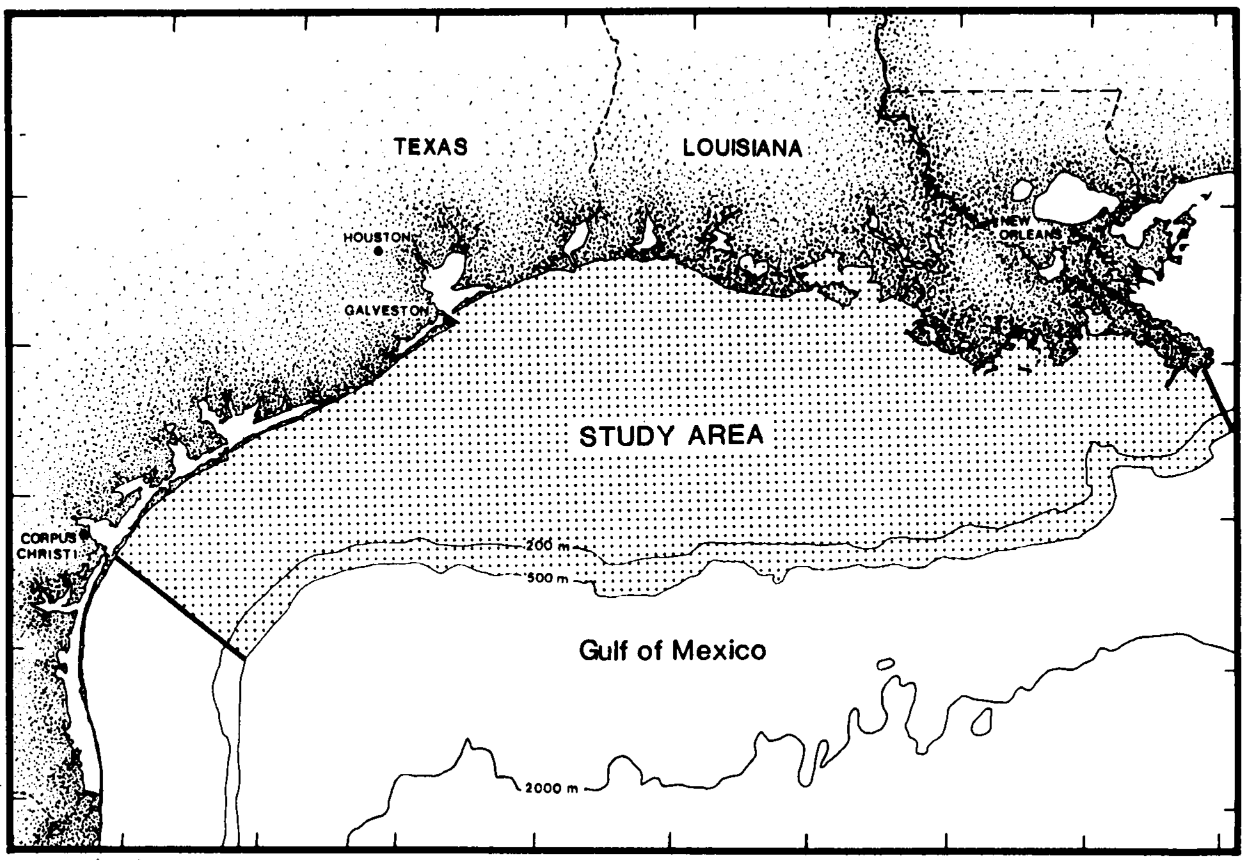
OCS Study
MMS 88-0066

Offshore Texas and Louisiana Marine Ecosystems Data Synthesis

Volume I: Executive Summary



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

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Offshore Texas and Louisiana Marine Ecosystems Data Synthesis

Volume I: Executive Summary

Editors

Neal W. Phillips
Bela M. James
Continental Shelf Associates, Inc.

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Continental Shelf Associates, Inc.
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College Station, Texas 77840

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- Paul N. Boothe (Ph.D., Marine Science, Stanford University, 1978). Chapter co-author: Marine chemistry--trace metals, radionuclides.
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- Rezneat M. Darnell (Ph.D., Biology, University of Minnesota, 1953). Chapter co-author: Marine biology, conceptual modeling.
- Frank J. Kelly (M.S., Oceanography/Mathematics, Texas A&M University, 1978). Chapter author: Physical oceanography and meteorology.
- Thomas L. Linton (Ph.D., Fisheries, University of Michigan, 1965). Chapter author: Socioeconomics.
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- Bela M. James (Ph.D., Oceanography, Texas A&M University, 1972). Program Manager.

- Neal W. Phillips (Ph.D., Ecology, University of Georgia, 1983). Scientific Editor.

- Donald R. Deis (M.S., Marine Biology/Ecology, Florida Atlantic University, 1978). Information Collection.

- David B. Snyder (M.S., Marine Biology/Ichthyology, Florida Atlantic University, 1984). Information Collection.

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- Pamela M. Hudson -- Contracts Manager.
- Pamela S. Jones -- Copy Editor.
- Kathleen S. Larson -- Editorial Assistant.
- Suzanne R. Short -- Graphic Artist.
- Alexandra M. Mazzoni -- Word Processor Operator.
- Michelle H. Merz -- Word Processor Operator.
- Adrienne B. Holt -- Clerical.

LIST OF ABBREVIATIONS

DDT	--	Dichlorodiphenyltrichloroethane
MMS	--	Minerals Management Service
OCS	--	Outer Continental Shelf
PCB	--	polychlorinated biphenyl
SPR	--	Strategic Petroleum Reserve
STOCS	--	South Texas Outer Continental Shelf
USDI	--	United States Department of the Interior

INTRODUCTION AND METHODS

The continental shelf off Louisiana and Texas is the most highly developed region in the world for offshore oil and gas drilling and production. The area is also known for its abundant fisheries, extensive coastal wetlands and wildlife resources, and offshore hard-bank communities, including the northernmost coral reefs in the Gulf of Mexico (Flower Garden Banks). This abundance of living marine resources in a region of intense petroleum industry activity poses many questions and problems for sound environmental management and protection.

The Minerals Management Service (MMS), an agency of the U.S. Department of the Interior (USDI), is responsible for leasing Federal submerged lands and supervising oil and gas exploration, development, and production. Part of the agency's responsibility is to protect marine and coastal environments while promoting development of the nation's oil and gas resources. The USDI has sponsored numerous scientific studies of coastal and offshore marine environments off Louisiana and Texas through the Environmental Studies Program, which began in 1974 under the Bureau of Land Management and was subsequently transferred to the newly created MMS in 1982. The MMS funded the present study to synthesize environmental and socioeconomic information from these prior USDI studies, as well as those sponsored by industry, the universities, and other government agencies. The goal was to assess current understanding of continental shelf ecosystems and processes, so that future study needs could be pinpointed.

The study area for the synthesis effort extends from Corpus Christi Bay, TX to the Mississippi River Delta, and from the shallow sublittoral to 500 m depth (Figure 1). The study area includes parts of two Planning Areas (Central and Western) used for oil and gas leasing.

MAJOR ENVIRONMENTAL STUDIES IN THE AREA

Several major environmental studies have been conducted off the Louisiana and Texas coasts, including both descriptive (baseline) studies and monitoring programs (Figure 2). Major studies include the following:

- South Texas Outer Continental Shelf (STOCS) studies.
- Topographic Features Studies (Flower Garden Banks and other banks off Texas and Louisiana).
- Northern Gulf of Mexico Continental Slope Study.
- Offshore Ecology Investigation.
- Central Gulf Platform Study.
- Buccaneer Gas and Oil Field Study.
- Strategic Petroleum Reserve Program.

A brief summary of each study is presented in the Introduction to Volume II. Other pertinent field studies and information sources are also cited there.

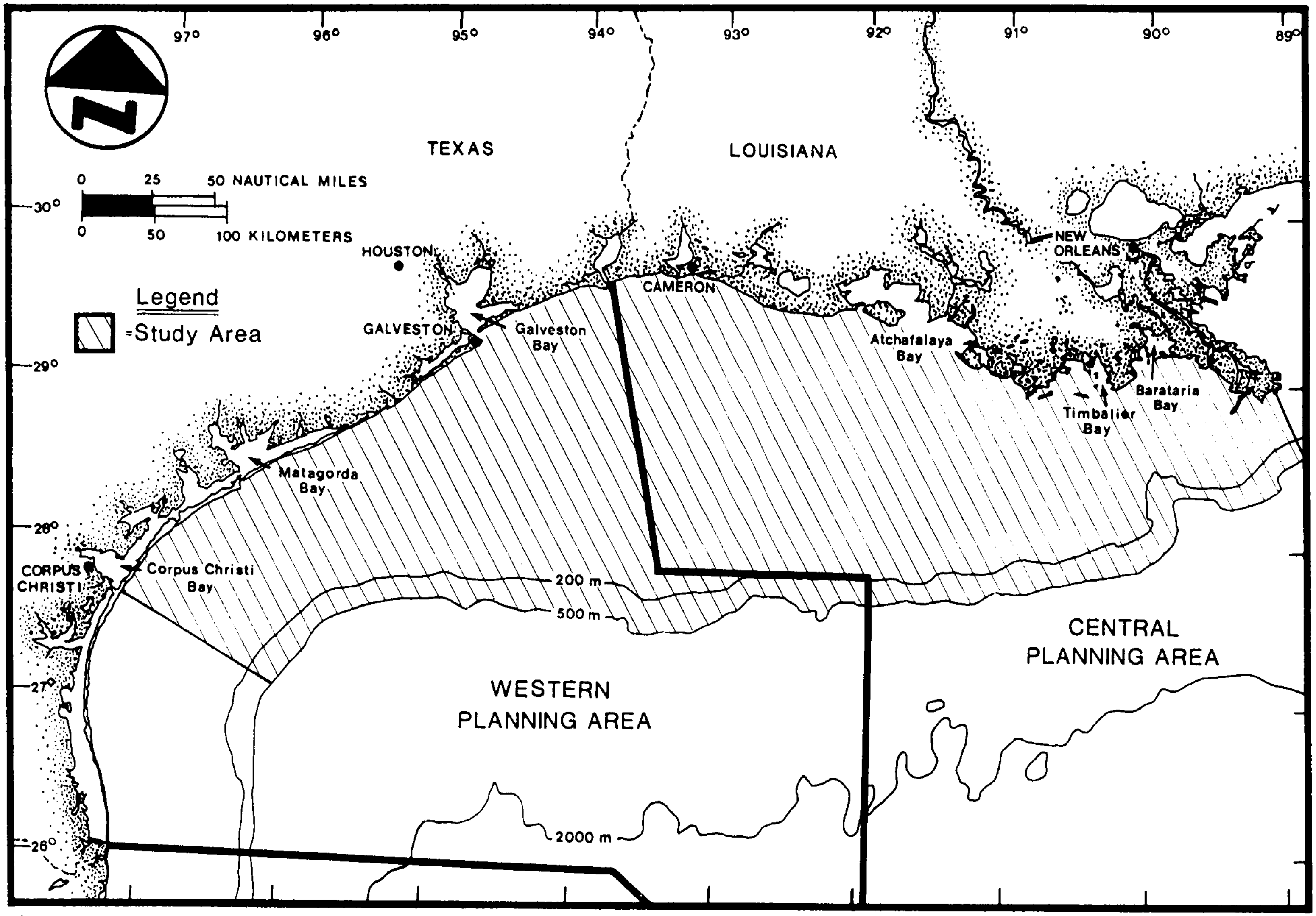

Figure 1. Study area for the synthesis effort.

