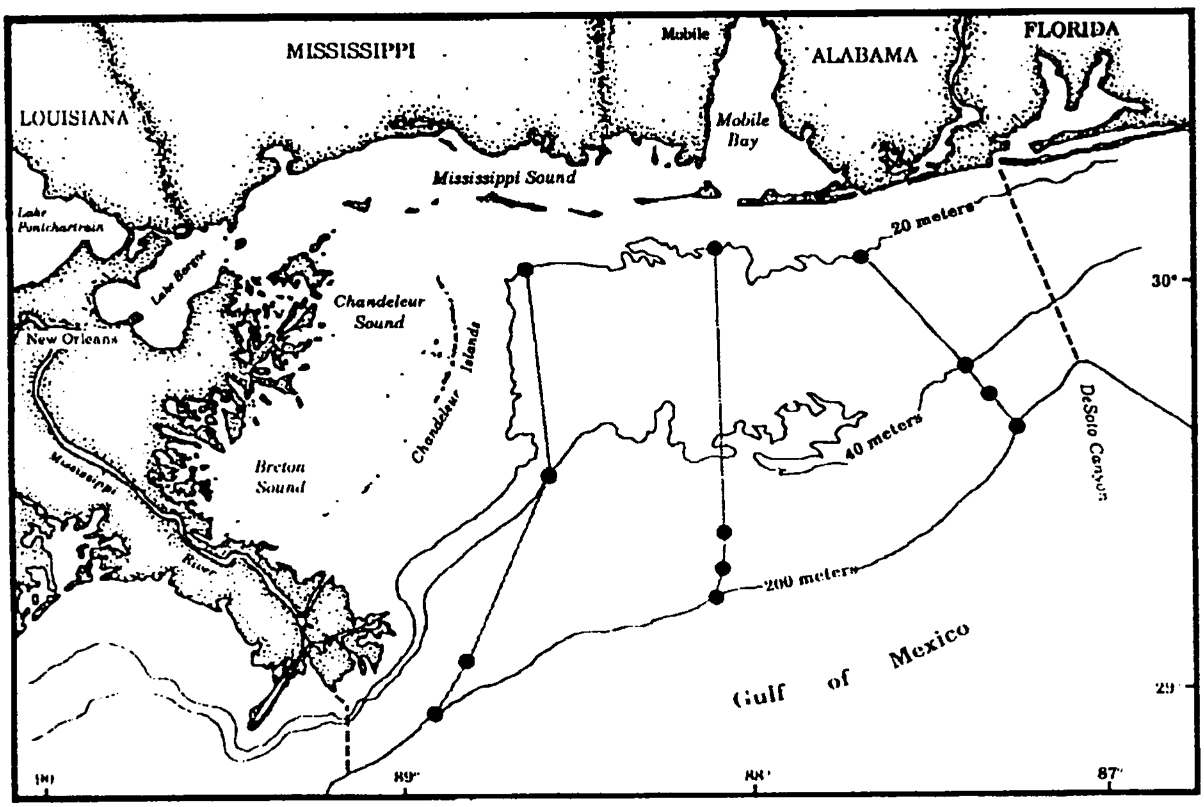
OCS Study
MMS 91-0062

Mississippi-Alabama Continental Shelf Ecosystem Study Data Summary and Synthesis

Volume I: Executive Summary



U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

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Mississippi-Alabama Continental Shelf Ecosystem Study Data Summary and Synthesis

Volume I: Executive Summary

Editors

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TABLE OF CONTENTS

LIST OF FIGURES

Executive Summary

James M. Brooks and Rezneat M. Darnell

Introduction

The Mississippi/Alabama continental shelf is an important multiple use area for human commerce, fisheries harvest, recreation, and other activities. It is also an area of considerable interest in relation to oil and gas exploration and development. Yet an overview of historical information reveals that our knowledge of the environment and biota of the area is quite fragmentary. Many knowledge gaps exist. The available information has never been synthesized into a coherent picture of the ecosystem, nor is the historical knowledge base adequate to permit a reasonable assessment of the potential effects of oil and gas development upon various components of the shelf system.

To partially remedy this situation, the Minerals Management Service has sponsored a large multi-year and multi-disciplinary effort to examine the continental shelf ecosystem off the coast of Mississippi and Alabama. Carried out over a period of three years, the investigation has involved study of the following components at regular stations (Figure 1):

–Water masses and circulation patterns using remote sensing imagery, moored current meter arrays, and water mass properties;

–Characteristics of the water column including profiles of temperature, salinity, dissolved oxygen, light transmission, and nutrients;

–Sediment properties including grain size distribution and the content of carbonate, total organic matter, ∂^{13}carbon, trace metals, and an array of high molecular weight hydrocarbons;

–Benthic and demersal biota including macroinfaunal and macroepifaunal invertebrates and bottom dwelling fishes;

–Food habits of the demersal fishes and trophic relations, in general; and

–Topographic high features including their distribution, topography, and biotic assemblages.

Detailed results of the individual investigations are presented as various chapters of the Final Report, and raw data appear in the appendices. An additional chapter gives a summary of the various studies and, supported

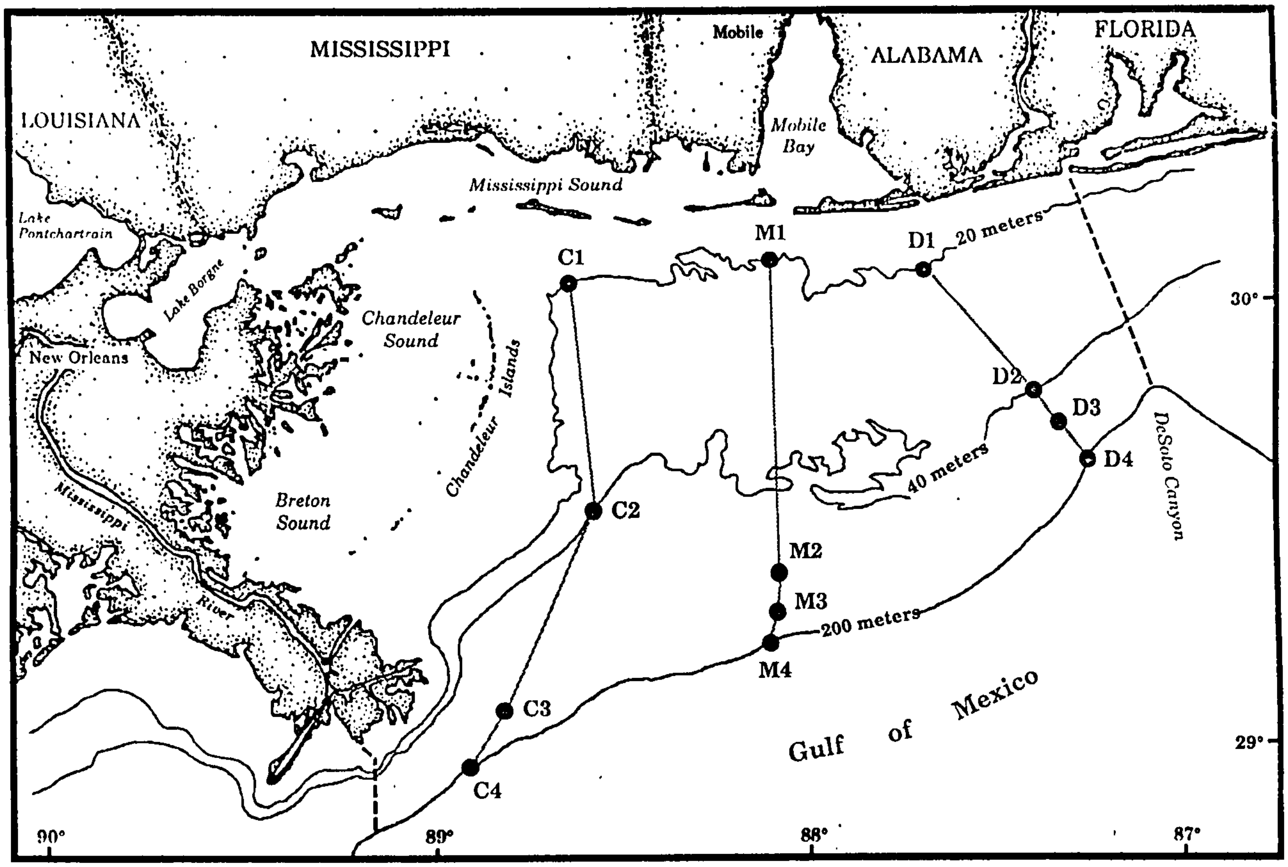

Figure 1. Map of the Mississippi-Alabama continental shelf and related waters. Regular semi-annual collecting stations were located along three transects (Chandeleur, Mobile, and De Soto Canyon).

by historical data and meteorological records, it provides an overview and interpretation of the shelf ecosystem. Management implications are discussed. The data base and interpretations put forth in the present report should provide a firm basis for assessment of the potential effects of oil and gas development upon the physical and biological resources of this important continental shelf area.

Background

Prior to considering results of the present study, it is informative to examine historical information concerning the ecological history and natural catastrophism as well as human influences in the area. Particular consideration is given to the inshore environments (bays, estuaries, and sounds) because of their important relations with the adjacent shelf. Most of the inshore water masses are ultimately transported offshore where they become mixed with shelf waters. Therefore changes in the quality or quantity of inshore waters will be reflected in waters of the shelf. Secondly, estuary related species historically make up a large component of the shelf biota, and any major changes in the environments or populations of the inshore nursery areas will likely result in changes in offshore populations of these species and in the food chains in which they are prominent.

Ecological History

During most of the Pleistocene period the Mississippi River debauched well to the west of the present delta, and the shoreline of the northern Gulf extended from Florida, across Alabama and Mississippi, and along the north shore of what is now Lake Pontchartrain. Associated with repeated advance and retreat of the continental ice sheets, the sea level receded nearly or quite to the outer edge of the present continental shelf and then rose again to approximately its present stand. With each retreat of the sea the shelf became exposed to subaerial erosion and oxidation, and streams passing through the area carved deep valleys. Subsequent rises in sea level saw filling of the valleys and smoothing of the surface except for salient rocky outcrops and other topographic high features.

