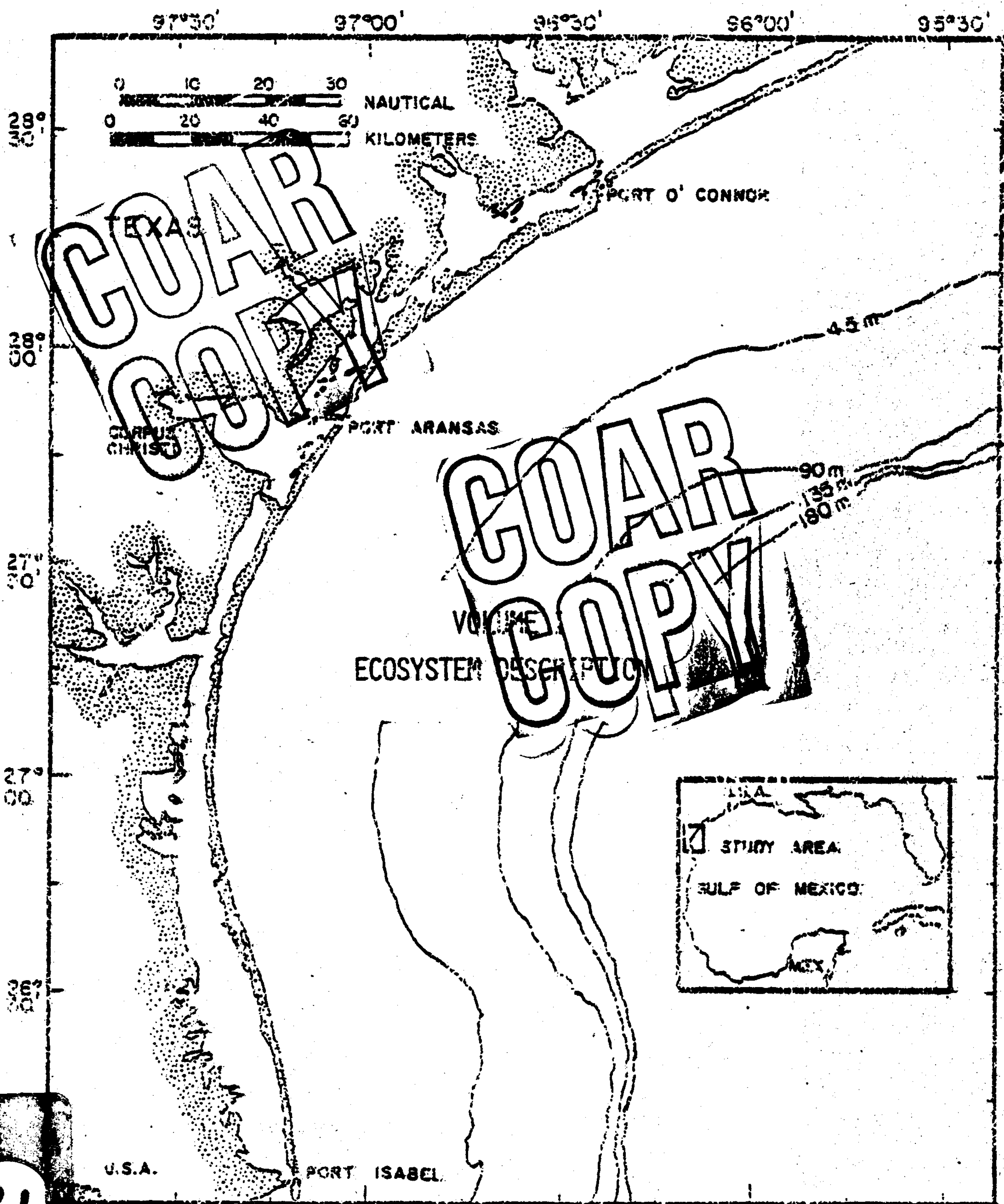
ENVIRONMENTAL STUDIES, SOUTH TEXAS OUTER CONTINENTAL SHELF, 1975-1977



VOLUME

ECOSYSTEM DESCRIPTION

ENVIRONMENTAL STUDIES,

SOUTH TEXAS OUTER CONTINENTAL SHELF,

1975-1977

VOLUME I

ECOSYSTEM DESCRIPTION

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To Debby Kalke without whose persistence and diligence throughout the years of this program we could not have arrived at a successful completion. A personal thanks from all of us.

FOREWORD

This study of the south Texas outer continental shelf (STOCS) was conducted on behalf of the U. S. Bureau of Land Management and with the close cooperation of personnel of that agency. The studies reported on herein constituted the fourth year of an environmental studies program of the STOCS. This study was part of an overall program that included the other elements of 1) geology and geophysics by the U. S. Geological Survey, 2) fisheries resources and ichthyoplankton populations by the National Oceanic and Atmospheric Administration/National Marine Fisheries Service, and 3) biological and chemical characteristics of selected topographic features in the northern Gulf of Mexico by Texas A&M University. The resultant data from this investigation represent the first petroleum exploration and development in the STOCS area. The central goal of these and other environmental quality surveys of continental shelf areas is the protection of the living marine resources from deleterious effects.

This investigation was the result of the combined efforts of scientists and support personnel from several universities. The hard work and cooperation of all participants is gratefully acknowledged.

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PREFACE

The present concern about the rate of fossil-fuel consumption and dependency upon import oil to supply current U. S. demands has resulted in a greater focus of interest by both the U. S. government and oil companies on the U. S. continental shelf for increased domestic production. The 1969 National Environmental Policy Act (NEPA) identifies the U. S. Department of the Interior as the responsible agency for protecting the marine environment of the continental shelf during periods of exploration and exploitation of natural resources. To obtain information upon which to base decisions concerning the orderly development of these resources while also protecting the environment, the Bureau of Land Management (BLM), an agency of the Department of the Interior, established a marine environmental studies program for the outer continental shelf.

This document is a presentation of the results of three years of field studies and data collection on the south Texas outer continental shelf, one of the BLM programs, integrating the information obtained into a statement of the ecosystem characteristics of this shelf area. The intent of the contributions contained within this document is to provide the initial information needed by the environmental managers in order to make sound decisions concerning natural resource exploitation in these shelf waters. Besides a general ecosystem description presentation, an attempt has been made in this document to present, in a meaningful fashion, those relationships that exist in this environment and those specific characteristics (variables) of this environment which are most important for prediction, assessment and management of impacts to the south Texas outer continental shelf ecosystem.