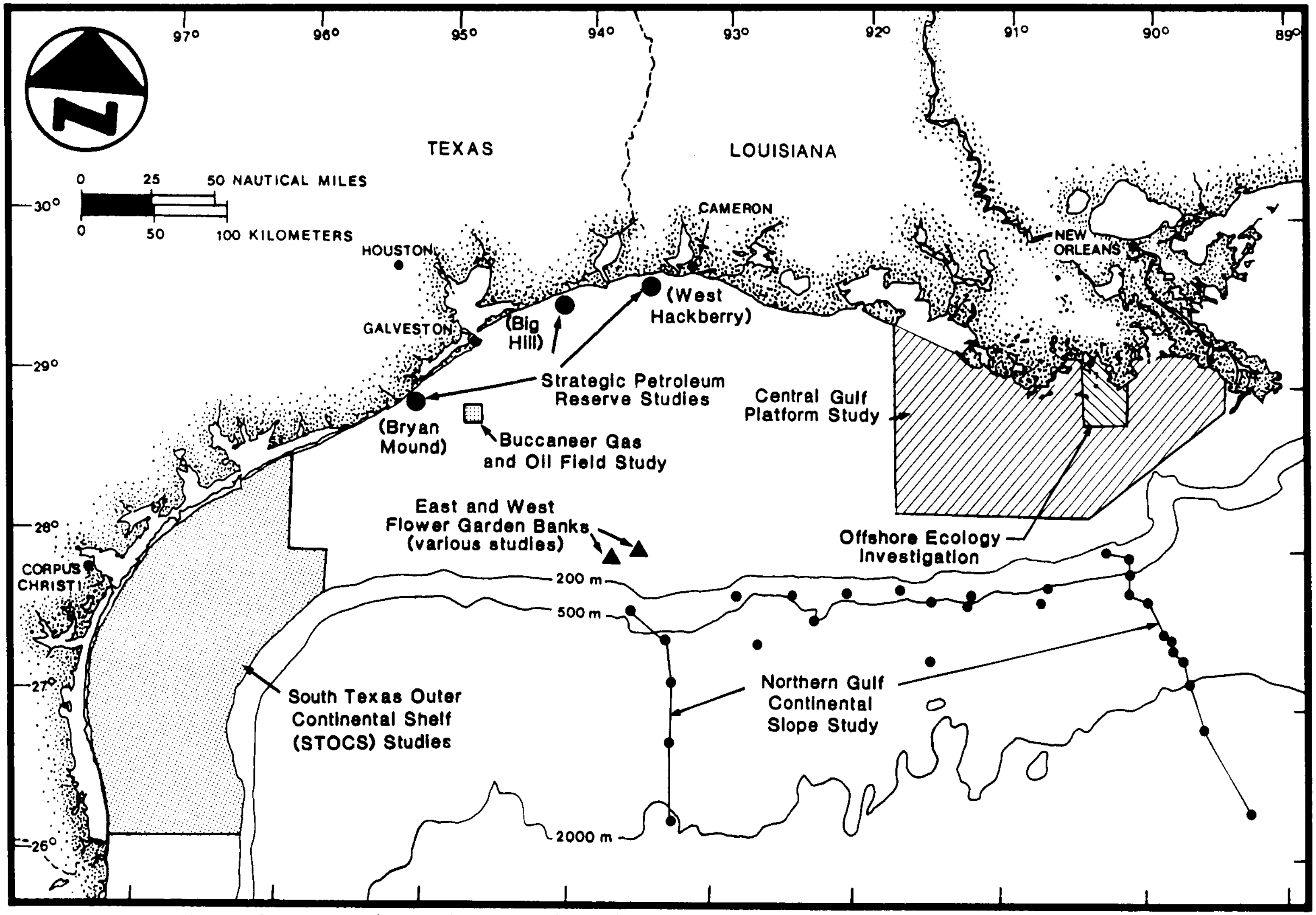

Figure 2. Locations of some major environmental studies on the Texas-Louisiana continental shelf and slope.

STUDY OBJECTIVES AND REPORT ORGANIZATION

The synthesis study had three main objectives:

- To identify, acquire, review, and annotate all pertinent environmental and socioeconomic literature (published and unpublished) for the study area.
- To synthesize information within major disciplines (geology, physical oceanography and meteorology, chemistry, biology, and socioeconomics) in order to describe the shelf environment and ecosystems.
- To identify major information gaps and recommend field studies to fill the gaps.

The study consisted of two tasks: (1) information collection and annotation, and (2) synthesis. In the first task, a literature search was conducted, and an annotated bibliography of 1,535 references was compiled. Topic areas for information collection were as follows:

- Marine geology.
- Physical oceanography and meteorology.
- Marine chemistry (including nutrients, trace metals, hydrocarbons, synthetic organics, radionuclides, and other constituents).
- Marine biology (including plankton, nekton, benthos, fisheries, endangered species, and biologically sensitive areas).
- Socioeconomics (including commercial and recreational fisheries, the oil and gas industry, and other maritime industries).
- Oil and gas industry activities and effects, including consequences of major oil spills.
- Effects of other maritime industries and human activities.

In the second task, the available environmental and socioeconomic information was synthesized in separate chapters devoted to Marine Geology, Physical Oceanography and Meteorology, Marine Chemistry, Marine Biology, and Socioeconomics. At the end of each chapter in Volume II is a discussion of data gaps and information needs. The main subject chapters are followed by a chapter devoted to modeling the influences of oil and gas operations and other human activities on the ecosystems of the Texas-Louisiana continental shelf and upper slope. A final chapter summarizes data gaps and information needs.

METHODS

Annotated Bibliography

One goal of the project was to produce a computerized, annotated bibliography of environmental and socioeconomic literature for the Texas-Louisiana continental shelf. The bibliography was compiled through a combination of computer searches, telephone contacts, library visits, and submissions from chapter authors. The final products consist of (1) a printed bibliography sorted by author and date; and (2) a set of data files, on IBM-compatible floppy disks, that have been indexed with a computer program (FYI 3000 Plus[1]) to allow searching by author, date, topic and geographic keywords, or words in the title and source. The annotated bibliography consisting of 1,535 references [of which 947 (62%) have abstracts], is contained in Volume III.

Synthesis

Chapter authors were responsible for summarizing and synthesizing the available information on their assigned topics. Each author was directed to include a discussion of data gaps and information needs at the end of the chapter.

The annotated bibliography was being compiled at the same time that the synthesis chapters were being written. Therefore, authors did not receive a complete printout of citations and abstracts for their topics. However, interim list of references in certain topic areas were printed on request for the authors. In general, the authors were already familiar with most of the pertinent references in their topic area(s).

Once the characterization chapters (Marine Geology, Physical Oceanography and Meteorology, Marine Chemistry, Marine Biology, and Socioeconomics) were completed in draft form, the Program Manager sent copies to Dr. Darnell for use in the Conceptual Modeling chapter. This information was used to decide on the major ecosystems of the study area and the selected components for modeling.

[1]FYI 3000 Plus is a trademark of FYI, Inc. of Austin, TX.

CONTINENTAL SHELF

The coastline of Louisiana and upper Texas, from the Mississippi River Delta to the level of Corpus Christi, is broadly arcuate and concave to the south and southeast. Seaward of this coastline lies the continental shelf, which is about 200 km wide in the center and which narrows at the eastern and western extremes. This shelf consists of a wedge of sediments brought down largely by the ancestral Mississippi River, with lesser contributions by the Colorado, Rio Grande, and other streams. Consisting mainly of terrigenous sandstones and shales, the wedge is approximately 15 km thick beneath the present coastline. Subbottom strata dip gently in a seaward direction. Diapiric salt structures, which occur from near shore to the shelf break, are usually subsurface features, but on the outer shelf many occur as topographic features with vertical relief sometimes exceeding 100 m. Sand, often mixed with shells, is found along the nearshore bottoms just off the coastal barrier islands, but most of the shelf is composed of sands and muds and mixtures of the two. From the Mississippi River Delta to the level of central Louisiana fine sediments predominate, and from there westward and southward, sands are the principal sediment type, locally mixed with finer materials. East of Matagorda Bay, local areas of subdued topography with sandstone, siltstone, claystone, or basalt outcrops appear associated primarily with salt diapir intrusions. Below the level of Matagorda Bay, occasional carbonate banks occur.

Hard banks are widely distributed on the continental shelf off Texas and Louisiana (Figure 3). A line drawn from Matagorda Bay to the shelf break divides the Texas continental shelf into a southern area of dead coralgal reefs that grew on a Pleistocene to Holocene carbonate shelf and an area of banks situated on salt diapirs to the east. The banks to the east of the line are, depending on their location on the shelf, either relatively bare bedrock outcrops, coralgal caps on salt diapirs, or mixtures of the two types.

CONTINENTAL SLOPE

Whereas the continental shelf is a broad, smooth, gently sloping plain, the upper continental slope is characterized by complex hill and basin topography which has resulted from extensive salt diapirism, sedimentation, and erosion. Surface sediments of the slope consist of terrigenous sandy clays, swept down from the continental shelf, mixed with calcareous foraminiferal remains. Sediments of the outer shelf and particularly of the upper slope are often unstable and subject to slumping and creeping. Local subsidence, mud flows, and larger downslope mass transport features are not uncommon.

SEDIMENT DYNAMICS

The nepheloid layer is significant phenomenon on the South Texas continental shelf. This layer, which is generated and maintained by

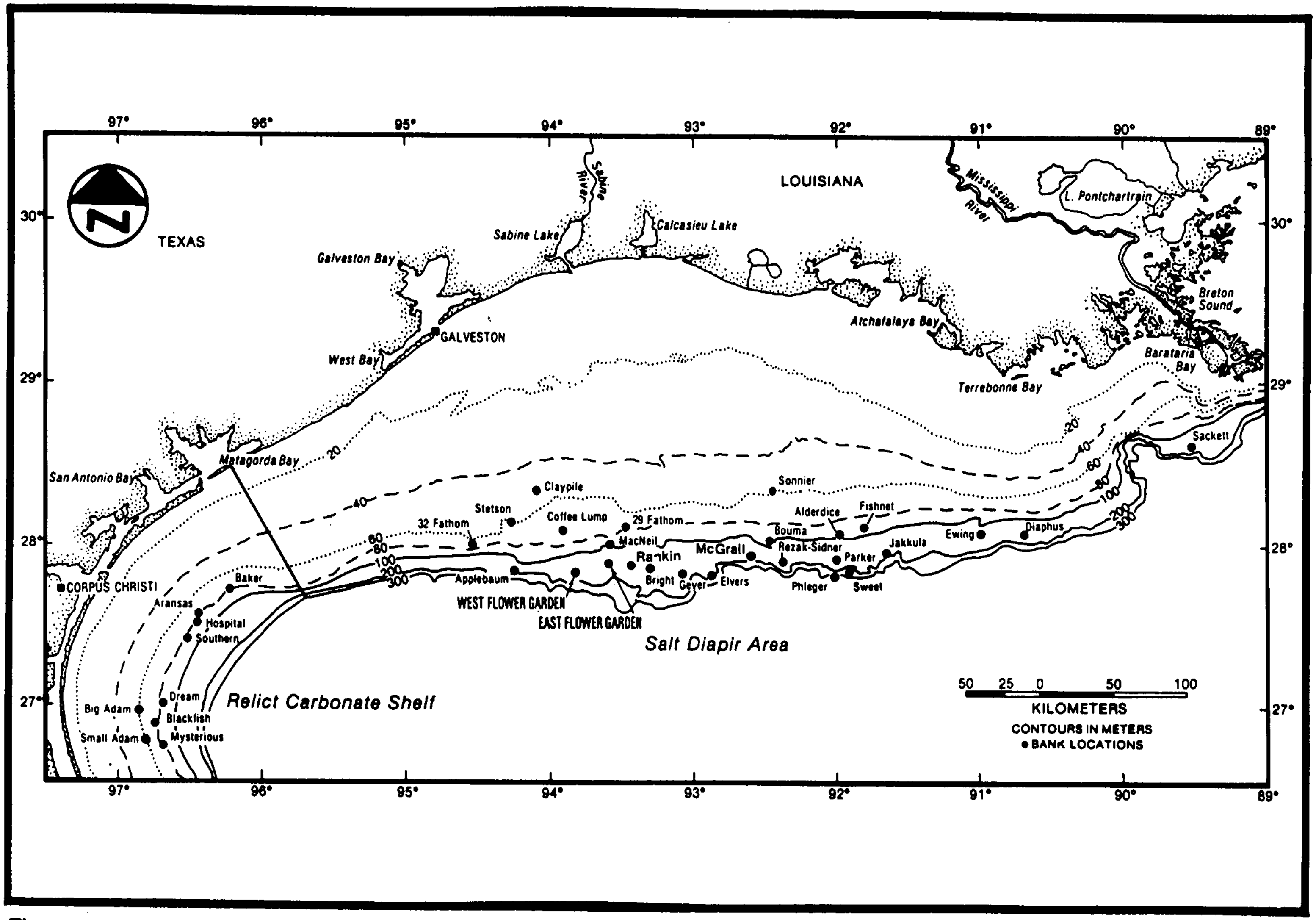

Figure 3. Location map of selected banks on the Texas–Louisiana shelf and upper slope (From: Rezak et al., 1985). The line from Matagorda Bay to the shelf break separates the Relict Carbonate Shelf from the Salt Diapir Area.

