment, ppm	1.50 (1.40)	11.7 (6.4)
Hydrocarbons/Organic Carbon	0.0009 (0.0006)	0.0023 (0.0009)
Hydrocarbons/Lipid x 100	4.09 (3.24)	5.77 (2.43)
Aliphatic HC/Lipids x 100	2.18 (1.74)	3.21 (1.67)
Aromatic HC/Lipid x 100	1.91 (1.67)	2.56 (1.11)
Aliphatic/Aromatic HC	1.15 (0.58)	1.36 (0.44)

Numbers in parentheses are standard deviations.

B Aliphatic hydrocarbons from sediments

Parameter	Area IV 10 samples	Area V 10 samples
Range	14--33	14--33
Major Peaks	C_{21}, C_{31}, C_{17}	C_{27}, C_{29}, C_{31} C_{16}, C_{17}, C_{18}
$\frac{\sum_{12}^{20} \underline{n}\text{-Alkanes}}{\sum_{21}^{35} \underline{n}\text{-Alkanes}}$	0.60	0.44
$\frac{\underline{n}\text{-}C_{27}+\underline{n}\text{-}C_{29}}{\underline{n}\text{-}C_{26}+\underline{n}\text{-}C_{28}}$	2.2	3.1
$\underline{n}$-C_{17}/Pristane[1]	2.59	2.03
$\underline{n}$-C_{18}/Phytane[1]	2.74	2.86
Pristane/Phytane[1]	1.62	1.84
K.I.2075[2]	5.7	2.9
K.I.2150[2]	3.0	3.0
K.I.2150/$\underline{n}$-C_{17}	1.28	0.38
Resolved/Unresolved	0.22(0.16)	0.34(0.10)
$\frac{\underline{n}\text{-}C_{15}+\underline{n}\text{-}C_{17}}{2(\underline{n}\text{-}C_{16})}$	1.23	1.07

[1] Geometric averages, other numbers are arithmetic averages.
[2] Percentage of total peaks.

chromatographically unresolved material (Figure 5.8a); (3) low values for n-C_{17}/pristane and n-C_{18}/phytane ratios (Table 5.6b); and (4) a smooth distribution of n-alkanes in the low molecular weight range with large amounts of n-C_{16}. "Fingerprint" properties of petroleum hydrocarbons, including low values for total n-alkanes/n-C_{16} and lack of odd/even preference in the high molecular weight range (Table 5.6b), are not seen due to the great influx of terrigenous-derived n-alkanes (Gearing et al., 1976; Alexander et al., 1977).

The aromatic fractions (benzene eluates) in the study area sediments were as complex and variable as those found in the aliphatics. Chromatograms typical of fractions from sediments in the Tuscaloosa Trend region (Area V) are compared with West Florida shelf sediments (Area I) in Figure 5.8b. Based on samples collected in 1975 (Lytle and Lytle, 1976) and in 1976-1978 (Boehm, 1979), some stations located on the Mississippi-Alabama shelf contained aliphatic hydrocarbons indicative of oil (e.g., large pristane/n-C_{17} and phytane/n-C_{18} ratio, even distribution of n-C_{12} to n-C_{20} components), as well as terrestrial influences (e.g., decided odd n-alkane preference among n-C_{21} to n-C_{32}). These petroleum hydrocarbons may have been introduced from the oil drilling, transporting, or processing activities in coastal southeast Louisiana to Alabama. This has been supported by recent surveys conducted in shallow waters south of Dauphin Island (Harmon Engineering, 1984). The source that appears most predominantly in the n-C_{12} and n-C_{20} range is similar to that of weathered oils. The high molecular weight hydrocarbon distribution found in Table 5.7 indicates a decrease in concentration of both aliphatic (1.847 to 1.147 ppm) and aromatic hydrocarbons (0.731 to 0.439 ppm) with depth of sampling stations (i.e., from north to south, respectively.) Other reports (Lytle and Lytle, 1976a,b) indicate that the anthropogenic source of hydrocarbons to shelf sediments decreased from 1975 to 1976. Additional evidence exists for transport of anthropogenic wastes from the Louisiana to Alabama coastal area along the continental slope to areas west of south Florida.

Throughout Mississippi Sound between 1979 and 1982, surface sediment has been collected and analyzed for anthropogenic hydrocarbons (Lytle and Lytle, 1983a). In sediments from marinas and an industrial seaway in the eastern Sound, hydrocarbon fractions yielded very complex low molecular weight assemblages of cycloalkanes, and polynuclear aromatics characteristic of mixtures of fresh and partially combusted fuel oils. In areas of no or little industrial activity, such as St. Louis Bay in the western Sound, aliphatic and aromatic hydrocarbons occurred at low levels (Lytle, 1978; Lytle and Lytle, 1981).

Lytle and Lytle (1983a) indicate that sediments along the mainland shore have both terrestrial and marine hydrocarbons as the natural hydrocarbon source, with a dominance of the former. Sediments at the island passes contain hydrocarbons derived from marine sources, thereby indicating that the land-derived pollutants do not extend beyond the offshore islands. Consequently, organic pollutants found in sediments outside the islands of western Mississippi Sound most likely do not originate from along the Mississippi coast. In addition, surface sediments from open areas of the western Sound contain significantly higher levels of all organic pollutants than do those collected from sites further east in the Sound (Lytle and Lytle, 1983b). The majority of pollutant residues that are transported into the open Sound appear to accumulate in this region. Rivers and bays in the central and eastern Sounds contain much greater quantities of organic pollutant residues than do the open Sound. However, this increase in sediment pollutants in a westerly

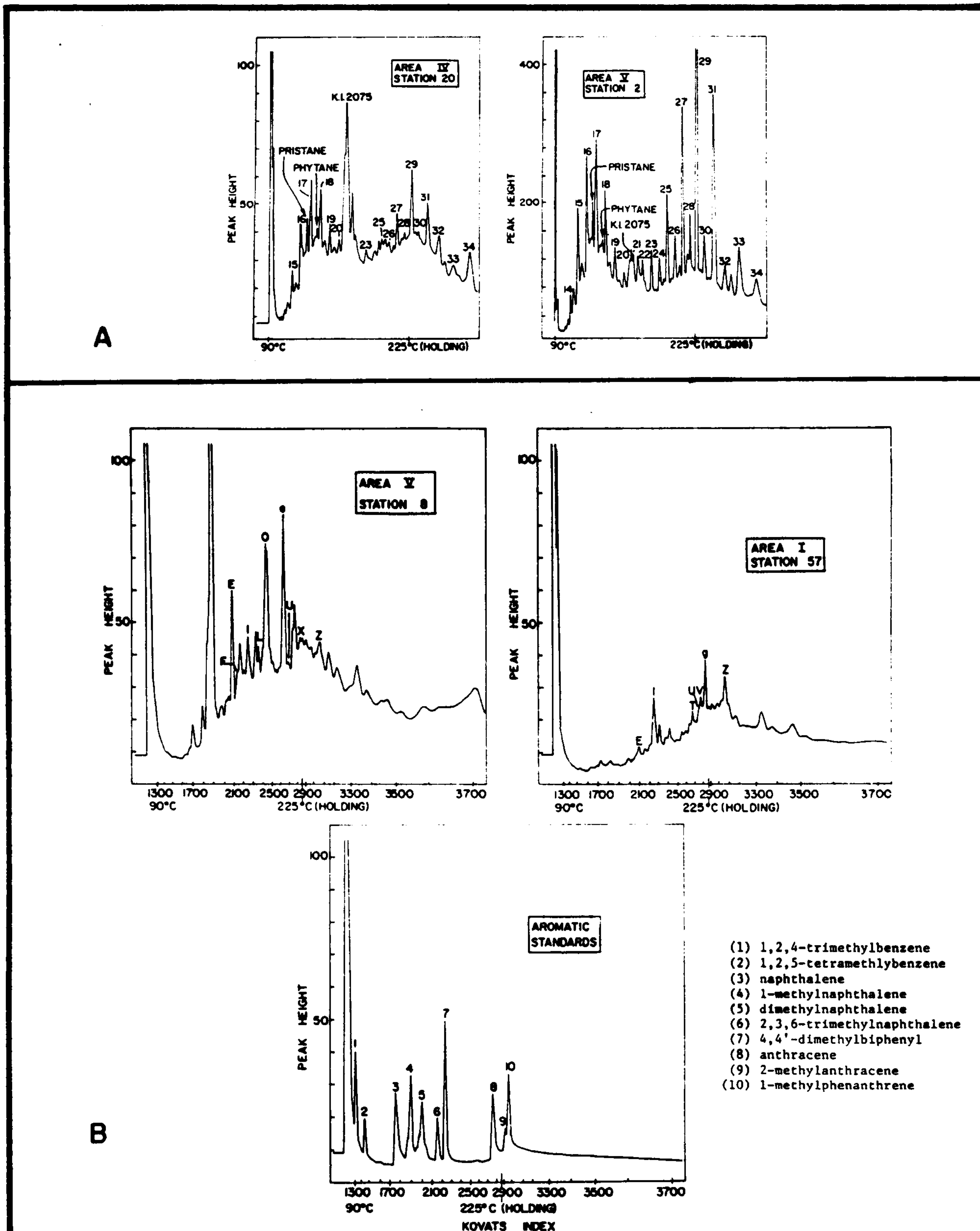


Figure 5. 8. Gas chromatograms of: (A) Aliphatic hydrocarbons, and (B) Aromatic hydrocarbons from typical 1975 MAFLA stations in Area IV and V. (Source: Gearing et al., 1976).

Table 5.7. High molecular weight hydrocarbon distribution in sediments south of Dauphin Island, Alabama. (Source: Harmon Engineering, 1984).

Parameter	Mobile North (9-17m depth)	Mobile South (17-24m depth
Aliphatics (ppm)	1.084-2.610	0.684-1.608
Aromatics (ppm)	0.465-0.997	0.251-0.626
n-alkanes/Aliphatics (%)	30.0-44.0	28.5-46.4
Pristane/n-C_{17}	0.67-1.10	0.50-0.97
Phytane/n-C_{18}	0.60-0.68	0.56-0.60
Odd/Even $\leq C_{20}$	0.93-1.24	1.02-1.11
Odd/Even $\geq C_{21}$	2.01-2.12	1.84-2.33
Odd/Even Totals	1.77-1.80	1.36-1.74

direction in the open Sound attests to the prevailing transport of pollutants to the west after introduction into Sound waters (Lytle and Lytle, 1983c). These pollutant residues are also highly correlated with the clay fraction gradient in the Sound sediments. The percent clay fraction increases significantly from east to west.

Sediment hydrocarbon concentrations within Chandeleur-Breton Sounds are affected by seasonal riverine inputs, open water petroleum operations, and waterborne traffic. Based on a recent survey along the Mississippi River-Gulf Outlet Channel, by the U.S. EPA (1982b), total sediment hydrocarbon concentrations in Chandeleur-Breton Sounds range from 5 to 28 ppm and are three to five times greater in late spring (June 1981) than late fall (December 1980). A similar seasonal trend was observed for aromatic and olefinic hydrocarbons (from 2 to 25 ppm), whereas saturated hydrocarbon levels (from 2 to 8 ppm) were similar during spring and fall. The increased concentrations of aromatic and olefinic compounds perhaps result from riverine inputs of fine sediments during high spring runoff (U.S. EPA, 1982b). These concentrations were slightly higher than the measurements reported by Gearing et al. (1976) for sediment hydrocarbon content near the Mississippi River Delta.

Hydrocarbons in sediments discharged from the Mississippi River reveal a lack of predominance of normal alkanes and a large unresolved envelope indicative of highly weathered hydrocarbons (core D38, Figure 5.9). By comparison, sediments in Chandeleur Sound away from petroleum operations, shipping, and Mississippi River discharge show markedly different chromatograms (sample 102, Figure 5.9); revealing low hydrocarbon content (McAuliffe et al., 1975).

Extensive sampling for sediment hydrocarbons was undertaken following the discharge of an estimated 65,000 barrels of 34° API gravity crude oil from the Chevron Main Pass Block 41C Platform east of the Mississippi River Delta in 1970. The highest values of $\underline{n}$-C_{12} to $\underline{n}$-C_{33} were observed in some samples taken near the MP41C platform (greater than 10 $mg \cdot l^{-1}$ wet sediment). Hydrocarbon concentrations in sediment samples from Chandeleur and Breton Sounds were considerably lower (McAuliffe et al., 1975). Evidence of spilled oil was apparent from the ratio of high molecular weight and total hydrocarbons, where the $\underline{n}$-C_{12} to $\underline{n}$-C_{33} fraction was 21% of the total sediment hydrocarbons in the vicinity of the platform, as compared to an average of 6.8% for Chandeleur-Breton Sounds (McAuliffe et al., 1975). Hydrocarbon concentrations measured after one year approached background levels.

5.5 <u>WATER COLUMN CHEMISTRY</u>

5.5.1 <u>SUSPENDED PARTICULATE MATTER/TRACE METALS</u>

Suspended matter, both biogenic and terrigenous, may have elevated trace metal concentrations from chemical processes such as chelation, adsorption, absorption, and flocculation. This material is often adsorbed to or ingested by small marine zooplankton who concentrate the metals and pass them on to the benthos or nektonic foragers via the food chain.

Suspended particulate loads can be valuable indicators of various processes affecting their horizontal, vertical, and seasonal distribution. The concentration of suspended particulates, may be affected by the proximity

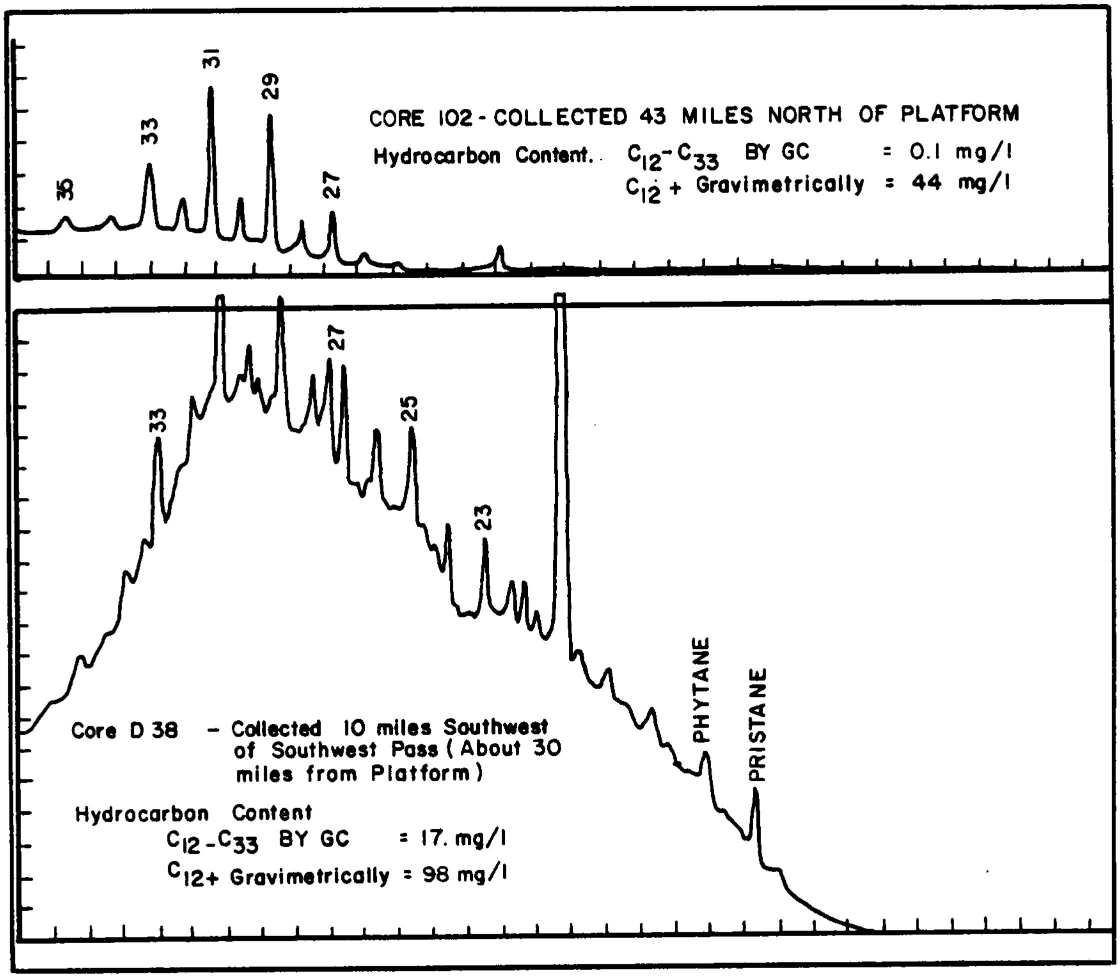


Figure 5.9. Gas chromatograms of hydrocarbons found in sediments near Mississippi River discharges and in Chandeleur Sound. (Source: McAuliffe et al., 1975).

fluctuations in salinity, particulate, and dissolved organic carbon, dissolved silica, and level of biotic productivity (Shokes, 1979b).

The concentrations of silica, aluminum, and iron in suspended particulate matter near Mobile reflect the proximity of a major particle source for the Gulf of Mexico. During all seasons (1977-1978) a substantial portion of the suspended particulate suites is composed of suspended clays. Particulate aluminum levels during the winter measured 27 $ug \cdot l^{-1}$ and 54 $ug \cdot l^{-1}$ for surface and bottom, respectively, compared to 2.4 $ug \cdot l^{-1}$ and 33 $ug \cdot l^{-1}$ for fall and 2.3 $ug \cdot l^{-1}$ and 7.2 $ug \cdot l^{-1}$ for summer (Betzer, 1979). Most of the material in suspension was alumino-silicates. Mean refractory iron concentrations were similar at surface and bottom during winter, whereas, during fall bottom water iron concentrations were twice those present in the surface waters. Other elements (cadmium, copper, lead) also showed seasonal changes possibly related to resuspension. Table 5.8 shows the comparison between mean trace metal composition of suspended particulate material and surface sediments of the Mississippi-Alabama shelf (Betzer, 1979). Shokes (1979b) found that levels of barium and vanadium in suspended particulates sampled offshore of Mobile Bay are likely the result of the dominant terrigenous input.

Betzer (1979) determined the concentrations of iron, copper, cadmium, lead, zinc, chromium, nickel, and vanadium in zooplankton during the BLM-MAFLA program to evaluate whether changes in suspended matter composition affect the composition of zooplankton. From the transect located off Mobile, the impact of terrigenous clay material was seen in the suspended particulate material iron content extracted from whole zooplankton; it was nine times greater than that for all transects on the West Florida shelf. The seasonal variation in trace metal concentration in zooplankton and neuston (organisms living within contact of the surface film of the water) for the study area is presented in Table 5.9 (Alexander et al., 1977). The average trace metal content of the neuston was generally less than that found in zooplankton during both fall and winter seasons.

Results of selected water column trace metal investigations in the Tuscaloosa Trend offshore area include particulate and dissolved fractions (see Table 5.10). Ranges of metal concentrations were generally consistent across the shelf, but were significantly lower than trace metal concentrations found in the water column in Mobile Bay, Mississippi Sound, and Chandeleur-Breton Sound (Table 5.11). With the exception of manganese, concentrations of metals in the dissolved fraction of bay and sound waters exceeded those found in the particulate fraction. Comparison of trace metal values with U.S. EPA standards do not indicate contamination.

5.5.2 PARTICULATE AND DISSOLVED ORGANICS

Particulate (POC) and dissolved (DOC) organic carbon are occasionally measured oceanographic parameters. The ratio of a measured organic pollutant to total dissolved or particulate organic carbon is useful in determining if the organic pollutant is of natural or anthropogenic origin. Particulate organic matter in sea water consists of a variable mixture of living organisms, debris, and organic matter on, or in, mineral particles. The particulate organic matter may have terrestrial, riverine, marine, atmospheric, or anthropogenic origins, particularly on the continental shelves. The dissolved organic carbon has similar origins, but represents organic material from decay

Table 5.8. Comparison between mean trace metal composition of suspended particulate material and surface sediments of the Tuscaloosa Trend region. (Source: Betzer, 1979)

	BLM-4 Station B (Miss. Delta) River Input			DM II 2639 (Mobile) Nepheloid Layer			DM III 2639 (Mobile) Winter Resuspension		
Element	sfc	bot	sed	sfc	bot	sed	sfc	bot	sed
Fe(%)	0.73 ±0.49	2.39 ±1.10	2.31 ±0.42	1.67 ±0.34	3.62 ±0.92	2.31 ±0.42	3.05 ±0.49	3.16 ±0.92	2.31 ±0.42
Pb(ppm)	100.7 ±96.1	83.1 ±33.8	16.0 ±1.4	65 ±94	25 ±90	16.0 ±1.4	18.1 ±18.0	16.7 ±23.4	16.0 ±1.4
Cd(ppm)	1.47 ±0.59	0.84 ±0.78	0.80 ±0.02	10 ±8	4 ±4	0.80 ±0.02	0.10 ±0.13	0.31 ±0.29	0.80 ±0.02
Cr(ppm)	64 ±74	44 ±60	41.20 ±0.02	145 ±81	95 ±11	41.20 ±0.02	129 ±43	152 ±13	41.20 ±0.02
Cu(ppm)	23.9 ±19.5	32.2 ±14.0	9.1 ±1.1	60 ±41	32 ±22	9.1 ±1.1	19.0 ±7.8	21.4 ±9.6	9.1 ±1.1
$CaCO_3$(%)	1.90 ±1.17	0.89 ±0.05	12.0 ±3.8	1.94 ±1.63	2.79 ±2.33	12.0 ±3.8	0.43 ±0.03	0.65 ±0.29	12.0 ±3.8

Note: All ± are one standard deviation.

Table 5.9. The average trace metal content (ppm) and the range of concentrations in zooplankton and neuston on MAFLA Transect IV during each season. (Source: Alexander et al., 1977)

ZOOPLANKTON				Metals			
Season	Cd	Cr	Cu	Fe	Ni	Pb	Va
Summer	5.6	1.2	18.03	254	2.4	2.1	9.8
(Range)	4.20-10.96	0.28-3.23	9.55-31.95	87-553	1.47-3.79	0.98-3.03	4.59-15.32
Fall	13.0	1.8	41.9	116	4.4	5.0	9.3
(Range)	2.65-23.99	0.21-5.46	16.71-88.01	49-237	1.23-9.75	0.66-13.37	0.92-34.92
Winter	3.9	1.0	17.7	679	2.4	0.8	9.7
(Range)	2.69-6.12	0.32-1.98	11.89-24.09		1.54-3.54	0.16-1.17	3.04-25.41

NEUSTON				Metals			
Season	Cd	Cr	Cu	Fe	Ni	Pb	Va
Fall							
Day	2.1	0.61	21.7	1,287.5	6.0	0.98	3.4
(Range)	1.00-3.52	0.30-0.84	11.86-38.30	467.0-2920	2.07-11.25	0.86-1.11	0.37-10.20
Night	2.0	0.34	25.8	231.9	2.9	1.79	1.6
(Range)	0.35-5.42	0.11-0.56	14.90-33.50	29.2-464	1.05-6.54	0.99-2.92	<0.37-2.65
Winter							
Day	2.2	0.57	10.5	215.5	2.8	3.13	4.7
(Range)	1.74-2.72	0.05-1.29	6.73-13.93	55.9-377.7	1.29-5.91	0.15-10.09	0.80-10.81
Night	2.0	0.95	14.7	297.6	1.5	2.92	2.1
(Range)	0.81-2.90	0.29-2.63	11.25-23.03	178.6-482.1	1.03-1.93	0.44-10.20	0.46-4.82

Table 5.10. Results of selected trace metal investigations in the Tuscaloosa Trend offshore area. Mean and (minimum-maximum) values are reported as $ug \cdot l^{-1}$ for dissolved and particulate fractions.

	OFFSHORE BARRIER ISLANDS					
	Ship Island (EPA, 1982a)		Dauphin Island (EPA, 1982a)		Dauphin Island (Harmon Engineering, 1984)	
					N(9-17m depth)	S(17-24m depth)
Metal	Particulate	Dissolved	Particulate	Dissolved	Dissolved	Dissolved
Barium						
Cadmium	(0.008-0.022)	(0.024-0.154)	(0.016-0.094)	(<0.010-0.085)	(0.0004-0.0006)	(0.0001-0.0009)
Chromium						
Copper					(0.002-0.016)	(0.001-0.012)
Iron						
Lead	(0.002-0.095)	(0.10-0.12)	(<0.005-0.039)	(<0.03-0.18)	(0.001-0.054)	(0.001-0.014)
Mercury	(<0.0003-0.002)	(<0.003-0.004)	(<0.0005-0.001)	(<0.003-0.018)	(0.0001-0.0007)	(0.0001-0.0003)
Vanadium						

	MAFLA TRANSECT VI Betzer (1979)		Shokes (1979b)		MAFLA TRANSECT IV (Alexander et al., 1977)	
	Surface	Bottom	Surface	Bottom	(refractory)	(weak acid soluble)
Metal	Particulate		Particulate		Particulate	
Barium			(232-573)	(183-365)	(0.0002-0.013)	(0.001-0.021)
Cadmium	0.0015	0.0008			(0.002-0.043)	---
Chromium	0.064	0.044			(0.0012-0.056)	(<0.0005-0.044)
Copper	0.024	0.032			(0.0003-0.018)	(0.001-6.12)
Iron					(0.005-0.077)	(0.004-0.097)
Lead	0.100	0.083				
Mercury						
Vanadium			(61-90)	(92-116)		

Table 5.11. Results of selected trace metal investigations in the Tuscaloosa Trend nearshore areas. Mean and (minimum-maximum) values are reported in $mg \cdot l^{-1}$. *(= soluble, ppb)

	Chandeleur-Breton Sound		Mississippi Sound	Mobile Bay
	Mississippi River-Gulf Outlet (EPA, 1982b)		St. Louis Bay* (Lytle, 1980b)	Mobile Bay (Isphording, 1983)*
Metal	Particulate	Dissolved	Dissolved	Dissolved
Arsenic	(0.057-0.17)	(0.92-1.9)		
Cadmium	(0.006-0.020)	(0.059-0.084)		
Chromium	(0.041-0.20)	(<0.10- 0.20)	<100	1
Cobalt			<20	12
Copper	(0.086-0.71)	(0.88-1.4)	<10	3.5
Iron			50	32
Lead	(0.09-0.47)	(0.05-0.74)		
Manganese	(0.93-11.0)	(0.33-2.2)		
Mercury	(<0.002-0.028)	<0.033		
Nickel	(<0.062-0.23)	(0.50-2.8)	<30	<10
Titanium			<300	<200
Vanadium			<200	<200
Zinc	(0.32-1.10)	(1.80-5.30)	78	35

of plankton, excretion or secretion by plankton, and may have riverine or marine origins. Both DOC and POC concentrations are two to five times higher in rivers than open-ocean surface water. In the open ocean, DOC concentrations are in the range of 0.7 to 1.2 mg $C \cdot l^{-1}$ and POC is in the range of 0.02 to 0.06 mg $C \cdot l^{-1}$ (Jeffrey, 1979a). The concentration in coastal waters is dependent on the amount of river input and is intermediate between that of river water and ocean water.

Dissolved and particulate organic carbon concentrations on the shelf in the Tuscaloosa Trend region were determined seasonally during the BLM-MAFLA program along Transect IV (Alexander et al., 1977) and time series stations south of Mobile Bay (Jeffrey, 1979a). POC levels were higher during the summer (0.15-0.47 mg $C \cdot l^{-1}$) than the fall and winter (0.04-0.24 mg $C \cdot l^{-1}$) and decreased with increasing distance from shore. Levels of particulate organic carbon are closely related to the amount of phytoplankton (as estimated by chlorophyll _a_) and zooplankton present in the summer and fall, especially nearshore. DOC levels, however, were higher during the winter (1.68-2.71 mg $C \cdot l^{-1}$) than both summer and fall (0.89-1.89 mg $C \cdot l^{-1}$). Microheterotrophs have their highest activity and shortest turnover times in shelf waters of 22°C and salinity of 25 °/oo and with the high concentrations of POC (Hanson, 1982).

Measurements of chlorophyll _a_ and net primary productivity for Tuscaloosa Trend shelf waters are presented in Table 5.12 (Alexander et al., 1977). Higher concentrations of chlorophyll _a_ were generally present in the near bottom waters; this is in part a function of phytoplankton dependence upon light for photosynthesis, the vertical distribution of nutrients, optimum temperature, and the location of the pycnocline. Higher concentration in deeper portions of the water column are typical of tropical and subtropical waters. The net primary productivity showed little variation between seasons, although the greatest range occurred during winter where activity increased with increasing distance from shore. Net primary productivity was greater in fall (8.7 g $C \cdot m^{-3} \cdot hr^{-1}$) than summer and winter (Alexander et al., 1977).

5.5.3 WATER COLUMN HYDROCARBONS

Water column hydrocarbon levels on the shelf range from 0.12 to 1.31 $ug \cdot l^{-1}$ for total dissolved hydrocarbons and from 0.06 to 3.61 $ug \cdot l^{-1}$ for particulate hydrocarbons (Alexander et al., 1977). Neither total dissolved nor total particulate hydrocarbons correlated with particulate organic carbon (Calder, 1976). Although the highest hydrocarbon concentrations are found in winter and lowest in fall, no petroleum contamination was observed in shelf waters (Jeffrey, 1979b). The concentrations of aliphatic hydrocarbons in both dissolved and particulate form were equivalent to, or less than, open-ocean values. Aromatic compound concentration levels were below the 0.01 $ug \cdot l^{-1}$ level. Unresolved components were present in both dissolved and particulate phases, especially near the Mississippi River which may be the source of this material (Calder, 1976). As previously mentioned for sediment hydrocarbons, natural sources appear to be a combination of terrigenous and marine biogenic processes.

Table 5.12. Average concentrations of surface and bottom chlorophyll *a* and seasonal primary productivity and observed range of concentrations along a transect on the Mississippi-Alabama shelf. (Source: Alexander et al., 1977).

Season	Chlorophyll *a* ($mg \cdot m^{-3}$) Surface	Bottom	Net Primary Productivity ($gC \cdot m^{-3} \cdot hr^{-1}$)
Summer	0.80	1.70	7.6
(Range)	0.39-1.48	0.51-4.37	6.3-9.1
Fall	0.33	0.27	8.7
(Range)	0.04-1.09	0.05-0.54	7.6-10.4
Winter	0.94	0.55	8.0
(Range)	0.54-1.73	0.28-1.04	6.7-13.6

Contamination by hydrocarbons and surfactants in the water column were reported during the 1970 Chevron platform oil spill. Within the low molecular weight hydrocarbons ($\underline{n}$-C_1 to $\underline{n}$-C_9), benzene, toluene, xylenes, and trimethyl benzenes composed about one-half of the aromatic fraction. Total dissolved hydrocarbons exceeded 0.002 ppm in the collected waters as far away from the platform as 1800 m. With time these dissolved hydrocarbons either became extremely dilute by dispersion, biodegradation, photo-oxidation, or evaporation. High molecular weight hydrocarbon ($\underline{n}$-C_{12} to $\underline{n}$-C_{30}) determinations yielded less conclusive results (McAuliffe et al., 1975).

In general, waterborne hydrocarbon analyses in the nearshore coastal areas of the Tuscaloosa Trend have focused on chlorinated hydrocarbons (e.g., PCB's, pesticides, and insecticides), primarily in the analysis of elutriate water during assays of sediments from dredged material disposal sites. Recent surveys (U.S. EPA, 1982a,b; Harmon Engineering, 1984) indicate that pesticide values are extremely low or non-detectable in areas adjacent to the barrier islands, and that elevated levels are probably restricted to the major sources of input along the coast, i.e., industrial complexes and rivers with large agricultural drainage systems (NOAA, 1984).

5.6 TISSUE CHEMISTRY

Waste materials introduced directly into the Tuscaloosa Trend study area are primarily in the form of dredged material from major ship channels (almost one million cubic meters per year). Other pollutant inputs include estuarine and riverine inflows of nutrients, pesticides and trace metals from upstream agricultural and manufacturing wastes and hydrocarbons from commercial waterborne transportation. Atmospheric wastes generated by the industrial areas along coastal Mississippi and Alabama can also contribute slight quantities of heavy metals, hydrocarbons, pesticides, and other potentially harmful substances to the offshore waters. Estimates of mass loadings to the estuarine systems in the study area are summarized in Table 5.13 by the NOAA-Strategic Assessment Branch (1984).

Chen and Selleck (1969) have described the relationships between concentration, biostimulation, and intoxication with simple population growth curves (Figure 5.10). True toxicants have adverse effects on aggregate growth rate at practically any concentration, while true nutrients have beneficial effects at most realistic concentrations. Many intermediate substances, such as trace metals commonly found in marine organisms, can be biostimulants, neutral agents, or toxicants, depending on concentration. Though simplified, the graphic representation demonstrates that toxicity is a relative term which can be accurately defined only in the context of an organism's natural chemical requirements (McLaughlin et al., 1975).

5.6.1 TISSUE TRACE METALS

Benthic biota are potentially valuable as indicators of environmental perturbation since they influence (and are influenced by) two geochemical reservoirs, the sediments and the water column; however, geochemically important reactions occur largely at the interfaces. This interface may extend below the surface of sediments into the bioturbation zone, or extend upward into the near bottom nepheloid layer. The availability of metals is a direct function of the manner by which they are partitioned in the bottom sediments

Table 5.13. Estimated mass loadings of heavy metals, petroleum hydrocarbons, PCBs and other chlorinated hydrocarbons to major estuaries in the Tuscaloosa Trend study area for a year circa 1980. (Source: NOAA, 1984). All values in 1000 pounds.

	Point Sources				Nonpoint Sources				Upstream Load				Total Mass Loading			
Estuary	Total[a/] Heavy Metals	Pet. HCs.	PCBs	Other[b/] Chl. HCs.	Total[a/] Heavy Metals	Pet. HCs.	PCBs	Other[b/] Chl. HCs.	Total[a/] Heavy Metals	Pet. HCs.	PCB's	Other[b/] Chl. HCs.	Total[a/] Heavy Metals	Pet. HCs.	PCBs	Other Chl. Hcs.
Perdido Bay/River	10.0	70.0	0.0	16.4	23.4	249.1	0.0	4.6	10.1	N.M.	0.0	0.0	53.5	319.1	0.0	21.0
Mobile Bay/River	707.3	2076.9	13.8	1461.9	144.2	1659.4	0.0	8.3	7210.6	N.M.	0.0	0.0	18062.1	3736.3	13.8	1470.2
Pascagoula Bay/ River/Escatawpa River	79.7	124.3	0.1	230.3	32.0	367.9	0.0	1.3	1923.7	N.M.	0.0	0.0	2035.4	492.2	0.1	231.6
Biloxi/Back Bays	117.2	112.9	0.1	0.1	15.7	367.9	0.0	0.4	16.0	N.M.	0.0	0.0	148.9	480.8	0.1	0.5
St. Louis Bay/ Wolf/Jourdan R.	1.0	13.9	0.6	0.2	8.6	0.0	0.0	0.6	30.5	N.M.	0.0	0.0	40.1	13.9	0.6	0.8
L. Pontchartrain/ L. Maurepas	65.6	1169.3	0.9	122.1	410.2	4918.3	0.0	6.1	207.8	N.M.	0.0	0.0	683.6	6087.6	0.9	128.2
Mississippi River/ Delta	5782.3	18000.0	191.6	4566.1	28.3	110.9	0.0	0.4	60024.9	739776.0	0.0	240.7	65835.5	757886.9	191.6	4807.2

Abbreviations: Pet. HCs., Petroleum Hydrocarbons; PCBs, Polychlorinated Biphenyls; Other Chl. HCs., Chlorinated Hydrocarbons other than PCBs; N.M., not measured.

[a/] Total heavy metals represent the sum of the amounts of Cu, Cd, Cr, Pb, As, Hg and Zn.

[b/] Other Chl. Hcs. is the sum of all chlorinated hydrocarbons monitored at a station and varies by station.

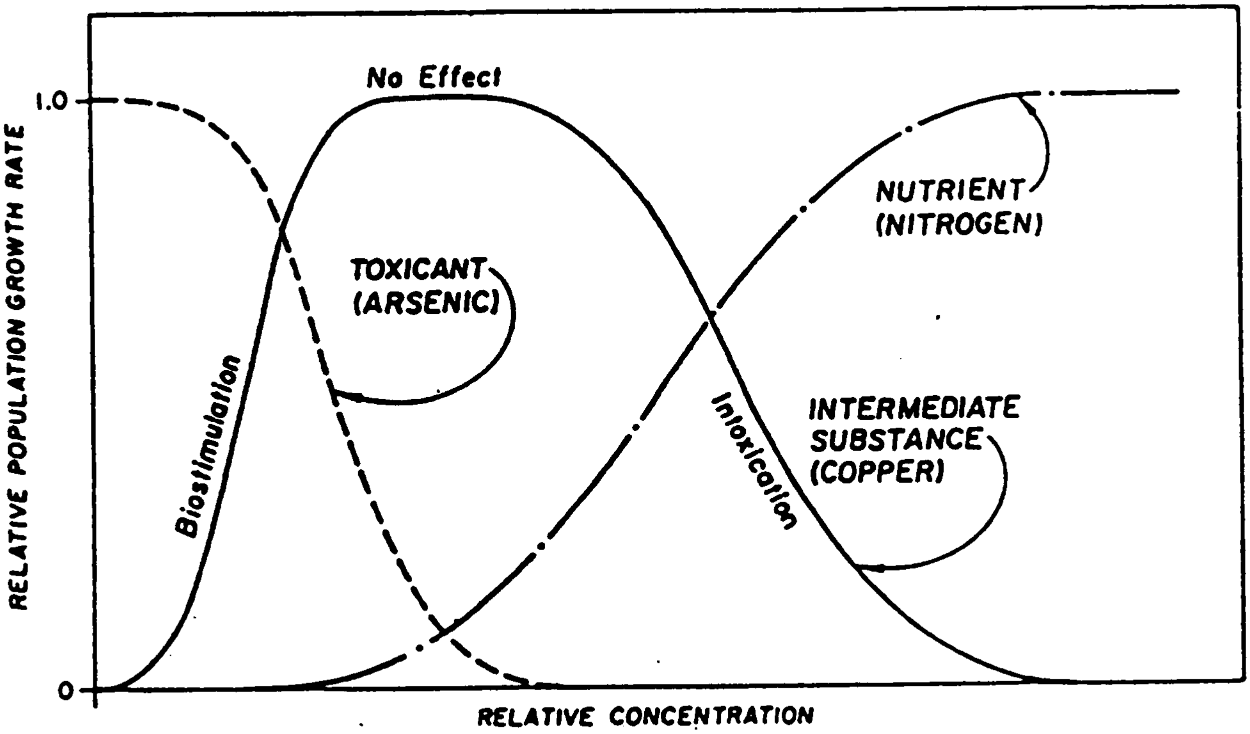


Figure 5.10. Hypothetical relationship between population growth rate and concentration for some typical chemical constituents (after Chen and Selleck, 1969).

and sediment-water interface (Isphording et al., 1983). The trophic status and feeding mode of benthic, epibenthic, and demersal species also dictate the uptake and possible accumulation of trace metals.

Tissue trace metal investigations on the Mississippi-Alabama shelf have evaluated several faunal groups (e.g., demersal fish, squid, shrimp and crabs, bivalve molluscs, and echinoderms; however, much of this information has been presented by group or species, and not necessarily by station or location along the shelf. In this case, only general statements by faunal group can be made. Results of the MAFLA program (Alexander et al., 1977; Johnson, 1979; Shokes, 1979c), indicate that the trace metal content of the demersal fish and macroepifauna reflects a relatively clean environment, with no indications of anthropogenic pollution impact. Seasonal changes in trace metal content of muscle of some species (e.g., the dusky flounder Syacium papillosum) may be reflective of diet (Johnson, 1979).

Recent investigations of tissue trace metal concentrations on the shelf include those of the U.S. EPA (1982a) and Harmon Engineering (1984). Fish and invertebrates were collected south of the Mississippi and Alabama barrier islands within proposed and existing dredged material disposal sites (Table 5.14). Only cadmium, copper, lead, and mercury concentrations were evaluated from four shrimp species,two crab species, one squid species, and five species of fish. A high degree of variability exists in the comparison of these trace metal data, perhaps due to the migratory behavior and size class of specimens and geographic areas collected; however, they do provide additional background levels for these species.

Recent studies on tissue trace metal concentrations of commercially important shellfish within the sounds and bays of the study area provide background levels for oysters and blue crabs. During an 18-month monitoring program of an exploratory drilling operation in Mobile Bay, oyster (Crassostrea virginica) meat and blue crab gill tissues (Callinectes sapidus) were analyzed for a suite of ten trace metals at five experimental and one control site (TechCon, 1980). Crab gill tissues contained greater concentrations of barium, chromium, copper, iron, lead, nickel, strontium, and vanadium than oyster tissues, while oyster tissues contained greater concentrations of cadmium and zinc than blue crabs.

Background levels of trace metal concentrations in tissues of filter-feeding bivalves Crassostrea virginica and the brackish-water clam Rangia cuneata from St. Louis Bay, Mississippi, were investigated by Lytle and Lytle (1982) prior to introduction of heavy industry. Of ten metals evaluated, arsenic accumulated in C. virginica to levels twice those found in R. cuneata, while, conversely, selenium was concentrated twice as much. Copper and zinc were effectively accumulated more by the oyster than the clam, whereas iron levels were greater in R. cuneata. The overall low tissue levels in both species are consistent with those observed in other bays throughout the Gulf of Mexico.

Since oysters are known to accumulate many heavy metals, they are considered good indicators of metal pollution in the estuarine environment (Zaroogian, 1980; Greig and Wenzloff, 1978; Siewicki et al., 1983). They have the ability to concentrate some metals to quantities in excess of those normally found in the form of low molecular weight metalloenzymes (metallothioneins), particularly the metals which oysters cannot regulate in their

Table 5.14. Results of metal analysis in tissue samples of fish and invertebrates collected offshore of Mississippi-Alabama barrier islands. Values are mg·kg^{-1} wet weight.

Invertebrates	Hg	Cd	Pb	Cu
Penaeus aztecus	0.03-0.08	0.05-0.08	<0.02-0.88	
Trachypeneus similis	0.04	0.04	<0.17	
Trachypeneus constrictus	0.06	0.12	<0.2	
Callinectes similis	0.46	0.47	<0.04	
Portunus gibbessi	0.04	0.35	0.14	
(U.S. EPA, 1982a)				
Fish				
Cynoscion arenarius	<0.1-0.2	<0.02-0.23	0.3-0.4	1.2-3.4
Anchoa sp.	0.1-1.8	0.08-0.19	0.3-0.4	0.9-4.0
Stenotomus caprinus	<0.1	0.02	0.1-0.2	1.7-2.0
Diplectrum bivittatum	<0.1	<0.02-0.08	0.2	1.3-4.5
Syacium papillosum	<0.1	<0.02	0.1	2.3
Invertebrates				
Trachypeneus similis	0.1	0.18	0.4	6.0
Lolliguncula brevis	<0.1-0.7	0.07-0.31	0.1-0.5	5-49
Penaeus setiferus	<0.1	0.30	0.7	30
(Harmon Engineering, 1984)				

tissues, such as cadmium (Zaroogian, 1980). The spillover of metals into the high molecular weight fraction may cause toxic conditions. The knowledge of how metals are partitioned in the environment (i.e., water, sediment, atmosphere) can provide an understanding, and possibly prediction, of toxic accumulation levels within organisms (Sick and Fair, 1983).

Isphording et al. (1983) extrapolated results of partitioned analyses of heavy metals in their interpretation of metal concentration in tissues of the commercial oyster Crassostrea virginica. Concentrations of cobalt, copper, iron, nickel, vanadium, and zinc measured in water, sediment, hydrosol (sediment-water interface) and oyster tissue samples from Mobile Bay are 10 to 100 times greater than metal concentrations measured in St. Louis Bay, Mississippi (Table 5.15). The accumulation of metals by oysters (and other filter-feeding organisms) is perhaps related to reactions occurring between tissue and the fine particulate organic and inorganic fraction present in the sediment-water interface, and less due to free or complex ions present in the water column, or in consolidated sediments. However, when fine sediment particles become resuspended, those metals held in exchangeable, reducible, or as organic complexes adsorbed to clay mineral lattices can be extracted by filter-feeding organisms (Isphording et al., 1983).

5.6.2 TISSUE HYDROCARBONS

Estuarine and marine ecosystems are facing increased pressures from the activities and by-products of technological operations located along the coasts or associated with the river drainage systems that enter the bays and estuaries. Of the many damaging materials that often enter the system, it is the organic pollutants of agricultural and industrial origin that are most often biologically detrimental. The impact of these pollutants on estuarine and marine ecosystems is well documented for certain contaminants such as crude oil, petroleum by-products, pesticides, chlorinated biphenyls (PCB's), etc. (National Reseach Council, 1980). A large number of aquatic and marine animals have been shown to bioaccumulate many of these type of materials either directly from the water or via ingested material, and a wide variety of physiological and pathological effects have been documented (Anderson et al., 1974; Anderson, 1977).

As discussed for tissue trace metals, bivalve molluscs have been employed as biological indicators for monitoring estuarine research, e.g., the International Mussel Watch (National Research Council, 1980). Bivalves, especially oysters, are used for the monitoring program since: (1) most are filter feeders and accumulate and concentrate a variety of contaminants; (2) their sessile nature allows an evaluation of local pollution problems; (3) there is a persistence of many pollutants in their tissues, even after long depuration periods (Neff et al., 1976; Boehm and Quinn, 1977); and (4) their high densities and relative ease of collecting make them readily available.

Deposit feeders, on the other hand, may be quite specific and selective in what is transported to their digestive system. Although the mean hydrocarbon composition and individual concentrations of deposited material from surface sediment analyses may be known, what eventually ends up in the digestive trace of a species may be substantially different.

Table 5.15. Average heavy metal levels in water, sediment, hydrosol, and tissues of *Crassostrea virginica* for St. Louis Bay, Mississippi and Mobile Bay, Alabama. *Data from Lytle (1980b). **Data from Lytle and Lytle (1982). (Source: Isphording et al., 1983)

	WATER		SEDIMENT		HYDROSOL		TISSUE	
	St. Louis Bay (ppb)*	Mobile Bay (ppb)	St. Louis Bay (ppm)*	Mobile Bay (ppm)	St. Louis Bay (ppm)	Mobile Bay (ppm)	St. Louis** (ppm)	Mobile Bay (ppm)
Cobalt	<20	12	8	29	1	5	< 0.04	11.0
Chromium	<100	1	10	63	12	76	<0.1	<0.1
Copper	<10	3.5	10	32	15	56	32.0	106.0
Iron	54	32	21,000	35,648	17,112	31,767	57.0	694.0
Nickel	< 30	< 10	8	57	7	70	<0.2	18.0
Titanium	<300	<200	278	4,944	166	1,755	<2.0	<1.0
Vanadium	<200	<200	6.4	163	9	93	< 2.0	63.0
Zinc	78	35	73	360	58	267	821.0	1,887.0

Hydrocarbon concentrations in tissues are mainly related to hydrocarbon residence times in the environment. Bieri (1979) notes that most hydrocarbons in animal tissue are transitory, and unless the concentrations reach levels that are toxic (either acute or chronic) over the time of exposure, there is little concern about tissue hydrocarbons. Since chronic toxicities are difficult to establish and since accumulation effects via the food chain are not well understood, research into all aspects of petroleum hydrocarbon pollution is still actively pursued.

Interpretation of tissue hydrocarbon data collected from the 1977-78 BLM-MAFLA program (Bieri, 1979) concluded that there was little evidence for the presence of petroleum, or petrogenic hydrocarbons, in zooplankton, macroepifauna, and fish (i.e., the dusky flounder Syacium papillosum) throughout the study area, including the Tuscaloosa Trend region. Several biogenic hydrocarbons from autochthonous sources were clearly indicated for $\underline{n}$-C_{17}, pristane, $\underline{n}$-C_{18}, $\underline{n}$-C_{19}, $\underline{n}$-C_{20}, and $\underline{n}$-C_{22}. The distinguishing feature in the zooplankton is the difference between seasonal peaks of biogenic hydrocarbons, thought possibly to reflect the biosynthesis by phytoplankton, the food source of zooplankton (Bieri, 1979).

Oysters monitored for hydrocarbon contamination in Mobile Bay showed some traces of refined petroleum hydrocarbons attributed to the high boat traffic in the vicinity of the oyster reefs (TechCon, 1980; Settine et al., 1983). Pesticide residues (DDT and its metabolites) attributed to agricultural runoff, were detected in some tissues following high river influx in spring and early summer (Settine et al., 1983). Traces of petroleum hydrocarbons from gill tissues of blue crabs (Callinectes sapidus) were lower at the end of two weeks than at the beginning of monitoring, suggesting depuration of pre-monitoring hydrocarbon levels (TechCon, 1980).

The hydrocarbon contents of shrimp, crabs, and fish tissues collected over an 11-month period following the Chevron Main Pass Block 41C platform oil spill in 1970 were generally low with no tissue hydrocarbons related to the spill. Oysters from reefs within Breton-Chandeleur Sound and more than 45 km from the platform, contained appreciable hydrocarbon concentrations (McAuliffe et al., 1975). However, there was no discussion of the composition of these hydrocarbons.

5.7 DATA GAPS

There is a general paucity of information on nutrient distribution on the shelf, particularly the outer shelf and any coupling with possible upwelling events during intrusion of the Loop Current.

Hypoxic conditions may occur on the shelf east of the Mississippi River, but this event has not been corroborated by sampling. There is the probability that freshwater discharges create an "envelope" of low salinity water overlying dense waters that may become hypoxic, affecting an area on the mid-shelf (20-40 m depth).

A better understanding is needed of the processes involved in transporting terrigenous pollutants to the shelf and slope. Additional information is required on the mechanisms by which specific pollutants associate themselves geochemically with silts and clays on the continental shelf. Studies should particularly address pollutants which are discharged into open shelf waters, such as drilling muds, hydrocarbons, and material from coastal maintenance dredging.

Further evaluation is required of biomagnification of trace metals through various food chains, including filter feeders, deposit feeders, and predators, inhabiting the near, mid, and outer shelf areas.

6.0 ECOSYSTEM STRUCTURE AND FUNCTION

6.1 INTRODUCTION

The coastal and continental shelf waters of the Tuscaloosa Trend study area comprise a highly productive ecosystem. This area of the northern Gulf coast is bounded by Mobile Bay and Mississippi Sound on the north and the Mississippi River Delta on the west. In addition to these mainland shoreline features, the barrier islands adjacent to the Mississippi Sound and Chandeleur Sound further serve to increase the land-sea interface. The ratio of shoreline to open water has been shown to have a direct effect on overall productivity of an ecosystem (Turner, 1982). High productivity is attributable in part to the extensive coastal marshes associated with these shoreline features, which contribute energy to the system through conversion of sunlight into plant material. Terrigenous nutrients delivered to the coastal zone via numerous rivers also contribute to high rates of primary production. The nutrient value of this plant material is further enhanced upon decomposition by serving as a substrate for bacteria and other microorganisms. This enriched, decomposed plant material (or detritus) forms the basis of a complex food chain in coastal and adjoining outer continental shelf (OCS) waters.

The communication and exchange of water between the OCS and estuarine area illustrate the important and dynamic relationship occurring within this ecosystem. During monthly tidal cycles, water and entire planktonic communities may be transported through tidal passes into or out of the estuary (depending upon season and relative abundance). Many species which live on the bottom as adults are recruited into the estuaries as planktonic larvae. Nektonic organisms may pass in and out of the estuaries without tidal assistance.

Ecological processes and functional interrelationships between components of the Trend ecosystems are presented in Chapter 2 CONCEPTUAL ECOSYSTEM MODELING and further discussed in Section 6.6 SUBSYSTEM INTERRELATIONSHIPS. This chapter is organized to characterize the biota and biological processes, moving from coastal marshes to estuarine waters to offshore or oceanic waters. Where possible, compartments (such as marsh grass production) are quantified in order to show the magnitude of energy flow through the system. Generally, however, ecological processes such as trophics and secondary production are incompletely defined in the Tuscaloosa Trend area, especially among offshore ecosystem components.

While the focus of this synthesis report is the OCS and possible impacts of oil and gas development, by far the majority of marine research in the area is concentrated in the estuaries, since the nearshore waters are more accessible and of more apparent importance to commercial fishing interests. With the exception of the 1974-78 Mississippi-Alabama-Florida (MAFLA OCS) benchmark study (Alexander et al., 1977; Dames and Moore, 1979), which included one transect in the present study area and documented biological and chemical oceanography of the eastern Gulf of Mexico continental shelf, no comprehensive characterization of ecological resources exists for the Tuscaloosa Trend region.

In this discussion, it is necessary to define the boundaries of the coastal and OCS environments. A convenient point of separation when discussing biological communities is the barrier islands, since the waters of the bays and sounds tend to be more estuarine in nature (i.e., experience depressed salinties and higher turbidity) and include certain biological habitats (e.g., coastal marshes) not present in the adjoining OCS . Therefore, the following discussion of ecological characteristics of the study area is presented in three parts: coastal marshes; estuarine area inside the barrier islands; and offshore area from the barrier islands to the 200 m isobath.

Animals which occur in the marsh, estuarine, and oceanic ecosystems discussed in this chapter may be grouped with respect to habitat as well as size. Categories referred to here are defined as follows:

Pelagic, or inhabiting the water column

Neuston - Those animals which live in the top few centimeters of the water column, including especially zooplankton;

Plankton - Passive drifters or weak swimmers, including zoo- and ichthyoplankton;

Nekton - Active and strong swimmers, including invertebrates, fishes, and some reptiles and mammals;

Benthic, or living in or on the bottom

Meiofauna - Animals ranging in size from 0.063 to 0.5 mm, including larvae and juveniles of larger species;

Macroinfauna - Animals which live within the sediment and which will not pass through a 0.5 mm mesh screen;

Macroepifauna - Animals which live on or just above the bottom and which will not pass through a 0.5 mm mesh screen.

6.2 COASTAL MARSHES

Coastal marshes which fringe the mainland in the northern Gulf of Mexico are typically low energy, highly productive ecosystems. They contribute large amounts of organic material to surrounding waters and serve as sediment traps for suspended particulates of terrestrial origin. Marshes act as a buffer zone between marine and terrestrial environments and provide a habitat for many animal species during critical periods of their life cycle. Marsh plant communities occupy defined zones and types, characterized especially by salinity and tidal amplitude. Other physical factors which determine species zonation within the marsh include frequency and duration of tidal flooding, elevation of the marsh soils, and degree and duration of freshwater flooding.

Coastal marshes within the Tuscaloosa Trend study area have been studied by many researchers (Chabreck and Condrey, 1979; Chabreck, 1982; de la Cruz, 1974, 1979; Gabriel and de la Cruz, 1974; Eleuterius, 1971, 1972; Montz, 1978, 1980, 1981; Stout, 1981; Stout and Lelong, 1981). Figure 6.1 depicts the area coverage of coastal marshes in the Tuscaloosa Trend study area. Marshes comprise approximately 268,547 ac (108,762 ha) of the Tuscaloosa Trend coastal zone (Costanza et al., 1983; Vittor and Stout, 1975). A discussion of the vascular plants characteristic of the three main marsh types follows, while marsh fauna are discussed in a subsequent section.

6.2.1 HABITAT CHARACTERISTICS

Hydrology

Coastal marshes of the Trend area experience wide fluctuations in degree of flooding as well as salinity. This is a result of tremendous freshwater output of the Mississippi River plus the Mobile River system and Pearl River. Salinities in coastal brackish marshes are generally lower (2 to 15 $^{o}/oo$) than in South Atlantic marshes (de la Cruz, 1981), although salt marshes are exposed to salinities of 18 to 20 $^{o}/oo$. Salinities in fresh marsh waters seldom exceed 1 $^{o}/oo$. Flooding frequency and duration have been reviewed by Gosselink (1984) for coastal Louisiana. Based on data for Barataria Bay (comparable data are not available for the Trend area), salt marshes are flooded up to 50% of the year, while the duration of the average flooding event is only from 16 to 27 hrs. Brackish marshes are flooded approximnately 40% of the year, with an average duration of from 28 to 50 hrs per event. Fresh marshes are also flooded at least 40% of the year, but for an average of 115 hrs per event. Seasonal differences in flooding are significant; in September and October, salt marshes may be flooded 80% of the time.

Marsh Soils

Marsh soils are characteristically saturated fine to medium sediments with a layer of organic detritus or peat as the upper layer. This organic matter becomes oxidized and provides the source of electrons for biological reduction (DeLaune et al., 1976). The chemical and microbiological oxidation-reduction (redox) processes occurring in the marsh soils influence marsh plant root zone conditions and the availability of plant nutrients. The lack or deficiency of oxygen results in the predominance of reduction processes that create an anaerobic root zone. In saturated soils, organic matter is not decomposed as rapidly or completely as under well-drained or aerated conditions, and organic acids and other toxic substances accumulate. Marsh plants have a specialized gas transport system which enables them to obtain atmospheric oxygen internally (DeLaune et al., 1976).

Depending upon prevailing winds and tidal conditions, the tidal marsh may be covered by from 2 cm to 60 cm of water for extended periods of time. Gas exchange between soil and air is accomplished by molecular diffusion through the interstitial water. This process is very slow and within a few hours of submergence, microorganisms use up the oxygen present in the interstitial water and deoxygenate the submerged soil (DeLaune et al., 1976).

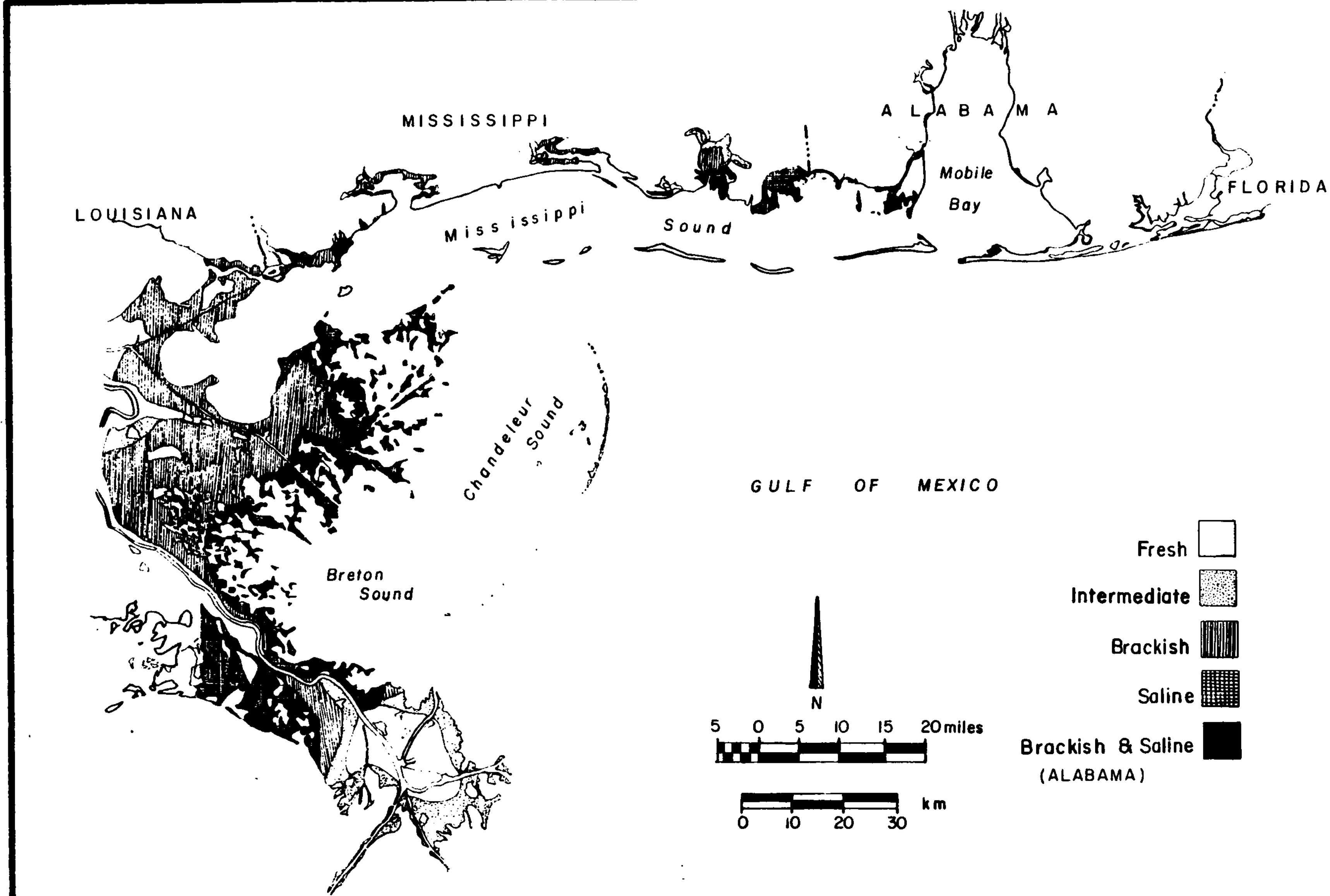


Figure 6.1 Areal coverage of coastal marshes within Tuscaloosa Trend study area (Source: Chabreck and Linscombe, 1978; Stout and Lelong, 1981).

Resulting anoxic conditions limit the diversity and abundance of fauna which inhabit marsh sediments.

The measurement of redox potential (Eh) is used as an indicator of the intensity of oxidation or reduction in the marsh soils. An oxidation-reduction reaction is a chemical reaction where electrons are passed from a donor to an acceptor. The electron donor loses the electron and increases its oxidation number, or is oxidized. Conversely, the electron acceptor receives electrons and decreases its oxidation number, or is reduced. The reduction of flooded marsh soils proceeds in a sequential manner (DeLaune et al., 1976). Oxygen is the first soil component to be reduced and is undetectable within one day of being submerged. The next oxidant to be attacked is nitrate, which begins after oxygen has been eliminated. Following nitrate in the reduction sequence is manganese, iron, and finally sulfate. The sulfate component is attacked by specialized anaerobic bacteria and is reduced to sulfide. After most of the sulfates have been reduced to sulfides, methane is produced.

Depending upon season and degree of biological activity, the sediment-water interface may be either oxygenated or totally devoid of oxygen. Oxygen in this region is renewed through molecular diffusion and convection currents. If biological activity at the sediment surface is high enough, oxygen in overlying waters can become depleted quicker than it can become renewed. The soil redox potential typically drops during summer when the temperature is higher and when prevailing southerly winds keep the soil inundated, and is higher in winter. Measurement of redox potential (Eh) is depicted in Figure 6.2 in relation to chemical cycling in marsh sediments.

Nutrient Cycling

Decomposition of organic matter in saturated soils occurs at a slower rate and the end products are different than those from well-drained or aerated soils (DeLaune et al., 1976). The organic matter in aerated soils disappears largely in the form of carbon dioxide from aerobic respiration of numerous microorganisms (Figure 6.2). By comparison, in saturated soils organic decomposition occurs almost entirely as the result of facultative anaerobes which work at a much lower energy level. The result is an accumulation of organic matter at various stages of decomposition in the soil.

The metabolic decomposition of carbohydrates is identical under aerobic and anaerobic conditions up to the point of pyruvic acid formation (DeLaune et al., 1976). From this point, pyruvic acid is converted to carbon dioxide, methane, hydrogen, organic acids, and hydrogen sulfide in saturated soils rather than entering the Krebs cycle where the end products are carbon dioxide and water as in the aerated condition.

During the metabolic decomposition of proteins under anaerobic conditions, the products of deamination ultimately result in ammonia, carboxylic acids and hydrogen sulfide. Under aerobic conditions, deamination products and carboxylic acids are channeled into the Krebs cycle and are ultimately oxidized to nitrate through the action of nitrifiers.

Methane (CH_4) is the typical end-product of organic decomposition in saturated marsh soils. The gas escapes in large amounts along with carbon dioxide, hydrogen sulfide, and hydrogen.

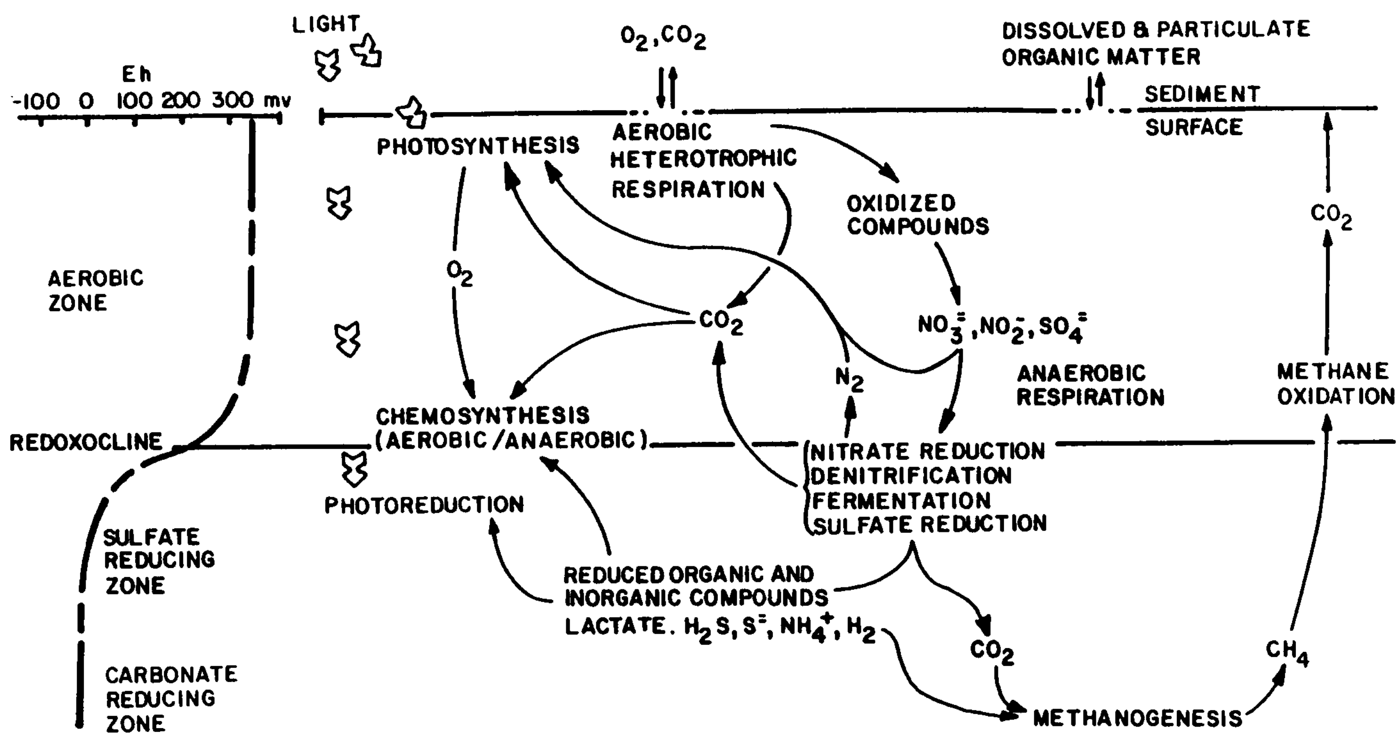


Figure 6.2. Schematic representation of chemical cycling in marsh sediments and soils.

Carbon dioxide (CO_2) is susceptible to anaerobic respiration by methane bacteria. Aerobic breakdown of organic materials to form methane proceeds in three steps: 1) hydrolysis of organic material by enzymes; 2) production of organic acids by facultative anaerobic bacteria; 3) production of methane by methogenic bacteria (Lawrence, 1971).

The process of marsh grass decomposition by bacteria and fungi enhances the caloric value of plant material. De la Cruz and Gabriel (1974) found decomposing marsh plant detritus to be a better and more nutritious food source on the basis of protein and caloric content than the living plant from which the detritus is derived. Caloric values increased from 4630 to 4911 g cal per ash-free gram. This increase in caloric values along with increased respiration rates in the detritus is attributed to microbial protoplasm associated with detrital decomposition.

Nitrogen occurs in saturated soils mainly as organic nitrogen and ammonium nitrogen (NH_3 or NH_4). Nitrate and nitrite are very unstable under reducing conditions. They rapidly undergo denitrification and consequently do not accumulate. The inorganic nitrogen fraction is the immediate source of nitrogen available to plants, while the organic form is unavailable until it is converted into the inorganic form (e.g., ammonium).

Denitrification is the biochemical reduction of nitrate into gaseous end products such as nitrogen (N_2) or N-oxides (nitrite). This process occurs due to the large numbers of autotrophic and heterotrophic bacteria and fungi, which inhabit saturated soils. These organisms operate only under very low oxygen concentrations.

Nitrogen fixation is the reduction of nitrogen gas to ammonia. Submerged sediments, which contain blue green algae and nitrogen-fixing photosynthetic bacteria, are a favorable environment for nitrogen fixation. Free ammonium is the only form of nitrogen available to plants in reduced soils (Gosselink, 1984).

6.2.2 MARSH PLANT COMMUNITIES

Salt Marsh

The saline, or salt, marsh is the most seaward of all the coastal marshes. Approximately 56,862 ac (23,029 ha) or 21.2% of the total marsh area within the study area is defined as saline marsh. This marsh is dissected by numerous tidal inlets, creeks, and embayments and consequently is subject to diurnal tidal fluctuations. Salinity in these marshes averages 18-20 $^o/oo$. The dominant plant species of this marsh type include smooth cordgrass (*Spartina alterniflora*), saltgrass (*Distichlis spicata*), black rush (*Juncus roemerianus*), glassworts (*Salicornia* sp.), and the black mangrove (*Avicennia nitida*), which is restricted to the southern Louisiana coast by sensitivity to severe freezes. The *S. alterniflora* zone is usually monotypic with the exception of a few epiphytic algal species as a result of *S. alterniflora's* relative tolerance for frequent tidal submergence. In some saline marshes *D. spicata* occupies a narrow band between *S. alterniflora* and *J. roemerianus*.

Brackish-Intermediate Marsh

The brackish-intermediate marsh lies just interior to the saline marsh and occupies approximately 168,087 ac (68,075 ha) or 62.6% of the total coastal marsh within the study area. The salinity of this marsh type is less (3-10 ^{o}/oo) than the saline marsh and water depths are greater. Small lakes and bayous are commonly associated with these marshes. The organic content of the soil, which is a measure of residual organic detritus, averages from 31% to 33% (Chabreck, 1982). This marsh is diverse in terms of plant community composition because both freshwater and halophytic species are present. Dominant plant species in more brackish area include wiregrass or saltmeadow cordgrass (*Spartina patens*), three-cornered grass (*Scirpus olneyi*), leafy three-square (*Scirpus robustus*), and, in shallow open waters, widgeongrass (*Ruppia maritima*). The dominant plant species in less brackish areas include deerpea (*Vigna repens*), wild millet (*Echinochloa walteri*), bulrush (*Scirpus americanus*), sawgrass (*Cladium jamaicense*), Roseau or common cane (*Phragmites communis*), and bulltongue (*Sagittaria falcata* and *S. lancifolia*).

Freshwater Marsh

The freshwater marsh is the most inland of all marsh types. It is sometimes mixed with forested wetlands. Approximately 43,598 ac (17,657 ha) or 16.2% of the coastal marsh within the study area is defined as freshwater marsh. The salinity here is very low (about 1 ^{o}/oo) and the soil organic content is high (52%). This marsh type is the most diverse in terms of the number of plant species present and includes some species found in the intermediate marsh. Dominant species include maidencane (*Panicum hemitomon*), water hyacinth (*Eichhornia crassipes*), spikerush (*Eleocharis* sp.), bulltongue (*Sagittaria falcata* and *S. lancifolia*), alligator weed (*Alternanthera philoxeroides*) and pickerel weed (*Pontederia cordata*). Christmas et al. (1973) found as many as 18 species in these marshes during the summer and over 30 species during a growing season. These marshes extend upriver except where riverbank vertical relief and canopy shading produce unsuitable habitat conditions.

Algae

Algae play an important role in the ecology of Louisiana coastal marshes. Where emergent marsh grass and algae grow together, the epiphytic algal community is responsible for only 4-11% of photosynthesis, but 64-76% of total respiration (Gosselink et al., 1977). However, along edges of the marsh where adequate light can penetrate to epiphytic algae, photosynthesis does exceed respiration (Stowe, 1972). Macrophytic algae found during the winter include *Enteromorpha* and *Ectocarpus*, while *Bostricha* and *Polysiphonia* are present especially during the summer. Dominant epiphytic diatoms include *Amorpha*, *Cocconeis*, *Melosira*, *Denticula*, and *Nitzschia*.

6.2.3 MARSH FAUNAL COMMUNITIES

The fauna of coastal marshes may be grouped into several categories, including pelagic forms (plankton, nekton), benthic forms (meiofauna, macroinfauna, macroepifauna), and wildlife such as reptiles, avifauna, and mammals. (See Section 6.1 for definitions of these categories.) Taxa representatives of these faunal groups in the Tuscaloosa Trend area are summarized below.

Zooplankton

Zooplankters found in coastal marshes represent a small subset of those found in open estuarine waters. These include copepods and the planktonic larvae of fish and invertebrates which utilize the shallow, productive waters and abundant vegetative cover of the marsh grass as nursery grounds and for protection from predators. Depending on the type of marsh (continuously saturated or tidally flooded), the zooplankton community may consist of permanent residents or of forms which move in and out with the tidal flow. The fish and invertebrate larvae migrate to deeper waters of the marsh as they mature, seeking additional food sources and shelter before migrating offshore to spawn. Cuzon du Rest (1963) found that the copepod *Acartia tonsa* dominates Louisiana marsh waters throughout the year. Other species include *Eurytemora hirundoides*, *Pseudodiaptomus coronatus*, *Paracalanus crassirostris*, and *Oithona* spp. Gillespie (1971) reported similar findings during the estuarine inventory for Louisiana.

Nekton

Marsh nekton include a great variety of fishes and macroinvertebrates. The latter are represented by penaeid shrimps (*Penaeus* spp.), blue crab (*Callinectes sapidus*), and other crustaceans, such as *Palaemonetes pugio* and *P. vulgaris* and *Ogyrides limicola*. Some species (e.g., penaeid shrimps) occupy marsh waters as postlarvae or juveniles, while others (e.g., blue crabs) are nekton as adults but are considered epifauna as juveniles. Invertebrate members of the marsh nekton in the Trend study area have been described by numerous investigators, including Welsh (1971, 1975; *Palaemonetes pugio*), Rekas (1973; penaeid postlarvae), Idyll et al. (1968; shrimps), St. Amant (1973; shellfish and crustaceans), Swingle (1971; Alabama survey), Perret et al. (1971; Louisiana survey), and Christmas and Langley (1973; Mississippi survey).