On 3 June 1979, while this document was in preparation, a well blowout occurred at the IXTOC I drilling site in the Bay of Campeche off the Mexican coast in the southwestern Gulf of Mexico. The events that followed this major disturbance to the marine environment of the Gulf, as the massive oil slicks entered U. S. waters, emphasized the value of this study program with its establishment of baseline conditions and ecosystem characteristics. Through the information presented in the following volumes, federal agencies associated with the National Oil Spill Response Team that monitored the IXTOC I spill and developed a damage assessment plan of research were able to identify critical components of the shelf environment and important variables that could be used to detect ecosystem change from the spill impact. It is only hoped that the reasons for conducting the south Texas outer continental shelf research program will not be forgotten. Now that the opportunity exists to evaluate the actual impact of a major perturbation related to natural resource exploitation, decision-makers need to take full advantage of the extensive data base available to fill out numerous information gaps so that future decisions involving any shelf environment and resource exploitation can be made without a feeling of apprehension and uncertainty.

Special acknowledgement is given to the scientists who served as previous Program Managers for the research program detailed in the following pages. These include Robert S. Jones, Robert D. Groover, and Connie R. Arnold. Acknowledgment is also given to Richard Casey, Jerry Neff, William Haensly, Particia Johansen, Chase Van Baalen, Samuel Ramirez, Helen Oujesky, William Van Auken, and Neal Guntzel for their overall scientific contributions to the South Texas Outer Continental Shelf Program even though they did not participate in the data synthesis aspect. We further thank the technical people in the Bureau of Land Management for their guidance during this program.

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EXECUTIVE SUMMARY

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The broad continental shelf of south Texas supports valuable commercial and sport fisheries, particularly for penaeid shrimp, along with potential sites for exploration and exploitation of oil and gas resources. An intensive, multidisciplinary three-year study (1975-1977) to characterize the temporal and spatial variation of both the living and non-living resources of the area was designed to provide the initial information needed by environmental managers to make sound decisions concerning natural resource exploitation. The synthesis and integration of these data resulted in an encompassing description of the physical, chemical and biological components of the system, identifying the temporal and spatial trends that best represented the ecosystem along with mathematical descriptions for unique relationships that would serve as "fingerprints" for future comparisons against which subsequent changes or impacts could be compared, particularly in the light of oil and gas development activities. The study included the pelagic environment with its physical characterization, biotic composition and productivity; the benthic habitat physical setting and biotic composition; and inherent natural petroleum hydrocarbon and trace metal levels in selected portions of the physical and biological components, both pelagic and benthic.

As research priorities were reassessed and additional information determined necessary, the study was amended appropriately to meet evolving study objectives. Sampling schemes varied from year to year and according to particular components of the overall study. In general the study area was traversed by four transects perpendicular to shore, each with six to

seven stations distributed from 10 to 130 m. The number of stations sampled varied with year, study element, and collection period. Samples were taken seasonally along all four transects during all three years. Monthly sampling was conducted on Transect II during 1976. Additional sites included stations near two hard bottom features, Hospital Rock and Southern Bank, and an exploratory drilling rig monitoring study site. The resultant large and encompassing data base was synthesized and integrated to describe characteristics and interactions of the physical, chemical and biological components of the south Texas continental shelf. A summarization of the highlights of this study follows.

The Texas shelf environment is a complex interaction of adjacent land masses, nearshore coastal waters influenced by estuarine systems and their inherent high productivity, riverine input in particular from the Mississippi River, and dynamics of open Gulf waters. The climate of south Texas is subtropical and dry, subhumid with an average yearly rainfall of 70 cm. Because of semiarid conditions, not only along the coast but landward for more than a hundred miles, no major streams flow to the Gulf of Mexico along the coast between Aransas Pass Inlet and the Rio Grande, 125 miles to the south. The general circulation of air near the Gulf surface over the south Texas coastal region follows the sweep of the western extension of the Bermuda high pressure system throughout the year. Relatively high surface water temperatures of the Gulf bring about a great warming and increase in moisture content of the overlying air masses. Water mass distribution in open Gulf waters result from the inflow through the Yucatan Channel, outflow through the Straits of Florida, surface conditions by local air-sea exchange processes and internal mixing of three well-defined water masses including Gulf basin water, a layer of Antarctic intermediate water, and a mid-Atlantic element. Thy hydrography is a mixture of these elements and is important as the basic setting for the resultant biological communities, which are a reflection of it.

In surface water layers from 10 to 100 m across the south Texas shelf there is a strong cross shelf temperature gradient during mid-winter that disappears with seasonal heating until the surface water is spatially isothermal at 29°C by late summer. The winter gradient produces lowest values of 14°C over the inner shelf and minimum values of 19 to 20°C over the outer shelf. Vertical stratification, nearly absent in shelf waters during the winter, is well-developed in the summer, being more prevalent with depth. Shelf salinities are high most of the year, except during a short period in spring and early summer, when a plume of Mississippi River water may cover the entire shelf, lowering salinities through the uppermost 20 to 30 m. There is suggestion of occasional upwelling of deep Gulf water at sites deeper than 100 m. An aspect of prime importance, particularly to the pelagic biological communities and the benthos, is the extreme variability of shallow waters and contrasting stability of deeper waters with both water temperature and salinity. At the shallower stations, salinity is almost totally influenced by local rainfall and riverine input. Also affecting shelf waters annually is a plume of Mississippi River water moving westward and southwestward along the northern rim of the Gulf of Mexico during spring and winter. This plume is especially pronounced along the coast but at times covers the entire shelf. The shelf is thus divided into three zones; 1) an inshore zone dominated by Texas riverine inputs, 2) a middle zone in which both Texas freshwater sources and the Mississippi River are influential with a gradation from one to the other with increased distance offshore, and 3) an offshore zone dominated by Mississippi River discharge.