resuspension of muddy seafloor sediment due to bottom turbulence, thickens offshore to a maximum of 35 m near the shelf break, and the concentration of suspended sediment in the nepheloid layer decreases from a maximum near shore to a minimum at the shelf break. Research on the east Texas-Louisiana shelf has demonstrated that the passage of polar fronts during winter months homogenizes the nearshore waters and produces surface gravity waves capable of resuspending sediments at depths as great as 40 m. As a consequence, the nearshore waters are filled with high sediment loads. Frontal passage also create cold saline waters that sink and flow offshore along the bottom because of their excess density. Sediment entrained in this bottom flow is carried to the outer shelf. The bottom mixed layer and the nepheloid layer thicken in the offshore direction as the bottom waters flow off the sloping shelf and out over water of equal density on the upper slope. The sediment is kept in suspension over much of the inner shelf by swift currents and turbulence. It is then advected to the shelf edge, where episodic deposition may take place. In the summer months, the supply of sediment to the outer shelf is restricted because of a lack of major wind events and the diminished supply of sediments at the coast.

PHYSICAL OCEANOGRAPHY AND METEOROLOGY

Each continental shelf region in the world has a different combination of meteorological, hydrological, astronomical, and deep ocean forces that act in concert with the local topography and geometry to produce a unique set of physical processes and water masses. The characteristics of the Texas-Louisiana shelf waters are determined principally by the large input of fresh water from one of the world's great rivers and an annual cycle of prevailing winds acting on a broad shelf with a coast that is arcuate, concave to the southeast. Astronomic tides, interaction with eddies and currents in the deep Gulf, and the momentum input and heat and mass exchange across the sea surface caused by intrusions of polar fronts and tropical cyclones, significantly modulate the effects of the principal factors, but do not obscure them.

METEOROLOGY

During the warmer months (March through October), the area is under the influence of tropical air masses, and most of the winds are from the southeast and south. These winds are persistent but generally of low velocity, except during brief tropical storms and hurricanes. These occur from May through October but peak in September. During the cooler months (November through April), polar and arctic air masses become stronger, and winds are frequently from northerly directions. Repeated cold fronts are often accompanied by gale force winds that homogenize the nearshore Gulf waters to depths of at least 40 m. Air temperatures range from nearshore highs of 29°C (July to August) and lows of 15.5°C (December to January) to offshore highs of 29°C and lows of 18°C. Sea fogs occur during the winter months, particularly December through February. Rainfall on the shelf averages about 101 cm/year and is heaviest from July through September.

METEOROLOGICAL FORCING

The annual progression of wind stress patterns is responsible for much of the low-frequency water circulation on the shelf, and monthly mean alongshore components of wind stress are important in generating coastal currents. From September through May, the surface flow on the shelf is cyclonic (counterclockwise), with a downcoast current nearshore and an upcoast counterflow at the shelf break. From June through August, when the wind is more directly from the south, there is a reversal, and for most of the area the flow along the inner shelf is upcoast. At this season, the surface current along the shelf break is quite weak. When the alongshore component is downcoast (during the cooler months), Ekman transport results in a sinking of the nearshore water (downwelling) and a slow seaward drift of the bottom water. When the alongshore component is upcoast (June through August), Ekman transport drives the surface water seaward with a compensating onshore drift of bottom water (upwelling). The downwelling tendency in the winter months is intensified by the episodic passage of cold fronts which chill the nearshore water and increase the salinity through evaporation. Then the dense coastal waters sink and sweep rapidly offshore, transporting large volumes of sediment to deeper water. Because the cold fronts tend to hit primarily the central sector of the coast, offshore transport of bottom water is greatest in this sector. The upwelling tendency during summer is intensified by vertical stratification of the water column at this season. Little mixing occurs, and fresher coastal water extends seaward along the surface while highly saline bottom water extends shoreward almost to the coast. Tropical storms and hurricanes that occur during the summer temporarily upset the stratification in shallow water, but this is reestablished within two or three days after the passage. Little effect is felt on deeper waters of the outer shelf.

RIVERINE INFLUENCES

The Mississippi/Atchafalaya River system contributes about 73% of the freshwater entering the area. About 20% is contributed by precipitation, and the remaining 7% enters through the smaller streams. During the period of spring floods (April), when the Mississippi River is carrying its maximum load of water and dissolved and suspended materials, the winds are largely from the southeast. Thus, the greatest load of nutrients and sediments is carried westward to be deposited on the Texas-Louisiana shelf. The annual renewal sediment blanket is deposited at least as far west as Galveston Bay. Turbulence in the nearshore waters resuspends the finest particles, creating a nepheloid layer that blankets the entire shelf throughout the year.

Large areas of hypoxia develop almost annually in Louisiana coastal waters west of the delta. Hypoxia also occurs in Texas coastal waters as far west as Freeport, but less frequently. The major flood of the Mississippi in 1979, in conjunction with the summer advent of upwelling favorable winds and currents, produced hypoxic and anoxic bottom conditions in June and July off Freeport, TX, that caused mass mortalities of benthic organisms. Although the spatial distribution of hypoxia has been mapped with fair resolution at times, virtually nothing is known about its local time-rate-of-change or the advection of hypoxic water masses.

SURFACE WAVES

A large amount of the total wave energy of the sea-surface is associated with gravity waves (gravity is the principal restoring force), which are generated by the action of the wind. Gravity waves are separated into two categories: seas, when the waves are under the influence of wind in a generating area, and swell, when waves move out of a generating area and are no longer subjected to significant wind action. Seas on the shelf generally have steep waves with short periods and lengths; the waves associated with swell have relatively long periods and wavelengths and, until they reach shallow water, low amplitudes. The height, period, and length of wind waves are determined by fetch, wind speed, wind duration, and decay distance. Water depth, if shallow enough, will also affect the size of wave that is generated.

A variety of wave statistics and wave observations are available for the Texas-Louisiana shelf, but the data base of objectively measured wave statistics is insufficient to generate a comprehensive climatology with spatial and seasonal resolution. At present, the most extensive climatologies are based on ship observations and hindcasts.

TIDES AND SEA LEVEL

A review of the tidal regime in the Gulf of Mexico shows that the diurnal tides have nearly uniform amplitudes and phases over the whole Gulf and are driven primarily by the in-phase volume transports through the Yucatan and Florida Straits. The contribution due to direct forcing is only about 15%. On the other hand, direct forcing accounts for about 55% of the signal of the semidiurnal tides. As a result of the relative magnitudes of the diurnal and semidiurnal constituents, the tide is characterized as mixed off Calcasieu Pass and becomes mainly diurnal off the Mississippi Delta and to the west of Galveston.

Sea level fluctuates because of the effects of long-period astronomic tides, local winds, local addition of mass, changes in atmospheric pressure, and changes in temperature and salinity, and thus, density, of the water column (steric effect). Along the Texas-Louisiana coast the annual range is about 25 cm. The annual variation has a semi-annual component; the absolute minimum and maximum values occur in January and September, respectively, and relative maximum and minimum values occur in May and July, respectively. For periods shorter than one month, coastal variability of sea level is driven substantially by wind forcing. Tropical cyclones can produce extreme changes in sea level over short periods.

CURRENTS

Wind stress and freshwater influx from the Mississippi-Atchafalaya River system are the dominant factors controlling the long-period motions and hydrographic characteristics, and much of the short-period variability, of the Texas-Louisiana inner shelf. Numerous studies of currents along the Texas-Louisiana coast demonstrate the strong coherence between the alongshore components of wind stress and current that results from the combination of wind stress, the Earth's rotation, and the presence of the coastal boundary.

Calculations of monthly mean geopotential anomalies from monthly mean temperatures and salinities provide a first approximation to the prevailing currents over the whole Texas-Louisiana shelf. In months other than June, July, and August, an elongated region of low geopotential dominates the shelf. On the inner shelf side of the cyclonic feature, downcoast flow prevails, in agreement with the downcoast wind component discussed above. There is a counterflow (eastward or northeastward) along the shelf break. During the summer months, there is upcoast flow along much of the inner shelf up to about 92.5°W, while a high in geopotential lies off the Louisiana coast; although there is a suggestion of eastward or northeastward flow along the shelf break, it is very weak. The summer situation is, thus, very different from the situation during the rest of the year when there is a distinct "low" in geopotential over the outer shelf. The annual progression of the patterns of geopotential anomaly provide a conceptual model that is consistent with the various aspects of shelf circulation and hydrography that have been described.

MARINE CHEMISTRY

Because the Texas-Louisiana shelf is the most heavily developed area of offshore oil and gas drilling and production in the world, alterations in the chemical environment due to oil and gas operations have been widely studied there. Studies of the sources, distribution, and transformations of chemical constituents (including trace metals, hydrocarbons, synthetic organics, and radionuclides) can reveal much about chemical pathways in the marine environment and the major natural and human influences on that environment.

NUTRIENTS

Near-surface nutrient concentrations are low in open Gulf waters and generally increase toward shore, especially in the regions of river runoff. Factors influencing nutrient concentrations within the study areas include river discharge (especially the Mississippi River), coastal currents and winds, intrusions of open Gulf waters, upwelling, biological activity, rainfall, and proximity to coastal marshes. Phosphate and nitrate levels near the mouth of the Mississippi River are at least 8 to 30 times greater, respectively, than levels found in open Gulf waters.

Within the study area, near-surface nutrient concentrations are negatively correlated with salinity; that is, the lower the salinity the higher the nutrient levels. Because salinities near the coast generally increase from east to west, the general trend for nutrient concentrations is to decrease from east to west. Nutrient concentrations are generally high off the Mississippi Delta, but at the western end of the study area, nutrient concentrations are typically low and representative of open Gulf surface water. Continental runoff can influence south Texas nearshore concentrations, especially in the spring. In addition, after spring and summer phytoplankton blooms, nutrient concentrations along the Texas continental shelf become substantially reduced but are generally replenished during the fall, and reach their maxima in early to mid-winter. In the deeper aspects of the study area, nutrient levels are relatively low in the upper 100 m of the water column, then generally increase in concentration and reach their maxima at around 400 to 600 m, which is within or slightly below the oxygen minimum layer.

TRACE METALS

Trace metals enter northern Gulf waters from river outflow, the atmosphere, and local human activities. For most nearshore environments, such as the area offshore Texas and Louisiana being considered here, most trace metals will come from the nearby land through river runoff. Once in the area, they may be dissolved or suspended in the water column, reside in the sediments, or concentrate in biological tissues.

Offshore oil and gas drilling operations are a major source of barium in the study area. The barium contained in the drilling mud that is dumped from the approximately 1,000 new wells drilled each year is slightly greater than the annual barium input from the Mississippi River.