Fishes which inhabit coastal marshes include larval or juvenile forms of many estuarine-dependent species, as well as permanent residents. Species in the latter category include the Gulf killifish (*Fundulus grandis*), marsh killifish (*F. confluentus*), longnose killifish (*F. similis*) sheepshead minnow (*Cyprinodon variegatus*), rainwater killifish (*Lucania parva*), and sailfin molly (*Poecilia latipinna*). Most of these species are herbivores or detritivores (Day et al., 1973) and exhibit tolerance for a wide range of salinity. They move through the marsh with tidal ebb and flood flows.

Fishes which occupy coastal marshes for only part of their life cycle have been reviewed by Benson (1982). Day et al. (1973) surveyed marsh and estuarine fishes typical of the central Louisiana coast; most of these taxa are equally representative of the marsh ichthyofauna of the Tuscaloosa Trend area as well. Swingle (1971), Perret et al. (1971), and Christmas and Waller (1973) surveyed the fishes of Alabama, Louisiana, and Mississippi, respectively. Predominant species include spot (*Leiostomus xanthurus*), croaker (*Micropogonias undulatus*), bay anchovy (*Anchoa mitchilli*), Gulf menhaden (*Brevoortia patronus*), sand seatrout (*Cynoscion arenarius*), speckled seatrout (*Cynoscion nebulosus*), striped mullet (*Mugil cephalus*), and tidewater silverside (*Menidia beryllina*).

Meiofauna

Marsh meiofauna include nematodes, harpacticoid copepods, kinorhynchs, ostracods, small polychaetes, and some insect larvae. Most meiofauna are deposit feeders selectively feeding on bacteria and particles of organic detritus. Harp (1980) compared the meiofaunal communities of two Alabama salt marshes (*Juncus*-dominated and *Spartina*-dominated) and found differences in both abundance and species composition, but diversity values were similar. Nematodes are by far the dominant fraction of the meiobenthic community. Rogers (1970), in a study of a Louisiana marsh, found that nematodes ranged from 685,000 to 4,165,000 individuals$\cdot m^{-2}$, representing 90% of the total number of meiobenthic organisms.

Macroinfauna

Marsh macroinfauna include especially polychaetes, molluscs, and crustaceans. Dominant species include the polychaetes *Manayunkia* spp., *Nereis succinea*, *Parandalia americana*, *Laeonereis culveri*, and *Heteromastus filiformis*; the bivalve *Rangia cuneata*; and crustaceans *Mysidopsis almyra*, *Edotea montosa*, *Cyathura polita*, and *Corophium louisianum*. The abundant polychaete taxa are predominately detrital feeders characterized as either subsurface or surface deposit feeders (Fauchald and Jumars, 1979). Subsurface deposit feeders burrow through the bottom sediments and seek buried food particles. Surface deposit feeders employ either motile feeding strategies or tactile feeding organs to obtain food from the sediment-water interface. Surface and subsurface deposit feeders are found generally in organic mud substrates, while suspension feeders that extract their nourishment from floating particles are commonly found in sandy substrates.

Most macroinfaunal species are found in the upper 15 cm of the sediment or above the reduced layer. Their burrowing activities rework the substrate to a point where particles below the surface are redeposited at the sediment water interface. Substrate turnover reduces anaerobic conditions and permits oxygen and bacteria to enter the substrate for decomposition. Macroinfauna are most abundant along marsh channels and ponds, where flowing water provides greater aeration of marsh sediments and where biological production is greatest (Gosselink, 1984).

Macroepifauna

Macroepifauna are those invertebrates which live on the surface of marsh soils or sediments as well as those which occupy burrows in the substrate. Dominant species include the bivalves *Modiolus demissus*, *Crassostrea virginica*, and *Brachidontes recurvus*; the gastropods *Neritina reclivata*, *Littorina irorata*, and *Melampus bidentata*; and the crustaceans *Panopeus herbstii*, *Rithropanopeus harrissii*, *Sesarma reticulatum*, *Menippe mercenaria*, *Uca* spp., *Callinectes sapidus* (juveniles), and *Palaemonetes* spp. Most motile species (e.g., most crustaceans) generally move through the marsh with ebb and flood tides, while sessile or less motile forms occupy habitats defined by degree and frequency of inundation (e.g., *Modiolus demissus*) or salinity (e.g., *Neritina reclivata*).

Wildlife Species

Wildlife diversity is highest in fresh marshes. Gosselink et al. (1979) found that 104 species of amphibians, reptiles, birds, and mammals occur in Louisiana salt marshes, while 140 species inhabit fresh marshes. Amphibians are poorly represented in coastal brackish and salt marshes but are relatively abundant in fresh marshes. Dominant species include the green tree frog (Hyla cinerea), southern leopard frog (Rana sphenocephala), bullfrog (Rana catesbiana), and three-toed amphiuma (Amphiuma tridactylum). Reptiles are somewhat more abundant and include the diamondback terrapin (Malaclemys terrapin pileata), Gulf salt marsh water snake (Natrix sipedon clarki), and cottonmouth moccasin (Agkistrodon piscivorus leucostoma). The American alligator (Alligator mississippiensis) is present within coastal marshes and is considered an endangered species in Mississippi and Alabama, while only threatened in Louisiana.

Marshes in the study area support a great variety of birds, including migratory waterfowl, shorebirds, wading birds, songbirds, and others. Numerous listings or studies of marsh avifauna have been reported (e.g., Chabreck, 1968; Lynch, 1968; Palmisano, 1973; Swingle et al., 1975; Portnoy, 1977; Hebrard and Stone, 1980). Hebrard and Stone (1980) listed 67 species of birds in marshes near Lake Pontchartrain, while Gosselink et al. (1979) reported as many as 92 species of birds in Louisiana chenier plain marshes. The following list is intended to identify representative bird species and is not all-inclusive: great blue heron (Ardea herodias), common egret (Casmerodius albus), Louisiana heron (Hydranassa tricolor), black-crowned night heron (Nycticorax nycticorax), laughing gull (Larus atricilla), clapper rail (Rallus longirostris), purple gallinule (Porphyrula martinica), seaside sparrow (Ammospiza maritima), belted kingfisher (Megaceryle alcyon), marsh hawk (Circus cyaneus), and peregrine falcon (Falco peregrinus).

Mammals common in coastal marshes include river otter (Lutra canadensis), opossum (Didelphis virginiana), marsh rice rat (Oryzomys palustris), cotton rat (Sigmodon hispidus), muskrat (Ondatra zibethicus), raccoon (Procyon lotor), nutria (Myocastor coypus), and white-tailed deer (Odocoileus virginianus). Species typical of coastal marshes in the Trend area have been surveyed by Richmond (1962), Palmisano (1972), Lowery (1974), Swingle et al. (1975), and Hebrard and Stone (1980).

6.2.4 PRIMARY PRODUCTION

Primary production of marsh algae has not been studied thoroughly in the Trend area. However, information obtained by Stowe (1972) in Barataria Bay and by Moncreiff (1983) in the Atchafalaya Delta may be related to biotic potential of algal communities in similar marshes along eastern Louisiana, Mississippi, and Alabama. Stowe (1972) reported that epiphytic algae associated with Spartina alterniflora at the water's edge had a rate of net carbon (C) fixation of 60 $g\ C{\cdot}m^{-2}$ per year, while algae approximately 1.5 m inland from the water's edge had a net loss of carbon, or -18 $g\ C{\cdot}m^{-2}$ per year. Moncreiff (1983) found that algal mats on the edges of fresh marshes had a net production rate of approximately 400 $g\ C{\cdot}m^{-2}$ per year.

The production of organic material by marsh grasses is also high. Estimates of 2.96 kg dry wt•m^{-2} per year have been reported from streamside marsh sides along the Louisiana coast at Barataria Bay (Day et al., 1973). The dominant plant in this salt marsh is *Spartina alterniflora*. This single species often comprises the bulk of the standing biomass (93-95%) and is the primary source of organic detritus in the salt marsh system (Day et al., 1973). *Juncus roemerianus* is the dominant species in the brackish marshes along Mississippi Sound, while *S. alterniflora* lines the banks of tidal creeks and bayous. *J. roemerianus* makes up 72 to 76% of Mississippi Sound marshes in Alabama and Mississippi, respectively (Stout and de la Cruz, 1981). A summary of primary productivity for Mississippi Sound marshes is given in Table 6.1. Net primary production in salt marshes in the Trend area ranges up to 3.08 kg dry wt•m^{-2} per year for *J. roemerianus* and 2.03 kg dry wt•m^{-2} per year for *S. alterniflora*. Assuming an average carbon content of 43% (de la Cruz and Gabriel, 1974), these rates are equivalent to 1.32 kg C•m^{-2} per year and 0.87 kg C•m^{-2} per year, respectively. Below-ground production estimates (as reflected by standing crop) range up to 9 kg•m^{-2} per year.

Brackish-intermediate marsh production levels are generally lower than those of salt marshes. *Distichlis spicata* and *Spartina patens* have been reported to have net production rates of up to 1.48 and 1.92 kg•m^{-2} per year, respectively.

Fresh marsh species (e.g., *Typha* spp.) have not been extensively studied in the Trend area. However, estimates from the Patuxent Estuary, Maryland (Johnson, 1970) indicate that this marsh zone generally produces less organic matter than brackish or saline marshes. Net production of the *Typha latifolia* community was 0.97 kg•m^{-2} per year, compared with a rate of 1.25 kg•m^{-2} per year for the *Spartina alterniflora* community.

6.2.5 DECOMPOSITION

Detritus produced by the decomposition of plant biomass is a major source of energy in the marsh ecosystem. The caloric value of plant matter varies greatly depending on species and decomposition environment. Dead leaves of *Spartina alterniflora*, for example, can achieve an 86% decomposition rate over one year (Stout and de la Cruz, 1981). Other species have lower decomposition rates: *S. patens* and *Distichlis spicata* decompose at an annual rate of 36 and 38%, respectively.

The role of bacteria and fungi in decomposition has been recognized for some time. Vast quantities of organic particulate matter in marsh systems serve as substrate for a wide variety of interrelated processes which result in increasing the nutritive value of the decomposing vegetation. Detrital grazing organisms, such as amphipods, have been shown to prefer detritus which has been aged in the water for several months over fresh detritus. The aging process is the period of time for detrital bacteria to increase (Heald, 1970).

Detritus has long been viewed as contributing substantially to organic matter in coastal waters. Kirby (1972) determined that the live standing crop of *S. alterniflora* reached a maximum in July-September and a minimum in January-March. He also showed that the seasonal distribution of the dead standing crop was nearly the reverse of this, with its maximum in January-March and minimum in June-September. Recently, however, researchers have

Table 6.1 Summary of estimates of annual primary production for the marshes of Mississippi Sound. Locations include: Dauphin Island, AL (DI), Point aux Pins, AL (PAP), Bay St. Louis, MS (BSL) and Bayou Cassotte, MS (BC). (After Stout and de la Cruz, 1981.)

		PRIMARY PRODUCTION (kg m^{-2} yr^{-1})		
Species	Location	Above Ground	Below Ground	Source
Spartina alterniflora	DI	0.66-2.03*	3.60 ($\bar{x}$)	Stout, 1978
	BC	1.96 tall (H)		de la Cruz, 1974
	BC	1.09 short (H)		de la Cruz, 1974
	DI	0.01-0.02 (PPM)	3-7 (SC)	Hackney et al., 1978
S. cynosuroides	BSL	2.90 (H)		de la Cruz, 1974
	BSL	0.48 (H)		Gabriel & de la Cruz, 1974
	BSL	1.74-2.86 (PPM)	6-9 (SC)	Hackney et al., 1978
S. patens	BSL	1.92 (H)		de la Cruz, 1974
	BSL		5-8 (SC)	Hackney et al., 1978
Juncus roemerianus	DI	1.18-3.08*	4.56 ($\bar{x}$)	Stout, 1978
	BSL		1.36 (PPM)	de la Cruz & Hackney, 1977
	BSL	1.70 (H)		de la Cruz, 1974
	BSL	0.39 (H)		Gabriel & de la Cruz, 1974
	BSL	0.58-0.75 (PPM)	5-7 (SC)	Hackney et al., 1978
	DI	0.06-0.46 (PPM)	2-4 (SC)	Hackney et al., 1978
		2.00		Eleuterius, 1972
Distichlis spicata	BC	1.48 (H)		de la Cruz, 1974
	BSL	0.06 (H)		Gabriel & de la Cruz, 1974
	PAP	0.01 (PPM)	1-3 (SC)	Hackney et al., 1978
Scirpus robustus	BSL	1.06 (H)		de la Cruz, 1974
S. olneyi	BSL	0.07 (H)		Gabriel & de la Cruz, 1974
Phragmites australis	BSL	2.33 (H)		de la Cruz, 1974

*Range of estimates for 4 methods of calculation.
H = Harvest Method of Milner and Hughes 1968.
PPM = Predictive Periodic Model of Hackney and Hackney 1978.
SC = Standing Crop.
$\bar{x}$ = Annual Mean.

suggested that organic carbon may not only be exported from the tidal marsh (Woodwell et al., 1977; Hackney and de la Cruz, 1979). Hackney and de la Cruz (1979) found a net import of particulate matter into the marsh they studied in Mississippi. They concluded that high vascular plant productivity may not be the most important function of the marsh relative to the overall productivity of the estuarine system. They found net export of organic particulates to be episodic, suggesting that the marshes may serve as a damper on the oscillation in the concentrations of suspended material transported to offshore waters. This results in a more even release of suspended material into estuarine waters.

6.2.6 TROPHICS

Figure 6.3 presents a schematic of trophic processes in coastal marshes. The following review of marsh trophics addresses herbivores, detritivores, omnivores, and carnivores. Previous information on the interrelationships between these trophic levels was presented in Chapter 2, which deals with a conceptual ecological model of the study area.

Herbivores

Marsh herbivores include the snail, Littorina irrorata, which grazes on epiphytic algae on Spartina alterniflora stems. Other grazing invertebrates include a variety of grasshoppers and other insects. Estimates of the contribution of grazing insects, such as grasshoppers, to the biomass in this ecosystem have ranged from 1.25 g dry wt$\cdot$m^{-2} by Smalley (1958) in Georgia, to 0.1 g dry wt$\cdot$m^{-2} by Day et al. (1973) in Barataria Bay, Louisiana. Their total food intake in a Louisiana marsh has been estimated at 51 g$\cdot$m^{-2} per year (Day et al., 1973), while Parsons and de la Cruz (1980) estimated that marsh grass consumption by grasshoppers in a Mississippi salt marsh was only about 5.4 g$\cdot$m^{-2} per year. Some meiofaunal species, including nematodes, ingest benthonic diatoms as well as other organic material.

Most herbivory in marshes occurs among vertebrates, including various fishes, reptiles, birds, and mammals. Herbivorous fishes include striped mullet (Mugil cephalus), menhaden (Brevoortia patronus), sheepshead minnow (Cyprinodon variegatus), diamond killifish (Adinia xenica), and threadfin shad (Dorosoma petenense). The southern painted turtle (Pseudemys picta) feeds on submersed grasses in fresh marshes.

The marshes of the study area provide a variety of feeding habitats for herbivorous birds. For example, plants such as three-cornered grass (Scirpus olneyi) are consumed directly by Bluegeese (Chen caerulescens), while dabbling ducks consume both submersed grasses and emergents. Martin and Uhler (1939) examined 200 gizzards of 17 species of ducks and found that 75.2% of the content was plant material and the remaining 24.8% was animal material. Stieglitz (1966) found that plant material made up 68.5% of the gut material in several species of diving ducks with the remaining 31.5% being composed of animal material, primarily molluscs. Similar grazing on marsh plants (stems, seeds, rhizomes) was reported by Beter (1956), Chamberlain (1959), Glasgow and Bardwell (1962), and Junca (1962).

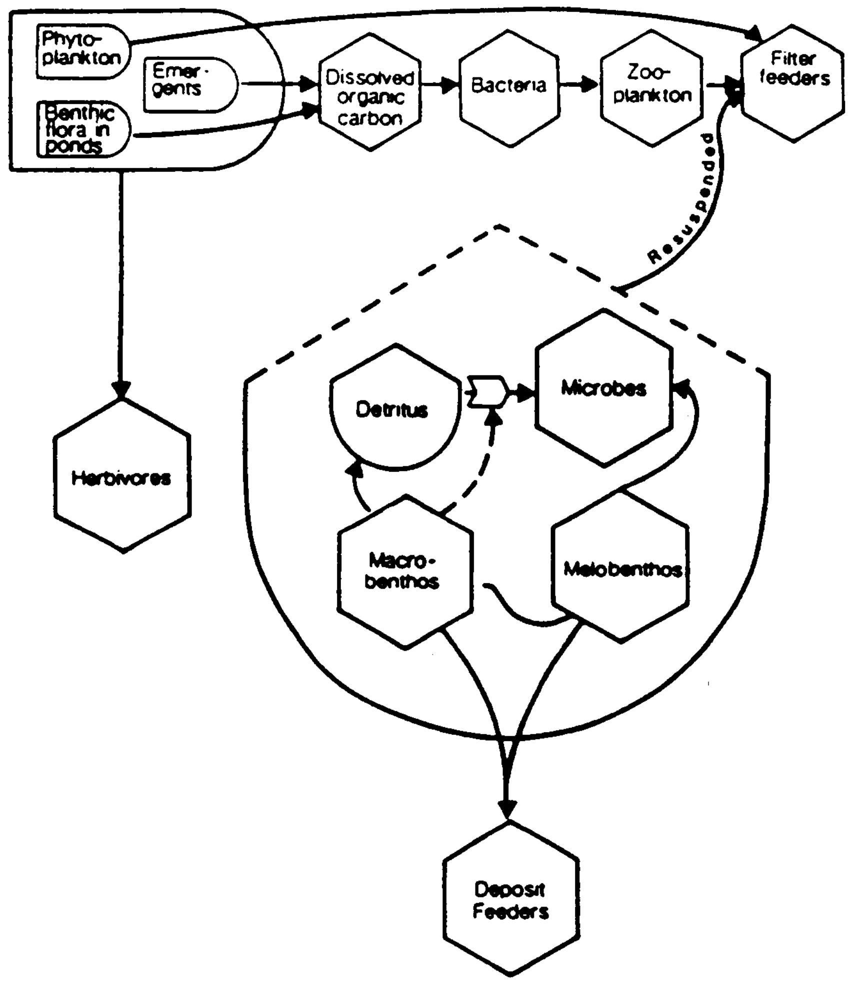


Figure 6.3 Simplified trophics diagram for coastal marshes in the Tuscaloosa Trend study area. (Modified from Gosselink, 1984)

The principal mammals which feed directly on marsh vegetation in the study area are muskrat (Ondatra zibethicus and nutria (Myocastor coypus). O'Neil (1949) reported that three-cornered grass (Scirpus olneyi) is the major component of the diet of the muskrat, which also uses the plant for house-building. While nutria can occupy similar habitats, they generally predominate in fresh marshes and feed on cattails (Typha latifolia) and alligator grass (Alternanthera philoxeroides). Muskrats are reported to consume one-third their weight daily, or approximately 0.3 kg (O'Neil, 1949). Nutria eat 1.5 to 2.0 kg of marsh grasses per day. Muskrats occur in densities up to 46 animals per ha and are capable of destroying large proportions of marshes it inhabits (Gosselink, 1984). Muskrats also damage 10 times more vegetation by digging and house-building than for food. White-tailed deer (Odocoileus virginianus) occur primarily in fresh marshes. Their feeding preferences are not well-known but they appear to eat nearly any succulent and green plants (Self, 1975). The carrying capacity of fresh marsh is roughly one deer per 12 ha.

Detritivores and Omnivores

Marsh ecosystems are dominated by detritus feeders and omnivores. Many species are both detrital suspension feeders and grazers on microflora and algae (e.g, menhaden, threadfin shad). Meiofauna are primarily deposit feeders and consume both detritus and associated microorganisms. For example, nematodes have strong buccal armatures which are used to ingest diatoms, bacteria, and lignins and cellulose of marsh grass, converting these compounds into microbial protein, fats, and sugars. Many meiofauna ingest detritus, digest the nutritious microorganisms, egest the indigestible plant fraction, and the process is repeated (Boaden, 1964). They, in turn, are preyed upon by larger meiobenthic organisms, macrobenthic organisms (juvenile shrimp) and small fish. Swedmark (1964) found some meiobenthic organisms to be at the top of the interstitial food chain as evidenced by the lack of predation upon them by animals at higher trophic levels.

Macroinfauna and macroepifauna in marshes are predominantly detritivores and omnivores. Polychaetes, oligochaetes, amphipods, small shrimps and mud crabs, fiddler crabs, and molluscs are representative of this trophic level. Estimates of consumption by macroinfauna are not available but it is clear that these animals assist in the decomposition of detritus through shredding of larger fragments. Valiela et al. (1982) estimated that this process could nearly double decomposition rates.

Nektonic detritivores or omnivores include both invertebrates (e.g., grass shrimp, blue crabs, penaeid shrimps) and vertebrates. The latter include juvenile and adults of a great number of species such as menhaden (Brevoortia patronus), threadfin shad (Dorosoma petenense), sheepshead (Archosargus probatocephalus), pinfish (Lagodon rhomboides), spot (Leiostomus xanthurus), croaker (Micropogonias undulatus), and mullet (Mugil cephalus).

Carnivores

As suggested above, numerous marsh animals are considered to be carnivorous. A great variety of fishes ingest, utilize meiofauna, macroinfauna, or zooplankton associated with detrital material in the bottom or suspended in the water column. Macro- and epifauna themselves often feed on smaller animals in similar fashion. Penaeids, for example, graze on infaunal polychaetes in the marsh (Idyll et al., 1968). Species which are primarily carnivores include a number of invertebrates, as well as vertebrates. The grass shrimp (Palaemonetes spp.) preys on meiofaunal nematodes (Sikora, 1977) and produces fecal pellets and dissolved organics over seven times faster than it produces biomass through growth (Welsh, 1975). Bell (1980) suggested that many polychaetes, amphipods, and other macrofauna limit meiofaunal populations through predation. These relationships have not been quantified effectively for marsh communities in the Trend area.

Dominant carnivorous fishes in fresher marshes include spotted gar (Lepisosteus oculatus), bowfin (Amia calva), brook silverside (Labidesthes sicculus), rough silverside (Membras martinica), flier (Centrarchus macropterus), and largemouth bass (Micropterus salmoides). Those which are typically found in brackish or salt marshes include bay anchovy (Anchoa mitchilli), bayou killifish (Fundulus pulverus), inland silverside (Menidia beryllina), chain pipefish (Syngnathus louisianae), spotted seatrout (Cynoscion nebulosus), black drum (Pogonias cromis), red drum (Sciaenops ocellatus), and code goby (Gobiosoma robustum). Predation on the snail (Melampus bidentatus) and amphipod (Orchestia grillus) by the salt marsh killifish (Fundulus heteroclitus) appears to be an important factor regulating those species abundance and size distribution (Vince et al., 1976).

Predatory marsh reptiles include the alligator (Alligator mississippiensis), which feeds on crustaceans when young (Chabreck, 1971). Adults also prey on other vertebrates, including birds, fish, muskrats, and turtles. Marsh turtles are generally carnivorous and prey primarily on fish, insects, birds, small mammals, lizards, amphibians, and snakes.

Carnivorous birds feed on a variety of fishes and invertebrates. The clapper rail (Rallus longirostris) feeds primarily on fiddler crabs (Uca spp.), crayfish, and snails (Bateman, 1965). Similar feeding habits are displayed by the little blue heron (Egretta caerulea), yellow-crowned night heron (Nycticorax nycticorax), western sandpiper (Calidris mauri), and willet (Catoptrophorus semipalmatus). Many species include fish and other vertebrates in their diets, in addition to a variety of invertebrates. These include birds such as the great blue heron (Ardea herodias), great egret (Casmerodius albus), snowy egret (Egretta thula), and other shore birds. Fishing species include the brown pelican (Pelecanus occidentalis), belted kingfisher (Ceryle alcion), black skimmer (Rhynchops nigra), and Caspian tern (Sterna caspia). Birds of prey such as the peregrine falcon (Falco peregrinus), osprey (Pandion haliaetus), and short-eared owl (Asio flammeus) prey on fish, small mammals, birds, and insects. The barn owl (Tyto alba) feeds almost exclusively on rice rats (Oryzomys palustris) in some areas of coastal Louisiana (Jemison and Chabreck, 1962).

Predatory mammals include primarily the rice rat (O. palustris), which feeds on a variety of insects and small crabs and the raccoon (Procyon lotor), which feeds on molluscs and crustaceans. The muskrat (Ondatra zibethicus) often feeds on animals such as crayfish, crabs, birds, fish, and insects in addition to marsh grasses. Mink (Mustela vison) are entirely carnivorous, feeding on crayfish, rodents, birds, fish, crabs, and frogs (Gosselink, 1984).

6.2.7 MARSH EXPORT TO ESTUARIES

The coastal marsh, in addition to providing a habitat to larval and juvenile fish and invertebrates, acts as a buffer zone and sediment trap between the terrestrial and marine environments. Fluctuating nutrient and sediment loads carried to the coast by the seasonal runoff in inland rivers and streams are deposited and temporarily stabilized in marsh sediments. Through the year these nutrients and organic materials are exported at an even rate to adjacent estuarine waters through tidal flushing via streams, creeks, and bayous. Costanza et al. (1983) estimates 1950 g dry $wt \cdot m^{-2}$ per year of organic matter (or 40% of total net production) is exported to nearby streams and estuaries. Tidal flushing provides an exchange of nitrogen, phosphorus, carbon, sediment and organisms between the marsh and coastal waters.

6.3 ESTUARINE WATERS

Estuarine waters of the Tuscaloosa Trend study area include the open waters of Chandeleur, Breton, and Mississippi Sounds, along with the waters of Mobile Bay, St. Louis Bay, and Lake Borgne. These inshore basins are typically shallow (averaging 3-4 m) with sediments composed of sands, silts, and clays. Salinities are typically lower than adjacent offshore waters due to the freshwater influence of the Mississippi and Mobile Rivers and other coastal rivers and streams. This estuarine system is characterized by high biological productivity as evidenced by the substantial commercial fishing industry in the area.

6.3.1 ESTUARINE FLORA COMMUNITIES

Phytoplankton

Phytoplankton are the most important primary producers in estuarine waters (Day et al., 1973), and are generally light limited during winter months, nitrogen limited during summer and fall, and phosphorus limited in spring (Dow and Turner, 1980; Stone et al., 1980). Phytoplankton blooms are related to nutrient flux within the estuarine system and generally contribute to periods of observed eutrophic conditions. Typically, freshwater environments characteristic of upper estuaries become susceptible to nutrient buildup. Gradually, these nutrients are dispersed throughout the estuary during flood events, and to coastal and offshore waters where tidal and longshore currents disperse high nutrient concentrations.

Temporal and spatial trends of nutrient flux in Mobile Bay were observed during a monthly collection and analysis of phytoplankton communities (1979-1980). Over 250 species of freshwater, estuarine, and marine phytoplankters were identified and related to nutrients and hydrographic conditions over a 14-month period (Don Blancher, University of South Alabama, personal communication). Freshwater and estuarine communities were predominant in the Bay during high river discharge periods; however, marine taxa inhabited wates of the lower Bay during low river flow, high salinity conditions (Blancher, unpublished data).

The occurrence of localized phytoplankton blooms in estuaries of the Tuscaloosa Trend area is common and is suggested as the cause of fish kills and/or jubilees noted along Mississippi Sound and Mobile Bay (Gunter and Lyles, 1979). Phytoplankton blooms are usually attributed to the proliferation of one species of dinoflagellates. The dinoflagellate Prorocentrum minimum has been associated with "reddish" water in Mississippi Sound (Perry and McLelland (1981) and Mobile Bay (Don Blancher, personal communication). A bloom of the toxic dinoflagellate Gonyaulax monilata (noted cause of red tides) was reported in Mississippi Sound (Perry et al., 1979).

Other common dinoflagellates are species of Noctiluca (noted for its bioluminescence) and Ceratium (Perry and Christmas, 1973). In addition to dinoflagellates, phytoplankton are represented by diatoms, green algae (Chlorophyta) and blue green algae (Cyanophyta). Listings of species in the study area are limited to surveys by Eleuterius (1975) and Sullivan (1981).

No estimates of productivity are available for the Trend estuarine waters. However, net primary productivity rates from four estuarine areas west of the Mississippi River average 208 g C$\cdot$m^{-2} per year or 462 g dry wt$\cdot$m^{-2} per year (Costanza et al., 1983). Results of these studies are summarized in Table 6.2.

Benthic Algae

Seventy-seven epiphytic or attached algal forms have been reported by Humm and Caylor (1957) from Mississippi Sound. Epiphytic red and brown algae are commonly associated with submerged grassbeds of shoal grass (Diplanthera wrightii), turtle grass (Thalassia testudinum), and manatee grass (Cymodacea manatorum). Attached algae, such as Cladophora sp. (a green alga) and red and brown algae, occur on sandy bottoms on shells, breakwater rocks, or on pilings and other structures. Morrill (1959) found that benthic algae communities change seasonally in Alabama estuarine waters, but are most abundant diverse in late winter and early spring. Dominant species at this time include Dasya pedicellata, Ectocarpus confervoides, Polysiphonia spp., Gracilaria spp., and Enteromorpha spp. Red algae such as Hypnea musciformis and Chondria leptacremon and brown algae (Dictyota dichotoma) are predominant during late summer. These plants provide habitat for a variety of small fauna, and also produce substantial organic matter.

Seagrasses

The submerged seagrasses along the coast usually occur in relatively shallow water due to depth limitations imposed by the relatively high turbidity of coastal waters. Submerged vegetation provides cover for many species of aquatic organisms as well as a substrate for many species of diatoms and algae. They are utilized as spawning areas for several estuarine fishes and invertebrates and serve as nursery grounds for many estuarine and marine species of fish. Seagrasses also anchor sediments and assist in reducing shoreline erosion.

Surveys of submerged grasses within Mobile Bay have been conducted by several researchers (Baldwin, 1957; Leuth, 1963; Borom, 1975; Stout and Lelong, 1981). Grassbeds in the Mobile Bay study are most abundant in the Mobile River Delta (Figure 6.4) around the rivers which enter the upper Bay. Stands of tape grass (Vallisneria americana), redhead grass (Pomatogeton

Table 6.2 Net primary productivity rates from Lake Pontchartrain and open-water areas west of the Mississippi River (modified from Costanza et al., 1983).

Location	Description	g $C \cdot m^{-2}$ per year	g dry $wt \cdot m^{-2}$ per year	Source
Barataria Bay, LA	Coastal estuarine bay	210	467	Day et al., 1973
Off Grand Isle, LA	Offshore, affected by Mississippi River	266	591	Sklar, 1976
Lake Pontchartrain, LA[b]	Very large brackish water lake	158	351	Dow and Turner, 1980
Airplane Lake, LA	Salt marsh pond	198	440	Stowe, 1972
AVERAGE		208	462	

[a]Grams dry wt = 2.22 x grams carbon (Whittaker 1975).

[b]Average of four Lake Pontchartrain stations.

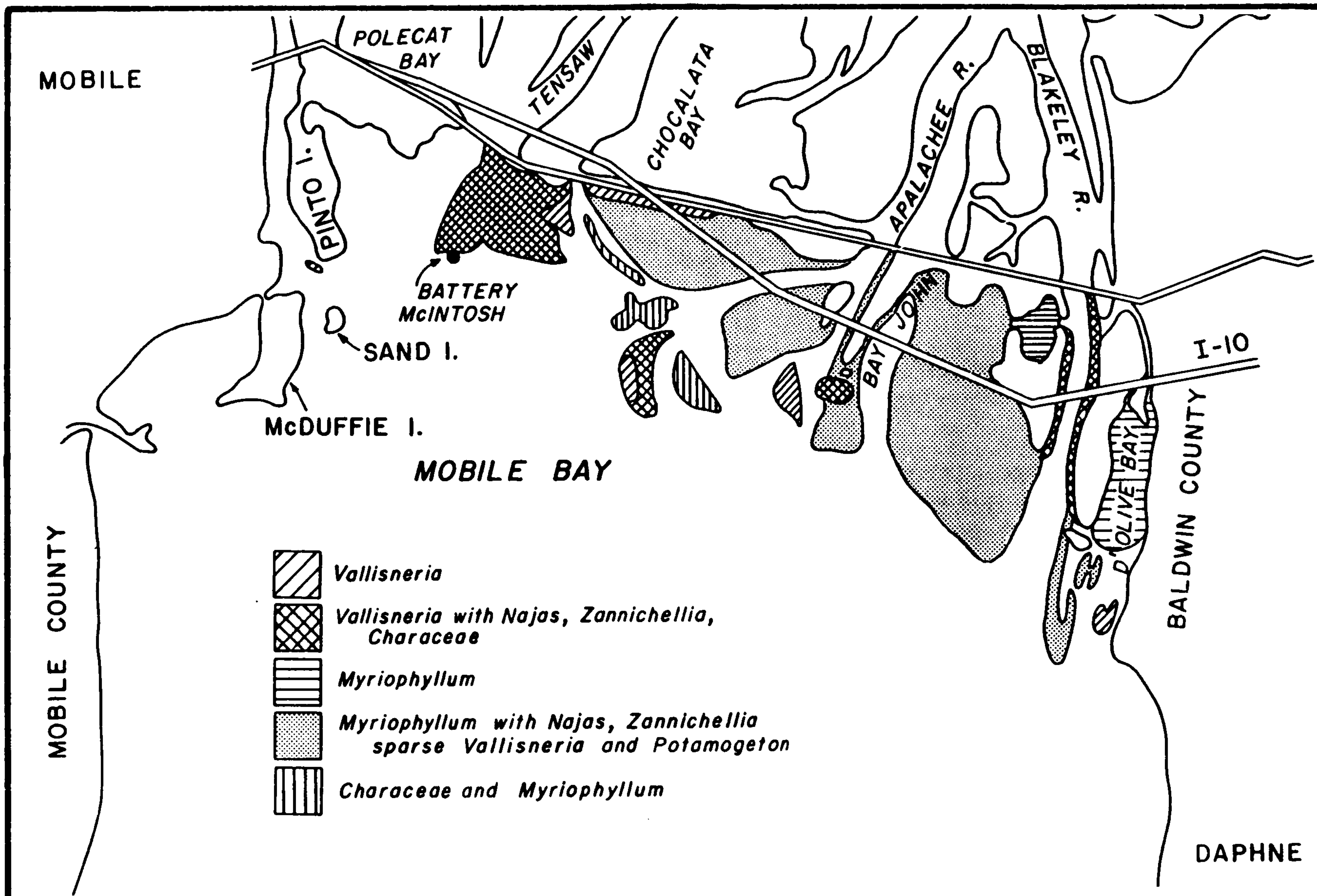


Figure 6.4 Distribution of submerged grassbeds of the lower Mobile River Delta, from 1980 inventory (after Stout and Lelong, 1981).

perfoliatus), water stargrass (Heteranthera dubia), Eurasian watermilfoil (Myriophyllum heterophyllum) and coontail (Ceratophyllum demersum) are present in the upper Bay. The widgeon grass (Ruppia maritima) and shoal grass (Halodule wrightii) are more euryhaline and are found in the lower Bay and in Mississippi Sound where the salinity is higher (Figure 6.5).

The shallow waters of Mississippi Sound support a large submerged vegetation community. The majority of sea grasses occurs in the bays and inlets along the coast and on the leeward side of the offshore islands. Eleuterius (1973) found five species of marine spermatophytes in Mississippi Sound. The most important are turtle grass (Thalassia testudinum), shoal grass (Halodule wrightii), and widgeon grass (Ruppia maritima); tape grass (Vallisneria americana) occurs adjacent to bayous, creeks, and rivers. He identified approximately 20,000 acres (8,100 ha) of grassbeds within the Sound, dominated by Halodule wrightii. No submersed plant assemblages were found south of Horn and Ship Islands.

The area around the Chandeleur Islands has been mapped by Garofalo (1982) in conjunction with the Mississippi Deltaic Plain Characterization. The seagrass beds adjacent to the barrier islands off Louisiana and Mississippi are composed of turtle grass (Thalassia testudinum), shoal grass (Halodule beaudettei), manatee grass (Cymodocea filiformis) and Gulf halophila (Halophila engelmannii). Hoese and Valentine (1972) and Laska (1975) described the leeward side of the Chandeleur Islands as typically shallow (less than 5 m depth) with dense carpets of turtle grass (Thalassia testudinum) occurring within the mile-wide sand flat. Shoal grass (Halodule wrightii) occurs in sparse patches in shallower depths. Turtle grass may be mixed with manatee grass (Cymodocea manatorum) far from shore.

6.3.2 ESTUARINE FAUNAL COMMUNITIES

Zooplankton

Zooplankton are a fundamental link in the food chain between phytoplankton and suspended detritus, and higher trophic levels in the estuary. Several investigations of zooplankton have been conducted within the Tuscaloosa Trend study area, in consideration of the importance of the area to commercial fishing. Even though the area has been studied for some time, many aspects of their interactions in the ecosystem have yet been elucidated, such as their production rates and quantitative contribution to higher trophic levels.

Zooplankton are divided according to the length of the life cycle spent in the water column. Meroplankton are those organisms which spend only part of their life in the water column (usually early developmental stages) and later enter the nekton as adults (e.g., ichthyoplankton) or become benthonic (or epibenthonic). Other examples of meroplankton are larval shrimp or other decapod crustaceans which drift into the estuaries in the water column and settle out after a series of molts, to an adult life stage that is epibenthic. Holoplankton, on the other hand, spend their entire life as part of the plankton community, e.g., copepods, cladocerans, etc. Other zooplankters include coelenterates such as jellyfish, protozoa, and ctenophores.

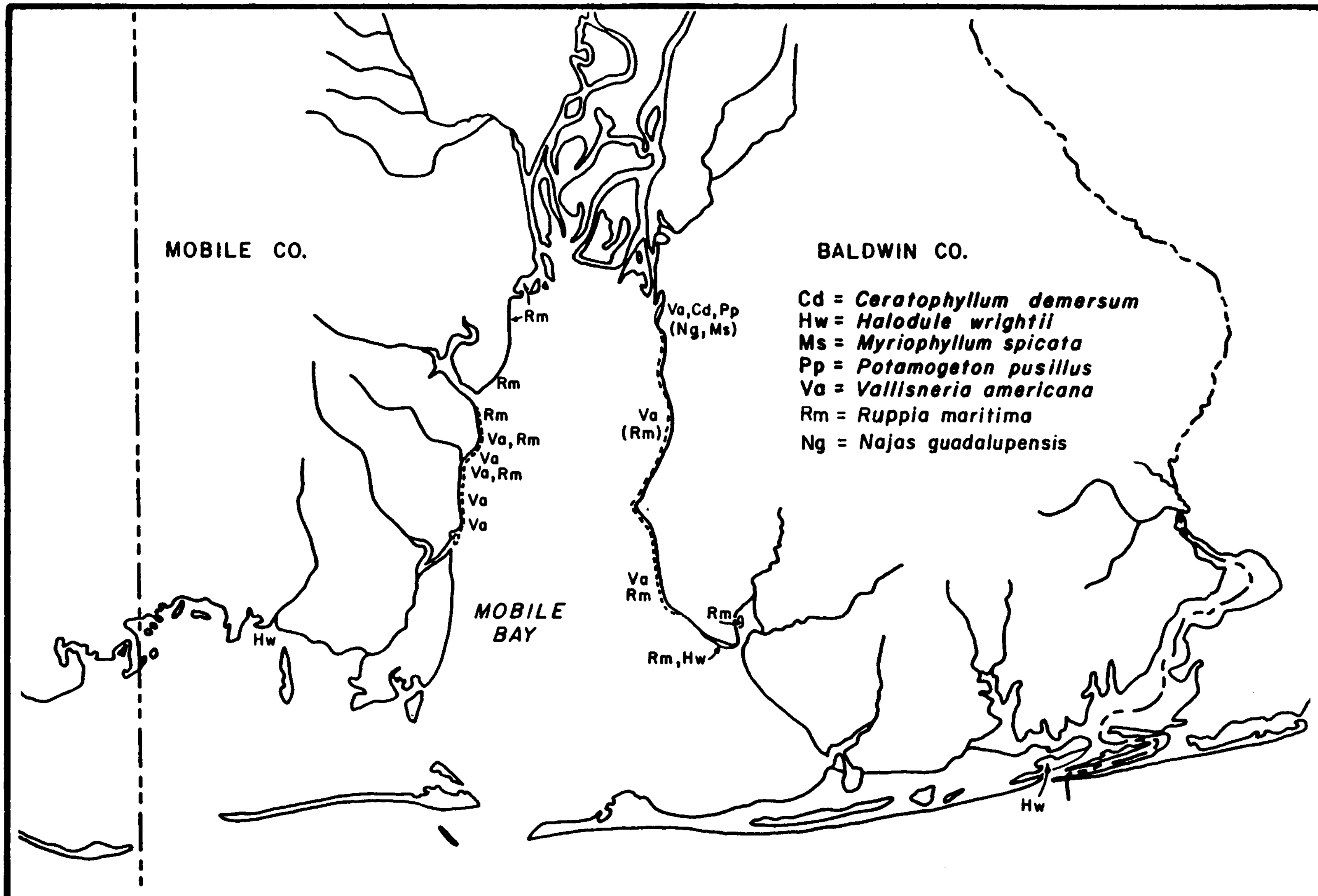


Figure 6.5 Distribution of submerged grassbeds of lower Mobile Bay, Alabama (after Stout and Lelong, 1981).

Seasonal variations of zooplankton standing crop within the study area are influenced by fluctuations in both temperature and freshwater influx. Nutrient-rich runoff from the Mississippi River peaks in the spring and fall. Zooplankton standing crop in the study area is highest in the summer and lowest in the winter (Gillespie, 1971; Perry and Christmas, 1973) corresponding to the interplay of nutrient input, salinity, and temperature fluctuation.

Summary reviews of zooplankton research in the northern Gulf of Mexico include O'Neil and Mettee (1982) for coastal Alabama and Mississippi Sound, Hopkins (1973) for the Alabama and Florida coastal areas, and Stone et al. (1980) for the Lake Pontchartrain-Lake Maurepas area of Louisiana. This section is intended to provide an updated review of zooplankton research within the study area (Table 6.3).

In the northern Gulf of Mexico, zooplankton biomass is greatest in estuarine waters and generally decreases with increased distance offshore (Hopkins, 1973). Zooplankton biomass (as measured by volumetric displacement) and diversity are greater in the summer than in the winter. McIlwain (1968) found this trend to hold true for copepods in Mississippi Sound as did Gillespie (1971) in coastal Louisiana, where biomass reached a maximum of 2.6 $ml \cdot m^{-3}$ in May and had a minimum of 0.04 $ml \cdot m^{-3}$ in August.

Protozoan investigations in the study area are limited to Mobile Bay. Jones (1974) sampled both pelagic as well as settling forms and listed 258 taxa encountered during a two-year study. He reported that protozoa, which feed on diatoms, bacteria, and detritus, decrease in abundance with increased turbidity, possibly as a result of reduced phytoplankton or benthic diatom population abundance.

The calanoid copepod Acartia tonsa is the most dominant species in the estuarine zooplankton community throughout the northern Gulf of Mexico. A. tonsa is the only copepod species present year-round in Mississippi Sound (McIlwain, 1968) and averages 60% of total plankton counts (Gillespie, 1971). During an impact survey of floodwaters from the Bonnet Carre and Morganza spillways on the coastal waters of Louisiana and Mississippi, A. tonsa was the most abundant copepod present in the zooplankton community (Perry and Christmas, 1973).

Shipp (1979) noted salinity preferences in decapod larvae from a series of stations along West Fowl River, Alabama, from Mississippi Sound to near freshwater conditions upriver. Fiddler crabs (Uca spp.) comprised 86% of the total collection. Several species were more abundant in bottom stations, corresponding to the higher salinity at the bottom. In Mississippi Sound, the zooplankton community is dominated by zoea and megalopa in the spring. These larval forms are also encountered to a lesser degree the rest of the year, reflecting a long reproductive period.

Tentaculate feeding macroplankton defined within the pelagic subsystem of the conceptual model (Figure 2.15), is represented by coelenterate medusae and ctenophores, commonly known as jellyfish. In a survey of coelenterates in Mississippi Sound and adjacent offshore waters, Burke (1976) reported seven species of cnidarians from the study area (Figure 6.6). Cabbagehead jellyfish (Stomolophus meleagris), stinging nettle (Chrysaora quinquecirrha), and Portuguese man-of-war (Physalia physalis) were the most abundant, with mauve stinger (Pelagia noctiluca), moon jelly (Aurelia aurita), sea wasp

Table 6.3 Summary of pertinent zooplankton research in the Tuscaloosa Trend study area.

	Study Area	Component	ZOOPLANKTON Standing Crop	Biomass	Seasonality
McIlwain, 1968	Miss. Sound	Copepods	X	--	X
Hopkins, 1973	East Central Gulf	Summary of Zooplankton	--	X	--
Gillespie, 1971	Coastal Louisiana	Zooplankton	X	X	-- X
Hawes and Perry, 1978	Pontchartrain Borgne, Miss. Sound	Zooplankton	--	--	--
Stone et al. 1980	Pontchartrain	Zooplankton	--	--	--
Perry and Christmas, 1973	Miss. Sound	Zooplankton	--	--	--
Shipp, 1979	Mobile Bay	Zooplankton	X	--	X
Swingle, 1971	Mobile Bay	Zooplankton	--	--	--
Turner and Allen, 1982	Miss. River Delta	Community Plankton Respiration	--	--	--
Jones, 1974	Mobile Bay	Protozoa	--	--	X

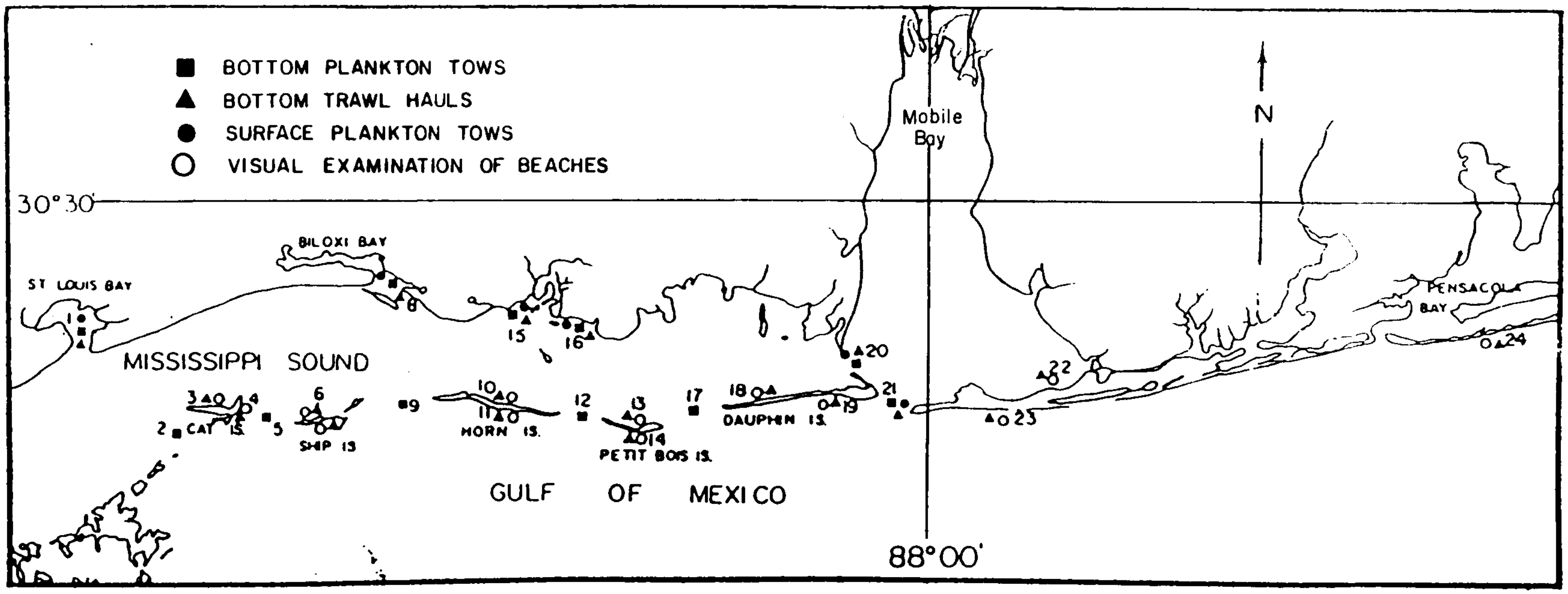


Figure 6.6 Coelenterate sampling sites in the northern Gulf of Mexico, April 1971-June 1973 (after Burke, 1976).

(Chiropsalmus quadrumanus), and the rhizostomatid medusa (Rhopilema verrilli) occurring less frequently. Perry and Christmas (1973) reported collecting only C. quinquecirrha during their survey of coastal Mississippi, while Gillespie (1971) found that the hydrozoan medusa Nemopsis bachei was particularly abundant in May in Louisiana estuaries east of the Mississippi River. Perry and Christmas (1973) suggested that this species may limit abundance of other zooplankters through grazing. Similar predation by the very abundant ctenophore Mnemiopsis mccraydyi occurs throughout the Trend area (Perry and Christmas, 1973), although few specimens were collected by Gillespie (1971).

Ichthyoplankton

In a study of ichthyofauna in Biloxi and Back Bays, Mississippi, LaRoche and Richardson (1982) found 95% of the total fish larvae represented by five taxa: Engraulidae (78%), Brevoortia patronus (7%), Gobiosoma bosci (4%), Microgobius thalassinus (4%), and Anchoa mitchilli (2%). Larval densities were observed higher in summer and early fall than in winter, and were seasonally more abundant at the bottom (857 individuals$\cdot$100 m^{-3} in August) than at the water column surface (118$\cdot$100 m^{-3} in August).

A spatial and temporal survey of fish eggs in Mobile Bay revealed distinct estuarine and coastal assemblages influenced by high river discharge and high salinity intrusions, respectively (Marley, 1982). These collections were represented by 11 families, 12 genera, and 14 taxa. The most abundant taxa included: Anchoa mitchilli, Sciaenidae, Harengula jaguana, Chloroscombrus chrysurus, Symphurus sp., Anchoa hepsetus, Trinectes maculatus, Orthopristis chrysoptera, Anchoa sp., Brevoortia patronus, and Synodus sp.

Ichthyoplankton surveys in progress at the Gulf Coast Research Laboratory in Ocean Springs, Mississippi, include a study of larval fishes of Mississippi Sound and adjacent waters during 1978-1983. Samples collected at 22 stations between Dauphin Island, Alabama and St. Louis Bay, Mississippi, are being analyzed for nearshore ichthyoplankton. In addition, two stations in Dog Keys Pass have been continuously sampled for 39 hours using surface and bottom oblique tows to identify movement of ichthyoplankton from near-offshore to the Mississippi Sound through the tidal pass.

Nekton

Nektonic organisms, by definition, are those which actively swim in the water column, independent of prevailing currents. This includes primarily fishes, although cephalopods, demersal crustaceans, mammals, and turtles are also included.

Invertebrates

The cephalopods of the northern Gulf include the families Loliginidae (squid) and Octopodidae (octopus). Cephalopods of Mississippi estuarine waters are represented by three nektonic species: Loligo pealei; Lolliguncula brevis; and Doryteuthis plei (Moore, 1961). There is some interest in developing a fishery for the most common squid L. brevis, the tenth most abundant nektonic animal collected in Alabama estuarine waters by Swingle (1971). They were most abundant in Mississippi Sound in salinities of from 15 to 30 °/oo (June through December). This squid was most abundant in the Pascagoula River and St. Louis Bay estuaries (Perry and Christmas, 1973.) Spawning may occur all year but appears to be most active from spring to fall.

Most other nektonic invertebrates in the estuary are crustaceans, including sergestids, palaemonids, squillids, penaeids, and portunids. The sergestid Acetes americanus is most abundant in coastal Alabama and Mississippi where salinities exceed 20 °/oo (Swingle, 1971; Perry and Christmas, 1973) and in Louisiana at salinities over 15 °/oo (Perrett, 1971). Grass shrimp (Palaemonetes pugio and P. vulgaris are found primarily in brackish waters (salinities of 2 to 15 °/oo) from Alabama to Louisiana (Perrett, 1971, Swingle, 1971; Perry and Christmas, 1973). These shrimps are omnivorous and are prey for estuarine fishes, herons, ducks, and rails (Heard, 1982). Mantis shrimp (Squilla empusa) also occur in estuaries throughout the Trend study area, although they generally prefer salinities over 15 °/oo (Perry and Christmas, 1973).

The shrimp fishery along the northern Gulf Coast is the largest fishery (in terms of ex-vessel dollar value) in the United States (Lassuy, 1983; Turner and Brody, 1983). The three species exploited are brown shrimp (Penaeus aztecus), white shrimp (P. setiferus), and pink shrimp (P. duorarum). Brown and white shrimp occur in both marine and estuarine habitats and have similar life histories, while pink shrimp prefer higher salinity waters and congregate around barrier islands. According to Van Lopik et al. (1979), the size of the shrimp population is environmentally rather than harvest controlled, although there is some disagreement concerning P. setiferus.

All three species have similar reproductive cycles which are separated into Gulf and estuarine components. Spawning and larval development occurs in offshore waters. Postlarvae are carried into the lower salinity waters of the estuaries via tidal passes. As they mature, subadults and adults migrate back offshore to spawn.

Penaeid postlarvae enter estuaries of the Trend area in early to late spring (Christmas and Van Devender, 1981). Loesch (1965) reported that juvenile brown and white shrimp occur in Alabama estuaries from March through November, and Christmas et al. (1966) found postlarvae of both species in Mississippi estuaries throughout the year, with peak abundance occurring from April through July. Some shrimp overwinter in the estuaries; Van Devender (1978) noted a large population of white shrimp in Mississippi Sound in the spring. White shrimp generally stay in the estuaries longer and attain a greater size than brown shrimp. Both occupy shallow mud bottoms and brackish marshes as nursery and feeding area and gradually move into deeper areas of the estuary as they grow larger (after 2 to 4 months).

Brown shrimp (Penaeus aztecus) tolerate a wide temperature and salinity range. Postlarvae and juveniles are most abundant at temperatures from 15° to 35°C and salinities over 5 °/oo but have been collected in 0.2 to 35.5 °/oo salinities (Swingle, 1971; Christmas and Langley, 1973). According to Loesch (1976), adult brown shrimp tolerate a wider salinity range (5 to 30 °/oo) in warm months than in cool months (10 to 15 °/oo). Few brown shrimp occur in Mississippi Sound or Mobile Bay at temperatures below 10°C (Swingle, 1971).

White shrimp (Penaeus setiferus) comprised approximately 16% of the annual average shrimp harvest in the Trend area from 1968 to 1977 (NMFS, 1981). Postlarvae and juveniles are most abundant in estuarine waters with temperatures above 25°C and salinities of 25 to 29 °/oo (Swingle, 1971). Adult white shrimp occur at temperatures of 4° to 31°C, but may be killed by temperatures of 4°C (Perez-Farfante, 1969). The optimum salinity range for adults in the Trend area is 10 to 15 °/oo (Gunter, 1961).

Other demersal shrimps present in Tuscaloosa Trend area estuaries include the rock shrimps (Sicyonia brevirostris and S. dorsalis), hardback shrimp (Trachypeneus spp.), and seabob (Xiphopeneus kroyeri). These species occur in the estuaries most of the year, although some (e.g., Trachypeneus) are most abundant when salinities are over 20 °/oo (Swingle, 1971; Perret, 1971). Perrett (1971) found that Trachypeneus constrictus is most abundant in December in Louisiana estuaries. X. kroyeri is more commonly known from Louisiana waters.

The commercial crab fishery in the northern Gulf is based on the blue crab (Callinectes sapidus) although some interest has been shown for the lesser blue crab (C. similis) and the stone crab (Menippe mercenaria). The blue crab fishery is an important one, ranking third in value of all food fisheries in the Gulf of Mexico (Perry, 1975). An estimated 900,000 kg were harvested in 1977 and 1978 by commercial fishermen in Mississippi (Benson, 1982). Sport crabbers took about 44,279 kg in 1976 from Mississippi waters alone (Benson, 1982).

Blue crabs mate from March through November in nearshore, higher salinity water. The female mates once (following the final molt) and stores the sperm, which are used to fertilize multiple spawnings. The female usually spawns around two months after mating. Eggs are carried on the underside of the female and can number over 2 million per female. The eggs take about two weeks to hatch and pass through two larval stages (zoea and megalopa). The zoeal stage generally resides in offshore waters. Megalops, however, are commonly found in estuarine waters. They are rarely found below 20°C or 21 °/oo, but can survive a broad temperature (13-32°C) and salinity (5-37 °/oo range). Megalops metamorphose into the first crab stage in inshore waters. Juveniles normally occupy mud bottoms in water temperatures from 20° to 26°C and salinities of 5 to 15 °/oo (Benson, 1982). Females stop molting following sexual maturity, but males continue to molt after maturation. Crabs reach commercial size within a year after hatching. Adult males inhabit low salinity areas while females occur mainly in salinities over 20 °/oo. Perry (1975) suggested that blue crab survival is related to adequate estuarine habitat and environmental conditions conducive to juvenile development on the nursery grounds.

Fishes

Demersal fish of the Tuscaloosa Trend study area have been relatively well surveyed because of their importance to local commercial fishery. Several large-scale baseline studies, as well as routine monitoring of fish stocks by state research institutions, have resulted in an extensive data base for demersal fishes and shellfish (Table 6.4). An example of trawl sites for important commercial species monitored in Mississippi coastal waters are depicted in Figure 6.7.

Table 6.4 Summary of major demersal fish data sets within the Tuscaloosa Trend estuarine waters.

SOURCE	AREA	TEMPORAL SPAN	NUMBER OF STATIONS	FREQUENCY	VARIABLES
Louisiana Department of Wildlife and Fisheries, Seafood Division	Lake Borgne, Chandeleur and Breton Sounds	1965-present	approx. 50	monthly or semi-monthly	total counts biomass length/frequency
Gulf Coast Research Lab, Fisheries Section	Mississippi Sound	1973-present	11	monthly or semi-monthly	total counts biomass length/frequency
Alabama Department of Conservation, Marine Resources Division	Mobile Bay, eastern Mississippi Sound	1977-present	15-30	monthly or semi-monthly	total counts biomass
Gulf of Mexico Estuarine Inventory (GMEI) Study (Perret et al., 1971) (Swingle, 1971) (Christmas and Waller, 1973)	Lake Borgne, Chandeleur and Breton Sounds, Mississippi Sound, Mobile Bay	1968-1969	variable	monthly	total counts biomass length/frequency

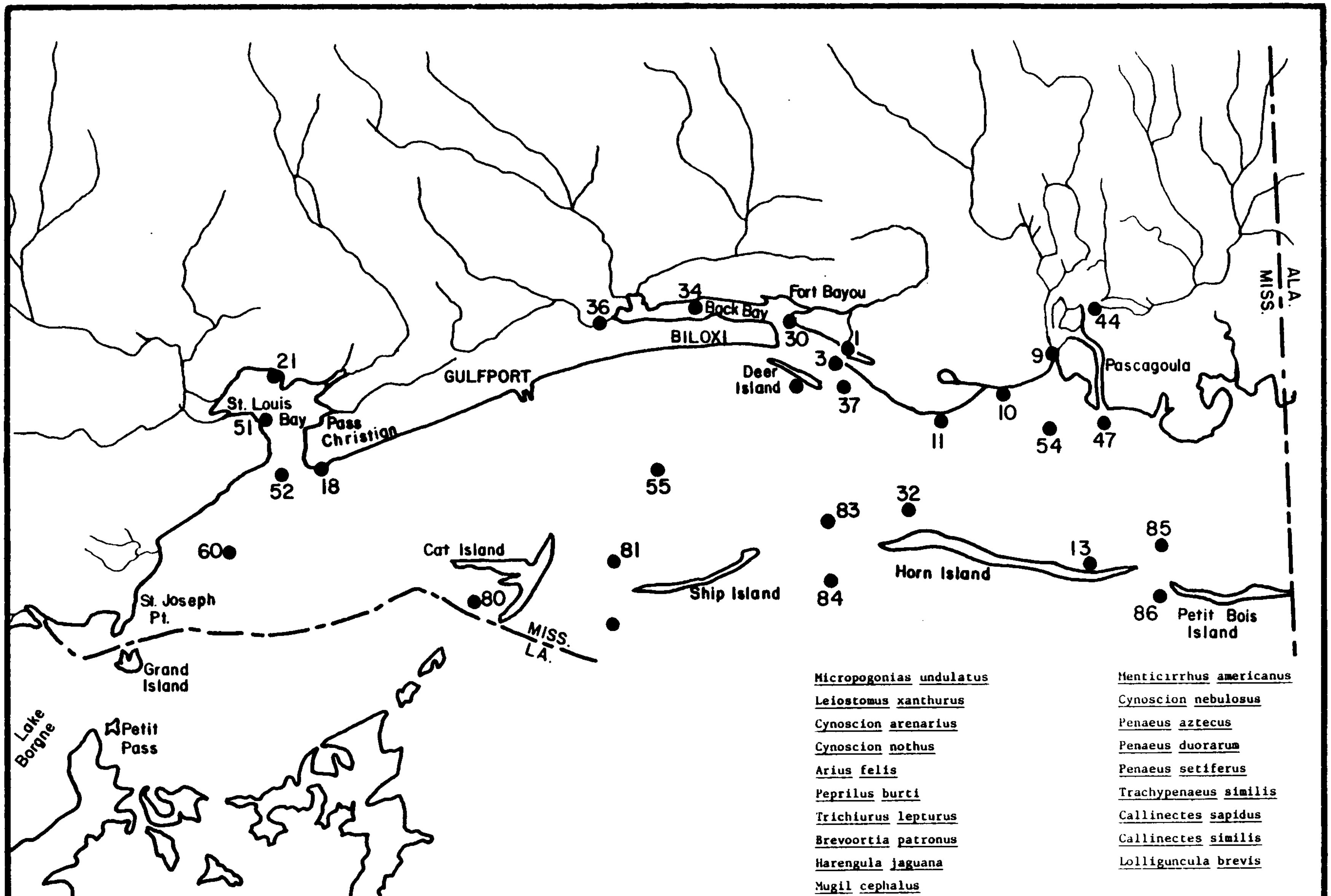


Figure 6.7 Location of stations sampled monthly (1973-present) and a list of species investigated for the Fisheries Monitoring and Assessment Program by Gulf Coast Research Laboratory (after Waller, 1983).

Estuarine fishes of the Tuscaloosa Trend study area include species which inhabit the estuary their entire life, such as killifishes (Fundulus spp., Cyprinodon variegatus) and livebearers (Gambusia affinis and Poecilia latipinna). These species dominate the estuary margin waters and are primarily associated with marsh habitats (Franks, 1970; Shipp, 1979). Other species found in this habitat include silversides (e.g., Menidia beryllina), mullet (Mugil cephalus), and ladyfish (Elops saurus). Juveniles of the latter two species use the margin habitat as a feeding ground. Fishes which enter this habitat to feed on the above species include southern flounder (Paralichthys lethostigma), spotted seatrout (Cynoscion nebulosus), sand seatrout (C. arenarius), and red drum (Sciaenops ocellatus).

Several species of fishes are primarily associated with the estuary bottom. Although considered here to be part of the nekton community, demersal fishes feed at, and/or occupy, the bottom. Included among this habitat group are especially detritivores, carnivorous scavengers, and carnivores. Dominant species include Atlantic croaker (Micropogonias undulatus), spot (Leiostomus xanthurus), sand seatrout (Cynoscion arenarius), sea catfish (Arius felis), silver perch (Bairdiella chrysura), hogchoker (Trinectes maculatus), and puffer (Sphoeroides parvus). Larger demersal fishes include Atlantic stingray (Dasyatis sabina) and alligator gar (Lepisosteus spatula). The latter is generally more abundant west of Mobile Bay and commercially harvested in Louisiana (Perrett, 1971; Swingle, 1971).

Pelagic zone estuarine fish assemblages are similar throughout the Trend study area (Shipp, 1979). The numerically dominant species, bay anchovy (Anchoa mitchilli), occur in very dense schools and are prey to a wide variety of other fishes (e.g., Spanish mackerel, Scomberomorus maculatus) and birds (e.g., common tern, Sterna hirundo). The bay anchovy feeds primarily on planktonic copepods such as Acartia tonsa and is an important link in the pelagic food chain (Sheridan, 1978). Other important fishes in the pelagic zone include menhaden (Brevoortia patronus), striped anchovy (Anchoa hepsetus), butterfish (Peprilus burti), threadfin shad (Dorosoma petenense), and bumper (Chloroscombrus chrysurus). Larger pelagic species include Spanish mackerel (Scomberomorus maculatus), bluefish (Pomatomus saltatrix), and bonnethead shark (Sphyrna tiburo).

Benthos

Meiofauna

As discussed in the benthic subsystem of the Tuscaloosa Trend conceptual model (Chapter 2), meiofauna are composed of larval and juvenile metazoans (temporary meiofauna) and small (63-500 um) adult metazoans (permanent meiofauna), such as nematodes, kinorhynchs, harpacticoid copepods, gastrotrichs, etc.). Trophically, the meiofauna occupy an ambivalent position. In fine sediments, they may contribute directly to macroinfauna and fishes as food sources, while in sand they function primarily in mechanically breaking down particles and packaging and recycling nutrients. Meiofauna also account for up to five times the oxygen consumption of macroinfauna.

Information of subtidal meiofauna of estuarine waters in the Tuscaloosa Trend study area is limited to an eighteen-month seasonal survey conducted in lower Mobile Bay as part of a drilling rig monitoring program

(TechCon, 1980). Family level identifications resulted in 22 major taxa including harpacticoid copepods (13), nematodes (28), gastrotrichs (4), kinorhynchs (3), molluscs (3), and tardigrades (1). Two distinct meiofauna communities were delineated based on their physical habitat: sand-dwelling forms and mud-dwelling forms. Habitats characterized by fine sediments (muds) tend to support greater numbers of individuals, especially nematodes (>90% composition), than sand inhabitats. At the major taxa level, many of the "soft-bodied" meiofauna (i.e., turbellarians, gastrotrichs, archiannelids) are usually absent, or present in low numbers within mud sediments. In sand habitats the fauna are richer in species diversity and represented by interstitial taxa typically suited for sand dwellers.

Seasonal variation in meiofauna populations reflect a similar pattern observed for macroinfauna populations at lower Mobile Bay (TechCon, 1980)—seasonal population peaks in late summer, declines in winter. Larval recruitment by macroinfauna were detected within meiofauna samples, especially of the polychaete Polygordius sp., which was abundant in meiofauna populations one season prior to its dominance in macroinfauna populations.

Macroinfauna

Many macroinfauna have pelagic or benthonic larvae but are relatively immotile during most of their adult life. As a result, they are exposed to generally unchanging sediment quality and thus are good indicators of environmental stress and perturbation. Many natural abiotic factors influence species distribution and density, including temperature, salinity, dissolved oxygen, depth, seasonality, wave shock, prevailing current patterns and intensity, substrate type, and pollution (natural and anthropogenic). Before defining cause and effect relationships between pollution and community impacts, it is necessary to understand the natural occurrences and variability of these communities. Toward this end, as well as to understand the mechanisms involved in the interrelationships of the ecosystem as a whole, many large- and small-scale benthic studies have been conducted in the estuarine waters within the Tuscaloosa Trend study area (see Table 6.5).

Major studies include: Parker (1956, 1960), McAuliffe et al. (1975), U.S. EPA (1982b) for coastal southeast Louisiana; Moore (1961), Christmas and Langley (1973); Taylor (1978), McBee and Brehm (1982), Shaw et al. (1982) for coastal Mississippi; and Taylor (1978), TechCon (1980), Shaw et al. (1982) for coastal Alabama. The Marine Environmental Sciences Consortium, Dauphin Island, Alabama conducted a 14-month benthic program in Mobile Bay (1979-1980); however, a final report has not been published. (Progress reports are available from the Alabama Department of Environmental Management.) Reviews of these studies appear in TerEco (1979), Vittor (1979), and Vittor & Associates (1983) along with recommendations for future studies. Results of the most notable studies were synthesized into a format that would allow for an ecological characterization of estuarine macroinfauna communities throughout the study area (Table 6.6). Station locations of major benthic surveys depicted in Figure 6.8 show the spatial distribution of available infauna data.

When comparing benthic studies from estuarine waters of the Tuscaloosa Trend study area, information on sediment characteristics, depth and infaunal community composition are considered. Table 6.7 summarizes sediment information for some of the most recent benthic characterization studies

Table 6.5 List of benthic studies conducted in estuarine waters of the Tuscaloosa Trend study area.

Study	Location	Types of Samples	Time Period
Parker, 1956	Chandeleur-Breton Sounds	Orange-peel grab	1951-1954
Moore, 1961	Mississippi	Variety	1961
Christmas and Langley, 1973	Mississippi Sound	Peterson grab	1968-1969
Markey, 1975	Mississippi Sound	Peterson grab	1974
McAuliffe et al., 1975 (Vittor & Associates, this study)	Chandeleur-Breton Sounds	Diver-collected suction corer	1970-1971
Taylor, 1978	Mobile Bay to Lake Borgne	Diver-collected hand corer	1976-1977
Coastal Area Board (no date)	Mobile Bay	Peterson grab	1979-1980
TechCon, 1980	Mobile Bay	Box corer	1978-1979
Marine Environmental Sciences Consortium, 1983	Mobile Bay	Peterson grab	1980-1982
Shaw, et al., 1982	Mississippi Sound	Box corer	1980-1981
Environmental Protection Agency, 1982 (Vittor & Associates, this study)	Breton Sound	Box corer	1980-1981
McBee and Brehm, 1982	St. Louis Bay	Ekman grab	1977-1979

Table 6.6 Major ecological characteristics of macroinfauna communities in the Tuscaloosa Trend estuarine waters.

INFORMATION/PRODUCTS	OPEN BAY CHANNELS (Taylor, 1978)	LOWER MOBILE BAY (TechCon, 1980)	MISSISSIPPI SOUND (Shaw et al., 1982)	MISSISSIPPI RIVER-GULF OUTLET (EPA, This Study)	CHANDELEUR-BRETON SOUNDS (CHEVRON, This study)
Community Structure Total No. Taxa	240	412	356	291	391
Density (ind/m^2)	32 to 19,072 ($\bar{x}$ = 1627)	488 to 11,128 ($\bar{x}$ = 3020)	1097 to 35,537 ($\bar{x}$ = 8245)	663 to 15,603 ($\bar{x}$ = 5188)	126 to 49,102 ($\bar{x}$ = 5389)
H' (range)	<1.0 to 2.88	1.1 to 3.4	0.23 to 3.62	1.13 to 2.83	0.36 to 3.78
J' (evenness)	----	0.23 to 0.77	0.15 to 0.81	0.32 to 0.79	0.12 to 0.96
D (species richness)	----	2.3 to 12.8	4.61 to 16.82	3.45 to 11.65	1.96 to 12.73
Biomass (range) g/m^2	----	----	0.87 to 203.60 (AFDW) ($\bar{x}$ = 28.19 AFWD)	1.32 to 431.95	-----
Dominant Taxa	*Mediomastus californiensis* (P) *Paraprionospio pinnata* (P) *Glycinde solitaria* (P) *Gyptis brevipalpa* (P) *Leitoscoloplos* sp. (P) *Streblospio benedicti* (P) *Macoma* sp. (M) *Ogyrides alphaerostris* (C)	*Mediomastus californiensis* (P) *Paraprionospio pinnata* (P) *Myriochele oculata* (P) *Owenia fusiformis* (P) *Mulinia lateralis* (M) *Micropholis atra* (E) *Branchiostoma caribaeum* (Ce) *Polygordius* spp. (P) *Lepidactylus* sp. A (C)	*Myriochele oculata* (P) *Owenia fusiformis* (P) *Paraprionospio pinnata* (P) *Mediomastus* spp. (P) *Hemipholis elongata* (E) *Paramphinome* sp. B (P) *Leitoscoloplos* sp. (P) *Branchiostoma caribaeum* (Ce) *Balanoglossus* cf. *auriantiacus* (H) *Mulinia lateralis* (M)	*Mediomastus* spp. (P) *Branchiostoma* spp. (Ce) *Mulinia lateralis* (M) *Spiophanes bombyx* (P) *Acanthohaustorius* sp. A (C) *Eudevenopus honduranus* (C) *Magelona* sp. H (P) *Polygordius* sp. (P) *Hemipholis elongata* (E)	*Mulinia lateralis* (M) *Mediomastus* spp. (P) *Abra aequalis* (M) *Myriochele oculata* (P) *Oxyurostylis smithi* (C) *Spiophanes bombyx* (P) *Nassarius acutus* (M) *Tellina versicolor* (M) *Magelona* sp. H (P)
Assemblages	One infaunal community associated with open bay mud habitats.	Three infaunal communities associated with bottom sediments at tidal inlet/open bay habitats. Mud, muddy sand, sand.	Five macroinfaunal communities associated with bottom sediments and depth: coastal margin, open sound, open bay, tidal pass. Mud, muddy sand, sand.	Three infaunal communities associated with bottom sediments at tidal inlet/open bay. Mud, muddy sand, sand.	Three major infaunal communities associated with open sound, tidal inlet, and near-shore inner shelf habitats.