The longshore current component of the northwestern Gulf circulation dominates for the majority of the year (October through March) toward the southwest and is responsible for advective transport of Mississippi River waters along the northwestern rim of the Gulf of Mexico at a time when discharge is the greatest. Between June and September the longshore component is weaker and reverses over short time scales to periodically produce perpendicular movements of water across the shelf. Nearshore surface currents are influenced by local prevailing winds. These water movements influence the transport of nutrients, heat, suspended solids, and planktonic life. The preceding description of hydrographic variables helps suggest some of the possible factors influencing the biotic components of the pelagic system.

Study of the pelagic biota shows that Texas shelf waters are extremely high in annual phytoplankton productivity. Primary production in inner-shelf waters is bimodal annually with peaks in spring and fall. There is a cross-shelf gradient of chlorophyll _a_ concentrations with a peak inshore and a steep drop to offshore. Although not as strong, there is also a north-south gradient for chlorophyll _a_ on the shelf. The northern part of the shelf is higher in chlorophyll _a_ at the surface and half the depth of the photic zone than the southern part. There is no north-south gradient of chlorophyll _a_ in the bottom waters, indicating a lack of mixing on the outer shelf. The higher concentrations of chlorophyll _a_ are often in the bottom waters, especially at shallow stations characterized by a pervasive nepheloid layer. In this layer, peak chlorophyll levels (primary producer biomass), adequate light transmittance, and evidence of nutrient regeneration leads to occurrence of photosynthesis in bottom waters.

The phytoplankton community is complex but relatively consistent and a reflection of different water masses on the shelf over annual cycles with temporal changes in community structure related to light intensity, day length, temperature, salinity, stratification, wind, and nutrient sources. Geographical trends in the phytoplankton are usually related to water depth or distance from shore with the highest abundances along the inner shelf. High spring phytoplankton numbers are correlated with riverine inputs and nutrient maxima.

Neuston, the biota living on or just beneath the surface film of marine water, varies considerably in abundance, either as total numbers or dry weight, as well as taxonomic composition. Part of the variability is a result of diel vertical migration; the remainder, a reflection of environmental heterogeneity. Cross-shelf variation in the distribution of some taxa, particularly the larval decapod crustaceans, occurs annually and is related to benthic distribution patterns of adults as well as estuarine influences. Neuston is significantly correlated with the amount of micro-tarballs. This relationship may be accounted for either from windrowing effects of surface water circulation or by the potential food source of epibiotic species associated with the well-weathered tarballs.

Zooplankton biomass and total density decrease with distance offshore. A few species, primarily female copepods, dominate the zooplankton density. There is considerable transect to transect variability suggesting the occurrence of pulsing inputs to the system which encourage zooplankton production but which are so limited that the entire length of the study area is not uniformly affected. The patchy distribution of zooplankton may be related to low salinity input from bay systems. Evidence for estuarine influence is the increased numbers of *Acartia tonsa*, a calanoid copepod abundant in bays and estuaries of the Gulf of Mexico in the spring when salinity is low at nearshore and mid-depth stations on the northern half of the study area. Salinity is related to several zooplankton variables at the shallow stations, but more frequently correlates with zooplankton variation at mid-depth stations. The implied relationships between zooplankton variables and salinity at the mid-depth stations may indirectly reflect a response of the zooplankton to changes in primary production which has been shown to be commonly associated with salinity changes in neritic waters. The direct relationship of zooplankton to phytoplankton at the deep stations reflects a close dependence of zooplankton on phytoplankton. The offshore zooplankton population may be controlled by food availability, while nearshore zooplankton populations may be controlled by predation.

The general feature of the sea bottom is a broad ramp-like indentation on the outer shelf between two ancestral deltaic bulges, the Colorado-Brazos in the north seaward of Matagorda Bay and the Rio Grande in the south. The sea floor is characterized by sand-sized sediments on the inner shelf which decrease in abundance seaward. Sand is transported seaward from the high energy zone of the innermost shelf. The encroachment of sand particles onto the Texas shelf from the north suggests a regional southward movement of sediment.

Within the study area at the deepest stations on all transects (106 to 134 m), sediments are characterized by silty (30%) clay of very uniform texture with occasional coarsening by winnowing of finest clays during the early spring. A slightly coarser, more variable silty clay is associated with stations in the northern three transects between 65 and 100 m water depth. These are transition stations between deeper clayey sediments and the silty sediments of between 36 and 49 m in the northern part of the study area, and farther landward (18 to 22 m in the northern half and

25 to 37 m in the southern half) are the most variable inner-shelf sandy muds. A similar group of stations with greater variability, at least partly because of coarse sand with some gravel, are located between 47 and 91 m on the Rio Grande delta. Two stations, 4/I and 1/IV, are characterized by moderately variable muddy sands near the barrier shoreface sand-offshore mud boundary, whereas two others, 4/III and 4/IV, are within the shoreface sands where variability is as low as the outermost stations due to efficiency of wave action constantly sorting the bottom sediments. At the inner-shelf stations, there is also a suggestion of seasonal coarsening in early spring with year-long coarsening that occurred in 1977, perhaps related to hurricane generated waves between spring and fall.

One of the major focuses of this multidisciplinary study was characterization of the subtidal benthic habitat. Unlike the water masses and associated biota which are in continual motion, the benthos is relatively stationary and thus serves as a barometer reflecting changes that occur in localized areas. Natural variations in the benthos occur in localized areas. Natural variation in the benthos and/or the transfer of materials through the community is important in understanding the essential links in the trophic dynamics of the Gulf of Mexico. The benthic community was studied by components determined categorically by taxa, size fraction, or relative position in the benthos and included microbiology, both fungal and bacterial; organisms living in the sediments, both the meiofauna (< 0.5 mm) and the macrofauna (> 0.5 mm); and those living above the sediments but closely associated with it, the invertebrate epifauna and the demersal fishes.

Marine fungi are present in benthic sediments with low numbers in the late winter significantly increasing through the year to fall. The abundance of fungi appears to be controlled by the replenishment of inoculum from the water column seasonally which in turn depends on deposition in the water column from continental air masses and by the availability of organic carbon locally. Fungi are short-lived in sediments where available carbon is a limiting factor. The pattern of increasing numbers is paralleled by an increase in numbers of taxa. Over 50% of the benthic fungi are capable of assimilating crude oil to overcome carbon limitations. Oil degradation potential decreases offshore. It is reasonable to presume at least some fungal oxidation of intrusive petroleum would occur in the area.