Other trace metals are present in much lower concentrations in drilling mud, but may in some cases be significant additives to local areas of the Texas-Louisiana shelf.

Due to possible sample contamination, most early trace metal analyses of water from the area are suspect, especially those for dissolved trace metals. Unfortunately, few seawater samples from the Texas-Louisiana shelf have been analyzed for dissolved trace metals with the care required to lend confidence to the data. However, reliable data are available for trace metal concentrations in suspended particulate matter, bottom sediments, plankton, fish, and benthic organisms.

In the STOCS area, concentrations of most trace metals are quite low (in the water column, sediments, and organisms) with local elevations off some estuaries and around some drilling platforms. Off Louisiana and upper Texas, however, trace metal concentrations tend to be much higher, with the greatest concentrations off the Mississippi River Delta, nearshore, and around some rigs and platforms. Clearly, the major supplier of trace metals is the sediment brought in by the Mississippi River, and this is supplemented by outflow from some highly polluted estuaries and by drilling muds and other waste associated with oil drilling and production activities. The element barium, of little concern as a pollutant, is of great importance as a tracer. Its distribution clearly indicates that surface sediments of the inner half of the Louisiana and upper Texas shelf are subject to suspension and redistribution by active bottom currents. These sediments and trace metals then become resettled on the outer shelf and upper slope where bottom currents appear to be less active. The Mississippi River contributes many trace metals in nearly their global-average crustal abundance, but some metals such as cadmium, lead, and zinc are enriched in Mississippi River-derived material. Nearshore sediments off Louisiana are similar to Mississippi River suspended matter, except for a depletion of manganese, which is mobilized by reducing conditions and is thereby lost from the sediment. Sediments around many drilling rigs may have elevated concentrations of trace metals--mainly barium, but also sometimes chromium and others; the concentrations decrease rapidly with distance from the source.

A number of studies have been carried out on trace metal concentrations in organisms and biological tissues. Some zooplankton samples have shown elevated levels of aluminum, iron, and nickel, indicating ingestion of clay particles. Near the Mississippi River Delta, some fishes have shown elevated tissue levels of chromium, nickel, and lead, but the possibility of sample contamination renders these results suspect. Produced (formation) waters, released in quantity around production platforms, contain trace metals which quickly become diluted in the Gulf waters.

HYDROCARBONS

Hydrocarbons enter northern Gulf waters from river outflow, the atmosphere, natural seepage, oil and gas production, local transportation and ship traffic, and oceanic transport from a distance (floating tar balls, etc.). The most important sources are Mississippi River outflow, local oil and gas production activities, and ship traffic (anchor damage to pipelines, bilge and sludge washings, etc.). Hydrocarbons in the sediments and water column tend to be much higher off Louisiana and east Texas than off south Texas (STOCS area). Concentrations are particularly high around the Mississippi River Delta, along the coast, and in the vicinity of some oil platforms and rigs. Louisiana shelf hydrocarbons include both natural petroleum compounds and anthropogenic hydrocarbons.

Tar balls, derived from various crude oils, tanker sludges, and fuel oil residues, reach their highest concentrations in the western Gulf. These are generally floating on the surface, and the concentration in the water column drops off rapidly with depth. High molecular weight hydrocarbons, which are low in sediments off south Texas, are very high in sediments off Louisiana and upper Texas, both in the nearshore and outer continental shelf areas. Many of these are unresolved complex mixtures including both weathered petroleum and anthropogenic fractions.

Volatile hydrocarbons are mostly low-molecular-weight, water soluble compounds. Included in this group are polynuclear aromatic hydrocarbons (napthalenes, etc.) which are often highly toxic. Some cause tissue damage, cancer, and genetic abnormalities. Although of low concentrations off south Texas, these compounds are present in high levels in the sediments and water column of Louisiana and upper Texas. Large quantities are released in the brine discharges and in the underwater venting of waste gases, and some derived from anthropogenic sources are brought in by river flow. Gaseous hydrocarbons show virtually the same distribution patterns as the volatile hydrocarbons. On the upper continental slope, there is much natural gas and oil seepage, particularly near the mouth of the Mississippi River. However, in general, the slope sediments have somewhat lower hydrocarbon concentrations than those of the Louisiana shelf.

Some studies have been carried out to determine hydrocarbon levels in biota. At the Flower Garden Banks, no petroleum contamination has been found in the water, sediments, macronekton, or the sedentary American thorny oyster (Spondylus). Off south Texas, hydrocarbons were found in zooplankton tissues, presumably derived from ingestion of micro-tarballs. Off Calcasieu Pass in nearshore waters of central Louisiana penaeid shrimp were found to be sporadically contaminated with petroleum hydrocarbons. At the Buccaneer Oil Field off Galveston, TX, the biofouling mat at a depth of 3 m was found to contain much fresh petroleum, and this also appeared in the blennies which fed upon the mat. Barnacles had weathered petroleum residues which also appeared it the sheepshead which feed upon the barnacles. Red snappers which come and go showed variable levels of contamination, and plankton-feeding spadefish contained lower levels of contamination. Off Timbalier Bay, LA, aromatic compounds (naphthalenes and derivatives) were present in tissues of the sheepshead and spadefish.

SYNTHETIC ORGANICS

Many synthetic organic chemicals are brought to the coastal waters of the northwestern Gulf by rivers and streams, and off the Mississippi River and the coastal bays and estuaries, high levels of synthetic organics have been observed. These include pesticides (such as DDT), polychlorinated biphenyls (PCB's), and related organochlorine compounds.

Samples of plankton and various species of fish, shrimp, and oysters from the study area have been analyzed for a variety of organochlorine residues. The organochlorine compounds most commonly found are DDT metabolites, PCB, and occasionally dieldrin. There is some evidence that estuarine biota contain higher levels of certain residues than do coastal pelagic organisms, but the differences, if any, are masked by large individual and interspecies variations in contaminant concentrations.

In a comprehensive study of organochlorine residues in Gulf coast estuarine fish conducted from 1972 to 1976, the three most common residues were total DDT, PCB, and dieldrin, which occurred in 39%, 22%, and 5% of the samples, respectively. Other pesticide residues appeared only rarely in biota. Data on the concentrations of PCB and DDE in oysters from several Gulf coast estuaries are also available from the Environmental Protection Agency Mussel Watch program.

RADIONUCLIDES

Radionuclides in the Gulf of Mexico are both natural and anthropogenic in origin. The property that distinguishes these chemical species from all others is their unstable nucleus, which leads to radioactive decay. Each radionuclide decays with a characteristic half-life, and this fact can, in some circumstances, be used as an indication of the rates of certain chemical and physical events. Radioactive decay also results in radiation that can, in some circumstances, be harmful to living organisms.

Most studies of radioactivity in Gulf of Mexico waters and sediments have been aimed at determining rates of processes--for example, rates of sediment accumulation, or rates of water movement. Little attention has been paid to possible harmful effects of radioactivity, because the levels of radioactivity in the Gulf are considered to be too low to have measurable effects on organisms. It should be noted, however, that much can be learned about how chemicals, including potentially toxic chemicals, move through the environment and interact with organisms by studying the behavior of radionuclides, whether the radionuclides have a direct effect on organisms or not.

The naturally-occurring radioactive elements uranium and thorium and their radioactive daughter nuclides have been among the most studied radionuclides in the Gulf of Mexico, as well as elsewhere in the world ocean. Those radionuclides have been used in a number of ways to provide a time frame for chemical, physical and biological processes. Uranium has several sources, sinks, and pathways to and through the Gulf of Mexico. Dissolved uranium concentrations measured in open Gulf waters are about the same as those seen in the rest of the world ocean. Uranium concentrations in nearshore Gulf waters are variable because rivers and other land runoff sources are variable in uranium concentration. Some Texas rivers are enriched in uranium because they drain uranium mining districts, and all rivers draining agricultural areas carry uranium that was associated with phosphate fertilizer.

The only radionuclide that might be added to the northwest Gulf of Mexico in measurable amounts as a direct result of offshore oil and gas operations is radium. It has long been known that radium concentrations are higher in subsurface brines (produced waters), such as those from oil wells, than in other natural waters. The possible accumulation by organisms of radium from oil-well produced water appears not to have been studied.

PLANKTON

Nutrient levels on the continental shelf are derived primarily from the Mississippi and Atchafalaya River systems, and to a lesser extent from the outflow of other streams and from upwelling. Consequently, phytoplankton levels tend to be much higher and more variable off Louisiana than off south Texas and higher and more variable inshore than offshore. Phytoplankton cell counts average around 1 million cells/m^3 nearshore off Louisiana, about 85,000 cells/m^3 nearshore off south Texas, and about 30,000 cells/m^3 in offshore waters of south Texas. Surface chlorophyll concentrations off central Louisiana average 8.5 mg/m^3; off nearshore south Texas, about 2.5 mg/m^3; and in offshore Texas waters, about 0.6 mg/m^3 (only slightly above the open Gulf value of 0.2). Depth integrated primary production (in mg C/m^2/h) off Timbalier Bay ranges from 15.54 to 283.89 and averages 98.82 in comparison with an open Gulf average of 6.07. Diatoms dominate the phytoplankton off Louisiana, with freshwater species being observed on the continental shelf in association with plumes of Mississippi and Atchafalaya River water. Dinoflagellates become more important off south Texas, and red tide blooms, which apparently begin off Galveston Bay, extend along the coast to Tampico, Mexico.

Zooplankton abundance values tend to parallel those for phytoplankton. Zooplankton is much more abundant in coastal waters of Louisiana than off south Texas and more abundant nearshore than offshore. Average standing crop values are as follows: nearshore Louisiana--85,408 individuals/m^3, nearshore south Texas--3,496 individuals/m^3, and offshore south Texas--1,055 individuals/m^3. Copepods make up a large fraction of the zooplankton at all seasons and localities, and nearshore, mid-shelf, and outer shelf groups are recognized. The small estuarine copepod, Acartia tonsa, is the dominant nearshore species, and it sometimes makes up over 90% of the total zooplankton (Figure 4).

The neuston has been investigated only off south Texas. This is a very diverse group and is rich in eggs and larvae of invertebrates and fishes. As a whole, neuston is more abundant in nearshore than in offshore waters, but individual taxa may reach their highest levels in nearshore, middle shelf, or outer shelf waters. Most groups peak during the spring months, but some have secondary peaks at other seasons of the year. For most groups, night-time collections show higher concentrations than those made during the day.

NEKTON

Nekton includes a variety of squids, fishes, sea turtles, and cetaceans. Inshore and offshore species assemblages are recognized, and many of the nektonic species are seasonal residents. Quantitative data for nektonic species are lacking.