About 2,600-2,800 years ago, as a result of natural upstream damming, the Mississippi River adopted approximately its present course, and early distributaries extended eastward forming the St. Bernard and Lagniappe Deltas. Spreading sediments as far eastward as Mobile Bay, these deltas established the southern boundaries of Lakes Pontchartrain and Borgne and created the Biloxi Marshes. Southward development of the Mississippi River Delta and winnowing and redistribution of the soft sediments have created the barrier islands and other familiar geomorphic features to the north and west of the Mississippi-Alabama shelf.

During periods of major advance of the continental ice sheets when sea level stood near the shelf break, very cold winds from the continental high swept the northern Gulf coast and nearshore waters. As in the case of the terrestrial biota, most of the shallow water marine species must have retreated to refugia further south (off southern Florida and the Mexican coast). Following the last glacial maximum, about 18,000 years ago, the sea level has risen to its present stand, and repopulation of the northern gulf shelf, bays, and estuaries has taken place. To these species have been added new tropical immigrants brought in by the Gulf Loop Current. Considering the variability of the environment, the recency of its availability, and the periodic addition of new faunal elements from the south, it is reasonable to conclude that processes of genetic adjustment are still underway.

Natural Catastrophism

The coastal environments of the northern Gulf of Mexico undergo regular cycles of seasonal changes in the atmospheric, hydrographic, and oceanographic factors, and the life histories of the various species likewise involve annual sequences of events in response to the regular environmental changes. However, on the continental shelf and in related coastal environments of the Mississippi-Alabama area certain major events occur on an irregular basis, and these episodic events may interrupt the normal biological patterns. Some are known to result in mass mortalities, and most likely place major stress on populations of the area. Biological effects of these events have not been well studied.

Cold Fronts

During exceptional winters major cold waves strike the northern Gulf coast and rapidly chill the estuarine and lagoonal waters. Invertebrates and fishes, immobilized by the sudden chill, are unable to escape, and they die in great numbers. Such events have been reported along most of the northern Gulf coast from south Texas through the Florida peninsula. Low temperature fish kills have been reported from coastal waters of Mississippi and from Mobile Bay. No effects of low temperature have been reported for populations of the shelf, but it is likely that some tropical species which have become established on the shelves of south Texas and peninsular Florida are excluded from the Mississippi-Alabama shelf by exceptional extremely cold conditions.

Floods

Flooding of low coastal areas in the Mississippi Delta area was a normal occurrence prior to the construction of artificial levees. Today it occurs east of the Delta when the Bonnet Carré spillway is opened to permit floodwaters to pass through Lakes Pontchartrain and Borgne and Mississippi Sound to the Mississippi-Alabama shelf. Flooding may also occur when heavy rains fall in the drainage basins of the coastal streams, particularly the Pascagoula and Mobile Rivers, or when the coastal areas are themselves inundated from winter rainstorms or summer tropical depressions. The immediate physical effects are to replace or greatly dilute the saline waters of bays, estuaries, and sounds; markedly increase the level of suspended sediments; reduce oxygen values in the hypolimnion; and deposit a carpet of new sediments on the bottom. Runoff erodes the banks and may bring much terrestrial debris into the bays and estuaries. Depending upon the season, the freshwater inflow may cause a dramatic temperature shift. These physical changes may also occur on the continental shelf if the flooding is persistent. Within bays and sounds marine plankton is replaced by freshwater species. Some benthic species die, and bottom areas suffer a reduction in species abundance and diversity. Immobile forms, such as the American oyster, are buried, and large populations simply perish. The young of estuary related species, such as shrimp and the Atlantic croaker, are unable to penetrate to the estuaries, and they remain on the inner continental shelf. Adults are forced to move to deeper waters of the middle or outer shelf. How much mortality occurs among these mobile species is not known, but certainly there must be major losses among the eggs, larvae, and juveniles which are barred from entering the nursery areas. The blanket of sediments laid down is generally rich in nutrients so that recovery begins the following year, and for a few years thereafter biological production may be higher than normal.

Major Storms

Major storms and hurricanes strike the northern Gulf coast with some frequency, and these are generally accompanied by high winds, torrential rains, elevated sea levels, heavy wave action, and extensive coastal flooding. Out on the continental shelf strong water currents are generated, and bottoms may be stirred to a depth of at least 80 m (262 ft). Impacts on coastal waters and on barrier islands and other land forms may be dramatic. Since the storms are generally accompanied by heavy precipitation, all the effects of flooding (discussed above) occur. In addition, the waves and strong water currents may cause direct physical damage to hard bottom species such as oysters, and they may also uproot submerged vegetation, tear up marshlands, and bury soft bottom species. There have been no reports on the effects of major storms on the biota of the Mississippi-Alabama continental shelf.

Hypoxic Events

Waters of the bays, lagoons, and continental shelf normally contain high levels of dissolved oxygen. However, under conditions of high organic loading, rapid bacterial decomposition, and poor circulation (often due to summer stratification of the water column), the oxygen in the near bottom waters may be reduced to very low levels (hypoxia) or used up completely (anoxia). Seawater is rich in sulfates, and under anoxic conditions the sulfate becomes chemically reduced to the highly toxic hydrogen sulfide gas and to metal sulfides, some of which are soluble in seawater. Depending upon the severity of the event, hypoxia may induce avoidance, stress, or death in a few sensitive species, or it may result in mass mortality in many species due to asphyxiation and hydrogen sulfide intoxication. In Lake Pontchartrain low diversity in benthic communities accompanied hypoxic conditions. Small fish kills have been associated with hypoxia in Mississippi. In Mobile Bay severe summer hypoxia results in mass avoidance and mass mortality of many invertebrate and fish species. Hypoxic conditions have not been reported from the Mississippi-Alabama continental shelf area.

Red Tide Outbreaks

Phytoplankton blooms are a regular occurrence in the inshore and nearshore waters of the northern Gulf. Two of the phytoplankton species produce chemical substances into the water which are extremely toxic to other marine life. These are the dinoflagellates *Gonyaulax monilata* and *Ptychodiscus breve*. When appropriate conditions prevail extremely dense populations of one or the other species may develop in the surface waters, giving the waters a reddish tint. Hence, the occurrence is called a "red tide". Such events have been recorded off most of the coasts of the northern Gulf. In the Mississippi-Alabama area a single red tide event was reported due to a bloom of *Gonyaulax monilata*. This bloom persisted for about two weeks until dissipated by a hurricane. It was most intense in the western sector of Mississippi Sound (south of St. Louis Bay), in the pass between Cat and Ship Islands, and in the upper portions of Chandeleur Sound. Lower concentrations extended eastward through Mississippi Sound into Alabama and on the nearshore shelf off Horn and Petit Bois Islands. Some of the Alabama blooms were apparently heavy. Only a small fish kill was reported.

Human Influences

Estuary related species of the Mississippi-Alabama area utilize four basic nursery areas, and all of these are heavily impacted by human activities.

Area 1. Mississippi River Delta through Biloxi Marshes

Leveeing of the lower Mississippi River during the past century has deprived much of the lower Delta of its normal annual nourishment of silt. As a result of this loss, subsidence and erosion are causing a land loss of over 4 m per year. The Mississippi River Gulf Outlet Canal (constructed in the early 1960s) and related waterways have modified drainage patterns and permitted saltwater encroachment well into the productive Biloxi Marshes.

Area 2. Lake Pontchartrain through western Mississippi Sound

During the past four decades the environment of Lake Pontchartrain has been substantially modified by human activities. Levees and stone revetments placed along the south shore have cut off shallow wetlands and reduced wave erosion of the marshes. As a result, prime nursery areas have been sealed off, and the major source of organic detritus, formerly important in the local food chains, has been eliminated. Persistent and extensive shell dredging has reduced most of the lake bottom to a thin clay gel incapable of supporting the weight of adult rangia clams. Virtual elimination of rangia and other benthic species has further reduced the food supply for estuary related species. Disposal into the lake of large volumes of domestic sewage (by municipalities of Jefferson Parish) and street runoff (by the City of New Orleans) have added organic matter and many chemical pollutants. Additional pollutants now enter the lake from agricultural and industrial sources along the northshore streams and from the Industrial Canal. The latter permits intrusion of a bottom saltwater wedge bringing various heavy metals and a high oxygen demand. Hypoxic areas ("dead zones") now occur periodically off the mouth of the Industrial Canal and extend well into the lake. Frequent openings of the Bonnet Carré Spillway during the past two decades have caused long periods of low salinity and high turbidity, and they have added fine sediments and additional chemical pollutants to the lake. Recent surveys have shown the submerged vegetation beds to be much reduced. As a result of these various human intrusions the usefulness of the lake as a nursery area for estuary related species has been greatly diminished.

The Pearl River marshes appear to be still largely intact, but sulfites and other chemicals from upstream paper mills and other industry may be reducing the quality of the water. Saint Louis Bay is affected by excess BOD loading, and hypoxic conditions with associated fish kills have been reported from this area.

Area 3. Central and eastern Mississippi Sound

The increasing human population has given rise to considerable land development, dredging and spoil placement, and dumping of municipal and industrial wastes. Such activities have been particularly prominent around St. Louis Bay, Biloxi Bay, and lower reaches of the Pascagoula River. This has resulted in much loss of estuarine habitat, chemical pollution, and creation or intensification of local hypoxic events accompanied by fish kills. Channel dredging and spoil placement have modified circulation patterns within the bays and facilitated saltwater intrusion. Spoil banks extending across the eastern sector of Mississippi Sound have created a virtual dam resulting in separate circulation patterns east and west of the banks. Undoubtedly these spoil banks constitute a barrier to the movement of many marine species, as well.

Area 4. Mobile Bay through Pensacola Bay

Mobile Bay has been extensively modified by land development, dredging and spoil placement, channelization, logging, influx of municipal and industrial wastes, and upstream channelization and agricultural runoff into the Mobile River. Documented changes in the bay include considerable loss of estuarine habitat and over 35 percent reduction of submerged vegetation beds. Remaining beds are being replaced by introduced and less desirable species. Circulation patterns have been altered by dredging and creation of spoil mounds, ridges, and islands. Channelization has facilitated saltwater intrusion. Chemical pollution of the waters, sediments, and oyster tissue is severe. Hypoxia in the bay appears to be a natural event, but it has certainly been exacerbated by human activities, especially through restriction of circulation and the addition of oxygen demanding chemicals. Perdido and Pensacola Bays are less severely affected by human activities, but land development has reduced estuarine habitat, and there is some municipal and industrial pollution.