Marine aerobic heterotrophic bacteria are found in sediments in numbers from 4.6×10^4 to 1.3×10^6 per ml wet sediment. Highest numbers are present during spring and lowest during winter. Highest populations occur at the nearshore stations and decrease with depth offshore. Benthic bacteria appear to increase with the high input of organic carbon to the sediments during periods of peak productivity in the overlying water column in spring and decrease with lower sediment temperatures in winter. Hydrocarbon degrading bacteria are present in sediments throughout the area and are also more numerous nearshore with decreasing numbers offshore. They are significantly correlated with the total alkanes in the sediments. Benthic bacteria are capable of degrading all n-alkanes (C_{14} to C_{32}) but exhibit a preference for lower-molecular-weight hydrocarbons (C_{14} to C_{20}). Stimulation of total anaerobic heterotrophic bacteria and hydrocarbon degrading bacteria by the addition of crude oil to the sediment occurs at the majority of stations examined.

The meiofauna are those organisms smaller than 0.5 mm but larger than 0.1 mm. This is a somewhat arbitrary size definition to distinguish these small metazoans from the larger macrofauna of the benthos. Further delineation to exclude the young of the macrofauna and include only species which even at the adult stage fit into the stated size and fit certain taxonomic categories (*i.e.* the permanent meiobenthos) provides a more operational definition in terms of sampling methods and a natural grouping with certain biological characteristics. This definition differs from that of macrofauna in respect to reproductive capacity and general metabolism, as well as the ecological niche the meiofauna fill. Meiofaunal populations diminish with increasing depth on the Texas shelf. Consistently Transect IV supports the highest populations inshore and Transect II the lowest. Populations of the deepest station of Transect II are almost as great as those of the shallowest station. In contrast, for the other three transects, populations at the deepest stations are only a small percentage of those of the shallowest stations. Nematodes are the most abundant meiofaunal taxa, averaging 93% of the total abundance of the permanent meiofauna. There is a marked increase in nematodes when the sand content of the sediment is 60% or more by weight.

The macroinvertebrate infauna groups into stations similar to the groupings derived from sediment data. Community variables exhibit trends consistent with these groupings. The number of species is highest at shallow stations with a significant drop for the mid-depth group. Density is also greatest for the shallow sites with decreases in deeper waters on the shelf. These variables result in high species diversity measures for shallow stations. The highest diversity, however, is seen at the three stations on Transect IV mentioned earlier. The shallow stations are characterized by a few dominant fauna in contrast to the more evenly distributed populations offshore. Specific faunal assemblages describe the station groups. The species groups are represented by shallow water, mid-shelf, deep and ubiquitous fauna. Polychaetes are by far the dominant faunal group throughout the shelf.

Analysis of physical variables associated with the benthos station groups indicates that there are environmental differences between them. Water depth is the dominant variable accounting for benthic community groupings on the shelf. Additionally, the sediment properties of sand/mud ratio, sediment grain size deviation, and percent silt account for variation between station groups. Factors related to water depth, the degree of food availability to the benthos and bottom water variability along the depth gradient, must also be considered. Chlorophyll a concentrations are highest and also most variable in shallow waters where highest densities of infauna occur. Lower concentrations of primary producers with less variable abundances in the deeper stations are associated with lowered densities of infauna and more evenly distributed population numbers within these assemblages. Temperature and salinity are also most variable at shallower depths with decreasing variability with increasing water depth. The shallow benthic habitat is more variable and less predictable in terms of environmental change and thus conducive to dominance by a few fauna.

As with the macroinvertebrate infauna, depth is also the most apparent factor controlling epifaunal distributions. The shelf is divided into two major regions based on benthic epifaunal communities: 1) a shallow (10 to 45 m) zone with variable bottom water temperature (10 to 29°C) and salinity (30 to 37 ‰) and sandiest sediments; and 2) a deeper region (> 45 m) with more stable temperature (15 to 25°C) and salinity (35 to 37 ‰) and highest clay content. Subdivisions of these groups are intermediate to these depths and degrees of variability in benthic habitats. Many of the species characteristic of the shallow shelf are motile decapod crustaceans found in inlets, bays and coastal waters in summer and early fall. Large numbers of species with low abundance characterize the outer shelf assemblage.

The demersal fish populations also align with depth on the shelf into three distinct station groups with seasonal migration patterns influencing the species associations. The shallow shelf zone exhibits low species diversity throughout the year with especially high numbers of individuals in winter and spring. The nearshore faunal association dissipates during late summer or autumn when shallow shelf water temperatures are highest. Mid-depth associations are the most diverse and more stable throughout the year. There is considerable species "shuffling" during the year in all faunal zones suggesting that species-dominated communities do not persist. Analysis of physical variables associated with demersal fish populations indicate that sediment mean grain size, salinity, percent silt, sediment skewness, and sediment grain size deviation account for the environmental differences between the depth-related stations. The fish abundance data are substantially less effective in defining station groups than the physical variables.

The minimal presence of hydrocarbons in Texas shelf waters and sediments indicates that the area is relatively pristine with those hydrocarbons observed attributed primarily to natural sources. Natural sources include both primary production and bacterial production, in highly active water layers near the air-water interface, riverine and estuarine input, and sediment seepage. Low-molecular-weight hydrocarbons vary considerably both with season and area of the shelf; but higher surface-water methane values are apparent in the more northern, nearshore stations and are probably related to the direct influence of riverine and estuarine factors. A unique higher occurrence of deeper waters of Transect IV observed in this study is attributed to natural gas seepage across the mud-water interface. Other areas of high methane are associated with the bottom water nepheloid layer, especially in summer. Micro-tarball concentrations in neuston samples are higher on the two northern transects and may be related to ship traffic in Aransas Pass Inlet and other points in the northern Gulf and also to extensive petroleum activities in waters north of the area.

The lack of evidence for the presence of aromatic hydrocarbons in sediments suggests minimal petroleum pollution. Petroleum pollution in the form of micro-tarballs in the water column apparently does not contribute a sufficient quantity of petroleum hydrocarbons to the sediments. Concentrations of light hydrocarbons in the top few meters of shelf and slope sediments are highest nearshore decreasing offshore and are generally of microbial origin controlled by biological oxidation and diffusion into the overlying waters. One area of anomalously high ethane and propane at stations on Transect IV corresponds to the seepage observed in the water column samples and suggests an input of thermocatalytic gas from the subsurface.