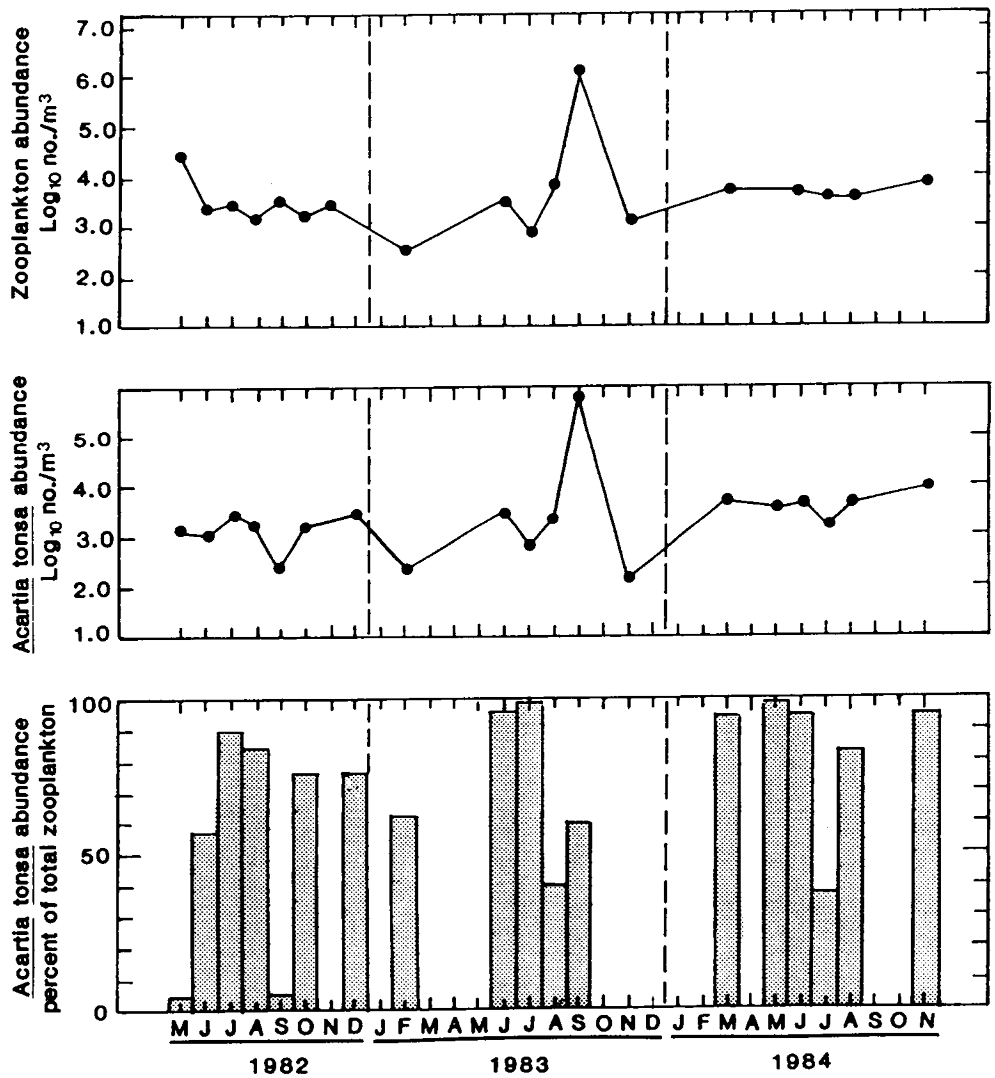

Figure 4. Characteristics of zooplankton off the Calcasieu River, LA (Data from: SPR studies).

DEMERSAL AND BENTHIC FAUNA

The demersal fauna of the Texas-Louisiana shelf has been fairly well studied. About 30% of the species are estuary related. The absolute density of penaeid shrimp is about one-third greater off Louisiana than off Texas, and the total fish population is much denser off Louisiana (four times as dense in the 14 to 27 m depth range and two times as dense in the 7 to 46 m range). On the outer shelf, the Louisiana and Texas fish population densities are about equal. Maximum densities of demersal fishes on the Louisiana shelf occur at depths of 14 and 27 m (23.1 and 21.5 kg/ha, respectively) and on the Texas shelf at depths of 73 and 82 m (7.6 and 8.2 kg/ha). In the inshore Louisiana waters, the catch is dominated by the Atlantic croaker, but numerical dominance in the inshore catch off Texas is shared by the Atlantic croaker, silver seatrout, and southern kingfish, all estuary related. At depths of 27 m and beyond, the longspine porgy dominates off both Louisiana and Texas. The white shrimp, which overwinters on the inner shelf, favors Louisiana, while the brown shrimp, which overwinters in deeper shelf waters, favors Texas. For the most abundant demersal species, seasonal depth-related density patterns are known. Food habits of important demersal fishes have been investigated, and trophic ecosystem models have been developed. Density estimates of the demersal fauna of the Louisiana upper slope have been provided.

The meiofauna is dominated by nematodes, with a variety of other invertebrate groups present in much lower numbers. At the Buccaneer Oil Field, the average meiofaunal density was 941 individuals/10 cm^2. Off south Texas, mean densities ranges from a high of 430 individuals/10 cm^2 (0 to 30 m) to a low of 30 individuals/10 cm^2 (120 to 140 m). On the Louisiana upper slope, the average meiofaunal density was 410 individuals/10 cm^2. The extent to which these density differences are due to sediment rain size is not clear.

On the south Texas shelf, average macrobenthos densities are high nearshore (2,901 individuals/m^2) and low on the outer shelf (394 individuals/m^2). At the Buccaneer Oil Field they are much higher, averaging 6,288 individuals/m^2. In the nearshore waters off central Louisiana, densities up to 18,736 individuals/m^2 were observed, but the mean annual density was low (2,600 individuals/m^2) due to the effects of hypoxic water during the summer months, which reduced densities at this seasons to a low of 266 individuals/m^2. On the Louisiana upper slope, macrobenthos densities averaged 3,816 individuals/m^2, but due to the use of a smaller mesh size, these values are not strictly comparable with the others. As in the case of the meiofauna, the macrofauna appears to be more abundant in shallower than deeper water and more abundant off Louisiana and upper Texas than off lower Texas. The macrobenthos constitutes a major food resources for the demersal fish fauna.

The megabenthos is not sharply distinguished from the demersal fauna, previously discussed. However, five benthic megafaunal species assemblages have been recognized for the Texas-Louisiana coastal waters. These include the inner shelf (4 to 20 m), intermediate shelf (20 to 60 m), outer shelf (60 to 120 m), and upper slope (120 to 200 m) assemblages, as well as a pro-delta assemblage (4 to 20 m) around the

Mississippi River Delta. For each, the environmental correlates and faunal compositions have been provided. Recent studies on the Louisiana upper slope reveal that the megafauna in the 300 to 500 m depth range is distinctly different from that of the previously proposed upper slope assemblage, suggesting a major faunal break in the 200 to 300 m depth range.

STRUCTURE-RELATED BIOTA

The structure-related biota includes those species associated with both natural and artificial hard substrates. The biota of the more prominent natural hard banks of the outer shelf have been studied in some detail. Seven biotic zones are recognized, and these zones are determined by depth in the water column, distance from shore, depth of the nepheloid layer, and related factors. Of particular interest are the high diversity coral reefs that cap the East and West Flower Garden Banks. No single bank possesses all the zones, but only one zone is missing from the Flower Garden Banks. Many tropical invertebrates and fishes are found in association with the outer shelf banks, and some of these species have not been encountered elsewhere in the area. Numerous smaller banks of the shelf have received little or no attention.

During the past half-century, the availability of anthropogenic hard substrate (particularly on rigs, platforms, and pipelines) has increased dramatically, and such substrate now provides a surface area of at least 40 km^2. This newly available habitat has been colonized by a great many species which together constitute a significant ecological system in its own right. Included are the attached biofouling mats, mat-associated organisms, and mobile species of the water column that are attracted to the structures. Species composition and biomass of the biofouling mat vary in relation to depth in the water column, distance from shore, and distance along the coast from the Mississippi River Delta. Inshore, the mat may be up to 12 cm thick and weigh up to 15.5 kg/m^2, whereas well offshore it is only 2 to 4 cm thick and weighs 1 to 5 kg/m^2. Sessile barnacles dominate inshore, bivalves are most common toward the outer shelf, and stalked barnacles dominate in oceanic water. Marine algae are limited to the euphotic zone, and in the aphotic zone hydroids, anemones, bryozoans, and tunicates are most important. In addition to the mat species, large populations of invertebrates and fishes and some sea turtles find food and haven around the structures. Many of these are also associated with the natural hard banks.

ENDANGERED AND THREATENED SPECIES

Fourteen species of marine vertebrates of the area are officially recognized as threatened or endangered. These include five species of sea turtles, five species of great whales, three species of birds, and one species of manatee. However, exclusive of the birds, only three species are considered to be at all common: the loggerhead and Kemp's ridley sea turtles (which may be found around rigs and banks) and the great sperm whale (which often occurs over the outer shelf and upper slope). Major threats include habitat loss and general disturbance along the coasts (sea turtles and birds), organochlorine pollutants (birds), plastic wastes (sea turtles and marine mammals), and major oil slicks (sea turtles, birds, and whales). Noise and underwater explosions may cause special problems for sea turtles and marine mammals.

BIOLOGICALLY SENSITIVE AREAS

In general terms, biologically sensitive areas of the Louisiana-upper Texas coastal waters include species spawning grounds, tidal passes, reefs and hard banks, areas associated with the mouths of rivers, and habitats of rare shelf species. In specific terms, only the Flower Garden Banks have been identified as being particularly important and sensitive. However, no specific search has been made. Potential candidate sites include Mississippi Delta environments, Mississippi Canyon environments, oozy bottoms off Louisiana, and "hill and valley" areas of the outer shelf and upper slope.

SOCIOECONOMICS

The Gulf of Mexico off Texas and Louisiana supports major commercial and recreational fisheries and supplies the great majority of the nation's offshore oil and gas production. About 40% of the nation's commercial fish landings and one-third of the marine recreational fishing activity are concentrated in the Gulf of Mexico, and much of this occurs on the Texas-Louisiana continental shelf. Over 90% of U.S. outer continental shelf oil and gas production comes from this area. The three main marine-related industries of the area (fishing, oil and gas, and shipping) also generate derivative activities in terms of services, supplies, sales, housing, recreation, etc., and thus play a large role in supporting the economy of the coastal region.

FISHERIES

Shellfish

The fishery offshore of Texas and Louisiana is composed of two major components: shellfish and finfish, with shellfish being the most important economically. The commercial shrimp fishery annually lands about 65 million pounds of brown and white shrimp, which provides the greatest dollar value catch. Shrimp landings in Louisiana in 1987 were valued at over $300 million.

One significant development that has greatly affected the shrimp fishery off Texas and Louisiana is the seasonal Texas closure of the brown shrimp fishery during the last seven years. The objectives of the Texas closure were to increase the yield of shrimp and to eliminate waste caused by discard of undersized shrimp in the Fishery Conservation Zone. Figure 5 shows the area of the 1986 Texas closure and also indicates the statistical reporting grids used by the National Marine Fisheries Service for tabulating fisheries landings.

Finfish

The finfish fishery has traditionally relied almost exclusively upon the menhaden and several species of the drum family, all estuary dependent. During the 1980's, however, the fishery has expanded, with a tripling of the number of major species landed and the number of species with a value over $1 million. The annual dollar value of the finfish catch now exceeds $84 million, distributed as follows: menhaden--65%, tuna--14%, drums--10%, snappers--5%, swordfish--2%, and the remaining species--about 4%. Most of the catch occurs in grids 13, 14, and 15 off the Louisiana coast (Figure 5), where the ever-increasing amount of hard substrate being added by offshore petroleum platforms may be a contributing factor. During the past 15 years, there has also been a major expansion of the marine recreational fishery, with much of this concentrated around the rigs and platforms.