C = Crustacean
Ce = Cephalochordate
E = Echinoderm
H = Hemichordate
M = Mollusc
P = Polychaete

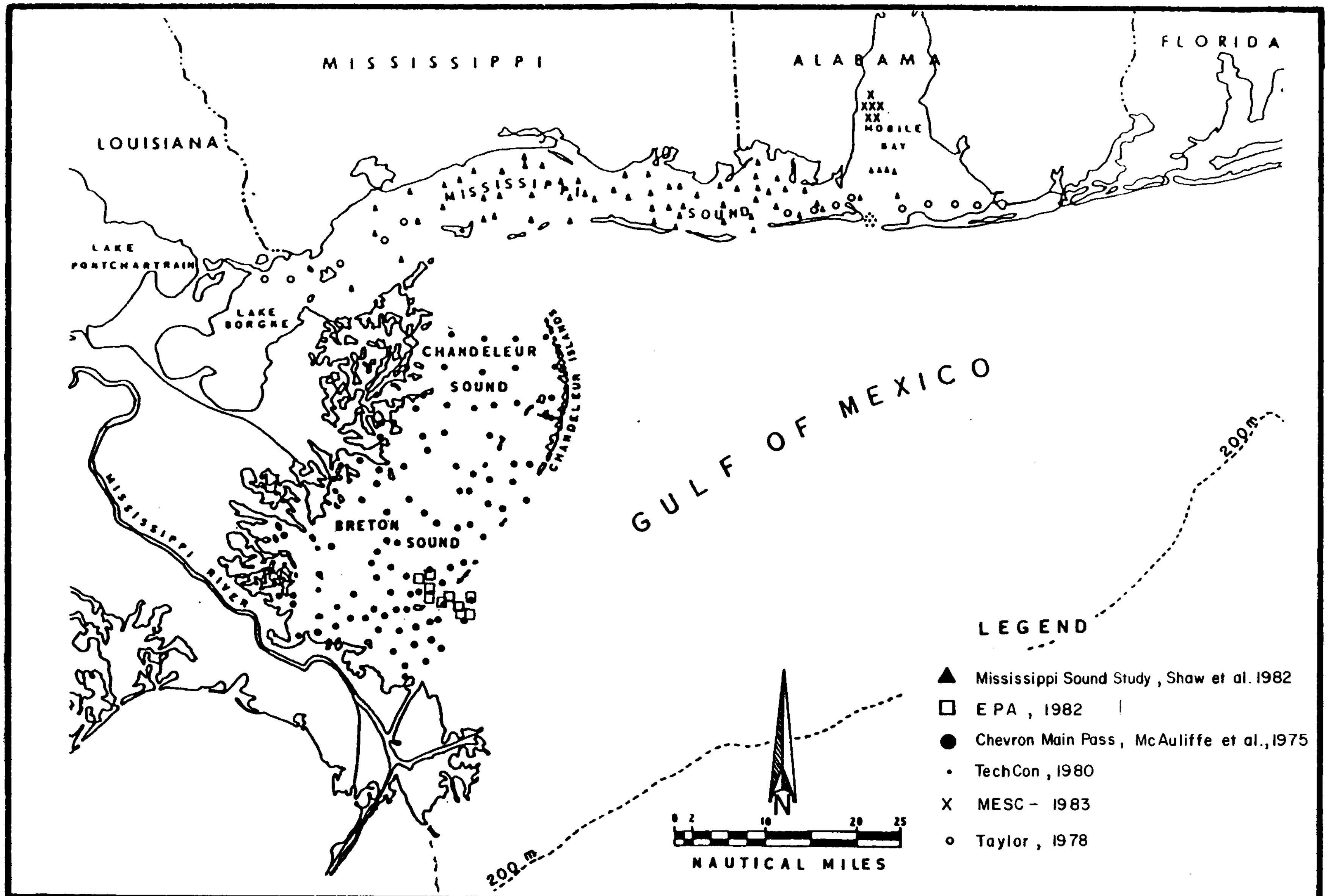


Figure 6.8 Station locations of major inshore benthic programs in the Tuscaloosa Trend study area.

Table 6.7 Selected sediment parameters characterizing benthic habitats among benthic studies conducted in the Tuscaloosa Trend study area estuarine waters.

Program	Habitat	Depth (m)	% Sand	% Silt-Clay	Sediment Type
Marine Environmental Sciences Consortium, 1978	Coastal Margin	2.6-3.8	1-10	60-30	Muddy silt
Taylor, 1978	Coastal Margin	2.3-4.3	1-12	60-30	Fine to coarse silt
	Tidal Pass	1.8	80-90	20-10	Coarse sand
TechCon, 1980	Tidal Pass	3.9	88-98	2-12	Coarse sand
	Nearshore (muddy sand)	4.5	78-88	22-12	Sand w/silty clay
	Open Sound	6.0	10-80	50-90	Muddy, fine sand, silt, clay
Shaw et al., 1982	Coastal Margin	2.6	35	80-82	Medium silt
	Lower Mobile Bay	3.4	7	90-99	Silt-clays
	Open Sound	4.0	42	50-70	Muddy sand
	Tidal Pass	4.4	95	2-11	Coarse sand
Mississippi River-Gulf Outlet (Appendix A)	Tidal Pass	4-7	84	3-5	Fine sand
	Open Sound	6-10	15	4-81	Medium silt
Chevron, 1984 (Appendix A)	Coastal Margin	----	----	----	----
	Tidal Pass	----	----	----	----

conducted within Mobile Bay, Mississippi Sound, and Chandeleur-Breton Sounds. Also included is a habitat description obtained by comparing characteristic species groups between the respective studies. All studies were compared with the Mississippi Sound benthic characterization study (Shaw et al., 1982). This qualitative comparison is limited by the accuracy of species groups identified from each study; four major habitat assemblages are presented in Table 6.8.

The Coastal Margin habitat extends from coastal Louisiana along the delta reaches of Chandeleur and Breton Sounds into Lake Borgne, eastward along the northern boundary of Mississippi Sound, and up the western shore of Mobile Bay. This habitat occurs in shallow estuarine waters that contain poorly sorted silt (mud) and undergoes considerable hydrographic variability. The sand content of these sediments range from less than 20% to 40% and depths from 1.5 to 4 m. Characteristic taxa of this estuarine habitat include polychaetes Polydora ligni, Leitoscoloplos sp., Parandalia americana; molluscs Nassarius acutus and Haminoea succinea; isopod Edotea montosa; and hemichordate Balanoglossus sp. These taxa prefer highly organic mud sediments. Taxa typically dominant in this habitat include polychaetes Myriochele oculata, Owenia fusiformis, Mediomastus spp., Paraprionospio pinnata and mollusc Mulinia lateralis (Table 6.8). This habitat is identified in Parker (1956), McBee and Brehm (1982), and Shaw et al. (1982).

The Open Sound habitat covers the deeper areas of Mississippi Sound from Cat Island, Louisiana, to Isle aux Herbes, Alabama, and Chandeleur and Breton Sounds (TechCon, 1980; Shaw et al., 1982; Vittor & Associates, Appendix A). This habitat occurs in deep water estuaries with less mud and organic content than the coastal margin habitat. Sand content ranges from 20-90% and depth ranges from 4-7 m. Characteristic taxa include polychaetes Cossura soyeri, Magelona cf. phyllisae, Nereis micromma; molluscs Nuculana concentrica; ophiuroids Hemipholis elongata, Micropholis atra; and sipunculid Phascolion strombi. Dominant taxa include those reported for the coastal margin habitat along with the polychaetes Cossura soyeri, Nereis micromma, Lumbrineris spp.; the sipunculid Phascolion strombi; and the pelecypod Nuculana concentrica.

The Open Bay mud habitat refers to an area within lower Mobile Bay which resembles the coastal margin mud habitat in terms of faunal assemblages but differs primarily with depth. The habitat has a sand content of less than 10%, an average depth of about 3.5 m, and is located adjacent to the Mobile Ship Channel. Dominant taxa include the polychaetes Leitoscodoplos sp., Mediomastus spp., Glycinde solitaria, Paraprionospio pinnata; molluscs Mulinia lateralis, Haminoea succinea, Utriculastra canaliculata; and cumacean Oxyurostylis smithi. Fauna associated with coastal margin and open bay mud habitats were also collected in upper Mobile Bay and areas adjacent to the Gulf Intracoastal Waterway (Taylor, 1978).

The Tidal Pass habitat is located between all barrier islands in the Trend study area and along shoaling areas of the Mississippi Sound and some ares of Chandeleur and Breton Sounds (TechCon, 1980; Shaw et al., 1982; Vittor & Associates, Appendix A). Sediment in these habitats is characterized by moderately sorted fine sands. The sand content is generally greater than 90% and depths range from 2 to 5 m. Taxa in this habitat are represented by typical sand dwellers including the polychaetes Polygordius sp., Poecilochaetus johnsoni, Armandia maculata, Spiophanes bombyx; cephalochordate

Table 6.8 Macroinfaunal assemblages associated with benthic habitats in estuarine waters of the Tuscaloosa Trend study area.

COASTAL MARGIN (MUD)	OPEN BAY (MUD)	OPEN SOUND (MUDDY SAND)	TIDAL PASS (SAND)
Balanoglossus cf. aurantiacus (H)	Oxyurostylis smithi (C)	Phascolion strombi (S)	Boguea enigmatica (P)
Parandalia americana (P)		Hemipholis elongata (E)	Semele nuculoides (M)
Polydora ligni (P)		Micropholis atra (E)	Crassinella lunulata (M)
Edotea cf. montosa (C)		Nuculana concentrica (M)	Metharpinia floridana (C)
Gammarus mucronatus (C)			Brania wellfleetensis (P)
			Poecilochaetus johnsoni (P)
			Lepidactylus sp. A (C)
		Nereis micromma (P)	Protohaustorius sp. A (C)
		Pinnixa pearsei (C)	Eudevenopus honduranus (C)
		Melinna maculata (P)	Acanthohaustorius sp. A (C)
		Asychis elongata (P)	Branchiostoma caribaeum (Ce)
			Polygordius spp. (A)
			Spiophanes bombyx (P)

← Cistena gouldii (P) →
Haminoea succinea (P)
Glycinde solitaria (P)
Leitoscoloplos sp. A (P)
Paramphinome sp. B (P)
Utriculastra canaliculata (M)

← Abra aequalis (M) →
Owenia fusiformis (P)
Myriochele oculata (P)
Paraprionospio pinnata (P)

← Mulinia lateralis (M) →
Mediomastus sp. (P)

A	= Archiannelid	M	= Mollusc
B	= Branchiopod	N	= Nemertean
C	= Crustacean	P	= Polychaete
Ce	= Cephalocordate	Ph	= Phoronid
E	= Echinoderm	S	= Sipunculid
H	= Hemichordate		

Branchiostoma caribaeum; pelecypod Crassinella lunulata; and amphipods Acanthohaustorius sp., Protohaustorius sp., Lepidactylus sp.

Vittor & Associates has reexamined several (49) benthic samples collected by McAuliffe et al. (1975) and qualitatively compared the species assemblages with those identified from the Mississippi River-Gulf Outlet (MR-GO) ocean dredged material disposal site (ODMDS) survey conducted for the U.S. EPA (1982b). Macroinfauna assemblages were associated with open sound, coastal margin, and tidal pass habitats identified through numerical classification. An inner shelf assemblage located east and west of the Delta is presented in the offshore section and Appendix A (Macroinfauna of Breton-Chandeleur Sounds). The MR-GO survey was limited geographically to the tidal inlet area adjacent to Breton Island. Thus, infaunal communities are represented primarily of sand-dwelling taxa, such as polychaetes Polygordius sp., Spiophanes bombyx; amphipods Acanthohaustorius sp., Eudevenopus honduranus; and lancelets Branchiostoma spp. Due to differences in sampling techniques, Chevron macroinfauna communities reflect greater crustacean and molluscan taxa while MR-GO macroinfauna communities are represented predominately by polychaetes.

Macroepifauna

Macroepifaunal invertebrates are a major component of the fauna of the north central Gulf of Mexico. Estuarine habitats provide food and shelter for larval and juvenile life stages. Dominant motile macroepifauna include gastropods such as the oyster drill (Thais haemostoma), which is a predator on the oyster (Crassostrea virginica). The drill generally inhabits areas where the salinity is at least 15 ^{o}/oo. The moon snail (Polinices lunulata) occupies silty sand habitats, where it feeds on detritus. Crustaceans such as the hermit crab (Clibanarius vittatus), mud crabs (Rhithropanopeus harrissii, Neopanope texana, and Panopeus herbstii) occur especially in shallow fringes of the estuary, over wide salinity ranges. Spider crabs (Libinia spp.) are found on silty sand, where they feed on dead animals and detritus. Several species of epibenthic echinoderms are found in estuaries of the Trend study area. These include the starfish (Luidia clathrata) and sandollar (Mellita quinquiesperforata). Both occur in higher salinity waters (over 20 ^{o}/oo); Perry and Christmas (1973) collected numerous individuals in St. Louis Bay. Sessile macroepifauna include the sea pansy (Renilla mulleri). This anthozoan was the most abundant invertebrate taken by trawl off Horn Island, Mississippi and Chandeleur and Breton Islands (Frank et al., 1972). Sessile crustaceans such as the acorn barnacles (Balanus spp.) are found throughout the Trend area, on hard surfaces such as pilings, rock jetties, and other structures (Parker, 1956; Hoese and Valentine, 1972; McAuliffe et al., 1975). Other encrusting forms such as the polychaete Spirorbis spp. are limited in abundance and distribution by the availability of suitable substrates.

The American oyster, Crassostrea virginica, is commercially harvested in the nearshore and estuarine waters of north central Gulf. This species thrives in salinities averaging between 10 and 20 ^{o}/oo and tolerates extremes of 2 to 39 ^{o}/oo for short periods. Completely anoxic conditions can be tolerated for up to a week, but prolonged hypoxia will kill oysters (Eckmayer, 1979).

Larval oysters are planktonic and dispersed by tides and currents. They eventually attach to a variety of hard, clean substrates including especially existing oyster reefs. They then metamorphose into spat and begin to grow. Growth rate varies depending upon environmental conditions such as temperature, salinity, and food availability. In Alabama, they reach marketable size in one year (O'Neil and Mettee, 1982). Mississippi oysters must be a minimum of 3 inches before legally harvested and this usually takes two years (Ladner and Franks, 1982). In Mississippi and Louisiana, the oyster fishery management includes leasing of water bottoms to oyster fishermen. The fishermen obtain "seed oysters" (those 1-3 inches in size) which are transported to private bedding grounds (leases). These lease areas are generally in more saline waters which are move favorable to the growth and quality of adult oysters.

Oysters are susceptible to disease by the protozoan *Perkinsus marinus* (formerly referred to as a fungus, *Labyrinthomyxa marina*). The disease is usually present throughout the year and may be transmitted by crabs, leeches, or planktonic larvae (Eckmayer, 1979). Oysters are most susceptible when both temperature and salinity are high; the infection may move rapidly through the population causing high mortalities. The sporozoan parasite *Nematopsis* is another cause of mortality among oysters (May, 1971). While the digenetic trematode *Bucephalus* sp. infects oysters but does not cause mortality, it does reduce the reproductive potential of the affected oysters (Eckmayer, 1979).

Oysters often occur in reefs, which are the most important aggregations in estuaries, since they are a major feature which influences patterns of sedimentation and provides habitats for a variety of invertebrates and fishes (Hedgpeth, 1957). Extensive reefs occur in estuarine areas of the Tuscaloosa Trend study area, on sand as well as mud substrates (although mud bottoms are generally too soft to support more than scattered individuals) (Butler, 1954). Four oyster reef categories designated by Butler (1954) are as follows:

Head of estuary -	salinities range from 0 to 15 ^{o}/oo and average 10 ^{o}/oo; small animals with low spatfall; serve as seed populations for down-estuary reefs;
Mid-estuary -	salinities fluctuate between 10 and 20 ^{o}/oo with a yearly average of 15 ^{o}/oo; highest population density, with distinct size classes and rapid growth;
Estuary mouth -	salinities range from 10 to 30 ^{o}/oo with an annual average of 25 ^{o}/oo; high growth rate and population density; heavy predation;
Estuary-Gulf junction -	consistently high salinities; low population density and growth rate; heavy predation and low reproductive potential.

Oyster reefs support complex associations of invertebrates and fishes, including many typical of fouling communities (Lee, 1979). Figure 6.9 depicts a generalized reef community (from Collard and D'Asaro, 1973), which is typical of the mid-estuary and estuary mouth macroinvertebrate assemblages

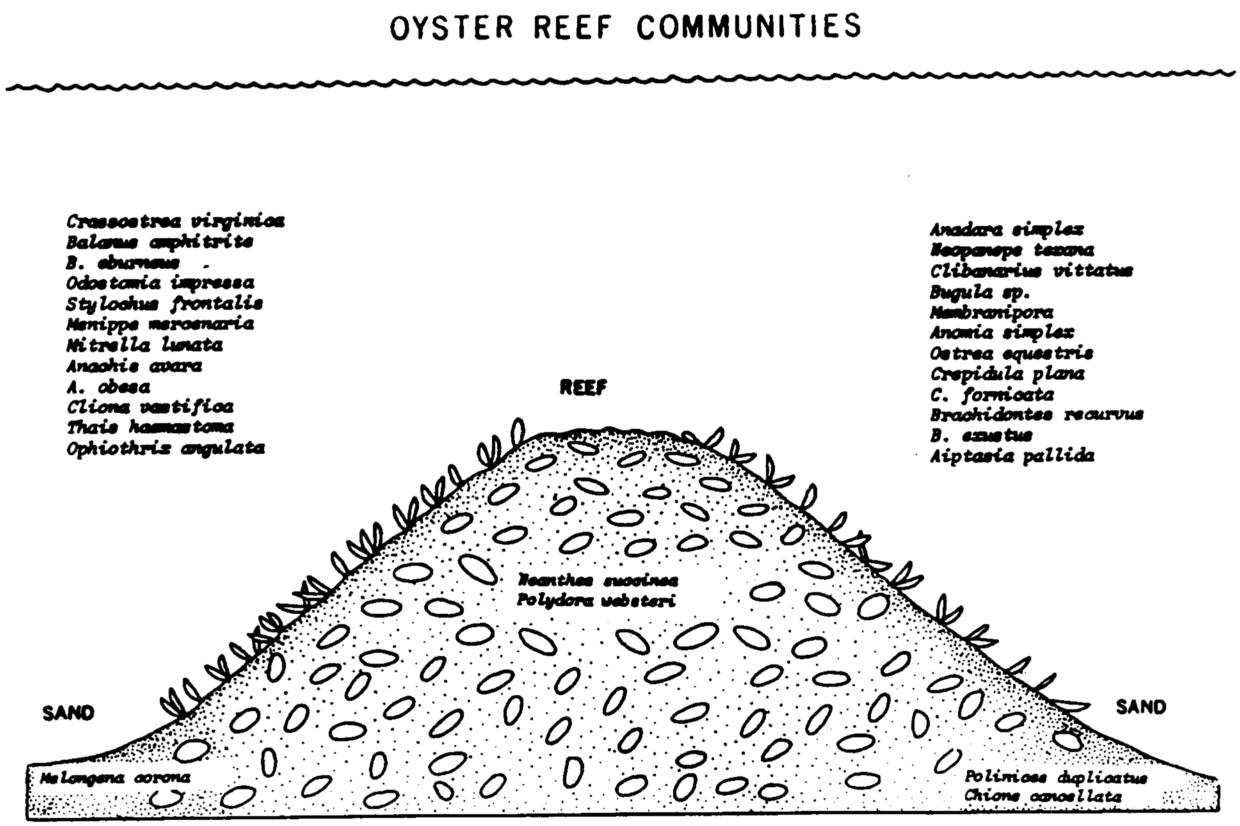


Figure 6.9 Subtidal oyster reef community with associated fauna present within the Tuscaloosa Trend estuarine waters (after Collard and D'Asaro, 1973).

in the Tuscaloosa Trend study area. Of particular importance to the survival and productivity of the reef is the predatory oyster drill (Thais haemostoma). Thais is unable to survive sustained salinities below 15 °/oo (Eckmayer, 1979) and thus is more limited in abundance and distribution than the oyster. During periods of low stream discharge, the drill enters more brackish estuarine waters and preys heavily on oyster populations until the salinity declines due to rainfall runoff and river discharge. May (1971) found drill densities as high as 11,616 per acre in Mississippi Sound.

Other important community members include the stone crab (Menippe mercenaria), which is relatively uncommon in areas such as Mobile Bay (Eckmayer, 1979), the mud crabs (Eurypanopeus depressus and Panopeus herbstii), balanoid barnacles (Balanus spp.), hermit crabs (Clibanarius vittatus), mussels (Brachidontes spp.), boring spanges (Cliona spp.), predaceous polyclads (Stylochus ellipticus), burrowing clams (Diplothyra smithii), and polychaetes such as Neanthes succinea and Polydora websteri.

Fishes associated with oyster reefs include black drum (Pogonias cromis), which can be a major predator on oysters (Eckmayer, 1979), and Gulf toadfish (Opsanus beta), which may be a major predator on mud crabs (as described by Maurer and Watling, 1973 for Delaware oyster reefs, regarding O. tau). Perrett (1973) reported that O. beta and the naked goby (Gobiosoma bosci) are very abundant around oyster reefs along the Louisiana coast.

6.4 CONTINENTAL SHELF WATERS

Areas seaward of the barrier islands to 200 m depth have been studied less extensively than the inshore areas of Mississippi Sound and Chandeleur-Breton Sounds. Much of the data collected were project-specific and not intended to provide a detailed view of the shelf ecosystem and its relationship to the inshore waters. The most comprehensive sampling effort within the study area was conducted by the Bureau of Land Management, Mississippi-Alabama-Florida (BLM-MAFLA) Outer Continental Shelf program, initiated in 1973 and continued until 1979 (SUSIO, 1975; Alexander et al., 1977; Dames and Moore, 1979). During this program, biological samples were collected to obtain baseline information on neuston, zooplankton, meiofauna, macrofauna, epifauna, and demersal fish. Only one station transect was located in the present study area. Other studies conducted by the U.S. Army Corps of Engineers and U.S. Environmental Protection Agency involved characterization of candidate dredged material disposal sites, and by petroleum exploration companies to prepare specific well site clearances. This section of the biology synthesis report will be a compilation of known information within the Tuscalooa Trend Outer Continental Shelf and a presentation of data gaps which future investigations should address.

6.4.1 OFFSHORE PLANT COMMUNITIES

Phytoplankton

Investigations of phytoplankton composition conducted within the Tuscaloosa Trend OCS are limited to the studies of Thomas and Simmons (1960), Simmons and Thomas (1962), and El-Sayed (1972). Diatoms usually comprise over 90% of the phytoplankton populations in abundance and outnumber dinoflagellates in total species. In general, dinoflagellates do not significantly contribute to phytoplankton standing crop or primary production (Fucik and El-Sayed, 1979).

Water masses in the eastern Mississippi Delta region are delineated in a scheme based on diatom species (Simmons and Thomas, 1962). The *Melosira-Cyclotella-Navicula* complex identifies river and plume river waters near the Mississippi River-Gulf Outlet, whereas the *Nitzschia*, *Thalassiothrix*, *Thalassionema*, *Skeletonema*, *Chaetoceros*, and *Asterionella* associations indicate saline Gulf waters. Both populations are mixed in the nearshore waters on the shelf. Maximum populations of phytoplankton were found from January through June in the fresher waters, and in late spring in the Gulf; minimum populations were found in fall (Simmons and Thomas, 1962).

Chlorophyll *a* measurements are generally used to indicate the quantity of phytoplankton populations in a given volume of water. Surface concentrations of chlorophyll *a* in the Tuscaloosa Trend region range from 0.04 to 1.73 $mg \cdot m^{-3}$ with an annual mean of 0.69 $mg \cdot m^{-3}$; bottom concentrations range from 0.05 to 4.37 $mg \cdot m^{-3}$ with an annual mean of 0.84 $mg \cdot m^{-3}$ (Alexander et al., 1977). In general, surface chlorophyll *a* was generally highest during winter and lowest during fall; bottom chlorophyll *a* was highest in summer and lowest in fall. Surface concentrations of chlorophyll *a* in the Trend region was over three times greater than that found for the open Gulf (annual mean of 0.2 $mg \cdot m^{-3}$; El-Sayed, 1972), but less than one-half measured for the shelf west of the Mississippi Delta (annual mean of 1.87 $mg \cdot m^{-3}$; Fucik and El-Sayed, 1972).

Measurements of productivity by means of average C^{14} were less comparable between regions east and west of the Delta. Average C^{14} uptake (surface) in the Trend region measured 8.1 mg $C \cdot m^{-3}$ per hour (Alexander et al., 1977) as compared to 27.0 and 17.5 mg $C \cdot m^{-3}$ per hour measured west of the Delta (Fucik and El-Sayed, 1972) and the open Gulf (El-Sayed, 1972), respectively.

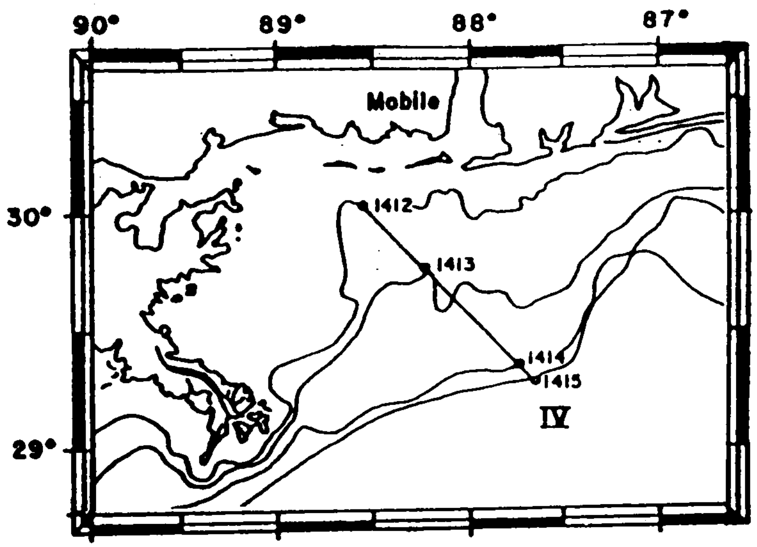
6.4.2 FAUNAL COMMUNITIES

Zooplankton

Zooplankton studies conducted on the continental shelf include two published reports which resulted from a joint Soviet-Cuban survey of Gulf of Mexico fishery potential (Bogdanov et al., 1968; Khromov, 1965) and the aforementioned baseline study conducted by the Bureau of Land Management of the northern Gulf shelf waters.

Bogdanov et al. (1968) identified three regions of high zooplankton production in the northern Gulf: 1) east of the mouth of the Mississippi River; 2) the southwest Florida shelf; and 3) northern Florida shelf. A combination of freshwater influx from the Mississippi River and vertical mixing of the coastal and shelf waters during the winter months contributes to the high productivity noted east of the Delta within the Tuscaloosa Trend study area.

Seasonal estimates of zooplankton density and biomass were made by Alexander et al. (1977) as part of the BLM MAFLA OCS program. Figure 6.10 depicts the dominant taxa identified from Transect IV, located within the



Sta.	Summer 1973	Fall 1975	Winter, 1976
1412	cladocerans, other calanoids, *Undinula vulgaris* (males)	*Centropages furcatus* *Acartia* sp.	fish eggs, foraminiferans, *Paracalanus* sp. *Eucalanus elongatus*
1413	anomurans, other calanoids	*Oncaea* sp., Doliolida	*Paracalanus* sp.
1414	other calanoids, *Rhincalanus coronatus* *Undinula vulgaris* (males)	*Paracalanus* sp., *Oncaea* sp.	*Paracalanus* sp., *Conchoecia* sp.
1415	other calanoids	cyclopoid copepodites, *Paracalanus* sp.	*Paracalanus* sp.

Figure 6.10 Station locations and dominant taxa groups of zooplankton (by season) collected in shelf waters of the Tuscaloosa Trend region (After Alexander et al., 1977).

Trend study area. During summer and fall, the general pattern of zooplankton observed was decreasing density with increasing distance from shore. Fall contained the lowest density and biomass estimates (also true for phytoplankton); the predominantly estuarine copepod Acartia sp. was collected several kilometers offshore. Zooplankton density and biomass was highest in winter (comparable to summer values), due primarily to large numbers of calanoid copepod Paracalanus sp. present throughout the transect. Paracalanus is considered an active winter breeder.

Ichthyoplankton

There have been few comprehensive studies of ichthyoplankton within the Tuscaloosa Trend study area. The National Marine Fisheries Service office in Miami, Florida has recently initiated a larval fish study in the Gulf of Mexico known as the Southeast Area Monitoring and Assessment Program (SEAMAP). Beginning in spring of 1982, Gulf waters were sampled using bongo, neuston, and ring nets. The areal coverage of this project is represented in Figure 6.11. Distribution and abundance data were collected for the families Engraulidae, Carangidae, Clupeidae, Lutjanidae, Serranidae, Coryphaenidae, Istiophoridae, Xiphiidae, and Scombridae. Previous investigations of ichthyoplankton of the northern Gulf of Mexico are limited to the offshore area east of the Mississippi River Delta (Arnold, 1958).

Nekton

The nektonic fish community (including demersal fishes and invertebrates) of the outer continental shelf has been studied by several workers (Franks et al., 1972; Alexander et al., 1977; Rogers, 1977; Shipp and Hopkins, 1978; Shipp and Bortone, 1979). In addition to these studies, a large data base has been accumulated and maintained by the National Marine Fisheries Service as a result of intense commercial fishing in the offshore waters. This community is probably the best understood of all the offshore biological communities.

Franks et al. (1972) collected seasonal trawl samples along a transect running southeast from Ship Island, Mississippi from January, 1967 to May, 1969. Data on relative abundance, seasonal bathymetric distribution and catch per unit effort were collected for the most abundant species. Five most numerically abundant species (American croaker Micropogonias undulatus, longspine porgy Stenotomus caprinus, butterfish Peprilus burti, spot Leiostomus xanthurus, and seatrout Cynoscion spp.) made up 80% of the total catch.

Shipp and Hopkins (1978) conducted an investigation of the limestone outcropping at the head of the DeSoto Canyon using a research submersible. Fourteen dives were conducted on the 50-60 meter reef. The ichthyofauna was dominated by deepwater reef species characteristic of Caribbean reefs. The habitat and abundance of thirty species were reported.

Shipp and Bortone (1979) examined the demersal fish fauna collected during the MAFLA benchmark program. Water depth and substrate were important factors in determining species composition of the 292 fish species collected. Less important factors were seasonality, water temperature, salinity, and latitude.

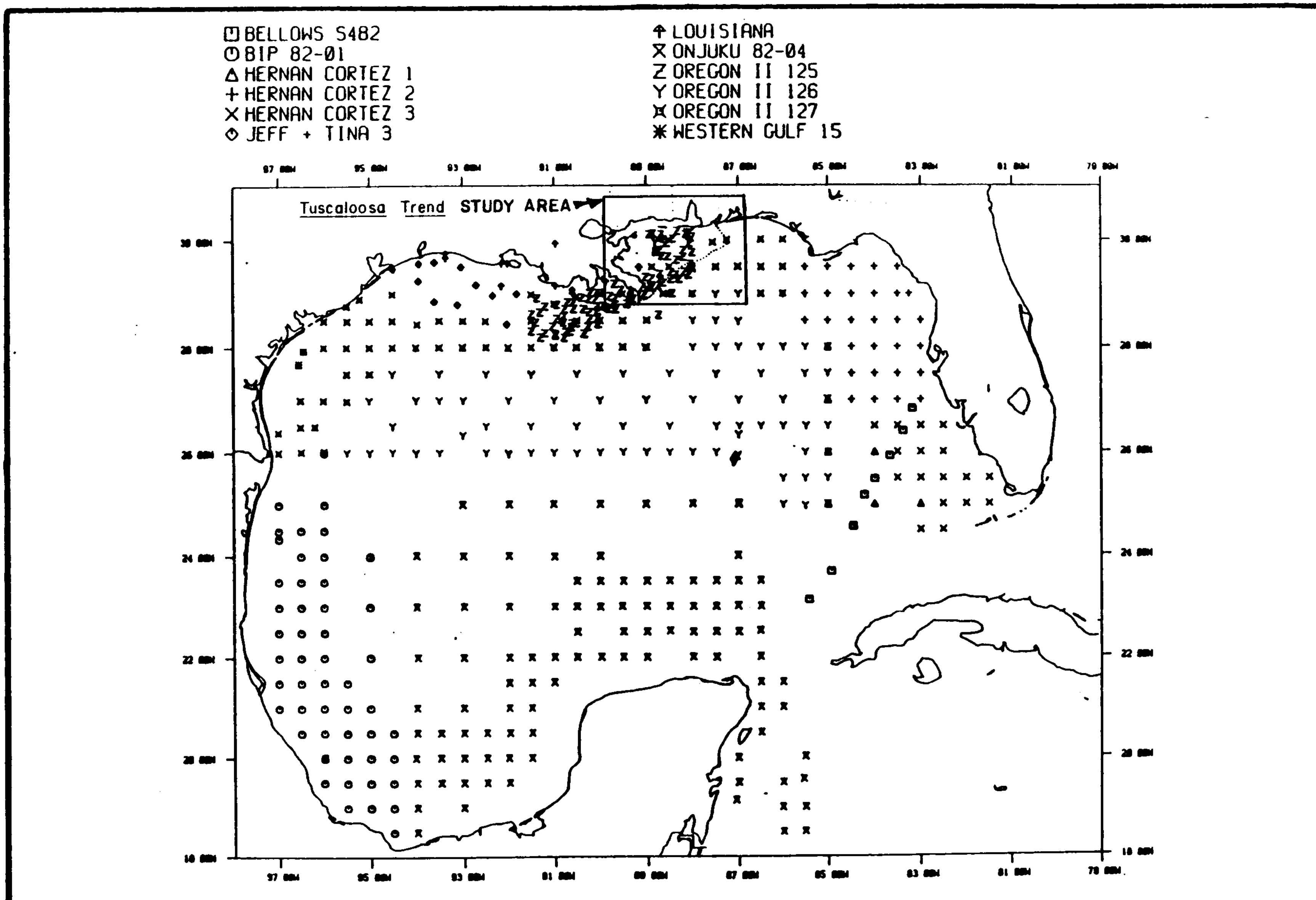


Figure 6.11 Areal coverage of the SEAMAP Ichthyoplankton survey (after Richards et al., 1984). Symbols represent collection periods and vessels used during surveys.

Another large data set collected on the demersal fish fauna in the study area resulted from the South Alabama Marine Environmental Resources Inventory (SAMERI). This study was designed to assess the demersal fish fauna along the 26 m (15 fathom) contour off the coasts of Mississippi, Alabama, and northwest Florida. Approximately 17 stations were sampled seasonally with an otter trawl from March, 1974 through March, 1977. This study was conducted by the University of South Alabama and fish collections are archived in their museum. A report was submitted to the Mississippi-Alabama Sea Grant, but no data have been published.

Darnell (see Appendix B) and Comiskey et al. (see Appendix C) have summarized commercial and recreational catch data from several data sets within the Trend study area. These include monthly transects across the shelf conducted by the Gulf Coast Research Laboratory (GCRL), monthly transects by the National Marine Fisheries Service in Galveston, Texas, spring season collections by Defenbaugh (1976), random collections from all seasons by McCaffrey (1981), and random collections by the National Marine Fisheries Service in Pascagoula, Mississippi. For all collections, taxonomy was updated and trawl data standardized. This combined data base includes 250 taxa and 201,585 individuals. Seasonal distribution maps are provided in Appendix B for several taxa. Figure 6.12 shows the seasonal distribution of all species compiled by Darnell and is given here to illustrate the format of these distribution maps. The data base examined by Comiskey et al.(Appendix C) is described in Table 6.9, and includes the Southeast Monitoring and Assessment Program (SEAMAP), NMFS Fishery Independent Survey for Groundfish, and NMFS Gulf Coast Shrimp Data.

The summary of these data syntheses is provided herein as a review of nektonic communities. (For additional information and seasonal distribution maps for specific taxa, the reader is advised to consult Appendix B and Appendix C.) Nekton assemblages are described on the basis of habitat/geographical location as well as degree of dependency on estuarine habitats.

Table 6.10 presents the taxa groups associated with habitats defined on the basis of salinity, depth, and sediment characteristics. Nekton species diversity indices are positively correlated with depth and salinity and negatively correlated with temperature, indicating that the deeper, more hydrographically stable habitat support a more diverse demersal nekton community. The integration and synthesis of results from pattern analyses of the 1982 and 1983 SEAMAP data yield five station groups (habitats) and eight taxa groups (communities).

Figure 6.13 presents the distributions of station groups (habitats) in the study area. Station Group 1 encompasses the shallow water, low salinity habitat located near the confluence of Mississippi Sound and Mobile Bay, and near the Mississippi Delta. A habitat characterized by high salinity waters overlying muddy sediments in the central portion of the study area east of the Mississippi River Delta is represented by Sample Group 2, whereas Sample Group 3 encompasses a similar habitat west of the Mississippi River Delta. Sample Groups 4 and 5 delineate nearshore and offshore habitats, respectively, and are characterized by high salinity waters overlying sandy sediments located in the central to eastern portion of the study area. Table 6.11 displays the relationship of eight taxa groups to the five station groups.

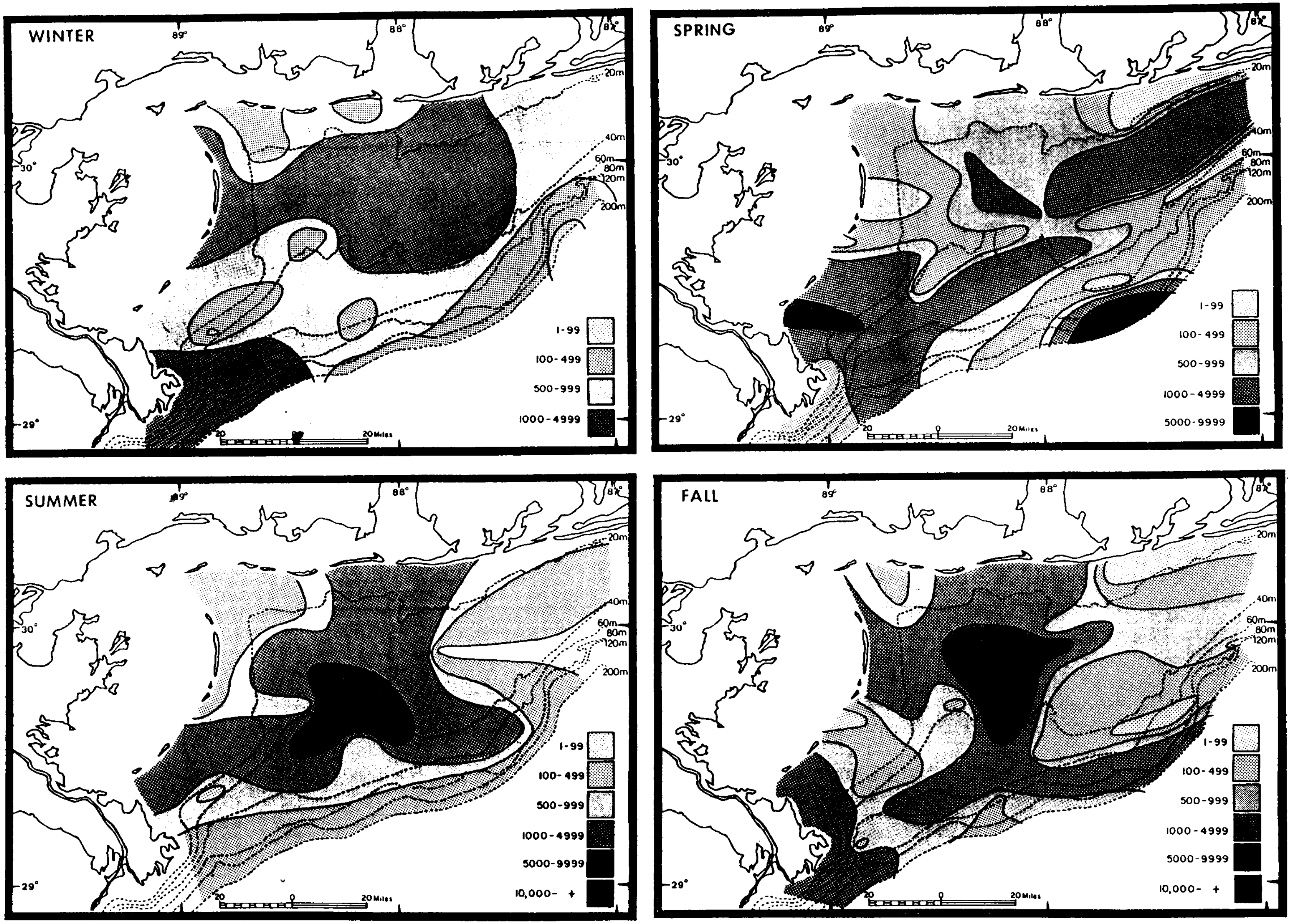


Figure 6.12 Seasonal abundance of the combined catch for all species considered in the synthesis of fish and shrimp collection data for the Tuscaloosa Trend region.(Source: Darnell, Appendix B)

Table 6.9 Summary of the regional demersal nekton and environmental data sets integrated into the Tuscaloosa Trend Project Data Base.

DATA SET	SOURCE	VARIABLES*	NUMBER OF STATIONS	TEMPORAL SPAN	FREQUENCY	PHYSICAL FORM
<u>Federal Sources</u>						
Fishery Independent Surveys for Groundfish	Dr. Walter R. Nelson/ Mr. Ken Savastano National Marine Fisheries Service	TC, B, LF, T, S, DO, TU, C XBT4	variable, 5-50 fathom depths	1972-1983	annually during fall, some seasonal coverage	magnetic tape
Southeastern Area Monitoring and Assessment Program (SEAMAP) A. Shrimp and Bottom Fish Survey B. Ichthyoplankton Survey C. Environmental Survey	Ms. Nikki Bane SEAMAP Coordinator Gulf States Marine Fisheries Commission	TC, B, LF, T, S, DO, TU, C XBT	variable, 1-50 fathom depths	1982-1983	annually during spring-summer	magnetic tape
Gulf Coast Shrimp Data	Mr. Darrell Tidwell National Marine Fisheries Service	TC, B, NT, DF	statistical area by 5-fathom depth zones	1960-1983	monthly	magnetic tape
River Discharge	U.S. Geological Survey Office of Water Data Coordination		12	1960-1983	monthly	magnetic tape
Precipitation and Winds	Mr. Warren Hatch National Climatic Data Center		4	1960-1983	monthly	magnetic tape
Tides	Ms. Janet Colt National Ocean Survey		1			magnetic tape
Ekman Transport	Dr. Andy Backun National Marine Fisheries Service Pacific Environmental Group		3° grids	1960-1983	monthly	magnetic tape
<u>State Sources</u>						
Louisiana Demersal Fisheries and Environmental Data	Mr. Harry E. Schafer, Jr. Dept. of Wildlife and Fisheries/Dr. Joan Browder National Marine Fisheries Service	TC, B, LF, T, S, DO, TU, NU	variable	1965-1983	monthly or semi-monthly	magnetic tape some hard copy
Mississippi Dermsal Fisheries and Environmental Data	Dr. Thomas McIlwain Gulf Coast Research Laboratory	TC, B, T, S, DO	11	1973-1983	monthly or semi-monthly	hard copy
Alabama Demersal Fisheries and Environmental Data	Mr. Walter Tatum/ Mr. Steve Heath Department of Conservation and Natural Resources	TC, B, T, S, DO	15-30	1977-1983	monthly or semi-monthly	hard copy

*TC = taxonomic count
B = biomass
LF = length/frequency
NT = number of trips
DF = days fished
T = temperature
S = salinity
DO = dissolved oxygen
TU = turbidity
NU = nutrients
C = chlorophyll
XBT = expendable bathythermograph

Table 6.10 Eight taxa groups resulting from a synthesis of community analyses of samples collected in and around the Tuscaloosa Trend study area during the fall 1982 and 1983 SEAMAP groundfish surveys.

Group 1. Taxa Most Characteristic of the Shallow Water, Low Salinity Habitat

Scientific Name	Common Name
Anchoa mitchelli	bay anchovy
Anchoa nasuta	longnose anchovy
Arius felis	hardhead catfish
Chloroscombrus chrysurus	Atlantic bumper
Larimus fasciatus	banded drum
Menticirrhus americaus	southern kingfish
Stellifer lanceolatus	star drum
Polydactylus octonemus	Atlantic threadfin
Trinectes maculatus	hogchoker

Group 2. Taxa Represented in Low Salinity Waters and in High Salinity Waters Overlying Muddy Sediments

Scientific Name	Common Name
Lolliguncula brevis	squid
Penaeus setiferus	white shrimp
Penaeus aztecus	brown shrimp
Callinectes sapidus	blue crab
Callinectes similis	crab
Anchoa hepsetus	striped anchovy
Cynoscion arenarius	sand seatrout
Leiostomus xanthurus	spot
Citharichthys spilopterus	bay wiff
Trichiurus lepturus	Atlantic cutlassfish
Peprilus burti	gulf butterfish
Symphiurus plagiusa	blackcheek tonguefish

Group 3. Taxa Widespread in High Salinity Waters Overlying Muddy Sediments

Scientific Name	Common Name
Sicyonia dorsalis	rock shrimp
Squilla LPIL	mantis shrimp
Trachypenaeus LPIL	hardback shrimp
Calappa sulcata	crab
Porichthys plectrodon	Atlantic midshipman
Brotula barbata	bearded brotula
Lepophidium graellsi	blackedge cusk-eel
Ophidion welshi	crested cusk-eel
Cynoscion nothus	silver seatrout
Prionotus rubio	blackfin searobin
Etropus crossotus	fringed flounder

Group 4. Taxa Most Characteristic of High Salinity Waters Overlying Muddy Sediments East of the Mississippi River Outfall

Scientific Name	Common Name
Portunus gibbesii	portunid crab
Saurida brasiliensis	largescale lizardfish
Urophycis cirratus	gulf hake
Urophycis floridanus	southern hake
Serranus atrobranchus	blackear bass
Prionotus tribulus	bighead searobin
Sphoeroides parvus	least puffer

Group 5. Taxa Most Characteristic of High Salinity Waters Overlying Muddy Sediments West of the Mississippi River Outfall

Scientific Name	Common Name
Parapenaeus	shrimp
Hoplunnis macrurus	silver conger
Antennarius radiosus	singlespot frogfish
Steindachneria argentea	luminous hake
Gunterichthys longipenis	gold brotula
Nezumia bairdi	grenadier
Bollmania communis	ragged goby

Group 6. Taxa Represented in High Salinity Waters Overlying Muddy and Sandy Sediments

Scientific Name	Common Name
Penaeus duorarum	pink shrimp
Solenocera	shrimp
Ovalipes guadulpensis	portunid crab
Portunus spinicarpus	portunid crab
Etrumeus teres	round herring
Synodus foetens	inshore lizardfish
Halieutichthys aculeatus	pancake batfish
Lepophidium jeannae	mottled cusk-eel
Ophidion grayi	blotched cusk-eel
Centropristis philadelphicus	rock sea bass
Diplectrum bivittatum	dwarf sand perch
Lutjanus campechanus	red snapper
Prionotus roseus	bluespotted searobin
Syacium gunteri	shoal flounder
Stenotomus caprinus	longspine porgy

Group 7. Taxa Most Characteristic of Nearshore High Salinity Waters Overlying Sandy Sediments

Scientific Name	Common Name
Doryteuthis plei	squid
Loligo pealeii	squid
Sicyonia brevirostris	rock shrimp
Raja eglanteria	cleannose skate
Centropristis ocyurus	bank sea bass
Haemulon aurolineatum	tomtate
Orthopristis chrysoptera	pigfish
Prionotus carolinus	northern searobin
Prionotus martis	barred searobin
Prionotus scitulus	leopard searobin
Sphoeroides spengleri	bandtail puffer

Group 8. Taxa Most Characteristic of Offshore High Salinity Waters Overlying Sandy Sediments

Scientific Name	Common Name
Synodus intermedius	sand diver
Synodus poeyi	offshore lizardfish
Trachinocephalus myops	snakefish
Urophycis regius	spotted hake
Ophidion holbrooki	bank cusk-eel
Lagodon rhomboides	pinfish
Neomerinthe hemingwayi	spinycheek scorpionfish
Scorpaena calcarata	smoothhead scorpionfish
Bellator militaris	horned searobin
Prionotus salmonicolor	blackwing searobin
Syacium papillosum	dusky flounder
Monacanthus hispidus	planehead filefish

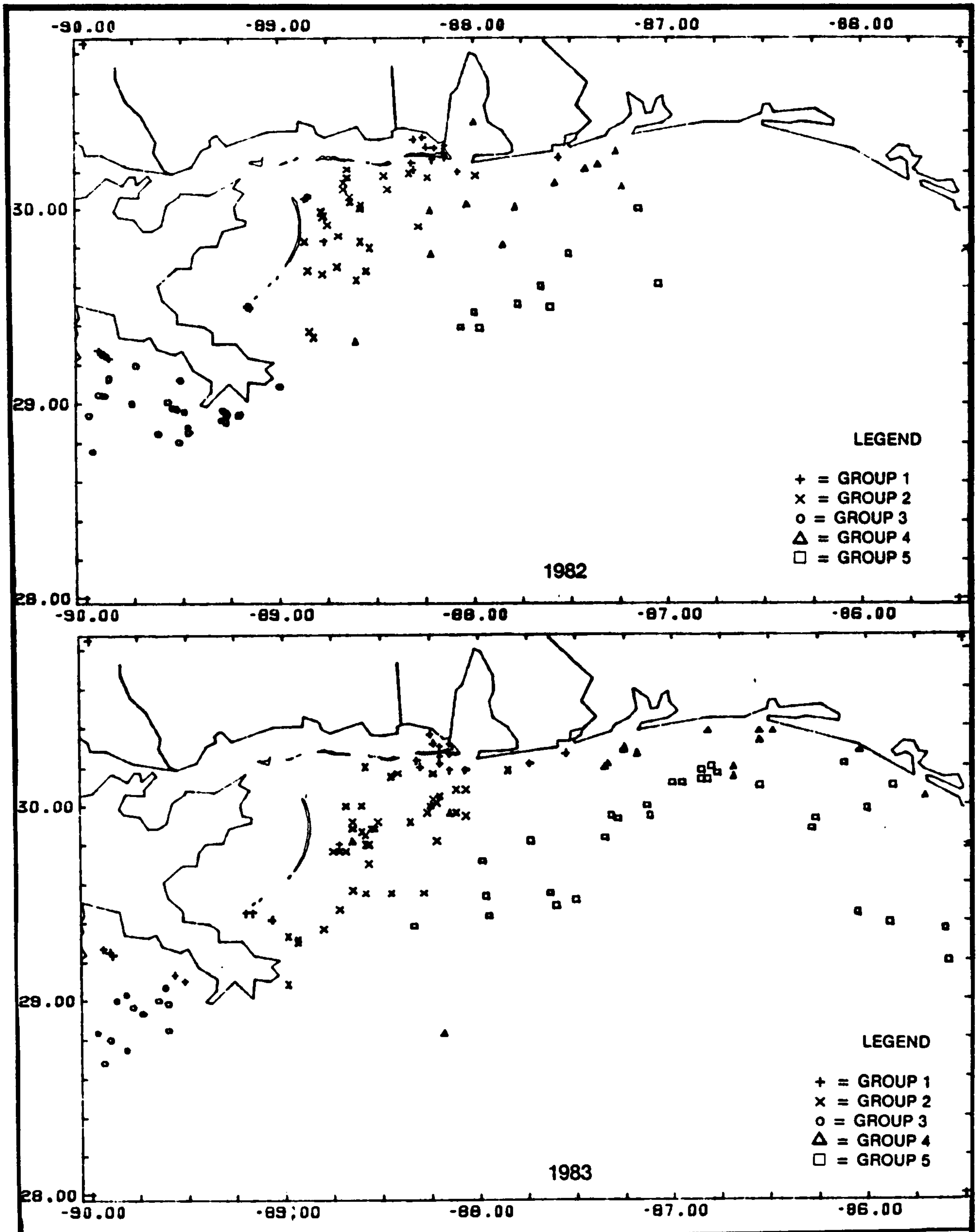


Figure 6.13 Map of SEAMAP groundfish survey area showing the membership of stations to five groups resulting from synthesis of community analyses of fall 1982 and fall 1983 surveys.

Table 6.11 A coincidence table displaying the relationship of the eight taxa groups to the five station groups resulting from a synthesis of community analyses of samples collected in and around the Tuscaloosa Trend study area during the fall 1982 and 1983 SEAMAP groundfish surveys (see Appendix C).

	STATION GROUPS				
	Group 1	Group 2	Group 3	Group 4	Group 5
TAXA GROUPS	Low Salinity	Muddy sediments east of Miss. River outfall	Muddy sediments west of Miss. River outfall	Nearshore high salinity Sandy sediments	Offshore high salinity Sandy sediments
Group 1	X				
Group 2	X	X	X		
Group 3		X	X		
Group 4		X			
Group 5			X		
Group 6		X	X	X	
Group 7				X	
Group 8					X

Taxa Group 1 includes those taxa most characteristic of the shallow water, low salinity habitat represented by Sample Group 1. Anchoa mitchelli, Arius felis, Micropogonias undulatus, and Polydactylus octonemus are among the taxa most representative of this group.

The taxa in Group 2 are also well represented in the shallow water, low salinity habitat of Sample Group 1 but are also prominent in the habitat characterized by high salinity waters overlying muddy sediments (Sample Groups 2 and 3). The taxa which define the ecological trend as expressed in the analysis include Cynoscion arenarius, Trichiurus lepturus, Symphiurus plagiusa, Callinectes sapidus, Callinectes similis, and Penaeus aztecus.

The taxa in Group 3 are widespread in high salinity waters overlying muddy sediments (Sample Groups 2 and 3). Porichthys plectrodon, Prionotus rubio, Squilla, and Trachypenaeus are among the taxa most representative of this group. The Group 4 taxa are most characteristic of the high salinity waters overlying muddy sediments east of the Mississippi River Delta (Sample Group 2). The occurrence of Sphoeroides parvus and Portunus gibbesii are taxa most closely associated with this habitat.

The taxa most characteristic of the high salinity waters overlying muddy sediments west of the Mississippi River Delta comprise Group 5. Some of the taxa most characteristic of this group include Hoplunnis macrurus, Gunterichthys longipenis and Bollmania communis. The Group 6 taxa are widespread in high salinity waters overlying muddy and sandy sediments (Sample Groups 2, 3, 4, and 5). Centropristis philadelphicus, Stenotomus caprinus, Penaeus duorarum and Solenocera are among the taxa most representative of this group. The taxa in Group 7 are most characteristic of nearshore high salinity waters overlying sandy sediments (Sample Group 4). Some of the taxa most characteristic of this group include Orthopristis chrysoptera, Prionotus martis, Prionotus scitulus, Sicyonia brevirostris and Loligo pealii.

Group 8 includes those taxa most characteristic of offshore high salinity waters overlying sandy sediments (Sample Group 5). Some of the taxa which depict the trends as expressed by analyses include Synodus intermedius, Trachinocephalus myops, Bellator militaris and Syacium papillosum.

These assemblage distributions indicate that the complex ecological patterns in the Tuscaloosa Trend ecosystem differ from those of a typical shelf ecosystem. In most shelf ecosystems, gradients of change in hydrographic conditions and sediments type and the associated changes in population and community structure usually vary in an onshore-offshore direction, with lower salinity waters and coarser-grained (sandy) sediments nearshore grading into higher salinity waters and finer-grained (muddy) sediments offshore. In the Tuscaloosa Trend ecosystem, the influence of the Mississippi River affects longshore gradients in hydrographic conditions and sediment type, with lower salinity waters and finer-grained sediments near the outfall grading into higher salinity waters and coarser-grained sediments away from the outfall. This combination of longshore and onshore-offshore gradients of environmental change produces a complex and dynamic ecosystem.

Results of statistical analyses conducted on the NMFS fishery independent seasonal groundfish data (fall 1974 to summer 1975) and annual groundfish data (fall surveys from 1973 to 1980 and 1982 to 1983) revealed trends in the distributions of finfish and shellfish taxa that were primarily related to geographic location, depth (annual data), hydrographic conditions (seasonal data), and sediment type. Six habitats and six faunal communities were identified from the seasonal data set and presented in Tables 6.12 and 6.13, respectively. Distributions of station groups (habitats) within the study area are presented in Figure 6.14. Results of the annual data set showed major dichotomies between the sandy bottom eastern region and the muddy bottom central and west regions. Within these two groups, habitats (stations) were revealed along depth gradients from shallow to deep. Results of further community analyses are presented in Appendix C.

Gulf Coast penaeid shrimp data collected by the National Marine Fisheries Service for statistical subareas 9-13, which encompass the Trend study area, were analyzed for the period 1960-1982. The five statistical subareas were aggregated into three regions representing a western region (statistical subarea 13 - west of the Mississippi Delta), a central region (statistical subareas 11 and 12), and an eastern region (statistical subareas 9 and 10 - sandy sediments off Alabama and Florida).

Figure 6.15 shows the trends in total catch for the four species of penaeid shrimp. Catches of pink shrimp (*Penaeus duorarum*) and seabob (*Xiphopeneus kroyeri*) were consistently lower than those of brown (*P. aztecus*) and white shrimp (*P. setiferus*). Seabob catch showed very high variability through time, with peak catch in 1981 (almost 1 million kilograms). Pink shrimp catch was less variable, and appears to have declined in recent years relative to that of seabobs.

Three of the penaeid species (all except pink shrimp) generally showed similar trends over the study area, with highest densities (as measured by catch/area or C/A), in the western region and lowest densities in the eastern region. The seabob demonstrated the weakest affinity for the two regions located east of the Mississippi River, and (therefore) showed the most restricted geographic distribution. It was caught in appreciable numbers only in the western region, where the vast majority of the catch was made in nearshore waters of less than 20 m (10 fathom) depths. Going west to east, the contribution of nearshore areas to total seabob catch increased. A lower relative amount of seabobs were caught in nearshore waters compared to the species of the genus *Penaeus*, consistent with the general feeling that seabobs are not estuarine-dependent.

White and brown shrimp showed geographic trends similar to those of the seabob (i.e., highest in the west and lowest in the east), but they were generally more widely distributed over the study area. While white shrimp were by far most abundant on the shelf in the western region, C/A for brown shrimp was more similar in the western and central region. For both species, nearshore areas of the western region were very productive, with C/A in the nearshore zones of the central and especially eastern regions being much lower. Even so, the vast majority of the white shrimp catch in the eastern region occurred in the estuaries, with virtually no offshore catch reported. This indicates that white shrimp migrate westward upon leaving the estuaries of the eastern region, taking up residence on the shallow shelf in the central region. The data clearly indicate that brown shrimp catch in the estuaries and nearshore zone offshore were dominated by the size class of smallest shrimp, while a substantial fraction of the white shrimp catch in these zones consisted of larger shrimp.

Table 6.12 A coincidence table displaying the relationship of six taxa groups to six station groups resulting from a synthesis of community analyses of three replicate samples collected at 154 stations in and around the Tuscaloosa Trend study area during the fall 1974 to summer 1975 NMFS Fishery Independent groundfish surveys.

	STATION GROUPS					
	Group 1 Nearshore waters primarily collected in winter & spring	Group 2 Nearshore waters primarily collected in spring & summer	Group 3 Nearshore waters overlying sandy sediments	Group 4 Deep waters overlying muddy sediments	Group 5 Mid-depth to deep waters overlying sandy sediments (spring & summer)	Group 6 Mid-depth to deep waters overlying sandy sediments (fall & winter)
TAXA GROUPS						
Group 1	X	x	x			
Group 2				X		
Group 3	X	X	x	X	x	x
Group 4	x	x	x	x	X	X
Group 5			x		X	X
Group 6					x	X

Table 6.13 Six taxa groups resulting from a synthesis of community analyses of three replicate samples collected at 154 stations in and around the Tuscaloosa Trend study area during the fall 1974 to summer 1975 NMFS Fishery Independent groundfish surveys.

Group 1. Taxa Most Characteristic of the Shallow Water Habitat

Scientific Name	Common Name
Lolliguncula brevis	short squid
Penaeus setiferus	white shrimp
Narcine brasiliensis	lesser electric ray
Brevoortia patronus	gulf menhaden
Opisthonema oglinum	Atlantic thread herring
Anchoa hepsetus	striped anchovy
Anchoa mitchelli	bay anchovy
Arius felis	hardhead catfish
Bagre marinus	gafftopsail catfish
Chloroscombrus chrysurus	Atlantic bumper
Archosargus probatocephalus	sheepshead
Larimus fasciatus	banded drum
Merticirrhus americanus	southern kingfish
Stellifer lanceolatus	star drum
Chaetodipterus faber	Atlantic spadefish
Polydactylus octonemus	Atlantic threadfin
Symphurus plagiusa	blackcheek tonguefish

Group 2. Taxa Most Characteristic of Deep Waters Overlying Muddy Sediments in the Western Portion of the Study Area and in the Vicinity of the Mississippi River Delta

Scientific Name	Common Name
Parapenaeus	shrimp
Solenocera	shrimp
Trachypenaeus	shrimp
Xiphopeneus	seabob
Congrina flava	yellow conger
Steindachneria argentea	luminous hake

Group 3. Taxa Widespread Across the Study Area, but Most Numerically Prominent in Waters Overlying Muddy Sediments

Scientific Name	Common Name
Penaeus aztecus	brown shrimp
Callinectes similis	lesser blue crab
Rhizoprionodon terraenovae	Atlantic sharpnose shark
Porichthys porosissimus	Atlantic midshipman
Selene setapinnis	Atlantic moonfish
Cynoscion arenarius	sand seatrout
Cynoscion nothus	silver seatrout
Leiostomus xanthurus	spot
Micropogonias undulatus	croaker
Trichiurus lepturus	Atlantic cutlassfish
Prionotus rubio	blackfin searobin
Citharichthys spilopterus	bay whiff
Paralichthys lethostigma	southern flounder

Group 4. Taxa Widespread Across the Study Area, but Most Numerically Prominent in Waters Overlying Sandy Sediments

Scientific Name	Common Name
Harengula jaguana	scaled sardine
Synodus foetens	inshore lizardfish
Halieutichthys aculeatus	pancake batfish
Centropristis philadelphicus	rock sea bass
Logodon rhomboides	pigfish
Peprilus burti	gulf butterfish
Cyclopsetta chittendeni	Mexican flounder
Etropus crossotus	fringed flounder
Syacium papillosum	dusky flounder

Group 5. Taxa Widespread in Waters Overlying Sandy Sediments

Scientific Name	Common Name
Loligo pealii	squid
Penaeus duorarum	pink shrimp
Sicyonia dorsalis	rock shrimp
Etrumeus teres	round herring
Saurida brasiliensis	largescale lizardfish
Diplectrum bivittatum	dwarf sand perch
Diplectrum radiale	sand perch
Decapterus punctatus	round scad
Trachurus lathami	rough scad
Lutjanus campechanus	red snapper
Lutjanus synagris	lane snapper
Pristipomoides aquilonaris	wenchman
Eucinostamus gula	silver jerry
Stenotomus caprinus	longspine porgy
Sphyraena guachancho	guaguanche
Syacium gunteri	shoal flounder
Lagocephalus laevigatus	smooth puffer
Sphoeroides parvus	least puffer

Group 6. Taxa Most Characteristic off Mid-Depth to Deep Waters Overlying Sandy Sediments

Scientific Name	Common Name
Scyllarides nodifer	lobster
Portunus spinicarpus	portunid crab
Trachinocephalus myops	snakefish
Scorpaena calcarata	smoothhead scorpionfish
Bellator militaris	horned searobin
Prionotus ophyrus	bandtail searobin
Prionotus roseus	bluespotted searobin

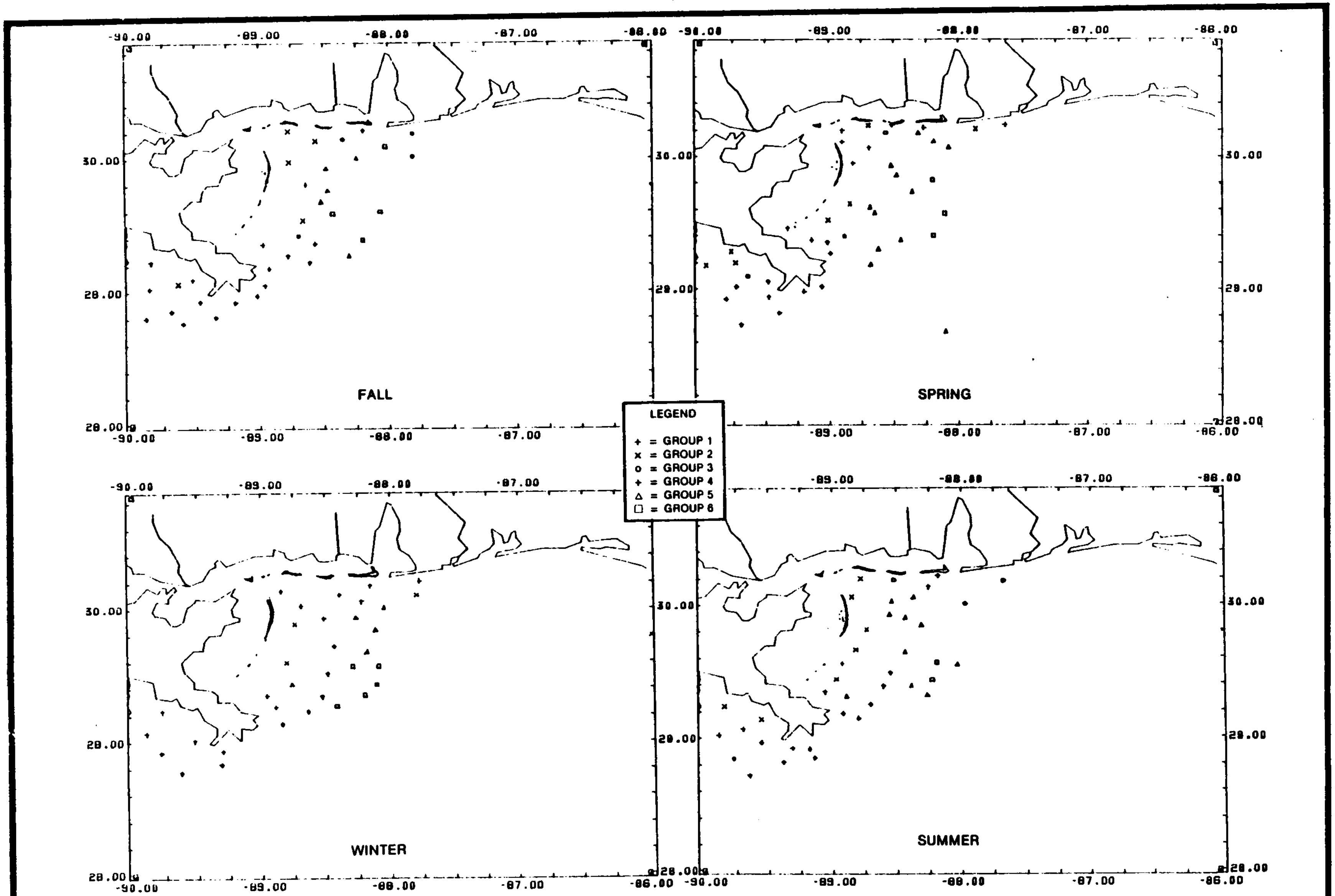


Figure 6.14 Map of the NMFS Fishery Independent groundfish survey area showing the membership of the stations to the six station groups resulting from a synthesis of the community analyses of the fall 1974 to summer 1975 NMFS Fishery Independent groundfish survey data.

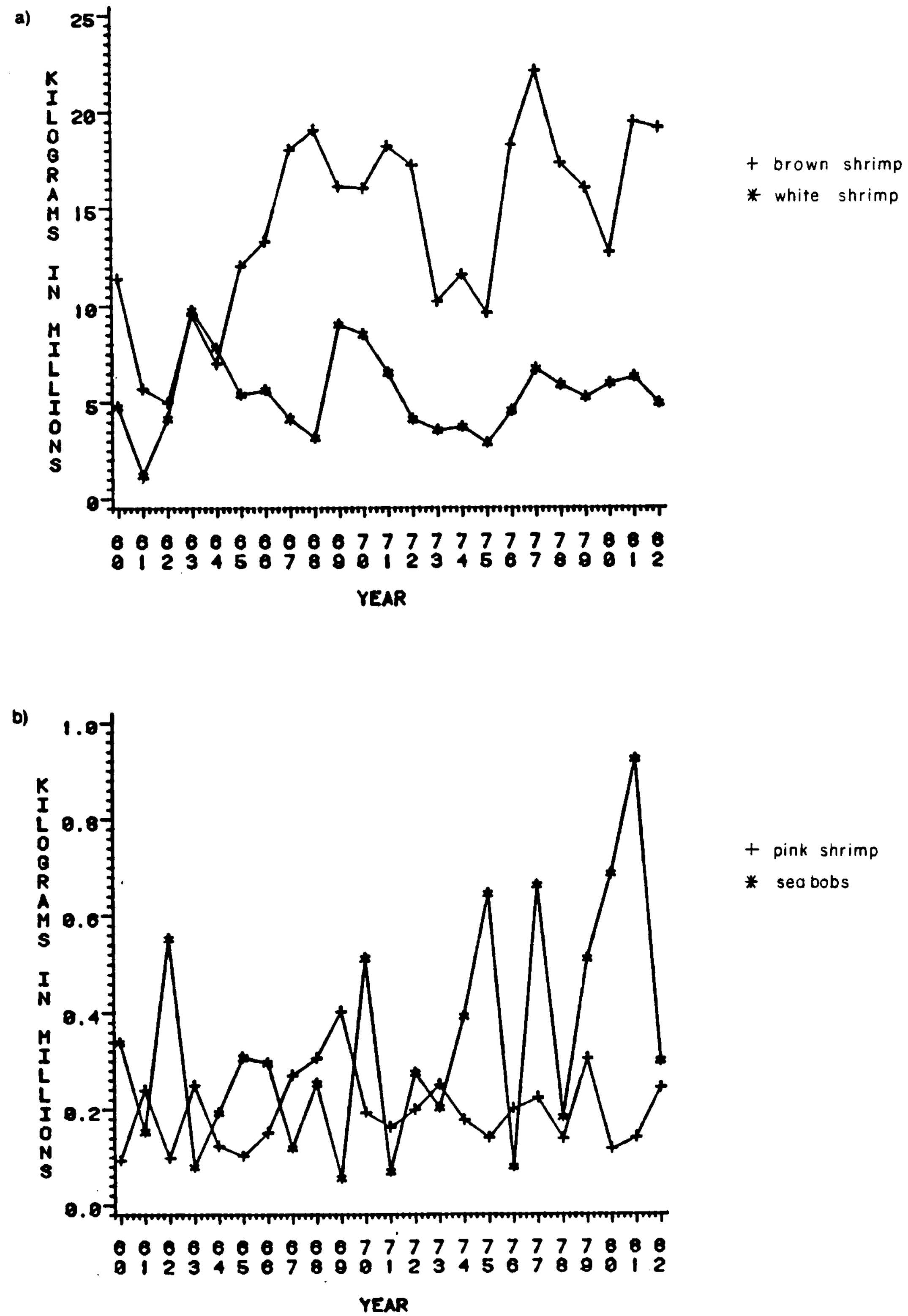


Figure 6.15 Total annual catch (kg, heads on) of: a) white and brown shrimp and b) pink shrimp and seabobs within the Tuscaloosa Trend area. (Source: Comiskey et al., Appendix C)

Estuarine-Dependent Species

As reflected in the distribution/abundance data reviewed above, the nekton of the Trend area include estuarine-dependent as well as estuarine-independent species. Table 6.14 provides summary data for major estuarine-dependent species. Two groups of such species are recognized: cold weather and warm weather spawners. Except for brown shrimp (Penaeus aztecus,) all the cold weather spawners are most abundant on the shelf during the fall and winter months (i.e., during their spawning seasons). Why P. aztecus deviates is not clear, but this species could be, in part at least, a fall spawner. Three of the warm weather spawners--sea catfish (Arius felis), sand seatrout (Cynoscion arenarius), and white shrimp (Penaeus setiferus)--are most abundant on the shelf during the fall and winter. The kingfish (Menticirrhus americanus) is most abundant on the shelf in the winter and about the same during the spring and fall. The pink shrimp (P. duorarum) is most abundant on the shelf during the spring and summer months (i.e., during much of its spawning season).

Estuarine-Independent Species

The second group of species resides on the continental shelf, and although some species may make use of bays, sounds, and estuaries, such areas are not critical to the life history. Summary data for this group are given in Table 6.15. Those species which occur only on the outer half of the shelf are of potential commercial and recreational importance, but they are under-utilized at present. Of those which occur on the inner half of the shelf, only four species appeared in any abundance in the fish data base (red snapper Lutjanus campechanus, silver seatrout Cynoscion nothus, harvestfish Peprilus alepidotus, and Gulf butterfish Peprilus burti). Most sharks, as well as the bluefish (Pomatomus saltatrix and cobia (Rachycentron canadum), are generally too mobile to be caught by trawls, and are obviously much more abundant on the shelf than present data would indicate. Groupers (Epinephelus itajara and E. morio) and the lane snapper (Lutjanus synagris) tend to remain around wrecks and reef structures of the middle and outer shelf where they are less vulnerable to capture by trawls. In the winter months Lutjanus campechanus shows a remarkable concentration at a depth of 30-40 m off Mobile Bay. Since spawning in this species occurs in the warmer months, it is suggested that the winter concentration is a reflection of the concentration in the same area by the demersal fishes and shrimp which make up its food supply. On the continental shelf the distribution of Cynoscion nothus does not appear significantly differ from that of C. arenarius except that the latter species is more abundant and extends to waters of greater depth. The two stromateids (Peprilus alepidotus and P . burti are, in part, pelagic. The life histories must be seasonally quite different. P. alepidotus was most abundant in the fall and winter, whereas P. burti was most abundant in spring and summer.

Estuarine-Independent Species Which Are Basically Summer Residents

A group of carnivorous species moves into the shelf area during the warmer months (Table 6.16), and these include the carangids, coryphaenids, scombrids, tunas, and billfishes. Some move in from deeper Gulf waters, and others are along-shelf migrators. Some appear to remain around the outer edge of the shelf, whereas others range broadly over the inner shelf and may even

Table 6.14 Estuarine dependent species of commercial and recreational importance collected on the continental shelf, giving numerical abundance in the fish or shrimp data base, percent abundance by season, and spawning season. For species with less than 50 individuals, seasonal percentage is not given.

Species	Number of individs.	Percent abundance on the shelf				Spawning season
		W	Sp	Su	F	
<u>Cold weather spawners</u>						
Brevoortia patronus	92.9	96.9	0.0	0.0	3.1	October-March
Archosargus probatocephalus	12.6	--	--	--	--	February-June
Leiostomus xanthurus	5,994.3	33.9	11.6	8.5	46.0	December-March
Micropogonias undulatus	32,102.5	15.4	13.0	12.8	58.9	October-April
Pogonias cromis	17.8	--	--	--	--	February-April
Sciaenops ocellatus	21.6	--	--	--	--	September-November
Mugil cephalus	0.2	--	--	--	--	October-May
Paralichthys albigutta	0.1	--	--	--	--	November-February
Paralichthys lethostigma	58.9	27.0	17.7	22.7	32.6	September-April
Penaeus aztecus	2,607.7	8.1	26.9	32.9	32.2	November-April
<u>Warm weather spawners</u>						
Arius felis	4,519.8	31.6	4.2	31.7	32.5	May-August
Cynoscion arenarius	3,005.0	48.2	18.2	11.9	21.7	March-September
Menticirrhus americanus	549.5	42.8	23.2	13.6	20.3	April-October
Penaeus duorarum	622.1	12.7	44.6	38.1	4.6	May-November
Penaeus setiferus	280.1	46.6	8.0	6.3	39.1	March-October

Table 6.15 Estuarine-independent species of commercial and recreational importance which are resident on the shelf, giving numerical abundance in the fish data base, percent abundance by season, and spawning season (where known). For species with less than 50 individuals, seasonal percentage is not given.