Studies of the effects of low level and chronic inputs of petroleum in marine biota are complicated by lack of information on background levels of hydrocarbons in unpolluted environments, problems in differentiating petroleum compounds from biogenic hydrocarbons, and the effects of degradation of hydrocarbons, sediment absorption, interstitial water hydrocarbons, and hydrocarbon assimilation in food uptake. Approximately 50% of the zooplankton hydrocarbon samples in 1977 showed the possible presence of petroleum-like matter. This was slightly more than observed in 1976 (30%) and considerably higher than 1975 (7%). These values are higher than similar values obtained for particulate hydrocarbons in the water column, suggesting that the majority of hydrocarbons in the zooplankton are not synthesized by them or by higher plants. The higher zooplankton values could be a reflection of bioaccumulation and tendencies of zooplankton to concentrate pelagic particulate matter during their feeding activities. Zooplankton will ingest micro-tarballs and other petroleum forms from the water column and pass them through their systems without digesting them. The increase of zooplankton hydrocarbons through the three years may be a reflection of the increased crude oils importation during this time.

The heavy hydrocarbon analysis of macroinvertebrate epifauna and demersal fishes indicates little, if any, petroleum contamination of the area. No significant spatial trends and few seasonal trends suggest relative stability in the hydrocarbon pools of the organisms studied. The studies did delineate an excellent data base of background information on indicator organisms for use in future monitoring.

The south Texas shelf appears to be free of any significant trace metal contamination in respect to those metals monitored. Trace metal pollution has been found in coastal, industrialized waterways of the area, but there is no evidence of large scale offshore transport of these contaminants to the outer continental shelf and thus little contamination of shelf sediments. The only meaningful spatial relationship is an increase in cadmium levels offshore, which is influenced in some way by the amount of suspended particulate matter in the water column. Aluminum and iron levels in zooplankton decrease with increasing distance offshore and also correspond well with observed seasonal fluctuations in suspended matter concentrations in surface waters. The levels of several trace metals in benthic biota are at or below detection levels, and even for metals present in detectable amounts there are no significant geographical trends. Seasonal patterns of aluminum levels in demersal fish are similar to those of the zooplankton and are a reflection of the more variable nearshore environment characterized by seasonal fluctuations in suspended aluminosilicate particulate matter.

CHAPTER ONE

INTRODUCTION

The chemical, physical, and biological interactions both internal and external to the world's oceans are among the most complex within the natural sciences. If the aspects and processes of these various interactions were understood, their scope and magnitude could be predicted for a given time and place. There are, however, many unknowns that must still be quantified.

The Texas coastal area is biologically and chemically a two part marine system, the coastal estuaries and the broad continental shelf. These two components are separated by a chain of barrier islands and connected by inlets or passes. The area is rich in finfish and crustaceans, many of which are commercially and recreationally important. Many of the finfish and decapod crustaceans of this area exhibit a marine-estuarine dependent life cycle, *i.e.* spawning offshore, migrating shoreward as larvae and postlarvae, and utilizing the estuaries as nursery grounds (Gunter, 1945; Galtsoff, 1954; Copeland, 1965). The broad continental shelf supports a valuable shrimp fishery which, as a living resource, contributes significantly to the local economy. Although an excellent overview of the zoogeography of the northwestern Gulf of Mexico is provided by Hedgpeth (1953), there are still many unknowns concerning the functioning of this complex marine system.

In 1974, the Bureau of Land Management (BLM) as the administrative agency responsible for leasing submerged federal lands, was authorized to initiate a National Outer Continental Shelf (OCS) Environmental Studies Program. As part of this national program, the BLM developed the Marine Environmental Study Plan for the South Texas Outer Continental Shelf (STOCS) to add to our understanding of this ecosystem. This plan was developed to meet the following four specific study objectives:

1) provide information for predicting the effects of OCS oil and gas development activities upon the components of the ecosystem;
2) provide a description of the physical, chemical, geological, and biological components, and their interactions, against which subsequent changes or impacts could be compared;
3) identify critical parameters that should be incorporated into a monitoring program; and,
4) identify and conduct experimental and problem-oriented studies as required to meet the basic objectives.

BLM contracted the University of Texas at Austin to act for and on behalf of a consortium program of research conducted by Rice University, Texas A&M University, and the University of Texas, to implement the Environmental Study Plan. This plan called for an intensive multidisciplinary three-year study (1975-1977) to characterize the temporal and spatial variation of the shelf marine ecosystem beyond 10 m water depth.

In addition to the biological, physical, and chemical components of this program which will be reported here, two other major field programs are conducted concurrently. The U. S. Geological Survey conducted a program designed to investigate suspended sediment flux, normal and storm transport and deposition of sediments, and sediment geochemistry in the STOCS area. The National Oceanic and Atmospheric Administration/National Marine Fisheries Service conducted studies to investigate the historical distribution and abundance of ichthyoplankton in the area, to elucidate the snapper and grouper fisheries resources, and to determine the magnitude and economic significance of the recreational and associated "commercial/ recreational" fisheries in the area. In addition to the above studies restricted to the STOCS study area, Texas A&M University conducted a major field survey of the biological and chemical characteristics of selected topographic features in the northwestern Gulf.

An ecosystem is defined as "any area of nature that includes living organisms and non-living substances interacting to produce an exchange of material between the parts" (Odum, 1959). The central theme of the STOCS study was to provide an understanding of the living and non-living resources of the shelf. In order to approach the objectives outlined above a broad program was designed which included:

a) water mass characterization;
b) pelagic primary and secondary productivity as described by floral and faunal abundances, standing crop, and nutrient levels;
c) sediment texture characterization;
d) benthic productivity as described by infaunal and epifaunal densities;
e) natural petroleum hydrocarbon levels in biota, water and sediment; and,
f) natural trace metal levels in biota and particulate matter.

The final year (1978-1979) of this study was devoted to the data synthesis and integration of the three previous years of sample collection and variable measurement. The goals of this synthesis and integration phase were two-fold:

1. Develop a physical, chemical and biological description of the STOCS ecosystem characterizing with confidence (95%) the temporal and spatial properties of those parameters that best represented the ecosystem between 1975 and 1977.
2. Develop mathematical descriptions for a few unique relationships defined by the data that will serve as "fingerprints" for future comparison by managerial decision makers and contribute information to the general conceptual model.