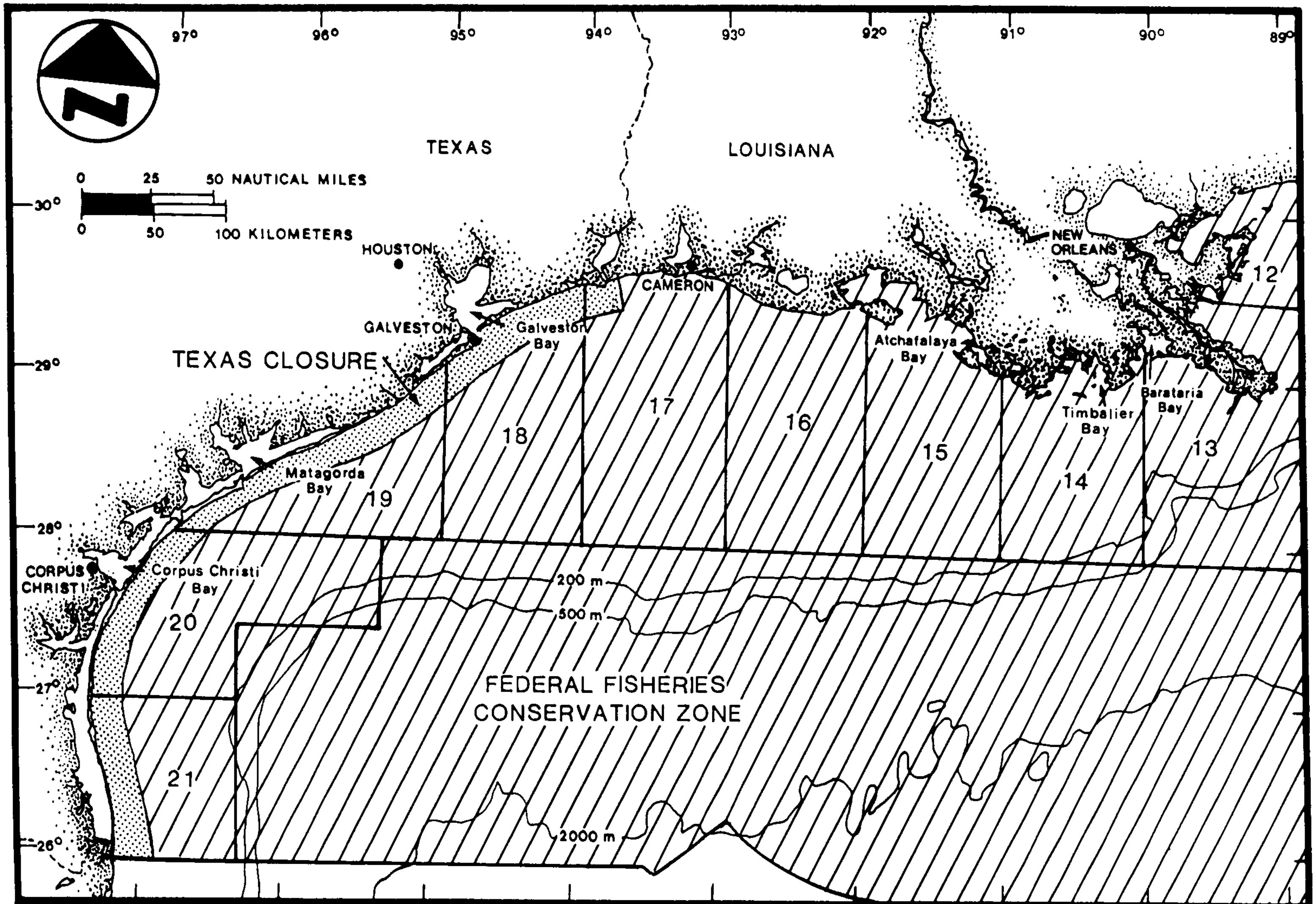

Figure 5. Location of the National Marine Fisheries Service statistical grid areas (numbers), the Federal Fisheries Conservation Zone (cross-hatching) and the Texas Closure Area (dot pattern).

OIL AND GAS INDUSTRY

About 90% of the nation's offshore oil and gas is derived from the Gulf of Mexico, primarily from the Texas-Louisiana shelf. Outer Continental Shelf (OCS) production off Louisiana and Texas since 1954 has totaled over 6 billion barrels of oil and 70 billion cubic feet of natural gas. In 1985, over 350 million barrels of oil and about 4 billion cubic feet of gas were produced on the Louisiana and Texas OCS.

During the late 1970's and early 1980's when oil prices ranged from $30 to $46 per barrel, exploration, development, and production reached all-time highs, but since 1986, when oil prices dropped to less than $20 per barrel, the industry has been at low ebb. The oil and gas industry has a good safety record. During the period 1970 to 1979, with around 2,000 structures operating, oil spills averaged only about 11,000 barrels per year (5.5 barrels per structure).

SHIPPING INDUSTRY

Considerable commercial shipping traffic enters and leaves northern Gulf ports. During 1986, about 300 million tons of cargo crossed the docks of ports from New Orleans to Corpus Christi, and about 65% was associated with the five major ports (Houston, the Louisiana Offshore Oil Port, New Orleans, Gramercy, and Corpus Christi). Much of this cargo was crude petroleum or petroleum products.

DEFINITION OF MAJOR ECOSYSTEMS

The major ecosystems of the Texas-Louisiana continental shelf and upper continental slope are diagrammed in Figure 6. Three basic systems are recognized: the water column, soft-bottom benthic, and hard substrate, structure-related systems. Between these basic types there are transitional systems. Two subsets of each of the major systems are recognized. For the water column system, there are the coastal and the oceanic subsystems. For the soft-bottom benthic system, there are the continental shelf and upper continental slope subsystems. For the hard-substrate, structure-related system, there are the natural substrate (hard bank) and artificial substrate subsystems.

The Texas-Louisiana shelf and upper slope area can be viewed as a simple, two-dimensional environmental gradient extending westward along the coast (increasing distance from the Mississippi River discharge) and seaward (increasing water depth and distance from shore). One extreme is in shallow water along the Mississippi River Delta and the other is in deep water at the southwest corner of the area. Although this may be an oversimplified picture, everything that exists or occurs in the area can be interpreted within this general context. It recognizes the overriding importance of the Mississippi River influence as well as the major influences flowing from the low salinity, highly productive Louisiana coastal bays and estuaries. It takes into account natural changes in the water column and benthic environments associated with depth and distance from shore. It recognizes the importance of the transition from continental to oceanic control of ecosystem composition and dynamics. The components of all the major biological systems appear to reflect this double gradient.

HUMAN INFLUENCES ON THE CONTINENTAL SHELF

The main focus of Chapter 8 in Volume II is the environmental effects of oil and gas operations; however, other human activities are also discussed to provide perspective. These include shore-based human activities, offshore construction, mineral extraction, biological harvesting, ship traffic, dumping of trash and debris, and recreational diving.

EFFECTS OF OIL AND GAS OPERATIONS

Effect Pathways

Oil and gas activities can be grouped into four main phases: Evaluation, Exploration, Development and Production, and Post-Production. Each phase involves a number of activities that may affect the biota and ecosystems of the continental shelf. The phases and major activities or processes that can affect the environment are shown in Table 1 (referred to as the "main model"). The table lists major activities and events during each phase, along with their "primary

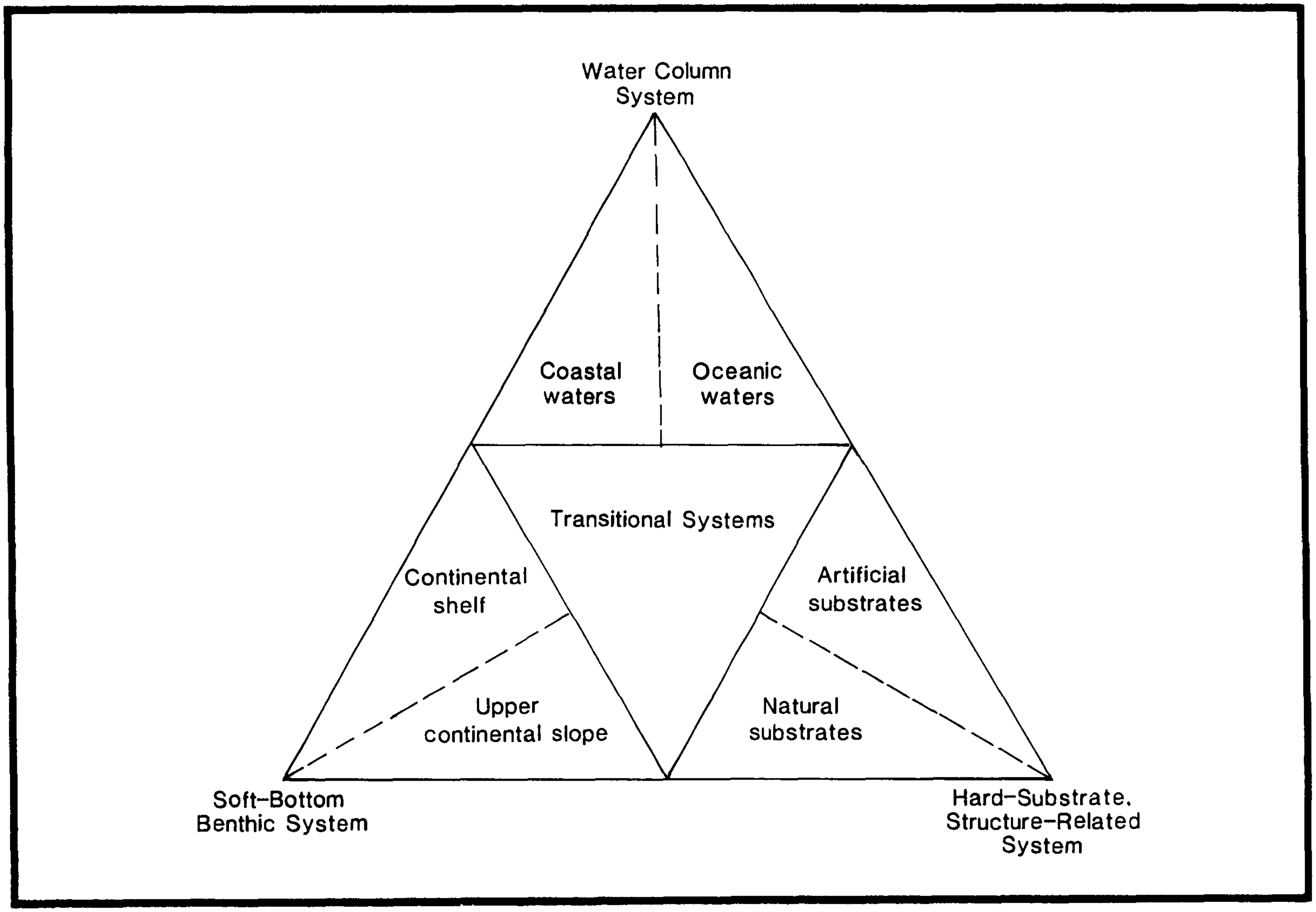

Figure 6. Conceptual diagram of the major ecological systems of the Texas-Louisiana continental shelf and upper continental slope.

Table 1. Main model of OCS oil and gas related operational phases, activities, and primary results. Derived results are illustrated in submodels A through L.