Species	Number of individs.	Percent abundance on the shelf				Spawning season
		W	Sp	Su	F	
Species which occur on the inner half of the shelf						
Carcharhinus acronotus	3.1	--	--	--	--	
Mustelus canis	6.2	--	--	--	--	
Rhizoprionodon terraenovae	14.5	--	--	--	--	July-August
Sphyrna tiburo	5.9	--	--	--	--	
Other shark species	--	--	--	--	--	
Epinephelus itajara	--	--	--	--	--	
Epinephelus morio	--	--	--	--	--	
Pomatomus saltatrix	0.5	--	--	--	--	August-April
Rachycentron canadum	9.4	--	--	--	--	April-August
Lutjanus campechanus	1,131.8	80.7	1.9	6.7	10.7	June-October
Lutjanus synagris	--	--	--	--	--	March-September
Cynoscion nothus	523.8	64.9	2.4	25.9	6.8	"Fall"
Peprilus alepidotus	144.8	30.4	0.5	0.0	69.0	"Spring"
Peprilus burti	12,931.3	3.3	66.3	27.4	3.0	Feb.-May, Sept.-Nov.
Species which occur only on the outer shelf						
Squatina dumerili	16.0	--	--	--	--	
Caulolatilus intermedius	90.4	71.6	0.0	3.4	25.0	
Caulolatilus microps	38.4	--	--	--	--	
Lopholatilus chamaeleonticeps	--	--	--	--	--	
Malacanthus plumieri	--	--	--	--	--	
Paralichthys squamilentus	49.5	1.3	12.5	1.6	84.5	

Table 6.16 Estuarine-independent species of commercial and recreational importance which are basically summer residents only, giving numerical abundance in the fish data base, spawning season (where known), and portion of the shelf primarily used.

Species	Number of individs.	Spawning season	Portion of shelf used		Comments
			Inner	Outer	
Carangids					
Caranx chrysos	86.4	Spring	x	x	
Caranx hippos	--	Spring-Summer	x	x	
Caranx latus	--	Summer	x	x	
Hemicaranx amblyrhynchus	40.0			x	
Seriola dumerili	19.9	Summer		x	
Seriola fasciata	--			x	
Trachinotus carolinus	--	Summer-Fall	x	x	
Coryphaenids					
Coryphaena equisetus	--			x	Shelf edge, rare
Coryphaena hippurus	--	Spring		x	
Scombrids					
Auxis thazard	--			x	Rare
Scomber japonicus	9.0			x	
Scomberomorus cavalla	--	Summer		x	
Scomberomorus maculatus	4.3	Summer	x	x	
Scomberomorus regalis	--			x	Rare
Tunas					
Euthynnus alletteratus	--	Summer	x	x	
Euthynnus pelamis	--	Summer		x	Shelf edge, rare
Thunnus albacares	--			x	shelf edge
Thunnus atlanticus	--			x	shelf edge
Thunnus thynnus	--			x	shelf edge
Billfishes					
Istiophorus platypterus	--	Summer		x	
Makaira nigricans	--	Summer		x	shelf edge
Tetrapterus albidus	--	Summer		x	shelf edge

enter the sounds and larger bays. Most are spring or summer spawners, and the young must make extensive use of the shelf and related coastal waters. These species are excellent swimmers and are only rarely taken in trawl collections. Most are of interest to sport fishermen.

It is probably no accident that the greatest utilization of the shelf by estuarine-dependent species is during the colder months (when most of the predators are absent) and that most estuarine-dependent species spawn during the colder months. There is a reverse movement of energy back into the estuary and related waters when the larvae and juveniles migrate to the nursery areas, and considering the organic matter which accompanies the young in the bottom waters, this shoreward movement of energy cannot be negligible. The interrelationship of the estuarine and offshore waters with respect to estuarine-dependent and estuarine-independent species are discussed for both demersal and pelagic nekton communities in section 6.6.

Benthos

The zoogeography of the northern Gulf has been described by several workers (Deevey, 1950; Hedgpeth, 1953; Defenbaugh, 1976). It has been termed the "Gulf Coast Disjunct" of the Carolinian Fauna of the western Atlantic by Deevey (1950). Both regions were continuous during the Pleistocene and are now separated by the Florida Peninsula. Within the northern Gulf, the DeSoto Canyon area is considered the zone of greatest transition between east and west Gulf fauna (Defenbaugh, 1976). Faunal differences are due to variations in sediment and circulation patterns between east and west Gulf rather than a barrier imposed by the Mississippi River (Shipp and Hopkins, 1978).

Continental shelves provide a vast majority of the shallow water marine benthic habitats represented by estuarine and offshore benthic communities that exist at depths of less than 200 m. Distribution of shelf populations and communities are generally interpreted along environmental gradients, such as bathymetry, temperature, and substrate. The combined influence of sediment and physical factors correlated with depth on bathymetric faunal zonation is demonstrated for shelf macroinfauna of central Louisiana (Southwest Research Institute, 1981), south Texas (Flint and Rabalais, 1981), and northeastern Gulf of Mexico (Shaw et al., in preparation). Biotic factors affecting abundance and distribution include predation, competition, food availability, physiological tolerance limits, and population characteristics (e.g., fecundity, longevity, and variability) (Flint and Rabalais, 1981). The following discussion is a synthesis of major benthic studies which address distribution of habitats and faunal assemblages in the Tuscaloosa Trend region.

The outer continental shelf within the Tuscaloosa Trend study area has been included incidentally in a number of benthic surveys and baseline environmental monitoring programs (Parker, 1960; Alexander et al., 1977; Dames & Moore, 1979; Shaw et al., 1982). Each study was designed to address specific objectives (Table 6.17). While data from these studies have contributed substantially to the body of knowledge regarding benthic communities, no cohesive plan has been formulated to adequately characterize the entire study area spatially or on a seasonal basis.

Table 6.17 Summary of benthic surveys on continental shelf of the Tuscaloosa Trend study area.

Author	Location	Sample Type	Time Period	Fauna Collected
Parker, 1956	Mississippi River Delta	Grab, Trawl	1951-1954	Macroepifauna
Alexander et al., 1975, 1977	MAFLA OCS	Trawl	1974-1976	Macroinfauna, macroepifauna, meiofauna
Defenbaugh, 1976	Northern Gulf of Mexico	Trawl	1970-1973	Macroepifauna
Rogers, 1978	Northern Gulf of Mexico	Trawl	1970-1973	Trophic relation
Dames & Moore, 1979	MAFLA OCS	Box Corer, Dredge	1977-1978	Macroinfauna, macroepifauna, meiofauna
CSA, 1981	Offshore Alabama	Box Corer, Trawl	1981	Macroinfauna, macroepifauna
Shaw et al., 1982	Offshore Alabama, Mississippi	Box Corer	1979-1980	Macroinfauna
EPA, 1982	Offshore Alabama, Mississippi	Box Corer	1980-1981	Macroinfauna, macroepifauna
Racal-Decca, 1982	Offshore Alabama	Box Corer, Trawl	1982	Macroinfauna, macroepifauna
Vittor & Assoc., this study (McAuliffe, 1975)	Mississippi River Delta	Suction Corer, Shipek Grab, Trawl	1971-1972	Macroinfauna, macroepifauna
Vittor & Assoc., this study (EPA, 1982)	Mississippi River-Gulf Outlet	Box Corer	1980-1981	Macroinfauna
Vittor & Assoc., 1984	Offshore Alabama	Box Corer	1983	Macroinfauna

Meiofauna

Meiofauna of the OCS has been studied by Alexander et al. (1977) and Ivester (1979) in conjunction with the MAFLA baseline survey. Only one transect (VI) occurred within the Tuscaloosa Trend study area (Figure 6.16). Trends in meiofaunal densities along this transect resembled those for other transects in the MAFLA Study (i.e., decreasing with depth). Densities ranged from 627 individuals$\cdot$10 cm^{-2} at the shallowest station (<30 m depth) to 155 individuals$\cdot$10 cm^{-2} at the deepest station (160 m depth). Marine free-living nematodes were found to dominate the meiofauna community followed by harpacticoid copepods and polychaetous annelids.

Macroinfauna

Ecological characteristics of macroinfaunal communities identified from major benthic surveys conducted within the Tuscaloosa Trend OCS are provided in Table 6.18. The benthic habitats for infaunal organism is closely tied to substrate type and texture (Table 6.19). Figure 6.17 illustrates a modification of sediment composition on the continental shelf, whereby sediments containing: less than 20% sand = mud; 20-50% sand = sandy mud; 50-90% sand = muddy sand; and greater than 90% sand = sand. This proves helpful in delineation of benthic habitats. Proceeding on a transect offshore to 200 m, a variety of sediment types may be encountered depending on location of the transect. Generally, however, the beach-related habitat is encountered first adjacent to the barrier island beaches out to 2-4 m. Seaward of this habitat is the inner shelf habitat (4-20 m), followed by the intermediate shelf habitat (20-60 m), and the outer shelf habitat (60-120 m) (Vittor & Associates, unpublished data). Within each of these areas, sediments may be composed of sands, silts, clays, or mixtures of each. There is an east-west transition from predominate sands along the west Florida shelf to terrigenous silts and clays along the southeast Louisiana shelf. Few of the benthic macroinvertebrate studies on this shelf have adequately characterized the communities along this east-west gradient (Shaw et al., 1982). Most have concentrated their sampling along north-south (depth) gradients (Parker, 1956; Franks et al., 1972; Defenbaugh, 1976; Alexander et al., 1977; Dames and Moore, 1979). Others have localized sampling efforts to near coast regions (McAuliffe et al., 1975; Shaw et al., 1982; EPA, 1982a,b).

The shallow beach habitat (2-4 m) is subject to temperature and salinity fluctuations as well as heavy wave action. Sediments consist of well-sorted sands and shell fragments. Characteristic species in this habitat include bivalve *Donax* spp., echinoderm *Mellita quinquiesperforata*, and amphipod *Protohaustorius* spp. This habitat is analogous to Parker's (1960) and Defenbaugh's (1976) surf zone habitat.

The inner shelf habitat (4-20 m) is adjacent to the barrier islands and includes some assemblages previously discussed for the estuarine waters. This habitat is composed of many euryhaline species that predominate during periods of high river discharge and low salinity conditions in the shallow offshore areas near the barrier islands and Mississippi Delta. Table 6.20 lists the infaunal assemblages associated with various habitats on the inner shelf. Three of these proposed assemblages exhibit narrow depth and sediment texture preferences. Other assemblages show transitional distributional patterns. The mud habitat assemblage (<20% sand) is represented by the

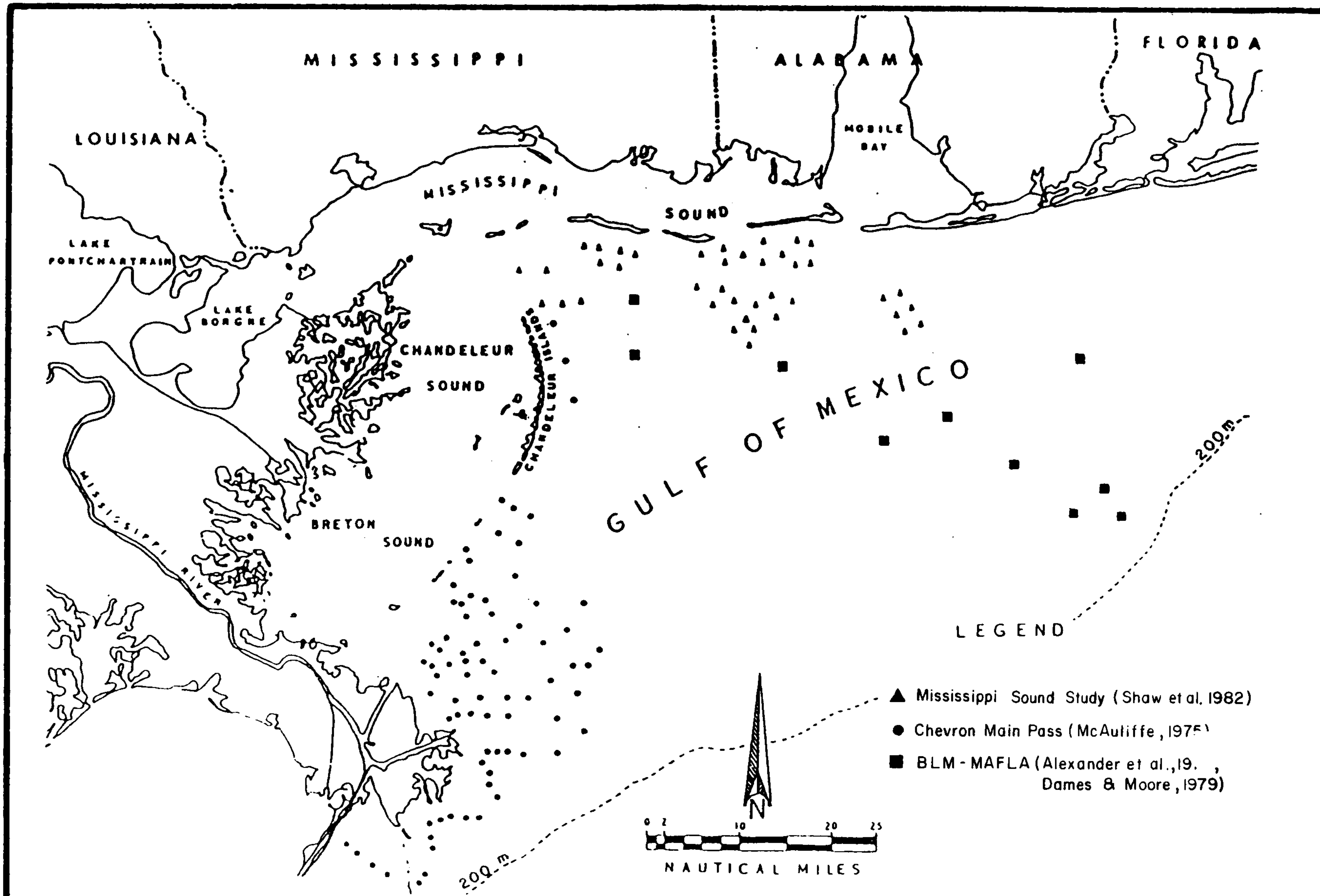


Figure 6.16 Station locations of major offshore macroinfaunal programs in the Tuscaloosa Trend study area.

Table 6.18 Major ecological characteristics of macroinfauna communities in the Tuscaloosa Trend offshore waters.

INFORMATION/PRODUCTS	MAFLA BASELINE STUDY (Alexander et al., 1977) (Dames and Moore, 1979)	MISSISSIPPI SOUND OFFSHORE SURVEY (Shaw et al., 1982)	GULFPORT, MOBILE, PENSACOLA OFFSHORE DISPOSAL (EPA, 1982)	MISSISSIPPI RIVER DELTA CHEVRON DATA (This Study)
Community Structure	(Polychaetes only)			
Total No. Taxa	31 to 131/station	410 spp. 65 to 242/station ($\bar{x}$ = 124/station)	Not Determined	------
Density (ind/m^2)	37 to 1,907 ($\bar{x}$ = 1073)	832 to 17,864	829 to 8612 ($\bar{x}$ = 3036)	293 to 49,102 ($\bar{x}$ = 5235)
H' (diversity)	H' = 2.51 to 4.02	H' = 2.20 to 4.21	------	0.77 to 3.78
J' (evenness)	------	J' = 0.48 to 0.86	------	0.23 to 0.94
D (species richness)	------	D = 8.43 to 26.69	------	3.31 to 12.73
Biomass (g/m^2)	Wet wt. 0.98 to 9.99	Ash-free dry wt. 0.51 to 84.20 ($\bar{x}$ = 7.32)	Wet wt. 9.85 to 100.80	------
Dominant Taxa	Paraprionospio pinnata (P) Mediomastus californiensis (P) Lumbrineris sp. A (P) Nereis micromma (P) Synelmis albini (P) Spiophanes bombyx (P) Paraonis lyra (P) Paleonotus heteroseta (P) Cossura soyeri (P) Onuphis pallidula (P) Aglaophamus verrilli (P) Cirrophorus lyriformis (P)	Magelona cf. phyllisae (P) Mediomastus spp. (P) Lumbrineris spp. (P Aricidea sp. C (P) Paraprionospio pinnata (P) Diopatra cuprea (P) Prionospio cristata (P) Myriochele oculata (P) Golfingia trichocephala (S) Oxyurostylis smithi (C) Polygordius spp. (P) Branchiostoma caribaeum (Ce)	Mediomastus spp. (P) Paraprionospio pinnata (P) Magelona cf. phyllisae (P) Cerebratulus lacteus (N) Linopherus-Paramphinome (P) Cossura soyeri (P) Mulinia lateralis (M) Cossura delta (P) Spiophanes bombyx (P) Golfingia trichocephala (S) Branchiostoma floridae (Ce) Acanthohaustorius sp. (C)	Mulinia lateralis (M) Oxyurostylis smithi (C) Tellina versicolor (M) Spiophanes bombyx (P) Owenia fusiformis (P) Mediomastus spp. (P)
Assemblages	Macroinfaunal communities associated with one inner shelf, three intermediate shelf, and two outer shelf habitats. Mud, sandy mud, muddy san, sand. Multivariate analysis includes classification.	Three macroinfaunal communities associated with inner shelf habitats. Mud, muddy sand, sand. Major groups associated with sediment patterns and depth zonation. Multivariate analyses: Ordination Correlation Factor	Three macroinfaunal communities associated with inner shelf (<20m depth) habitats. Mud, muddy sand, and sand.	Macroinfaunal community associated with inner shelf muddy sand habitat.

C = Crustacean, Ce = Cephalochordate, M = Mollusc, N = Nemertean, P = Polychaete, S = Sipunculid

Table 6.19 Selected sediment parameters characterizing benthic habitats among benthic studies conducted in the Tuscaloosa Trend study area - Outer Continental Shelf.

Program	Habitat	Depth	% Sand	% Silt-Clay	Sediment Type
BLM-MAFLA, 1978	a. Inner Shelf	20	28.4	64.8-80	Medium silt
	b. Intermediate Shelf	39	78.5	0-21	Coarse medium sand
	c. Outer Shelf	118	77.5	0-41.0	Medium fine sand
	Inner Shelf (sandy mud)	13	42	13-41	Sand w/silt-clay
Shaw et al., 1982	a. Inner Shelf (mud)	11.3	39	40-30	Medium silt
	b. Inner Shelf (sandy mud)	18m	76	17-14	Very fine sand
Continental Shelf Assoc., 1981	c. Inner Shelf (sand)	16-3	93	5-2	Fine sand
Vittor & Associates, this study collected by US EPA, 1982b	Inner Shelf (sand-Sta. 4-8,10)	4-11	90	3-13	Muddy sand
Racal-Decca, 1982	Inner Shelf (muddy sand)	13	85	5-10	Fine sand
Vittor & Associates, this study collected by McAuliffe et al., 1975	Inner Shelf (muddy sand)	--	--	----	Muddy sand
Vittor & Associates, 1984	Inner Shelf (sand)	9-14	99	1	Clean, fine sand

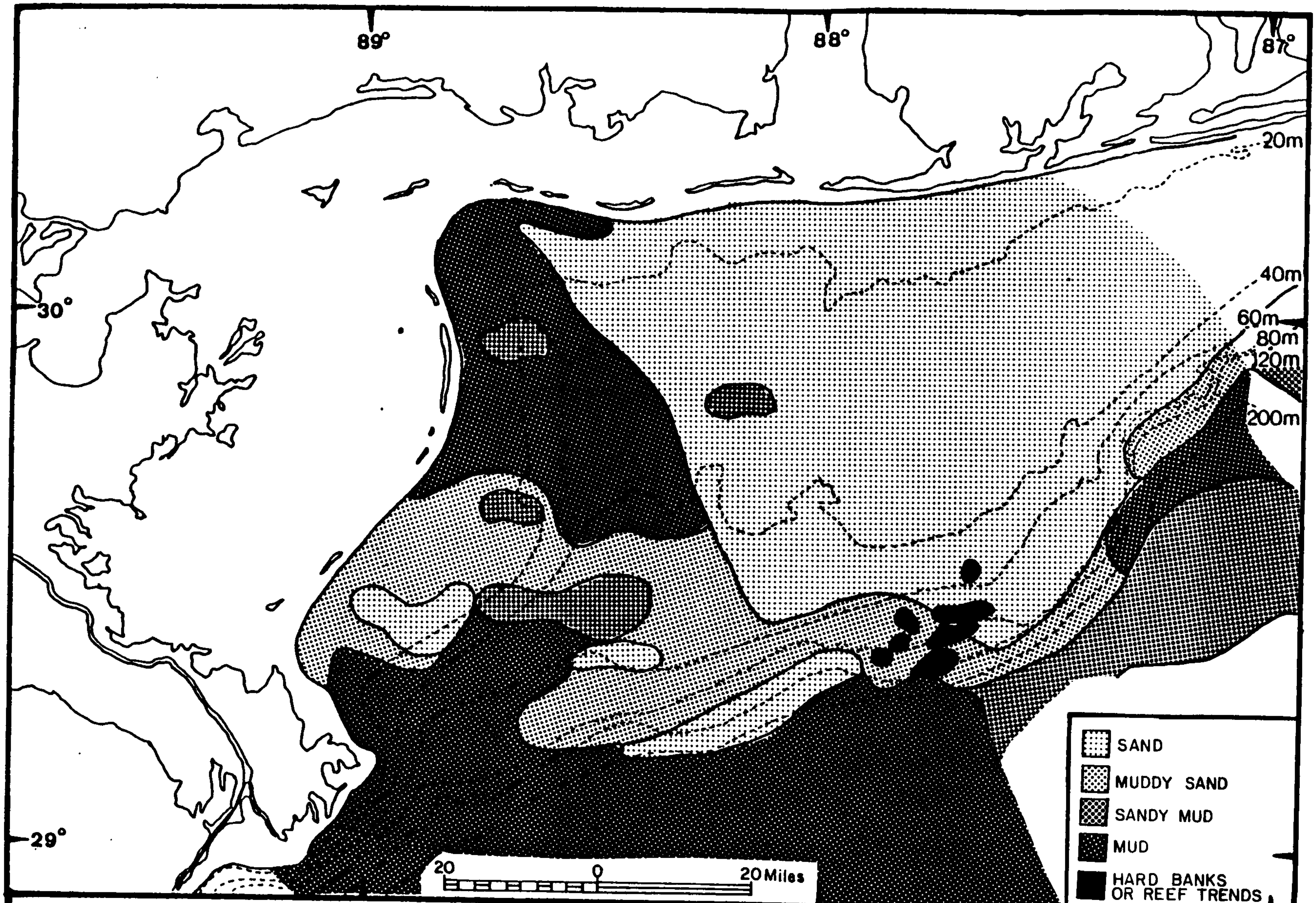


Figure 6.17 Bottom sediments within the Tuscaloosa Trend study area. Source: U.S. Department of the Interior, MMS, 1983.

Table 6.20 Proposed infaunal assemblages associated with habitats on the inner continental shelf (<20m) in the Tuscaloosa Trend study area.

MUD (<20% Sand)	SANDY MUD (20-50% Sand)	MUDDY SAND (50-90% Sand)	SAND (>90% Sand)
Balanoglossus cf. *aurantiacus* (H) *Paramphinome* sp. B (P) *Utriculastra canaliculata* (M) *Nassarius acutus* (M)	*Hemipholis elongata* (E) *Micropholis atra* (E) *Nuculana concentrica* (M) *Pinnixa pearsei* (C)		*Nephtys picta* (P) *Dispio uncinata* (P) *Onuphis nebulosa* (P) *Magelona* cf. *riojai* (P) *Aricidea wassi* (P) *Apoprionospio pygmaea* (P) *Brania wellfleetensis* (P) **Crassinella lunulata* (M) **Acanthohaustorius* sp. A (C) *Protohaustorius* sp. A (C) **Branchiostoma caribaeum* (Ce) **Polygordius* spp. (A) **Lepidactylus* sp. A (C)
←	*Glycinde solitaria* (P) *Sabellides* sp. A (P) *Sigambra tentaculata* (P) *Cossura delta* (P) *Cossura soyeri* (P) *Oxyurostylis smithi* (C) →		
	←	*Nereis micromma* (P) *Tellina versicolor* (M) *Cerebratulus lacteus* (N) *Phascolion strombi* (S) *Phoronis* sp. A (Ph) →	
		←	*Armandia maculata* (P) *Spiophanes bombyx* (P) *Goniada littorea* (P) *Xenanthura brevitelson* (C) *Glottidia pyramidata* (B) →
←	*Diopatra cuprea* (P) *Magelona* cf. *phyllisae* (P) *Paraprionospio pinnata* (P) *Asychis elongata* (P) *Mulinia lateralis* (M) *Abra aequalis* (M)	→	
	←	*Golfingia trichocephala* (S) *Owenia fusiformis* (P) *Mediomastus californiensis* (P) *Myriochele oculata* (P)	→

*Characteristic of tidal inlet habitat (coarse sand or shell substrate).

A	= Archiannelid		M	= Mollusc	
B	= Branchiopod		N	= Nemertean	
C	= Crustacean		P	= Polychaete	
Ce	= Cephalocordate		Ph	= Phoronid	
E	= Echinoderm		S	= Sipunculid	
H	= Hemichordate				

hemichordate Balanoglossus cf. aurantiacus, polychaete Paramphinome sp. B, and molluscs Utriculastra canaliculata and Nassarius acutus. The sandy mud (20-50% sand) habitat assemblage includes ophiuroids Hemipholis elongata and Micropholis atra, bivalve mollusc Nuculana concentrica, and pinnixid crab Pinnixa pearsei. The sand habitat (>90% sand) includes a large number of polychaetes Nephtys picta through Brania wellfleetensis, amphipods Acanthohaustorius sp., Protohaustorius sp., Lepidactylus, cephalocordate Branchiostoma carribeum, and archiannelid Polygordius sp., which are found in well-sorted sands characteristic of tidal inlets. Five groups of transitional species assemblages are represented on the inner shelf habitat, each with affinities for broad ranges of sediment composition. Some of these ubiquitous species include polychaetes Magelona cf. phyllisae, Paraprionospio pinnata, Mediomastus californiensis, Sigambra tentaculata and Spiophanes bombyx. Species such as the mollusc Mulinia lateralis, and polychaetes Myriochele oculata, Owenia fusiformis, and P. pinnata are typical of estuarine fauna and their presence indicate an extension of these euryhaline species into the offshore waters.

The intermediate shelf faunal assemblages (20-60 m) is presented in Table 6.21. Two primary faunal assemblages illustrate the dichotomy of sediment distribution (i.e., mud and sand) along the intermediate shelf of the Tuscaloosa Trend. The intermediate shelf mud habitat (<20% sand) is characterized by polychaetes Cirrophorus lyriformis, Nephtys incisa, and Notomastus daueri. The intermediate shelf sand assemblage is characterized by the polychaete Aricidea wassi, and crustaceans Metharpinia floridana, Kalliapseudes sp. C and Ampelisca agassizi. Faunal assemblages characteristic of transitional habitats within the intermediate shelf include polychaetes Cossura soyeri, Nereis micromma, Sigambra tentaculata and Aglaophamus verrilli.

The outer shelf infaunal assemblages are represented in Table 6.22. Some of these habitats (mud, <20% sand) have not been adequately sampled in the Tuscaloosa Trend OCS area. Faunal assemblages proposed here are based on studies of similar areas west of the Mississippi River Delta (i.e., the Central Gulf Platform Study, Bedinger and Kirby, 1981).

The mud habitat (<20% sand) within the outer continental shelf is relatively homogeneous in composition from the inner to the outer shelf. Consequently, species inhabiting this habitat type are distributed according to salinity, depth, and distance from shore. This habitat is characterized by the polychaetes Notomastus latriceus, Nereis grayi, Cirrophorus lyriformis and Nephtys incisa, with the latter two species characteristic of the true marine environment. The exclusion of ubiquitous species such as polychaetes Paraprionospio pinnata and Mediomastus californiensis from the outer shelf sediments exemplifies the distribution limits of these euryhaline species.

The fine sand and muddy sand habitats represent the results of the MAFLA sites located near the DeSoto Canyon. Polychaetes Sphaerosyllis pirifera, Mooreonuphis pallidula, and Synelmis albini are characteristic species of these outer shelf habitats. No sand-restricted assemblage was collected on the outer shelf. However, polychaetes Eunice vittata, Filograna implexa, and Chloeia viridis are characteristic of hard bottom or coralline rubble habitats and are presumed to inhabit the hard bank outcrops near the shelf break.

Table 6.21 Proposed infaunal assemblages associated with habitats on the intermediate continental shelf (20-60m) in the Tuscaloosa Trend study area.

MUD (<20% Sand)	SANDY MUD (20-50% Sand)	MUDDY SAND (50-90% Sand)	SAND (>90% Sand)
Cirrophorus lyriformis (P) Nephtys incisa (P) Notomastus daueri (P)			Metharpinia floridana (C) Kalliapseudes sp. A (C) Ampelisca agassizi (C) Aricidea wassi (P) Prionospio cristata (P) Mooreonuphis pallidula (P) Magelona sp. F (P)
← Ninoe nigripes (P) Asychis elongata (P) Sigambra tentaculata (P) →	← Tauberia gracilis (P) Aglaophamus verrilli (P) Apseudes sp. A (C) Apseudes sp. B (C) Ampelisca verrilli (C) →	← Goniada littorea (P) Typosyllis hyalina (P) Synelmis albini (P) Spiophanes bombyx (P) Glottidia pyriamidata (B) Aspidosiphon albus (S) Apanthura magnifica (C) →	
←	Prionospio cirrifera (P) Nereis micromma (P) Paraprionospio pinnata (P) Cossura soyeri (P) Lumbrineris crassidentata (P) Lumbrineris verrilli (P)	→	
	←	Golfingia trichocephala (S) Armandia maculata (P) Tharyx annulosus (P) Aricidea sp. C (P)	→
←	Mediomastus californiensis		→

A = Archiannelid
B = Branchiopod
C = Crustacean
Ce = Cephalochordate
E = Echinoderm
H = Hemichordate
M = Mollusc
N = Nemertean
P = Polychaete
Ph = Phoronid
S = Sipunculid

Table 6.22 Proposed infaunal assemblages associated with habitats on the outer continental shelf (60-120 m) in the Tuscaloosa Trend study area.

MUD (<20% Sand)	SANDY MUD (20-50% Sand)	MUDDY SAND (50-90% Sand)	SAND (>90% Sand)
Cirrophorus lyriformis (P)			*Aglaophamus verrilli* (P)
Notomastus latericeus (P)			*Sphaerosyllis pirifera* (P)
Nereis grayi (P)		←	*Mooreonuphis pallidula* (P) →
Nephtys incisa (P)		←	*Ampharete americana* (P) →
			Horolanthura vipex (C)
			Apanthura magnifica (C)
			Synelmis albini (P)
←	*Ninoe nigripes* (P)		**Eunice vittata* (P)
←	*Prionospio cirrifera* (P) →		**Filograna implexa* (P)
←	*Ceratocephale oculata* (P)		**Chloeia viridis* (P)
	← *Tauberia gracilis* (P) →		

*Characteristic of hard bottom/rubble habitat (coral and/or shell)

A = Archiannelid
B = Branchiopod
C = Crustacean
Ce = Cephalochordate
E = Echinoderm
H = Hemichordate
M = Mollusc
N = Nemertean
P = Polychaete
Ph = Phoronid
S = Sipunculid

Macroepifauna

Major investigations on the macroepifauna of the Tuscaloosa Trend OCS region include: Parker's (1956; 1960) surveys of molluscan fauna off southeast Louisiana which resulted in defining faunal assemblages to characterize habitat types; analysis of benthic macroepifaunal organisms collected for the MAFLA OCS program by Alexander et al. (1977) and Dames and Moore (1979); and dredge and trawl collections of benthic fauna offshore of Mississippi and Louisiana barrier islands by Franks et al. (1972). However, the most detailed account of benthic macroinvertebrates of the northern Gulf was based on extensive collections by Defenbaugh (1976). He identified twelve faunal assemblages for the northern Gulf, five of which fall within the Tuscaloosa Trend study area (Figure 6.18). The following habitat assemblages reflect components of the aforementioned studies, especially Parker (1960) and Defenbaugh (1976).

The pro-delta fan assemblage is restricted to the area adjacent to the Mississippi River Delta. The bottom sediments are composed of soft mud. Depths range from 4-20 m with bottom salinities from 30-36 $^{o}/oo$. The most predominant taxa include the sea pansy Renilla mulleri; molluscs Nassarius acutus, Nuculana concentrica; shrimp Penaeus aztecus, P. setiferus, Trachypeneus similis; and crabs Portunus spp., Callinectes similis (Table 6.23).

The pro-delta sound assemblage includes the inshore and nearshore OCS from the Chandeleur Islands to the eastward boundary of the study area. These sediments are composed primarily of soft mud mixed with sand or shell hash; however, sediments are sandy east of Mobile Bay. Depths range from 4-20 m and bottom salinities range from 24-36 $^{o}/oo$. Equivalent to Parker's (1960) open sound habitat, this assemblage is composed of such taxa as sea pansy Renilla mulleri; baby's ear gastropod Sinum perspectivum; bivalves Noetia ponderosa and Chione clenchi; brown shrimp Penaeus aztecus; purse crabs Persephone spp.; shame-face crabs Calappa sulcata and Hepatus epheliticus; and echinoderms Hemipholis elongata and Mellita quinquiesperforata (Table 6.23).

The intermediate shelf assemblage is a relatively broad area seaward of the pro-delta sound assemblage. Sediments are composed of muddy sands or sand. The depth ranges from 20-60 m and bottom salinities are about 36 $^{o}/oo$. This habitat contains the following taxa representative of the faunal assemblage: gastropods Strombus, Murex, Busycon and Fasciolaria; bivalves Argopecten, Tellina, and Pitar; shrimps Penaeus and Sicyonia; crabs Calappa, Portunus, Anasimus, Libinia, and Parthenope; echinoids Encope and Stylocidaris; and starfish Luidia and Astropecten (Table 6.23).

The outer shelf assemblage lies seaward of the intermediate shelf assemblage. These sediments are typically composed of soft mud. Depths range from 60-120 m and bottom salinity is around 36 $^{o}/oo$. This is equivalent to Parker's (1960) outer shelf habitat and contains taxa characteristic of deep water, mud environments, especially echinoderms and crabs. Representatives of this assemblage include gastropods Turritella exoleta and Polystira albida; bivalves Anadara spp. and Verticordia ornata; crabs Munida, Raninoides and Myropsis; echinoids Echinocardium and Brissopsis; and starfish Astropecten and Cheiraster (Table 6.23).

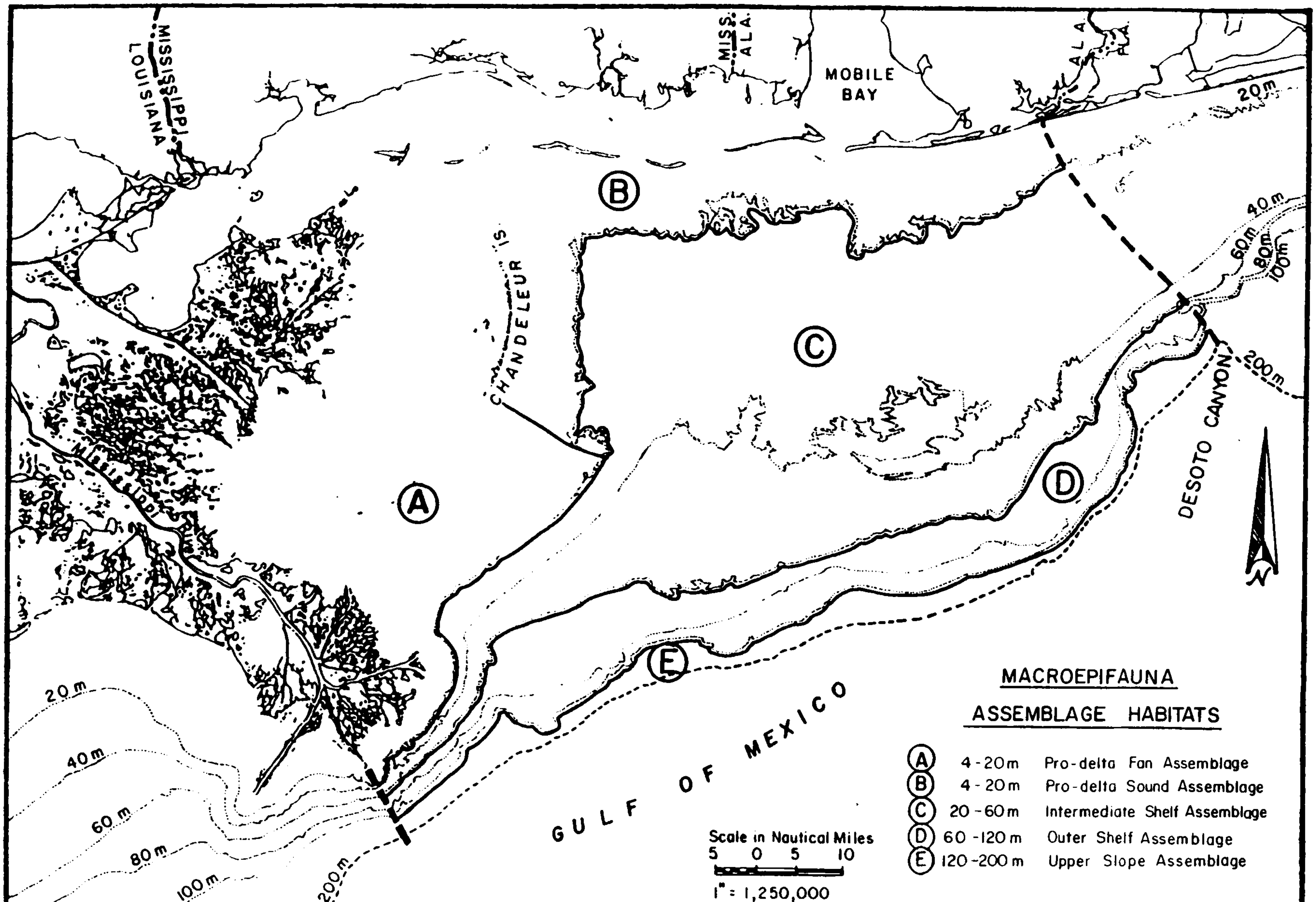


Figure 6.18 Macroepifauna assemblage habitats on the Tuscaloosa Trend continental shelf. (modified from Defenbaugh, 1976)

Table 6.23 Macroepifaunal assemblage of the northern Gulf of Mexico as they pertain to the Tuscaloosa Trend study area. (After Defenbaugh, 1976)

PRO-DELTA FAN ASSEMBLAGE (4-20m)

Cnidaria
- *Renilla mulleri*

Gastropoda
- *Cantharus cancellarius*
- *Nassarius acutus*

Bivalvia
- *Nuculana concentrica*
- *Macoma tageliformis*
- *Abra lioica*

Natantia
- *Penaeus aztecus*
- *Penaeus setiferus*
- *Sicyonia dorsalis*
- *Trachypeneus similis*

Reptantia
- *Persephona crinata*
- *Callinectes similis*
- *Portunus gibbesi*
- *Portunus spinimanus*

Stomatopoda
- *Squilla empusa*

PRO-DELTA SOUND ASSEMBLAGE (4-20m)

Cnidaria
- *Renilla mulleri*
- *Leptogorgia virgulata*

Gastropoda
- *Sinum perspectivum*
- *Cantharus cancellarius*

Bivalvia
- *Noetia ponderosa*
- *Chione clenchi*

Natantia
- *Penaeus aztecus*
- *Sicyonia dorsalis*
- *Trachypeneus similis*

Reptantia
- *Pagurus pollicaris*
- *Persephona aquilonaris*
- *Persephona crinata*
- *Calappa sulcata*
- *Hepatus epheliticus*
- *Callinectes similis*
- *Portunus gibbesi*

Stomatopoda
- *Squilla empusa*

Echinodermata
- *Luidia clathrata*
- *Hemipholis elongata*
- *Ophiolepis elegans*
- *Mellita quinquiesperforata*

INTERMEDIATE SHELF ASSEMBLAGE (20-60m)

Annelida
- *Diopatra cuprea*

Gastropoda
- *Strombus alatus*
- *Distorsio clathrata*
- *Tonna galea*
- *Murex fulvescens*
- *Busycon contrarium*
- *Fasciolaria l. hunteri*
- *Conus austini*
- *Polystira albida*
- *Pleurobranchaea hedgpethi*

Bivalvia
- *Amusium papyraceus*
- *Argopecten gibbus*
- *Tellina nitens*
- *Tellina squamifera*
- *Pitar cordata*
- *Gouldia cerina*
- *Chione clenchi*

Reptantia
- *Petrochirus diogenes*
- *Persephona crinata*
- *Calappa sulcata*
- *Hepatus epheliticus*
- *Callinectes similis*
- *Portunus gibbesi*
- *Portunus spinicarpus*
- *Portunus spinimanus*
- *Anasimus latus*
- *Libinia emarginata*
- *Parthenope serrata*

Stomatopoda
- *Squilla chydaea*
- *Squilla empusa*

Echinodermata
- *Luidia alternata*
- *Luidia clathrata*
- *Astropecten duplicatus*
- *Ophiolepis elegans*
- *Clypeaster ravenelli*

Table 6.23- (Continued)

INTERMEDIATE SHELF ASSEMBLAGE (Continued)

Natantia
- Penaeus aztecus
- Penaeus setiferus
- Sicyonia brevirostris
- Sicyonia dorsalis
- Trachypeneus similis

Echinodermata
- Encope michelini
- Echinaster sp.
- Stylocidaris affinis

OUTER SHELF ASSEMBLAGE (60-120m)

Gastropoda
- Turritella exoleta
- Distorsio c. macgintyi
- Polystira albida

Bivalvia
- Anadara baughmani
- Anadara floridana
- Amusium papyraceus
- Argopecten gibbus
- Pitar cordatus
- Verticordia ornata

Natantia
- Parapenaeus longirostris
- Penaeus aztecus
- Sicyonia brevirostris
- Trachypeneus similis

Reptantia
- Munida forceps
- Raninoides lousianensis
- Myropsis quinquespinosa
- Calappa springeri
- Calappa sulcata
- Portunus spinicarpus
- Anasimus latus
- Leiolambrus nitidus

Stomatopoda
- Squilla chydaea

Echinodermata
- Anthenoides piercei
- Luidia elegans
- Astropecten nitidus
- Cheiraster echinulatus
- Echinocardium fulvescens
- Brissopsis alta
- Brissopsis atlantica

UPPER SLOPE ASSEMBLAGE (120-200m)

Cnidaria
- Anemone C

Annelida
- Protula tubularia

Gastropoda
- Sconsia striata
- Murex beauii
- Polystira albida

Bivalvia
- Yoldia solenoides
- Limopsis sulcata
- Cyclopecten nanus
- Cyclocardia armilla
- Nemocardium perambile

Natantia
- Parapenaeus longirostris
- Solenocera vioscai
- Hymenopenaeus tropicalis

Reptantia
- Munida forceps
- Raninoides lousianensis
- Myropsis quinquespinosa
- Iliacantha subglobosa
- Pyromaia arachna
- Acanthocarpus alexandri
- Calappa sulcata
- Portunus spinicarpus
- Thalassoplax angusta
- Anasimus latus
- Stenocionops spinimana
- Parthenope agona

Stomatopoda
- Squilla chydaea

Echinodermata
- Anthenoides piercei
- Luidia elegans
- Astropecten nitidus
- Cheiraster echinulatus
- Echinocarium fulvescens
- Brissopsis alta
- Brissopsis atlantica

The upper slope assemblage, which may appear transitional to true slope assemblages, occupies the depth range from 120-200 m in typically soft mud sediments with bottom salinities approximately 36 $^{o}/oo$. This assemblage is equivalent to the (1960) upper continental slope habitat described by Parker (1960). The outer shelf and upper slope assemblages share many taxa, especially echinoderms. Characteristic taxa of the upper slope include bivalves Yoldia, Cyclopecten and Nemocardium and crabs Acanthocarpus, Thalassoplax and Pyromaia (Table 6.23).

Artificial Reef Communities

Seven liberty ship hulls were sunk offshore of Mississippi (2) and Alabama (5) between 1974 and 1976 in efforts to create sports fishing habitats at water depths of approximately 24 m (see Figure 7.7). Colonization of ichthyofauna and invertebrate epifauna at Anderson, Edwards, Sparkman, and Wallace Reefs (Alabama) and Waterhouse Reef (Mississippi) was monitored by SCUBA divers for 28 months (Crozier, 1977; de Mond, 1978; Lukens, 1981; Barnes, 1982). Epifaunal colonizers included barnacles, serpulid polychaetes (Hydroides spp. and Pomatocerus americanus), hydroids, and extensive mats of encrusting sponges and bryzoans. Extreme seasonal variability reported for the invertebrate community is probably due to seasonal water temperature fluctuations which is reflected by the cyclic recruitment of tropical and subtropical species in the northern Gulf of Mexico (Crozier, 1977; de Mond, 1978; Barnes, 1982).

Of the 55 and 60 fish species recorded at Anderson and Waterhouse Reefs, respectively, over one-half were considered primary reef fishes and potential residents. Trophic positions of resident and incidental artifical reef fishes found in the Tuscaloosa Trend study area are presented in Table 6.24. Dominant sports fish on nearshore reefs include Lutjanus campechanus (red snapper) and Epinephelus nigritus (Warsaw grouper), while those on the outermost reefs include L. campechanus, Seriola dumerili (greater amberjack), and Mycteroperca bonaci (black grouper).

Rates of recruitment of all fish species observed was approximately two species per month in Mississippi waters (Lukens, 1981) and five species per month in Alabama waters (Crozier, 1977). Artificial reefs in Alabama apparently exhibit higher rates of recruitment due to their proximity to other recruitment areas (e.g., Florida reefs), deeper water, and location on a sandy substrate. Artificial reefs in Mississippi are located on a substrate of mud and silt.

6.5 ESTUARINE AND MARINE WILDLIFE AND THREATENED AND ENDANGERED SPECIES

The Endangered Species Act of 1973 set the national policy with regard to species which are in peril of extinction. The policy and legislation was designed to protect and conserve endangered and threatened species and the ecosystem upon which they depend. The agencies responsible for administering the act are the U.S. Fish and Wildlife Service and the National Marine Fisheries Service; however, all federal agencies are required to consult with the administering agencies prior to approving actions which might jeopardize the

Table 6.24 Trophic positions of resident and incidental artificial reef fishes found in the Tuscaloosa Trend study area. (Source: Crozier, 1977)

	RESIDENTS	INCIDENTALS
Planktivores	Decapturus punctatus	Pristipomoides aquilonaris
	Equetus acuminatus	Etrumeus teres
	Apogon pseudomaculatus	
	Chromis enchrysurus	
	Chromis scotti	
Algae-detritus Feeders	Holacanthus spp. (juv.)	Eupomacentrus partitus
	Blennius marmoreus	Aluterus schoepfi
	Acanthurus chirurgus	Hypleurochilus geminatus
	Lythrypnus nesiotes	Holacanthus tricolor (juv.)
	Coryphopterus punctipectophorus	
	Gobiosoma longipala	
Sessile Animal Feeders	Eupomacentrus variabilis	Chaetodon sedentarius
	Chaetodipterus faber	Balistes capriscus
	Holacanthus spp.	
	Archosargus probatocephalus	
Omnivores	Halichoeres bivittatus	Pomacanthus arcuatus
	Lagodon rhomboides	
	Orthopristis chrysoptera	
	Centropristis philadelphica	
	Centropristis ocyurus	
	Serranus subligarius	
Generalized Carnivores	Lutjanus campechanus	Echeneis naucrates
	Lutjanus griseus	Epinephelus nigritus
	Lutjanus synagris	Epinephelus nineatus
	Rhomboplites aurorubens	Brotula barbata
	Haemulon aurolineatum	Scorpaena calcarata
	Scorpaena brasiliensis	Rachycentron canadum
	Rypticus saponaceous	
	Diplectrum bivittatum	
	Diplectrum formosum	
Piscivores	Mycteroperca bonaci	Mycteroperca phenax
	Seriola dumerili	Seriola rivoliana
		Sphyraena barracuda
		Caranx bartholomaei
		Caranx chrysos
		Elagatis bipinnulata
		Euthynnus alletteratus

continued existence of endangered or threatened species or their critical habitat.

The Marine Mammal Protection Act of 1972 specifically addresses marine mammals. This Act prohibits the hunting, capture, killing, or harassment of any marine mammal unless exempted under provisions in the Act. The agencies charged with administering this Act are the Department of Commerce, National Marine Fisheries Service (responsible for cetaceans and pinnipeds except walruses) and the Department of the Interior, Fish and Wildlife Service (responsible for walruses, sea otters, manatees, and dugongs). The Department of the Interior is also responsible, under this Act, for determining whether outer continental shelf oil and gas activities will threaten marine mammal populations. Threatened and endangered species found in the Tuscaloosa Trend study area are listed in Table 6.25.

6.5.1 BIRDS

Several species of marine birds, such as boobies, petrels, shearwaters, gannets, etc. occur in the Tuscaloosa Trend continental shelf region (MMS, 1983). Marine birds primarily feed and roost offshore, and come onshore only for nesting or when storms force them ashore. Generally, the largest concentrations of marine birds are found in upwelling areas near the continental slope edge and in areas of high productivity (Fritts et al., 1983).Population and distribution data for marine birds are limited.

Pelican

The brown pelican (Pelecanus occidentalis carolinensis) is a common shorebird in the study area. It is a summer resident, sometimes occurring in large numbers. It prefers secluded locations (such as delta and offshore islands) for colonies. Gilliard Island, a newly created dredge spoil island in Mobile Bay, Alabama, has had nesting pairs of brown pelicans since 1983 (Paul Bradley, U.S. Army Corps of Engineers, Mobile, personal communication).

Brown pelican populations have been stressed by the biomagnification of pesticides from island agricultural sources transported by riverine systems that enter the food chain and accumulate at the highest trophic level--the pelican. As a result, eggs are often thin-shelled and broken by parental movements on the nest. Human disturbances cause the adults to flee the nest, exposing the eggs and young to extreme temperatures and predation by other birds.

6.5.2 REPTILES

Sea turtles live in the open ocean and normally nest in sand on open beaches. They range in size from two to five feet and may be found in coastal waters feeding on seagrasses and invertebrates. There has been a steady decline in sea turtle populations due to excessive predation of eggs and young, disturbance of nesting habitat, and incidental drowning in fishing nets.

Table 6.25 Threatened and endangered species found within the Tuscaloosa Trend study area. (Sources: National Fish and Wildlife Laboratory, 1980a; Schmidly, 1981; Mettee and O'Neil, 1982)

Species Name	Common Name	Occurrence
Balaenoptera physalus	Fin whale	Off Louisiana
Megaptera novaeangliae	Humpback whale	Off Louisiana
Balaenoptera borealis	Sei whale	Off Louisiana
Physeter catodon	Sperm whale	Off Louisiana, Mississippi, Alabama
Trichechus manatus	West Indian manatee	Mississippi, Alabama
Chelonia m. mydas	Atlantic green turtle	Off Louisiana, Mississippi, Alabama
Eretmochelys i. imbricata	Atlantic hawksbill turtle	Off Louisiana, Mississippi, Alabama
Dermochelys c. coriacea	Atlantic leatherback turtle	Off Louisiana, Mississippi, Alabama
Lepidochelys kempi	Kemp's ridley turtle	Nesting on Chandeleur Islands
Caretta caretta	Loggerhead turtle	Nesting on Chandeleur Islands
Alligator mississippiensis	American alligator	Alabama, Mississippi, Louisiana in coastal zone
Pelecanus occidentalis carolinensis	Brown pelican	Coastal zone of Louisiana, Mississippi, Alabama
Haliaeetus leucocephalus	American bald eagle	Coastal zone of Louisiana, Mississippi, Alabama

Five species of sea turtles probably occur in the Tuscaloosa Trend continental shelf waters (O'Neil and Mettee, 1982). These include Atlantic green turtle (Chelonia m. mydas), Atlantic hawksbill turtle (Eretmochelys i. imbricata), Atlantic loggerhead turtle (Caretta c. caretta), Kemp's ridley turtle (Lepidochelys kempi), and Atlantic leatherback turtle (Dermochelys c. coriacea). All five species are included on the Federal threatened and endangered species list. Kemp's ridley turtle has been recorded from bays and sounds in the study area. The loggerhead has nested on Dauphin Island and Fort Morgan Peninsula in Alabama; Petit Bois, Horn and Ship Islands in Mississippi (Jackson and Jackson, 1970; Christmas and Waller, 1973); and Chandeleur Islands (Garofalo, 1982).

Kemp's Ridley turtle (Lepidochelys kempi) has a carapace width ranging between 50-70 cm and is one of the smallest sea turtles. This is a coastal turtle which seems to prefer shallow water. It feeds on a variety of coastal invertebrates including crabs, barnacles, gastropods, and clams (National Fish and Wildlife Laboratory, 1980). This turtle has been included on the endangered species list and is particularly vulnerable due to its coastal habitat, incidental capture in shrimp trawls, and unsuccessful reproduction due to nesting perturbations. Fuller (1978) notes that 1978 nesting data indicate as few as 400-500 sexually mature females. This is in striking contrast to the nearly 40,000 nesting turtles on one beach reported by Carr (1963).

The loggerhead sea turtle (Caretta caretta) is a medium-sized turtle, attaining a carapace length of 79 cm (Caldwell, 1959). They are found along the continental shelf in warm waters and often enter bays, lagoons, and other estuarine areas (Ernst and Barbour, 1972). They feed on submersed grasses and marine invertebrates. This species is considered threatened but their numbers are so widespread that it is uncertain how many are left. This turtle, like others, falls prey to raccoons at the nest and is taken in shrimp trawls as adults.

Alligator

The American alligator (Alligator mississippiensis) ranges throughout the coastal region of the southeastern United States from North Carolina to Texas and up the Mississippi River Valley to Oklahoma and Arkansas. Adult alligators feed on any animal small enough to be captured, including birds, snakes, turtles, fish, and small mammals. Small alligators primarily feed on crayfish, insects, and molluscs. The chief threat to the American alligator is the rapid urbanization underway in the wetlands of the southeast and the resulting destruction of alligator habitat. This species is considered endangered in Mississippi and Alabama, but only threatened in Louisiana. It has shown a rapid resurgence in number due to conservation efforts in many areas of its range and managed harvests are now being made in three Louisiana parishes (National Fish and Wildlife Laboratory, 1980b).

6.5.3 MAMMALS

With the exception of the Atlantic bottlenosed dolphin (Tursiops truncatus) and spotted dolphin (Stenella plagiodon), most marine mammals within the Tuscaloosa Trend shelf waters are considered threatened or endangered. Aerial surveys and tagging programs of bottlenosed dolphin populations have recently been conducted in Mississippi Sound by NMFS (Dr. M. Solangi, Marine Life, Gulfport, MS personal communication). The ecology and population dynamics of these species is poorly known; therefore, a thorough management program is lacking. They are accidentally taken in fish nets and drowned.

The saddleback dolphin (Delphinus delphis) generally measure from 2.3 to 2.6 m. Saddlebacks are distributed widely in temperate and tropical wates of all oceans. These dolphins prefer offshore habitats, particularly along the continental slope in association with topographic features (Schmidly, 1981). Sitings of this dolphin occurred along the slope near the DeSoto Canyon, adjacent to the study area.

The fin whale (Balaenoptera physalus) reaches a length of 20-24 m, with males slightly longer than females of the same age. They are cosmopolitan and occur in all oceans. In the Gulf of Mexico they have been stranded along the coast of Louisiana. These whales are not numerous but are still widely hunted. In the North Atlantic they feed mostly on pelagic crustaceans and herring. They come close to shore in pursuit of fish, which may account for their frequent strandings. Schmidly (1981) reported sightings off the Louisiana coast in winter, summer, and fall, which may suggest an isolated population.

Bryde's whale (Balaenoptera edeni) is limited to tropical and temperate waters between 40°N and 40°S. These whales closely resemble sei whales in appearance and also reach a maximum length of 14 m. They feed in relatively warm water, usually on small schooling fish such as sardines, mackerel, and clupiid fishes, and pelagic crustaceans. Their distribution within the Gulf of Mexico is noted from strandings along west Florida and southeast Louisiana coasts (i.e., Chandeleur region of Louisiana) (Schmidly, 1981).

The humpback whales (Megaptera novaeangliae) reach lengths of about 16 m. They occur in all oceans and are coastal species, a fact accounting for their long history of being exploited by hunters. Those found in the Gulf probably represent part of the stock from the Bahamian Archipelago. Humpbacks commonly approach trawlers, probably feeding on fish escaping the net. They also frequently approach stationary ships. Schmidly (1981) reports sightings of humpback whales south of Mobile Bay near the 200 m isobath.

The sei whale (Balaenoptera borealis) is found in all oceans but is rare in tropical and polar seas. The females reach sexual maturity between 7 and 8 years of age and reach 13-14 m in length. In the North Atlantic they are known to feed on copepods and euphausiids and some small schooling fish. They are widely distributed in nearshore and offshore waters. In the Gulf they have been reported from strandings from Gulfport, Mississippi, and from the Chandeleur region of Louisiana.

The sperm whale (Physeter catodon) attains sizes of 15-18 m with females being much smaller than males. They occur throughout the eastern and western hemispheres typically in the temperate and tropical latitude. They were once found in great abundance in the Gulf of Mexico and supported a full-scale whaling industry. They are most frequently encountered from April through July in the Gulf. Schmidly (1981) suggests the possibility of a separate population in the Gulf. Sightings within the study area include one capture near the Mississippi River Delta. They feed on a variety of pelagic fish and invertebrates. These whales are among the longest and deepest diving of all whales (up to 90 minutes and 1100 meters).

The dwarf sperm whales (Kogia simus) are similar in appearance to pygmy sperm whales. Their total length ranges from 2.1 to 2.7 m. Their range overlaps that of the pygmy sperm whale, but is thought to inhabit primarily deep water. Along the western Atlantic they are found from Virginia to the Lesser Antilles. Within the study area a dwarf sperm whale was reported stranded at Biloxi, Mississippi (Schmidly, 1981).

Ziphius cavirostris, the goosebeaked whale, is a cosmopolitan species extending from tropic to subpolar waters in all oceans. These whales, which measure 5.5 to 8.5 m, are generally found in the eastern Gulf of Mexico. The only stranding report from the study area is from the Chandeleur Islands (Schmidly, 1981). These whales feed primarily on squid (Caldwell and Caldwell, 1974).

The short-finned pilot whale (Globicephala macrorhyncha) is probably present in the Gulf throughout the year, but is rare in winter. Linsly (1970) reported a specimen of this species washed onto the beach at Alabama Point in September, 1962.

The West Indian manatee (Trichechus manatus) occupies spring-fed, warm rivers along the west coast of Florida in the winter. During the summer they disperse and move along the Gulf Coast, occasionally as far west as Louisiana and Mississippi (Gunter, 1954; Caldwell and Caldwell, 1973; Gunter and Corcoran, 1981). Emergent and floating plants and even some fish are consumed in large quantities by these docile mammals. Water temperature below 20°C stimulates migration into warm water. Although no sitings are reported in the Tuscaloosa Trend study area prior to 1970, sitings in Breton Sound, Mississippi Sound near Gulfport, Biloxi and Pascagoula, and on Ship Island are summarized by Powell and Rathbun (1984).

Specimens of California sea lion (Zalophus californianus) have been recorded from offshore Alabama and Louisiana. In 1966, an adult female was seen resting on a channel buoy south of Mobile Bay. Sightings were made of this same female for a period of 18 days during June (Gunter, 1968). This species exists in the South Atlantic and it is possible that individuals might wander into the Gulf.

6.6 SUBSYSTEM INTERRELATIONSHIPS

The structure and dynamics of the Tuscaloosa Trend area ecosystem are a function of the interrelationships of three major systems: coastal marshes; estuarine waters; and the offshore area itself. The mechanisms through which these systems interact include physical transport processes such as riverine discharge, tidal and wind-driven currents, and turbulence. Exchange also occurs through biological processes such as migration and trophic interactions. The purpose of this section is to provide an overview of the interrelationships between the Tuscaloosa OCS Trend and the coastal marshes and estuaries adjacent to it. The conceptual model representation of this ecosystem presented in Chapter 2 is further discussed herein.

6.6.1 PHYSICAL PROCESSES

The principal driving force behind current patterns in the Tuscaloosa Trend study area results from an interplay between the major oceanic current systems (i.e., the Loop Current), tidal currents, wind-driven circulation, and freshwater discharges from coastal rivers (see Chapter 3.0 Physical Oceanography).

Since many species of fishes and invertebrates undergo planktonic larval development, prevailing currents and water circulation patterns are responsible for their distribution, as well as the entire planktonic community, within the coastal and offshore waters. These planktonic larvae float passively in the water column for a specific period of time until the proper environmental conditions are reached after which they develop through their respective life stages.

The current patterns within the coastal waters are influenced primarily by tidal currents through the island passes, freshwater discharge, and the prevalence of longshore currents. Vertical mixing of lighter freshwater with denser seawater generally occurs in the shallow estuaries; however, periods of low riverflow coupled with low wind conditions can result in stratified conditions. Reduced salinities, combined with the abundance of food and nutrients, make these protected inshore waters ideal nursery grounds for many estuarine-dependent species. Tidal inlets are important for the direct transfer of nutrients and biomass between coastal and offshore waters.

Currents and circulation patterns also determine the characteristics of bottom sediments through transportation of suspended particulate loads and subsequent deposition of these suspended solids as current velocity decreases. Since many faunal assemblages are associated with sediments (e.g., benthic communities), the distribution of sediment types is an important determinant of habitat suitability. Some species' larvae (e.g., oysters) actually sample the bottom sediments and will settle out only when the appropriate substrate for attachment is found.

Inshore benthic communities are subject to wide fluctuations in physical conditions. As a result, species which make up these communities are generally opportunistic and must maintain their resilient populations by having short life cycles and large reproductive capacities. Some offshore, deep water benthic species undergo direct development through benthic larval forms. As a result they are more restricted to their habitat and consequently more susceptible to habitat perturbations.

Other physical parameters such as solar radiation, freshwater discharge and turbidity influence both phytoplankton and zooplankton populations by reducing the food supply (lower photosynthetic activity) and diluting the food supply (increased inorganic particles). However, dissolved inorganic nutrients from terrigenous sources increase primary production in areas adjacent to high turbidity zones. This is reflected in the high primary productivity levels offshore of the Mississippi River Delta. This high primary production results in an increase in secondary production of marine zooplankton.

6.6.2 MIGRATORY PATTERNS

Four general types of life cycles are apparent in the study area, based on the degree of dependence of the particular taxon on the estuarine environment. These are (in order of decreasing estuarine dependence) estuarine, estuarine-dependent, estuarine-related, and estuarine-independent life cycles.

Estuarine taxa spend their entire life cycles in the estuaries. The postlarvae drift and swim to the marshes fringing the open water, where they spend their first months. The amount of marsh/estuarine habitat available to the postlarvae and juveniles of the various nekton taxa depends on the salinity and temperature regimes in the estuaries and the response of the taxa to these regulators.

Estuarine-dependent fishes and invertebrates exhibit seasonal migratory patterns during their life cycle. These include many commercially important species such as blue crab, penaeid shrimp, and industrial bottomfish. Their life cycle is typically composed of two phases: (1) an offshore spawning and larval development phase and (2) an estuarine growth phase for juveniles and subadults. The critical link between these two phases is the migration into and out of the estuaries, which provide the shelter, food, and lower salinities necessary for larval development. The typical estuarine phase of the life cycle begins as the eggs, larvae or post-larvae are transported through the island passes by prevailing currents and tides during the late winter and early spring (Figure 6.19). The larvae take refuge in the marsh grasses and feed on the abundant detritus and meiofaunal organisms. They grow rapidly and after a few months begin their offshore migration to the spawning grounds, again through the island passes. The timing of the arrival of larvae in the estuaries, as well as their developmental phase, is a species-dependent variable and is influenced by estuarine water temperature and salinity. Table 6.26 summarizes the spawning and migration characteristics of a variety of estuarine dependent species, many of which are exploited commercially during their seasonal migration.

In order to enter the shelf, the estuarine-dependent species utilize the various passes, while different passes appear to be more important for different species. Two areas seem to stand out in this connection: the mouth of Mobile Bay and the Petit Bois-Dauphin Island channel, on the one hand, and the passes between the Chandeleur Islands and the Mississippi Delta marshes, on the other. Once on the continental shelf, many of the estuarine-dependent species appear to display highest densities near the passes and in less than 20 m of water. This group includes the following species: *Arius felis*, *Archosargus probatocephalus*, *Menticirrhus americanus*, *Pogonias cromis*, *Sciaenops ocellatus*, and *Penaeus setiferus*. Two species (*Brevoortia patronus* and *Mugil cephalus*) become pelagic and disappear from the bottom fishery almost as soon as they arrive at the shelf. Of the remaining estuarine-dependent species, *Leiostomus xanthurus*, *Micropogonias undulatus*, and to some extent, *Penaeus aztecus* and *Cynoscion arenarius*, develop dense populations beyond 20 m depth. There appears to be a major area of cold weather concentration of most of these species at a depth of 20-40 m southeast of Mobile Bay. Some of the species which travel seaward near the eastern flank of the Mississippi Delta marshes appear to concentrate in cold weather in waters deeper than 60 m.

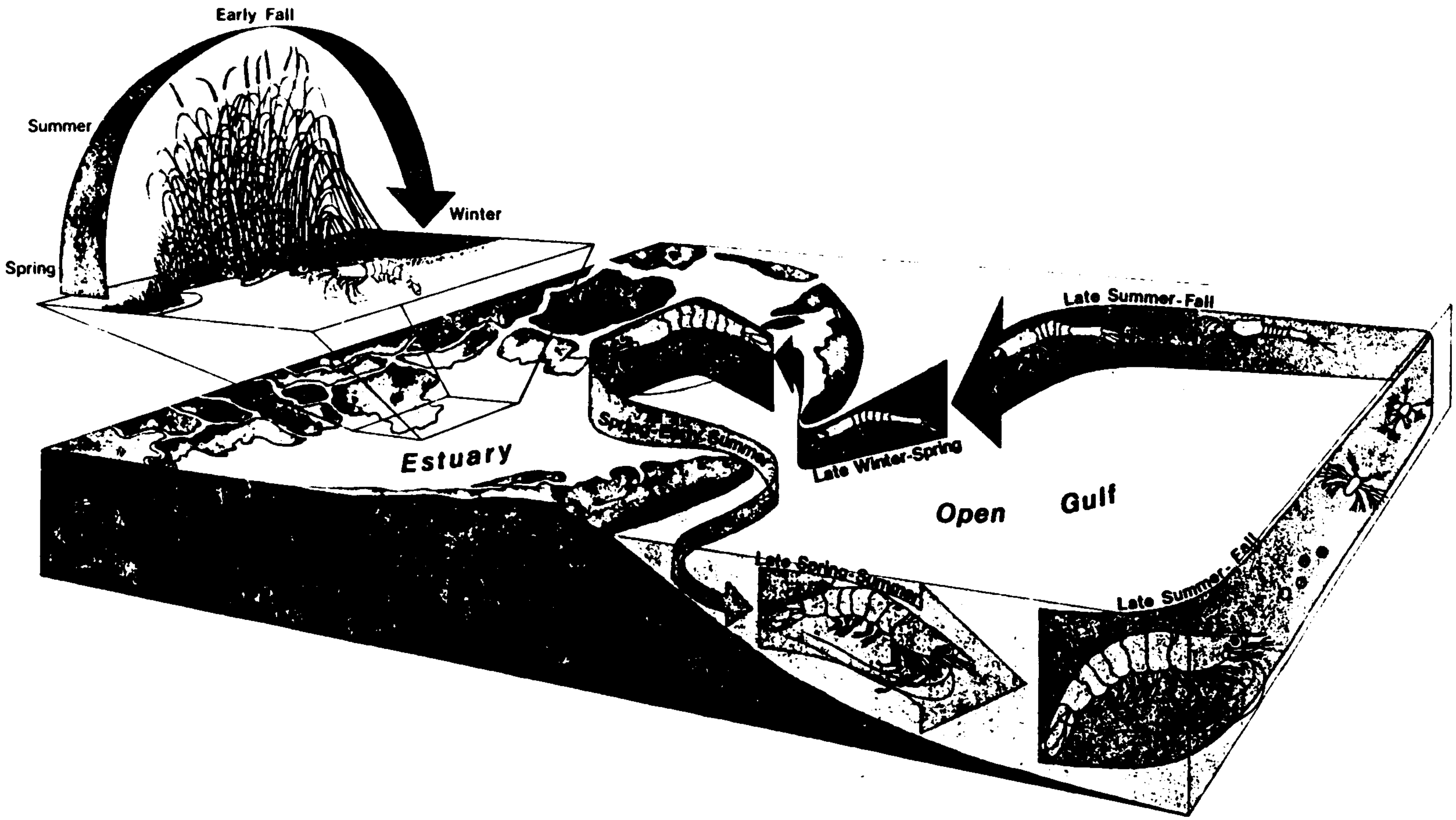


Figure 6.19 Sketch of brown shrimp seasonal movements between the Gulf and estuaries. Brown shrimp occurrence in marsh nursery areas is simultaneous with maximum production of food from adjoining marshes (from Gosselink 1980).

Table 6.26 Summary of spawning and migration characteristics of estuarine dependent species in the Tuscaloosa Trend study area.

Species	Common Name	Spawns	Enter Estuaries as:	Larvae Peaks	Migration	Use
Penaeus aztecus	brown shrimp	Offshore	Postlarvae	March-April	Offshore-May/June	Shellfish
Penaeus setiferus	white shrimp	Nearshore	Postlarvae	May-June	Offshore-August/September	Shellfish
Penaeus duorarum	pink shrimp	Offshore	Postlarvae	July	Remain in high salinity	Shellfish
Callinectes sapidus	blue crab	Near islands	Megalopa	----	Near barrier islands	Shellfish
Leiostomus xanthurus	spot	Offshore	Postlarvae	January-April	2nd year	Commercial
Menticirrhus americanus	kingfish	Offshore	Eggs and larvae	----	----	Commercial
Menticirrhus littoralis	kingfish	Offshore	Eggs and larvae	----	----	Commercial
Menticirrhus focaliger	kingfish	Offshore	Eggs and larvae	----	----	Commercial
Micropogonias undulatus	croaker	Offshore	Larvae	November-December	Offshore-late spring	Commercial/Sport
Pogonias cromis	black drum	Tidal passes	Larvae	February-April	Offshore-spring/fall	Sport
Sciaenops ocellatus	red drum	Near islands	Larvae	September-November	3rd year	Sport
Cynoscion arenarius	sand seatrout	Offshore	Postlarvae	April-September	----	Sport/Commercial
Cynoscion nebulosus	spotted seatrout	Nearshore	Larvae	Summer	Remains in estuary	Sport/Commercial
Mugil cephalus	striped mullet	Offshore	Postlarvae	November-May	3rd year	Sport/Commercial
Archosargus probatocephalus	sheepshead	Nearshore	Larvae	March-May	Late Fall	Sport/Commercial
Paralichthys lethostigma	flounder	Offshore	Postlarvae	February-April	Late Fall	Sport
Lutjanus campechanus	red snapper	Offshore	Juveniles	June-August	Late Fall	Sport/Commercial
Brevoortia patronus	menhaden	Offshore	Larvae	October-April	April-October	Commercial

Adult brown shrimp (Penaeus aztecus) spawn offshore from mid-November through April in water 30-120 m deep. Eggs develop to postlarvae stage in offshore waters. Kutkuhn (1966) showed that postlarvae may spend considerable time offshore before they move inshore. These postlarvae are first to enter estuaries in the spring, arriving as early as February, but with peak concentrations occurring during March and April (Christmas and Van Devender, 1981). Christmas et al. (1976) documented the movement of postlarvae through the tidal passes into shallow estuaries in one or two tidal cycles. Most movement occurs near the surface at night (Benson, 1982). Juvenile shrimp begin migrating to deeper water beginning in May-June depending on temperature and salinity regimes. Most movement is during ebb tide and in deeper areas (e.g., navigational channels). Subadults are commercially harvested migrating back to the open Gulf. Peak commercial shrimp catches during the day are along the bottom while those at night are near the surface.

Adult white shrimp (Penaeus setiferus) spawn offshore from March through October in waters generally less than 10 m deep, but may range from 8 to 30 m deep. Demersal eggs which hatch into larvae are found throughout the water column (Subrahmanyam, 1971). The first postlarvae begin entering the estuary through the tidal passes in May-June during flood tides. As benthic feeders, postlarvae move into shallow muddy bottom areas of the estuary. Within the nursery areas larger individuals tend to congregate in the lower end of estuaries while smaller individuals prefer the upper regions (Perez-Farfante, 1969). After two to four months in nursery areas, subadults begin moving into deeper estuarine areas where they become available to the shrimp fishery. White shrimp tolerate greater ranges of temperature and salinity than brown shrimp and generally remain in estuaries longer before migrating to deeper water offshore. (Dr. Ed Klima, National Marine Fisheries Service, Galveston, Texas; personal communication.)

Adult pink shrimp (Penaeus duorarum) spawn offshore from May through November at depths between 4 and 52 m. Their pelagic eggs pass through a series of molts to the postlarval stage. The postlarvae begin entering the estuaries in July-August. Heaviest concentrations of pink shrimp occur in seagrass beds north of barrier islands (Christmas and Van Devender, 1981). This species prefers firm sand or mud bottoms and higher salinity. Juvenile pink shrimp are nocturnal, migrating offshore near the surface from April-September during ebbtide (Russell, 1965). Because of its preference for firm substrate, P. duorarum is more restricted in distribution than other commercial shrimp species.

Blue crabs (Callinectes sapidus) mate from March through November in higher salinity waters outside the estuary. The female generally spawns approximately two months after mating. Optimal salinities for hatching are between 23 and 30 $^{o}/oo$ (Sandoz and Rogers, 1944), while temperatures generally range from 19° to 29°C. Crab zoea generally remain offshore where salinities are optimal for growth and ecdysis (21 to 28 $^{o}/oo$) and are rarely found in estuarine waters (e.g., less than 21 $^{o}/oo$). Megalopae (the next larval phase) tolerate a wider salinity range (5 to 37 $^{o}/oo$), but are most abundant between 15 and 25 $^{o}/oo$ (Benson, 1982). They enter the estuaries of the Trend area through the island passes and metamorphose to the first crab (juvenile) stage. Juveniles occur in the estuarine nursery grounds throughout the year and grow at a rate of 24 to 25 mm per month (Benson, 1982). Adult crabs generally migrate into deeper, more saline waters as water temperatures drop. Some overwinter in deeper areas of the estuary, such as channels.