Continental Shelf

The Mississippi-Alabama continental shelf has been modified by dredging and spoil disposal, channelization, creation of artificial reefs, and limited development of oil and gas resources. Whatever the local influences may have been, these activities are not considered to have caused major or widespread effects on the environment or biota. Commercial fishing on the shelf has been growing since the Second World War, and it has been particularly intense during the past decade and a half. Activities include purse seining for menhaden, trawling for demersal shrimp and fish species, and use of hook and line (trolling, bottom lining, and longlining) for reef related as well as coastal and offshore pelagic species. The port of Pascagoula, Mississippi reports the third highest level of commercial fish landings in the nation. Since 1980 there has been a dramatic increase in the harvest of reef related and pelagic species. Recreational fishing has also increased greatly during this period with more fisherman using party/charter boats and private or rented craft, many capable of harvesting deeper reefs and larger pelagic species.

Intensified fishing efforts have been accompanied by alarming declines in the estimated sizes of remaining fish stocks. Between 1960 and 1988 the menhaden harvest more than doubled, and the shrimping effort almost quadrupled. Between 1972 and 1987 the biomass of bottom fishes declined from 116 kg/ha to around 26 kg/ha, approximately 22 percent of the original level. Between 1979 and 1986, despite greatly intensified fishing effort, the annual red snapper harvest declined from 7.26 million to about 2 million kilograms. During the same period the spawning stock of king mackerel declined to about a third of its former level. Similar decreases have been observed in the Spanish mackerel as well as in offshore pelagic species (including bluefin tuna, swordfish, and others). Overfishing appears to be the primary reason for the declines. However, as noted earlier, there has been a simultaneous reduction in both the extent and quality of the nursery areas for estuary related species. Significant diminution in the annual crop of estuary related species would reduce the level of prey species and modify food chains of the continental shelf. This, in turn, would likely be reflected in food chains supporting the larger predators just beyond the shelf edge. Undoubtedly, both overfishing and inshore habitat deterioration are responsible for this decline of fish stocks.

In conclusion, the continental shelf ecological system has undergone certain long term changes related to sea level stands, bottom subsidence, and Mississippi River sediment deposition. On shorter time scales the system is subject to modification by natural catastrophic events some of which may alter population levels over periods of one or two years. Imposed upon these natural trends and events is the recent massive intrusion by human activities which have had major effects upon both the nearshore and offshore environments and populations. The contributing factors are many and complex, and the biological data are too recent and unrefined to permit association of each cause with its specific effects or to understand synergistic effects of several factors acting in combination. It is against this background that efforts must be made to interpret the present day ecological systems of the Mississippi-Alabama continental shelf and the related coastal waters.

Physical Environment

Water Masses and Circulation

The water masses of the Mississippi-Alabama shelf are quite dynamic and are responsive to several external forces. The most obvious of these are the wind (speed, direction, and persistence), major storms and hurricanes, the Gulf Loop Current (and its northern plumes and filaments), and deepwater currents of the Gulf. Wind was found to be highly correlated with surface currents at mid-shelf (30 m) over periods of 2-10 days, but the correlation was much weaker over longer periods and at deeper stations. Tropical storms and hurricanes as far away as Yucatan were found to influence the currents and hydrography of the area. Such effects may be pronounced, increasing the speed and influencing the direction of currents to a depth of at least 57 m. Loop current filaments frequently control water masses along the outer shelf, but they sometimes intrude across the shelf, essentially replacing most of the shelf water within a few days. Current measurements reveal that near-bottom water of the middle shelf flows southwesterly much of the time, whereas near-bottom currents at the 200 m depth persistently flow along the isobath toward the northeast. As a result of the various currents and forces discussed above, the shelf waters appear to exhibit short residence times, being replaced frequently during the period of a year. In this respect, the influence of the Gulf Loop Current is substantial.

Temperature

Nearshore surface waters to about 20 km offshore of the barrier islands tend to reflect fluctuations in air temperatures, but further from shore the conformity decreases. Likewise, bottom waters tend to conform with surface waters at shallow depths, but they deviate progressively with depth and distance from shore. Stratification of the water column, which begins during late spring, may be well developed by late summer. Surface water temperatures average 18.0°C (nearshore) to 21.7°C (offshore) during the winter and 29.1°C (nearshore and offshore) during the summer. Bottom temperatures average 17.2°C (nearshore) and 14.1°C (offshore) in the winter and 27.7°C (nearshore) and 12.0°C (offshore) in the summer. Bottom waters at depths of 60-200 m show annual temperature differentials of only about 2.0°C.

Salinity

Salinity patterns of the continental shelf off Mississippi and Alabama are highly variable due to river and tidal inlet plumes and aperiodic Loop Current intrusions. Under certain wind conditions freshwater discharge from the Mississippi River flows eastward across the shelf. Filaments from the Gulf Loop Current often trap parcels of Mississippi River water and spin these eastward toward DeSoto Canyon. The salinity regimes of the shelf at any given moment result from freshwater outflows from the north and west and from high salinity inflows from the open Gulf. These water masses may remain relatively distinct, or they may result in zones of mixing. During both seasons surface and bottom salinities tend to be lower nearshore and along the Chandeleur transect. Summer stratification, based primarily upon temperature, may be reinforced by salinity differences.

Light Transmission

Water clarity is inversely related to the amount of suspended matter in the water column. This, in turn, relates to sources of suspended material (rivers, plankton, and bottom sediments) and to stratification and the turbulent energy of the water (due to currents, internal waves, etc.). Bottom disturbance by schools of demersal animals may be locally important. Previous authors have described a bottom nepheloid layer as well as turbid lenses of brackish water near the surface. Offshore, clear water sometimes occurred between surface and bottom turbid layers. Surface light penetration off Mississippi and Alabama is generally considerably less than off West Florida, a few miles to the east. During the present study light transmission was fairly high due, in part, to the fact that the shelf was covered much of the time with clear oceanic waters from Loop Current intrusions.

Dissolved Oxygen

Bottom dissolved oxygen values ranged from 2.93 mg/l to 8.99 mg/l, and the lowest summer value was 4.63 mg/l. Although it does appear possible for this shelf area to be affected by bottom hypoxia during an unusual season, such events are not considered to be of frequent of widespread occurrence on the Mississippi-Alabama shelf.

Dissolved Nutrients

Nitrates and phosphates dissolved in surface waters are important in supporting phytoplankton populations. Data from the present study show that nitrates were uniformly low during the summer months but fairly high during the winter, especially along the Chandeleur transect. Surface phosphate values were uniformly low during both seasons. Undoubtedly, these values would become elevated during the period of spring runoff when much freshwater is brought to the shelf.

Summary of the Physical Environment

Waters of the Mississippi-Alabama shelf are influenced by major forces external to the system, and they are quite variable. Rivers as well as local storms and heavy rainfall bring fresher water from the west and north. At times these may be laden with fine clay, silt, dissolved nutrients, and particulate organic material. Input of fresher water is particularly prominent in the spring and early summer, but it may occur at any time of the year. Eddies and filaments from the Gulf Loop Current have been shown to entrap parcels of Mississippi River water and spin them eastward along the outer shelf. Storms and hurricanes as far away as Yucatan can induce strong currents, hastening the mixing processes and sweeping fine sediments to deeper water reservoirs. Intrusions of saline, nutrient poor water from the open Gulf periodically sweep the shelf, displacing a large portion of the shelf water. Current measurements reveal that near-bottom waters at mid-shelf trend toward the southwest and that at the 200 m depth throughout the year near-bottom currents prevail along the isobath toward the northeast.

Water temperature alone varies on a regular seasonal basis. It is low in the winter and high in the summer, and summer stratification of the water column appears to be a regular occurrence. The remaining characteristics are more variable and more loosely coincident with a particular season. Surface salinity is generally lower nearshore and along the Chandeleur transect, and it increases seaward and with depth. However, parcels of low salinity Mississippi River water are frequently encountered over the outer shelf. Freshwater intrusions due to local storms may occur at any season. Light transmission values were found to be highest in the summer and lowest in the winter, and this appears to reflect summer stratification and winter vertical mixing of the water column. Bottom dissolved oxygen values never approached true hypoxia during the summer, but on one winter cruise, low oxygen values were widespread over much of the area. Bottom dissolved oxygen tended to be highest in shallow water, but it was quite low at a depth of 200 m. This is an area of accumulation of organic material, but the temperature is very low, reducing the rate of decomposition, and waters at this depth represent the oxygen minimum layer which coincides with the shelf here. Dissolved phosphates were found to be low at both seasons, probably due to adsorption onto clay particles and subsequent deposition. Nitrates were low during the summer, but they were high during the winter, particularly on the Chandeleur transect and at some stations on the Mobile transect. This probably reflects the injection of new nitrates into the system as well as local regeneration and vertical mixing.

In general, water quality characteristics tended to be most variable at the nearshore station off Mobile Bay and along the entire Chandeleur transect. They were least variable on the DeSoto Canyon transect. On this transect summer salinities were higher and more uniform. During the winter the temperature was more uniform, surface nitrate values were lower and less variable, and bottom oxygen values were higher. Here light transmission values were uniformly high during the winter and at most stations during the summer.

Bottom Sediments

The bottoms of the Mississippi-Alabama continental shelf consist of a smooth plain composed of soft sediments punctuated in some areas with rocky outcrops and topographic high features. In the present study various characteristics of the surface sediments were analyzed including their content of high molecular weight hydrocarbons and trace metals.

Sediment Characteristics

Clay

The clay fraction presents very clear distribution patterns. Highest clay levels are found toward the southwest, and lowest levels appear toward the northeast. This relationship holds during both seasons. There is also a general depth relationship. All of the 20 m stations show a relatively low clay content (<25%) and all of the 200 m stations have a relatively high clay content (>37%). The highest value (79%) is located closest to the Mississippi River Delta during the winter, and the next highest values occur at the adjacent stations. For most of the shallower stations the seasonal differences in clay content are minor, but at the deepest stations winter values exceeded those of the summer by about 10% or more.