Operational Phase	Activity/Event	Primary Result	Submodel for Derived Effects
EVALUATION	Geological and geophysical surveying	Boat and ship traffic	A
		Seafloor disturbance	B
		Noise	C
EXPLORATION	Drilling rig installation and removal	Boat and ship traffic	A
		Seafloor disturbance	B
		Noise	C
		Presence of structures	E
	Routine drilling operations	Boat and ship traffic	A
		Seafloor disturbance	B
		Noise	C
		Drilling mud discharges	F
		Drill cuttings discharges	G
		Other liquid waste discharges	I
		Release of solid debris	J
		*Minor spills (e.g., fuel)	K
	Blowout*	*Seafloor disturbance	B
		*Noise	C
		*Release of solid debris	J
		*Major or minor oil spill	K
DEVELOPMENT AND PRODUCTION	Platform installation	Boat and ship traffic	A
		Seafloor disturbance	B
		Noise	C
		Presence of structures	E
	Routine drilling operations	Boat and ship traffic	A
		Seafloor disturbance	B
		Noise	C
		Drilling mud discharges	F
		Drill cuttings discharges	G
		Other liquid waste discharges	I
		Release of solid debris	J
		*Minor spills (e.g., fuel)	K
	Blowout*	*Seafloor disturbance	B
		*Noise	C
		*Release of solid debris	J
		*Major or minor oil spill	K
	Routine production operations	Boat and ship traffic	A
		Noise	C
		Produced water discharges	H
		Other liquid waste discharges	I
		Release of solid debris	J
		*Minor oil spills	K
	OCS pipeline installation and routine operation	Boat and ship traffic	A
		Seafloor disturbance	B
		Noise	C
		Presence of structures	E
		*Minor oil leaks or spills	K
		Dredging and channelization	L
	Moorings and offshore ports	Boat and ship traffic	A
		Seafloor disturbance	B
		Noise	C
		Presence of structures	E
		*Minor oil spills	K
	Pipeline rupture*	*Major or minor oil spill	K
	Tanker/barge accident*	*Major or minor oil spill	K
POST-PRODUCTION	Platform removal	Boat and ship traffic	A
		Seafloor disturbance	B
		Noise	C
		Explosions	D
		Release of solid debris	J
	Platform disposal	Boat and ship traffic	A
		Seafloor disturbance	B
		Noise	C
		Presence of structures	E

*Indicates an accidental event or result. All others are either intentional, or a normal consequence of routine activities.

results." These primary results are not environmental effects per se, but rather major factors that can lead to environmental effects. Each primary result is explored further in a submodel that is listed in the right hand column of the table. The 12 submodels (A through L) are listed below:

A. Boat and Ship Traffic
B. Seafloor Disturbance
C. Noise
D. Explosions
E. Presence of Structures
F. Drilling Mud Discharges
G. Drill Cuttings Discharges
H. Produced Water Discharges
I. Other Liquid Waste Discharges
J. Release of Solid Debris
K. Oil Spills
L. Dredging and Channelization

An example of a submodel (E. Presence of Structures) is shown in Figure 7. The other submodels are shown and discussed in Volume II, Chapter 8.

Effects on Major Ecosystems

The information about effect pathways is applied to the major ecosystems defined above (water column system, soft-bottom benthic system, and hard-substrate, structure-related system) in Tables 2, 3, and 4. In each case, the effects listed are of three types: widespread effects (W), those that may affect a large area; local effects that are of concern where rare species or unique resources are present (LR); and local effects that can cumulatively be considered important (e.g., in heavily developed areas, or in shallow water where dispersion is limited) (LC).

Effects of potential widespread importance to the water column system are major oil spills and release of trash and debris (Table 2). In both cases, the material released can be widely dispersed and result in effects over a wide area. Local effects on rare species or unique resources include potential collisions of boats and ships with marine mammals; effects of noise on marine mammals; and mortality or injury of marine mammals and sea turtles due to explosions during platform removal. Local effects of possible cumulative significance in areas of limited dispersion include turbidity from dredging and channelization, other seafloor disturbances, and drilling mud discharges; and chronic, low-level contamination of the water column by produced water discharges and wastes from boats and ships. Another local effect of cumulative importance is the concentration of fishes near structures, which leads to enhancement of recreational and commercial fisheries. In some instances, this effect could also lead to over-fishing of certain species.

CAUSES/ SOURCES	PRIMARY RESULT	DERIVED EFFECTS		OTHER SUBMODELS
DIRECTLY RELATED TO OIL AND GAS: • Drilling rig and platform construction • Pipeline installation • Moorings and offshore ports	---> Presence of Structures --->	Physical Environment	Addition of hard substrate, vertical relief Local changes in flow field ---> scouring of bottom sediments	
		Chemical Environment	Minor leaching of metals through corrosion of structures	
		Biological Environment	Attraction of sessile invertebrates (biofouling species) Attraction of reef fishes and pelagic fishes Benthic enrichment (biological "fallout" from structures) Interference with migrations of demersal species (pipelines) Concentration of biota near contaminant sources	
OTHER SOURCES: • Shipwrecks • Artificial reefs* • Other solid debris		Human Environment	Increased recreational and commercial fishing Possible depletion of some fish stocks (over-fishing) Interference with trawling; gear damage† Hazards to navigation†	

*Partly or indirectly related to offshore oil and gas development.
†Effect may be lessened, avoided, or compensated through existing regulations.

Figure 7. Submodel E relating oil and gas activities to the derived effects of the presence of structures.

Table 2. Main existing and potential effects of OCS oil and gas operations on water column ecosystems of the Texas-Louisiana continental shelf and upper slope.

Submodel	Main Environmental Effects of Concern	Nature of Concern*		
		W	LR	LC
A. Ship Traffic ---------->	Chronic, low-level pollution			x
	Potential for collisions w. marine mammals, turtles		x	
	Potential for oil spills	x		
B. Seafloor Disturbance -->	Turbidity, pollutant release through resuspension of bottom sediments			x
C. Noise ----------------->	Disturbance/altered behavior of marine mammals		x	
D. Explosions ------------>	Mortality, injury to marine mammals, turtles		x	
E. Presence of Structures >	Enhancement of recreational and commercial fishing			x
	Possible over-fishing of some species			x
F. Drilling Mud Discharges ------------>	Intermittent turbidity			x
G. Drill Cuttings Discharges ------------>	Negligible effects			
H. Produced Water Discharges ------------>	Local elevations in hydrocarbons, metals, radionuclides, etc.			x
I. Other Liquid Waste Discharges ------------>	Negligible effects			
J. Release of Solid Debris ---------------->	Mortality of fishes, mammals, turtles through entanglement, ingestion	x		
K. Oil Spills ------------>	Toxicity, sublethal effects, etc.	x		
L. Dredging and Channelization -------->	Turbidity, pollutant release through resuspension of bottom sediments			x

*W = Widespread effects.
LR = Local effects on rare species or unique resources.
LC = Local effects that can accumulate, particularly in heavily developed areas, or in shallow water where dispersion is limited.

Table 3. Main existing and potential effects of OCS oil and gas operations on soft-bottom benthic ecosystems of the Texas-Louisiana continental shelf and upper slope.

Submodel	Main Environmental Effects of Concern	Nature of Concern*		
		W	LR	LC
A. Ship Traffic ---------->	Chronic, low-level pollution of sediments			x
	Potential for collisions, oil spills	x		
B. Seafloor Disturbance -->	Crushing, burial of benthos			x
C. Noise ----------------->	Negligible effects			
D. Explosions ------------>	Mortality, injury of benthic organisms			x
E. Presence of Structures >	Habitat alteration (hard substrate)			x
	Benthic scouring			x
F. Drilling Mud Discharges ------------>	Shading of light sensitive species (e.g., benthic algae) due to turbidity			x
	Altered sediment grain size, mineralogy			x
	Smothering, interference with filter feeding			x
G. Drill Cuttings Discharges ------------>	Burial, smothering of benthos			x
	Attraction of fish and motile invert. predators			x
H. Produced Water Discharges ------------>	Possible local depression of benthic fauna			x
I. Other Liquid Waste Discharges ------------>	Negligible effects			
J. Release of Solid Debris ---------------->	Altered benthic habitats (heavy solid debris)			x
K. Oil Spills ------------>	Acute toxicity and chronic, sublethal effects, smothering, coating, etc.	x		
L. Dredging and Channelization -------->	Crushing, burial of benthos			x
	Habitat alteration			x
	Indirect effects through destruction of nursery habitat (coastal wetlands)			x

*W = Widespread effects.
LR = Local effects on rare species or unique resources.
LC = Local effects that can accumulate, particularly in heavily developed areas, or in shallow water where dispersion is limited.

Table 4. Main existing and potential effects of OCS oil and gas operations on hard-substrate, structure-related ecosystems of the Texas-Louisiana continental shelf and upper slope.

Submodel	Main Environmental Effects of Concern	Nature of Concern* W	LR	LC
A. Ship Traffic ---------->	Anchor damage to reef corals on hard banks		x	
	Potential for collisions, oil spills	x		
	Transport of biofouling species	x		
B. Seafloor Disturbance -->	Damage to reef corals (anchoring)		x	
C. Noise ----------------->	Negligible effects			
D. Explosions ------------>	Destruction of platform associated biota during removal			x
E. Presence of Structures >	Provision of additional habitat			x
	Enhancement of recreational and commercial fishing			x
	Possible over-fishing of some species			x
F. Drilling Mud Discharges ------------>	Shading of light sensitive species (e.g., hermatypic corals) due to turbidity		x	
	Altered substrate on hard banks		x	
	Smothering, interference with filter feeding		x	
G. Drill Cuttings Discharges ------------>	Burial, smothering of benthos		x	
	Altered substrate on hard banks		x	
H. Produced Water Discharges ------------>	Minor, local reduction in platform fouling community			
	Bioaccumulation of contaminants by platform associated species			x
I. Other Liquid Waste Discharges ------------>	Negligible effects			
J. Release of Solid Debris ---------------->	Negligible effects			
K. Oil Spills ------------>	Toxicity, chronic and sublethal effects, coating, smothering, etc.	x		
L. Dredging and Channelization -------->	Habitat destruction (if allowed to occur on hard-bottom area)		x	

*W = Widespread effects.
LR = Local effects on rare species or unique resources.
LC = Local effects that can accumulate, particularly in heavily developed areas, or in shallow water where dispersion is limited.

For the soft-bottom benthic system, the only widespread effects of concern are those resulting from major oil spills (Table 3). All other effects listed are local influences on the benthic communities that may be significant cumulatively in certain areas. Examples include dredging and channelization (particularly for pipeline installation on the OCS and in coastal wetlands), crushing and burial of benthic organisms by seafloor disturbance, scouring of sediments around production field structures, and shading of light-sensitive species (e.g., hermatypic corals) due to drilling mud discharges. The effects of operational discharges--particularly drilling muds and produced waters--are considered to be of possible concern, especially in heavily developed areas where dispersion is limited (e.g., coastal bays).

For the hard-substrate, structure-related system, widespread effects include those resulting from major oil spills and transport of biofouling species by ship traffic (Table 4). The latter is a positive influence, in that ship traffic helps to bring in potential colonizers of exposed hard substrate. Local effects on rare species or unique resources include anchor damage to reef corals at the Flower Garden Banks; effects of drilling mud and cuttings discharges on reef biota at the Flower Garden Banks (if allowed; currently, all discharges must be shunted, thereby preventing exposure); and effects of dredging and channelization (if allowed to occur in a hard-bottom area). A local effect of great cumulative importance is the presence of structures, which provide habitat for the biofouling community and which attract fishes, leading to enhancement of recreational and commercial fishing. Concentration of fishes near structures may expose some fish populations to over-fishing, however. Another local effect of possible cumulative importance is the mortality to platform biota (both the biofouling community and associated nekton) during platform removal.

Summary of Main Effects

The widespread effects of most concern are as follows:

- A major oil spill resulting from a tanker or barge accident, pipeline rupture, or blowout. Although there could be direct effects on continental shelf biota, the main concern is fouling of the coastal wetlands that serve as nursery areas for many species of fish and invertebrates.

- Proliferation of trash and debris, particularly plastic items. Ingestion and entanglement are the main problems, and effects on endangered or threatened sea turtles and marine mammals are of particular concern.

The following environmental effects (or potential effects) are the result of activities that probably are not of much concern except when carried out in the presence of rare species or unique resources. In most cases, the likelihood or severity of effects is not well known or documented.

- Effects of explosions (during platform removal) on fishes, marine mammals, and sea turtles.

- Collisions of boats and ships with marine mammals and sea turtles.

- Effects of noise on behavior of marine mammals and sea turtles.

- Anchor damage to reef corals at the Flower Garden Banks.

- Surface discharges of drilling mud and cuttings at or near the Flower Garden Banks (if allowed). Under the current stipulations requiring shunting, these discharges are not expected to affect the corals atop the banks.

- Dredging or channelization on or near hard bank areas (if allowed).

Finally, the effects listed below are local when taken individually, but can be of cumulative significance, particularly in heavily developed areas, or in areas of limited dispersion.

- The presence of thousands of structures on the continental shelf and upper slope has provided hard substrate for biofouling communities and attracted many nektonic and demersal species, including groupers, red snappers, and sea turtles. On the positive side, the structures have enhanced recreational and commercial fisheries. On the negative side, some fishes such as the groupers and snappers, which become residents, can become vulnerable to over-fishing. Also, association of fishes and sea turtles with the platforms can lead to mortality during platform removal.