It was assumed that understanding the naturally inherent variability of this ecosystem would contribute immensely to evaluating potential impact to the environment from perturbations resulting from oil and gas exploration and production.

Using statistical techniques it was believed that we could integrate the data base to the extent that an initial understanding of a typical marine ecosystem similar to the one depicted in Figure 1 could be documented. As shall be illustrated in the following chapters, in some cases we were relatively successful in developing an understanding concerning parts of this overall conceptual model while in other cases, because of lack of sufficient information either within the data base or the supporting literature, we were not able to add detail to this model.

The reporting of the data synthesis and integration efforts for the STOCS Environmental Studies Program takes three forms. This volume

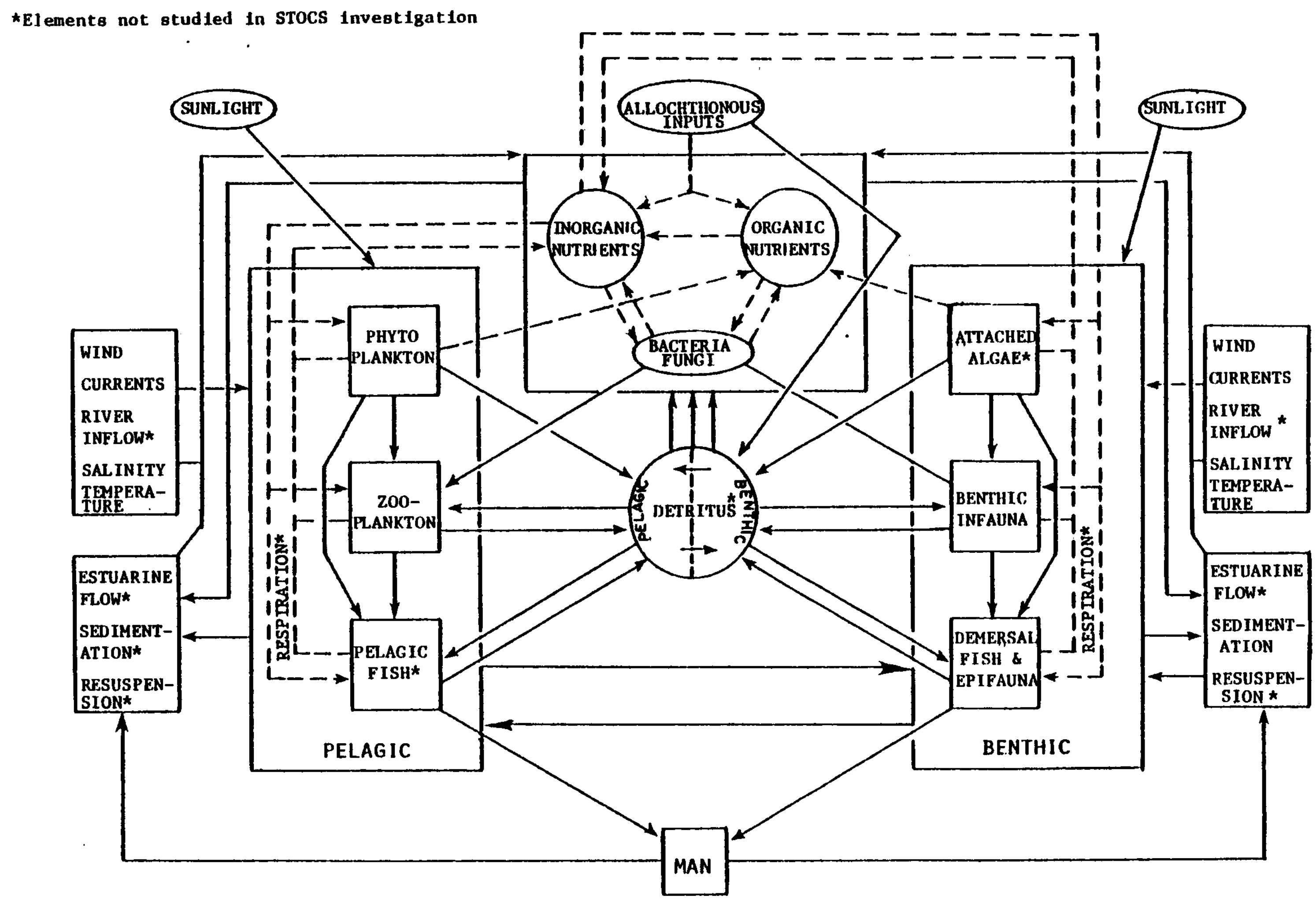

Figure 1. Ecosystem conceptual model of the south Texas continental shelf.

(Volume I) is devoted to the program description and history along with a presentation integrating all study element results into a characterization of the STOCS ecosystem. Within the STOCS ecosystem there are many interrelated physical, chemical, and biological processes. In this volume some of these important factors are described and a conceptual model illustrating the manner in which they interact is developed. Also included in this volume as Appendices A and B is a listing with statistics of all important study variables as identified either by the scientists in the study or by distinguishing spatial-temporal trends. The purpose of these appendices is to provide decision makers and environmentalists assigned to the task of future monitoring with a quick reference concerning certain ecosystem variables along with their general statistical patterns.

The second volume in this series (Volume II) is devoted to the data management of the program and includes a description of data file maintenance and archiving as well as the analysis strategies employed in the STOCS synthesis and integration effort. Volume III contains the individual scientific investigator's reports for the respective study elements detailed during data synthesis and integration. The reader is referred to these reports for more detail concerning any specific aspects of the ecosystem description contained in Volume I.

Acknowledgment is given to all the scientists involved in this multidisciplinary program and the contributions they provided in developing Volume I of this report. For further reference concerning their specific contributions, besides Volume III of the present report, see Parker (1976), Berryhill (1977), Groover (1977a), Griffin (1979), and Flint and Griffin (1979).

Study Area

The general area of study corresponds to that portion of the Gulf of Mexico off the Texas coast designated by the Department of the Interior for future oil and gas leasing (Figure 2). The area covers approximately 19,250 km^2 and is bounded by 96°W longitude on the east, the Matagorda Bay complex on the north, the Texas coastline on the west, and the Mexico-United States international border on the south. The Texas continental shelf has an average width of 88.5 km and a relatively gentle seaward gradient that averages 2.3 m/km.