Menhaden (Brevoortia patronus), mullet (Mugil cephalus), spot (Leiostomus xanthurus), croaker (Micropogonias undulatus),red snapper (Lutjanus campechanus), and several species of sea trout (Cynoscion spp.) are also estuarine-dependent species. Spawning generally occurs in the nearshore Gulf, although some fishes such as menhaden and mullet may spawn considerably further offshore. Eggs hatch offshore and larvae are transported toward the estuaries by advection and turbulence, associated with the atmospheric processes, with local wind-driven currents becoming important in the nearshore area. Considering the predominantly longshore current drift in the northern Gulf of Mexico, transport processes appear to be ideal for dispersal of larvae and postlarvae across suitable estuarine systems. Once in the estuaries, their early life is similar to that of estuarine species. As they grow they migrate from the marshes into the estuaries and ultimately to the nearshore and middle continental shelf. Adult red snapper occupy deeper waters of the outer shelf in the winter and move onto the mid-shelf (16 to 37 m) during warmer months. They spawn on the mid-shelf from June to October (Benson, 1982). Young red snapper are known to enter shallow waters of Mississippi Sound and adjacent bays during the warmer months and return to the open Gulf as temperatures cool.

Estuarine-independent fishes are generally carnivorous species that move onto or along the shelf following high densities of prey organisms in the warmer months. Included among these are demersal fishes such as groupers (e.g., Epinephelus niveatus) and tilefish (Caulolatilus spp.), and ocean pelagic fishes such as billfishes (e.g., family Istiophoridae), tunas (e.g., Euthynnus spp. and Thunnus spp.), and dolphins (e.g., Coryphaena hippurus). Their entire life cycle occurs offshore. Ocean pelagic fishes follow the blue ocean waters onto the shelf (100-200 m) in spring and summer, especially near the DeSoto Canyon. Many remain around the shelf break and are sought by sport fishermen.

Several coastal pelagic fishes do not require estuarine conditions for reproduction or growth and may be considered estuarine-related. However, while species such as bluefish (Pomatomus saltatrix), mackerels (e.g., Scomberomorus cavalla), and jacks (e.g., Caranx hippos) are not estuarine-dependent, juveniles and occasionally adults of these coastal pelagic species enter estuaries to feed. Since these taxa are less tolerant of salinity changes (i.e., more stenohaline) than the euryhaline estuarine and estuarine-dependent taxa, their entry into estuaries may be restricted to periods of low river discharge and high salinities. They often migrate westward along the shelf during the warm months and return eastward to warm Florida shelf waters during winter (Bill Fable, National Marine Fisheries Service, Panama City, Florida; personal communication).

6.6.3 TROPHIC PROCESSES

The following discussion of trophic processes will include both pelagic and benthic subsystems of the Tuscaloosa Trend ecosystem depicted as a conceptual representation in Chapter 2. The pelagic subsystem (Figure 6.20) encompasses primary and secondary productivity, as well as top food chain fish production.

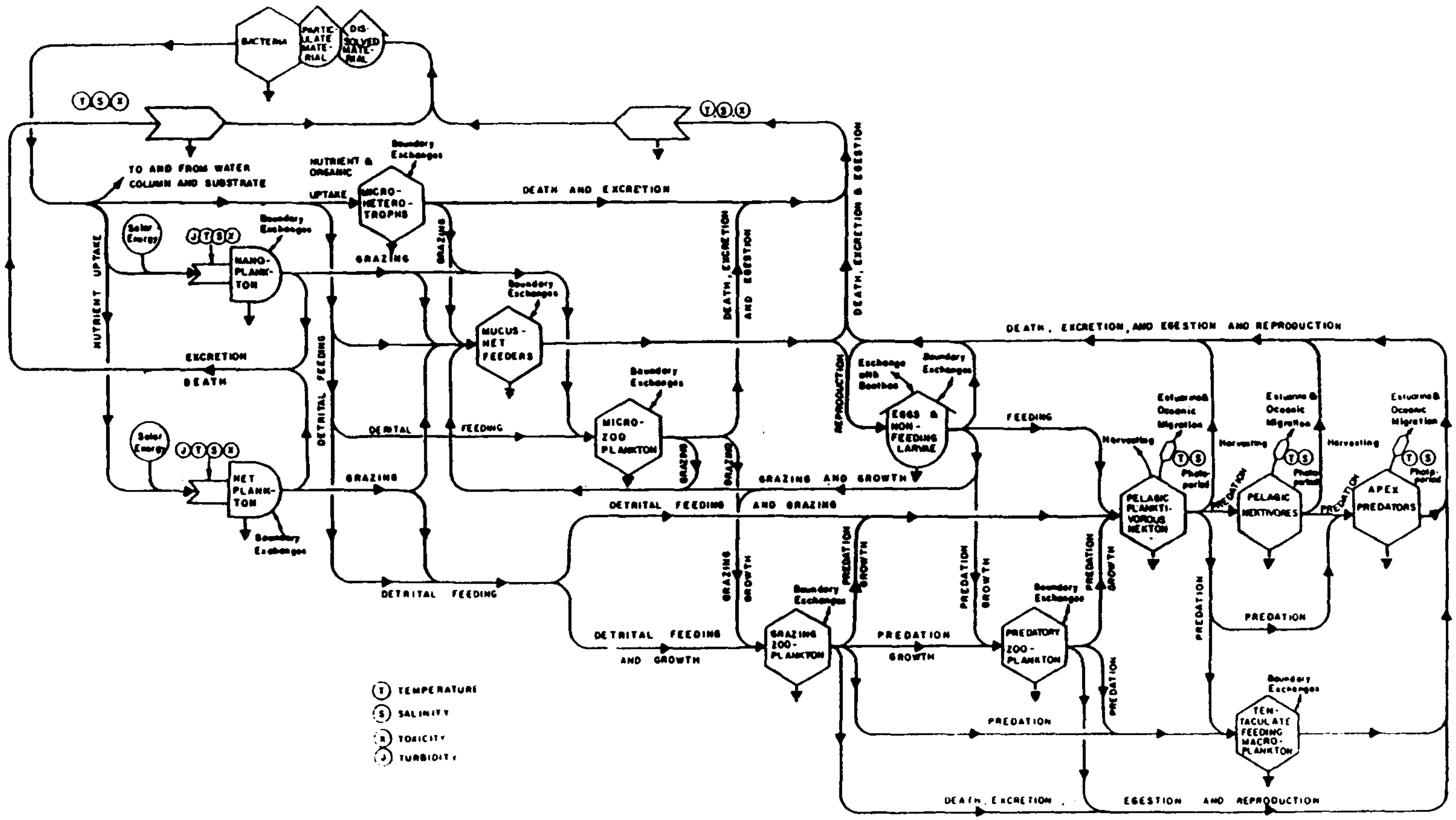


Figure 6.20 A conceptual representation of trophic processes in the pelagic subsystem of the Tuscaloosa Trend ecosystem.

Pelagic Trophic Dynamics

Major factors affecting phytoplankton production on the Tuscaloosa Trend OCS are light, temperature, concentrations of nutrients, density stratification and turbulence. Primary production is not homogeneous throughout the water column; instead, it decreases exponentially with depth, as regulated by available light (see Figure 2.16 Conceptual Ecosystem Modeling). Growth rate is not highest at highest light intensities (i.e., at or very near the surface) due to photo-inhibition. The optimum light intensity lies somewhere between the light intensity required for maintenance (compensation light) and the light incident at the sea surface. Assuming no nutrient limitation and a well-mixed upper water layer, photosynthesis will decrease in proportion to light extinction. If water column respiration is constant with depth, there will exist a depth at which primary production by a typical phytoplankton cell just equals respiration (no net gain or loss). This is the compensation depth, or the depth at which the population can just maintain itself. The compensation depth defines the bottom of the euphotic zone. Growing populations of phytoplankton can increase turbidity enough to decrease the depth of the euphotic zone, thereby decreasing overall primary production. The upper water column may or may not correspond exactly to the euphotic zone, depending on the relative positions of the pycnocline and compensation depth.

Because of mixing processes, phytoplankton become distributed below the compensation depth, leading to a second depth of interest, the critical depth. This is the depth at which total water column productivity equals total water column respiration. According to Sverdrup's critical depth hypothesis, if the critical depth is less than the depth of mixing (i.e., the depth of the pycnocline), no net production can occur in the water column and a phytoplankton bloom cannot occur. If the critical depth lies below the pycnocline, there will be net positive water column production, triggering a phytoplankton bloom. While Sverdrup's critical depth hypothesis has been questioned by many, it does provide a means of conceptualizing important production relationships in open waters of the Trend study area.

Nannophytoplankton (Figure 6.20) are those phytoplankters smaller than 20 um. They have much higher rates of metabolic activity at similar standing stocks (biomass/volume) than net phytoplankton, which are larger than 20 um, indicating that they process more material for their size (i.e., primary production is higher) than do net phytoplankton. Also, only the mucus-net feeders and microzooplankton can graze on these very small nannophytoplankton. Because of their small size, nannophytoplankton-based food webs include more "steps" or links to the top carnivores which are of greatest commercial interest. At each stage, energy is lost just sustaining life, thereby decreasing the potential fish yield at the top of the chain. Net phytoplankton, on the other hand, can be consumed directly by grazing zooplankton as well as by some planktivorous nekton such as menhaden (Brevoortia patronus), thereby greatly shortening the chain from primary producer to fish biomass.

Data from other shelf areas such as the South Texas OCS study area (Flint and Rabalais, 1981) indicate that close to the coast, in that portion of the shelf influenced by land runoff, net phytoplankton constitute a greater fraction of the primary producer component than further offshore. This is generally attributed to higher concentrations of nutrients in this nearshore region, permitting unrestricted growth over some time scales and the flourishing of species of larger size. Since nearshore phytoplankton communities exist in an environment that is more seasonally variable (temperature, salinity, nutrients), they generally show more distinct seasonal changes in standing stocks and productivity. In the nearshore Gulf, a major spring phytoplankton bloom and a small fall increase are typical, at least for the net phytoplankton.

In more nutrient-limited areas (e.g., further offshore), the average size of a typical phytoplankton taxon is smaller. Therefore, moving offshore across a typical shelf ecosystem, one would expect to observe a shift toward smaller phytoplankton, longer food chains, and less efficient fish production. No studies have been performed to determine whether these spatial trends occur in the Tuscaloosa Trend ecosystem. Although methodological problems exist which prevent extended generalization, it appears that nannophytoplankton production should predominate in nearshore waters as well as blue waters of the open ocean environments in the Trend area.

In addition to phytoplankton, free-living and attached microbes (bacteria and fungi) are part of the pelagic food web. Microbes associated with particulate material in the water column and sediments are separated from the microheterotroph compartment, which consists of free-living forms. Because of their small size, these microheterotrophs are grazed only by microzooplankton and mucus net feeders (Figure 6.20).

Microzooplankton consist mainly of ciliated protozoans that graze on free-living and particle-associated bacteria and fungi as well as on nannophytoplankton. Many ecologists feel they are a major trophic interface between phytoplankton and zooplankton because they can feed on components which are generally unavailable to grazing zooplankton (i.e., nannoplankton and microheterotrophs). The microzooplankton can then be consumed by grazing zooplankton, which are part of the food chain leading to nekton production. Besides the microzooplankton, only the mucus net feeders can graze directly on nannoplankton (Figure 6.20).

Grazing zooplankton, which include both herbivorous and omnivorous holozooplankton (i.e., true plankton), are an important link in marine food chains. They feed on net phytoplankton and microzooplankton as well as eggs and detritus, and are, in turn, consumed by predaceous zooplankton, planktivorous nekton, and tentaculate-feeding macroplankton. The grazing zooplankton are numerically dominated by small copepods.

Predatory zooplankton include both holoplankton (e.g., chaetognaths and predaceous copepods) and meroplankton (taxa that are part of the plankton community only as eggs and larvae). The temporary plankton include a benthic component and a nekton component (ichthyoplankton). They consume other zooplankton and are, in turn, consumed by planktivorous nekton and tentaculate-feeding macroplankton (Figure 6.20).

Fecal pellets egested by zooplankton constitute a substantial fraction of the autochthonous organic material reaching the seafloor. Flint and Rabalais (1981) noted a significant positive correlation between zooplankton nickel burdens and sediment nickel burdens, suggesting that zooplankton fecal pellets provide an important input to the sediment detrital pool in the South Texas OCS area.

Pelagic planktivores, which were identified above as being able to feed on net phytoplankton, are the main link to the pelagic nektivores, which comprise many of the species most important to the commercial and sport fisheries. Pelagic planktivores (e.g., menhaden) strain eggs, grazing zooplankton, and predatory zooplankton from the water, and also consume large amounts of detritus in the process. The importance of detritus in their diets is not well known. Planktivorous nekton and pelagic nektivores are both consumed by apex predators such as sharks.

There are two possible "dead ends" in the pelagic food chain, the mucus net feeders and the tentaculate-feeding macroplankton. These two compartments may not be preyed upon by nekton themselves or by compartments which serve as prey for nekton. The mucus net feeders, which filter their food from the water column by means of mucus secretions, include appendicularians and herbivorous pteropods. They are essentially functional hybrids of the microzooplankton and grazing zooplankton, consuming detritus, microheterotrophs, net and nannophytoplankton, and pelagic eggs. They are not generally considered to be suitable food for other organisms, and much of their production is probably directed to detritus. The tentaculate-feeding macroplankton, which are dominated by coelenterate medusae (e.g., Nemopsis bachei) and ctenophores (e.g., Mnemiopsis mccradyi) feed on grazing and predatory zooplankton as well as small and/or immature nekton. Most of their production may be directed toward detritus production and microbial decomposition; however, whales and especially sea turtles are thought to feed on these two compartments.

Benthic Trophic Dynamics

The detailed representation of benthic trophic processes on the Tuscaloosa Trend OCS is shown in Figure 6.21. The benthic community derives the majority of its food from dissolved and particulate organic detritus (with associated microbial decomposers) of the lower water column and substrate. While there may be some photosynthesis occurring below the pycnocline (e.g., that associated with the nepheloid layer), the food web of the lower water layers and substrate is primarily detritus-based (see Figure 2.18). Results from the South Texas OCS study (Flint and Rabalais, 1981) indicate that densities of meiofauna and macroinfauna were positively and significantly correlated with density of bacteria in sediments, while the relationship with sediment organic carbon was not as distinct. This indicates that the benthic animals utilize bacteria and not the detritus itself as a food resource. Unfortunately, similar studies of bacterial significance to meiofauna and macroinfauna have not been performed in the Trend area.

Except for ocean boundary inflows, the subsystem below the pycnocline is dependent on the "rain" of plankton and detritus from the euphotic zone for its source of food. While processing of detritus occurs in the euphotic zone as well, it is the dominant trophic activity in the lower dysphotic zone. Much of this organic material is transported across the pycnocline from the upper water layer by gravitational settling. The relative importance of allochthonous and autochthonous sources (i.e., food resources originating outside and inside the Tuscaloosa Trend ecosystem, respectively) of this organic material varies with season and location in the Trend area. The importance of allochthonous material (derived mainly from terrigenous sources such as marshes) generally decreases with distance offshore. Benthic communities in shallower depths closer to land would be expected to show more distinct

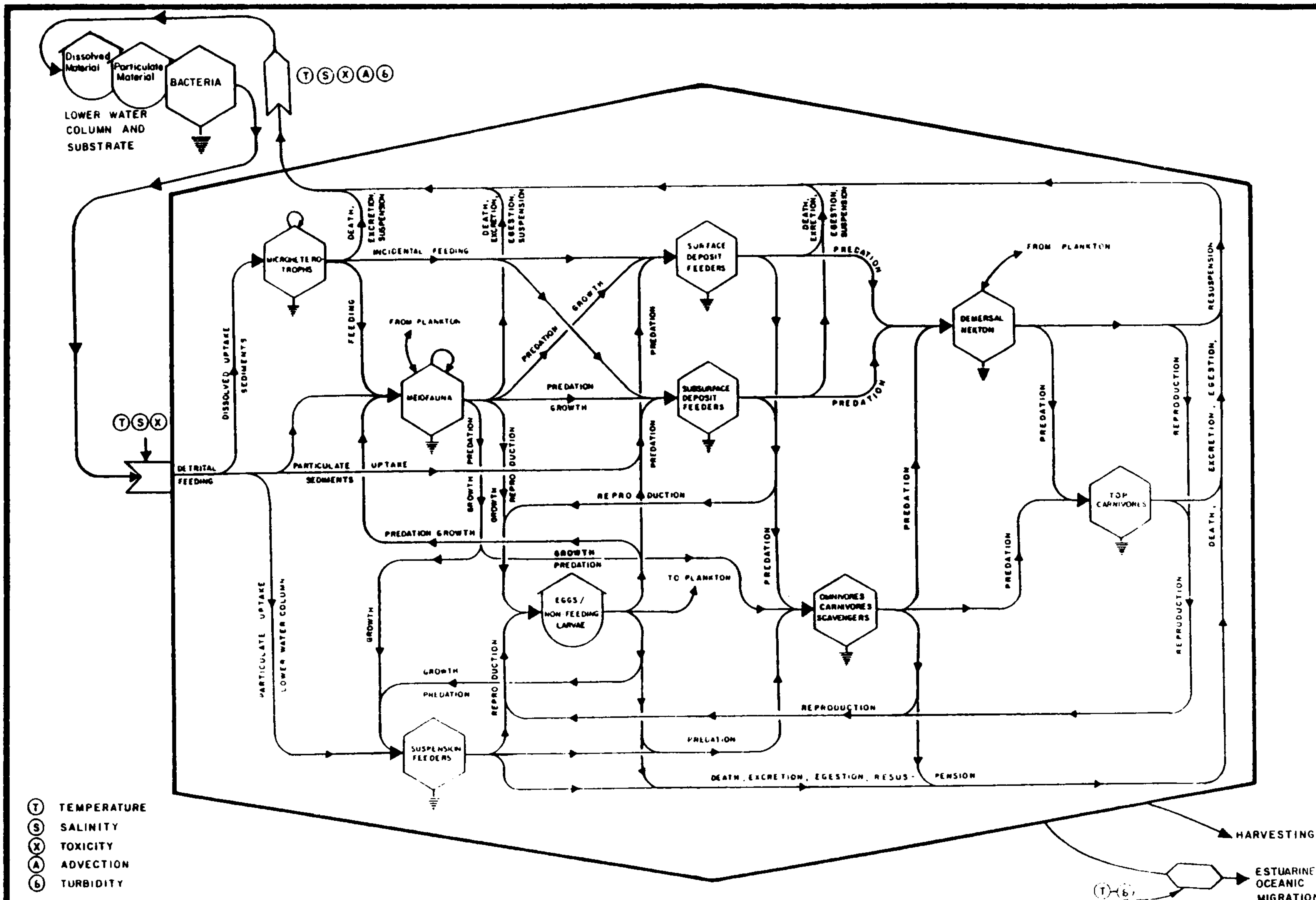


Figure 6.21 A conceptual representation of trophic processes in the benthic subsystem of the Tuscaloosa Trend ecosystem.

seasonal patterns in productivity and standing stock as compared to communities located further offshore, where allochthonous inputs are less important. As the distance offshore increases, the benthic community becomes more dependent on productivity in the upper layers of the water column. On most continental shelves, benthic standing stock, productivity and species richness all decrease with depth, due, presumably, to food resources that all decrease offshore. Again, due to the complex and atypical hydrography of the Tuscaloosa Trend ecosystem, these patterns may or may not be occurring.

Once introduced, this detrital complex may be attacked by microheterotrophic organisms such as protozoa and diatoms that consume attached and free-living bacteria. Many of these microheterotrophs show a high degree of feeding specificity with some being restricted to feeding on only one or several species of bacteria. The microheterotrophs are then consumed along with the associated detrital particles by meiofauna and macrofauna (Figure 6.21).

The meiofaunal compartment includes metazoans (i.e., multicellular organisms) that fall into an arbitrary size range of approximately 0.063 to 0.5 mm as determined by sieving. They are not strictly classified by feeding mode except possibly based on size of the food resource. Meiofauna process smaller-sized organic particles than do the larger benthic detritivores, and can apparently display a high degree of selectivity in feeding. Meiofauna appear to be particularly efficient at conditioning detritus for microbial decomposition by mechanically breaking down the particles and increasing the surface to volume ratio. Apparently, some meiofauna can also absorb and assimilate dissolved organic material. Meiofauna include representatives of all the feeding groups which are disaggregated to separate compartments when the organisms become larger in size. In addition to organic detritus (with and without microheterotrophs), meiofauna consume eggs and larvae of all trophic groups and also eat each other. The meiofauna compartment includes the permanent meiofauna (groups such as nematodes, harpacticoid copepods, ostracods, tardigrades, oligochaetes, kinorynchs, rotifers and small polychaetes) that remain as part of the meiofauna throughout their life cycles. The compartment also include temporary meiofauna, such as larval and juvenile members of the macrofauna, that will be considered part of one of the several macrofaunal compartments (e.g., suspension, surface and subsurface deposit, and predatory/omnivorous/scavenger feeding types) as they grow and mature (Figure 6.21). Since the meiofauna compartment includes larvae and juveniles of all benthic taxa whose larvae reside in the sediments, the macrobenthos feeding compartments depend on the meiofauna compartment for recruitment. Surface and subsurface deposit feeders as well as some predators/omnivores all consume meiofauna, which may include their own young.

The four macrobenthos feeding types could be further disaggregated to include such distinctions as whether the organisms are infaunal or epifaunal forms as well as whether they are hard- or soft-bodied. For example, infaunal taxa, and especially subsurface deposit feeders, are less susceptible to predation by epifauna and nekton than are epibenthic taxa. Similarly, shelled organisms are preyed on by an entirely different group of organisms than are soft-bodied taxa. The four feeding mechanisms are not necessarily mutually exclusive, with some organisms being able to switch modes of feeding to suit the prevailing environmental conditions. Many polychaetes appear capable of several different types of feeding, which makes it difficult to classify a particular polychaete taxon into only one feeding mode.

Subsurface deposit feeders, which include burrowing polychaetes such as the capitellids (*Mediomastus* spp., *Notomastus* spp.) and lumbrinerids (*Lumbrineris* spp.) and labile palp-feeding molluscs (e.g., *Nuculana concentrica*) are necessarily infaunal, consuming large quantities of detrital and sedimentary material and associated microheterotrophs below the sediment surface. Subsurface deposit feeders also consume meiofauna, eggs and non-feeding larvae. Depending on the particular taxon, egested material can be deposited in the sediment or on the sediment surface. Although it was once thought that subsurface deposit feeding was a relatively indiscriminant act, more recent evidence suggests considerable selectivity is at least possible. The current feeling is that feeding based on particle size selection occurs widely in deposit feeding assemblages and, along with vertical location in the sediment, determines food resource allocation in benthic assemblages.

Surface deposit feeders include infaunal and epifaunal taxa that feed on organic material on the sediment surface itself. Infaunal taxa include such polychaete genera as *Magelona* and *Paraprionospio*, as well as sipunculids, holothuroideans, and bivalve molluscs. Many of the polychaete taxa probe the sediment surface with tentacles, while the bivalves (e.g., *Tellina*) siphon deposits from the sediment surface with their labial palps. Epifaunal taxa include polychaetes (e.g., *Sigambra*), ophiuroids (e.g., *Micropholis*), crabs, gastropod molluscs, and some shrimp. They generally have greater mobility than the infauna, and may prey on them to some degree. Predation by epibenthic carnivores/omnivores/scavengers and demersal nekton on surface deposit feeders can be severe, and their populations may be predator-limited in more biologically-accommodated environments.

Deposit feeding is very important in determining the distribution of materials in the sediment system. The process of mixing the sediments through the activity of the resident benthic community is termed bioturbation. Tube-building activities provide channels through which oxygen can reach deep into sediments, making organic matter available for aerobic decomposition.

Suspension feeders, which include bivalve molluscs, amphipods and some polychaete taxa, remove suspended material from the water column overlying the sediments, either by passive filtering or active pumping of water over a filter. Infaunal taxa include the polychaete families Sabellaridae, Sabellidae and Serpulidae, as well as ampeliscid amphipods, cumaceans, mysids, pinnixid crabs, and lophophorates. Most of these taxa are tube dwellers. Also included among the infaunal suspension feeders are hard-bodied taxa such as the bivalve genera *Mulinia* and *Lyonsia*. These taxa remain buried except for extending the filtering apparatus (tentacles or siphons) above the surface. Epifaunal suspension feeders include the sea pansies (*Renilla muelleri*), anemones (e.g., *Paranthus*), sponges and ophiuroids. All the suspension feeders are heavily preyed on by benthic and nektonic predators.

The omnivores/predators/scavengers include mainly predaceous macrobenthos that feed on all the other macrobenthos compartments as well as on some meiofauna and each other. However, they will also consume animal detritus. They are, in turn, preyed on by demersal nekton, top carnivores, and each other. They are represented by a number of the more mobile macrofaunal taxa, including polyclad and nemertean worms, polychaetes, gastropods (e.g., *Turbonilla* and *Natica*), pycnogonids, echinoderms (e.g., *Astropecten*) and decapod crustaceans. Some of the polychaete families in this compartment include members of the families Goniadidae, Nephtyidae, Sigalonidae, Syllidae and

Polynoidae, all of which are predominately carnivores, and members of the families Nereidae, Lumbrinereidae, Onuphidae and Eunicidae, which are more omnivorous than carnivorous (Fauchald and Jumars, 1979).

The taxa comprising the macrobenthic community are adapted to particular sedimentary habitats through differences in morphological, physiological, reproductive, and behavioral characteristics (i.e., autecology). Feeding or trophic type is one of the autecological aspects most closely related to the sedimentary habitat (Sanders 1956, 1958, 1960; Rhoads 1974). In general, coarse sediments in high current habitats where organic (i.e., food) particles are maintained in suspension in the water column favor the occurrence of filter-feeding taxa that extract food particles from the water column. In addition, coarse sediments frequently contain many carnivorous taxa that feed on the organisms encrusting gravel-sized particles and occupying interstitial habitats (Fauchald and Jumars, 1979). Surface and subsurface deposit feeders do poorly in this habitat due to the low organic content of the sediments.

At the other extreme, habitats with fine-textured sediments and little or no current are characterized by the deposition and accumulation of organic particles, thereby favoring the occurrence of surface and subsurface deposit feeding taxa. The fine particles characteristic of this habitat tend to clog the filtering apparatus of suspension feeding taxa, further excluding them from the finer-textured sedimentary habitats (Rhoads and Young 1970, 1971a,b,c; Levinton, 1977). Of course, many other factors are also involved in determining benthic community composition, structure and distribution (most notably anthropogenic influences, predation, competition and habitat interference or disruption). In the Tuscaloosa Trend study area, sediment change is greatest in a longshore direction, with the fine-textured sediments in the western portion being replaced to the east by sandy sediments more typical of the west Florida shelf. These trends have a substantial influence on benthic community structure and dynamics.

Many studies have been conducted recently concerning the trophic interactions between estuarine-dependent species and their associated prey items (Chao and Musick, 1977; Ross, 1977; Overstreet and Heard, 1978a,b; Overstreet, 1983). The subjects of most investigations have been species of commercial or recreational importance, or those which are readily accessible. By understanding the interplay between an organism and its environment, conclusions can be drawn as to cause and effect relationships: How is a particular fishery effected by environmental perturbation impacting a seemingly unrelated segment of the ecosystem? Investigations conducted in the Tuscaloosa Trend study area which depict various patterns of feeding strategies both within species (intraspecific) and between species (interspecific) are summarized in Table 6.27.

The range of food items available to a particular species is largely determined by its foraging behavior and feeding morphology. Most species are opportunistic in their choice of food items, selecting anything they can accommodate. A species that forages in different geographic localities may eat different food items due to the availability of dominant prey organisms. Examples of opportunistic feeders include such commercially important species as the croaker Micropogonias undulatus (Hansen, 1969; Roussel and Kilgen, 1975), pinfish Lagodon rhomboides (Hansen, 1969), and juvenile pompano Trachinotus carolinus (Bellinger and Avault, 1971).

Table 6.27 Trophic studies of selected finfishes within the Tuscaloosa Trend study area.

Species	Common Name	Feeding Habits	Source
Trachinotus carolinus	Juvenile pompano	Opportunistic	Bellinger and Avault, 1971
Fundulus similis	Killifish	Diurnal; crustaceans dominate	Bennett, 1973; Benson, 1982
Sciaenops ocellatus	Red drum	Fish, shrimp, crabs, seasonal changes	Boothby and Avault, 1971; Bass and Avault, 1975; Overstreet and Heard, 1978a
Diplectrum formosum	Sand perch	Shrimp, crabs, fish, omnivore	Bortone, 1971; Darnell, 1958, 1961
Paralichthys sp.	Flounder	No sex or size difference in diets	Fox and White, 1969
Sphoeroides spp.	Pufferfishes	Ontogenetic changes	Gathof, 1981
Lagodon rhomboides	Pinfish	Omnivore	Hansen, 1969
Serraniculus pumilio	Pygmy seabass	Crustaceans	Hastings, 1972
Stenotomus caprinus	Long-spined porgy	Omnivore	Henwood et al., 1978
Micropogonias undulatus	Atlantic croaker	Crustacean, polychaetes, molluscs, fish	Hansen, 1969; Roussel and Kilgen, 1975; Rogers, 1977; Overstreet and Heard, 1978b
Leiostomus xanthurus	Spot	Omnivore	Parker, 1971
Cynoscion arenarius	Sand seatrout	Fish and crustaceans	Overstreet and Heard, 1982
Cynoscion nebulosus	Spotted seatrout	Fish and crustaceans	Overstreet and Heard, 1982
Cynoscion nothus	Silver seatrout	Fish and crustaceans	Overstreet and Heard, 1982
Pogonias cromis	Black drum	Crustaceans, pelecypods, polychaetes	Overstreet and Heard, 1982
Archosargus probatocephalus	Sheepshead	Crustaceans, molluscs, polychaetes, fishes	Overstreet and Heard, 1982
Paralichthys lethostigma	Southern flounder	Fish and penaeid shrimp	Overstreet and Heard, 1982

Within a species, dietary changes may be associated with a variety of factors. They may change over the course of a 24-hour period (diurnal/nocturnal), over the course of a year (seasonal), or over the period of the organism's life (ontogenetic). Benson (1982) reported increased crepuscular feeding periods in the blacktip shark (Carcharhinus limbatus), although like most sharks, it will take food both day and night. Two spatially coexisting species that forage in a similar manner would encounter different food organisms if one species forages during the day and the other forages at night.

Overstreet and Heard (1978a) examined the food of the red drum (Sciaenops ocellatus) and noted significant ontogenetic and dietary changes by season. Seasonally blue crabs were consumed in the spring and summer and penaeid shrimp in the winter and fall. Benson (1982) notes that the red drum larvae feed on zooplankton (especially copepods), while juveniles select amphipods, mysid shrimp, palaemonid shrimp, small crabs, polychaetes, and some small fish. As the red drum becomes larger, there is a shift in emphasis away from polychaetes and palaemonid shrimp (Overstreet and Heard, 1978a) and blue crabs become more important (Yokel, 1966). Rogers (1977) graphically demonstrates ontogenetic dietary changes in the rock sea bass Centropristis philadelphicus found within the study area (Figure 6.22).

The morphology of an organism generally reflects the feeding behavior for which the species is best adapted. Bottom feeders usually have well-developed lips and mouths oriented ventrally to facilitate bottom feeding. Species which feed in the water column have poor lip development and terminal or dorsoterminal mouths. For example, the Gulf menhaden (Brevoortia patronus) possesses a terminal mouth with a large gape and numerous gill rakers. Darnell (1958) and Gunter and Christmas (1960) reported menhaden as filter-feeding omnivores with phytoplankton the most important food item; however, detritus, bacteria, plant fragments, and zooplankton are also taken. The black drum, on the other hand, is an opportunistic benthic carnivore. It has a subterminally oriented mouth with a well-developed pharyngeal apparatus for crushing molluscs. A barbel on the chin assists in locating oysters and clams. A pelagic feeder such as the spinner shark (Carcharhinus brevipinna) has a well-developed mouth armed with sharp cutting teeth to capture and eat pelagic fish.

Rogers (1977) postulated two food chains for the continental shelf of the northern Gulf. The first is a planktonic food chain in which energy fixed by phytoplankton is transferred to zooplankton and then to fish. The second is a benthic food chain in which energy fixed in organic detritus (both planktonic and estuarine) is transferred to detritus feeders, benthic consumers, and then to consumers in the water column.

An alternative to examining the gut contents of fishes to determine trophic relationships is to examine the food resources available to them. Lunz and Kendall (1982) have developed a Benthic Resource Assessment Technique (BRAT) which analyzes information from benthic invertebrate community surveys and then classifies the invertebrate taxa according to their size and distribution of their biomass relative to sediment surface. When these data are combined with information on the demersal fishes inhabiting an area, an estimate of the potential prey biomass (g wet wt$\cdot$m^{-2}) available to the fish in a particular feeding guild can be obtained. They have developed this model to

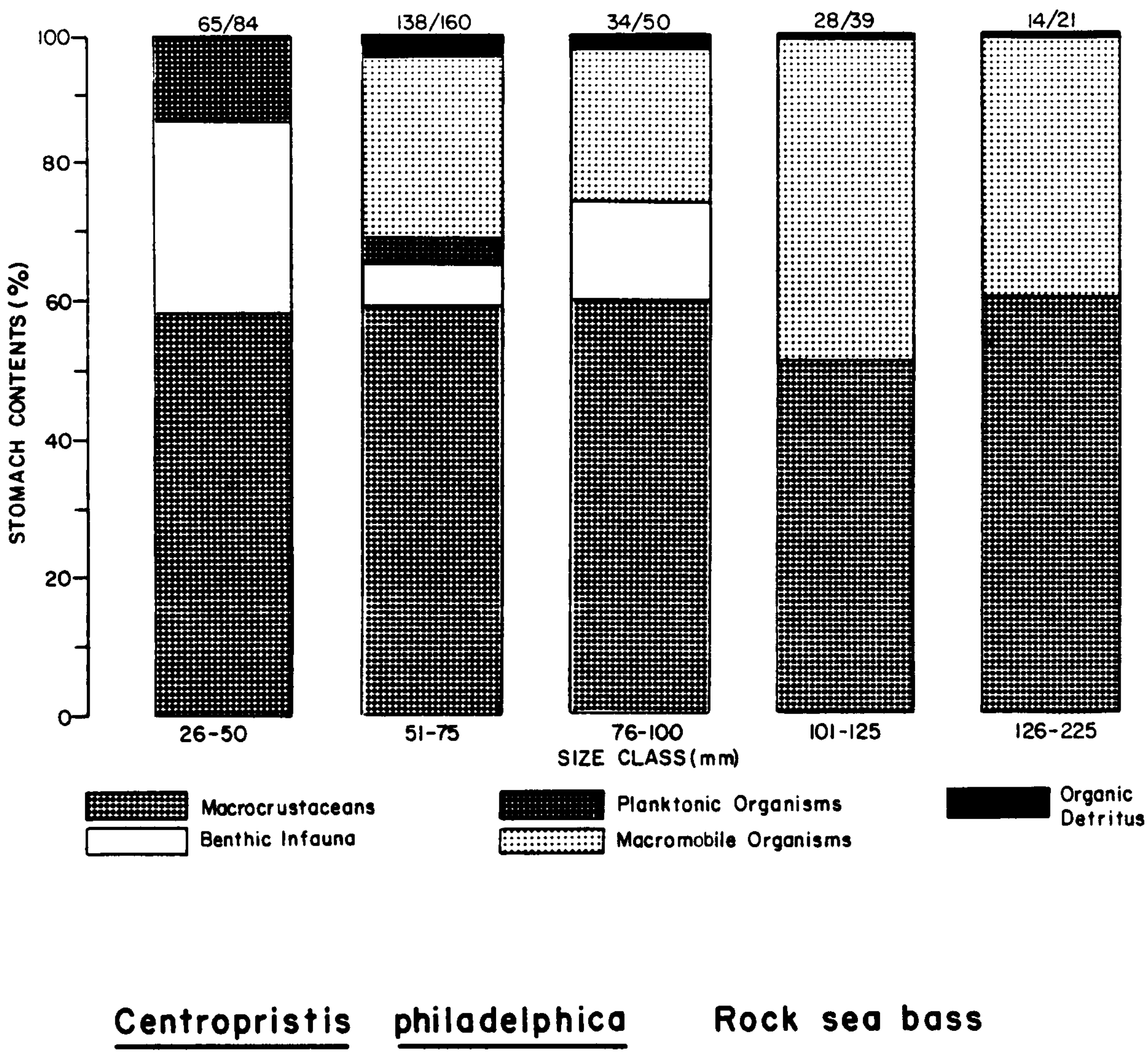


Figure 6.22 Changes in diet of *Centropristis philadelphica* with respect to size class (Source: Rogers,1977).

determine the relative impact of the Corps of Engineers dredged material disposal program on the macroinfaunal populations and the demersal fish population feeding on these organisms.

6.6.4 BIOACCUMULATION

Bioaccumulation is the process by which pollutants such as heavy metals and pesticides are concentrated in the tissue of an organism at levels higher than those found in the surrounding environment. A related phenomenon known as biomagnification is the process by which a pollutant level is increased as a result of organisms at higher trophic levels feeding on organisms that have previously concentrated the pollutant in their tissues. In this sequence, each succeeding trophic group is exposed to a more concentrated level of the pollutant than the trophic group below it. A prime example of this process has been highly publicized in the fate of some of the larger fish-eating birds (i.e., pelican) and the negative effect that the pesticide DDT has had on the development of their eggshells.

When a pollutant enters the ecosystem it may result in lethal, sublethal, or nonlethal effects on the biotic community (Duke, 1976). Lethal effects eliminate sensitive populations rapidly and decrease food supply to higher trophic levels. Effects which do not cause immediate mortalities in the population of organisms exposed to the pollutant are considered sublethal. These may include such ecological effects as changes in breeding habits, orientation and migration, feeding behavior, ability to escape predation, competition for habitat, and even genetic structure (Ketchum, 1974). These effects may ultimately reflect changes in population dynamics and the ability of the species to survive as a population. Long-term sublethal consequences are often more ecologically devastating than short-term consequences because once the problem is manifested the pollutant may be well distributed throughout the ecosystem.

Once a pollutant enters the ecosystem it is subject to numerous changes--some beneficial, some detrimental. Pesticides, for example, are subject to chemical, photochemical, and biologically mediated changes. These changes may convert the pollutant into a more environmentally compatible form or a more damaging one. Many pollutants are removed from the water column through sorption onto, or chemical reaction with, suspended material which is later deposited on the bottom as sediment. As a result, sediments often act as large reservoirs for metals and pesticides. However, the availability of the pollutant to the ecosystem is dependent on its "binding capacity" with the particulate material. Estuarine systems readily accumulate pollutants in their sediments due to the mixing of fresh- and saltwater which frequently results in the precipitation of pesticides from the water column. These contaminated sediments, in turn, expose infaunal organisms to levels much higher than those naturally found in the environment.

Another important aspect of bioaccumulation is the potential for transportation by the marine organisms. Large amounts of pesticides and heavy metals can be transported from an estuary to the open ocean through the seasonal migration of organisms that have concentrated it from their inshore environment. Pelagic fish are a good example. As a result, pollution effects may be observed great distances from where it actually occurs.

Water pollution introduced on the outer continental shelf is another source of perturbation. These sources include ocean disposal of dredged material, discharge from drilling operations, and potential sources due to accidents (i.e., ships, oil rigs, and burning hazardous waste at sea). An accident involving pesticides, hydrocarbons, or trace metals could have wide-ranging impacts on that community and the inshore community through trophic and migratory pathways.

6.7 DATA GAPS

In general, the coastal portion of the Tuscaloosa Trend study area has been well-studied with respect to benthos, demersal fishes and invertebrates, and nekton. Studies of phytoplankton, zooplankton, biological production, and trophic dynamics are lacking or inadequate. Few ecological studies have been done on the open shelf and essentially all aspects of ecological resources are insufficiently known to define processes and interrelationships in the ecosystem. The following recommendations for future investigation reflect the paucity of information for the shelf:

1. Movements of biota through the tidal passes should be described to determine energy flux between coastal and OCS waters;

2. Shelf benthic communities should be defined, with emphasis on habitats (sediment types) not previously described, near major points of riverine discharge, and near-slope environments (including the DeSoto Canyon);

3. Plankton communities should be described for the shelf with emphasis on primary and secondary production, and correlated with physical and chemical processes to assess relationships between shelf/coastal waters/riverine discharge and OCS biotic potential;

4. Further analysis of trophic relationships among the biotic components of the shelf ecosystem should be conducted, with emphasis on energy transfer within and between pelagic and benthic components.

7.0 SOCIOECONOMICS

7.1 INTRODUCTION

Historically, the socioeconomics of the Tuscaloosa Trend region have been closely tied to the resources and transportation systems offered by the Gulf of Mexico and adjacent waters. The two Louisiana parishes, St. Bernard and Plaquemines, are both physically dominated by water and rely on the Gulf for the principal industries, fisheries and petrochemicals. The offshore oil and gas industry is currently undeveloped and less important to the Alabama and Mississippi coastal counties, but the fisheries industry and well-developed waterborne transportation systems are primary attributes of the region's character.

The waterborne transportation system includes well-developed ports and harbors with access to vast inland areas, especially via the Mississippi River and the completed Tennessee-Tombigbee Waterway through Mobile. The Port of New Orleans is the second largest in the United States. These ports, and others on the Mississippi Coast, carry on extensive domestic and international commerce. An extensive network of coastal channels, the Gulf Intracoastal Waterway, and open Gulf fairways and anchorages ensure adequate access to all significant markets.

Travel, tourism, and recreation represent significant economic activities in the area. Alabama's coastal region offers over 180 km of waterfront access on the bays, Mississippi Sound, and Gulf of Mexico and is the focus of very rapid recreational developoment. The Mississippi Coast has been a major regional tourist center since the 19th century, and possesses the longest manmade beach strand in the world (42 km). Contrastingly, Louisiana's recreational resources are primarily tied to the extensive wildlife habitats provided by the wetlands and excellent fishing opportunities. The importance of recreational fisheries is reflected in the economic input of the industry Gulfwide. Marine recreational fishing in the Gulf region resulted in an estimated $1.32 billion in retail sales in 1980, representing over one-third of such sales in the United States.

The commercial fisheries industry is a similarly important economic activity. In 1983, over $316 million entered the economies of Alabama, Mississippi, and Louisiana through the value of the region's fisheries catch alone. The most significant single commercial catch is shrimp, which was valued at over $81 million in 1983.

Notwithstanding the importance of other regional resources, the petrochemical industry and the potential, undeveloped offshore hydrocarbon resources may have the most widespread economic impact. Virtually all the hydrocarbon production from the United States outer continental shelf occurs in the Gulf of Mexico basin. In 1982, oil and gas production in the Gulf accounted for 90% and 99%, respectively, of the total U.S. outer continental shelf production. Though offshore exploration is just beginning in much of the study area, estimates suggest that tremendous hydrocarbon resources are available.

Resources introduced thus far have been associated primarily with the region's economic character, but the region's cultural resources represent a significant contribution to the nation's heritage. Historic sites date to the first voyages of exploration and colonization into the Gulf of Mexico. Prehistoric archaeological sites may exist on the floor of the Gulf dating to times when the sea was much lower than current levels. During the lower sealevels, large expanses of the continental shelf were available for human settlement. Prehistoric onshore archaeological sites date from approximately 12,000 BP in the study area.

The Tuscaloosa Trend region exhibits a broad range of socioeconomic characterteristics. These features show a great deal of geographical variation, and in some instances the study area does not appear to possess the singular trait necessary to define it as a region. However, in each of the somewhat diverse coastal and offshore areas discussed, the unifying feature is the proximity to the Gulf of Mexico and its abundant resources.

7.2 TRANSPORTATION

7.2.1 WATERWAYS

The waterborne transportation network consists of an intricate system of waterways linking the major ports and providing access to international and domestic commerce. Coastal waterborne traffic within the study area generally flows through the Gulf Intracoastal Waterway (GIWW). The GIWW is 3.7 m deep and 45.7 m wide from Mobile to New Orleans and the Mississippi River, a distance of 212.8 km. In 1981, 27,864 vessels, primarily barges, traversed this stretch of waterway transporting 15.7 million metric tons (MT) of freight. The tonnage figure dropped during 1982 to approximately 13.8 million MT (U.S. Army Corps of Engineers, 1984). A wide variety of materials is transported. The single greatest commodity moved (2.9 million MT) was coal and lignite, but crude petroleum and grain were also major commodities handled (U.S. Army Corps of Engineers, 1984). Crude petroleum represents over 20% (by weight) of all commerce shipped on the Louisiana-Mississippi section of the GIWW. Crude petroleum shipments have historically held a stable percentage of the commodities shipped on the Mississippi River and GIWW. Since 1955, 17% to 19% of the commodities on the Mississippi River and 17.1% to 23.5% of GIWW commodities have been crude petroleum (Larson et al., 1980). Figure 7.1 illustrates the nearshore transportation system utilized by barge traffic within the relatively well-protected waters of Mobile Bay and Mississippi Sound.

Deep draft vessels must utilize the offshore fairway network established as safe corridors for ocean shipping. As Figure 7.2 illustrates, the fairways link the major ports of New Orleans, Gulfport, Pascagoula, and Mobile and ensure obstruction-free access through several areas--primarily offshore Louisiana--which currently has a dense network of petroleum platforms. Throughout the Gulf there are over 1287 km of 3.2 km wide fairways in daily use. The U.S. Army Corps of Engineers has jurisdiction over these restricted zones and prohibits the construction of fixed structures. Thus, the fairways and anchorages are critical areas in the Tuscaloosa Trend area due to high traffic congestion. Further, use of the offshore northern Gulf is not confined to commerce and mineral extraction; three military warning areas exist in the study area (Figure 7.2).

7.2.2 ALABAMA PORTS AND HARBORS

Waterborne transportation in Alabama revolves around the Port of Mobile. Alabama is the only state that owns, administers, and operates its own inland and deepwater port facilities (Alabama State Docks). The traffic handled by the Alabama State Docks represents approximatley 50% of the trade in the Mobile Port. The Alabama State Docks' (ASD) main facilities are principally devoted to general cargo and container handling, a public grain elevator, a dry bulk-handling plant, and the McDuffie Coal Terminals. General cargo is handled at 27 general cargo piers on the western bank of the Mobile River. Only one of these berths (Berth No. 2) handles containerized cargo. The public grain elevator is also on the west bank of the Mobile River and is located above the Interstate Highway 10 twin tunnels. A dry bulk-handling terminal for bauxite, iron ore, and imported coal is located at Three Mile Creek. McDuffie Coal Terminals, located south of the IH-10 twin tunnels, however, is the principal coal-handling facility. Warehouses for dry and cold

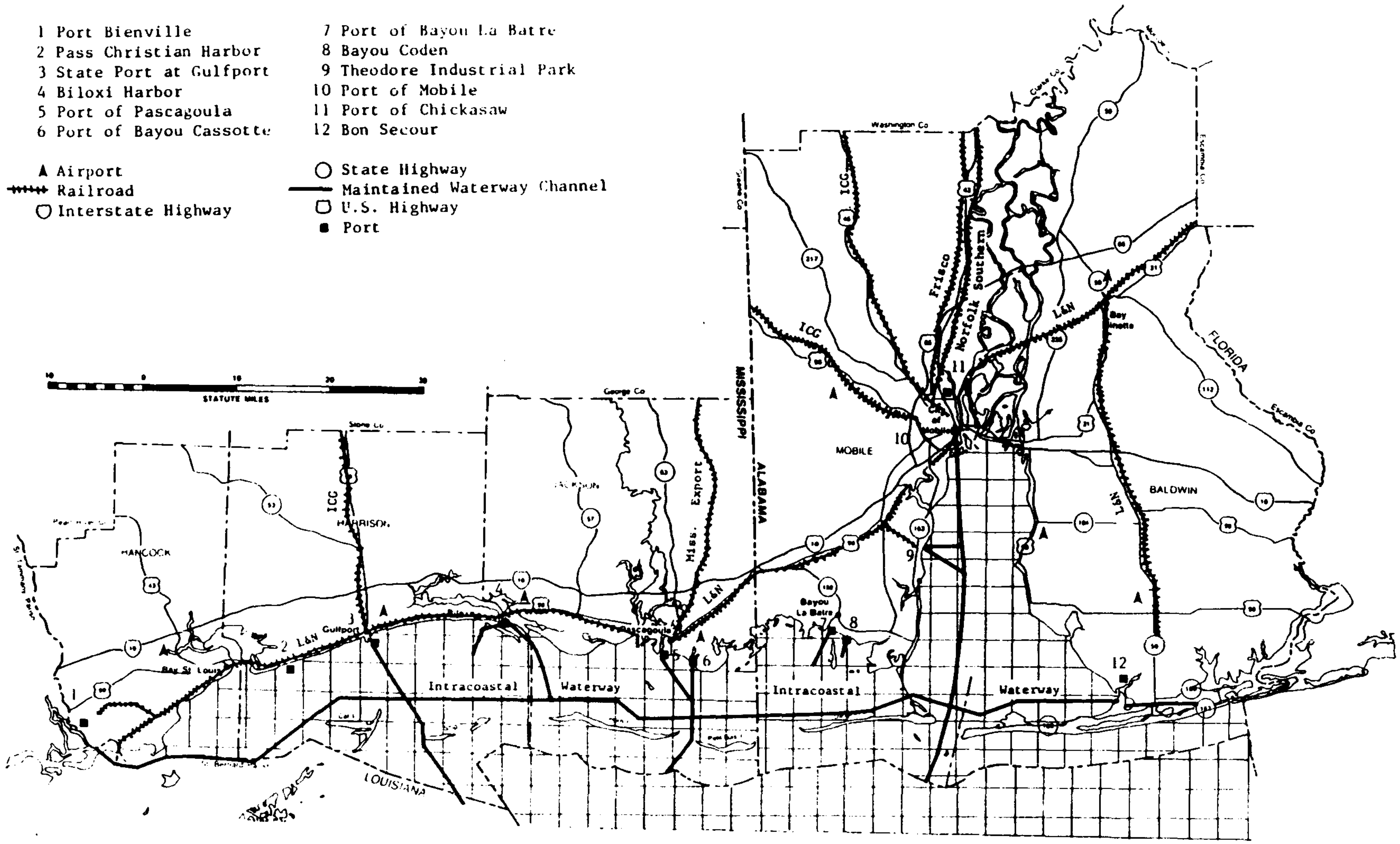


Figure 7.1 Ports, nearshore transportation system, rail and highway systems. Source: U.S. Army Corps of Engineers, 1984

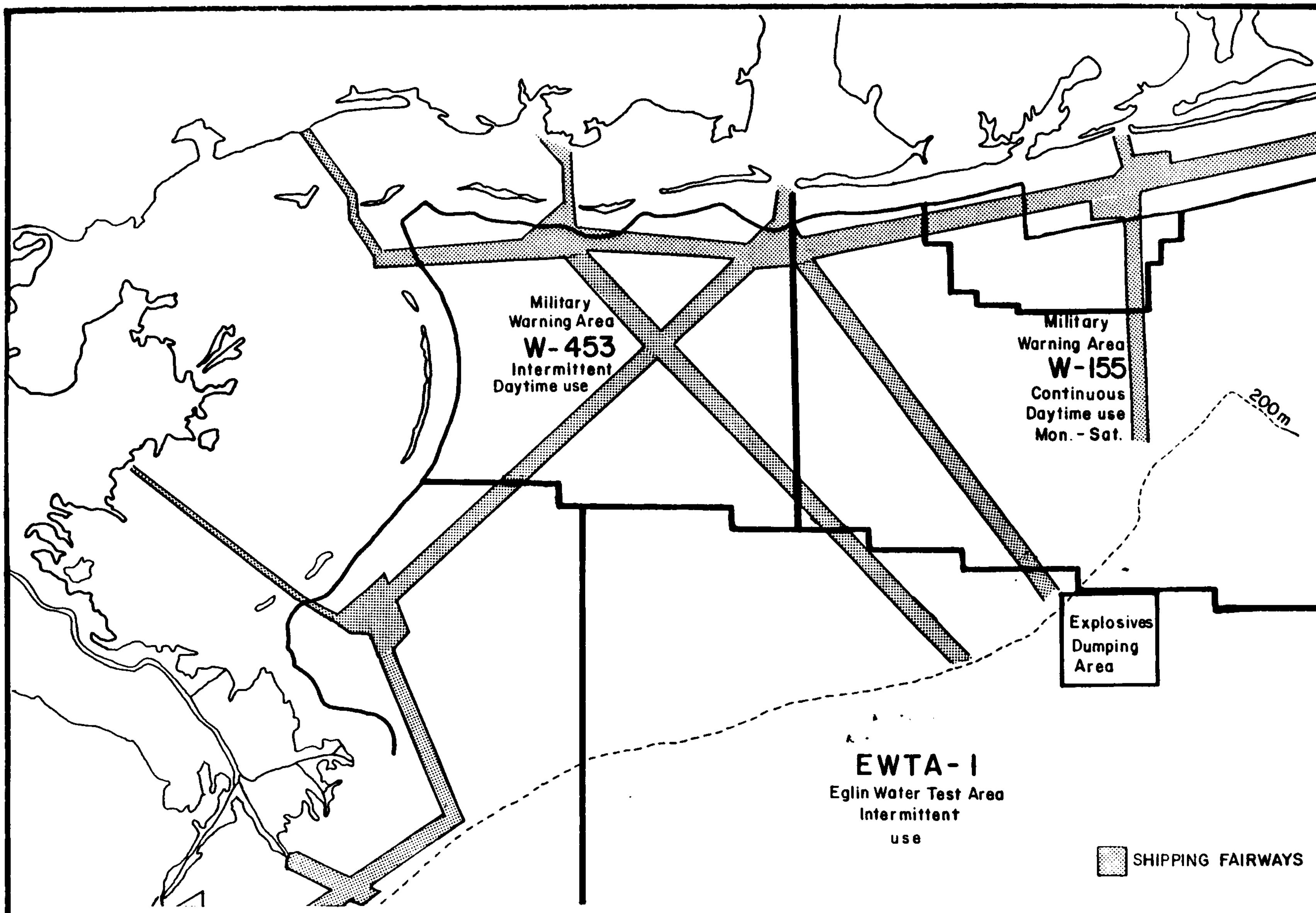


Figure 7.2 Shipping fairways and military warning areas. Source: MMS, 1983

storage are accessible by rail and arterial highway. The Terminal Railway functions to facilitate and coordinate shipments from ships to commercial carriers.

In addition to the Alabama State Docks, the Port of Mobile is also served by private industrial facilities. Major private dock facilities include the Amerada-Hess and Citmoco Terminals that store and ship crude oil received through pipelines from oil fields in northwest Florida, central Mississippi, and north Mobile County. The Chevron Asphalt Refinery also receives shipments of crude oil, but via small tankers and barges; the asphalt products are shipped by barge. The Texaco Terminals receive refined petroleum products by small tanker. Ergon also receives refined petroleum products as well as chemicals, but Ergon uses small barges. Pro Rico Industries imports molasses in small tankers.

During calendar year 1983, the Port of Mobile handled approximately 31.7 million MT of cargo. In the first six months of 1984, the Port handled 16.6 million MT of cargo, an increase of 481,763 MT over the same period in 1983 (Alabama State Docks Department, 1984).

The Port of Mobile is served by an extensive network of deep draft channels, barge canals, anchorages, and turning basins. The commercially significant channels have been constructed and are maintained by the U.S. Army Corps of Engineers. Material dredged in maintaining the channel network is deposited in approved disposal areas. One such area is Gilliard Island which was constructed to receive only maintenance dredged material from the Theodore Ship Channel.

The Mobile Harbor consists of 67.6 km of channels within the bay and adjacent river. Smaller, peripheral channels are also maintained in Dog River, Dauphin Island Bay, Bayou La Batre, Fowl River, and Bayou Coden on the western bay shore. On the eastern shore, small channels are also maintained in Fly Creek and Bon Secour Bay.

The Gulf Intracoastal Waterway (GIWW), one of the main arteries for waterborne transport, traverses lower Mobile Bay and Bon Secour Bay, becomes a canal through a portion of Baldwin County, and passes into Perdido Bay, then eastward into Florida. The waterway is utilized by shallow-draft vessels, principally barges, that are unsuitable for open-Gulf navigation.

Theodore Ship Channel is a 12.2 m deep by 121.9 m wide channel which trends northwesterly from the Main Ship Channel from a point about 4.5 km north of Middle Bay Light to the western shore of Mobile Bay. The land-cut extends 3.1 km inland, is 12.2 m deep and 91.4 m wide, and terminates in a turning basin.

The basin area and channel approach are part of the newly developed Theodore Industrial Complex. Primary potential industries include chemicals and allied products, petroleum, refining and related products, and general cargo and bulk materials shipping.

The Tennessee-Tombigbee Waterway is peripheral to the Tuscaloosa Trend study area, but because of the significant projected impacts on waterborne traffic, the Tennessee-Tombigbee Waterway merits a brief review. The U.S. Army Corps of Engineers began construction on the waterway in 1972 and will have completed the project in June, 1985. Once completed, barge traffic will be able to move through Mobile from the Tennessee and Ohio River systems. The Tennessee-Tombigbee Waterway will connect the Black Warrior-Tombigbee River systems with the Tennessee River in the northeastern corner of Mississippi, creating a 373.5 km navigable network with a 2.7 m minimum depth and an average width of 91.4 m.

7.2.3 MISSISSIPPI PORTS AND HARBORS

Based on the OCS Regional Transportation Management Plan (Gulf of Mexico Regional Technical Working Group, 1981), the Port of Pascagoula, Port of Gulfport, and Port Bienville are currently capable of receiving, or may be prepared to receive, barge or ship traffic for the transport of petroleum hydrocarbons from offshore oil and gas activities.

Port of Pascagoula

The Port of Pascagoula encompasses two harbors: Pascagoula River Harbor (West Harbor) and Bayou Cassotte (East Harbor). These harbors, with a 12.2 m deep channel, are accessible to the Gulf of Mexico through Horn Island Pass. There is a large ship mooring cluster with a 7.3 m deep approach south of the grain elevator and a barge fleeting area south of Ingalls Shipbuilding Division of Litton Industry's West Bank Facility with a 96 barge capacity and a 11.6 m deep approach.

The associated land area is used for dock and harbor operations and multipurpose port facilities capable of accommodating ocean shipping, barge traffic, commercial fishing and recreational craft. Within the harbor areas there are storage facilities for anhydrous ammonia, a 8,804,000 hectoliters (3.1 million bushel) storage capacity grain elevator and nearly 54,000 m^2 of covered storage. Additional holding facilities exist with a capacity for about 200 million liters (1 million barrels) of crude oil and 2 billion liters (9 million barrels) of petro-chemicals.

Ingalls Shipbuilding Division of Litton Industries occupies much of the West Harbor with two large shipbuilding facilities. Privately owned docks at the East Harbor include Chevron U.S.A., Mississippi Chemical Corporation's Bulk Handling Plant, and First Chemical Corporation's barge terminal facility. Public docks are owned by the Jackson County Port Authority.

Total tonnage handled by the Port of Pascagoula peaked in 1980 at approximately 25.7 million MT, dropped in 1981 to 23.1 million MT, and declined again in 1982 to 17.3 million MT. However, in 1983 the tonnage handled rose 13.0% to 19.5 million MT (Jackson County Port Authority, 1984a,b). The tonnage handled at the Port increased in 1984: the January-June total Port tonnage for 1984 increased 49% over the same period in 1983.

The Port facilites are connected to a network of railroads including the Mississippi Export Railroad joining the Illinois Central Gulf Railroad and the Seaboard Systems Railroad. Additional transportation access is provided by the interstate highway system (Interstate Highway 10) and the GIWW.

Port of Gulfport

The Port of Gulfport is the second largest port facility on the Mississippi coast. The state-owned manmade harbor has two piers that project into Mississippi Sound and bracket a 402.3 m wide turning basin. Water access is provided to the GIWW, which is 8 km offshore, and the open Gulf of Mexico 24 km offshore via a 9.1 m deep, 91.4 m wide ship channel that extends through Ship Island Pass. Land access is provided through the rail services of the Illinois Central Railroad and the Seaboard Systems Railroad and through trucking lines utilizing nearby U.S. Highway 90 and Interstate Highway 10.

The Port of Gulfport primarily handles general cargo. Approximately 50% of the cargo imported through the facilities is bananas and plantains, while principal exports are rice, meat, paper and paperboard products. In FY 1984 the Port registered an 8.6% increase in tons of goods handled in 1983. Though the amount of tonnage handled has fluctuated, the tonnage handled in 1984 is nearly 21% greater than that moved in 1978 (Mississippi State Port Authority, 1984).

Port Bienville

Port Bienville is primarily a barge port with an adjacent 5928-hectare industrial park. It is reached via a 1340 m, 4.9 m deep barge channel and 6340 m of 3.7 m deep barge channel. Facilities include a concrete wharf, transit storage, and outside storage available at the adjacent industrial park. A port rail system ties into the coastal Seaboard Systems Railroad.

Biloxi Harbor

Biloxi Harbor is a multi-use facility utilized by commercial fishing vessels, tugboats, and barges. The commercial docking facilities on the Harrison County Industrial Seaway handle coal and lignite barge traffic and have access to the Seaboard Systems Railroad and Interstate Highway 10 (I-10).

7.2.4 THE PORT OF NEW ORLEANS

The Port of New Orleans is the second largest in the United States, following only the Port of New York in tons of material handled (Larson et al., 1980). The Port handled a record 52.9 million MT of foreign waterborne commerce in 1981, and over 171 million MT. In 1982, even though the foreign tonnage handled dropped to 42.7 million MT, reflecting the impact of the recent economic recession, that figure is still the second largest recorded at the Port. The total tonnage handled dropped to 160.8 million MT, the third largest on record (Board of Commissioners of the Port of New Orleans, 1983). In 1983 the total foreign tonnage continued to fall, declining to 33.2 million MT, the lowest figure since 1975 (Board of Commissioners of the Port of New Orleans, 1984).

Barge traffic represents nearly half of the waterborne traffic at the Port of New Orleans (Table 7.1). A wide variety of commodities are transported by barge. The overwhelming majority of the material carried in 1982 was grain- and petroleum-related products (Table 7.1).

Table 7.1. Port of New Orleans Barge Information (in short tons).

BARGE ACTIVITY DURING THE PAST 10 YEARS:

YEAR	NUMBER OF BARGES			BARGE TONNAGE		
	INBOUND	OUTBOUND	TOTAL	INBOUND	OUTBOUND	TOTAL
1973	48,352	47,674	96,026	44,633,000	24,748,000	69,381,000
1974	51,171	50,258	101,429	48,680,000	23,429,000	72,109,000
1975	51,193	51,087	102,280	50,117,000	21,248,000	71,265,000
1976	55,665	55,788	111,453	57,835,000	21,923,000	79,758,000
1977	53,849	53,928	107,777	55,547,000	22,946,000	78,493,000
1978	50,995	51,326	102,321	53,568,000	25,564,000	79,132,000
1979	50,789	51,092	101,881	54,660,000	23,067,000	77,727,000
1980	55,606	54,718	110,324	63,485,000	19,749,000	83,234,000
1981	61,382	59,149	120,531	71,192,000	17,437,000	88,629,000
1982	55,269	55,472	110,741	66,097,000	15,039,000	81,136,000

YEAR	TOTAL TONNAGE	PERCENTAGE CHANGE	BARGE TONNAGE	PERCENTAGE CHANGE	BARGE % OF TOTAL
1973	136,104,000	+ 8	69,381,000	+ 7	50.98
1974	144,189,000	+ 6	72,109,000	+ 4	50.01
1975	140,409,000	- 3	71,265,000	- 1	50.76
1976	155,990,000	+11	79,758,000	+12	51.13
1977	162,992,000	+ 4	78,493,000	- 2	48.16
1978	160,612,000	- 1	79,132,000	+ 1	49.27
1979	167,135,000	+ 4	77,727,000	- 2	46.51
1980	177,316,000	+ 6	83,234,000	+ 7	46.94
1981	188,851,000	+ 6	88,629,000	+ 6	46.93
1982	177,302,000	- 6	81,136,000	- 8	45.76

PRINCIPAL COMMODITIES VIA BARGE 1982:

COMMODITY	TONNAGE
Grain	35,750,000
Petroleum & Related Products	22,100,000
Coal	8,444,000
Grain Mill Products	2,100,000
Animal Feeds	2,095,000
Iron & Steel Products	1,714,000
Chemicals	1,566,000
Marine Shells, Unmanufactured	1,016,000
Liquid Sulphur	1,011,000
Fertilizers	346,000

Source: Board of Commissioners of the Port of New Orleans
Marketing Division, 1984

The Port of New Orleans is served by nearly 100 steamship lines and consists of two deepwater harbors. The older Mississippi River wharves stretch along 20.5 km of riverfront, mostly on the east bank, and a newer tidewater Inner Harbor Navigation Canal connects the Mississippi River with Lake Pontchartrain lying at the junction of the Mississippi River-Gulf Outlet. The older port facilities are accessed from the Gulf of Mexico via a 12.2 m deep river channel. The Mississippi River-Gulf Outlet is a 10.9 m deep, 152.4 m wide waterway constructed in the 1960's to provide an alternative, shorter route to the Gulf of Mexico. The 121.6 km long channel is 70.4 km shorter than the Mississippi River to deep Gulf waters (Board of Commissioners of the Port of New Orleans, 1983).

Railroad services are provided to the Port by six major rail lines and the New Orleans Public Belt Railroad. The major rail lines include the Kansas City Southern, Illinois Central Gulf, Norfolk Southern Corporation (Southern Railway), the Seaboard System Railroad, the Southern Pacific, and the Union Pacific-Missouri Pacific Railroad.

The extensive port facilites at the Port of New Orleans are itemized in Table 7.2. There are 30 general cargo berths with 10,878 m of frontage encompassing 929,000 m^2 for handling cargo. Other facilities include five container terminals, special service berths and passenger terminals. Seven berths are used for ship repair and there are four marshalling areas. In total, these facilities cover nearly 20,000 m of wharf frontage, encompassing nearly 2 million m^2 (Board of Commissioners of the Port of New Orleans, 1983).

7.2.5 RAILWAY SYSTEMS

Alabama

Coastal Alabama is served by four line-haul companies, three of which terminate in Mobile, and all offer container "piggy-back" and traditional freight-carrying services (Figure 7.1). The five lines are: (1) Norfolk-Southern; (2) Illinois Central Gulf; (3) Seaboard Systems; (4) Burlington Northern; and Terminal Railroad. Baldwin County, however, is served by only one line, Seaboard Systems. The southern extension of that line is scheduled to be discontinued in 1984.

Mississippi

Three rail lines provide coastal and inland access to coastal Mississippi. The primary coastal line is Seaboard Systems which links Pascagoula, Biloxi, and Gulfport to Mobile and New Orleans. Pascagoula has north-to-south rail access with the Mississippi Export Co., which connects Pascagoula with the Illinois Central Gulf Railway at Lucedale. The Illinois Central Gulf Railway also provides a north-to-south connection between Gulfport and Hattiesburg (Figure 7.1).

Louisiana

Ten rail lines currently serve southeast Louisiana. The Southern Pacific, Kansas City Southern (Louisiana and Arkansas), and Missouri Pacific (Texas and Pacific) open Louisiana to western markets. The midwest grain-producing regions are linked to Louisiana through the Illinois Central Gulf

Table 7.2. Port Facilities - Port of New Orleans.

GENERAL CARGO BERTHS	MOORING FRONTAGE LIN.FT.	WHARF FRONTAGE LIN.FT.	WHARF AREAS COVERED S.F.	OPEN S.F.	MARSHALLING AREA S.F.	TOTAL S.F.
Henry Clay Avenue	----	842	95,020	216,325	154,126	465,471
Nashville Avenue	----	2,759	756,000	353,061	875,588	1,984,649
Napoleon Ave. A and A Open	----	1,099	155,177	172,442	97,845	425,464
Napoleon Ave. B	----	762	100,381	120,508	57,991	278,880
Napoleon Ave. C and Open	----	1,375	199,859	196,592	22,903	419,354
Milan Street	----	1,270	107,081	122,244	28,232	257,557
La. Ave. E, F, & G	----	1,590	48,915	261,964	----	310,879
Harmony Street	----	1,089	135,652	168,831	64,675	369,159
Seventh Street	----	1,196	119,280	180,271	----	299,551
First Street	----	1,275	147,427	140,665	10,907	298,999
St. Andrew Street	----	1,598	212,954	89,706	----	302,660
Celeste Street	----	1,200	194,407	57,337	----	251,744
Market Street	----	1,015	178,405	49,715	----	228,120
Orange Street	----	1,017	199,879	45,439	----	245,318
Robin Street	----	1,216	226,701	65,609	----	292,310
Thalia Street	----	860	146,639	61,183	72,414	280,236
Erato Street[1]	----	987	----	----	----	----
Julia Street[1]	----	1,189	----	----	----	----
Upper Poydras Street[1]	----	530	----	----	----	----
Bienville Street	----	1,664	257,100	124,797	----	381,897
Gov. Nicholls Street	----	1,211	156,617	103,935	----	260,552
Esplanade Avenue	----	584	99,031	30,201	----	128,232
Mandeville Street	----	1,121	146,035	56,461	----	202,496
Press Street	----	958	72,259	69,122	----	141,381
Congress Street	----	968	121,033	101,466	54,768	277,267
Pauline Street	----	582	85,084	67,871	----	152,955
Poland Street	----	932	85,000	147,138	----	232,138
Alabo Street	----	1,316	125,310	272,664	207,849	605,823
Galvez Street	----	2,475	452,000	189,132	62,500	703,632
Perry Street	----	1,009	160,000	99,349	33,368	292,717
Sub-Totals	----	35,689	4,783,246	3,564,028	1,743,166	10,090,440

[1] Leased to L.W.E. thru term of fair.

CONTAINER TERMINALS	MOORING FRONTAGE LIN.FT.	WHARF FRONTAGE LIN.FT.	WHARF AREAS COVERED S.F.	OPEN S.F.	MARSHALLING AREA S.F.	TOTAL S.F.
France Road Berth 1	----	830	[2]	140,148	1,459,260	1,599,408
France Road Berth 4	----	700	[2]	115,594	1,036,002	1,151,596
France Road Berth 5	----	900	[2]	128,667	1,458,869	1,587,536
France Road Berth 6 (Class "A&B" Ro/Ro)	500	800	[2]	118,200	1,749,201	1,867,401
Jourdan Road Berths 4 & 5	----	1,400	142,400	289,445	440,460	872,305
Sub-Totals	500	4,630	142,400	792,054	6,143,792	7,078,246

SPECIAL SERVICE BERTHS	MOORING FRONTAGE LIN.FT.	WHARF FRONTAGE LIN.FT.	WHARF AREAS COVERED S.F.	OPEN S.F.	MARSHALLING AREA S.F.	TOTAL S.F.
Harmony St. Annex (Barge)	----	88	10,260	5,183	----	15,443
Dwyer Road (Class "A" Ro/Ro)	500	310	[2]			
Florida Ave. (2 Berths Class "A" Ro/Ro)	500	482	86,400	43,103	212,639	342,142
Public Grain Elevator	----	2,694	----	79,700	----	79,700
Westwego Grain Elevator	----	1,221	----	17,667	----	17,667
Public Bulk Terminals	----	2,036	----	59,212	----	59,212
Westwego Barge Fleeting	1,995	----	----	----	----	----
Bermuda St. (Rest. & Fireboat)	----	860	----	----	----	----
La. Ave. A, B, C, & D (Barge)	----	1,876	224,063	58,107	----	282,170
Washington Avenue	----	871	162,949	15,912	----	178,861
Third Street	----	605	65,352	27,130	----	92,482
Louisa Street (Barge)	----	1,061	46,530	122,525	----	169,055
Piety Street (Barge)	----	523	61,500	39,356	----	100,856
Desire Street (Water Taxi)	----	440	100,760	31,107	----	131,867
Morrison Yard (Class "A" Ro/Ro)	----	898	[2]	40,729	62,046	102,775
Sub-Totals	2,995	13,965	757,814	548,153	599,251	1,905,218

Table 7.2 - (Continued)

	MOORING FRONTAGE LIN.FT.	WHARF FRONTAGE LIN.FT.	WHARF AREAS COVERED S.F.	OPEN S.F.	MARSHALLING AREA S.F.	TOTAL S.F.
PASSENGER TERMINALS						
Poydras Street	----	840	416,269	57,774	----	474,043
Canal Street (Harbor Cruise)	----	459	----	46,004	----	46,004
Toulouse Street (Harbor Cruise)	----	449	----	89,375	----	89,375
Sub-Totals	----	1,748	416,269	193,153	----	609,422
SHIP REPAIR BERTHS						
Andry Street	----	1,322	28,800	37,644	----	66,444
St. Maurice Ave.	----	1,121	10,660	75,494	154,178	240,332
Surekote Rd.	----	802	----	25,531	----	25,531
Powder Street	----	180	----	14,675	----	14,675
Hines Lane	----	1,970	6,081	106,617	----	112,698
Merrill St. Wharf	----	1,725	----	99,060	----	99,060
Odeon St.	----	1,712	----	77,381	----	77,381
Sub-Totals	----	8,832	45,541	436,402	154,178	636,121
MARSHALLING AREAS						
Louisiana Ave. "C,D,E & F"	----	----	----	----	184,276	184,276
Louisiana Ave. "Field G"	----	----	----	----	75,629	75,629
France Road Berths 2 & 3	----	----	----	----	829,304	829,304
Louisiana Ave. "A & B"	----	----	----	----	31,928	31,928
Sub-Totals	----	----	----	----	1,121,137	1,121,137
TOTALS	3,495	64,864	6,145,270	5,533,790	9,761,524	21,440,584

WHARVES 12.8 miles

[2]Covered areas incl. in marshalling areas.

[3]Under construction.

Annual Directory, 1983-84

Source: Board of Commissioners, Port of New Orleans, 1983

Railway and the Missouri Pacific Railroads. The south region and Atlantic coast are tied to Louisiana by the Seaboard Systems, and Norfolk-Southern railroad systems. Locally, the New Orleans and Lower Coast Railroad serve Plaquemines Parish (Figure 7.1).

7.2.6 HIGHWAY SYSTEMS

Alabama and Mississippi

The southernmost portions of Alabama and Mississippi are easily accessed by an extensive, modern highway system (Figure 7.1). Interstate Highway 10 skirts the coast from Mobile to New Orleans and is paralleled by U.S. Highway 90. No bridges link the Mississippi barrier island to the mainland, while Dauphin Island, Alabama is tied to south Mobile County by a new high rise bridge which replaced the bridge destroyed by Hurricane Frederic in 1979. Coastal Baldwin County is served by State Highway 59 which connects with Interstate Highway 10.