- Continued destruction of coastal wetlands through dredging and channelization for OCS pipelines. Although oil and gas activities account for a fraction of the total wetland loss in Louisiana, the cumulative losses could have significant, long-range effects on the biota of the continental shelf because many of the shelf species are estuarine dependent.

- Chronic chemical pollution of heavily developed, shallow areas where dispersion is limited, by contaminants from ship traffic and OCS operational discharges (drilling muds, produced waters).

- Chronic water column turbidity resulting from drilling mud and cuttings discharges and various sources of seafloor disturbance (resulting in sediment resuspension). This effect would be of particular concern in shallow areas with limited dispersion, and especially those not already influenced heavily by turbid outflow from the Mississippi River.

- Effects on benthic communities in the immediate vicinity of drilling rigs and platforms. These effects may result from operational discharges (drilling muds, cuttings, produced waters), scouring of sediments around structures, and/or predation by fish and motile epibenthos attracted to the structures and to biological debris and cuttings piles on the bottom.

DATA GAPS AND INFORMATION NEEDS

Each chapter in Volume II includes a brief section discussing data gaps and information needs. The major points from each chapter are summarized below, followed by suggestions for future field studies.

MARINE GEOLOGY

Data gaps were identified in four main areas: salt tectonics, sediment accumulation rates, chemosynthetic communities, and sediment transport.

- Salt Tectonics. Little is known concerning the dynamics of salt tectonics. We know that the forces affecting the topographic expression and internal structure of salt domes are active, but no one has monitored a salt dome to determine what is really happening.

- Sediment Accumulation Rates. Current knowledge concerning sediment accumulation rates on the outer continental shelf and slope is woefully inadequate. An accurate knowledge of sediment accumulation rates would aid in interpretation of meiofaunal and macroinfaunal data. It would also be important in modeling the trajectories of solid pollutants in the water column.

- Chemosynthetic Communities. Hydrocarbon seeps support chemosynthetic communities, including microbial mats that cause the precipitation of carbonate cements in the sediments with which they are associated. The interaction of these bacteria with the inorganic sediment may be an important factor in the stabilization of sediments in the vicinity of seeps.

- Sediment Transport. McGrail's work was just beginning to give us an understanding of the sediment transport processes on the outer continental shelf. A continuation of the accumulation of the same kinds of data over a larger area of the Texas-Louisiana shelf and over a span of two or three years would improve our ability to predict the fate of particulate pollutants.

PHYSICAL OCEANOGRAPHY AND METEOROLOGY

Five main areas of information needs were identified in the physical oceanography/meteorology chapter: circulation patterns; exchange processes between the shelf and open Gulf waters; river discharge effects on salinity; structure and behavior of frontal zones; and dynamics of changes in dissolved oxygen concentrations.

- **Circulation Patterns**. The variability about the mean pattern of surface circulation is largely unknown except in the regions of the Department of Energy Strategic Petroleum Reserve studies. The spatial pattern of mean bottom circulation over the shelf, and its variability, also need to be described and related to the surface circulation and hydrographic variability.

- **Exchange Processes**. Information about the exchange processes between the shelf and the oceanic Gulf regions is very limited. The influence of Loop Current eddies, the export of water masses created by cold-air outbreaks, the flushing of fresh water discharge on to the shelf, upwelling of deep ocean water masses onto the shelf, and transport of sediment off the shelf are important yet relatively unexplored topics for this shelf.

- **Effects of River Discharge**. Our understanding of the effects and fate of the fresh water from the Mississippi-Atchafalaya River System is based largely on the salinity data from the GUS III cruises in the years 1963 to 1965, when river discharge was lower than average. The distribution of salinity on the shelf should be mapped with greater spatial resolution, both horizontally and vertically, during a year with above-normal volumes of river discharge.

- **Frontal Zones**. The structure and the dynamic behavior of the intense frontal zones on this shelf should be studied through a combination of observation and modeling, with a view towards defining the effect the stratification, both horizontal and vertical, has on the mixing, distribution and transport of nutrients, plankton and pollutants.

- **Dissolved Oxygen**. The rate at which the concentration of dissolved oxygen changes locally in bottom waters when there is vertical stratification is unknown. All terms in the diffusion equation for dissolved oxygen need to be studied: local rate of change, advection, production, consumption, and turbulent mixing, both vertical and horizontal.

MARINE CHEMISTRY

More information is needed on the sources and fate of trace metals, the distribution of trace metals, the fate of drilling mud discharges, the distribution of aromatic hydrocarbons, spatial and temporal trends in benthic and pelagic tar, body burdens of hydrocarbons in seep organisms, and radionuclides in produced waters.

- **Sources and Fate of Trace Metals**. More work is needed on the forms of dissolved metals in Mississippi River water, the behavior of river-borne particulates as they mix with seawater, and the fate of Mississippi River-derived trace elements. Also, the mass and fate of metals from other sources, such as the atmosphere and industrial discharges, need further study. Effects of bottom water hypoxia on sediment trace metal geochemistry should also be investigated further.

- **Distribution of Trace Metals**. Concentrations of dissolved trace metals in seawater are poorly known, as few seawater samples from the Texas-Louisiana shelf have been analyzed with the care required to lend confidence to the data. Trace metal concentrations in surficial sediments are much better documented, but information on temporal variability is very limited. Data on trace metals concentrations in biota from the east Texas and Louisiana continental shelf and slope are lacking. Trace metal concentrations also need to be measured in sediments and biota near petroleum seeps.

- **Fate of Drilling Mud Discharges**. Further work is needed using trace metals to study the fate of drilling mud discharges, particularly in the near-field around drillsites.

- **Distribution of Aromatic Hydrocarbons**. Distributions of aromatic hydrocarbons in northwestern Gulf sediments and organisms need further study. Regional and temporal distributions of aromatic hydrocarbons should be studied using National Oceanic and Atmospheric Administration "Status and Trends" methodologies.

- **Benthic and Pelagic Tar**. More information is also needed on spatial and temporal trends in benthic and pelagic tar distributions. Additional information on the sources of benthic and pelagic tar is needed, as there is little information that is less than ten years old.

- **Seep Hydrocarbons**. More data is needed on the body burdens of hydrocarbons in benthic organisms around petroleum seeps, and on the relationships between seep hydrocarbons and benthic organism body burdens.

- **Radionuclides in Produced Waters**. The mass and fate of radionuclides in produced waters needs further study. Also, the possible accumulation by organisms of radium from oil well produced water appears not to have been studied.

MARINE BIOLOGY

Several data gaps and information needs were identified in the Marine Biology chapter. The long-term goal of future studies is the development of a complete understanding of the major ecosystems of the area, possibly leading to the construction of predictive mathematical models.

- **Coupling Mechanisms**. Information is needed on the coupling mechanisms between the inshore marshes, bays, and estuaries, on the one hand, and the continental shelf ecological systems, on the other.

- **Influence of the Mississippi and Atchafalaya Rivers**. More information is needed to understand the influence of the Mississippi and Atchafalaya Rivers on shelf ecosystems. The spatial and temporal extent of these influences, and the relationships to meteorological factors, need to be investigated.

- **Interactions of Oceanic Waters with Coastal Systems**. Interactions of oceanic waters with coastal waters and habitats need to be better understood, and their influence on the distribution of the biological components of the systems needs to be determined.

- **Nepheloid Layer**. Relationships between the nepheloid layer and biological systems of the shelf and upper slope need to be studied.

- **Hypoxic Zones**. Influences of hypoxic zones on biological systems need to be studied.

- **Oxygen Minimum Layer**. Relations of the oxygen minimum layer with shelf/slope biota are also not well known.

- **Water Column Biota**. Quantitative information is needed on the seasonal and areal distribution of phytoplankton, zooplankton, and neuston, especially in relation to water masses.

- **Benthos**. Quantitative information is needed on the density and distribution of meiofauna, macrofauna, and megafauna in relation to sediment types.

- **Hard Banks**. The outer shelf banks have been well studied, but hard banks of the middle shelf and upper slope are not well known. The distribution and biological characteristics of these banks need to be documented.

- **Sea Turtles**. Additional research is needed to develop safe methods of platform removal. Current methods involving bulk explosive charges can injure or kill sea turtles. In addition to developing alternative removal methods, it would be desirable to find methods to keep sea turtles away from the vicinity of platforms during removal.

- **Special Systems**. Information is needed on the composition and ecological characteristics of certain areas: the Mississippi River near-delta environments (e.g., Pro-Delta Fan Assemblage), Mississippi Canyon environments, areas of oozy bottom off Louisiana, and hill-and-basin environments of the outer shelf and upper slope.

SOCIOECONOMICS

The major topic for further study cited in the Socioeconomics chapter concerns the nature of changes in commercial finfish landings over the last seven years. These changes raise some important questions that deserve further study. In particular, the possible relationships between these changes and the high density of petroleum platforms off Louisiana need to be investigated.

SUGGESTIONS FOR FUTURE FIELD STUDIES

Based on the information needs identified in the various chapters and highlighted above, we can make suggestions for future field studies of the Texas-Louisiana shelf and upper slope. These suggestions are general recommendations concerning study locations, scheduling, and design considerations. It is premature to make specific recommendations for study components, sampling equipment, and methodologies.

We suggest that the study area should extend from the Mississippi River Delta to Brownsville, TX, and from the shallow sublittoral to the 500-m isobath. Based on the data gaps that have been identified and an understanding of the dynamics of the study area, we suggest that primary sampling transects for future studies should extend from nearshore to the 500-m isobath at three locations:

- south-southeast from Freeport, TX.
- south from Cameron, LA.
- southeast from Isles Dernieres, LA (90°50'W).

These proposed transects cross areas containing major data gaps in most of the oceanographic disciplines. In addition, the two transects off Louisiana are shoreward extensions of transects occupied during the MMS Northern Gulf of Mexico Continental Slope Study. About five or six stations should be located along each transect, and a full oceanographic sampling program should be conducted at each station, including long-term current meter arrays. To support the interpretation of results gathered from the above transects and stations, it is recommended that (1) seasonal, high resolution, quasi-synoptic hydrographic surveys be conducted within the suggested study area; (2) two meteorological recording stations be installed at approximately the 200- to 300-m isobath at about 92°W and 95°W Long.; and (3) an additional line of current meter arrays be concurrently located off south Texas along about 27°N Lat. Location of offshore stations should be chosen to complement data sets from ongoing or planned deep-sea investigations.

In order to build a credible data base and to document temporal variations, there should be three years of field sampling, followed by one to two years of data integration and synthesis. Year 1 activities could concentrate on sampling the primary transects, placement of meteorological sensors, and performing high-resolution hydrographic surveys. Years 2 and 3 could continue sampling of primary transects and high-resolution hydrographic surveys, and add the south Texas current meter array and biological and chemical sampling in special interest locations--e.g., Mississippi River near-delta environments, Mississippi Canyon area, and macro oil- or gas-seep regions on the upper slope (200 to 500 m), and selected hard banks.

Due to the dynamic nature of the Texas-Louisiana continental shelf and the interrelationships of its biological, chemical, geological, and physical environments, it is essential that any large-scale study be an integrated data collection program. Concurrent collection of data within these different disciplines will ensure the maximum usefulness of the data sets produced. In general, the biological, chemical, geological, and physical data should be collected at the same transects and stations, with some exceptions for special studies that may be needed in each discipline.

Previous studies have used various sampling methods and laboratory analyses whose results are not necessarily comparable (e.g., different mesh sizes for sieving macroinfauna). In order to make the most of the existing data in any future synthesis effort, it would make sense to standardize the methods to match or closely approximate those of one of the previous major studies. Alternatively, if new and different methodologies are to be used, then the relationships between the data sets produced by the old and new methods should be established.

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. The 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.