No ecosystem is a completely self-contained unit, and the STOCS system is no exception. It is influenced by adjoining regions such as the open Gulf of Mexico, the Mississippi River to the northeast, the Rio Grande to the south, and the land masses to the west. These adjacent regions have a marked influence on the climate and are the sources of many inputs into the system. Although we can look at the region as a somewhat discrete unit, we must continually keep in mind the influence of these contiguous territories.

During the first year of study (1975) 12 sites corresponding to Stations 1-3 on four transects (Figure 3) were sampled. Thirteen (13) additional transect sites were sampled during the second and third year of study which included Stations 4-6 of Transects I - III and Stations 4-7 on Transect IV (Figure 3)[1]. These additional stations were added to increase shelf coverage of three special areas: 1) the shallow shelf environment (about 15 m depth) and its associated sandy sediments; 2) a zone in the middle of the study area that appeared anomalous in sediment

[1]For hydrographic studies a seventh station was included on Transect II.

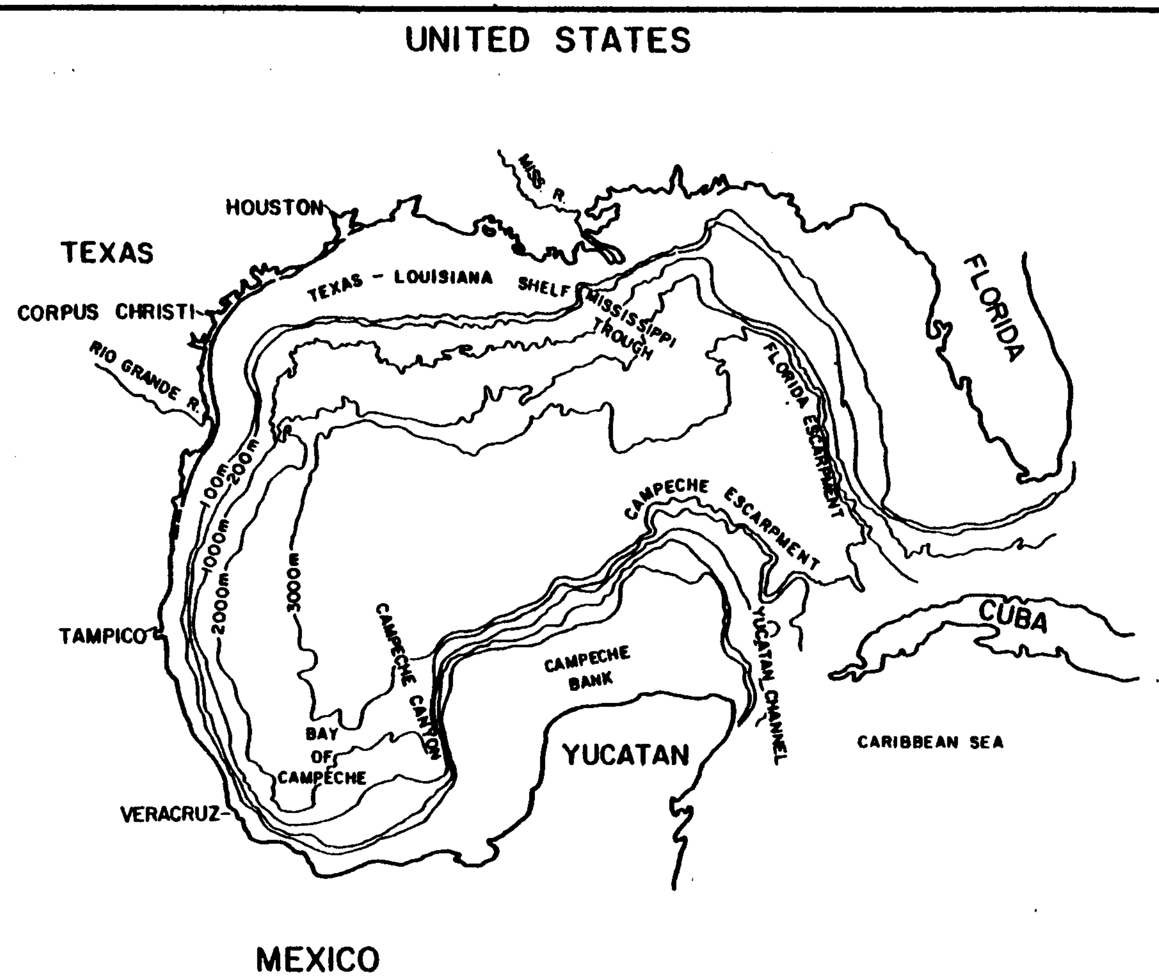

Figure 2. Bathymetric map of the Gulf of Mexico.