Louisiana

Southeast Louisiana's coastal lowlands are not easily accessed by roads and highways. Southern Plaquemines Parish is served by one highway, State Highway 23, which runs along the west bank of the Mississippi River, and ends at Venice. The eastern half of Plaquemines Parish is accessible only by boat south of Bohemia (Figure 7.3). St. Bernard Parish fairs only slightly better, with road access via State Highway 300 to Delacroix, Highway 46 to Shell Beach on Lake Borgne, and Highway 624 to Hopedale.

7.2.7 HYDROCARBON INFRASTRUCTURE

The Gulf of Mexico possesses an intricate network of supply bases for offshore services, platform construction yards, pipeline yards, oil refineries, and petrochemical and gas processing plants. The refineries and gas processing plants are listed in Table 7.3. The regional distribution of oil refineries and gas processing plants reflects the history of oil and gas exploration in the Gulf. Of the three refineries listed within Mobile County, Alabama, none receives hydrocarbons from offshore production. Coastal Mississippi, however, has one oil refinery, the largest capacity refinery on the Gulf coast east of the Mississippi River, and receives petroleum originating from southern Louisiana, Saudi Arabia, Mexico, and Alaska. Thus, Louisiana refineries are the primary facilities currently utilizing Gulf of Mexico OCS hydrocarbons in the study area. In addition to the three existing plants in Mobile County, Alabama, Mobil Oil and Exxon intend to construct plants to process the hydrocarbons produced from their leases in south Mobile Bay and offshore Alabama.

Offshore, the predominant oil and gas features are fixed platforms, and an associated network of pipelines. Pipelines fall into two general types: gathering lines and transmission lines. Gathering lines collect hydrocarbons from scattered platforms and fields and transfer the material to a central location. Transmission lines move the collected hyhdrocarbons to an onshore processing facility (U.S. Department of the Interior, Minerals Management Service (MMS), 1983).

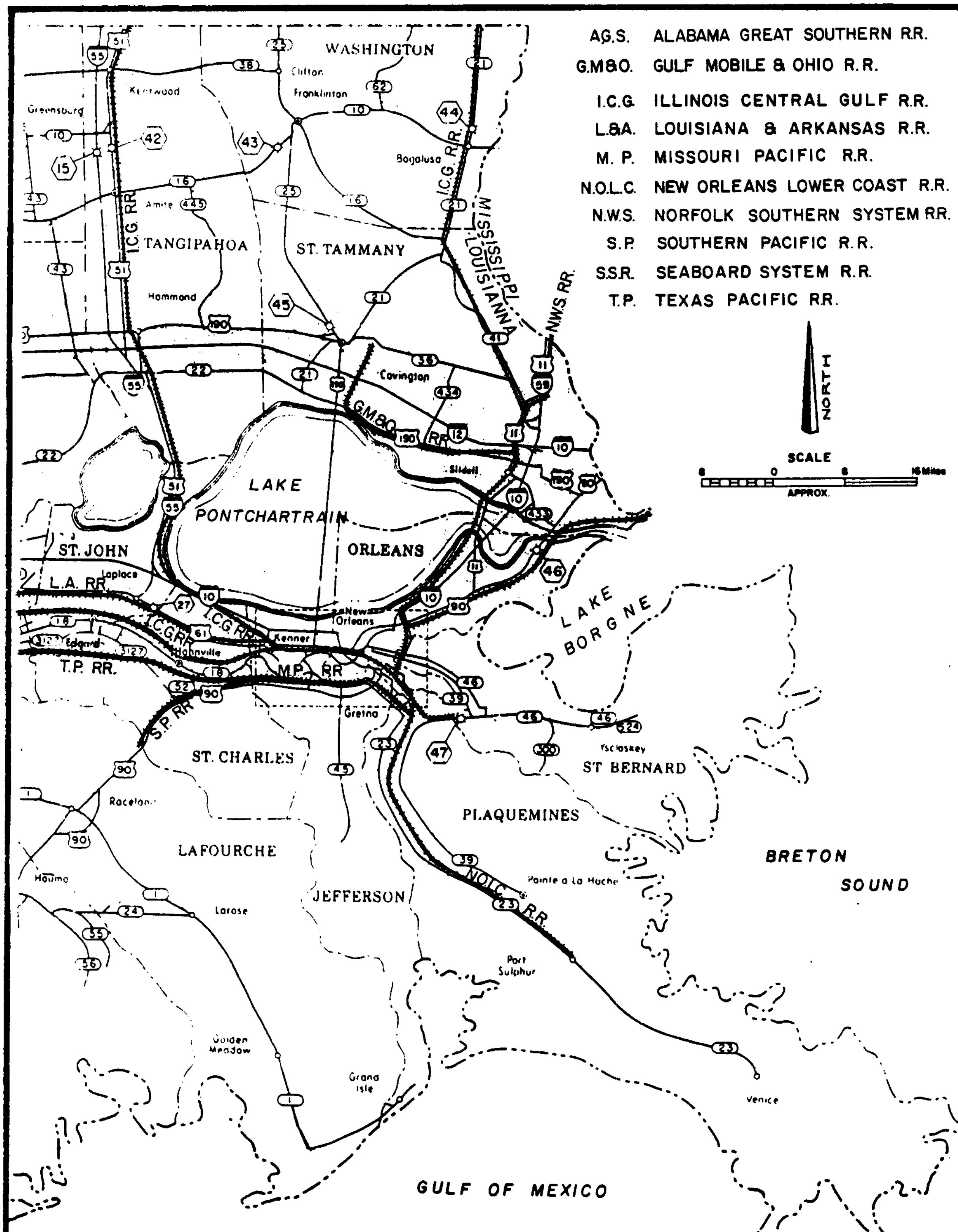


Figure 7.3 Southeast Louisiana highway and railroad systems.
Source: Louisiana Highway Department, 1984

TABLE 7.3. Refineries and Gas Processing Plants.

REFINERIES

State	Company	Capacity (bbl/day)	Location County/Parish	Location Town
ALABAMA				
	Louisiana Land and Exploration Company	80,000	Mobile	Saraland (Mobile)
	Marion Corporation (in bankruptcy)	27,000	Mobile	Theodore
	Mobile Bay Refining Company	80,000	Mobile	Mobile (Chickasaw)
LOUISIANA				
	Gulf Oil Corporation	205,000	Plaquemines	Belle Chase
	Murphy Oil Corporation	92,500	St. Bernard	Meraux
	Tenneco Oil Company	114,000	St. Bernard	Chalmette
MISSISSIPPI				
	Chevron U.S.A., Inc.	295,000	Jackson	Pascagoula

GAS PROCESSING PLANTS

State	Company/Plant	Capacity (mmcfd)	Location County/Parish	Location Town
ALABAMA				
	Getty Oil Company	50	Mobile	Satsuma
	Union Oil Company of California	57	Mobile	Chunchula
LOUISIANA				
	Getty Oil Company	65	Plaquemines	Buras
	Getty Oil Company (Bastian Bay)	150	Plaquemines	Buras
	Warren Petroleum Company	819	Plaquemines	
	Shell Oil Company	850	St. Bernard	Toca
	Shell Oil Company	1,850	St. Bernard	Yscloskey
	Southern Natural Gas Company	525	St. Bernard	Chalmette (on emergency standby only)
	Gulf Oil U.S.	1,000	Plaquemines	Venice
	Union Texas Petroleum Corporation	160	St. Bernard	Toca
MISSISSIPPI				
	Damson Oil Corporation	100	Hancock	Kiln
	Crystal Oil Company	96	Hancock	Waveland

Source: MMS, 1984

The historic trends in the development of hydrocarbon extraction in the Tuscaloosa Trend region are revealed by the locations of existing pipelines in the study area (Figure 7.4). There are currently no OCS pipelines making landfall in Alabama, and only two which enter Mississippi, though no production platforms lie immediately offshore from Mississippi. Oil and gas activity has traditionally centered on the southern Louisiana area and is manifested by a clustered network of pipelines and platforms.

7.3 TRAVEL, TOURISM AND RECREATION

7.3.1 ALABAMA

Alabama's coastal region has about 80 km of beach fronting the Gulf of Mexico and 103 km on Mobile Bay, Wolf Bay, Weeks Bay, Perdido Bay, and along the eastern Alabama portion of Mississippi Sound. The Gulf beaches are broad, white, sandy strands, and are generally more popular than the estuarine and sound beaches. Visitors swim, sunbathe, fish, surf, and search the tideline for shells.

Gulf beaches are located along two stretches, separated by Main Pass at the mouth of Mobile Bay. Dauphin Island has 24 km of Gulf beach and the Pleasure Island area in Baldwin County provides an additional 51 km of Gulf access. Most of the Gulf beachfront is privately owned. The State of Alabama owns a 5 km stretch of beach, with public facilities, associated with the Gulf State Park. The City of Gulf Shores operates a 458 m long public beach, while on Dauphin Island there is an additional 0.8 km of public beachfront.

The south Baldwin County Gulf shoreline has been extensively developed as a resort area, including condominiums, hotels, and seasonal residences. In 1982, about 1.5 million people visited the Gulf State Park and 114,000 visited nearby Fort Morgan. In 1983 nearly 1.6 million visitors utilized the park's facilities. As of May 1984, 824,287 individuals had utilized the facilities as compared with 649,020 for the same period in 1983 (Alabama Dept. of Conservation and Natural Resources, Division of State Parks, 1984).

Mobile and Baldwin Counties have excellent water areas for recreation. The surface water area for the Mobile River Delta, Little Lagoon, Mississippi Sound (in Alabama) and Perdido Bay totals more than 161,000 ha. The adjacent open Gulf waters provide additional, vast, readily available opportunities for boating and fishing. Access to these tremendous recreational resources is primarily through nearly 4,500 ha of publicly owned or maintained shorefront recreational areas (Figure 7.5) (U.S. Corps of Engineers, 1984).

Coastal Alabama also has four special management areas, thus designated for their unique environmental attributes or values. These are: (1) the Audubon Wildlife Sanctuary on Dauphin Island; (2) the Bon Secour Wildlife Refuge; (3) the Mobile-Tensaw River Delta; and (4) Point aux Pins in Mississippi Sound. The Audubon Wildlife Sanctuary, leased by the National Audubon Society, encompasses 64 ha on the eastern end of Dauphin Island. The sanctuary is also protected as an "Area for Preservation and Restoration" by the Alabama Coastal Area Management Plan. The Bon Secour Wildlife Refuge is actually several noncontiguous tracts that the U.S. Fish and Wildlife Service has proposed to acquire and include in the National Wildlife Refuge System. When all of the land is acquired there may be nearly 2400 ha of beach dune and

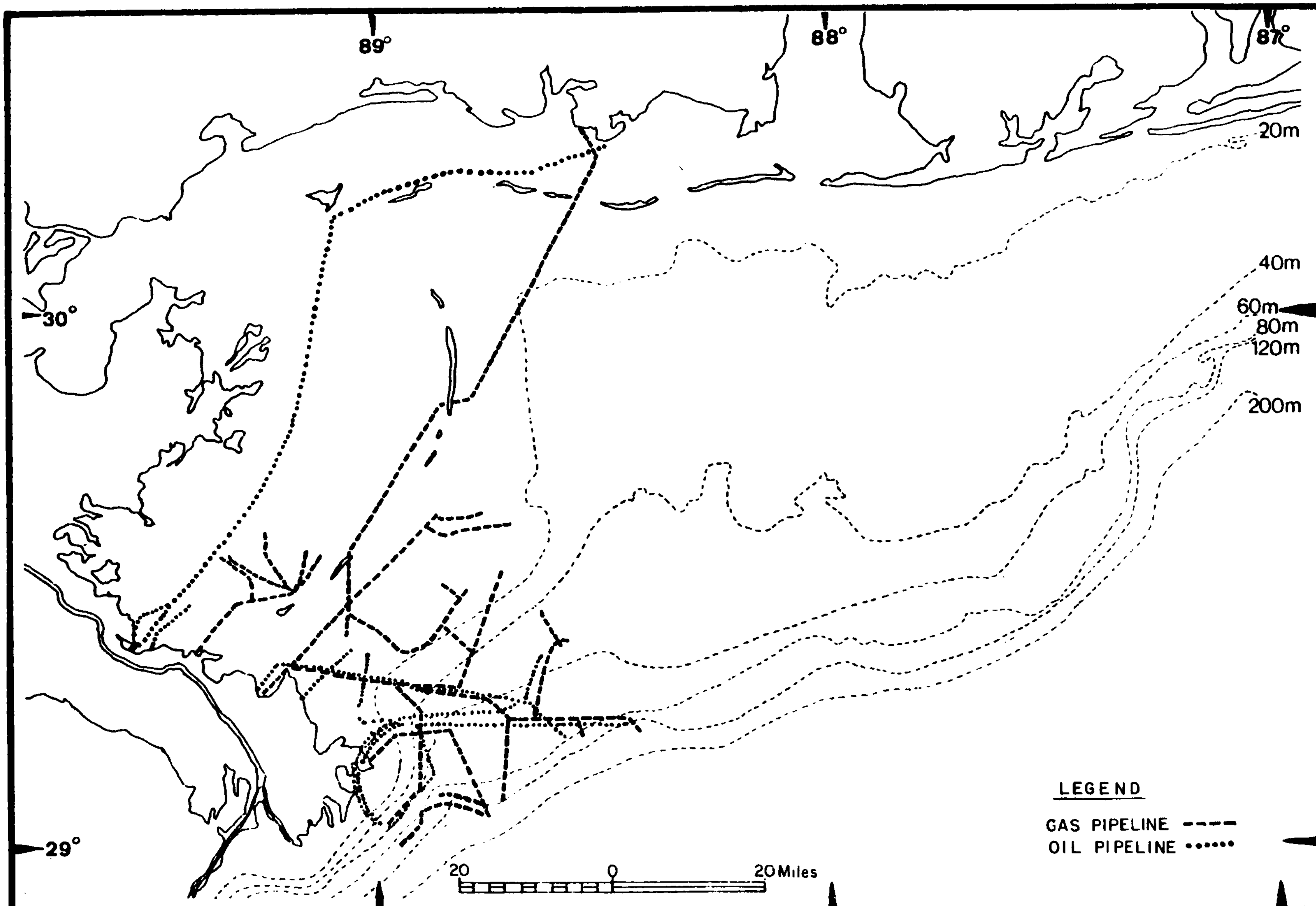


Figure 7.4 Offshore oil and gas pipeline system. Source: MMS, 1983

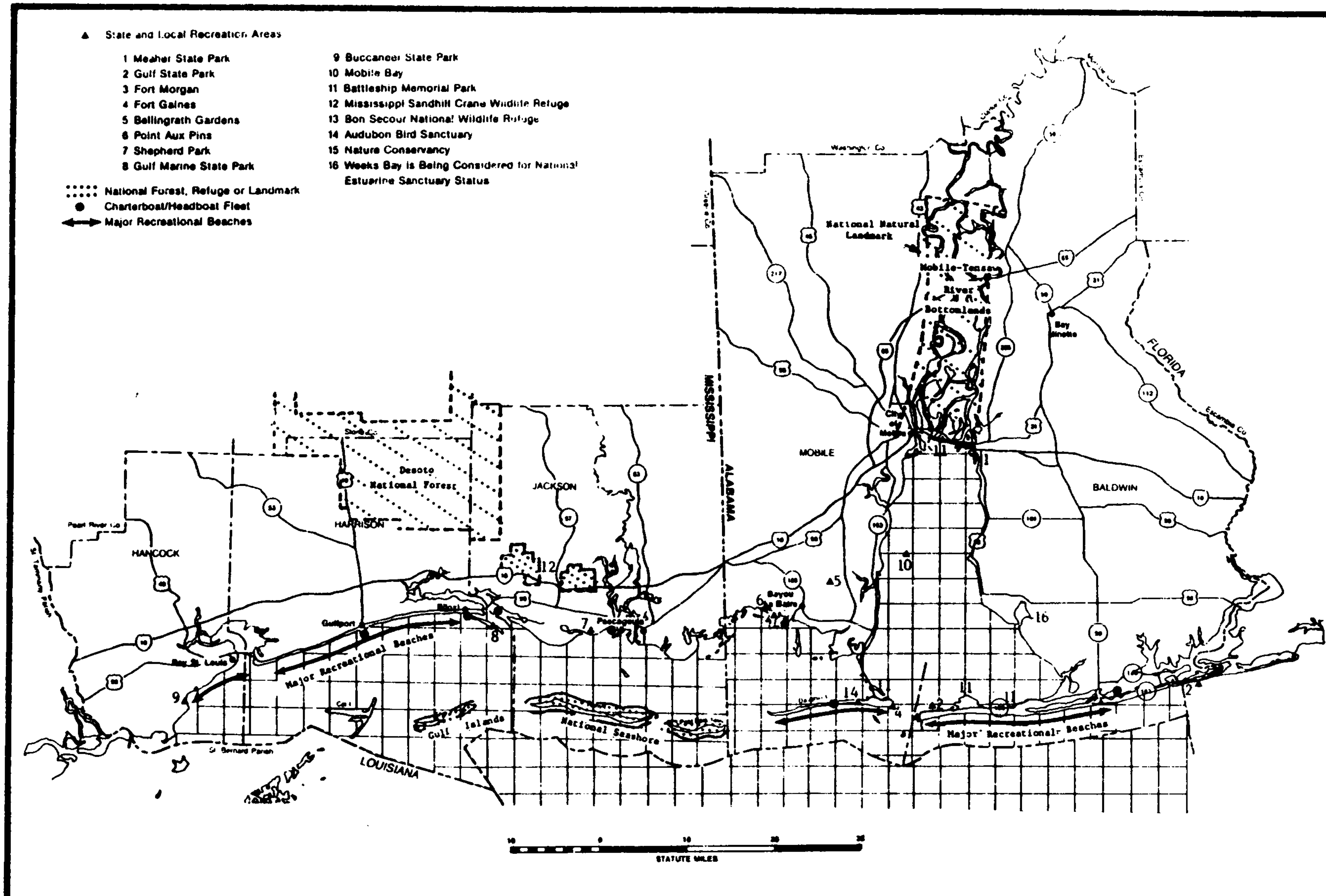


Figure 7.5 Coastal recreation areas. Source: U.S. Army Corps of Engineers, 1984

backshore habitat. Four tracts have thus far been purchased: the Purdue tract, Beneficial tract, and Sand Bayou on Fort Morgan Peninsula; and Little Dauphin Island, in the lee of the east end of Dauphin Island. The Mobile-Tensaw River Delta encompasses approximately 541 km^2 of bottomland forest, swamp and open-water which bounds Mobile Bay on the Bay's northern end. The Delta has been placed on the National Register of Natural Landmarks. The fourth special management area is Point aux Pins, situated between Grand Bay on the west and Portersville Bay on the east. Point aux Pins is owned by the Board of Trustees of the University of Alabama and is used as an open-air laboratory and wildlife refuge. It has been designated as an "Area for Preservation and Restoration" by the Alabama Coastal Management Plan (Gulf of Mexico Regional Technical Working Group, 1981).

In addition to the natural recreational resources afforded by the Gulf of Mexico and adjacent shoreline Alabama's coastal region also provides organized, developed recreational activities which attract tourists to the region. Bellingrath Gardens and Home in southern Mobile County generally attracts 100,000 people annually, generating about $4.1 million. Bayou La Batre in southern Mobile County holds an annual Fleet Blessing which attracts about 14,000 people who spend approximately $200,000 (U.S. Army Corps of Engineers, 1984). Other similar events and attractions include the Alabama Deep Sea Fishing Rodeo on Dauphin Island, sailing regattas, seafood festivals, and the battleship, USS Alabama.

In 1983, 28 million out-of-state residents travelled to or through Alabama. Another 35 million recreational travelers were Alabama residents, for a total of 63 million travelers, a 2.2% increase from 1982 (Adams and Edwards, 1983). Travelers in Alabama generated an estimated $2.9 million, 22% of which was spent in the Gulf region. Nearly 12% of all travel parties in Alabama in 1983 reported "visiting the beaches" as a motivation for coming to the state (Adams and Edwards, 1983). Almost 26% of the Alabama residents who travelled in Alabama noted "visting the beaches" as a travel objective, as opposed to 11% of the non-Alabama residents. The seasonal variation of visitors who cited the Gulf beaches or Mobile as the destination is slight, ranging from 6.4% in the winter to 9.9% in the spring (Adams and Edwards, 1983). The springtime peak perhaps reflects the influx of visitors from northern states.

7.3.2 MISSISSIPPI

The Mississippi Gulf coast has traditionally provided regional recreational amenities. Bay St. Louis in Hancock County attracted large numbers of tourists from New Orleans in the 19th century. In the 19th century, the main economic foundation for the resort trade in Jackson County centered around the therapeutic springs at Ocean Springs. The tradition as a coastal resort area has generated numerous modern-day tourist attractions such as the Longfellow House, the Tullis Manor, Spanish House, French House, Beauvoir, and Ballymere. Other attractions include Old Spanish Fort, Fort Maurepois, and Fort Massachusetts on Ship Island. However, 20th century recreation is primarily oriented towards water-based recreational activities.

The coastal cities of Bay St. Louis, Waveland, Pass Christian, Long Beach, Gautier, Moss Point, and Pascagoula collectively present a broad range of coastal, year-round recreational activities. The beaches, which can accommodate more than 100,000 users at one time, attract the largest number of visitors. Mississippi's 42 km beach is the longest man-made sand beach in the world. This littoral zone and the offshore barrier islands provide a visual focus for the tourist industry. Biloxi, which accounts for more than 50% of the beach users at peak season, is the center of coastal Mississippi's tourist industry. The Biloxi area contains most of the hotel-motel properties. Harrison County, of which Biloxi is the principal urbanized area, claims 85% of the coastal tourist trade (Larson et al., 1980).

In addition to the man-made beach and associated resort developments, there are three state parks and the Gulf Islands National Seashore available as recreational areas. Buccaneer State Park at Waveland provides swimming and camping and has the first wave pool in Mississippi. The park serves both the Mississippi coast and the nearby greater New Orleans area. More than 530,000 visitors utilized the park's facilities in 1983 (Mississippi Department of Natural Resources, 1984).

The Gulf Marine State Park at Biloxi is a water-oriented facility providing a fishing pier, a food service outlet, and a picnic area overlooking the Gulf of Mexico. Nearly 157,000 visitors utilized the facilities in 1983 (Mississippi Department of Natural Resources, 1984). The third state-run facility, Shepard State Park, is still in the developmental phase, and is located on 121 hectares between Gautier and Ocean Springs. The Mississippi Sandhill Crane Refuge is located on the Pascagoula River. The establishment of the Gulf Islands National Seashore has protected a large expanse of sensitive barrier island environment and assured public access to over 700 ha of Gulf and Soundside recreational beaches. The barrier islands, Petit Bois, Horn, and East and West Ship Island are accessible only by boat and retain their integrity as natural scenic areas, supplying a strong contrast to the heavily developed mainland recreational areas. Nearly 850,000 people visited Mississippi's Gulf Islands National Seashore in 1983, a 29% increase from 1982 (Bureau of Business Research, University of Southern Mississippi, 1984).

Coastal Mississippi's favorable position on the Mississippi Sound provides ideal locations for boat access. Two-thirds of the State's marinas and a quarter of Mississippi's boat launching ramps are on the coast. There were more than 60 marinas and 104 launching ramps in 1978. A recent survey conducted by the Department of Geography and Area Development at the University of Southern Mississippi (1984) determined that there are 45 marinas along the coast utilized primarily for recreational boating on the Sound or Gulf. Privately owned marinas constitute over half of those surveyed. Coastal marinas cluster in St. Louis Bay and around the Pascagoula River area, but form a linear pattern between the two clusters.

The travel and recreational industry on Mississippi's Gulf coast has a significant impact on the local economy. The lodging industry has been used as an index of the magnitude of the economic influence on the region. It has been estimated that for every dollar spent on lodging, two more are spent for related goods and services (U.S. Army Corps of Engineers, 1984). There are more than 5,500 hotel/motel rooms available on the Mississippi Coast. In 1983 $51,687,000 was spent on lodging (Bureau of Business Research, University of Southern Mississippi, 1984). Thus, in 1983, hotel/motel sales generated more than $155 million in other travel-related sales.

7.3.3 LOUISIANA

Recreational activities along southeast Louisiana's irregular coastline are either directed inland to the wetlands or to the Gulf of Mexico, where abundant saltwater fisheries supply year-round recreation. (Saltwater recreational fisheries are addressed in section 7.4.4.) The extensive coastal marshes also provide a variety of seasonal recreational opportunities. In the fall and winter months, hunters, trappers, and fishermen exploit the waterfowl, muskrat, nutria, and alligator, as well as fresh and saltwater fish. Spring and summer are important seasons for water-based recreation when shrimp, crab, crawfish, and saltwater fish are abundant.

Much of the marshy region is accessible only by water and there is no efficient transportation network to provide a conduit to the recreational resources. Thus, in order to gain entry to these rich recreational areas, the tradition of establishing seasonal camps has developed. These seasonally-occupied camps provide bases for summertime fishing and wintertime hunting and trapping. While there are restrictive guidelines for the construction of marsh camps established for property owners, there are many camps in the coastal parishes. Plaquemines Parish contained 1,090 camps and Orleans Parish had 1,051 camps in 1979 (Larson et al., 1980).

Even though much of the region consists of open marsh, bayous, and canals, there are two developed state parks which provide recreational opportunities. These are St. Bernard State Park in St. Bernard Parish and Fort Pike State Commemorative Area in Orleans Parish. Fort Pike State Commemorative Area is located on a 51-ha site. The fort was constructed after the War of 1812 to defend the channels heading to New Orleans. In 1983, 184,604 people visited this park (Personal communication, Carolyn Montgomery, Louisiana Department of Culture, Recreation and Tourism). St. Bernard State Park is dominated by the riverine landscape, encompassing about 142 ha on the Mississippi River and offers opportunities for fishing and canoeing in a network of man-made lagoons. Visitation to the park has shown steady increases. In 1983, 80,610 people utilized the park's facilities, a substantial increase from attendance of 46,208 recorded in 1980 (Personal communication, Carolyn Montgomery, Louisiana Department of Culture, Recreation and Tourism).

In addition to the two state parks in the region, there is a small National Historical Park in the northwestern section of St. Bernard Parish. Chalmette National Park encompasses a 57-ha site including the most significant section of Jackson's defensive line against the British Army's General Pakenham during the War of 1812.

A large portion of eastern Plaquemines Parish, most of the northeast section of St. Bernard Parish, and all of the offshore barrier islands are either state or federal wildlife management areas. There are three state-managed wildlife management areas, Biloxi Wildlife Management Area, Bohemia Wildlife Management Area, and Pass A Loutre Wildlife Management Area (Table 7.4). The Biloxi Wildlife Management Area is located in northeastern St. Bernard Parish, only 64 km east of New Orleans, but is accessible only by boat. There are two commercial boat launches, at Hopedale and Shell Beach. The 16,000-ha tract is primarily low brackish to salt marsh interspersed by many bayous, sloughs, and potholes. Bohemia Wildlife Management Area is in central Plaquemines Parish, situated on 9,300 ha east of the Mississippi River. Though there is no vehicular access, visitors may enter the area on

Table 7.4. Land owned or leased by Louisiana Department of Wildlife & Fisheries for public use--Wildlife Management Areas.

Name of Area	Acreage	Location	Recreational Activities Available: Hunting									Sport			Commercial				Facilities	
			Deer	Squirrel	Rabbit	Turkey	Waterfowl	Quail	Doves	Woodcock	Snipe	Bass	Bream	Crappie	Catfish	Buffalo	Gaspergou	Salt Water Species	Camping Area	Boat Ramps
Biloxi	39,583	St. Bernard Parish, Hopedale, 9 miles south; Shell Beach 6 miles southwest Hwy. 46	X	X	X		X		X		X		X					X		
Bohemia	33,000	Plaquemines Parish, 4 miles south of East Point-a-la-Hache	X	X	X		X		X		X	X	X	X					X	
Pass A Loutre	66,000	Plaquemines Parish, 10 miles south of Venice, access by boat on Mississippi River			X		X				X	X	X	X	X				X	X

Source: Brunett and Wills, 1981

foot from the end of Hwy 39, or by boat from back levee canals, oil canals, or the Mississippi River. Bohemia Wildlife Management Area is characterized by high forested levee ridges along the river, gradually dropping to salt marsh to the east. On the river there are black willows, red maple, and live and water oak. A one-hectare camping site is located at the north entrance. Recreational opportunities exist for boating, camping, crabbing, shrimping, blackberry picking, and birdwatching. Pass A Loutre Waterfowl Management Area is located on the southernmost part of Plaquemines Parish, at the mouth of the Mississippi River, ten miles south of Venice. It is accessible only by boat via Mississippi River distributaries. The area is owned by the Louisiana Department of Wildlife and Fisheries, and encompasses nearly 27,000 ha of river channels, pass banks, bayous and man-made canals, separated by intermediate and freshwater marshes. Widespread subsidence has created large ponds. Recreational opportunities exist for salt and freshwater fishing, boating, picnicking, nature study, and crabbing.

In addition to the state-managed wildlife areas, there are also two federally-managed refuges, Delta National Wildlife Refuge at the southern end of Plaquemines Parish, and Breton National Wildlife Refuge which is composed of the Chandeleur Islands and Grand Gossier and Breton Islands. There are also seven state-designated wild and scenic rivers in St. Bernard Parish: Bayou Dupre; Lake Borgne Canal; Bashman Bayou; Terre Beau Bayou; Pirogue Bayou; Bayou Bienvenue; and Bayou Chaperon. The Delta National Wildlife Refuge includes over 19,000 ha of river channels, bayous, canals, and intermediate and freshwater marshes. Annual visitation to the refuge has been estimated to be about 2,000 people (Personal communication, Steve Joyner, U.S. Fish and Wildlife Service, 1984). Visitors utilize the area primarily for fishing and waterfowl hunting. The Breton National Wildlife Refuge (which includes the Chandeleur Islands) encompasses 2,000 ha of barrier island habitat consisting of low dunes, back-barrier marsh and mangrove. Annual visitation is estimated to be about 2,000 people (Personal communication, Steve Joyner, U.S. Fish and Wildlife Service). Visitors primarily use the area for fishing, though individuals sometimes camp on the islands.

In 1982, travellers in Louisiana spent nearly $3.3 billion on transportation, accommodations, meals, entertainment, and other recreation, representing a 3.9% increase over 1981 and a 49.8% increase since 1978 (U.S. Travel Data Center, 1983). Much of the tourist trade in the Louisiana portion of the study area is dominated by New Orleans, which offers such attractions as Mardi Gras, Jazz and Heritage Festivals, the Sugar Bowl, and the 1984 World's Fair. Orleans Parish, including the City of New Orleans, ranked first in the state in travel spending, attracting $1.9 billion, or approximately 57% of the state's total. Plaquemines Parish contributed over $7.8 million in travel related expenditures and ranked 20th. St. Bernard Parish provided $982,000 in travel-related expenditures, and ranked 49th (U.S. Travel Data Center, 1983). Tourist money brought into the state is recycled within the local economy almost four times before it is absorbed by savings, purchases of out-of-state goods and services, or taxes (Larson et al., 1980). Thus, the indirect economic impacts of tourism may be much greater than the expenditures indicate.

7.4 RECREATIONAL FISHERIES

7.4.1 GULFWIDE RECREATIONAL FISHERIES

Marine recreational fishing in the Gulf of Mexico is both a very popular activity and an important contribution to the local and national economy. The National Marine Fisheries Service (NMFS, 1980) estimates that over 3.2 million coastal and non-coastal residents of the Gulf states participated in marine recreational fishing in the Gulf of Mexico in 1979. There were an estimated 19.6 million marine recreational fishing trips made in 1979 in the Gulf region. Marine recreational fishing in the Gulf of Mexico resulted in an estimated $1.32 billion in retail sales in 1980 (Table 7.5). This represents 33.2% of such retails in the United States and is the highest of any region (Figure 7.6) (Sport Fishing Institute, 1983). The marine recreational fishing industry is defined as "those establishments which produce, distribute, and sell goods and/or services to consumers, that are used or consumed as part of a marine fishing trip" (Sport Fishing Institute, 1983). The average value of the sportfishing equipment alone in 1981, based on original purchase price, including rods and reels, special clothing and other tackle, was $376.76 per fisherman for the Gulf region (Hiett et al., 1983).

Overall expenditures for saltwater sportfishing increased 185% between 1972 and 1980, unadjusted for inflation; 27% when adjusted for inflation. The largest percent increases were for food, lodging, transportation, and boat fuel. The smallest increase was in boats, motors, trailers, and boat insurance (Sport Fishing Institute, 1983). Actual trip costs for an individual in the Gulf region averaged $46.06 in 1980 (Hiett et al., 1983); however, this figure varies with the mode of fishing. Fishing from piers or jetties, for example, was the least expensive means, as opposed to utilizing party/charter boat services, which was the most expensive fishing mode. The fishing expenses incurred from pier, jetty, or surf fishing are generally restricted to food, bait, and incidental equipment purchases. Party and charter boat fishing expenses include the initial fees, but also greater food expenditures than shore-based fishing. Private boat owners, after the initial expenditure for the boat, have fuel costs as their greatest expense. These costs are not directly related to the distance travelled from the mainland. Well over half of all monies spent on fishing trips occurs within five miles of the fishing location (Hiett et al., 1983).

The Gulf recreational fisherman fished an average of 20.1 days in 1980. Most fishing trips (70%) are made to locations within three miles of the mainland (Hiett et al., 1983). Though the majority of Gulf recreational fishermen are year-round residents of the region, nearly a third of the saltwater fishermen are visitors on vacation (Hiett et al., 1983). As may be expected, the mode of fishing varies between these two groups. The local resident tends to fish from private or rental boats, while the transient will more likely fish from a party or charter boat. Nearly 45% of the marine Gulf fishermen own their own boats, which are generally single engine, open boats. The National Marine Fisheries Service (NMFS, 1980) estimates that 8,625,000 fishing trips were made in 1979 by Gulf coastal residents using private or rental boats as opposed to 484,000 trips made on party or charter boats. Nearly 64% of party/charter boat use in the Gulf in 1981 was by visitors or part-time residents (Table 7.6) (Hiett et al., 1983). Estimated revenues from charter and party boats for Louisiana, Mississippi, and Alabama totalled

Table 7.5. Economic activity associated with marine recreational fishing in the Gulf regions: Florida, Alabama, Mississippi, Louisiana, Texas.

	Sales (thousands of dollars)	Value Added (thousands of dollars)	Employment (person-years of dollars)	Wages and Salaries (thousands of dollars)	Capital Expenditures (thousands of dollars)
Fishing Tackle:					
Manufacturing	20,060	11,539	342	5,031	692
Wholesale	15,595	4,025	77	1,572	126
Retail	58,104	21,034	701	8,489	1,289
Boats:					
Manufacturing	67,657	29,151	1,326	14,413	1,300
Retail	102,623	19,795	724	10,150	722
Motors:					
Manufacturing	14,846	6,827	130	2.998	614
Retail	20,012	3,865	142	1,987	144
Trailers:					
Manufacturing	5,454	1,878	81	1,156	181
Retail	6,538	975	45	650	36
Marinas:	168,919	51,872	1,829	42.155	4,262
Commercial Sportfishing Vessels	40,706	24,440	1,470	6,594	3,406
Food					
Manufacturing	110,801	51,407	666	21,600	2,767
Wholesale	132,558	19,745	381	8,206	1,321
Retail	172,583	36,598	1,405	17,765	2,924
Restaurants	60,620	31,693	2,031	14,620	2,798
Lodging	58,073	37,761	1,869	16,130	4,590
Public Transportation	22,261	13,080	993	11,539	1,918
Private Transportation:					
Manufacturing	119,919	18,834	65	4,433	2,767
Wholesale	135,954	15,375	327	4,339	1,352
Retail	169,722	32,071	1,478	11,791	3.899
Bait	91,212	28,643	1,245	12,136	1,918
Boat Fuel:					
Manufacturing	165,682	26,006	90	6,130	3,827
Wholesale	219,949	24,852	539	7,044	2,203
Retail	274,602	51,908	2,395	18,964	6,321
Boat Insurance	19,687	9,645	232	3,937	---
Other	54,143	15,595	675	6,760	1,132
Total	1,320,805[1]	588,614	21,258	260,589	52,509

[1] Retail trade only.

Source: SportFishing Institute, 1983

Distribution of Retail Sales to Fishery Management Council Regions, 1980

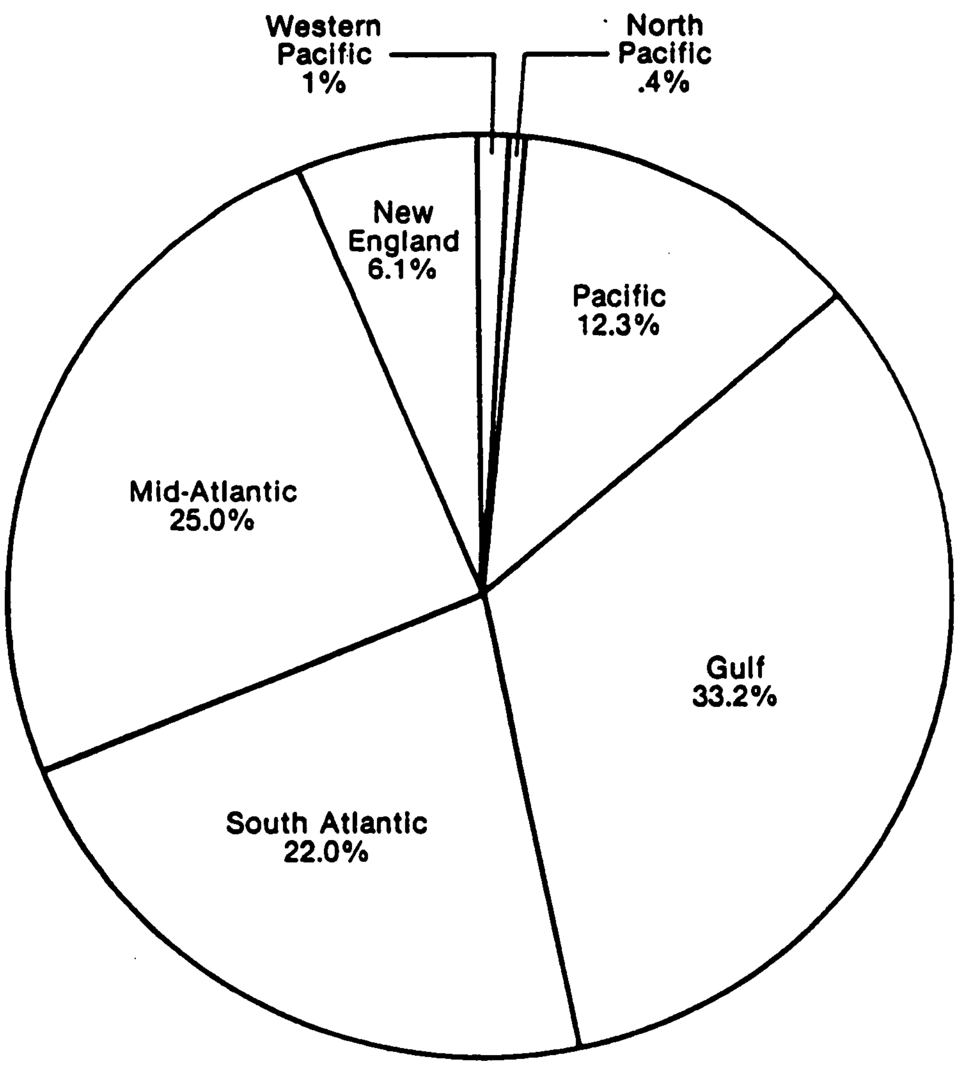


Figure 7.6 Distribution of retail sales to fishery management council regions, 1980. Source: Sport Fishing Institute, 1983

Table 7.6. Percentage distribution of fishermen by resident-visitor status and mode: Gulf Coast.

Residential Status	Shore Modes: Man-Made Structure	Shore Modes: Beach-Bank	Boat Modes: Party-Charter	Boat Modes: Private-Rental	Total
All Year	60.6	63.2	37.4	68.5	58.3
	27.7	19.3	14.6	38.4	100.0
Part Year	3.9	5.7	8.1	6.7	6.1
	17.0	16.8	30.1	36.1	100.0
Visitor on Vacation	33.3	30.0	47.8	23.6	32.9
	27.1	16.3	33.2	23.4	100.0
Visitor on Business	1.6	1.1	5.4	0.4	2.0
	21.6	9.9	62.5	6.0	100.0
Other	0.6	0.0	1.3	0.8	0.7
	21.8	0.0	41.6	36.6	100.0
Total	100.0	100.0	100.0	100.0	100.0
	26.7	17.8	22.8	32.7	100.0

Source: Hiett et al., 1983

$2,778,531 in 1981. Gulfwide, charter/party boat revenues totalled $45,827,445 in 1980 (Sport Fishing Institute, 1983).

The Gulfwide survey conducted for NMFS in 1981 (Hiett et al., 1983) suggests that spotted seatrout is a preferred targetted species with nearly 25% of the respondents (Table 7.7). An examination of catch by species on a state level, however, shows a tremendous variation from state to state (NMFS, 1980) (Table 7.8). Fishermen based in Alabama caught an estimated 68,000 spotted seatrout in 1979, whereas Mississippi-based fishermen brought in 485,000; and those fishing from Louisiana caught nearly 4.3 million spotted seatrout. It is also noteworthy that more than half of the Gulf fishermen reported no species preference, which may be due to the wide variety of available species. Private boat fishermen are slightly more likely to have species preferences than those who fish from jetties, piers, or other means (Table 7.9).

Almost half of the individuals who fish in the Gulf of Mexico are satisfied with their marine recreational experience. Overall, however, boat fishermen reported higher levels of satisfaction than those who fished by other modes. Not surprisingly, the number of fish caught, regardless of species, was the most important factor determining satisfaction, even if the fish were not kept. The species which were most likely to be retained included bluefish, spotted seatrout, tuna, mackerel, and snapper (Hiett et al., 1983).

There are numerous artificial reefs in the Tuscaloosa Trend study area. Reefs include deliberately-sunk Liberty ships, tugs, or discarded oil platforms, as well as bridge remnants and other rubble. The locations of these permitted structures are shown on Figure 7.7. Many fish species, such as groupers, are only found concentrated around petroleum platforms and other reefs in the northern Gulf of Mexico. Platforms in the northern Gulf provide recreation to fishermen and scuba divers, and in the northwestern Gulf attracted more fishing than any other structure, natural or artificial (Gallaway and Lewbel, 1982).

Recreational billfish surveys have been conducted in the Gulf of Mexico since 1971 to monitor trends in recreational billfishing catch and effort (NMFS, 1984a). There appears to be a continuing decreasing trend in the availability of billfish to anglers in the northern Gulf. When the indexes of relative abundance for each of three species (white marlin, blue marlin, and sailfish) were analyzed in relation to the 13-year average, it was found that in 1983 the number of fishes hooked per hour of trolling (HPUE) was 1% below that in 1982, and 3% below the 13-year average (NMFS, 1984a). Figure 7.8 presents an index of the number of billfishes that surface to take a bait, divided by the number of hours fished within a sampling grid square. Table 7.10 gives statistics on fishing effort and catch for sportsfishing harbors within the Tuscaloosa Trend study area. As can be seen from Figure 7.8, abundant billfish catches occurred at the head of DeSoto Canyon, along the shelfbreak south of Mobile Bay, and southeast of the Mississippi River Delta.

Surveys conducted for the Gulf States Marine Fisheries Commission (Brown et al., 1980) estimated that Gulf-wide over 239,000 recreational shrimpers made over 700,000 inshore boat trawl trips in 1979. During the May-October survey period, these recreational shrimpers caught an estimated 4.8 million kg of shrimp.

Table 7.7. Marine anglers' stated species preferences with percentages, in the Gulf of Mexico.

Species	Percent	S.E.
Spotted Seatrout	24.5	3.57
Red Drum	15.0	2.96
Other Drum	9.3	2.19
Sea Bass-Grouper	8.0	1.51
Sheepshead	7.3	2.83
Tuna-Mackerel	5.6	1.54
Red Snapper	5.4	1.53
Other Snapper	3.6	1.34
King Mackerel	2.4	0.87
Atlantic Croaker	1.3	0.71
Jacks	0.9	0.60
Sharks-Skates-Rays	0.6	0.48
Summer Flounder	0.6	0.55
Bluefish	0.3	0.38
Porgies-Scup	0.1	0.27
All Other Fish	15.4	2.66

Source: Hiett, et al., 1983

Table 7.8. Estimated total number of fish caught by marine recreational fishermen, by species group and state. January 1979 - December 1979.

		Thousands		
		Alabama	Mississippi	Louisiana
1.	Barracudas	*	*	*
2.	Basses, Sea	*	*	*
3.	Bluefish	36	36	300
4.	Blue Runner	85	—	*
5.	Bonito, Atlantic	—	*	—
6.	Catfishes, Sea	296	425	4,345
7.	Catfishes, Freshwater	*	*	156
9.	Croaker, Atlantic	553	1,017	5,888
11.	Dolphins	*	*	—
12.	Drum, Black	—	—	894
13.	Drum, Red	—	—	1,450
14.	Drums	—	*	125
15.	Eel, American	—	—	—
16.	Flounders, Summer	80	—	760
18.	Flounders	—	44	—
19.	Groupers	—	*	—
20.	Grunt, White	*	*	*
21.	Grunts	—	—	*
23.	Herrings	422	—	—
24.	Jack, Crevalle	—	—	—
25.	Jacks	31	—	56
26.	Kingfishes	681	79	—
27.	Ladyfish	127	79	61
28.	Little Tunny	—	—	—
30.	Mackerel, King	—	*	—
31.	Mackerel, Spanish	269	—	88
32.	Mackerels and Tunas	*	*	—
33.	Mullets	—	248	37
34.	Perch, Sand	*	*	*
35.	Perch, Silver	—	—	—
38.	Pigfish	—	34	*
39.	Pinfish	213	32	30
41.	Porgies	*	*	*
42.	Puffers	*	—	*
43.	Scup	*	*	*
44.	Searobins	—	—	*
45.	Seatrout, Sand	90	527	2,225
46.	Seatrout, Silver	*	*	*
47.	Seatrout, Spotted	68	485	4,271
48.	Sharks	93	—	—

Table 7.8. (Continued)

		Alabama	Mississippi	Louisiana
		- - - - - - - - - Thousands	- - - - - - - - - - - -	
49.	Sharks, Dogfish	*	*	*
50.	Sheepshead	_	53	598
51.	Skates and Rays	_	_	_
53.	Snapper Gray	*	*	*
54.	Snapper, Red	150	_	714
55.	Snapper, Vermillion	_	*	*
56.	Snappers	_	*	_
57.	Spadefish, Atlantic	_	_	65
58.	Spot	*	_	*
59.	Striped Bass	*	*	_
61.	Toadfishes	_	_	_
63.	Trigger and Filefishes	_	*	_
66.	Other Fish	69	99	163
	TOTALS	3,468	3,386	22,424

NOTE: An asterisk (*) denotes none reported.

NOTE: An underscore (_) denotes less than thirty thousand reported. However, the figure is included in row and column totals.

Source: NMFS, 1980

Table 7.9. Percentage distribution of fishermen by mode and indicator of species preference.

Level of Preference	Shore Modes		Boat Modes	
	Man-Made Structure	Beach-Bank	Party-Charter	Private-Rental
Atlantic				
Specified Target	49.9	49.1	56.5	75.0
No Preference	50.1	50.9	43.5	25.0
Gulf				
Specified Target	32.5	30.2	42.1	60.3
No Preference	67.5	69.8	57.9	39.7
Pacific				
Specified Target	42.0	54.4	49.1	66.8
No Preference	58.0	45.6	50.9	33.2

Source: Hiett et al., 1983

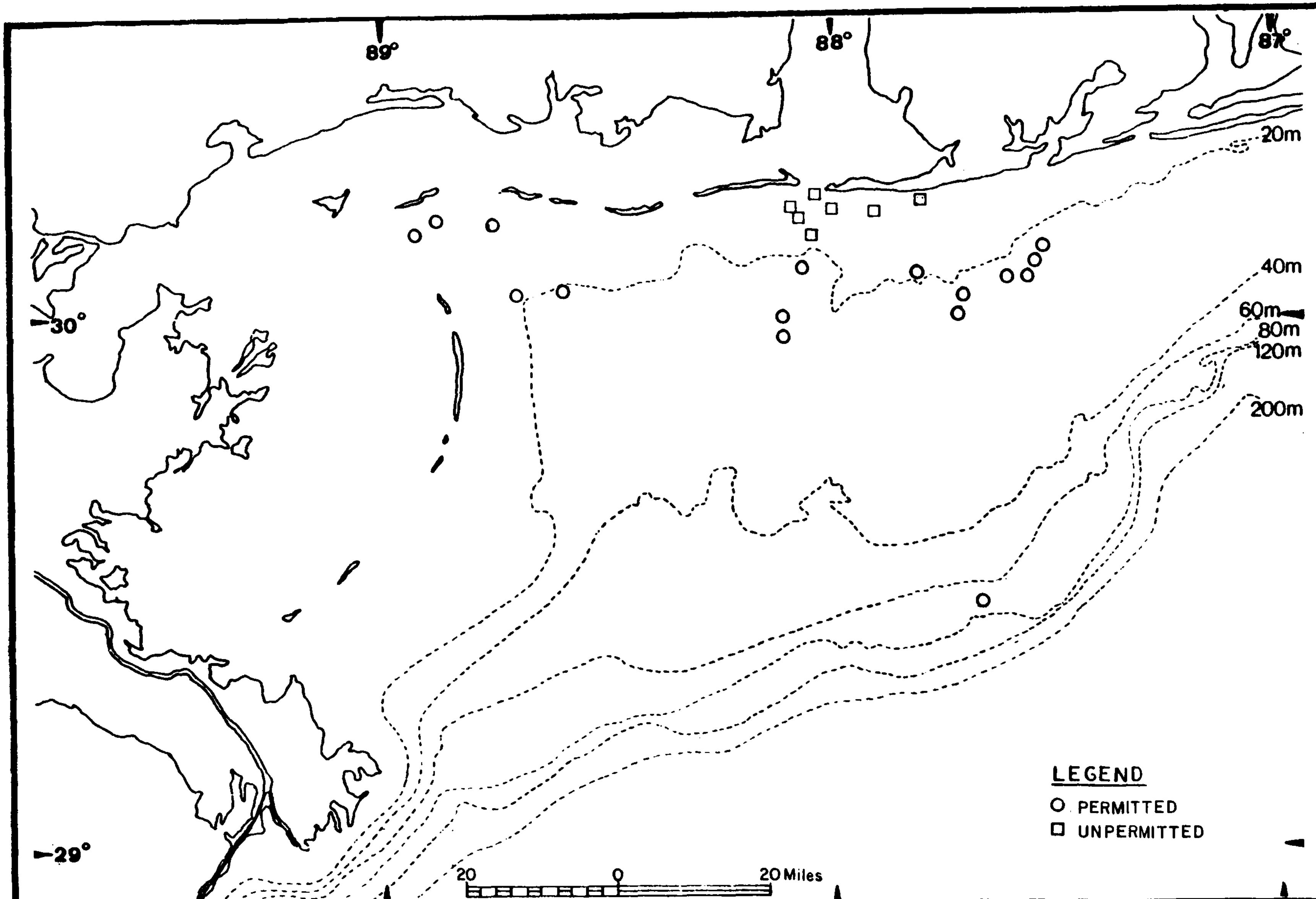


Figure 7.7 Artificial fishing reefs. Source: MMS, 1984

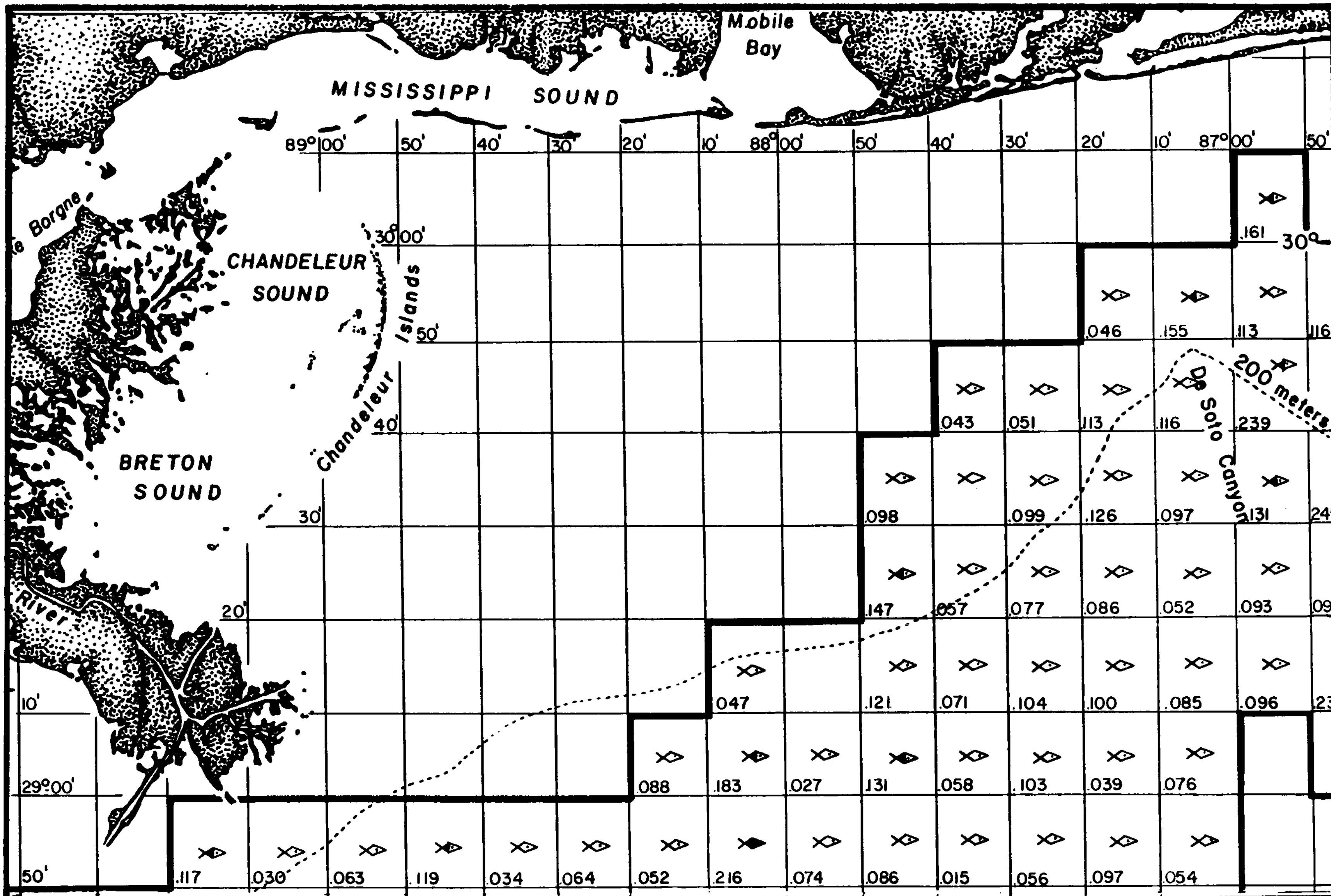


Figure 7.8 Numbers of billfishes hooked per hour of trolling (HPUE) by time of day in the Tuscaloosa Trend study area, 1983. Source: Modified from NMFS, 1984

Table 7.10. Hours trolled and billfishes raised (R), hooked (H), and boated/released [B(R)] in the northern Gulf of Mexico, 1983.

		Blue marlin			White marlin			Sailfish			Swordfish			Spearfish			All species combined		
	trolled	R	H	B(R)	R	H	B(R)	R	H	B(R)	R	H	B(R)	R	H	B(R)	R	H	B(R)
Pensacola	2,611	88	80	15(10)	251	193	50(50)	17	17	10(2)	0	0	0(0)	0	0	0(0)	356	290	75(62)
Mobile	4,581	130	115	50(6)	277	233	67(62)	20	18	14(1)	6	6	5(0)	0	0	0(0)	433	372	136(69)
South Pass	8,111	369	233	65(40)	536	354	111(149)	9	9	5(3)	1	1	0(0)	0	0	0(0)	915	597	181(192)
Total all areas																			

Source: NMFS, 1984a

7.4.2 ALABAMA RECREATIONAL FISHERIES

Marine recreational fishing is a popular pastime along the Alabama coast. In 1979, there were estimated to be 106,000 coastal participants, 41,000 non-coastal Alabama residents, and 57,000 out-of-state marine fishermen, for a total of 204,000 individuals fishing marine waters out of Alabama (National Marine Fisheries Service, 1980). Estimates from the same survey indicate that these anglers caught nearly 3.9 million fish. Kingfish were the most numerous species landed (681,000), followed by Atlantic croaker (553,000) (Table 7.8). Only 68,000 spotted seatrout, the species most often specified by fishermen Gulf-wide who seek a particular species, were estimated to have been landed by fishermen out of Alabama.

Boat ownership is an index of the local participation in marine recreational fishing. Wade (1977) estimated that about 76% of the fishing man-hours and 86% of the landings, by weight, were from private boats. The number of Class I and Class II boats increased 91% in coastal Alabama between 1959-1980 (Table 7.11). In 1983, there were 29,000 motorboats registered in Mobile and Baldwin counties (Alabama Marine Police, 1984). Wade (1977) estimates that privately owned boats made 247,858 trips into marine waters in 1975. The National Marine Fisheries Survey (NMFS, 1980) estimates that 958,000 fishing trips were made out of Alabama waters in 1979.

The charter boat industry is another important component of recreational fishing in Alabama. The Sports Fishing Institute (1983) estimates that charter and headboats in Alabama generated $819,086 in revenues in 1980. Currently, 24 charter boats operate out of coastal Alabama. The principal harbor for the charter fleet is at Orange Beach in Baldwin County.

Recreational shrimping, with 4.9 m (16-ft.) trawls, and sometimes cast nets, is an important local sports fishery. In Alabama, shrimping is allowed year-round, except where the waters are permanently closed. During the closed commercial season the daily limit is set at 2.5 kg per person, or a maximum of 6.8 kg per boat. The open commercial season limit increases to 11.3 kg per person. No license is required for 4.9 m (16-ft.) trawls, if the catch is not sold. Peak shrimping is in late June through August.

7.4.3 MISSISSIPPI RECREATIONAL FISHERIES

Marine recreational fishing is also a major activity in Mississippi. There were nearly 24,000 motorboats registered in Mississippi's coastal counties through July 1984, a 20% increase over 1980 (Personal communication, Jordon, Mississippi Game and Fish Commission, 1984). A 1977 study (Etzold et al., 1977) found that the majority of non-resident fishermen surveyed visited the Mississippi coast to go fishing. In surveying participants of the coast's charter boat industry, the study found that 83% of the anglers were either from inland counties of Mississippi or were from out-of-state (57%). Only 17% indicated they were from the three coastal counties. Etzold et al. (1977) also estimated that for every dollar spent on charter fees, three more dollars go to other businesses. Currently, there are 19 charter boats operating on the Mississippi Gulf Coast, 17 of which are located in Biloxi (NMFS, 1984b). The Sports Fishing Institute (1983) estimates that charter and headboats in Mississippi generated $830,756 in revenues in 1980. Thus, the recreational

Table 7.11. Number of boat licenses sold by boat classes[a], Mobile and Baldwin Counties, Alabama, for selected years through 1980.

County, license type	1959-60	1964-65	1969-70	1974-75	1979-80
Mobile County					
Class I	7,703	8,534	10,557	11,962	11,886
Class II	1,869	2,457	3,607	4,632	5,775
Class III	362	393	NA	361	429
Class IV	29	19	NA	23	34
Subtotal	9,963	11,403	NA	16,978	18,124
Baldwin County					
Class I	2,774	2,199	2,704	4,701	4,686
Class II	425	377	686	1,757	2,036
Class III	125	53	NA	170	175
Class IV	11	5	NA	14	18
Subtotal	3,335	2,634	NA	6,642	6,915
Coastal Region					
Class I	10,477	10,733	13,261	16,663	16,572
Class II	2,294	2,834	4,293	6,389	7,811
Class III	487	446	NA	531	604
Class IV	40	24	NA	37	52
Total	13,298	14,037	NA	23,620	25,039

[a]Class I - boats less than 16 ft. in length; Class II - boats at least 16 ft. but less than 26 ft.; Class III - boats at least 26 ft. long but less than 40 ft.; Class IV - boats 40 ft. or more in length.

NA - Not available.

Source: Friend et al., 1982 from Alabama Department of Conservation and Natural Resources, Division of Marine Police.

fishing potential on the Mississippi coast is not only a significant attraction to non-coastal tourists, but is also a boost to the local economies.

Another indication of the importance of the marine recreational fisheries to the Mississippi coast was provided by the National Marine Recreational Fisheries Survey (NMFS, 1980). NMFS estimated that 88,000 coastal residents, 15,000 non-coastal Mississippi residents, and 52,000 out-of-state fishermen fished in Mississipppi. The Atlantic croaker was the primary species caught (1,017,000), followed by the sand seatrout (527,000), and the spotted seatrout (485,000) (NMFS, 1980). In total, sportfishermen caught nearly 3.4 million fish in 1979 (NMFS, 1980) (Table 7.8).

7.4.4 LOUISIANA RECREATIONAL FISHERIES

Fishing is a year-round recreational activity in southeast Louisiana. The targetted species varies according to breeding cycle of the fishes, water levels, fishing pressure, and habitat productivity. Saltwater fishermen primarily catch spotted seatrout, Atlantic croaker, red fish, and black drum. In 1979, NMFS (1980) estimated that the spotted seatrout comprised 19% of the catch in Louisiana by numbers.

Louisiana's offshore waters differ from those off Mississippi and Alabamna for sportfishing purposes due to the presence of numerous oil and gas platforms. The presence of oil and gas production platforms has greatly enhanced the offshore sportfishery in Louisiana. The structures provide solid substrate where none existed previously, thus attracting a much more diverse range of fish species. Since the advent of construction of the offshore structures, the great barracuda (*Sphyraena barracuda*), which was previously unknown in sport catches, has been found in Louisiana waters (Dugas et al., 1979).

Dugas et al. (1979) subdivided offshore rig fishing into a sharply delineated vertical two-story fishery, and a more gradual, geographically nearshore "green water" and offshore "blue water" fisheries. The former is composed of a bottom stratum with benthic and groundfish species, and a mid-level/surface stratum based on a variety of pelagic and free-swimming species. Geographically, there is an ecological gradient from nearshore estuarine-dependent species, and coastal nearshore species to offshore oceanic species. Off Louisiana, "blue water" varies from 56-120 km, depending on seasonal meteorological and/or hydrological regimes. Blue water trolling does not depend solely on oil platforms, but "blue water" fishermen make a concerted effort to troll adjacent to oil rigs whenever the opportunity presents itself (Dugas et al., 1979).

Table 7.12 presents a summary of the dominant and targetted species for each type of oil rig fishing offshore Louisiana. Generally, drift fishing and trolling land the midlevel and surface species, while bottom fishing takes the benthic species. The most highly prized species are speckled trout, silver seatrout, and red snapper in nearshore areas, while red snapper and grouper are the most highly prized species in "blue water" areas (Dugas et al., 1979). Preferred pelagic (migratory) species caught by troll and drift fishing include red drum, cobia, and king mackerel nearshore, while wahoo, dolphin, blue marlin, white marlin, and sailfish are the targetted "blue water" species (Dugas et al., 1979).

Table 7.12. Summary of major game species caught at oil rig platforms by bottom, drift, and troll fishing in nearshore and blue-water areas.

	Bottom		Drift		Trolling	
	Nearshore	Blue-water	Nearshore	Blue-water	Nearshore	Blue-water
Shark (several species)			X	X		
Arius felis (sea catfish)	X					
Bagre marinus (gafftopsail catfish)	X					
Epinephelus spp. (grouper)		X				
Mycteroperca phenax (scamp)		X				
Pomatomus saltatrix (bluefish)			X		X	
Rachycentron canadum (cobia)			X			
Caranx crysos (blue runner)			X		X	
Caranx hippos (crevalle jack)			X		X	
Seriola dumerili (greater amberjack)		X		X		X
Coryphaena hippurus (dolphin)						X
Lutjanus campechanus (red snapper)	X	X				
Lutjanus griseus (gray snapper)	X	X				
Lutjanus synagris (lane snapper)		X				
Archosargus probatocephalus (sheepshead)	X					
Cynoscion arenarius (sand seatrout)	X					
Cynoscion nebulosus (speckled seatrout)	X					
Cynoscion nothus (silver seatrout)	X					
Menticirrhus americanus (southern kingfish)	X					
Micropogon undulatus (Atlantic croaker)	X					
Pogonias cromis (black drum)	X					
Sciaenops ocellata (red drum)			X			
Sphyraena barracuda (great barracuda)				X		X
Acanthocybium solanderi (wahoo)						X
Euthynnus alleteratus (little tuna)					X	
Sarda sarda (Atlantic bonito)			X		X	
Scomberomorus cavalla (king mackerel)			X		X	
Scomberomorus maculatus (Spanish mackerel)					X	
Thunnus albacares (yellowfin tuna)				X		
Thunnus atlanticus (blackfin tuna)		X		X		
Istiophorus platypterus (sailfish)						X
Makaira nigricans (blue marlin)						X
Tetrapturus albidus (white marlin)						X

November-December 1979

Source: Dugas et al., 1979.

Charter boats based in Venice, the Mississippi River Gulf Outlet, and other locations transport sportfishermen to excellent fishing spots. The estimated revenue from charter and headboats was $1,128,689 in 1980 (Sport Fishing Institute, 1983). There are currently 37 charter boats operating out of Louisiana, 9 of which will accommodate charter dive parties (NMFS, 1984b).

The popularity of fishing in southeast Louisiana is manifested by the number of fishing licenses sold. In 1983, nearly 31,000 resident, 1550 seasonal non-resident, and 949 non-resident trip licenses were issued in Orleans, Plaquemines, and St. Bernard parishes (Table 7.13). For the period from 1979 through 1983, there was a 24% increase in recreational fishing licenses sold in these parishes. The percentage of fishing license holders who fish the sounds and Gulf waters is not known, but an estimate of the number of participants in marine recreational fishing in 1979 suggests there were 489,000 coastal participants and 46,000 out-of-state marine fishermen (NMFS, 1980). It is estimated that these anglers caught 22,424,000 fish in 1979. The Atlantic croaker contributed the greatest number (5,888,000) followed by the sea catfish (4,345,000) and spotted seatrout (4,271,000).

There were 12,061 boats registered in Orleans Parish, 3,492 in Plaquemines Parish, and 5,838 boats registered in St. Bernard Parish in 1983 (Louisiana Department of Wildlife and Fisheries, 1984). These figures must be interpreted with care, as there are undoubtedly many trailered boats from other parishes and states which utilized the parishes' access areas and fishing waters.

7.5 COMMERCIAL FISHERIES

Commercial fisheries provide a valuable resource to the coastal economies within the Tuscaloosa Trend study area. In 1983, nearly $42.6 million entered Alabama's economy via Gulf of Mexico commercial fisheries, nearly $26 million of which came from Federal OCS waters (NMFS, 1984c). Mississippi commercial fishery landings generated $48.4 million for the state's economy, $14.8 million of which was derived from Federal OCS waters (NMFS, 1984c). Louisiana has the largest commercial fishery of the three states studied, and brought in over $225 million from the Gulf of Mexico waters (NMFS, 1984c), $71.5 million of which were derived from between 5 and 320 km from U.S. shores:

	Total	OCS Waters
Alabama	42.6	25.9
Mississippi	48.4	14.8
Louisiana	225.2	71.5

Even though it is clear from the figures above that a considerable amount of the commercial fisheries activity occurs at least 5 km offshore, much of the commercial catch is composed of estuarine-dependent species (i.e., Atlantic croaker, Atlantic flounder, mullet, porgy, spotted seatrout, the white seatrout, menhaden, shrimp, and blue crabs.

Table 7.13. Fishing licenses sold by Parish, 1979-1983.

	1979-80			1980-81			1981-82			1982-83		
	resident	non-resident (season)	non-resident (trip)	resident	non-resident (season)	non-resident (trip)	resident	non-resident (season)	non-resident (trip)	resident	non-resident (season)	non-resident (trip)
Orleans	17489	1855	1564	22588	2944	1738	24846	3238	10136	19999	1466	754
Plaquemines	2597	22	20	3124	18	91	2715	28	72	3377	41	137
St. Bernard	4879	45	25	6391	37	44	7130	26	53	7553	44	58
TOTAL	24965	1922	1609	32103	2999	1873	34691	3292	10261	30929	1551	949

Source: Personal communication, Smith, Louisiana Wildlife and Fisheries Commission, 1984

In Alabama, 92% of the catch by weight and 98% of the value of the commercial catch is composed of estuarine-dependent species. The commercial catch in Mississippi is at least 87% estuarine-dependent species by weight and 88% by value. Over 99% of Louisiana's commercial fisheries catch by weight and 98% by value is estuarine-dependent (Table 7.14).

Table 7.14. Contribution of Estuarine Dependent Species to Commercial Fisheries, 1983.

	Thousand Pounds	%	Thousand Dollars	%
Alabama	19,162	92	41,659	98
Mississippi*	382,192	87	42,704	88
Louisiana	1,778,107	99	220,647	98

*Published landings for the Atlantic croaker, an estuarine-dependent species, are substantially less than actual landings due to disclosure restrictions. Therefore, these low percentages must be interpreted accordingly.

Source: NMFS, 1984c

7.5.1 ALABAMA COMMERCIAL FISHERIES

Shrimping

The commercial shrimping industry is by far the most economically important fishery in Alabama, contributing over $40 million to the economy in 1983 (Table 7.15). In 1983, it comprised 74% of the weight and 94% of the value of the total Alabama seafood landings. The majority of the shrimp catch came from between 5 and 320 km offshore, at $24.8 million.

The Alabama shrimping industry consists of two general boat types and shrimping areas, bay and inshore shrimping, and offshore shrimping. The Alabama inshore or bay boat shrimping fleet is composed of boats less than 4.5 MT. This class of boat shrimps primarily from June to October. However, the relative economic importance of the inshore fleet has diminished appreciably in recent years. The inshore fleet landed only 7% of the catch in 1972 compared with 30% in 1964, even though the total shrimp landings for Alabama more than doubled during that time. The difference reflects the increasing importance of the offshore fleet.

Three species of shrimp occur in Mobile Bay: white shrimp (*Penaeus setiferus*); brown shrimp (*P. aztecus*); and pink shrimp (*P. duorarum*). Pink shrimp comprise only about 1% of the landings. Brown shrimp comprise 70% of the landings from Mobile Bay (Heath, 1979).

Table 7.15. Commercial Shrimp Landings.

	ALABAMA	
	Lbs.	Value ($)
1979	20,408,463	48,431,296
1980	15,157,969	30,658,698
1981	21,249,897	38,096,113
1982	16,797,000	41,400,000
1983	15,416,000	40,025,000

Source: NMFS, 1982a, 1982b, 1982c, 1984c

There is a degree of seasonality in the inshore shrimping industry. Brown shrimp are harvested in Mobile Bay and Mississippi Sound from May to August (Benson, 1982). Brown shrimp begin migrating offshore in June and continue until November. The commercial size brown shrimp population within Mobile Bay from June through August has been estimated to range from 52 to 135 MT (Loesch, 1976). However, the white shrimp are most abundant in Mississippi Sound and Mobile Bay from July to November. Commercial size white shrimp in Mobile Bay during this time period has been estimated to be from 30 to 121 MT (Loesch, 1976).

Blue Crabs

Among the Alabama fisheries, the blue crab fishery has been the least studied; therefore, knowledge of the commercial and recreational involvement is limited. There is no license requirement for commercial or recreational crab fishermen in Alabama, and the number of fishermen and fishing units (pots) is unknown. Approximately 20% of the commercial crab catch is harvested by recreational crabbers. Tatum (1979) feels that this estimate is very conservative.

The crab fishery represented only 4.5% of the total weight of seafood landed, and 1.1% of the total seafood value in 1972. In 1983, those figures were 3.5% and 1.3%, respectively (Table 7.16). Although the general catch trend for blue crabs is considered stable, there are considerable year-to-year fluctuations. The crab catch in 1977 was 60% greater than the 1976 catch, but it was approximately the same as the 1945, 1966, and 1967 catches (Tatum, 1979).

The blue crab fishery is plagued by biological and socioeconomic limiting factors. Crabbing is generally accomplished with trap lines. Approximately 5% of the total blue crabs landed are harvested by shrimp trawl, while the remainder are caught in traps. Crabbers typically set lines with 200-1000 traps in the spring and rarely move them until November. The trap catch drops as the water temperatures fall in November. Through the peak harvest months of July, August, and September, there are periods in which unpredictable masses of oxygen-deficient water engulf the trap lines, killing the trapped crabs. Peak harvest months occur simultaneously with the peak shrimping season, which attracts crabbers to the more lucrative shrimp fishery.

Table 7.16. Commercial Blue Crab Landings.

	ALABAMA	
	Lbs.	Value ($)
1979	1,340,690	390,823
1980	1,556,674	464,583
1981	2,462,333	849,922
1982	1,266,153	478,987
1983	1,412,000	514,000

Source: NMFS 1982a, 1982b, 1982c, 1983, 1984c

Crab fishermen generally prefer to catch male crabs to female crabs. The males are larger and bring more money for an individual crab. Crab pickers are usually paid by picked weight of crab meat, and spend an equal time cleaning small, low-yield females as they do the larger males. Thus, the male blue crab is more profitable for both the fishermen and the processor.

Oysters

Alabama's oyster industry revolves around southern Mobile Bay and eastern Mississippi Sound, although only 10% of the oyster landings in 1977 were taken from Mobile Bay (Eckmayer, 1979). The major producing oyster reef is at Cedar Point (Figure 7.9). Cedar Point Reef is being overfished, as .pa evidenced by certain depleted areas, and little cultch remains for future spat fall. Sand Reef and Buoy Reef, on the other hand, support dense populations of oysters, but are not as easy to harvest Cedar Point Reef, due to periodic inaccessibility and greater water depth (Eckmayer, 1979).

The overall trend for oystering in Mobile Bay has been a shift of the centers of production to the south and west portions of the estuary. The total areas of natural oyster reefs, however, have remained relatively constant with 1,256 ha (3,105 ac) first reported in 1894 (Eckmayer, 1979). Though several of the early principal reefs have nearly disappeared, substantial growth of the Cedar Point Reef has compensated for the loss.