Silt

The distribution of silt in the surface sediments roughly parallels that of clay. However, the summer values tended to exceed winter values along the Chandeleur transect and at all stations at the 200 m depth.

Sand

The distribution of sand in the surface samples was the inverse of the above patterns. The sand fraction was highest toward the northeast where the percentage of clay and silt was lowest. The small differences in seasonal percentages showed no real pattern.

Gravel

The gravel fraction, mostly biogenic carbonate material (coralline algae, mollusk shells, and bryozoan remains), was highest at the two deepest stations of the DeSoto Canyon transect, and these stations fell in the area of high carbonate sediments, discussed below. Seasonal differences tended to be small and suggest accidental collection of shell patches rather than general trends.

Phi

The statistic ϕ is a derived measure expressing particle size, and the larger the value of ϕ, the smaller the average particle size of the sample. Therefore, in the present study the distribution of ϕ values closely paralleled the distribution patterns of clay and silt. Although seasonal differences were small, summer values generally exceeded those of the winter.

Calcium Carbonate

During both seasons the percentage of calcium carbonate was highest at 100 m on the Mobile transect and at the three deepest stations on the DeSoto Canyon transect where it exceeded 50%. The clear oceanic water in the vicinity of DeSoto Canyon appears to be a more hospitable environment for mollusks and other calcareous species than is the more turbid, clay and silt laden water close to the Mississippi River.

Organic Carbon

During both seasons organic carbon values were highest at the deepwater stations. The deepwater sediments are clearly the repository for organic material swept from the shallower shelf. During the summer the organic carbon values were elevated at the western stations, whereas during the winter they were elevated toward the east. This suggests some seasonal shift in the deep water currents responsible for deposition.

Delta C-13

All $\delta^{13}C$ values are negative and are expressed as ‰. Values for temperate marine phytoplankton range from -18 to -24‰ but average about -21‰. Most terrestrial and riverine sources range higher (riverine and estuarine algae = -24 to -30, riverine POC = -25 to -27, riverine sediments = -25 to -27‰, and sewage = -24). Therefore, marine values above -21 are considered to be influenced by riverine or estuarine water and/or sediments.

Sediment samples analyzed during the present study show that during the winter all $\delta^{13}C$ values appear to represent marine phytoplankton except the two stations off Mobile Bay which show a terrestrial influence. However, during the summer months evidence of terrestrial influence was widespread, affecting all stations on the Chandeleur transect, three on the Mobile transect, and two on the DeSoto Canyon transect.

High Molecular Weight Hydrocarbons

During the present study quantitative chemical analyses were carried out for a variety of high molecular weight hydrocarbons associated with the sediments. Four groups are discussed here because of their importance in relation to goals of the project. The aromatic hydrocarbons and unresolved complex mixture represent primarily derivatives of natural petroleum, and these could be derived from natural seeps or from human transport and transfer activities. Total extractable organic matter could be derived from either natural petroleum or from recent biological production. Odd-numbered alkanes of long chain length (n=23-31) are considered indicative of plant bio-waxes of recent terrestrial origin.

Concentrations for all four groups are quite low indicating that the shelf is not polluted with petroleum hydrocarbons. For all groups the concentrations increased with depth and were generally highest on the Chandeleur and lowest on the DeSoto Canyon transect. For the total extractable organic matter quantitative levels for the winter and summer seasons were quite similar, but for all the remaining groups mean summer values were roughly twice the winter values.

Together these data imply that the spring season of high river runoff annually charges the shelf with petroleum hydrocarbons and terrestrial plant bio-waxes and that the source of much of this material is to the west, i.e., the Mississippi River, Louisiana marshes, Gulf Outlet Canal, Pearl River and Lake Pontchartrain drainages, or a combination of these. The data clearly show that under normal conditions some of the hydrocarbon groups which accumulate on the shelf during the spring and summer months are largely biodegraded or swept away by the following winter. However, the data show that during one winter cruise the hydrocarbons were greatly elevated suggesting the occurrence of some major episodic event. This will be discussed in a later section.

Trace Metals

During the present study fourteen different types of trace metals were analyzed in order to characterize the spatial and temporal patterns of these elements in sediments of the study area. Data for three of the metals (barium, cadmium, and iron) will be examined here to illustrate the types of results obtained. Despite the different physical and chemical properties of the various metals, the distribution patterns are remarkably similar, although they do vary in detail. For all the metals and for both seasons concentrations were greater on the Chandeleur than on either of the other two transects, and they tended to be greatest at the deepest stations on all transects. In the case of barium and iron, the lowest values generally occurred on the DeSoto Canyon transect, but for cadmium lowest values tended to be found on the Mobile transect. For iron the values were relatively high at the 100 m depth. For all three metals seasonal differences tended to be quite small.

The results show that the trace metals are generally in greatest concentrations in areas of high clay and silt content and low in sandy areas. This simple pattern is complicated by other factors such as the high carbonate content of sediments near DeSoto Canyon. Despite these minor variations, the concentrations of the trace metals appear to be well within the ranges of natural background levels on an unpolluted shelf.

Topographic Features

During the project a special study was conducted to provide high resolution geophysical data concerning the general topography and special topographic features south and southeast of Mobile Bay in the depth range of 38-330 m. The results have been presented in an Atlas. The features were found to range from less than two to over 20 m in height. Most are patch reefs which may occur singly or in clusters, often along preferred isobaths. There are also numerous linear ridges and scarps up to eight meters in height. These appear to represent ancient shoreline ridges of sand, shell, and gravel which have become cemented together. In deeper water are found sharply peaked features called pinnacles, and these occur singly or in groups.

The arrangement of bottom reflectivities and topographic features along isobaths suggests several episodes of reef formation during pauses in the Holocene rise in sea level. The most obvious groups of features include the following:

Pinnacles - These are the deepest and apparently the oldest; ca. 105 m.

Patch reefs - These are at shallower depth and of intermediate age; ca. 65-75 m.

Ridges and scarps - These are the shallowest and youngest; ca. 60 m.

Summary of Bottom Sediments

The bottoms of the Mississippi-Alabama shelf consist of soft sediments containing fields of rocky outcrops and higher topographic features in certain areas. In deeper water the major groups of features tend to favor certain isobaths and appear to have been formed near sea level during temporary stillstands of the Gulf during the post-glacial rise in sea level. Prominent among the features are pinnacles (ca. 105 m), patch reefs (65-70 m) and sub-parallel ridges and scarps (ca. 60 m). The soft sediments consist of particles in the size ranges of clay, silt, sand, and gravel.

Most of the central and eastern shelf out to a depth of about 100 m is covered by a massive sand sheet. The western third of the shelf consists of mixtures of clay, silt, and sand in various proportions and distributed in complex patterns. All along the shelf the sediments grade seaward to finer particles, and by a depth of 200 m clay and silt account for more than 90% of the particulate material. Seasonal changes in distribution patterns of these three sediment components support the following conclusions. Sand may be moved around somewhat by the bottom currents at depths of 20 and 60 m, but only rarely are the currents strong enough to displace this material at greater depths. Silt appears to be quite mobile. Entering primarily on surface waters during the spring floods, it settles to the bottom, especially in the southwest half of the shelf where it is observed during the summer months. By the winter season most of the silt has been swept away. Clay particles, although easily carried in water column, packs tightly in the sediments and remains on the Chandeleur transect and at all the deeper stations after much of the silt has been swept away. Gravel-sized particles consist primarily of biogenic remains (of algal, molluscan and bryozoan origin), and this material was prominent only at the 60 and 100 m stations of the DeSoto Canyon transect. Calcium carbonate achieved levels of over 15% at the 100 m station on the Mobile transect and at the three deepest stations on the DeSoto Canyon transect.

During both seasons at all stations at 20 and 60 m sediments were poor in organic carbon (<1.0%), but at all deeper stations the sediments were rich in organic carbon (>1.0%). Sediments underlying colder waters of the outer shelf serve as a repository for organic matter swept from the shallower shelf. At most stations $\delta^{13}C$ values were relatively low during the winter and high during the summer, suggesting the following scenario. Fine particulate terrestrial plant detritus brought in by the spring floods sinks from the surface waters and is deposited throughout the shelf. Mixed with marine phytoplankton debris, it persists throughout the summer. However, by the winter it has either been swept away or biodegraded, and it is replaced by a blanket of marine phytoplankton detritus.

High molecular weight hydrocarbons are present in the sediments in very low concentrations suggestive of an unpolluted shelf, but the levels are within the range of measurability permitting them to be used as tracers and revealing information about the environment. Concentrations tend to be highest on the Chandeleur transect and lowest on the DeSoto Canyon transect and to increase with depth in the water column. For those hydrocarbon groups for which there is a seasonal change, summer values are about twice the winter values. These results suggest that the spring runoff brings to the shelf both natural petroleum hydrocarbons and terrestrial plant bio-waxes and that the source of this material is to the west and north, i.e., the Louisiana marshes, Mississippi River, Gulf Outlet Canal, Pearl River, Lake Pontchartrain basin, and Mobile Bay. Much of this material remains during the summer, but by the following winter it has undergone biodegradation or has been swept away. Some of the hydrocarbon data also reflect the occurrence of a major episodic event which will be discussed later.

Distribution patterns of the various trace metals in the bottom sediments are remarkably similar and differ only in minor details. For all metals and for both seasons concentrations are highest on the Chandeleur transect and at the deepest stations on all transects. The levels of most metals are so low as to suggest natural background concentrations of an unpolluted shelf. The element barium which is associated with drilling muds, is slightly elevated on the Chandeleur transect.

The Biota

Phytoplankton and Primary Production

Phytoplankton was not examined during the present study, but historical information provides the following picture. Both estuarine and Gulf species are present. Maximum populations occur during the winter and spring months and minimum populations occur in the late summer and fall. Surface chlorophyll values range from 0.04 to 1.73 mg/m^2 and average 0.69 mg/m^2. This value is about three times those of the open Gulf but somewhat less than half those observed on the shelf west of the Mississippi River Delta. Primary productivity measured as carbon uptake has been recorded as 8.1 $mg\ C/m^3/hr$. This is over an order of magnitude greater than average values for the open Gulf but only about a third of the average uptake rates recorded for the shelf west of the Mississippi River Delta.