The abundance of oysters fluctuates, with periods of high landings often followed by poor harvest. The average annual landing from 1880 through 1977 was 463,495 kg (1,021,594 lbs.) of oyster meats (Eckmayer, 1979). Since 1979, oyster landings have varied from 29,424 kg in 1980 (after Hurricane

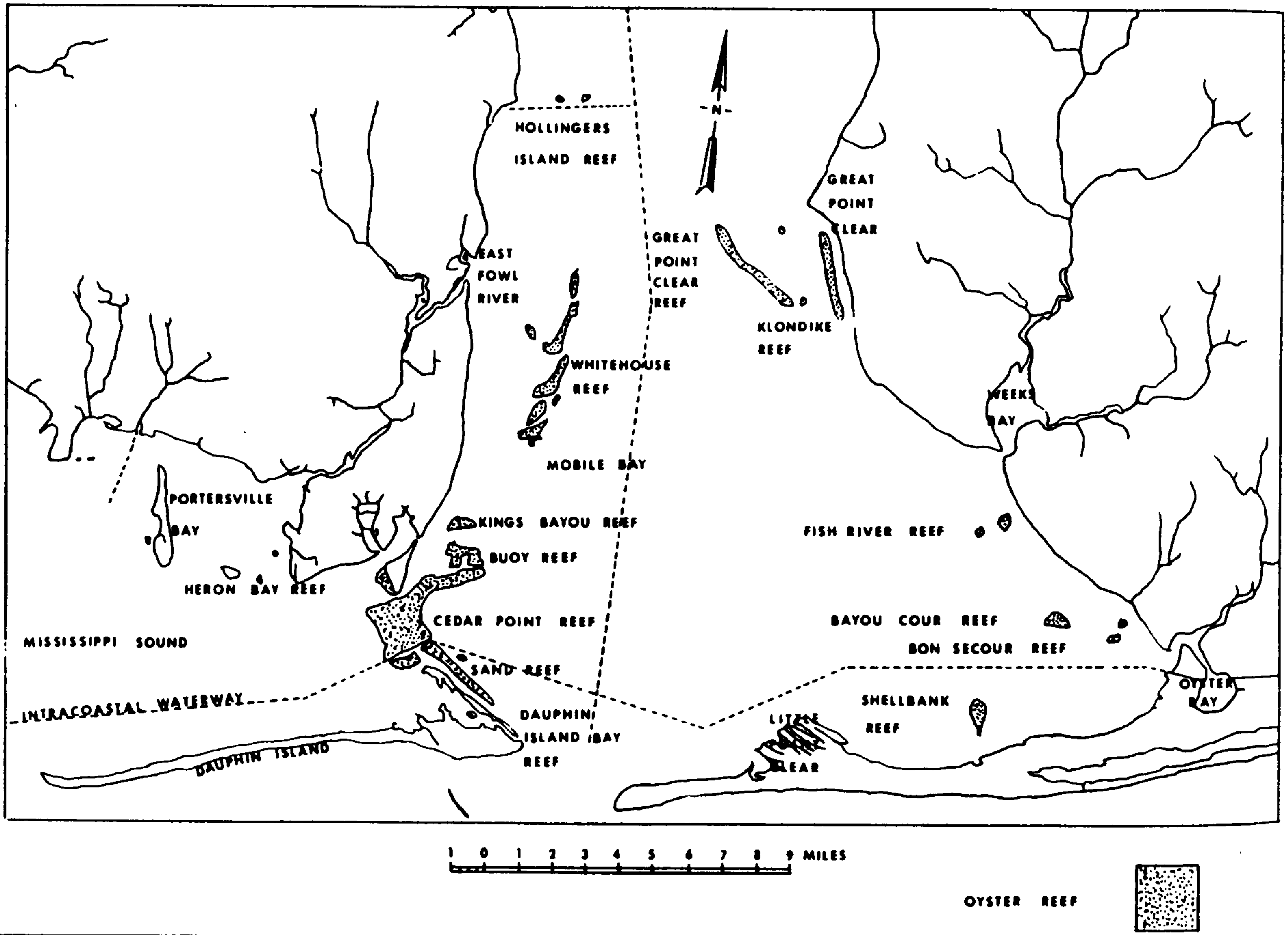


Figure 7.9 Locations of oyster reefs in Bon Secour Bay, Mississippi Sound, and Mobile Bay.
Source: Eckmayer, 1979

Frederic) to 496,062 kg in 1981 (Table 7.17). Landings statistics for the Alabama oyster, however, may be 30% to 40% underestimated (Personal communication, van Hoose, Alabama Department of Conservation and Natural Resources, 1984). There is no program within the Alabama Department of Conservation and Natural Resources established for monitoring the industry, especially the small-scale "backyard" oyster industry.

Table 7.17. Commercial Oyster Landings.

	ALABAMA	
	Lbs.	Value ($)
1979	598,810	479,137
1980	54,755	72,265
1981	1,329,925	2,002,392
1982	1,496,949	2,150,500
1983	335,766	417,000

Source: NMFS 1982a, 1982b, 1982c, 1983, 1984c

Marine Finfish

The marine finfish industry in Alabama provided over $1.6 million to the economy in 1983, or only 3.8% of the total economic value of commercial fisheries landings (Table 7.18). Nearly $1.2 million of this came from waters from 5 to 320 km offshore. The principal commercial fish species landed in Alabama in 1983 was the red snapper, followed by the Atlantic Gulf flounder, mullet, and the Atlantic croaker (NMFS, 1984d) (Table 7.19). However, in previous years the Atlantic croaker has dominated the commercial catch.

Table 7.18. Commercial Finfish Landings.

	ALABAMA	
	Lbs.	Value ($)
1979	7,748,344	1,874,808
1980	8,022,005	2,026,302
1982	7,837,458	3,025,404
1982	5,402,840	2,368,687
1983	3,656,000	1,616,000

Source: NMFS 1982a, 1982b, 1982c, 1983, 1984c

Table 7.19. Principal Commercial Finfish Species, 1983.

Species	ALABAMA Lbs.	Value ($)
Red Snapper	536,000	653,000
Flounder	510,000	248,000
Mullet	567,000	148,000
Croaker	437,000	143,000

Source: NMFS, 1984c

7.5.2 MISSISSIPPI COMMERCIAL FISHERIES

Shrimping

The commercial shrimping industry account for over $21.8 million, or 45% of the value of the total commercial landings in Mississippi in 1983 (NMFS, 1984c) (Table 7.20). Unlike in neighboring Alabama, slightly less than half of the catch came from between 5 and 320 km offshore. Based on NMFS landings statistics since 1978, the 1983 shrimp catch was better than recent harvests.

Table 7.20. Commercial Shrimp Landings.

	MISSISSIPPI Lbs.	Value ($)
1979	8,533,090	16,678,399
1980	5,966,745	10,790,527
1981	8,364,258	10,954,146
1982*		
1983	10,661,000	21,833,000

*Annual catch summary unavailable at time of compilation.

Source: NMFS, 1982a, 1982b, 1982c, 1983, 1984c

Blue Crabs

Mississippi's blue crab fishery provided only 0.7% of the value of the total commercial fisheries at approximately $332,000 in 1983. The 1983 landings weighed 425,220 kg (Table 7.21), which is somewhat less than the 20-year average (1953-1972) of 638,576 kg (Perry, 1975).

Table 7.21. Commercial Blue Crab Landings.

	MISSISSIPPI	
	Lbs.	Value ($)
1979	1,312,650	316,443
1980	2,759,600	692,905
1981	1,866,550	518,667
1982*		
1983	1,140,000	332,000

*Annual catch summary unavailable at time of compilation.

Source: NMFS, 1982a, 1982b, 1982c, 1983, 1984c

Mississippi's blue crab fishery, as in Alabama, is primarily seasonal. Crabbing declines dramatically in the colder months. Where commercial crabbers will work a five-to-six-day week in the peak summer months, the reduced number of crabbers in winter work only a three-to-four-day week. Oystering is a winter alternative for crabbers. Winter crabbing is concentrated in the vicinity of Cat Island and Pass Marianne, with a few crabbers working in Biloxi Bay and south of Deer Island (Perry, 1975). During the spring and summer months, crabbing within the Mississippi Sound is much more widespread. The seasonality of the fishery is reflected in the monthly breakdown of catch per unit effort (CPUE). Catch per unit effort (lbs./per day) is low during spring and fall, peaking in the summer (Figure 7-10). Rises in catch per unit effort closely follow the migration periods of mature female crabs into the Sound. Peaks are associated with the fall-winter arrival of females from Lake Borgne, and the summer migration of females from the Gulf (Perry, 1975).

Oysters

Mississippi's oyster fishery is characterized by considerable year-to-year fluctuations. In 1972, 540,000 kg were harvested from the Mississippi portions of Mississippi Sound. Production dropped to 125,000 kg in 1977, then increased to nearly 630,000 kg in 1977 (Larson et al., 1980). Production had decreased to 101,493 kg in 1979 and dropped further in 1980 to 7,753 kg. In 1983, oyster production in Mississippi was over 1.5 million kg, valued at $4 million at the dock (NMFS, 1984c) (Table 7.22).

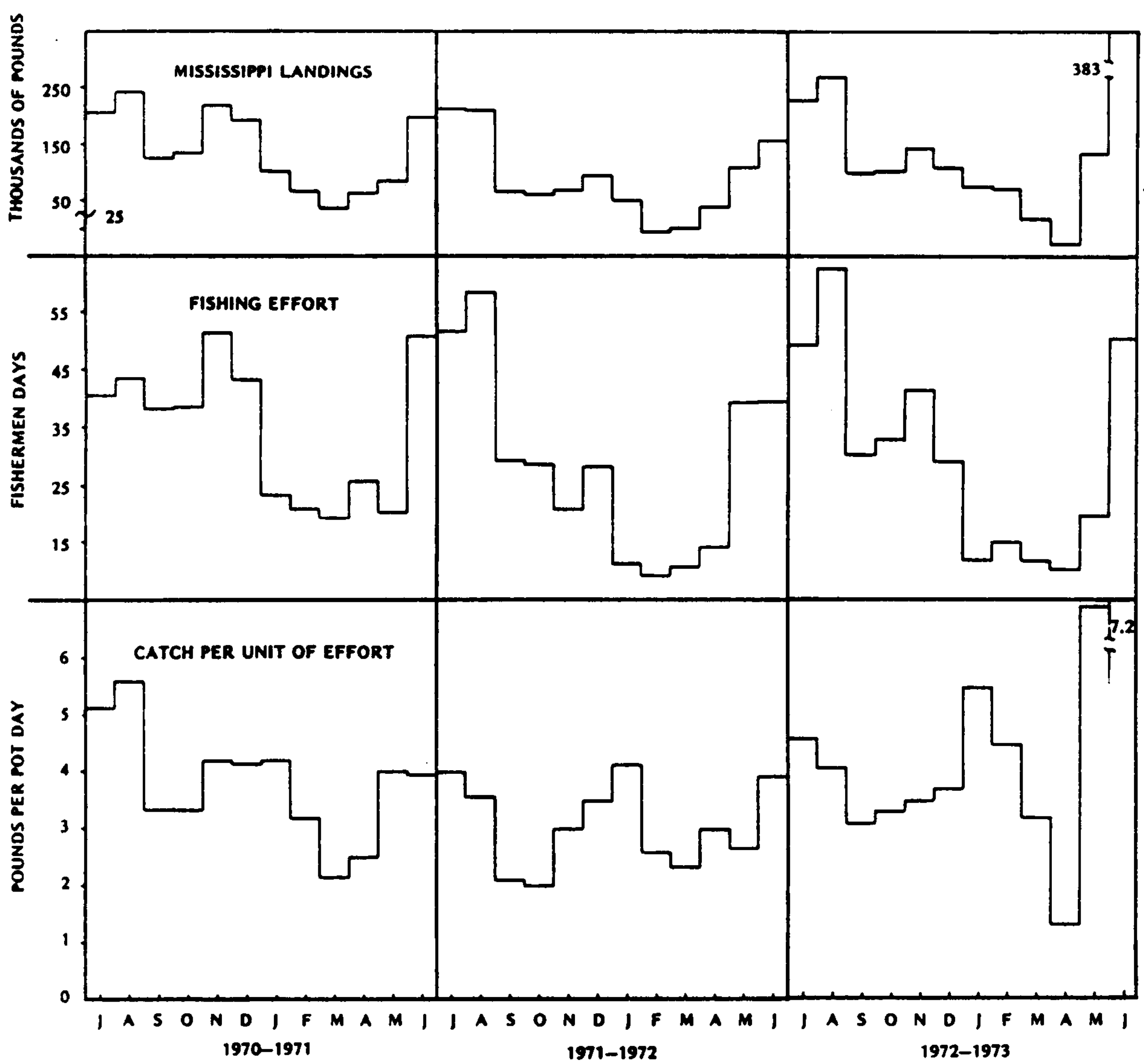


Figure 7.10 Monthly blue crab landings, fishing effort, and CPUE in Mississippi Sound. Source: Perry, 1975

Oyster reefs in Mississippi stretch, as patches, from Pearl River to the Mississippi-Alabama state line. The largest reef, Square Handkerchief Reef, is located south of Pass Christian and covers almost 18,525 ha. In total, there are more than 24,700 ha of live oyster reefs in Mississippi waters (Larson et al., 1980).

Table 7.22. Commercial Oyster Landings.

	MISSISSIPPI	
	Lbs.	Value ($)
1979	272,100	275,471
1980	20,786	21,995
1981	467,070	472,729
1982		
1983	4,109,000	4,110,000

Source: NMFS, 1982a, 1982b, 1982c, 1983, 1984c

Marine Finfish

The marine finfish industry in Mississippi provided over $22.1 million in catch value alone to the economy in 1983, or 46% of the total commercial fisheries landings (NMFS, 1984c) (Table 7.23). Approximately 80% of the finfish catch came from 5 km or less from the shoreline. Menhaden accounted for nearly 73% or $16.1 million of the catch by value (Table 7.23), all of which was harvested 5 km or less from the mainland. The menhaden catch is followed by red snapper in both weight and value ($1.5 million). Unlike menhaden, almost all of the red snapper was harvested between 5 and 320 km offshore. It is noteworthy to add that the published landings for the Atlantic croaker in Mississippi are substantially less than the actual landings because of disclosure problems (Personal communication, Gordon, Mississippi Bureau of Marine Resources). There is a single processing plant located in Biloxi.

7.5.3 LOUISIANA COMMERCIAL FISHERIES

Shrimping

The commercial shrimping industry is the single most valuable commercial fishery in Louisiana. The annual shrimp harvest in 1983 was valued over $133 million at the dock, with nearly 29 million kg (NMFS, 1984). Slightly more than half of the catch came from 5 km or less offshore. Though no landings data by parish are available for 1982 or 1983, annual shrimp landings by parish are available for several earlier years. Thus, a rough comparison can be made between the state as a whole and St. Bernard and Plaquemines

Table 7.23. Commercial Fish Landings.

	MISSISSIPPI	
Finfish	Lbs.	Value ($)
1979	323,799,910	14,928,444
1980	270,119,710	13,360,451
1981	199,311,700	10,750,338
1982		
1983	423,379,000	22,137,000
Menhaden		
1979	318,248,800	12,990,085
1980	262,165,500	11,343,146
1981	193,553,000	8,530,587
1982		
1983	365,084,000	16,105,000

Source: NMFS, 1982a, 1982b, 1982c, 1983, 1984c

parishes (which occur within the Tuscaloosa Trend study area). Shrimp production in Plaquemines and St. Bernard Parishes has consistently been 14% to 16% of the total shrimp production in Louisiana (Table 7.24). In 1981, that represented values of $16.5 million for Plaquemines Parish and $3 million for St. Bernard Parish.

Blue Crabs

Louisiana's blue crab fishery provided only 2.4% of the value of the total commercial fisheries in 1983. The crabbing industry yielded nearly 6.2 million kg of blue crabs, valued at over $5.4 million at the dock in 1983 (NMFS, 1984). Though no landings data by parish are available for 1982 or 1983, annual blue crab landings by parish are available for 1979 through 1981. A rough comparison can be drawn between the state as a whole and Plaquemines and St. Bernard Parishes, based on these years. Table 7.25 presents the blue crab harvest relationshiop between the State blue crab harvest and Plaquemines and St. Bernard Parishes. These two parishes account for approximately 10.3% of the blue crab landings in Louisiana annually.

Oysters

Louisiana's oystering areas are divided into State-controlled regions and oyster grounds that are set aside for leasing by private individuals. The State manages approximately 280,000 ha, of which 6,650 ha are managed as Seed Ground Reservations (Dugas, 1977). Seed Ground Reservations are

Table 7.24. Commercial Shrimp Landings.

LOUISIANA

	Plaquemines Parish		St. Bernard Parish	
	Lbs.	Value ($)	Lbs.	Value ($)
1979	11,076,459	15,777,058	2,928,423	4,245,653
1980	13,825,847	16,173,833	2,479,013	2,699,820
1981	15,872,983	16,528,806	3,000,567	3,029,950
TOTAL:				
1979	14,004,882	20,022,711	78,449,638	122,681,673
1980	16,304,860	18,873,653	90,102,639	120,977,528
1981	18,873,550	19,558,756	112,312,912	136,464,807

PERCENT OF STATE (Value):

1979	16.3%
1980	15.6%
1981	14.4%

Note: No parish level statistics available from 1982, 1983.

Source: NMFS, 1982a, 1982b, 1982c

Table 7.25. Commercial Blue Crab Landings.*

	LOUISIANA			
	Plaquemines Parish		St. Bernard Parish	
	Lbs.	Value ($)	Lbs.	Value ($)
1979	593,609	127,551	1,439,629	306,925
1980	526,556	121,887	2,214,666	500,240
1981	366,654	102,723	1,155,661	317,168
TOTAL:				
1979	2,033,238	434,476	21,480,505	5,114,026
1980	2,741,222	622,127	18,300,842	4,600,749
1981	1,522,315	419,891	16,337,040	4,707,007

PERCENT OF STATE (Value):

1979 8.5%

1980 13.5%

1981 8.9%

Average = 10.3%

*Includes hard, soft, and peeler crabs. Statistics for 1982 and 1983 unavailable for individual parishes.

Source: NMFS, 1982a, 1982b, 1982c

usually entire bays stretching along the coast, harvested on alternate years. Approximately 270,000 ha are managed by the State east of the Mississippi River. In 1976, about 86,200 ha were leased by private individuals in the entire coastal area (Dugas, 1977) (Figure 7.11).

Louisiana leads the Gulf states in oyster production and ranks second nationally, behind Maryland. In 1983, over 4.4 million kg of oysters were harvested from Louisiana waters, yielding nearly $14.6 million at the dock (NMFS, 1984c). Production averages approximately 3.4 million kg per year. This amount is relatively consistent except for instances when major environmental catastrophes disrupt the reefs (Dugas, 1977). The oyster fishery in Louisiana relies heavily on reef management. Commercial oystermen utilize State-managed Seed Ground Reservations as sources for seed oysters. These small (2.5-7.6 cm) seed oysters are approximately one year old and are relocated to other reefs or bedding grounds for 3 to 5 months or longer, depending on the commercial market (Dugas, 1977). Oysters transplanted to high salinity areas throughout the summer are often impacted by high mortalities due to predation from the oyster drill and fungus infections.

Plaquemines and St. Bernard Parishes together produce approximately half of the oysters annually in Louisiana (Table 7.26). In 1981, the oyster harvest in these parishes was valued at $7.5 million, as compared to $16 million for the state as a whole.

Marine Finfish

The marine finfish industry in Louisiana provided nearly $72 million in catch value alone to the economy in 1983, or 32% of the total commercial fisheries landings (NMFS, 1984c) (Table 7.27). Approximately 88% of the catch by weight and 86% by value were obtained from 5 km or less offshore. Menhaden accounted for over 92% or $66.3 million of the finfish catch in value. The menhaden catch is followed by red snapper in value of catch at $1.2 million, and by king mackerel in weight at nearly 0.5 million kg (Table 7.28). Nearly all of the commercial red snapper and king mackerel catch came from between 5 and 320 km offshore.

Table 7.27. Commercial Finfish Landings - Louisiana, 1983.

Distance Offshore	Lbs.	Value ($)
0-5 km	1,476,040	61,611,000
5-320 km	202,660	10,340,000

Source: NMFS, 1984

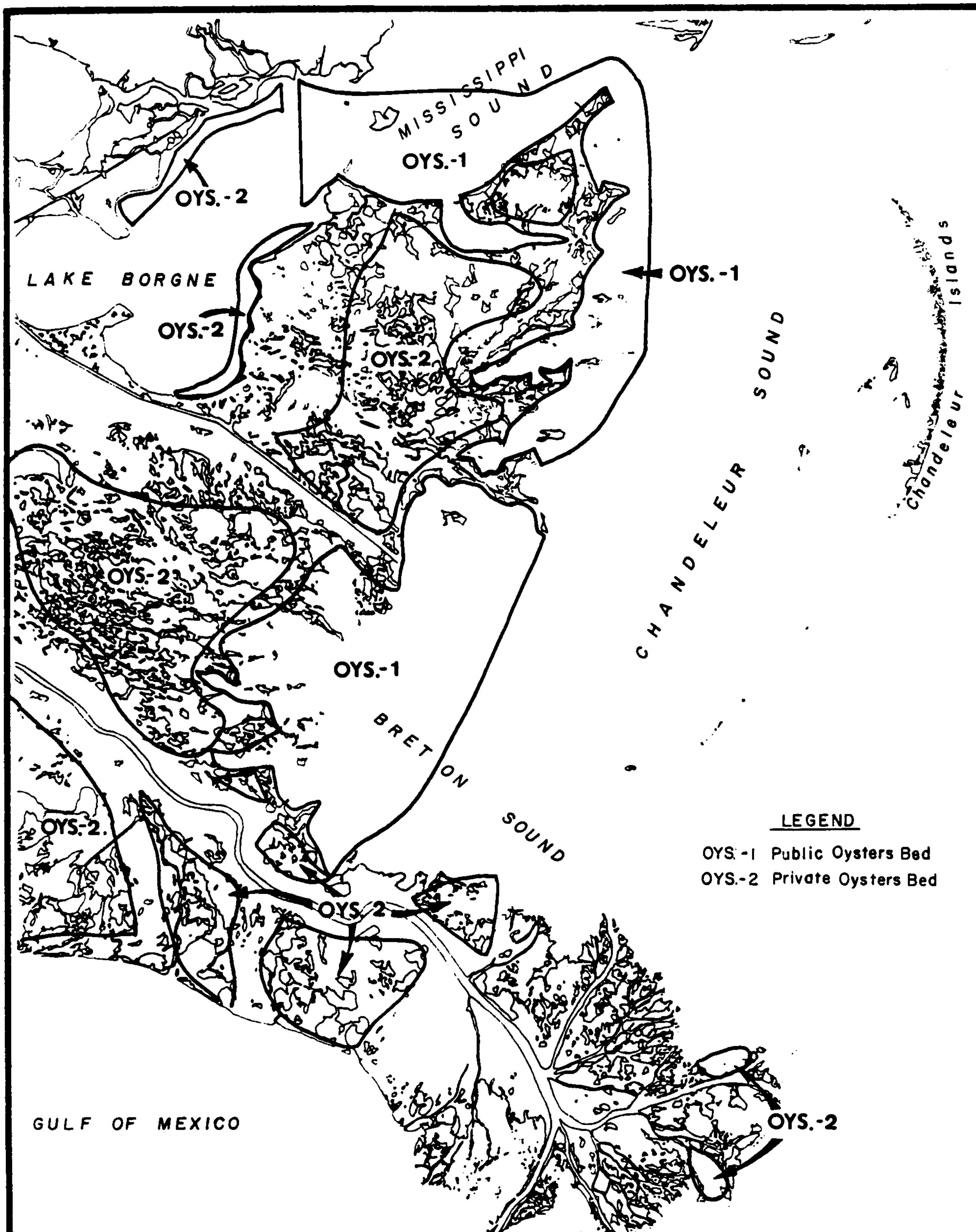


Figure 7.11 Louisiana oyster reefs within and adjacent to the Tuscaloosa Trend study area. Source: Perret et al., 1971

Table 7.26. Commercial Oyster Landings.

LOUISIANA

	Plaquemines Parish		St. Bernard Parish	
	Lbs.	Value ($)	Lbs.	Value ($)
1979	2,798,413	4,018,423	921,041	1,100,336
1980	2,840,912	4,607,701	650,452	1,091,439
1981	3,597,970	6,361,444	712,868	1,109,073
TOTAL:				
1979	3,719,454	5,118,759	7,714,450	10,882,635
1980	3,491,364	5,699,140	6,947,458	11,299,075
1981	4,310,838	7,470,517	9,092,576	16,163,072

PERCENT OF STATE (Value):

1979 47.0%

1980 50.4%

1981 46.2%

Source: NMFS, 1982a, 1982b, 1982c

Table 7.28. Principal Commercial Finfish - Louisiana, 1983.

Species	Thousand Lbs.	Value ($)
Menhaden	1,671,038	66,340,000
Red snapper	744	1,248,000
King mackerel	1,290	1,126,000
Spotted seatrout	1,133	1,061,000

Source: NMFS, 1984c

7.6 MINERAL PRODUCTION

7.6.1 SHELLS

Oyster shells have been hydraulically dredged from Mobile Bay and Mississippi Sound since the early 1950's. The shell removed is processed into cement and masonry block, poultry feed supplement, chemicals, metals, and utilized as road materials (Friend et al., 1982; Demoran, 1979). Alabama was ranked third, nationally, in oyster shell production, averaging approximately 1.5 million m^3 annually from 1950-1970. From 1970 to 1978, production declined to 1.1 million m^3 and ceased in 1981. In 1978, the available recognized shell resources in Alabama waters amounted to 35.3 million m^3. By 1980 the remaining reefs were estimated to comprise 23.9 million m^3 (Friend et al., 1982).

Shell dredging in the Mississippi portion of Mississippi Sound has been conducted primarily in the western portions on deposits located south of the intracoastal waterway from 8.0 to 9.6 km from the mainland (Demoran, 1979). The dredging in this region occurred from 1951 through 1973 and extracted 3,450,174 m^3 of shell. A recent survey of recoverable reef shell directed by Demoran (1979) identified an additional 1,430,845 m^3 of reef valued at more than $13 million in 1979, based on $9.17 per m^3 (Table 7.29).

The Louisiana shell dredging industry has historically included both oyster shell dredging and clam shell (Rangia cuneata) dredging. Oyster shell dredging in the study area was permitted from 1925 through 1939 covering a large area in Chandeleur Sound and Lake Borgne. Since 1939, the year the lease lapsed, no leases have been issued for dredging in these waters (Burford et al., 1969). Though leases were issued to dredge the Cabbage Reef in Mississippi Sound, no dredging has occurred in recent years.

Lake Pontchartrain is peripheral to the geographical focus of the this study and is not generally included in the discussions of the region's socioeconomic characteristics. However, the clam shell industry in Lake Pontchartrain has a significant and wide sphere of economic influence within the coastal zone and merits some treatment. The clam shell industry contributes about $450 million to coastal Louisiana annually (Personal

Table 7.29. Reef locations, size amount of shells in deposit and value, Mississippi Sound, Mississippi.

Reef	Location	Size	Amount	Value
A	Lat. 30°13'37"W Long. 89°14'08"W	77.3 acres	1,122,396 cu. yds.	$ 7,856,772.00
B	Lat. 30°14'04"N Long. 89°13'07"W	25.0 acres	242,000 cu. yds.	$ 1,694,000.00
C	Lat. 30°14'18"N Long. 89°12'28"W	7.7 acres	10,000 cu. yds.	$ 70,000.00
D	Lat. 30°20'30"N Long. 88°35'24"W	23.0 acres	496,000 cu. yds.	$ 3,472,000.00
TOTAL			1,870,396 cu. yds.	$13,092,772.00

Source: Demoran, 1979.

communication Benson-Rodenbaugh, Louisiana Department of Conservation and Natural Resources, 1984). From 4.6 to 6.1 million m^3 of clam shells are dredged statewide, annually, with a wholesale value of about $80 million. Lake Pontchartrain is the single greatest contributor of shells to the state industry. As Table 7.30 indicates, over 3.8 million m^3 of clam shells are dredged annually from Pontchartrain. Even though the industry clearly presents an important economic activity, no precise estimate of the resource base, the amount of shells recoverable in Pontchartrain, has been achieved. Techniques that have been used to assess oyster shell resources are not effective in estimating clam shell densities, since clam shells do not form reefs. Dugas et al. (1974) compiled a density distribution of clam shells based on surface sampling (Figure 7.12). The surface distribution of shells, however, may not reflect the true extent of the buried resource.

Table 7.30. Clam shell dredged from Lake Pontchartrain 1977-1981.

Year	Cubic Yards
1977	6,484,594
1978	5,259,939
1979	5,314,253
1980	5,122,209
1981	5,076,666

Source: Personal communication, Benson-Rodenbaugh, Louisiana Department of Conservation and Natural Resources, 1984.

A large area of unexploited buried oyster reef was identified by Kindinger et al. (1982) east and south of the Chandeleur Islands (Figure 7.13). No estimate of the recoverable volume or value of these shell (or gravel) deposits has been made.

7.6.2 SAND AND GRAVEL

Historically, sand and gravel operations have not been conducted within the limits of the Tuscaloosa Trend study area. Nonetheless, the Mississippi Mineral Resources Institute has conducted preliminary investigations assessing the feasibility of exploiting heavy mineral deposits and specialty sands within Mississippi Sound and seaward of the barrier islands (Woolsey, 1984; Personal communication, Woolsey, Mississippi Mineral Resources Institute, 1984). High concentrations of heavy minerals occur in laminae along the Mississippi barrier beaches. However, several of the barrier islands are now part of the Gulf Islands National Seashore, thus, rendering these deposits inaccessible. Consequently, the most promising zone for economic investigation lies in the waters between Petit Bois Island and Dauphin Island (Woolsey, 1984). Van Andel (1960) found sands in this area which contain greater than four percent heavy minerals. The industrially significant minerals are oxides of titanium and zirconium.

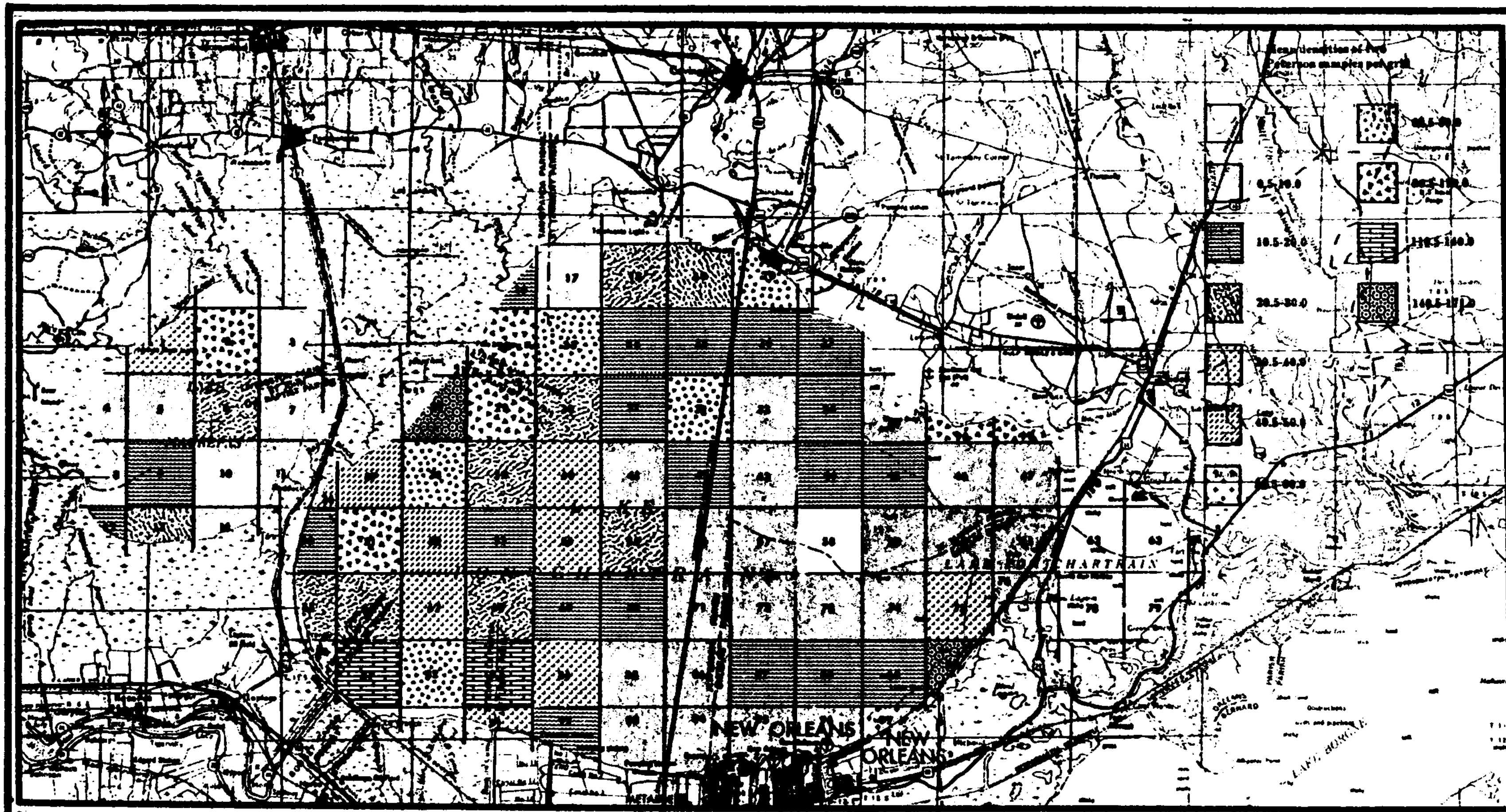


Figure 7.12 Rangia cuneata distribution and density--Lake Pontchartrain. Source: Dugas et al., 1974

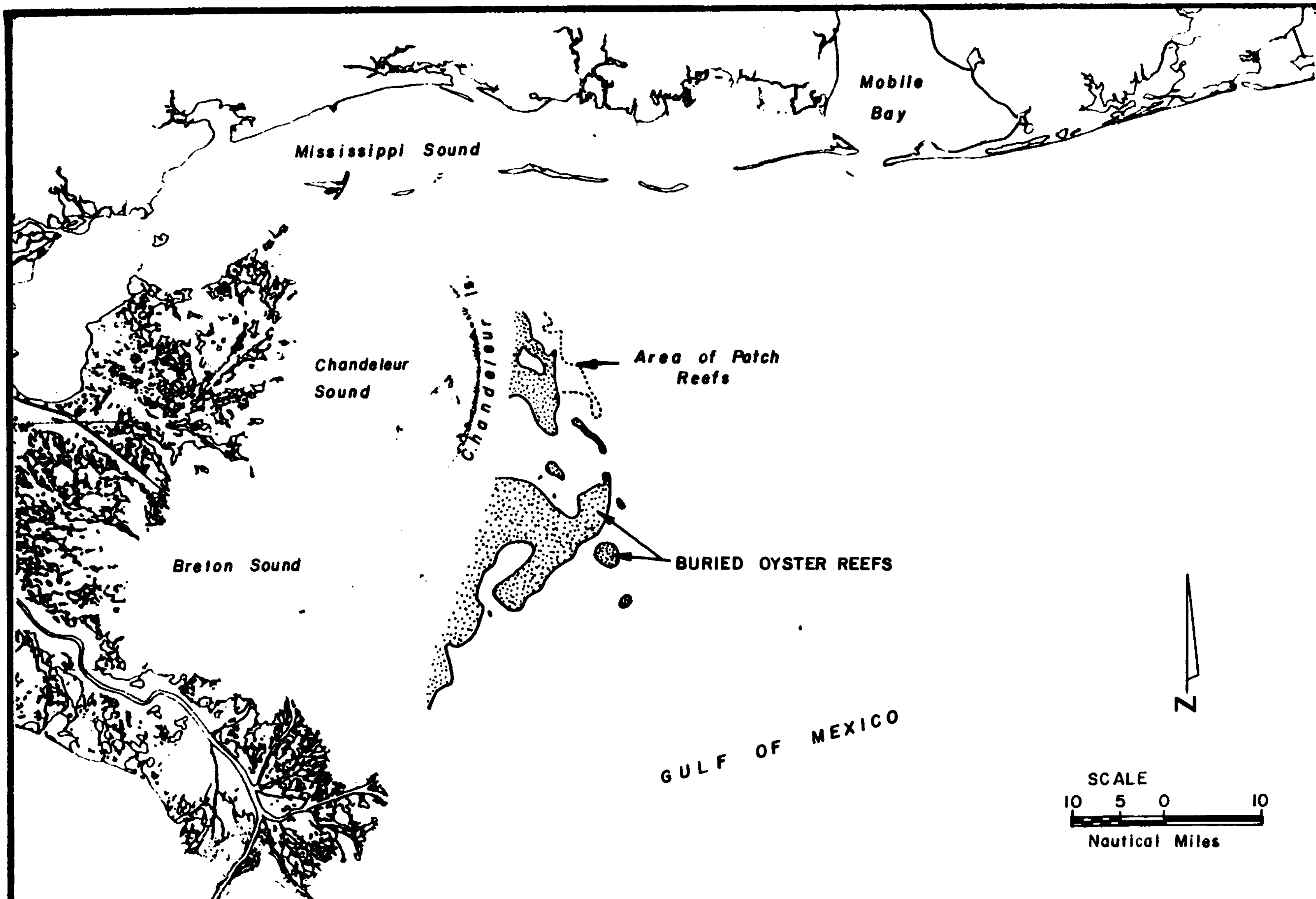


Figure 7.13 Distribution of buried oyster shells in vicinity of the Chandeleur Islands.
Source: Kindinger et al., 1982

In addition to the potentially important heavy minerals, specialty sands are found on and offshore of the Mississippi barrier islands. Specialty sands are typically used in glass manufacturing as blasting sands and as foundry sands. Each use requires different silica sand characteristics. Glass sands must contain greater than 90% SiO_2 and no more than 0.0030% iron or 0.003% chromium. Glass sands have previously been excavated from Cat Island (Woolsey, 1984). Foundry sands are very fine sands used to manufacture copies as molds in metal casting after they are washed, graded, and dried very fine quartz sands. The assessment of concentrations and potential economic value of these heavy minerals and sands is still being conducted by the Mississippi Mineral Resources Institute (Personal communication, Woolsey, Mississippi Mineral Resources Institute, 1984).

7.6.3 HYDROCARBON AND GEOTHERMAL RESOURCES

Geothermal Resources

Geothermal resources are represented by the thermal energy that could be extracted at costs competitive with other forms of energy at a foreseeable time, under reasonable assumptions of technological improvement and economic favorability. The energy may take the form of a fluid resource base. The fluid resource base refers to the energy contained in the interstitial water of the sand and shale beds within the geopressured reservoirs. These fluids are hot, confined under higher pressures than normal, and are presumed to be saturated with dissolved methane at ambient conditions. The fluid resource base consists of thermal energy (heat), mechanical energy, and the energy represented in the dissolved methane (Muffler, 1979).

Geothermal resources have been assessed for certain geopressured basins within the United States (Muffler, 1979) (Figure 7.14). A geothermal assessment is the estimation of the amount of thermal energy that might be recovered and used economically at some reasonable future time. One of the areas assessed is the Northern Gulf of Mexico Basin, which extends into the western portion of the study area (Wallace et al., 1979). The resource's energy potential is presented in units of energy called joules(J); 10^{18}J are approximately 10^{15} British thermal units (Btu), which in turn equals one quad (a quadrillion Btu). Geothermal resources vary from over 100×10^{15}J/km^2 (250×10^{12} Btu/mi^2) in Chandeleur Sound to less than 40×10^{15}J/km^2 (100×10^{12} Btu/mi^2) in Breton Sound. The greatest resource potential lies in a tongue extending southeastward through Lake Borgne across the Chandeleur Islands, nearly to the 200m isobath (Figure 7.14). The depth to the top of the geopressured zone ranges from less than 1829 m west of the Chandeleur Islands in an area near the 50 m isobath, to more than 2743 m in Breton Sound.

Oil and Gas Resources

Virtually all hydrocarbon production from the United States Outer Continental Shelf occurs in the Gulf of Mexico basin. In 1982, the oil (including condensate) and gas production in the Gulf of Mexico accounted for 90% and 99%, respectively, of U.S. OCS production with 290 million barrels (46 million m^3) of oil and 4.66 trillion cubic feet (130 billion m^3) of gas (Wiese et al., 1983). In 1983, the Gulf yielded 320 million barrels of oil (50 million m^3) and 4.1 trillion cubic feet (116 billion m^3) of gas (Hewitt et al., 1984). Figure 7.15 illustrates the long-term trend of oil and gas production

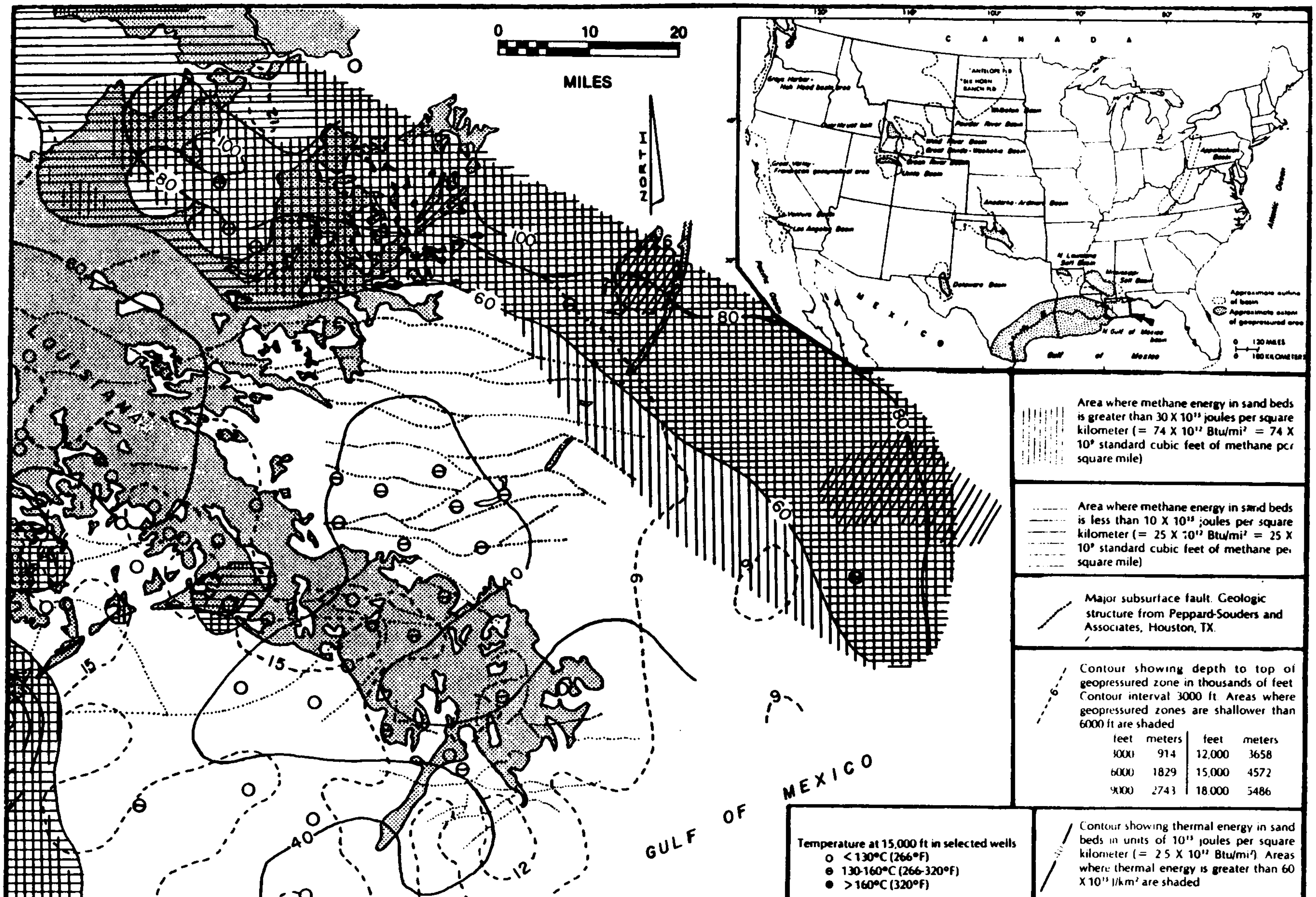


Figure 7.14 Geothermal resources in the Tuscaloosa Trend study area. Source: Muffler, 1979; Wallace et al., 1979

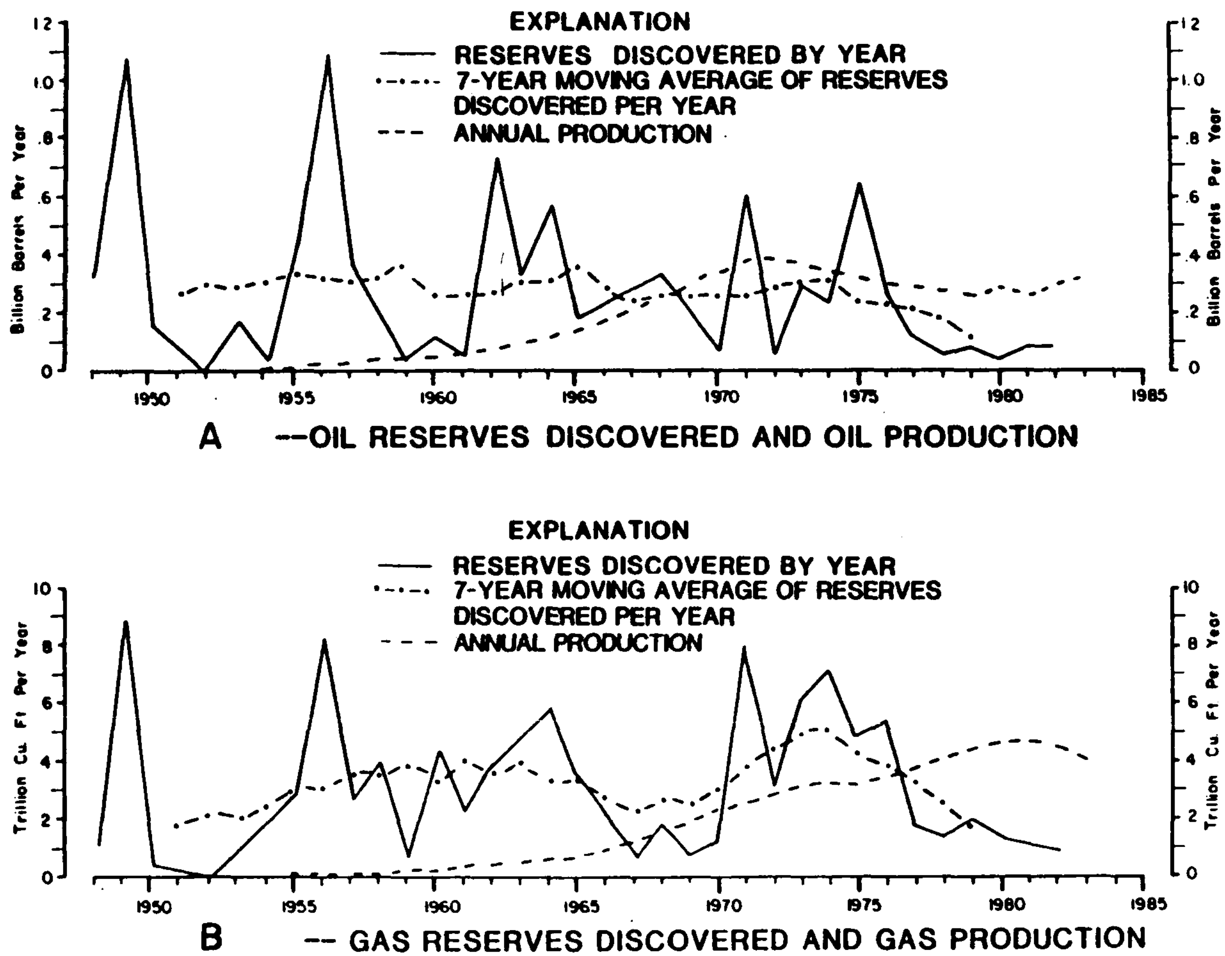


Figure 7.15 Oil and gas production trends in the Gulf of Mexico. Source: Hewitt et al., 1984

in the Gulf of Mexico. Table 7.31 shows the hydrocarbon production totals for Louisiana state waters within the Tuscaloosa Trend study area for the years 1980 through 1983 (Louisiana Department of Natural Resources, 1981, 1982, 1983, 1984). No production activities have yet been initiated for state waters in Alabama or Mississippi.

Hewitt et al. (1984) estimate the remaining recoverable hydrocarbon resources to be approximately 3.41 billion barrels of oil (541 million m^3) (including condensate) and 43.7 trillion cubic feet of gas (1.2 trillion m^3) (Table 7.32). Table 7.33 presents estimates of demonstrated oil and gas reserves for lease areas which are either wholly or partially within the Tuscaloosa Trend study area. These statistics must be interpreted in the light that demonstrated reserves refer to economically identified resources estimated from geologic evidence directly supported by engineering measurements, combined with "known productive reservoirs in existing fields expected to respond to improved recovery techniques" (Hewitt et al., 1984), and thus, do not reflect undiscovered or undeveloped fields.

Undiscovered, recoverable oil and gas resources have, however, been appraised for three broad Regional Planning Areas in the Gulf of Mexico (Figure 7.16) (MMS, 1983). The Tuscaloosa Trend study area falls within portions of two planning areas, the Central Planning Area and the Eastern Planning Area, including all of subarea C-4 and the northeastern portion of subarea C-3 in the Central Region and the western portion of subarea E-1 in the Eastern Region. Undiscovered, recoverable oil and gas resources are defined as "resources estimated to exist outside known fields, that can be economically produced using existing technology, assuming current price/cost relationships and short-term technological development" (Wiese et al., 1983). These resource estimates are presented in Table 7.34. The appraisals are based on the total undiscovered resources for each area (mean conditional estimates) and on assumptions on the proportion of the total resources that would be developed (MMS, 1983). It is noteworthy that even though only one subarea (E-1) lies partially within the study area, over 90% of the gas resources expected to be extracted from the Eastern Planning Area are in subarea E-1.

The U.S. Army Corps of Engineers in the Final Generic Environmental Impact Statement of Exploration and Production of Hydrocarbon Resources in Coastal Alabama and Mississippi (U.S. Army Corps of Engineers, 1984) provides estimates for recoverable hydrocarbons for areas corresponding to portions of the Tuscaloosa Trend study area (Figure 7.17). These areas are Mobile Bay, Mississippi Sound, the Mississippi and Alabama state waters of the Gulf of Mexico, and adjacent Federal waters. Adjacent Federal waters include the Mobile Lease Area; the portion of the Pensacola and Destin Dome Lease Areas south of Alabama state waters, as well as the Chandeleur and Main Pass East Addition Lease Areas. The Corps' hydrocarbon resource estimates are presented in Table 7.35. Additional data that became available too late to be incorporated in the resource estimates suggest the need to adjust the nearshore gas and condensate figures (U.S. Army Corps of Engineers, 1984). The Alabama Oil and Gas Board notes that the high resource estimate for natural gas in Alabama waters of the Gulf of Mexico may be low, while the condensate estimates for the same area may be inflated. The Mississippi Oil and Gas Board adds that the estimates for Mississippi waters may also be low.

Table 7.31. Production Totals, 1980-1983 (cubic feet).

Lease Area	1980	1981	1982	1983	Total Since 1979
Condensate					
Breton Sound	526,402	377,959	171,126	135,892	1,123,915
Eloi Bay	0	1,045	0	574	1,619
Main Pass	33,911	27,442	20,225	8,421	89,999
South Pass	53,553	33,635	23,055	21,796	132,039
Total	526,402	440,081	214,406	166,683	1,347,572
Casinghead Gas					
Breton Sound	2,842,894	2,862,983	2,340,391	2,878,257	10,924,525
Eloi Bay	629,693	401,606	579,006	614,316	2,224,621
Main Pass	5,452,584	5,805,016	6,304,295	5,988,518	23,550,413
South Pass	3,878,238	3,806,776	3,302,313	4,001,905	14,989,232
Total	12,803,409	12,876,381	12,526,005	13,482,996	51,688,791
Natural Gas					
Breton Sound	28,420,614	25,177,157	18,374,119	16,890,707	88,862,597
Eloi Bay	0	9,631	0	31,972	41,603
Main Pass	18,023,036	17,103,511	12,787,547	10,654,529	58,568,623
South Pass	3,327,622	2,655,243	8,839,639	11,762,006	26,584,510
Total	49,771,272	44,945,542	40,001,305	39,339,214	174,057,333
Crude Oil					
Breton Sound	5,040,878	5,727,433	5,484,250	4,716,266	20,968,827
Eloi Bay	1,450,994	1,282,104	1,194,632	1,200,273	5,128,003
Main Pass	4,714,445	4,566,586	5,095,512	5,456,159	19,832,702
South Pass	5,997,082	5,336,551	4,997,123	5,168,939	21,499,695
Total	17,203,399	16,912,674	16,771,517	16,541,637	67,429,227

Source: Louisiana Department of Natural Resources, 1981, 1982, 1983

Table 7.32. Summary and comparison of remaining, recoverable oil and gas reserves as of December 31, 1982, and December 31, 1983: Gulf of Mexico.

	Oil (billion bbl.)		Gas (trillion cu. ft.)	
Previous est., as of 12/31/82 (Hewitt and others, 1983)		2.98		39.8
Discoveries	+0.11		+1.7	
Revisions	+0.64		+6.3	
Adjustments	0.00		0.0	
Production during 1983 (preliminary)	-0.32		-4.1	
Net change		+0.43		+ 3.9
Estimate, as of 12/31/83		3.41		43.7

Source: Hewitt et al., 1984

Table 7.33. Estimated demonstrated oil and gas reserves for selected areas of the Outer Continental Shelf and Slope, December 31, 1983.

(Demonstrated reserves: the sum of measured and indicated reserves. Oil expressed in millions of barrels, gas in billions of cubic feet. "Oil" includes crude oil and condensate; "gas" includes associated and nonassociated gas. Remaining reserves estimated as of December 31, 1983.)

Area(s)	Studied		Not studied	Active with production	Original recoverable reserves		Cumulative production through 1983		Remaining recoverable reserves	
	Active	Depleted			Oil	Gas	Oil	Gas	Oil	Gas
South Pass.	10	0	1	8	760	2,200	460	1,200	300	1,000
Main Pass, Breton Sound, and Chandeleur Area . . .	27	2	4	23	760	3,400	440	2,000	320	1,400
Continental Slope* and MAFLA**	16	0	3	4	320	1,950	60	150	260	1,800
Total	53	2	8	35	1,840	7,550	960	3,350	880	4,200

*Continental Slope includes the following areas: Corpus Christi, East Breaks, Garden Banks, Green Canyon, Ewing Bank, Mississippi Canyon, and Viosca Knoll.

**MAFLA includes the areas off the Mississippi, Alabama, and Florida coasts.

Source: Hewett et al., 1984

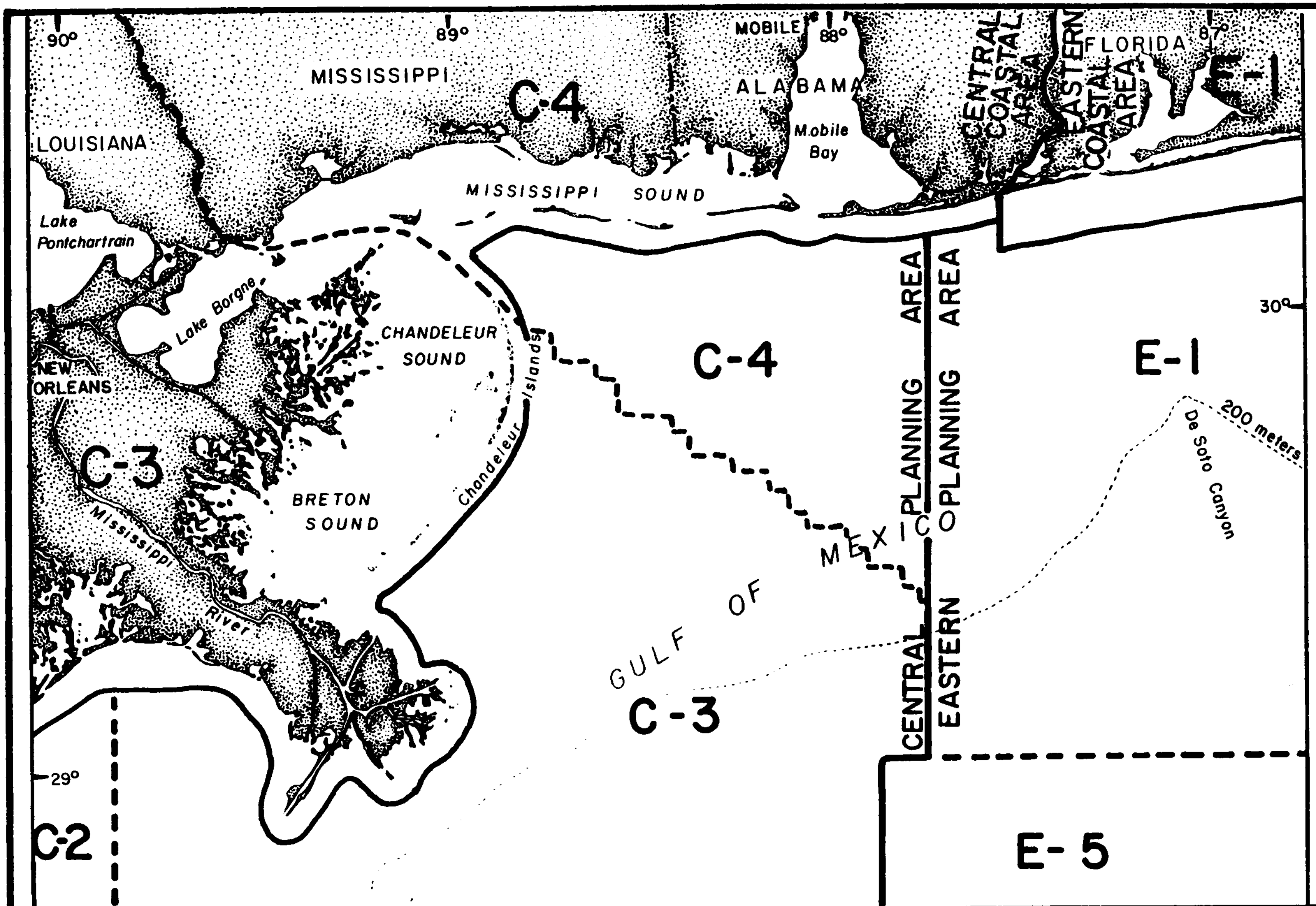


Figure 7.16 Regional planning areas and subareas--Tuscaloosa Trend study area. Source: MMS, 1983

Table 7.34. Estimated distribution of resources: Central Planning Area and Eastern Planning Area, within the Tuscaloosa Trend study area.

	C-3		C-4		E-1	
	M Scenario	T Scenario	M Scenario	T Scenario	M Scenario	T Scenario
Resources Recovered						
Oil (billion bbls)	0.040	1.173	0.008	0.071	0.031	0.242
Gas (tcf)	0.314	10.06	0.052	1.67	0.147	0.920

Source: MMS, 1983

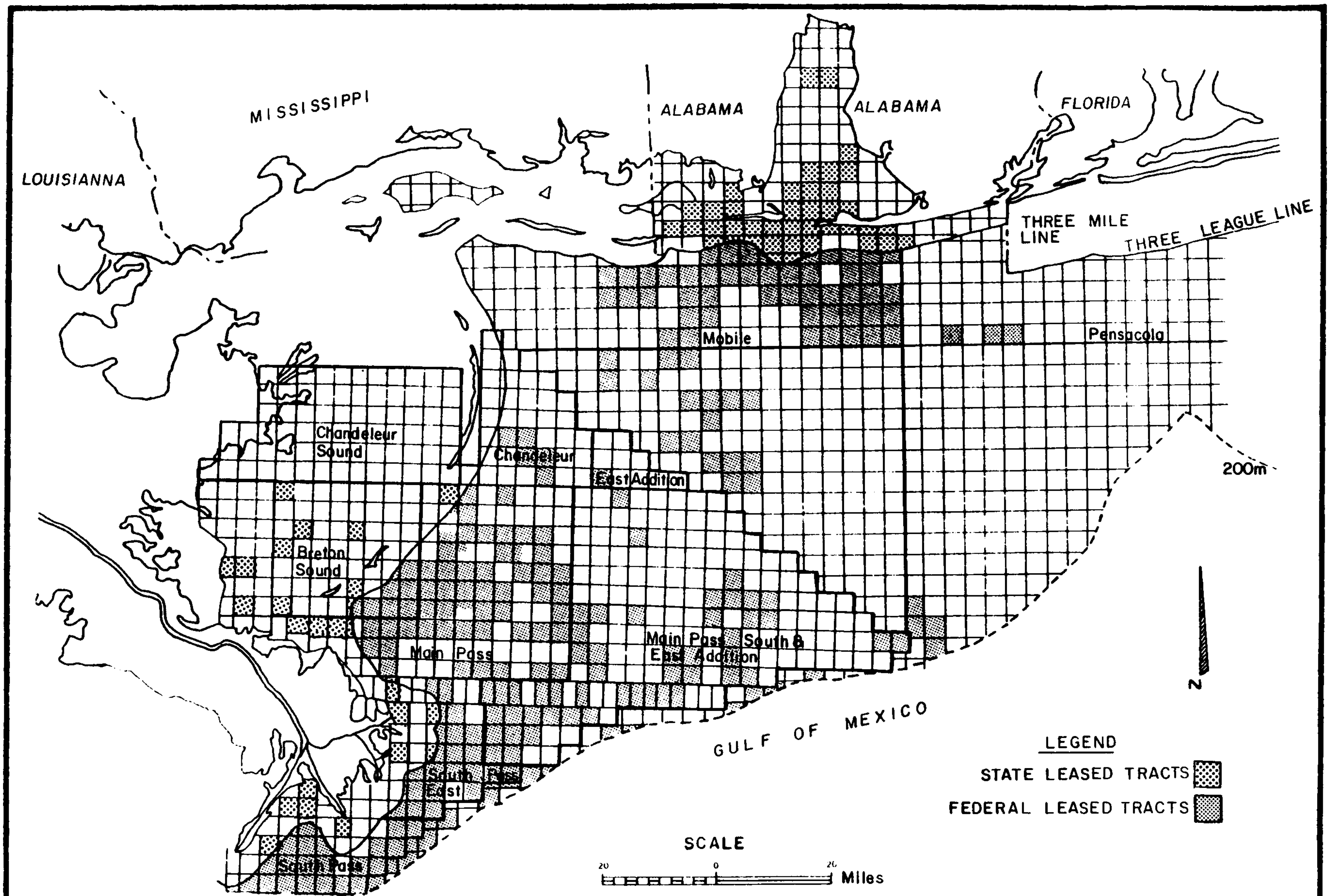


Figure 7.17 Offshore oil and gas lease areas and tracts. Source: Louisiana Department of Natural Resources, 1984; MMS, 1984

Table 7.35. Estimate of recoverable hydrocarbon resources in the study region and adjacent federal waters.

Location	Resource	Units	Estimate of Quantity[a] High	Moderate	Low
Mobile Delta[b]	Oil	MM bbl	130	88	60
	Condensate	MM bbl	330	260	213
	Gas	Tcf	2.2	1.8	1.5
Mobile Bay[c]	Oil	MM bbl	13	0	0
	Condensate	MM bbl	440	110	87
	Gas (Tcf)		3.3	2.6	2.1
Mississippi Sound	Oil	MM bbl	5	0	0
	Condensate	MM bbl	22	4.4	1.3
	Gas	Tcf	1.1	0.32	0.09
Alabama Waters of the Gulf of Mexico[d]	Oil	MM bbl	55	0	0
	Condensate	MM bbl	14	6.2	2.9
	Gas	Tcf	1.1	0.51	0.23
Mississippi Waters of the Gulf of Mexico	Oil	MM bbl	0	0	0
	Condensate	MM bbl	25	0	0
	Gas	Tcf	0.88	0	0
Total Delta and State Waters	Oil	MM bbl	200	88	60
	Condensate	MM bbl	830	380	300
	Gas	Tcf	8.6	5.2	3.9
Federal Outer Continental Shelf	Oil	MM bbl	610	340	71
	Condensate	MM bbl	400	220	42
	Gas	Tcf	28	15	1.7
Total State plus Federal	Oil	MM bbl	810	430	130
	Condensate	MM bbl	1200	600	350
	Gas	Tcf	37	20	5.6

OCS = Outer Continental Shelf
MM bbls = Million barrels
Tcf = Trillion cubic feet

[a] Includes stratigraphic traps
[b] Includes Movico Field
[c] Includes Mary Ann Field
[d] Mary Ann Field included in Mobile Bay estimate

Source: U.S. Army Corps of Engineers, 1984

In conjunction with these resource estimates, the Corps has also provided data for the potential revenues to states for three possible levels of resource development. As is presented in Table 7.36, total revenues to the State of Mississippi range from 22 million to 1.36 billion dollars. For the State of Alabama, the potential royalties are greater, ranging from 7.12 billion to 21.49 billion dollars (Table 7.37). Total revenue figures assume that all of the postulated resources are recovered at current (late 1983) value, taxed at current rates, and that the royalty structures do not change.

There are currently (September, 1984) 36 state-owned tracts under lease to oil and gas companies for exploration in Alabama coastal waters. Leases were awarded in October 1969 on four tracts, in March 1981 on 13 tracts, in September 1982 on one tract was leased, and in August 1984 on 18 tracts. Through 1983, test wells have been completed on the four tracts leased in 1969, all of which have tested as gas producers (Mink, 1984). In the latest lease sale in August 1984, in Alabama state waters there were $347.5 million in bids accepted on 18 of 24 lease tracts offered. Exxon Corporation supplied the bulk of the accepted bids, $330 million for 15 of the 18 tracts. The remaining three tracts were leased to SOHIO (2) and Union Oil Corporation (1), for $8.6 million and $9.3 million, respectively.

Ten wells have been drilled in the Mobile Bay and Alabama waters in Mississippi Sound. Two were drilled in Tracts 19 and 37 in the 1950's, but both were subsequently plugged and abandoned. Mobil Oil Exploration and Producing Southeast, Inc. (MOEPSI) discovered significant quantitites of natural gas in 1979 on Alabama Tract 76 and drilled four more exploration wells to verify the find and delineate the Lower Mobile Bay--Mary Ann Field. The Mary Ann Field is the first offshore Jurassic discovery in the northern Gulf of Mexico. Three appraisal wells, yielding natural gas, were completed on Alabama Tracts 77, 94, and 95, and one appraisal well on Tract 76 was temporarily abandoned but will be tested at a later date. Shallow, Miocene gas was also found on Alabama Tract 95. Exxon has temporarily abandoned a wildcat well on Alabama Tract 62 and MOEPSI is currently (1984) drilling a wildcat well in Mississippi Sound on Tract 72 (Mink, 1984).

7.7 DREDGE-SPOIL DISPOSAL

Designated open ocean dredged material disposal sites in the Tuscaloosa Trend area receive dredged material from the Pensacola Entrance Channel, Mobile Bar Channel, and the Gulfport-Ship Island Bar Channel. Disposal sites for the Mississippi River-Gulf Outlet Channel are within Chandeleur-Breton Sounds adjacent to the channel. The U.S. Army Corps of Engineers, which performs the dredging operations, has determined that ocean disposal is the most reasonable disposal method at present (U.S. EPA, 1982a).

Hopper dredges currently remove an average of 566,608 m^3 (every 4 to 5 years) from the Pensacola Entrance Channel, 371,619 m^3 (every 1-3 years) from the Mobile Bay Channel, and 496,706 m^3 (every 1 to 3 years) from the Gulfport-Ship Island Bar Channel per dredging cycle (dredging does not occur on a consistent annual basis) (U.S. EPA, 1982a).

The existing disposal sites (Figure 7.18) (Table 7.38) have been utilized since at least 1970. Limited site surveys detected no significant adverse effects on the water or sediment quality, and no cumulative changes in the

Table 7.36. Potential revenues for the State of Mississippi from offshore hydrocarbon resource development under the high, moderate, and low resource scenarios.

Resource Scenario	Resource	Assumed Unit Value (dollars per quantity)	Total Resource Amount	Total Value (billion dollars)	6% Severance Tax (million dollars)	20% Royalty To State (million dollars)	Maintenance Tax (2¢/BBL liquid, .2¢/$1000 CFGAS)	Total State Revenue (billion dollars)
High	Oil							
	Condensate	21-42/BBL	30.5 MMBBL	.640-1.28	38.4-76.8	128-256	610,000	.167-.333
	Gas	3.45/MMBTUs[a]	1.15 TCF	3.97	238	794	2.3 million	1.03
							Total	1.19-1.36
Moderate	Oil							
	Condensate	21-42/BBL	1.1 MMBBL	.023-.046	1.3-2.76	4.6-9.2	22,000	.006-.012
	Gas	3.45/MMBTU[a]	.08 TCF	.276	16.5	55.2	160,000	.072
							Total	.078-.084
Low	Oil							
	Condensate	21-42/BBL	.325 MMBBL	.0068-.014	.408-.816	1.36-2.72	6,500	.002-.0035
	Gas	3.45/MMBTU[a]	.0225 TCF	.0776	4.65	15.5	45,000	.020
							Total	.022-.023

[a]1000 BTU = 1 cubic foot of gas.

Source: U.S. Army Corps of Engineers, 1984.

Table 7.37. Potential revenues for the State of Alabama from offshore hydrocarbon resource development under the high, moderate and low resource scenarios.

Resource Scenario	Resource	Assumed Unit Value (dollars per quantity)	Total Resource Amount	Total Value (billion dollars)	8% Severance Tax for Offshore Resources (billion dollars)	25% Royalty To State (billion dollars)	Total State Revenues (billion dollars)
High	Oil	30/BBL	198 MMBBL	5.94	.475	1.48	1.95
	Condensate	21-42/BBL	800 MMBBL	16.8-33.6	1.34-2.69	4.20-8.40	5.54-11.09
	Gas	3.45/MMBTU[a]	7.42 TCF	25.6	2.05	6.4	8.45
						Total	15.94-21.49
Moderate	Oil	30/BBL	88 MMBBL	2.64	.211	.660	.871
	Condensate	21-42/BBL	379 MMBBL	7.97-15.9	.638-1.27	1.99-3.97	2.63-5.24
	Gas	3.45/MMBTUs[a]	5.15 TCF	17.8	1.42	4.45	5.87
						Total	9.37-11.98
Low	Oil	30/BBL	60 MMBBL	1.8	.144	.450	.594
	Condensate	21-42/BBL	304 MMBBL	6.38-12.7	.510-1.02	1.6-3.17	2.11-4.19
	Gas	3.45/BBTU[a]	3.89 TCF	13.4	1.07	3.35	4.42
						Total	7.12-9.20

[a]1000 BTU = 1 cubic foot of gas.

Source: U.S. Army Corps of Engineers, 1984.

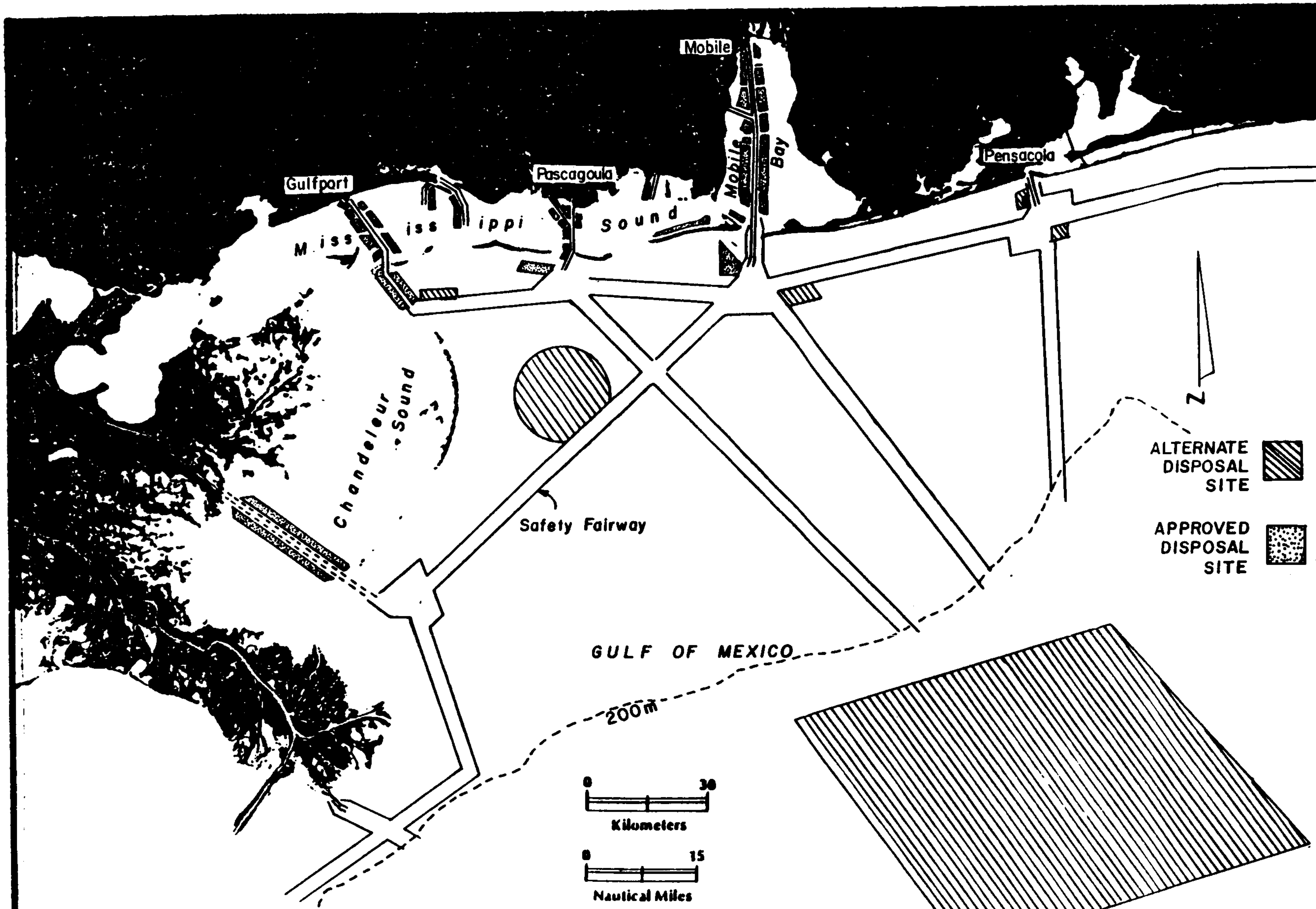


Figure 7.18 Offshore dredge spoil disposal sites. Source: U.S. Environmental Protection Agency, 1982; U.S. Army Corps of Engineers, 1983.

Table 7.38. Geographical position, depth of water, bottom topography, and distance from coast for dredged spoil disposal sites.