Zooplankton

Historical data show that, like the phytoplankton, the zooplankton is composed of estuarine and open Gulf species. Taxonomic diversity is quite high and includes eggs, larvae, juveniles, and adults of many invertebrate groups and fishes. Seasonal changes in species composition and abundance are evident. Zooplankton volumes are highest nearshore and tend to decrease with distance from shore. Surface zooplankton volumes average 80-108 ml in waters shallower than 40 m, 67 ml at a depth of 55 m, and 36 ml at depths greater than 70 m. Zooplankton tends to be most abundant in the winter, fairly high during the summer, and least in the fall.

Nekton

The nekton was not investigated in the present study. This group includes the larger free-swimming animals of the water column. Available evidence indicates that the Mississippi-Alabama shelf is characterized by a diverse and abundant nektonic fauna. This includes medusae, ctenophores, cephalopods, cartilagenous and bony fishes, sea turtles, and marine mammals. The bong fishes are particularly diverse and include estuary-related, shelf, and deep Gulf species. Some are year around residents, while others appear in he area only during the summer months.

Macroinfauna

The macroinfauna is a very diverse group of small animals, largely invertebrates, which inhabit the surface sediments. In the present study it was found that polychaetes make up about 60% of all the specimens taken, and mollusks and crustaceans each constitute about 15%, so that together these three groups constitute about 90% of the fauna. The remaining 10% represents over a dozen different phyla. Numerical dominance of the polychaetes was observed at every station.

Macroinfaunal density was found to be closely related to the sediment type. Highest densities occurred in the northeast stations (coarse sediments of sand and shell), and lowest densities appeared in the southwest stations (silt and clay). This pattern was also followed by the individual invertebrate groups (polychaetes, mollusks, and crustaceans). The data do not show any clear evidence of seasonality.

Macroepifauna

During the study over 23,000 epifaunal invertebrates were taken representing about 310 recognizable species. Decapods made up 77.8%, echinoderms 9.8%, and mollusks 7.7% of the specimens taken, and together these groups accounted for 95.3% of the catch. Numerical dominance of the decapods was due primarily to the large numbers of shrimp taken.

Distribution patterns for total invertebrates and decapods were quite similar. For these two groups the highest densities during the summer months occurred at all depths on the Chandeleur transect, and during the winter highest densities occurred at the two deeper stations on the Chandeleur transect and the deepest station on the Mobile transect. This suggests a relationship between these groups and the Louisiana marshes during the summer and a migration to deeper water during the winter. The echinoderms showed higher densities at the deepest stations and a relative avoidance of the Mobile transect. Mollusks were clearly more widespread and abundant during the summer months than during the winter, but otherwise they displayed no clear distributional patterns. In contrast with the macroinfauna, the macroepifaunal abundance patterns were not closely associated with sediment type.

Demersal Fish Fauna

During the present study 16,182 fish specimens were collected representing 207 fish species. These represented a density of only 6.22 kg/ha which is considered to be an under-estimate due to the small size of the trawl and trawl boards, inclusion of low density deepwater stations, and inclusion of data from one season when the populations were greatly diminished (reflecting the effects of major episodic events).

The number of species per standardized tow varied from 5 to 30. In the summer the most speciose stations included the three shallowest stations of the Chandeleur transect and the station at 100 m on the DeSoto Canyon transect. In the former case there was probably some effect of the proximity of the Louisiana marshes, and in the latter case the high diversity probably reflects the variety of available habitats (sand and shell bottoms and rocky outcrops) from which the fish species could be drawn. During the winter species diversity was greatest at the three deepest stations of the Mobile transect as well as the 100 m station of the Chandeleur transect. The general reduction in diversity at the shallowest stations and increase in diversity at deeper stations during the winter suggests offshore migration to greater depths during the colder months, at least on the Chandeleur and Mobile transects.

The average density (no./ha) during the summer months was almost a third greater than during the winter months (445 vs. 345) which might be expected if many juveniles were present during the summer. Summer densities were highest at the three shallowest stations of the Chandeleur transect and at the 60 m station of the DeSoto Canyon transect. At this season the density closely paralleled diversity. However, during the winter the density distribution pattern was complex and not easily interpreted. The likely reason for this is that some of the fish species probably exist in schools during the colder months, causing catch densities to appear more patchy. On the Chandeleur and Mobile transects densities at the deeper stations increased during the winter which is again consistent with the idea of migration to greater depths at this season. Fishes on the DeSoto Canyon transect could have found deep water by migrating to the Canyon itself.

Data from size class analysis show that most of the demersal fish species of the Mississippi-Alabama shelf have short life histories, i.e., from one to two years (and occasionally three years). These data also suggest that in some species the spawning season is rather short, whereas in others it is more prolonged. The data show that about 45% of the species are year around residents at a given depth, and the remainder change depth with the seasons. The data also indicate that about 37% are residents on a given transect, and the rest change transects with the seasons. Thus, over half of the species appear to move around on a seasonal basis.

It was emphasized earlier that during the past two decades there has been a major decline in the estimated density of demersal fishes of this continental shelf area. A comparison of data from the present study with historical information reveals that there has been a marked selective decline in estuary related species and that this decline is not due simply to their greater vulnerability to capture by bottom trawls. Other factors, such as reduction in quality and quantity of nursery area availability, must also be involved.

Demersal Fish Food Analysis

Fishes are efficient samplers of the living and non-living organic materials within an ecological system, and for the most part, their food materials can be identified. Thus, they provide a unique insight into the pathways by which nutrients and energy actually move through the system. In the present study the food of 4,675 specimens of fishes was analyzed, and this number represented 28.9% of all the specimens captured. Forty-nine different species were examined, and these species together accounted for 78% of all the specimens taken. All of the top 25 species were examined except for one species about which there was some taxonomic question. Thus, the resulting information should be highly representative of what is consumed by the demersal fish community. Food of the individual species is given elsewhere, and broader community-related results are given here.

Considering all the food of all the species examined, about 23% of the material was unidentifiable animal material. This appeared to consist largely of the flesh of polychaetes, shrimp, and fishes. Of the identifiable material crustaceans accounted for about 62%, fishes 19%, and polychaetes 17%, and together these three groups made up around 98% of the identifiable food items. Among the crustaceans about 7% of the material could not be ascribed to a particular group. Of the identifiable crustaceans shrimp made up about 63%, crabs 11%, and amphipods 10% for a combined total of 84% of the identifiable crustacean food. In the fish stomachs examined, the three most important items were shrimp 36%, fishes 19%, and polychaetes 17% for a total of 72% of the identifiable food. A great many other food items, belonging to a variety of taxonomic groups were encountered, but individually these represented very small percentages of the total food consumed.

The fish food may also be examined from the standpoint of ecological rather than taxonomic groupings. Of the identifiable food materials zooplankton constituted 2%, small benthic animals 9%, larger benthic infauna 18%, larger mobile animals (cephalopods, shrimp, crabs, and fishes) 70%, and organic detritus only 2%. Clearly the larger mobile fauna dominated the food of the demersal fishes, and this food was taken well up in the water column (supra-benthic environment) as well as on the bottom.

Observed food distribution patterns in relation to depth and transect were tested for statistical significance by the Chi-Square method. Zooplankton, small benthic crustaceans, and small cephalopods were all consumed most heavily at the shallowest stations, and their consumption tapered off with depth. Fishes were consumed least at the shallowest stations but about equally at all other depths. Benthic microcrustaceans were eaten heavily at 20 and 100 m but lightly at 60 and 200 m. All the other groups tested (polychaetes, crustaceans in general, and larger mobile crustacean species) showed no significant deviations from the pattern of uniform consumption at all depths.

Transect patterns also produced interesting results. Fishes were consumed most heavily on the Chandeleur transect, zooplankton on the Mobile transect, and benthic micro-crustaceans on the DeSoto Canyon transect. All other groups tested (cephalopods, polychaetes, crustaceans in general, small benthic crustaceans and larger mobile crustacean species) showed consumption patterns which were essentially uniform with respect to transect.

Further information derives from examination of those stations where maximum consumption of particular food items occurred. Calenoid copepods and amphipods were consumed in abundance only at certain very shallow stations. Shrimp, although consumed heavily everywhere, were particularly prominent in the food at C-3 and the three deeper stations of the DeSoto Canyon transect. Crabs achieved some importance at two deepwater stations. Stomatopods were taken most heavily at mid-depths. Fishes were most prominent at mid-depth and also at the deepest station on the DeSoto Canyon transect. Although nowhere important, organic detritus was taken at two shallow and three fairly deep stations. These complex feeding patterns result from the availability of food items and availability of particular species and size classes coinciding at the same time and same station. However, it is almost axiomatic in shallow aquatic systems that if a food resource is available in reasonable supply there will be consumer species available to take advantage of the supply, and this results, in part, from long-term co-evolution of species within the system. Therefore, the patterns shown above are interpreted as representing primarily the places where particular food supplies are most available to the consumer species.

Biota of Hard Bottoms and Topographic High Features

On the Mississippi-Alabama continental shelf rocky outcrops occur at depths of around 20 m off Mobile Bay, at various depths around the head of DeSoto Canyon, and along most of the shelf at depths of 50-100 m. These features vary in size, composition, and vertical relief, some reaching a height of at least 20 m. They may occur singly, in groups or ridges, or in vast fields of individual outcrops. These features have been variously described as ragged bottoms, boulder fields, flat-top reefs, and pinnacles. Since they provide hard substrate for the attachment of sessile organisms, they support "live bottom" communities of especial interest. Attention is here focused on the biota of the live bottom communities in the depth range of 50-100 m.

It has been determined that biological abundance and species diversity increase in relation to the amount of solid substrate exposed and to the variety of habitats available. Thus, low relief features (<2 m high) are characterized by low biological abundance and diversity. Features of intermediate relief (2-6 m high) may exhibit low or high abundance and diversity depending upon habitat complexity. High relief features (>6 m) have dense and diverse biotas whose composition varies with habitat type (i.e., flat reef tops vs. ragged reef sides). Depth in the water column appears not to play a major role in determining species composition except in the case of coralline algae, which have not been encountered below a depth of 78 m. Since most of the major species are suspension feeders, susceptibility to sedimentation does appear to limit species composition. Areas closest to the Mississippi River Delta are most affected, and this influence extends eastward for up to 115 km (70 miles) from the Delta. Living hermatypic corals have not been observed on topographic features of the Mississippi-Alabama shelf.