Site/Area	Boundary Coordinates	Water Depth (m)	Bottom Topography	Distance Offshore
	Pensacola			
Existing Site	30°16'48"N, 87°19'00"W 30°16'42"N, 87°18'18"W 30°16'18"N, 87°18'12"W 30°16'30"N, 87°19'24"W 30°16'00"N, 87°19'24"W Area = 0.64 nmi^2	8 to 14	Slope 0.003 to SSW; sand	2.3 nmi from Perdido Key
Nearshore Alternative Site	30°17'24"N, 87°18'30"W 30°17'00"N, 87°19'50"W 30°15'36"N, 87°17'48"W 30°15'15"N, 87°19'18"W Area = 2.48 nmi^2	8 to 18	Slope 0.003 to SSW; sand	1.5 nmi from Perdido Key
Mid-Shelf Alternative Site	30°12'33"N, 87°15'42"W 30°10'33"N, 87°15'42"W 30°12'51"N, 87°13'26"W 30°10'54"N, 87°13'26"W Area = 4.00 nmi^2	21 to 23	Slope 0.003 to SSE; hard sand	7.2 nmi from Perdido Key
	Mobile			
Existing Site	30°10'00"N, 88°07'42"W 30°10'24"N, 88°05'12"W 30°09'24"N, 88°04'42"W 30°08'30"N, 88°05'12"W 30°08'30"N, 88°08'12"W Area = 4.75 nmi^2	12 to 16	Slope 0.001 to SW; sand and silt	4.2 nmi from Mobile Point
Nearshore Alternative Site	30°05'15"N, 87°58'20"W 30°05'39"N, 87°55'45"W 30°06'18"N, 87°59'15"W 30°06'48"N, 87°56'39"W Area = 4.05 nmi^2	14 to 18	Slope 0.001 to SW; hard sand	7.2 nmi from Mobile Point

Source: U.S. Environmental Protection Agency, 1982.

Table 7.38 (Continued)

Site/Area	Boundary Coordinates	Water Depth (m)	Bottom Topography	Distance Offshore
		Mobile-Gulfport		
Mid-Shelf Alternative Area	29°54'00"N, 88°32'00"W (center coordinates of circular area) Area = 130 nmi^2 (approximate)	23 to 29	Slope 0.0007 to SE; sandy	24 nmi from Ship Island; 25 nmi from Mobile Point (approximate)
		Gulfport		
Existing Site (Eastern)	30°11'10"N, 88°58'24"W 30°11'12"N, 88°57'30"W 30°07'36"N, 88°54'24"W 30°07'24"N, 88°54'48"W Area = 2.47 nmi^2	7 to 9	Slope 0.0004 to SE; silt, clay, and fine sand	1.2 nmi from Ship Island
Existing Site (Western)	30°12'00"N, 89°00'30"W 30°12'00"N, 88°59'30"W 30°11'00"N, 89°00'00"W 30°07'00"N, 88°56'30"W 30°06'36"N, 88°57'00"W 30°10'30"N, 89°00'36"W; Area = 5.22 nmi^2	6 to 9	Slope 0.0006 to SE; silt, clay, and fine sand	0.7 nmi from Ship Island
Nearshore Alternative Site	30°09'30"N, 88°48'48"W 30°09'18"N, 88°54'30"W 30°08'00"N, 88°48'42"W 30°07'48"N, 88°54'24"W Area = 7.50 nmi^2	9 to 12	Slope 001 to SE; sand and silt	4.3 nmi from Ship Island
		Pensacola, Mobile, and Gulfport		
Deepwater Alternative Area	29°10'00"N, 88°00'00"W 29°20'00"N, 87°10'00"W 28°50'00"N, 86°40'00"W 28°38'00"N, 87°35'00"W Area = 1,500 nmi^2	493 to 2376	Slope 0.03 to SE; clay, silt, fine sand, and rock in Canyon	61 nmi from Perdido Key; 64 nmi from Mobile Point; 81 nmi from Ship Island (approximate)

Source: U.S. Environmental Protection Agency, 1982.

biota. Minor, temporary effects may include some increases in suspended sediment concentrations, mounding, and smothering of benthic infauna (U.S. EPA, 1982a). Alternative sites nearshore and midshelf disposal sites are being evaluated by the U.S. Army Corps of Engineers (U.S. Army Corps of Engineers, 1983). Military waxing areas are noted in Figure 7.2.

7.8 CULTURAL RESOURCES

Assessing the cultural resources within the Tuscaloosa Trend study area presents several interesting problems. Perhaps the greatest problem is the geography of the study area. The Tuscaloosa Trend is an offshore zone bounded by the coast, and includes only the barrier islands as upland areas. Thus, the discussion of the state-of-the-knowledge of cultural resources is geographically confined to the coastal parishes and counties for terrestrial prehistoric and historic sites, while knowledge of the offshore cultural resources is limited to often inexact information on shipwrecks and speculation concerning the presence of prehistoric sites.

Cultural resources may be any objects or features that are man-made or modified by human activity. Significant cultural resources are defined by 36 CFR 60.6 to "include properties greater than 50 years old which are associated with events that have made a significant contribution to the broad patterns of our history; are associated with the lives of persons significant in the past; embody the distinctive characteristics of a type, period or method of construction; represent the work of a master; possess high artistic values; represent a significant and distinguishable entity whose components may lack individual distinction; or may have yielded, or may be likely to yield, information important in prehistory or history" (MMS, 1983). Cultural resources that may be encountered within the study area include historic and prehistoric sites eligible for, or on the National Register of Historic Places, all recorded prehistoric and historic archaeological sites, and the probable or known locations of significant shipwrecks. Offshore, prehistoric sites are discussed from a paleogeographical perspective, identifying those environments, both nearshore and on the continental shelf, which would have been likely habitation sites during periods when large areas of the shelf were exposed at lower sea levels than presently exist.

7.8.1 PREHISTORIC

Potential for Submerged Prehistoric Archaeological Sites

The recent geologic history of the offshore portions of the study area has been subjected to periodic inundations and exposures related to a series of sea level fluctuations associated with Late Pleistocene glacial events. Approximately 18,000 years ago sea level and the shoreline were about 121 m lower than current levels. Prior to reaching its lowest level, the sea had been slowly receding for over 50,000 years. The ocean then rose irregularly but rapidly to reach its present level approximately 3500 years ago. During the decline to its lowest point and through the subsequent rise, large expanses of the continental shelf were available for human settlement. The erosional processes occurring during the low levels undoubtedly obliterated many possible sites. Similarly, the erosional power of wave action associated with the transgressing seas probably truncated or completely obliterated many geomorphic features and any associated sites. Nonetheless, advantageously positioned or protected sites may have survived these events and are preserved on the ocean floor. The assumptions that site preservation on the shelf is possible, coupled with the strong correlation between geomorphic features, settlement patterns, and resource use, plus the assumption that the targetted physiographic features are sufficiently preserved as to be recognizable, are the foundations on which a search for submerged prehistoric sites are built.

Coastal Environments, Inc. (CEI) (1977a) conducted a Gulfwide study armed with these assumptions. That study focused primarily on the locations of former shore zones on the shelf during the Late Quaternary. Relying heavily on bathymetric data, CEI (1977a) suggests that a well-preserved relict topography exists offshore of Mississippi, outside the influences of the St. Bernard Delta, and Alabama. CEI (1977a) particularly emphasized the existence of barrier island-split complexes south-southeast of Mobile (Figures 7.19 and 7.20). It must be noted, however, that there are no more substantial data to support the paleogeographical reconstructions than map interpretations of the seafloor's topography. Further research must be conducted, including core data and high resolution seismic data, to corroborate these interpretations, or furnish other explanations on the genesis of the features.

Former shorelines may not be evident on the shelf in some locations as a result of recent sedimentation. Sedimentation rates of hundreds of feet per century have been documented by Frazier (1974) in the active Mississippi River Delta. Such rapid sediment accumulations would hinder the discoverability and recoverability of prehistoric sites. However, rapid burial may enhance the preservation potential of the site. Wooden artifacts, cordage, and other perishable material were recovered from alluvially buried Tchefuncte and Coles Creek Period sites (ca. 500 BC to 1000 AD) in the now abandoned St. Bernard deltaic lobe (CEI, 1977a).

Prehistoric archaeological cultural sequences associated with the growth and decline of the St. Bernard deltaic lobe have been discussed in recent reports (CEI 1977a, 1979). The progradation of the St. Bernard deltaic lobe began about 4800 years ago (Frazier, 1967). Consequently, surface finds of the oldest known culture in the region, the Paleo-Indian (1200 to 8000 BP), are nonexistent in the eastern Mississippi Delta. The developmental phase of the St. Bernard Delta up to 250 AD may be viewed as an unstable period characterized by active, rapid progradation and aggradation accomplished through frequent floods. Even though such an environment may not have been very hospitable, two Poverty Point period sites (1500-500 BC) (Figure 7.21) have been located on St. Bernard deltaic sediments (CEI, 1979). The following culture periods, the Tchula period and the Marksville period (500 BC - AD 200), coincided with the greatest seaward extension of the deltaic lobe (Figure 7.22). There is evidence, in the form of an increase of known archaeological sites, that there was a larger population inhabiting the eastern delta region. Nonetheless, the region's population was small in proportion to the vast amount of available land (CEI, 1979). This, as during earlier Poverty Point times, may be due to the relatively inhospitable environment in the rapidly prograding delta. Most of these early recorded Marksville sites are situated in older, more stable portions of the delta containing the greatest density of mature, well-developed natural levees. Natural levees provided high, well-drained locations near abundant freshwater supplies and were, thus, often chosen as settlement areas. However, one early Marksville site has been documented on

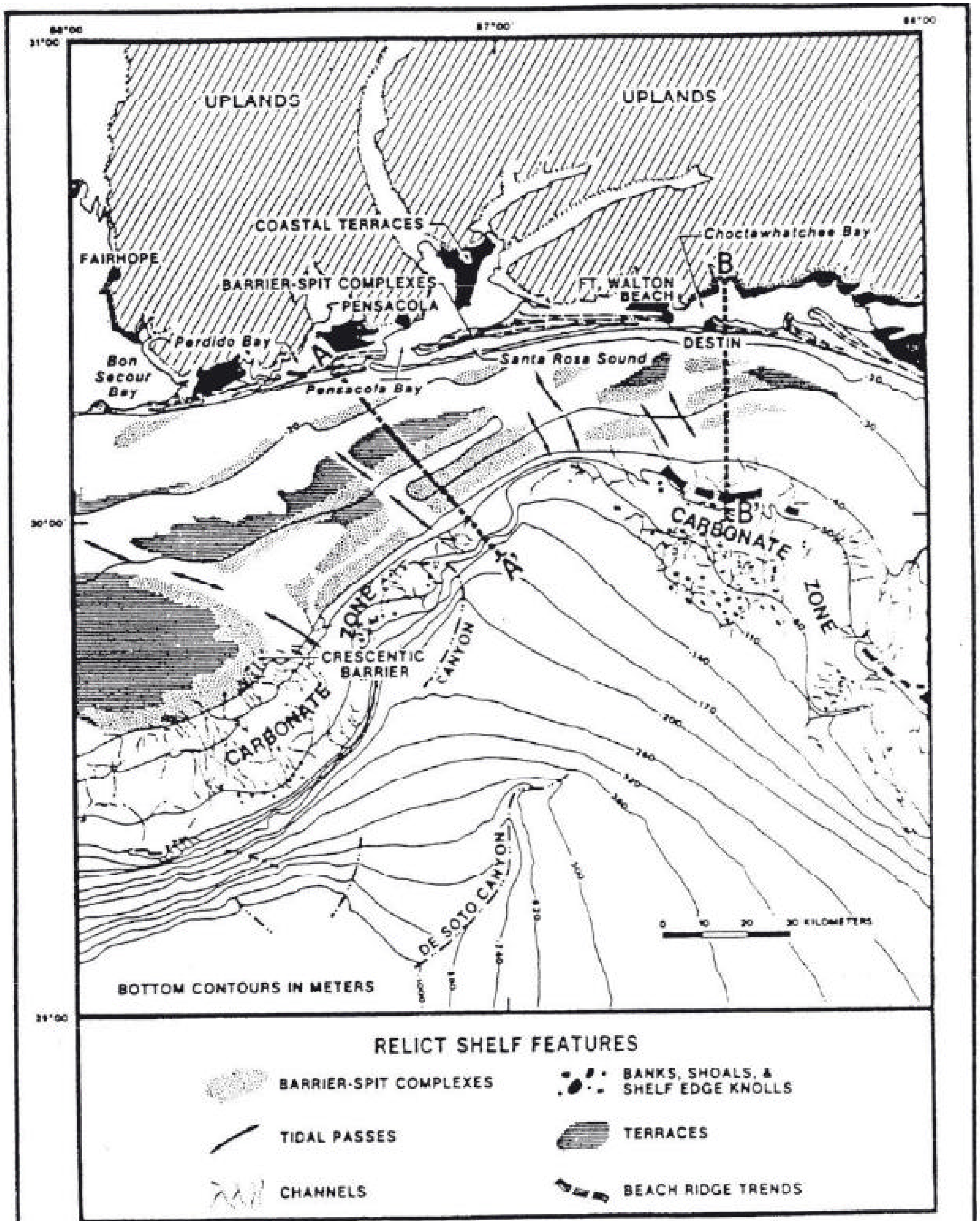


Figure 7.19 Interpretation of relict topography in the Alabama-West Florida area. Source: Coastal Environments, Inc., 1977a.

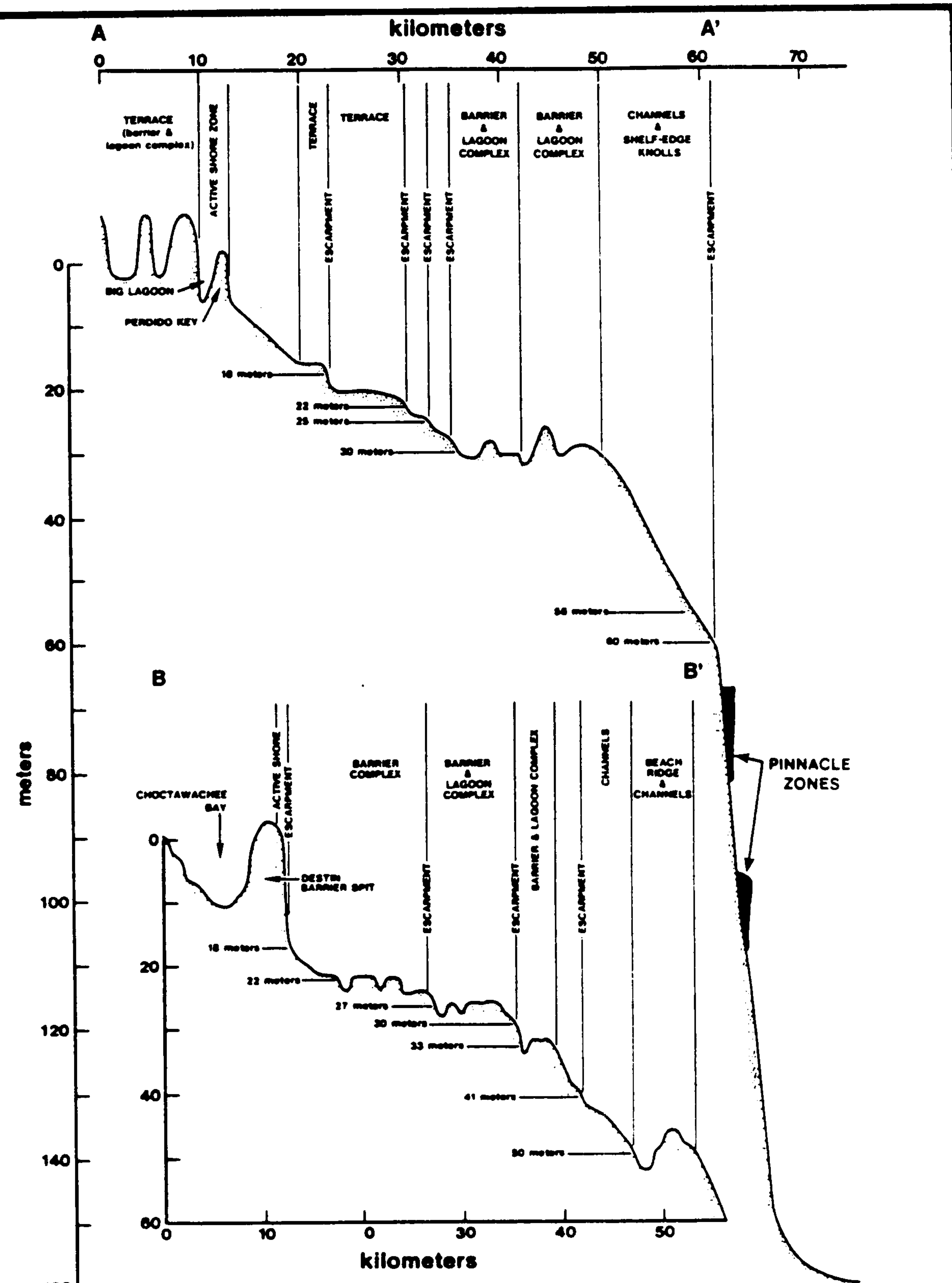


Figure 7.20 Profiles and interpretation of relict topography in the Alabama-West Florida area. Source: Coastal Environments, Inc., 1977

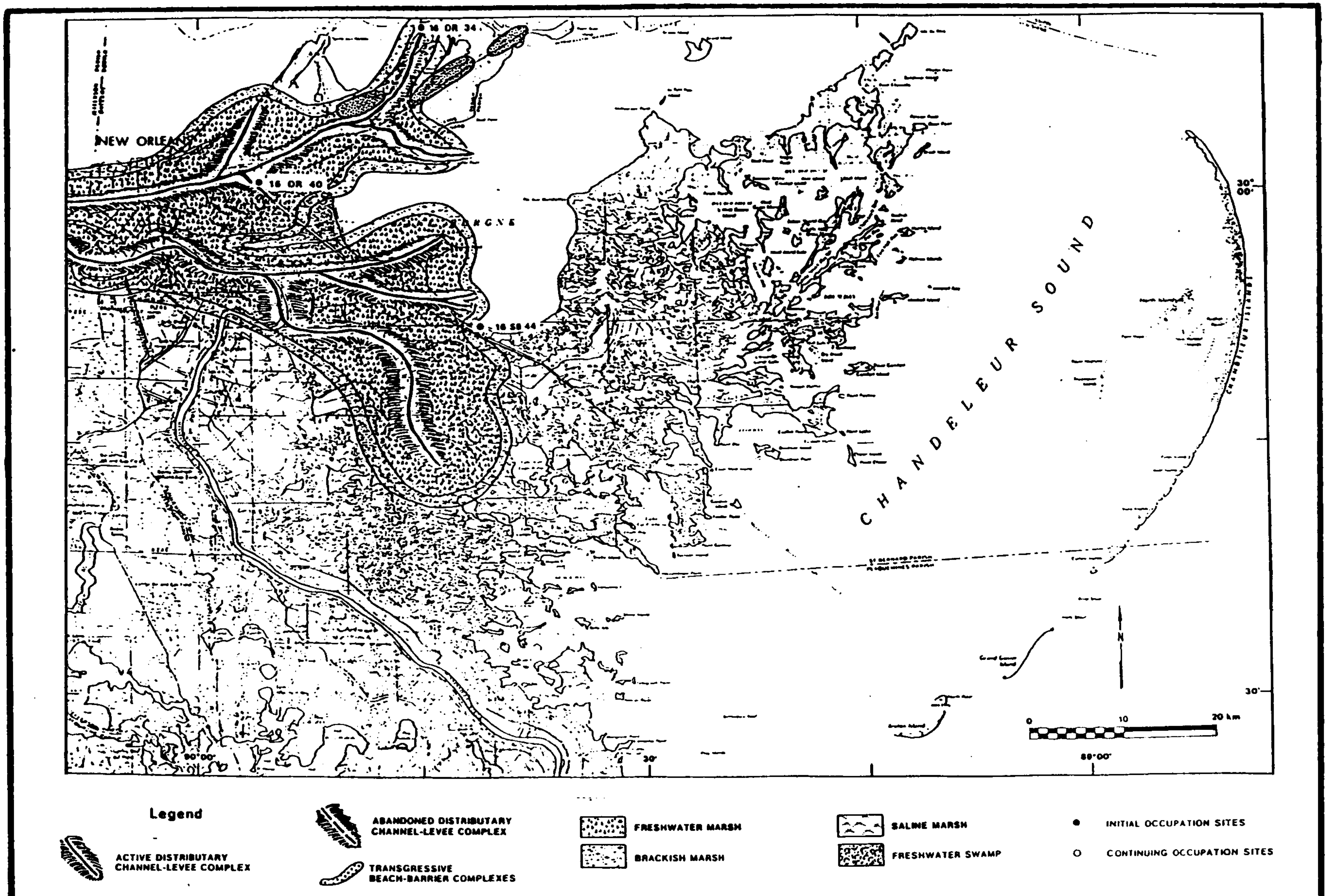


Figure 7.21 The St. Bernard Delta during the Bayou Jasmine and Garcia phases of the Poverty Point period (1500 B.C. to 500 B.C.). Source: Coastal Environments, Inc., 1979

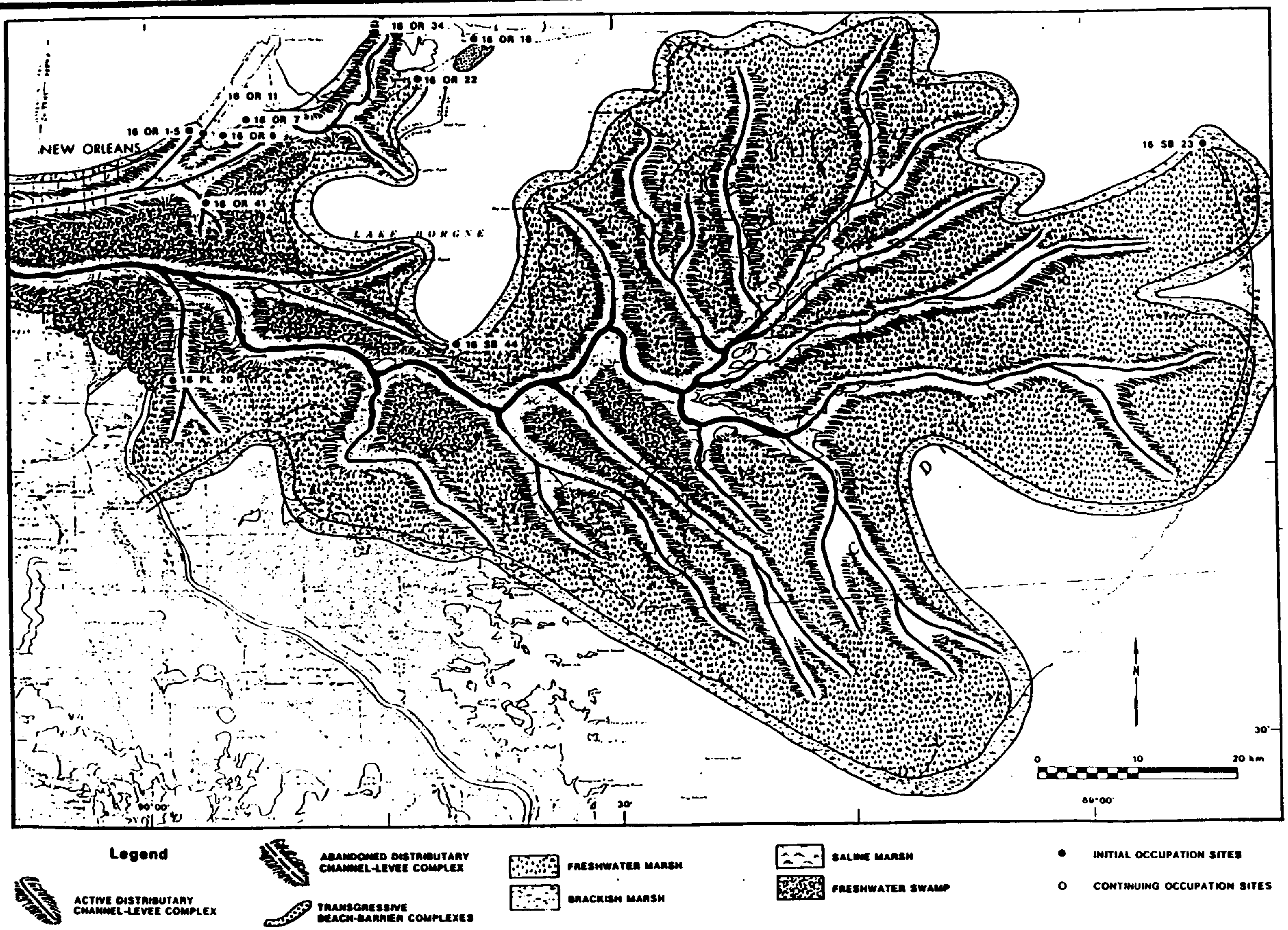


Figure 7.22 The St. Bernard Delta during the latter part of the period between 500 B.C. and A.D. 200 (Pontchartrain phase of the Tehula period and Labranche phase of the Marksville period). Source: Coastal Environments, Inc., 1979

North Island in the Chandeleur barrier island chain, suggesting that the more seaward portions of the delta were utilized at least within the time range from 500 BC to AD 200.

The subsequent, Late Marksville, people (AD 200 - AD 400) coincide in time to the beginning of the abandonment of the St. Bernard Delta lobe by the main trunk of the Mississippi River. During this phase, with reduced sediment input, the unconsolidated sediments began to subside, forming lakes on the outermost portions of the delta, and freshwater marshes replaced the cypress swamps further inland (Figure 7.23). Subsidence and erosion from the adjacent sea has continued and has resulted in the formation of Chandeleur Sound and Breton Sound and an enlarged Lake Borgne.

The close interrelationship between the St. Bernard Delta lobe's growth and subsequent destruction, and prehistoric Indian settlement patterns suggest the potential for the presence of prehistoric Indian sites beneath Breton Sound and Chandeleur Sound. Archaeological sites are documented within the region dating from the delta lobe's growth through its destruction. The subaerial portions of the existing delta are especially rich in archaeological resources (CEI, 1979). There is also evidence that there are a number of prehistoric sites unrecorded that have subsided beneath the marsh (CEI, 1979). Such instances of site subsidence and protection by the overlying sediments may produce likely candidates for preservation beneath the waters of Chandeleur Sound and Breton Sound, and perhaps seaward of the barrier island chain. However, no submerged, intact prehistoric archaeological sites have yet been located beneath these waters.

Southern Plaquemines Parish, encompassing the Modern Birdfoot Delta, is even geologically younger than the St. Bernard Delta lobe, beginning its growth onto the continental shelf and slope about 1000 years ago (Frazier, 1967). Consequently, such immature land would not be a setting for a lengthy chronology of prehistoric archaeological sites, but as Figure 7.24 illustrates, several Plaquemine-Mississippian age sites (1000 AD-1500 AD) have been documented in the older portions of this recent delta complex.

Mistovich and Knight (1983) and Mistovich et al. (1983) have addressed the potential paleogeographic environments for prehistoric habitation in the Mobile Bay region and the Pascagoula Harbor/Mississippi Sound environs, respectively. Mistovich and Knight (1983) suggest that the gradual inland encroachment of the Gulf shoreline following the Pleistocene created suitable habitation environments for Paleo-Indian and Archaic peoples in what is now Mobile Bay and the Mobile-Tensaw River Delta, and that sites might well exist beneath the Bay waters or beneath the Holocene sediments in the Delta. They sought to identify key elements of prehistoric occupation along the ancestral Mobile Bay. These include identifying areas which exhibit a high potential for prehistoric occupation and were subsequently inundated. Areas presenting evidence of marine resource subsistence may take the form of reefs containing a high percentage of edible bivalves. High potential areas identified include the ancient confluences of streams currently entering the Bay. A hypothetical drainage pattern was devised for Mobile Bay for a period 15,000 years ago when sea level was more than 65 m below current levels (Figure 7.25). Five stream confluences are thus produced: the Dog River, D'Olive and Bay Minette Creeks, with the ancestral Mobile River; and the Escatawpa and Fish Rivers.

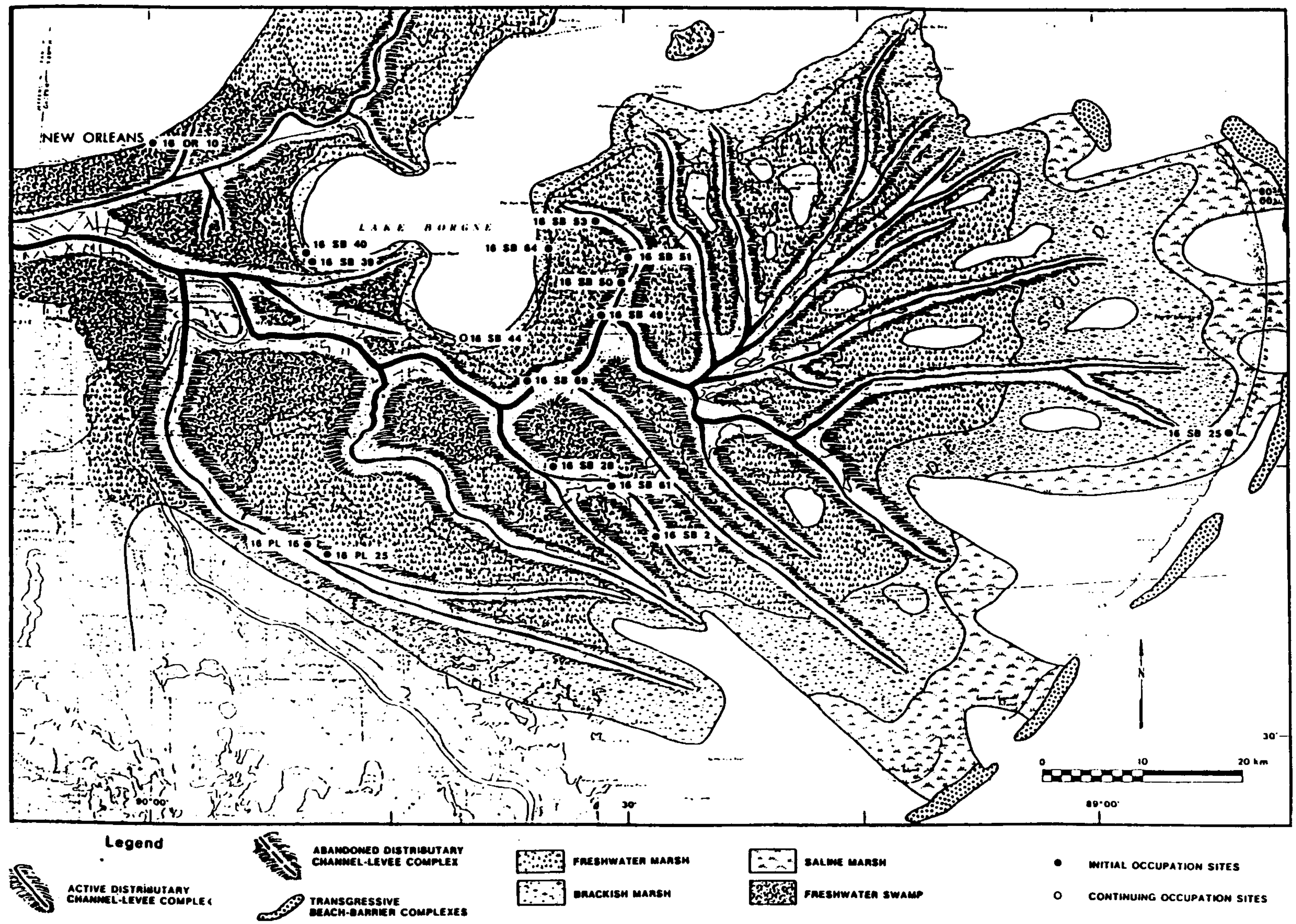


Figure 7.23 The St. Bernard Delta during the Magnolia phase of the Marksville period (A.D. 200 to A.D. 400). Source: Coastal Environments, Inc., 1979

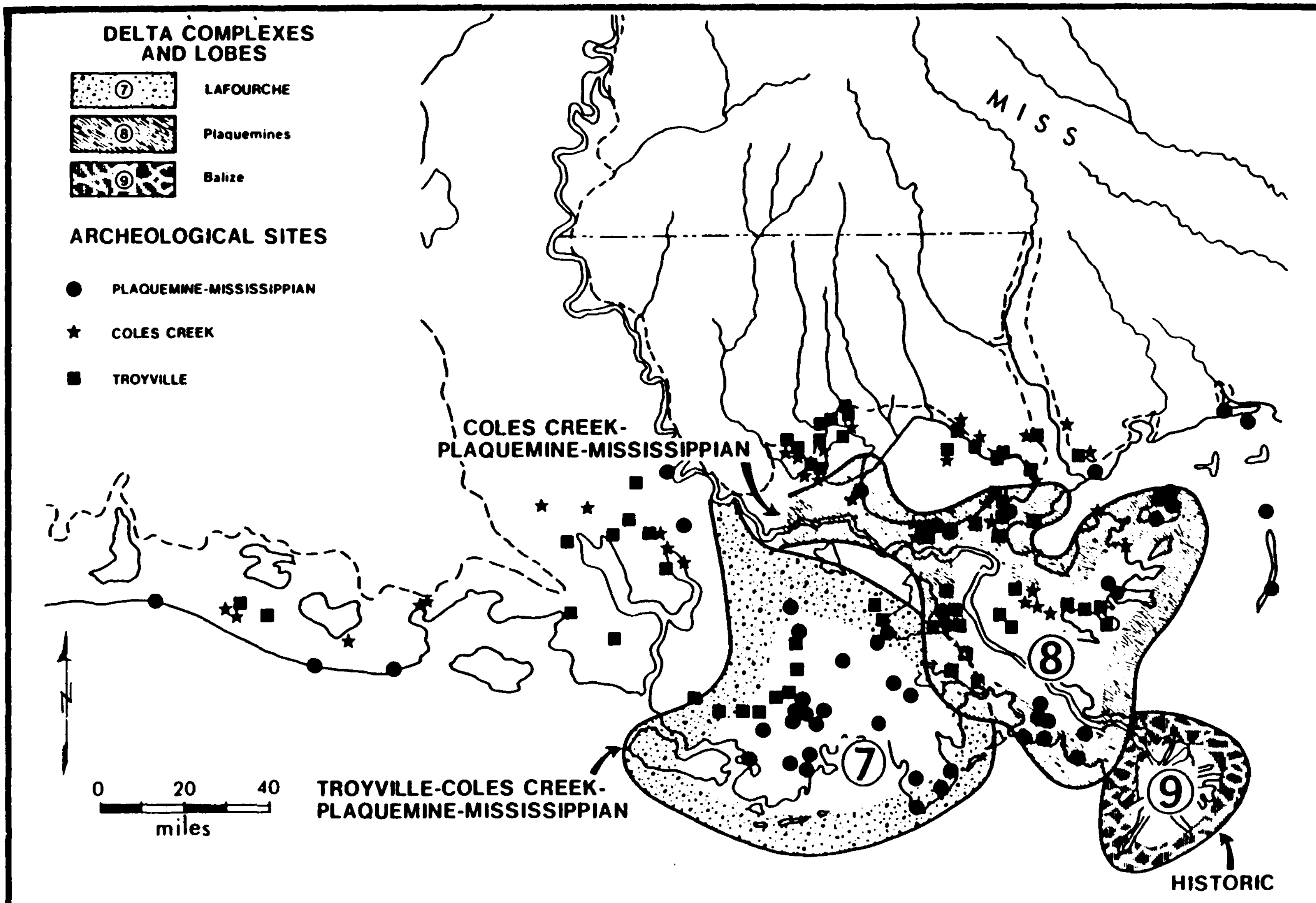


Figure 7.24 Major delta complexes and lobes of the Mississippi River and archaeological sites for the interval from 1700 B.P. to present. Source: Coastal Environments, Inc. 1977

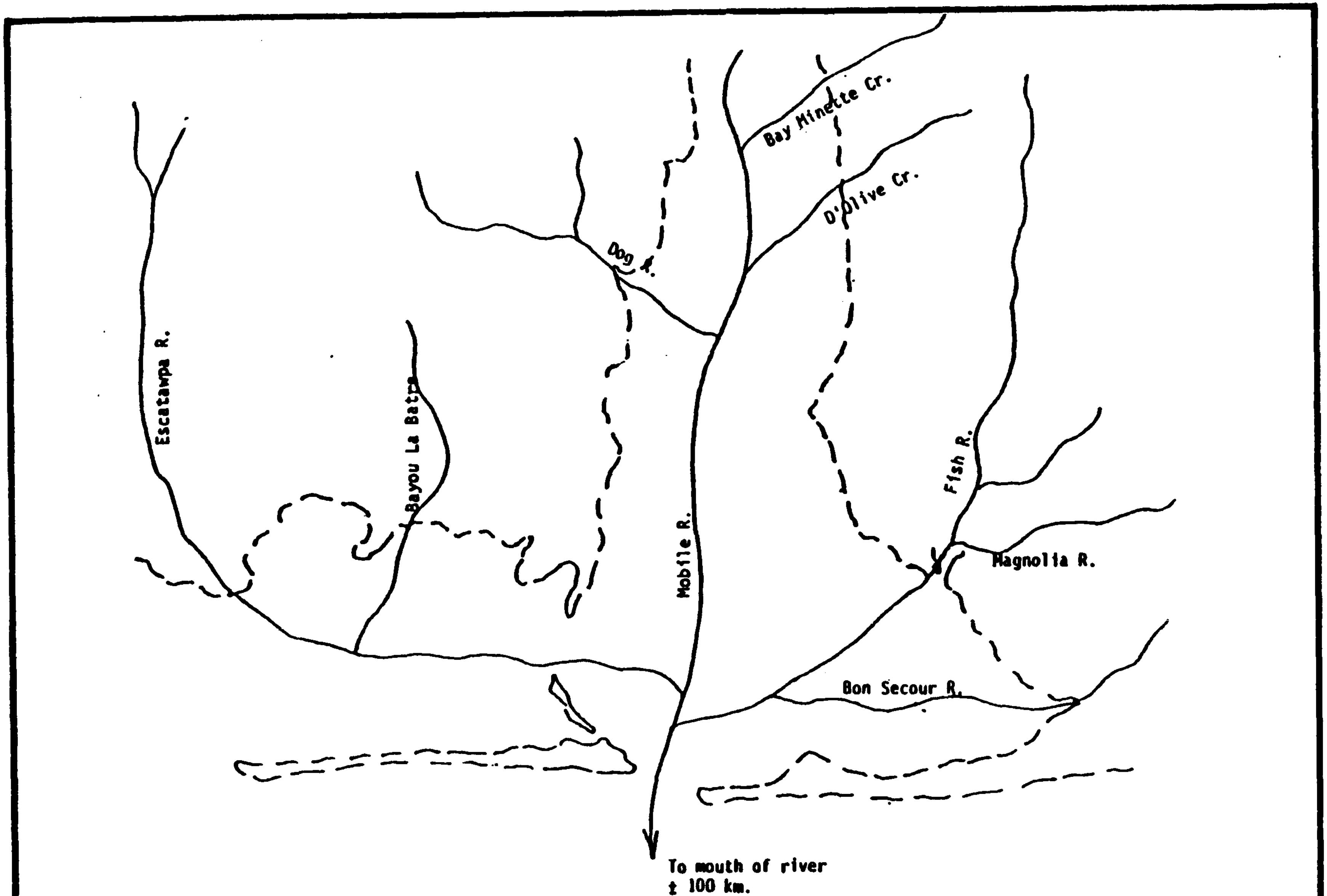


Figure 7.25 Hypothetical drainage pattern 15,000 years B.P. Source: Mistovich and Knight, 1983

Locating shell midden sites in the Mobile Bay and Delta must be approached with the realization that with adjusting sea level, in the estuarine areas, there is an adjustment in salinity regime and movement of oyster reefs. Relict oyster reef deposits have been located through coring in Mobile Bay. The majority of relict deposits were found in the upper Bay. Carbon 14 analysis of these reefs provided dates ranging from 140 years BP on reefs 3.7 m below the present Bay surface to 5710±220 year BP at nearly 12 m below the Bay surface (Mistovich and Knight, 1983). The relationship between shell reef distribution and depth and age corresponds to the Bay's recent geologic history. As the barrier islands developed and the Mobile-Tensaw River prograded, salinity ranges favorable to oyster growth migrated farther down the Bay. The oldest reefs then were buried beneath about 7.6 m of the deltaic deposits. Farther down the Bay the younger reefs were also eventually buried. Most of the lower Bay and Mississippi Sound relict reefs are covered with about one meter of overburden. However, it is possible that more deeply buried reefs may be found in the lower Bay region, corresponding to the time of river systems initial drowning.

The Pascagoula region on Mississippi Sound presents a somewhat different paleogeographic setting. As with the Mobile Bay region, Mistovich et al. (1983) feel that the earliest human occupation of Mississippi Sound dates to the Early Paleo-Indian period (ca. 11,000-12,000 BP). Evidence of Early Paleo-Indian occupation has been limited to isolated discoveries of Clovis-like fluted projectile points with no stratigraphic context. Only one point has been documented from Jackson County, but a site in the Lake Pontchartrain area (16 OR 34) dates to this period (Mistovich et al., 1983).

The time range of 15,000 to 9,000 BP in Mississippi Sound is characterized by the gradual transgression of the Gulf. Erosional processes associated with wave action appear to have been significant, implying that any Paleo-Indian or early Archaic period occupation sites were subject to extensive post-depositional disturbance (Mistovich et al., 1983). The subsequent time span from 9,000 to 6,000 BP, however, is distinguished from the earlier period by some sea level stabilization, associated barrier island formation, and increased sedimentation rates in the Sound. Middle Archaic peoples may have established settlements along the new shoreline. Such sites present a greater potential for preservation than earlier period occupations due to the possibility of encapsulation and protection beneath the accumulated sediments. The average thickness of Holocene sediments in the Sound is about 5 m in the northern portions (Otvos, 1982) as opposed to 12.2-18.3 m at the barrier islands (Ludwick, 1964).

Terrestrial Prehistoric Archaeological Sites

As noted above, data pertaining to the presence of prehistoric archaeological sites beneath the waters offshore of Louisiana, Mississippi, and Alabama are sparse and based primarily on speculation. However, knowledge of the terrestrial prehistoric archaeological sites is much more extensive. Synthesis reports by Mistovich and Knight (1983) on the Mobile Bay region, Mistovich et al. (1983) focusing on Pascagoula Harbor and environs, and a statewide survey of archaeological sites in Louisiana (Louisiana Department of Culture, Recreation, and Tourism, 1983) provide a glimpse of the timeframe and hypothesized interrelationships of the regional prehistoric peoples. Table 7.39 is a count of recorded archaeological sites in the relevant counties and parishes. However, these figures may be misleading for several reasons. In

Table 7.39. Archaeological sites recorded in the Tuscaloosa Trend study area.

Louisiana*		Mississippi		Alabama	
St. Bernard	133	Harrison	129	Mobile	70
Plaquemines	122	Hancock	80	Baldwin	260
Total	255		353		330

*Includes historic and prehistoric sites

Source: Louisiana Department of Culture, Recreation and Tourism, 1983
Mississippi Department of Archives and History, 1984;
Office of Archaeological Resources, Personal Communication, 1984

the Alabama coastal counties, over 90% of the recorded prehistoric sites are within one mile of the coastal waters (Personal communication, Eugene Futato, Office of Archaeological Research). Also, the table does not yield information on the frequency of recorded sites related to prehistoric chronology. Lewis (1982) examined recorded archaeological sites along the Mississippi coast. The survey did not include all the sites currently known to the Mississippi Department of Archives and History, but does shed some light on the region's prehistoric chronology. Table 7.40 clearly illustrates the increased frequency of archaeological sites progressing toward historic times. Determining the number of prehistoric sites and their distribution in the relevant Louisiana parishes presents special problems. Archaeological site inundation and loss as a result of sea level fluctuation is exacerbated in Louisiana by coastal erosion and subsidence. A survey of archaeological site loss in nearby Jefferson parish revealed that 40% of the recorded sites have been lost due primarily to coastal erosion and subsidence (Personal commmunication, Kathleen Byrd, Louisiana Department of Culture, Recreation and Tourism). No such survey has yet been performed in Plaquemines or St. Bernard Parishes, but Table 7.41 (Gagliano et al., 1981) presents figures on land loss rates in and around the study area. These numbers suggest that loss of archaeological sites in St. Bernard and Plaquemines Parishes may be quite significant.

Assessing the number of prehistoric archaeological sites in Louisiana also presents an unforeseen complication. Archaeological sites on file at the Louisiana Department of Culture, Recreation and Tourism are but a small percentage of the sites that have been surveyed by private contractors such as Coastal Environments, Inc. Therefore, Table 7.42, which lists, for example, one Marksville age site in St. Bernard Parish, conflicts with Figures 7.22 and 7.23 which indicate thirteen Marksville period sites. Other private contractors may have additional site files containing descriptions of the archaeological site components.

Table 7.40. Mississippi Coast Sites by Period (includes Hancock, Harrison, and Jackson counties.

Period	#	%
Late Archaic	2	2.3
Poverty Point	7	8.1
Tchefuncte	11	12.8
Marksville	16	18.6
Troyville/Coles Creek	10	11.6
Plaquemine/Moundville	22	25.6
Historic	12	14.0
Woodland Cultural Tradition	6	7.0
Total	86	100.0

108 other components of undetermined age are not included in this table.

Source: Lewis, 1982

Table 7.41. Land loss rates - Coastal Louisiana.

Parish	Remaining Land (in acres)	1980 Projected Loss Rate (in acres)	Life Expectancy (in years)
Lafourche	650,541	3,179	205
St. Bernard	257,816	1,695	152
Terrebonne	699,782	6,851	102
Plaquemines	457,523	8,831	52

Source: Gagliano et al., 1981

Table 7.42. Recorded archaeological components* in Orleans, St. Bernard, and Plaquemines parishes, Louisiana (Current 1983).

	Paleo-Indiana	Archaic	Poverty Point	Tchefuncte	Marksville	Troyville-Coles Creek	Plaquemine	Mississippian	Caddo	Historic Contact	Exploration and Colonization	Antebellum	War and Aftermath	Industrialization and Modernization	Total Components Identified @	Total Sites+
Orleans	0	0	1	10	4	8	0	5	0	1	6	20	22	6	83	76
Plaquemines	0	0	0	0	0	2	1	0	0	0	5	10	13	28	59	80
St. Bernard	0	0	0	0	1	5	5	7	0	0	8	13	6	15	60	117

*Based on Division of Archaeology's records

@Some sites are multicomponent

+Many sites have no component recorded

Source: Louisiana Department of Culture, Recreation and Tourism (1983)

7.8.2 HISTORIC PERIOD CULTURAL RESOURCES

Historic Overview

Historic period cultural resources within the Tuscaloosa Trend study area date to the initial voyages of discovery and exploration into the Gulf of Mexico. The northern Gulf coast may have been discovered, mapped, and superficially explored prior to 1519. Evidence, however, is limited to ca.1500 maps of the New World depicting an indented Gulf of Mexico. Such an early cartographic rendition may have arisen from the erroneous assumption that North America was the Indies (Mistovich and Knight, 1983). Nonetheless, no European contact before Pineda's 1519 voyage of exploration can be proven. Pineda skirted and mapped the northern coast from Texas to Appalachicola, Florida, and is credited for discovering Mobile River and Bay, which he named Espiritu Santo. He remained at the river mouth 40 days while repairing his ships, and traded with local Indians. Nine years later, in 1528, Narvaez traversed the northern Gulf coast during his ill-fated expedition. The remnants of Narvaez's forces discovered the mouth to the Mississippi River. After these preliminary contacts and later expeditions by DeSoto and Bazares, little European colonial activity occurred until the last decades of the 17th Century. In 1682, Rene Robert Cavalier, Sieur de la Salle explored the Mississippi River, beginning in Illinois, travelling southward to the River's mouth, and formally claimed the entire basin for France, naming it Louisiana. This pivotal event marks the beginning of an active period of European settlement along the northern Gulf coast.

The first permanent European settlements in the study area were established by the French. In 1698, Pierre LeMoyne d'Iberville and Jean Baptiste de Bienville landed at Dauphin Island, Alabama, with the intention of developing a colony. The close proximity of the Spanish in Florida, however, influenced d'Iberville to shift his colonial efforts westward to Ship Island near Biloxi, Mississippi. Fort Maurepas was then constructed, in 1699, across the bay from present-day Biloxi, establishing the first French settlement on the Gulf of Mexico. The following year, Fort de la Boulaye was built on the Mississippi River downstream from the present location of New Orleans. The capital of French Louisiana was transferred to 27-mile bluff on the Mobile River north of present-day Mobile in 1701, where it remained until 1711. The oldest historic cultural resources in the form of historic sites and shipwrecks within the study area date to this period.

The European colonial experience in the eastern Mississippi Delta region differed sufficiently from elsewhere in the study area to merit a separate discussion. Early historic-period settlements were more sporadic and less successful in the eastern Mississippi River Delta, including St. Bernard Parish and Plaquemines Parish. Unlike the generally upland areas east of the Mississippi River Delta, land suitable for settlement in the Delta area was confined to broad, low, natural levees of the River and its distributaries. The intervening marshes were utilized primarily as hunting and fishing areas. Structures in the marshes were generally hunting and fishing camps. The region's strategic position in relation to New Orleans during later historical times contributed to the establishment of military settlements on passes with access to the city.

European settlement of the Delta region began during the period of French colonization from 1719-1722. The settlers, however, were primarily Germans from Rhineland. Little or no growth occurred until Spain acquired the region in 1762. In the first few years of Spanish rule, more immigrants arrived than during the entire French period. The new immigrants had diverse origins; many were Acadians driven from French Canada by the British. Fifteen of the twenty-three surnames identified as belonging to the earliest immigrants in St. Bernard Parish are French, one is Dutch or German, one Italian, one English, and one Spanish (CEI, 1979). The region's physiography did not lend itself to the development of large settlements. Few permanent settlements were founded. Terre aux Boeufs and Chalmette, the main centers, grew sporadically and were built on natural levees. Fort Proctor, one of two National Register sites in St. Bernard Parish, begun in 1856 at Proctor's Landing on Bayou Yscloskey, was not completed until after the Civil War.

A situation alluded to in the discussion of prehistoric archaeological sites in the vicinity of the St. Bernard Delta lobe, subsidence, is equally true for historical sites and structures. Lighthouses and port towns were built in the Modern-Balize Delta. One such port town, Balize (1734-1888), has subsided and has been covered by sediment (CEI, 1977b).

Shipwrecks in the Gulf of Mexico and Nearshore Waters

The earliest known shipwreck in the Gulf of Mexico occurred in 1520 (CEI, 1977b). Since that initial sinking, perhaps 3,000 ships have wrecked in the Gulf. Seventy percent or more of these are relatively recent, dating from the beginning of the 19th Century. The remainder sank during the 16th, 17th, and 18th centuries. Estimates of shipwreck numbers must be interpreted broadly due to the incomplete and inexact historical records recounting such events. However, missing vessels in Gulf waters number in the thousands and such a potentially large shipwreck population constitutes an important cultural resource. Shipwrecks possess a time capsule quality lacking in most terrestrial archaeological sites. The rapidity of shipwreck disasters generally insures the presence of a broad cross-sectional sample of the material culture of the period, which can sometimes be accurately situated in time, even to the day.

Coastal Environments, Inc. (1977b) evaluated the northern Gulf of Mexico for the presence of historical cultural resources, focusing on the potential for the occurrence of shipwrecks. That study resulted in a series of maps depicting high probability areas for the occurrence of wrecks from 1500-1945. More locally, Mistovich and Knight (1983) conducted a cultural resources evaluation of Mobile Harbor, including an inventory of shipwrecks in the Mobile Bay vicinity. Mistovich et al. (1983) evaluated Pascagoula Harbor and environs in a similar manner.

Coastal Environments, Inc. (1977b) estimated that about two-thirds of the total population of wrecks in the northern Gulf are within 1-5 km of the coast. Perhaps another 500 wrecks lie in a zone between 1.5 km and 10 km from the shore. That study found, not surprisingly, that wrecks are associated with approaches to seaports, straits, shoals or reefs, and along well-established sailing routes. Table 7.43 lists the number of shipwrecks known to have occurred throughout the Gulf of Mexico, organized by broad chronological groupings. It is noteworthy that less than 2% of the pre-20th Century wrecks and less than 10% of the ships reported lost prior to 1945 have known

Table 7.43. Known shipwrecks and reported losses in the Gulf of Mexico.

Historic Period	Number of Wrecks*	Location Known**
1500 to 1699 A.D.	146	0
1700 to 1819 A.D.	275	1
1820 to 1899 A.D.	719	10
Totals: Pre-20th Century	1,140	11
1900 to 1945 A.D.***	398	90
Unknown Date	51	9
Totals: All Periods	1,589	110

*It should be noted that the above numbers are only approximations since many losses of entire fleets are listed as single wrecks, and since it cannot be determined whether several wrecks reported by different sources are the same wreck or not.

**Some of the wrecks had such broad locations given (i.e., covering an entire latitude and longitude) that they were not included in the category "location known."

***Some wrecks from this period include World War II casualties. Although most World War II wrecks may not be considered historically significant at this time, their historic significance in terms of the National Register criteria will have to be addressed within the life of the lease which result from the proposed lease sales.

Source: MMS, 1983

locations. Furthermore, as Table 7.44 clearly shows, no shipwrecks with known locations in the outer continental shelf portion of the study area occurred before 1900.

The Mobile Harbor study (Mistovich and Knight, 1983) and the Pascagoula Harbor study (Mistovich et al., 1983) provide a dramatic contrast to the numbers of shipwrecks identified by CEI (1977b) for the outer continental shelf. The Mobile Harbor study area included the entire Bay, Mobile Bar at the mouth of the Bay, and the Mobile Inner Harbor. The Pascagoula Harbor study encompasses Mississippi Sound roughly from Petit Bois Pass on the east to Bellfontaine Point on the west. The southern margins of Horn Island and Petit Bois Island are included, as are Horn Island Pass Channel and its surroundings. Mistovich and Knight (1983) identified 209 shipwrecks which may yet lie in or around Mobile Bay. The oldest sinking is the French merchant vessel, Bellone, which sank on the south side of Dauphin Island on April 1, 1725. The U.S.S. Tecumseh, listed in the National Register of Historic Places, is probably the best known of all the vessels sunk in the study area. The Tecumseh was hit by a torpedo during the Battle of Mobile Bay and sunk on August 5, 1864, near Fort Morgan. Mistovich et al. (1983) accumulated 72 shipwreck entries in the inventory of the Pascagoula Harbor region. The earliest shipwreck event occurred on August 23, 1780 when an unknown number of small, Spanish, Bercha Class vessels bound for Mobile from New Orleans were lost during a hurricane.

Inventories, such as those noted above, provide valuable data concerning the potential for historic maritime resources. However, actually locating a targetted shipwreck presents a variety of difficulties. The quality of wreck location information varies according to the historic documentation available. In addition, the remains of wrecks that occurred in shallow water may be widely dispersed by storms and wave action. When, in the course of performing a cultural resources survey related to oil and gas activities, a potentially significant anomaly has been encountered, the potentially significant cultural resource has always been avoided. Thus, the identities of these features have never been verified and no excavations have occurred.

Coastal Historic Sites and Sites Included in the National Register of Historic Places

The cultural resources that have been included in the National Register of Historic Places (Table 7.45, Figure 7.26) provide an excellent picture of the region's cultural significance. Prehistoric as well as historic cultural resources have been recognized. The Claiborne site (22 Ha 501), a Poverty Point-age (ca. 1200 BC) habitation near the Pearl River's mouth in Hancock County, Mississippi, represents, along with the nearby Jackson Landing Site (Mulatto Bayou, 22 Ha 500, ca. 800 BC - historic contact), some of the earliest major habitations known in the region. It is noteworthy that other, even older, important archaeological sites are present in the vicinity (e.g., the Cedarland site adjacent to the Claiborne site) but are not included on the National Register at this time. Further east in coastal Alabama, the Indian Mound Park is the site of six large prehistoric shell mounds, and the Bottle Creek Indian Mound complex in the Mobile-Tensaw Delta is the largest temple mound complex in South Alabama.

Historic cultural resources meriting mention date from the first European colonial ventures. The site of the first fort on the Gulf, Fort

Table 7.44. Shipwrecks with known locations in the OCS - Tuscaloosa Trend

Name	Type	Date			Block Number	Other Blocks Within Which Wreck Could Lie
		Built	Sunk	Recorded		
Unknown	Barge		1942	1945	Pensacola 977	None
Bayrd	Passenger/ cargo		1942	1945	Main Pass 140	None
Tulsa	Cargo/ schooner	1909	1943	1943	Mobile 1000	None
Paul Warner	Tanker	1912	1942	1942	South Pass 45	South Pass 44
Fairhope	Steamer	1899	1918		South Pass 37	South Pass 45
Louisiana	Cargo	1919	1926	1926	South Pass 30, 31	None
Yuma	Cargo		1926	1945	South Pass 43	None

Source: MMS, 1983, 1984

Table 7.45. National Register Sites.

County	City	Site		Year Included
MISSISSIPPI				
Hancock	Bay St. Louis	Bay St. Louis N.R. District*	(4)	1980
Hancock	Mulatto Bayou	Jackson Landing Site	(3)	1973
Hancock	Pearlington	Claiborne Site	(3)	1982
Harrison	Pass Christian	Scenic Nat. R. Drive	(5)	1979
Harrison	Long Beach	W. J. Quarles House	(6)	1980
Harrison	Gulfport	U.S. Post Office and Courthouse	(7)	1984
Harrison	Gulfport	Milner House	(8)	1972
Harrison	Gulfport	Hewes Building	(7)	1982
Harrison	Biloxi	West Beach Historic District	(10)	1984
Harrison	-	Fort Massachusetts (Ship Island)	(12)	1971
Harrison	Biloxi	West Central Historic District	(7)	1984
Harrison	Biloxi	Tullis House	(11)	1976
Harrison	Biloxi	Reed House	(11)	1979
Harrison	Biloxi	Margaret Emilie (SailBoat)	(11)	1973
Harrison	Biloxi	Magnolia Hotel	(11)	1973
Harrison	Biloxi	Gillis House	(10)	1978
Harrison	Biloxi	Biloxi Lighthouse	(11)	1973
Harrison	Biloxi	Biloxi Garden Center	(11)	1973
Harrison	Biloxi	Biloxi City Hall	(11)	1978
Harrison	Biloxi	Beavoir	(9)	1971
Jackson	Gautier	Colonel A.E. Lewis House	14 (26)	1980
Jackson	Hurley	Degroote Folk House	(15)a	1982
Jackson	Moss Point	Griffin House	(15)	1983
Jackson	Ocean Springs	Louisville & Nashville RR Depot	(16)	1979
Jackson	Pascagoula	Front St. Historic District	(16)	1984
Jackson	Pascagoula	Louisville & Nashville RR Depot	(16)	1974
Jackson	Pascagoula	Old Spanish Fort	(15)b	1975
Jackson	Pascagoula	Pascagoula Central Fire Sta. #1	(16)	1978
ALABAMA				
Mobile	Mobile	Barton Academy	(24)	1970
Mobile	Mobile	Battle House Royale	(24)	1975
Mobile	Mobile	Bishop Poitier House	(24)	1970
Mobile	Mobile	Bragg-Mitchell House	(24)	1972
Mobile	Mobile	Brisk and Jacobson Store	(24)	1973
Mobile	Mobile	Carolina Hall (Yester House)	(24)	1973
Mobile	Mobile	Church St. East Historic District	(24)	1971
Mobile	Mobile	City Hall - City Market	(24)	1969
Mobile	Mobile	City Hospital	(24)	1970
Mobile	Mobile	DeTonti Square Historic District	(24)	1972
Mobile	Bucks	Ellicott Stone	(**)	1973
Mobile	Mobile	Emanuel-Staples-Pake Building	(24)	1978
Mobile	Mobile	Fort Conde - Charlotte	(24)	1969

Table 7.45.- (Continued)

County	City	Site		Year Included
ALABAMA (Continued)				
Mobile	Mobile	Fort Conde - Charlotte House (Kirkbridge House)	(24)	1973
Mobile	-	Fort Gaines	(18)	1976
Mobile	-	Fort Louis de la Louisiane	(**)	1976
Mobile	Mobile	Gates-Daves House	(24)	1974
Mobile	Mobile	Georgia Cottage	(24)	1972
Mobile	Mobile	Gulf-Mobile & Ohio Terminal	(24)	1975
Mobile	Mobile	Horst House	(24)	1971
Mobile	-	Indian Mound Park	(17)	1973
Mobile	Mobile	Marine Hospital	(24)	1974
Mobile	-	Middle Bay Light	(22)	1974
Mobile	-	Nanna Hubba Bluff (Blue Fording Landing)	(**)	1974
Mobile	Mobile	Oakleigh	(24)	1971
Mobile	Mobile	Oakleigh Garden Historic District	(24)	1972
Mobile	Mobile	Pincus Building	(24)	1976
Mobile	Mobile	Protestant Children's Home	(24)	1973
Mobile	Mobile	St. Louis St. Missny. Bpt. Church	(24)	1976
Mobile	Mobile	Semmes House	(24)	1970
Mobile	Mobile	S. Lafayette St. Creole Cottages	(24)	1976
Mobile	Mobile	Springhill College Quadrangle	(24)	1973
Mobile	Mobile	State St. A.M.E. Zion Church	(24)	1978
Mobile	Mobile	First National Bank of Mobile	(24)	1978
Mobile	Mobile	Carlen House	(24)	1981
Mobile	Mobile	Tschiener House	(24)	1982
Mobile	Mobile	Common St. District	(24)	1982
Mobile	Mobile	Miller-O'Donnell House	(24)	1982
Mobile	Mobile	Lower Dauphin St. District	(24)	1982
Mobile	Mobile	Cavellero House	(24)	1982
Mobile	Mobile	Weems House	(24)	1982
Mobile	-	Bellingrath Home and Gardens	(23)	1982
Mobile	Mobile	Coley Building	(24)	1982
Mobile	Mobile	Murphy High School	(24)	1982
Mobile	Mobile	Davis Ave. Branch, Mobile Public Library	(24)	1983
Mobile	Mobile	Fire Station No. 5	(24)	1983
Mobile	Mobile	Vickers and Schumacher Bldgs.	(24)	1983
Mobile	Mobile	Dahm House	(24)	1984
Mobile	Mobile	Denby House	(24)	1984
Mobile	Mobile	Meaher-Zoghby House	(24)	1984
Mobile	Mobile	Metzger House	(24)	1984
Mobile	Mobile	Monterey Place	(24)	1984
Mobile	Mobile	Neville House	(24)	1984
Mobile	Mobile	Phillippi House	(24)	1984
Mobile	Mobile	Scottish Rites Temple	(24)	1984
Mobile	Mobile	St. Francis St. Methodist Church	(24)	1984

Table 7.45 - (Continued)

County	City	Site		Year Included
ALABAMA (Continued)				
Mobile	Mobile	Hawthorn House	(24)	1984
Mobile	Mobile	Termite Hall	(24)	1983
County	City			
Baldwin	-	Blakeley Site	(**)	1974
Baldwin	-	Bottle Creek Indian Mounds	(**)	1974
Baldwin	Tensaw	Fort Mims Site	(**)	1972
Baldwin	-	Fort Morgan	(21)	1960
Baldwin	Montrose	Montrose Historic District	(25)	1976
Baldwin	-	Sand Island Light	(19)	1975
Baldwin	-	U.S.S. Tecumseh	(20)	1975
LOUISIANA				
Parish				
St. Bernard		Fort Procter	(1)	-
St. Bernard		Magnolia Mound Archaeological Site	(2)	-

*Includes 15 houses

**Not shown

Sources: Alabama Historic Commission, 1978; Mississippi Dept. of Archives and History, 1984; Louisiana Dept. of Culture, Recreation and Tourism, 1983.

Note: Numbers in parentheses relate to locations shown on Figure 8.26.

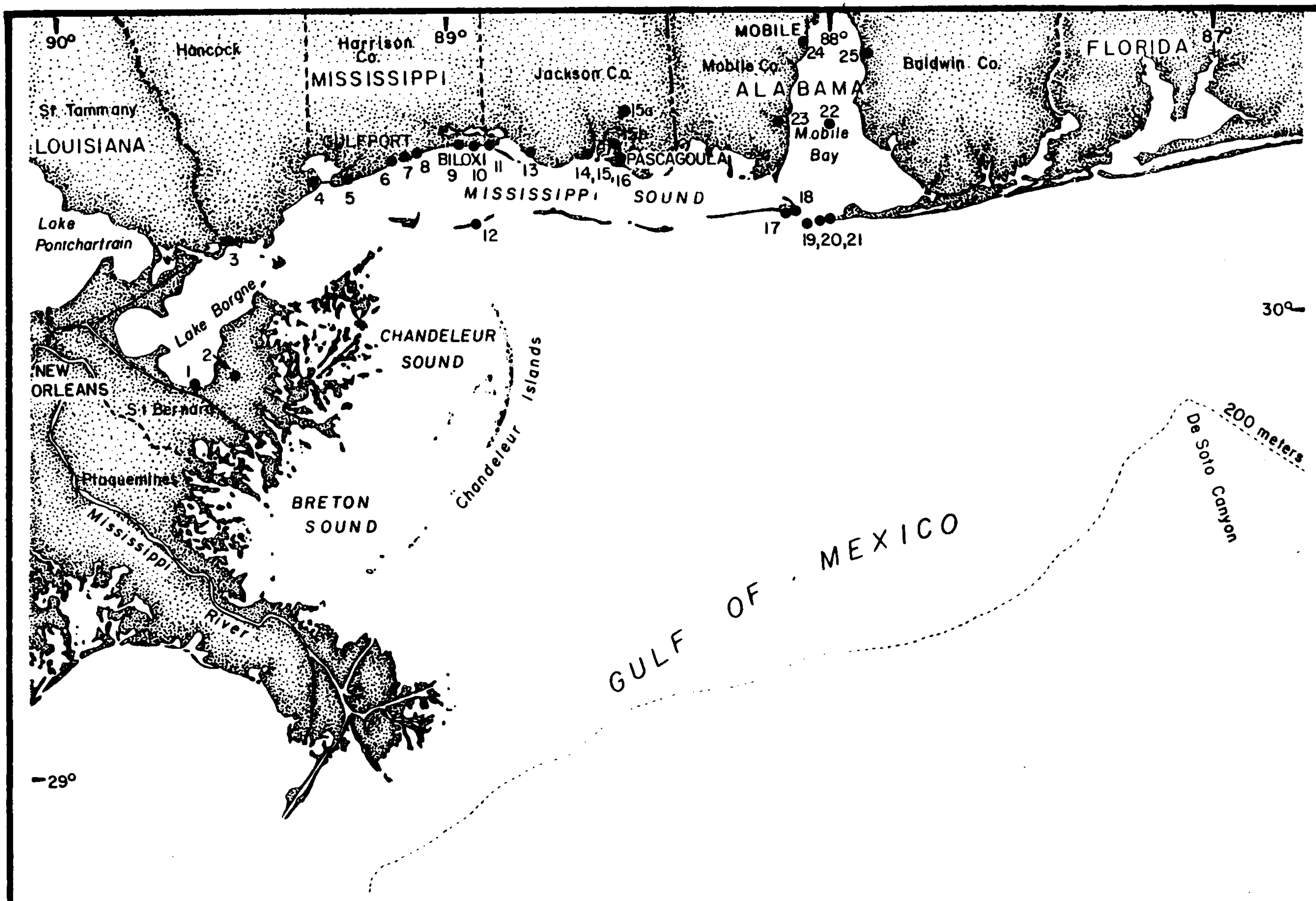


Figure 7.26 National Register sites. Source: Mississippi Department of Archives and History, 1984; Louisiana Department of Culture, Recreation and Tourism, 1983; Alabama Historic Commission, 1978

Maurepas, is in Ocean Springs, Mississippi, while the Rotten Bayou Cemetery in Bay St. Louis dates to the 1700's and is one of the oldest cemeteries on the Gulf coast. Coastal Alabama's contribution to historic resources includes early French fort sites and two extant forts, Fort Gaines (1818) and Fort Morgan (1833). The Union ironclad U.S.S. Tecumseh lies in nine meters of water in Mobile Bay north of Fort Morgan.

7.9 MULTIPLE USE CONFLICTS

Friend et al. (1982) offer a working definition of multiple use conflicts which, due to its clarity and conciseness, is adopted for this discussion. A multiple use conflict is "an activity by man that is incompatible with, or at variance with, other life forms (including man)." For example, the waterborne transportation industry depends on access to the coastal ports from the open Gulf in order to function. The natural resource involved is the water itself, and a potential conflict exists between the shipping industry and the oil and gas industry for use of the surface waters. This potential conflict has been partially alleviated through the establishment of the fairways and anchorages which provide unimpeded shipping access by restricting obstructions associated with oil and gas exploration and production developments. For general advisory purposes, the states of Mississippi and Alabama have prepared guides regarding the location of pipeline corridors in the coastal zone for the transportation of OCS-produced oil and gas. The guides outline landfall areas and pipeline siting locations that are unsuitable for siting, or only suitable with stipulations. Louisiana has not prepared such a comprehensive plan, but has designated the barrier islands of the Mississippi River Deltaic Plain as unsuitable for pipeline siting (Gulf of Mexico Regional Technical Working Group, 1981). This planning approach, by identifying sensitive areas and specifying specific oil and gas transport corridors, minimizes the potential for major conflicts for valuable coastal resources. Recognition of multiple use conflicts requires knowledge of the individual socioeconomic activities, the functions and values of ecosystems, and analysis of the potential overlap, impact, or competition for natural resources. The topics addressed briefly below were selected to illustrate the conflicts that might result from the further development of an offshore oil and gas industry within the Tuscaloosa Trend study area.

7.9.1 TRANSPORTATION

Potential conflicts between oil and gas industry activities and the shipping industry range from competing for port and harbor space to collisions between shipping vessels and slow-moving, pipeline-laying vessels. Additional pressure may be placed on harbor facilities in Mobile Bay, Mississippi Sound, and Louisiana. In Alabama, for example, crew transfer points and staging areas for offshore development would be at the Theodore Industrial complex and Bayou La Batre, while Bayou Cassotte-Pascagoula will most likely serve this function in Mississippi. The small Bayou La Batre harbor, which is primarily utilized by the commercial fisheries fleet, has also been studied as a potential offloading port for commerce with Central America. Since a space conflict between commercial fishery and oil and gas service vessels has been established (U.S. Army Corps of Engineers, 1984), the same potential conflict exists between the oil and gas industry and the shipping industry.

Another potential multiple use conflict may result from the increased boat traffic. Additional numbers of oil and gas industry service boats, barges, drilling and mud ships will be utilizing the open Gulf waters, but they will be operating outside the customary traffic lanes and patterns. This increased traffic will tend to concentrate at the main passes into Mississippi Sound and Mobile Bay, and thus may increase the probability of vessel collision. During the initial development of the oil and gas pipeline infrastructure, slow-moving, pipeline-laying vessels would be operating in the vicinity of waterborne transport routes. This activity may interfere with established shipping for the duration of the pipeline laying.

After the infrastructure, including drilling and production platforms, is developed, there is still a possibility of collision. Shipping fairways and anchorages have been established to minimize potential collision and regulations made to cover general requirements for lights and signals. The minimum separation is 0.6 km between a structure and a navigation channel. Nonetheless, from 1964-1982 there were 20 significant collisions with OCS structures in the Gulf of Mexico (MMS, 1984b).

7.9.2 TRAVEL, TOURISM, and RECREATION

Multiple use conflicts between travel, tourism, and recreation activities and offshore oil and gas activities could result from aesthetic detraction of the resources, primarily beaches and coastal wetlands, and adverse impacts on sportfish species resulting from a major oil spill or similar catastrophe. The Minerals Management Service (1984b) estimates that exploration, development, transportation, and production of the remaining recoverable oil reserves in the northern Gulf are likely to result in at least one major spill. Such a spill would cause serious but short-term damage to specific beach areas. In 1970, about 65,000 barrels of crude oil was discharged from a Chevron oil platform about 18 km east of the Mississippi River Delta. An additional 2,000 barrels of chemical dispersants were then sprayed on the platform and surrounding water surface. The impacts of this significant spill were not documented sufficiently to ascertain the extent of damage to the environment. The more recent and better-documented IXTOC oil spill in the Bay of Campeche in 1979 resulted in 500,000 metric tons of oil being discharged into the Gulf. Approximately 4,000 to 11,000 metric tons of IXTOC oil later washed onto the beaches in southern Texas. The economic impact on the Texas coast was estimated to have been $3.8 million lost from reduced tourism, and another $3 million directly lost to the recreation industry (Restrepo and Associates, 1982). A less catastrophic aesthetic loss may result from the accumulation of oil and gas industry related debris, such as oil drums, tarballs, and miscellaneous material, on important recreational beaches.

Similarly, a conflict between marine recreational fisheries activities and the oil and gas industry may arise in the event of a major oil spill or similar catastrophe. Events of that magnitude may disrupt the food web relationships of primary targetted sportfishing species (e.g., speckled trout). In the case of estuarine-dependent species, additional damage may result if valuable wetland habitat is impacted. It must be noted, however, that the presence of oil and gas structures also function as artificial reefs which enhance certain types of sportfisheries.

7.9.3 COMMERCIAL FISHERIES

The potential multiple use conflict between offshore oil and gas activities and commercial fisheries primarily revolves around competition for space. Production platforms remove as much as two hectares of trawling space (MMS, 1984b). Also, in order to avoid a drilling rig, a structure could generally be fished no closer than 46-61 m. This would effectively close 1.5 to 3 ha around the rig to any commercial fishing using towed nets (U.S. Army Corps of Engineers, 1984). Use of commercially valuable fishing grounds by the oil and gas industry has resulted in losses of trawls, shrimp catch, business downtime, and occasional vessel damage. Gulfwide, there were 117 damage claims filed by commercial fishermen in 1983, due to conflicts with oil and gas structures (MMS, 1984b).

There is also potential competition between commercial fishing vessels and oil and gas service vessels for port and harbor space. Such competition has already been documented at Bayou La Batre (U.S. Army Corps of Engineers, 1984). If the oil industry were to outbid the commercial fisheries industry for such limited space, commercial fisheries could be impacted.

However, the greatest potential resource use conflict between the oil and gas industry and the fisheries industry would result from oil spill contact with coastal marshes, bays, and estuaries (O'Neil et al., 1983). The majority of commercial fish species in the northern Gulf are estuarine dependent, and destruction of habitat essential to the species' life cycle would result in adverse impacts on the region's fisheries.

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The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Minerals Revenue Management** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.