For each community type the biota potentially consists of coralline algae, attached invertebrates, mobile invertebrates, and the fish fauna. The latter includes species which swim or hover in the water column above the reef as well as those which live on the substrate or inhabit crevices. Large bacterial colonies are associated with gas and brine seeps over a salt dome. As an aid in the visualization of the distribution of biota on the larger features, based upon the best available information, sketches have been made of submerged landscapes showing flat-top reefs (Figure 2) and deepwater pinnacles (Figure 3).

The definitely identified fish fauna includes a total of 70 species. Of this number, exactly half have been taken by bottom trawls and are listed as soft bottom species. The remaining 35 species appear to be unique to the rocky and topographic high habitats. These include cryptic and hovering

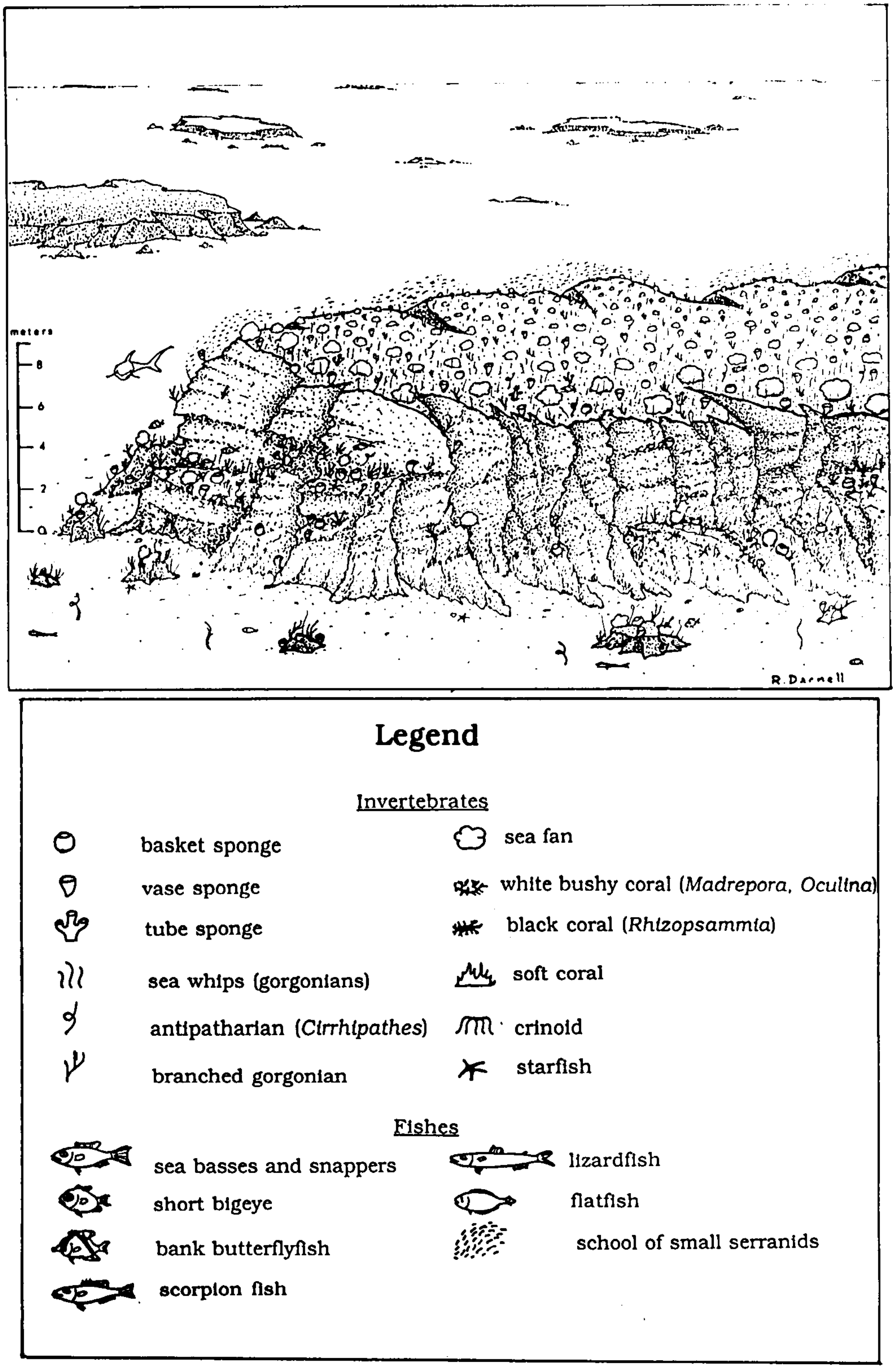

Figure 2. Perspective sketch of the submerged landscape of a flat-top reef province as visualized from side-scan sonar and ROV information. The biota are identified in the accompanying legend.

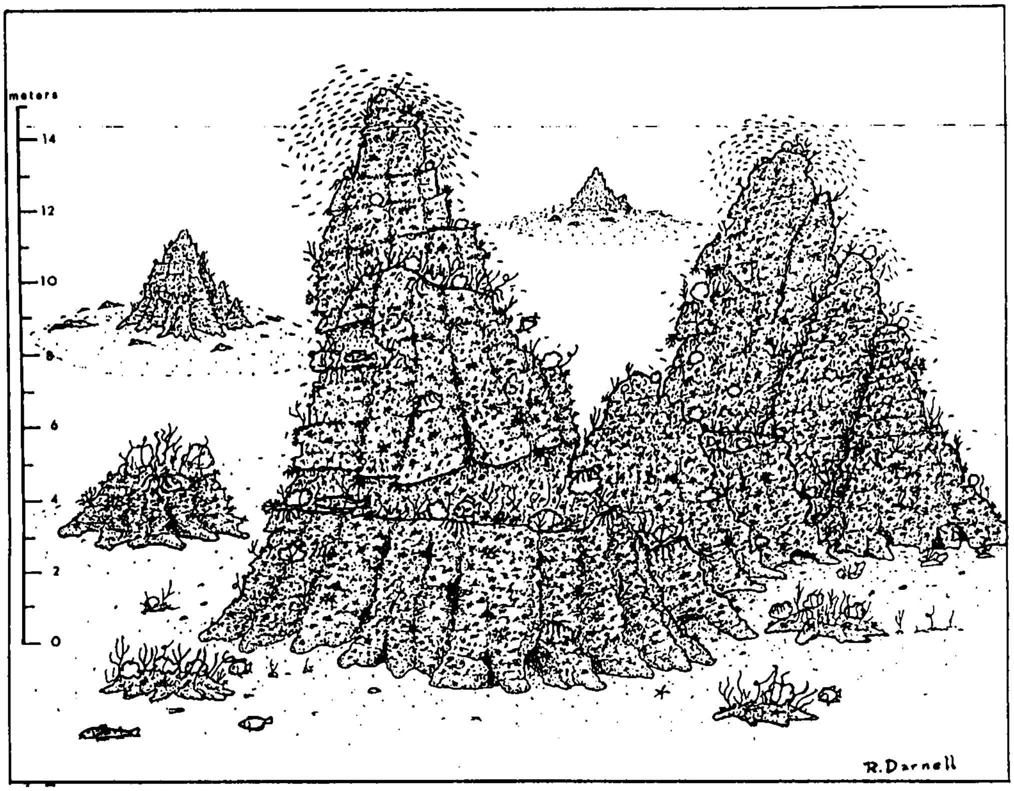

Figure 3. Perspective sketch of the submerged landscape of a pinnacle province as visualized from side-scan sonar and ROV information. The biota are identified in the legend accompanying Figure 2.

reef-related species, larger predatory forms of the open water column, and strays from other areas and habitats.

In the absence of edible vegetation, consumer species of the hard bottom communities are trophically dependent upon imported organic material. Suspension feeders, which strain small particles from the near-bottom water currents, constitute the dominant feeding group, and these include the sponges, antipatharians, gorgonians, ahermatypic corals, bryozoans, and comatulid crinoids, among others. Some deposit feeders (sand dollars and heart urchins) and scavengers (sea urchins) also are present. The fish community includes zooplankton feeders, infaunal grazers, browsers, and predators.

The invertebrate and fish faunas of the topographic features of the Mississippi-Alabama continental shelf bear a clear relationship with the faunas of other topographic features of the northwestern and eastern Gulf of Mexico as well as with those of the outer shelf reefs off the south Atlantic coast. These communities are considered to be highly sensitive to human disturbance, particularly to chemical pollution and to increased suspension of inorganic sediments.

Ecosystem Synthesis

The Seasonal Cycle

The accumulated information concerning characteristics of the water column and sediments provides a coherent picture of regular seasonal changes on the Mississippi-Alabama continental shelf. During the winter when the water column becomes vertically mixed, nitrogen is released from the sediments and lower column into the surface water stimulating the major annual phytoplankton bloom which occurs earlier inshore and somewhat later offshore. Fresher water sources to the west and north during the spring and early summer bring to the shelf quantities of silt, natural petroleum hydrocarbons, finely particulate terrestrial plant detritus, and plant bio-waxes. These probably arrive primarily in plumes and lenses of fresher water which remain for a time at the surface. Much of the material is precipitated near the origin (along the Chandeleur transect), but some is deposited in widespread fashion around the shelf. Traces of these materials appear in the summer sediment samples. As the spring turns to summer the surface water heats up, stratification sets in, nutrients are lost to the hypolimnion, and phytoplankton populations decrease. By the following winter bottom currents have swept most of the sedimented materials southwestward toward deeper water near the Mississippi River Delta, and there they are deposited or redistributed by deepwater currents. Since much of the organic material has been removed from the shallow and mid-depth shelf, the nitrogen released through regeneration in the bottom sediments is sufficient to support only a modest phytoplankton bloom, somewhat greater than that of the open Gulf, but considerably less than that of the Louisiana shelf west of the Mississippi River Delta where much different circumstances prevail.

The Benthic and Demersal Biota

Faunal Characterization

The macroinfauna was found to be dominated everywhere by polychaetes and with fair representation of mollusks and crustaceans. A diverse array of other invertebrate groups made up only about 10% of the fauna. Infaunal densities coincided closely with particle size of the sediments. Higher densities occurred in the coarser sediments and lower densities appeared in the clay and silt bottoms. There appears to be a seasonal cycle of macroinfaunal abundance with very low density in winter (January) and high density in spring and summer. Mollusks were more strictly limited to coarse sediments than were polychaetes and crustaceans.

The macroepifauna was dominated by decapod crustaceans (primarily shrimp), although mollusks and echinoderms were well represented. Highest invertebrate densities occurred on the Chandeleur transect. The macroepifauna was more abundant in shallow water during the summer and deeper water during the winter suggesting seasonal migration patterns. This was especially true for the shrimp. Echinoderms were more dense at the deeper stations. Mollusks were relatively abundant and widespread during the summer but rare during the winter suggesting that they burrow deeper in the substrate during the colder months.

As in the case of the macroepifauna the demersal fishes achieved greatest densities along the Chandeleur transect. They were most abundant in shallow waters during the summer and in the deeper waters during the winter. Also during the winter the average number of fish species at the 200 m stations was almost double the number present during the summer. Thus, the fishes, like the mobile invertebrates, appear to migrate toward deeper water during the winter months. Over half the fish species appear to change transects or depths during the different seasons.

In general, the data reveal a demersal fish community that is highly mobile. Greatest densities occur on the Chandeleur transect with highest summer densities in the shallower waters and highest winter densities in the deeper waters. The same general pattern also applies to the mobile macroinvertebrates, particularly the shrimp. Non-mobile macroinvertebrates do not change stations with the seasons, but the mollusks which are widespread in the summer, are rare in winter collections suggesting that during the winter they burrow deeper into the substrate where they are less vulnerable to capture. The infauna are substrate limited and do not move around, but the densities do change with the seasons.

Species Assemblages

In order to determine statistical patterns of species associations all three faunal groups were examined by cluster analysis techniques. These procedures take into account both the distribution of species and their abundances at the different stations. Results of the analyses are presented below.

Macroinfauna

	C	M	D
1	A	A	A
2	B	A	A
3	B	B	A
4	C	C	C

Macroepifauna

	C	M	D
1	A	A	A
2	A	B	B
3	C	C	B
4	C	C	C

Demersal fishes

	C	M	D
1	A	A	A
2	A	a	a
3	b	b	a
4	B	B	B

The macroinfauna consists of three species assemblages. Assemblage A occupies those stations to the northeast characterized by coarse sediments (clay content <25.0%). Assemblage C occurs at the deepest stations of all transects. Here the clay and silt content is very high, the sediments are rich in organic carbon, year around temperatures are low, and there is little light. Assemblage B occurs at intermediate depths on the Chandeleur and Mobile transects, but the environmental correlates are not clear. All the assemblages are rich in polychaetes, but bivalves, amphipods, decapods and other groups are also prominent in some cases.

Patterns of the macroepifauna and demersal fishes bear little relationship with those of the macroinfauna, but they are quite similar to each other. For the macroepifauna three assemblages were found. Assemblage A includes all the shallow stations as well as the 60 m station on the Chandeleur transect. Assemblage B includes the 60 m station on the Mobile transect and the 60 m and 100 m stations on the DeSoto Canyon transect. Assemblage C includes the remaining stations at 100 m as well as all the 200 m stations. The demersal fishes were found to include two major assemblages, each with two subgroups. Subgroup A of the first assemblage exactly corresponds with assemblage A of the macroepifauna. Subgroup a exactly corresponds with assemblage B of the macroepifauna. Assemblage B and b of the demersal fishes corresponds with assemblage C of the macroepifauna. This correspondence of macroepifaunal and demersal fish assemblages was totally unexpected since both groups contain highly mobile species which could be expected to respond in different ways to the various environmental factors.

In general, it would appear that assemblage A of the macroepifauna and subgroup A of the demersal fishes represent shallow water forms and some estuary related species which favor sandy bottoms and very dynamic water conditions. Macroepifaunal assemblage B and demersal fish subgroup a inhabit coarse calcareous bottoms and appear to relate more to DeSoto Canyon. Macroepifaunal assemblage C and demersal fish assemblage B and b occur in deeper water on fine sediments and relate to conditions influenced by the Mississippi River and its Delta.

Major Episodic Events

Droughts, storms, and Loop Current intrusions are non-cyclic episodic events which may affect the environment of the continental shelf. Droughts are most prominent in the summer, but they may be of prolonged duration. Major tropical depressions are most prominent during the late summer and fall, but storms may occur at any season. Gulf Loop Current intrusions are observed during periods when this current reaches its most northerly extent, and presumably this could occur at any season. Extreme environmental conditions and intrusive events may induce biological signals in terms of greatly elevated or reduced population levels. During the present study such signals were detected and they are discussed here along with the environmental correlates.

During the mid-February cruise of 1989 populations of macroepifauna and demersal fishes were extremely low compared to data from the other two winter cruises. The mean epifaunal density was only 36.7% and the demersal fish density was 25.5% of the corresponding means for the other winter cruises. In the case of both groups the density reduction was widespread. During the abnormal cruise the sediments were extremely rich in terrestrial plant material (bio-waxes) and this material was almost four times the mean of the other two winter cruises. Reference to meteorological and hydrographic data revealed that the previous year had been marked by the worst drought in half a century. However, during the late summer and fall the area was affected by a series of major weather disturbances. Tropical storm Beryl (August 8-10), which formed from a low pressure area off Louisiana, had maximum sustained winds of 80 kph. During the month of August 26.5 cm of rainfall were measured at Mobile, Alabama. In September three hurricanes visited the Gulf. Hurricane Debbie (August 31 - September 5) was confined to the southern Gulf. Hurricane Florence (September 7-11) formed in the south-central Gulf and made landfall over southeastern Louisiana. Maximum sustained winds reached 80 mph. Hurricane Gilbert, one of the strongest of the century, formed in the Atlantic and made landfall on the Yucatan peninsula. During that stormy September 35.7 cm of rainfall were recorded at Mobile, Alabama. October was a quiet month, but in November tropical storm Keith moved eastward through the Gulf below Mississippi and Alabama and made landfall on the west coast of Florida. In November, 1988, a Loop Current intrusion almost reached 29.0°N, and in February, 1989, during the period when cruise B-4 was underway, a Loop Current intrusion was sweeping the shelf well above 29.5°N (Figure 15-13). The record shows that the B-4 sampling period was preceded by a major drought, two periods of very heavy rainfall, three hurricanes, two tropical storms, and a Loop Current intrusion and that during the sampling period a major intrusion was in progress.

In the face of so many disturbances, it is little wonder that the macroepifauna and demersal fish populations were devastated. If a single event were to be identified as the primary cause of the faunal reduction it would have to be Hurricane Florence which headed directly across the area in September. However, all the events likely had some effect. On the basis of all the available evidence it is tentatively concluded that the major reduction in mobile fauna resulted from a coincidence of three sets of major events, each acting as follows:

- Extreme drought - reduced recruitment and survival of estuary related species;

- Major storms and hurricanes - brought heavy rainfall and induced strong currents, disrupting normal migration and distribution patterns; and

- Major Loop Current intrusions - displacing shelf waters and driving mobile species to peripheral refuges.

Nutrients and Trophic Relations

Nutrient Flow

Nutrients may reach continental shelves by a number of pathways. Outflow from rivers, coastal marshes, estuaries, bays, and lagoons may transport to the shelf dissolved nutrients (nitrates, nitrites, ammonia, phosphates, and silicates) as well as particulate organic and inorganic materials. The particulates may include living plankton. Estuary related species actively migrate back to the shelf in the late summer and fall. On the Mississippi-Alabama shelf the presence of higher $\delta^{13}C$ values and plant bio-waxes during the summer attest to the importance of these outflows associated with the spring floods. Tropical storms and hurricanes, often accompanied by heavy local rainfall are known the ravage marshes and other coastal environments and bring quantities of organic material to the shelf regardless of their season of occurrence. Filaments and eddies spun from the apex of the Loop Current have been shown to entrap parcels of nutrient rich Mississippi River water, transporting them northeastward over the outer shelf. Waters from nutrient rich deeper layers of the Gulf may intrude upon and bring nutrients to the shelf through entrainment or upwelling, and there is evidence of upwelling in the DeSoto Canyon area.

Once on the shelf the nutrients are available to support phytoplankton growth so long as they are not trapped below the pycnocline in a stratified water column (which can occur during the summer). Living estuarine plankton species may flourish for awhile so long as the salinity remains low. Nonliving particulate organic material may be consumed in the water column, or it may settle to the bottom along with the inorganic particles. Regeneration in the sediments permits nutrients to return to the water column, and if vertical mixing occurs, the nutrients will be transported to the surface layer where they are again available to support phytoplankton growth.

Nutrients are lost from the shelf by bottom water transport into the bays and estuaries and by advective transport to the offshore waters by surface and bottom currents. A small amount may also be lost by the emigration of living organisms. Of particular importance is the fact that the Mississippi-Alabama shelf is often swept by fairly strong currents and by the intrusion of Loop Current waters. Evidence has been presented for the fact that silt and organic material deposited during the spring and early summer has disappeared by the following winter, and the presumption is that these materials are swept from the shelf to deeper Gulf water by the strong currents of the area. Such currents also transport shelf waters to the open Gulf, thereby removing much dissolved and suspended material including plankton. It has also been shown that Loop Current intrusions replace the shelf waters with nutrient poor water from the open Gulf. The general picture is one of nutrient flow from inside waters to the shelf in the spring and early summer, nutrient loss from the surface to deeper waters during the period of summer stratification, and nutrient sweeping from the shelf during the fall. Despite some backflow, the net transport is from inside waters to the shelf and from there to the open Gulf. Residence time on the shelf is considered to be a matter of a few months at the most.

Trophic Relations

Food of the demersal fish species has been classified into six ecological groups: organic detritus (essentially decaying plant matter), zooplankton (calanoid and cyclopoid copepods), micro-bottom animals (very small bottom invertebrates, primarily crustaceans), benthic infauna (polychates and bivalves), macro-crustaceans (shrimp, lobsters, crabs, and stomatopods), and macro-mobile animals (fishes and cephalopods). From knowledge of the percent consumption of each of these food groups it has been possible to construct a food web depicting trophic relations of the shelf community. This includes three interrelated food chains, pelagic, supra-benthic, and benthic. The supra-benthic chain is included because of heavy dependence upon shrimp which appear to be consumed above the bottom.

The basic organic material which supports the consumer food chains is considered to be the phytoplankton together with fine non-living organic particles (organic detritus) derived from the phytoplankton and from terrestrial sources and coastal waters, transported to the shelf primarily during the spring and early summer. Living phytoplankton is available in the water column but only organic detritus is accessible to the bottom feeders. The fist consumer level is made up of zooplankton (largely copepods) in the water column and a variety of small invertebrates (primarily small polychaetes and crustaceans) in the sediments. The second consumer level includes squids, shrimp, and young stomatopods, as well as larval and adult fishes which inhabit the upper and lower layers of the water column. Second level consumers of the benthos include larger polychaetes, crustaceans (shrimp, lobsters, small crabs, and small stomatopods), and a variety of fish species. Tertiary consumers were not well represented in the trawl samples. These include the fishes which feed upon macromobile species as well as some of the larger crabs and sea turtles. Nevertheless, there does appear to be a trophic step missing because the small fishes taken during the study are probably not the main food of the larger predatory species (sharks, snappers, groupers, jacks, mackerels, tunas, billfishes, and porpoises) which make up the top consumers of the shelf ecosystem. Thus, there appear to be four consumer levels rather than three, as is often depicted. A great deal of vertical migration takes place among the consumer species, and the three food chains are intimately connected with one another to form a three dimensional food web. Being agile swimmers, the top carnivores feed at all levels of the water column.

Evolutionary Considerations

The environment of the Mississippi-Alabama continental shelf undergoes regular seasonal changes which, due primarily to meteorological factors, may sometimes become extreme. In addition, major non-seasonal intrusive events, reflective of both meteorological and oceanographic factors, may occur singly or they may coincide to produce a sequence of extreme episodic conditions. Historical information has been cited demonstrating that the coastal waters which bound and provide nutrients to the shelf are also subject to seasonal and episodically extreme conditions. The question naturally arises as to how the biological species are able to cope and survive in an annually variable and unpredictably catastrophic environment.

Available life history data reveal that the most abundant species have very short life spans (1-3 years) and that most produce pelagic eggs and/or larvae. Egg production is very high and keyed to survival probabilities. Non-estuary related shelf species produce between 40,000 and 45,000 eggs per adult female. Estuary related species produce between 300,000 and 1,000,000 eggs per adult female. Since the pelagic eggs and larvae may be swept along the coast in the alongshore currents, the species are capable of rapid recolonization of devastated areas. Fast growth rates and short life histories allow the species to reach adulthood and reproduce quickly thereby avoiding some of the ravages of predation and other vicissitudes of a hostile and capricious environment. These are in effect "weed species" with high capacity for maturation, reproduction, invasion and recolonization. These same traits characterize both the benthic infauna and most of the macroepifauna. Such forms are what ecologists call "R-type" species as opposed to "K-type" species which inhabit stable and predictable environments. Despite the possibility of major set-backs during unfavorable years, the shelf species are quite resilient and are capable of bouncing back when favorable conditions are reestablished. Because of their life history adjustments these species have become long term survivors capable of existence under the variable physical conditions of the Mississippi-Alabama shelf environment. The remarkable thing is that so many species have made these adjustments.

Hard Bottoms and Topographic Features

The present section addresses the ecological significance of the live bottom communities in the biological economy of the continental shelf. In shallow water off Mobile Bay some of the hard bottoms support living algae which increase the primary productivity of the area. These particular outcrops also serve as spawning grounds for certain fishes such as the spot and Atlantic croaker. However, due to turbidity of the water and the depth factor, most of the hard bottoms of the shelf are not able to support photosynthetic plants except for some coralline algae which are virtually useless as a food supply for animals. Most of the live bottoms support numerous filter feeding organisms which extend a meter or more up into the water column. These structures intercept and retain much plankton and organic detritus which would otherwise be swept away. Some is consumed directly by the filter feeders, but much more is precipitated in the relatively still waters around their bases providing habitat and a rich food supply for a variety of benthic and supra-benthic organisms. Many of these species are unique to the live bottom communities. Thus, despite the fact that little primary productivity takes place here, the live bottom communities greatly increase the biological productivity and species diversity of the shelf system, in general.

It has been shown that half the fish species encountered around the live bottoms have also been taken by trawls from soft bottoms. Whether or not this ratio holds, it is likely that many invertebrates are also common to the two habitat types. This suggests that some of the smaller benthic and demersal species may move between the two areas, and it is certain that the top predatory species forage in both habitats. Thus, there is evidence for some ecological interdependence between the soft bottom and live bottom communities of this shelf area.

Perhaps the most significant aspect of the hard bottoms and topographic features of the Mississippi-Alabama shelf lies in the fact that they form part of a chain or archipelago of such features lying at comparable water depths around the entire rim of the Gulf of Mexico and supporting similar biological communities. Located in a central position, they must facilitate genetic exchange between the faunas of such communities both to the east and to the west. Furthermore, lying directly in the path of Loop Current intrusions, these are likely the first hard bottom communities to be encountered by species transported from the Caribbean. Thus, they may serve as centers of dispersal for successful colonizers from the tropics. In these respects the hard bottoms and topographic features are of importance in terms of the larger Gulf of Mexico ecological system as a whole.

Management Implications

Knowledge gained in the present study together with historical data provides information on issues relevant to the management of resources of the Mississippi-Alabama continental shelf ecological system.

Normal Variation

Although some data gaps still exist, the present study has provided a reasonable baseline picture of the composition and the physical and biological dynamics of the shelf ecosystem. Information is available concerning the physics and chemical nutrients of the water column and characteristics of the sediments. Infaunal and epifaunal invertebrate and demersal fish populations have been delineated and interpreted within both areal and seasonal contexts. Some knowledge has been provided concerning the ranges of normal variation in the above factors.

Episodic Intrusion and Catastrophism

The study has demonstrated that meteorological and oceanographic forces subject the area to frequent major intrusive events. These include drought, storms and hurricanes, and Loop Current intrusions. Although the specific causal connections cannot yet be made, these factors, singly or in combination, have been shown to devastate the macroepifaunal and demersal fish populations. Such major community changes due to extreme natural causes could confound efforts to assess the effects of human intrusion.

Biological Resiliency

Subject to the annually variable and episodically catastrophic environment, biological species of the Mississippi-Alabama shelf exhibit extreme population fluctuations. However, as a result of long adaptive adjustments they are quite resilient and are capable of rapid and complete recovery from devastations brought about by natural causes. They should likewise be capable of rapid recovery from major short term human-induced mortality events.

Long-term Human-induced Pressures

During the past few decades the epifaunal invertebrates and demersal fish populations have been subject to increasingly severe pressure due to estuarine habitat deterioration and commercial and recreational fishing activities on the continental shelf. The increased pressure has been accompanied by reduced population densities of shelf fishes with differentially low populations of estuary related species. What the long term effects on the biological populations may be are not yet clear, but it does appear that further reductions in populations of these species due to oil and gas activities would be difficult to distinguish from mortality due to natural factors and to the long term human intrusions.

Chemical Pollution

Despite heavy chemical pollution of neighboring bays and estuaries, the continental shelf shows no real evidence of being polluted in terms of trace metals and high molecular weight hydrocarbons. Normal circulation patterns tend to retain pollutants within the estuaries, and strong water currents appear to sweep the shelf clean every few months. Any future contamination of the continental shelf by oil and gas development activities should be immediately detectable, but due to the dynamic physical environment the effects should be very short lived.

Topographic High Features - Areas of Special Concern

Larger topographic features in the depth range of 60-105 m support extensive development of live bottom communities characterized by high biological production, high species diversity, and the presence of many species unique to the area. Such areas are demonstrably fragile and are certainly features of special concern. This is particularly true of the tallest features called pinnacles. The live bottom communities appear to be sensitive to the effects of suspended sediments, and areas closest to the Mississippi River Delta are those most greatly affected. This influence extends eastward for up to 115 km (70 mi.) from the Delta. Although all the live bottom areas are of interest, those least influenced by Mississippi River effluent support the most diverse faunas and are the systems of greatest concern. These particular systems should be afforded special protection by federal agencies.

Research Needs

Many gaps still remain in our understanding of the Mississippi-Alabama shelf ecosystem, but not all of these are of equal concern from the management perspective. Several of the more salient knowledge gaps likely to be of management interest are addressed briefly below.

- There is a need to understand the relationships between water currents, depth, and transport of sediments of different particle sizes and densities.

- There is a need to develop a more thorough understanding of the effects of tropical storms, hurricanes, and Loop Current intrusions upon all aspects of the shelf environment and the biota.

- Studies should be conducted on factors associated with the development and maintenance of summer stratification.

- Data from the present study have shown that with respect to the sediments, chemistry, biota and probably the water masses and currents the Chandeleur transect is unique and strongly influenced by the inshore waters and marshlands to the west and north. A more detailed study of the relationships between the shelf and these inshore waters and shorelands would aid in understanding the flow of water, nutrients, sediments, and biota between the various sectors of this complex area.

- Relationships of DeSoto Canyon with surrounding continental shelf environments are poorly understood, but enough is known to suggest that the influence is quite significant. At certain times the Canyon appears to serve as a conduit funneling deep Gulf waters to the shallow shelf, inducing upwelling. At other times it appears to guide filaments and eddies from the Loop Current shoreward where they may affect adjacent shelves. The Canyon bottom may serve as a funnel for the transport of shelf sediments to the deep Gulf. As a result of these and related processes, the water masses, sediments, and biota of this area are in many respects different from those further west. Increased knowledge of the DeSoto Canyon area would likely show that it is unique in the northern Gulf and that due to its physical position and configuration it guides water masses which greatly influences the ecology of neighboring continental shelves. Because of its special fauna and its likely influence on current patterns and transport processes, the DeSoto Canyon area merits special research attention.

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 the wisest use of our land and water resources, protecting our fish and wildlife, 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 assure that their development is in the best interest of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.