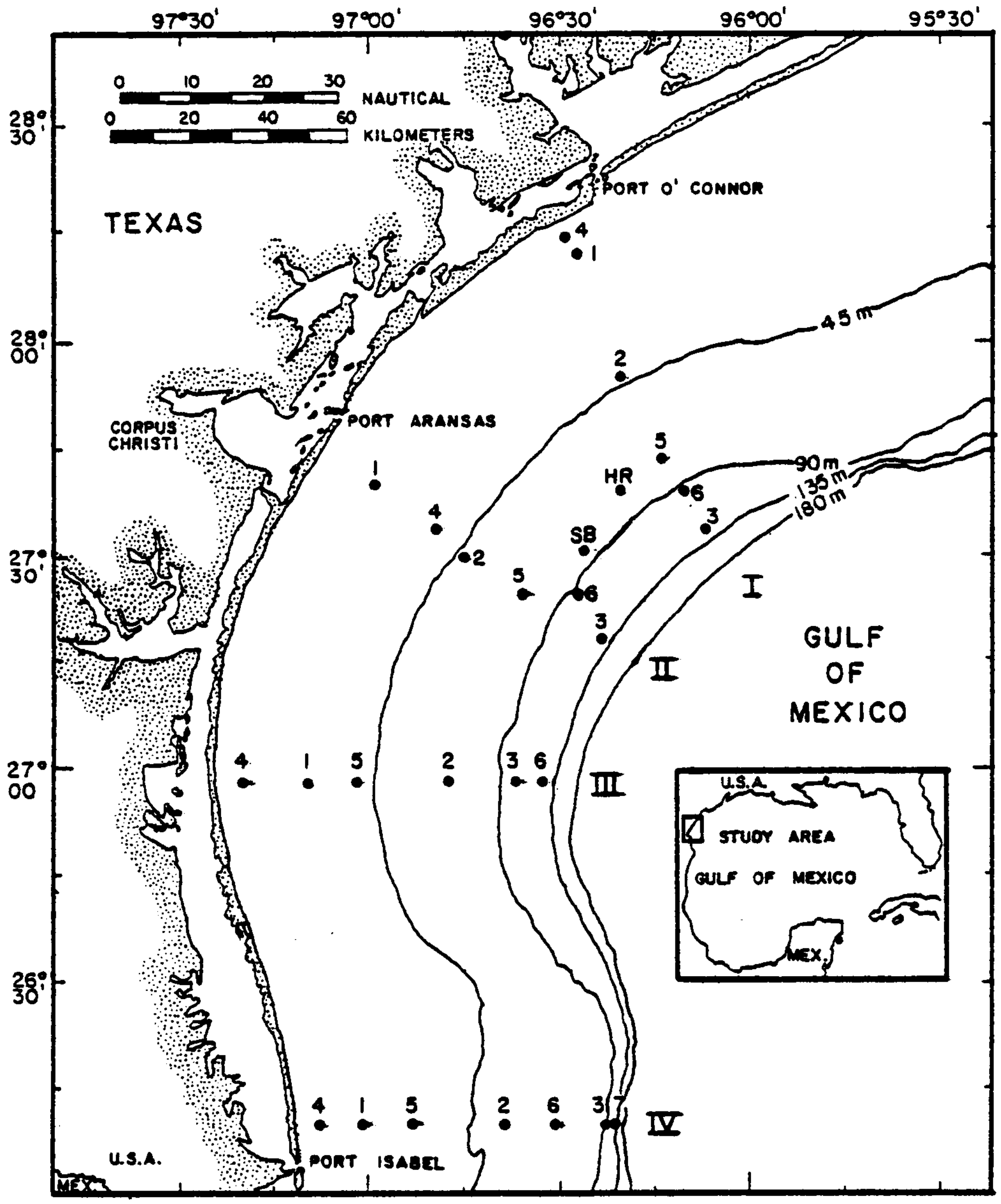

Figure 3. Map showing the south Texas continental shelf bathymetry and location of sampling sites. Insert shows location of study area in respect to entire Gulf of Mexico.

characteristics, sediment trace metal content and distributions of certain biological populations; and 3) a zone of active gas seepage near the shelf-slope break. In addition to the transect stations, four stations on each of the two submarine carbonate reefs, Hospital Rock (HR) and Southern Bank (SB) were sampled in 1976 (Figure 3). Collections were decreased to two stations at each reef in 1977. Table 1 lists the LORAN and LORAC coordinates, latitude, longitude, and depth of each site sampled during the three year study.

Program Description

The field investigations for the first year of the study began in early December 1974, and were completed by mid-October 1975. Laboratory analyses were completed by January 30, 1976. The final report for the chemical and biological component of the 1975 study was submitted to BLM in July 1976, and the final integrated report of all components of the STOCS study was submitted to BLM in April 1977.

Samples were collected for the first year of study (1975) during three biological-meteorological seasons from Stations 1-3 of all transects. The three seasons were winter (December-February), Spring (April-May), and Fall (September-October). For more exact cruise dates see Parker (1976).

The field sampling for the second year of study was initiated in mid-January 1976, and was completed in mid-December 1976. Laboratory analyses were completed by February 1977. The final report for the chemical and biological components of the 1976 study was submitted to BLM in April 1978.

Samples were collected in 1976 during three biological-meteorological seasons from all transects and the bank stations. The three seasons were Winter (January-February), Spring (May-June), and Fall (September-October). In addition to the seasonal sampling, Transect II and the bank stations were sampled in the six months (March, April, July, August, November and December)

TABLE 1

BLM STOCS MONITORING STUDY STATION LOCATIONS

TRAN.	STA.	LORAN		LORAC		LATITUDE	LONGITUDE	DEPTH	
		3H3	3H2	LG	LR			METERS	FEET
I	1	2575	4003	1180.07	171.46	28°12'N	96°27'W	18	59
	2	2440	3950	961.49	275.71	27°55'N	96°20'W	42	138
	3	2300	3863	799.45	466.07	27°34'N	96°07'W	134	439
	4	2583	4015	1206.53	157.92	28°14'N	96°29'W	10	33
	5	2360	3910	861.09	369.08	27°44'N	96°14'W	82	269
	6	2330	3892	819.72	412.96	27°39'N	96°12'W	100	328
II	1	2078	3962	373.62	192.04	27°40'N	96°59'W	22	72
	2	2050	3918	454.46	382.00	27°30'N	96°45'W	49	161
	3	2040	3850	564.67	585.52	27°18'N	96°23'W	131	430
	4	2058	3936	431.26	310.30	27°34'N	96°50'W	36	112
	5	2032	3992	498.85	487.62	27°24'N	96°36'W	78	256
	6	2068	3878	560.54	506.34	27°24'N	96°29'W	98	322
	7	2045	3835			27°15'N	96°18.5'W	182	600
III	1	1585	3880	139.13	909.98	26°58'N	97°11'W	25	82
	2	1683	3841	286.38	855.91	26°58'N	96°48'W	65	213
	3	1775	3812	391.06	829.02	26°58'N	96°33'W	106	348
	4	1552	3885	95.64	928.13	26°58'N	97°20'W	15	49
	5	1623	3867	192.19	888.06	26°58'N	97°02'W	40	131
	6	1790	3808	411.48	824.57	26°58'N	96°30'W	125	410
IV	1	1130	3747	187.50	1423.50	26°10'N	97°01'W	27	88
	2	1300	3700	271.99	1310.61	26°10'N	96°39'W	47	154
	3	1425	3663	333.77	1241.34	26°10'N	96°24'W	91	298
	4	1073	3763	163.42	1456.90	26°10'N	97°08'W	15	49
	5	1170	3738	213.13	1387.45	26°10'N	96°54'W	37	121
	6	1355	3685	304.76	1272.48	26°10'N	96°31'W	65	213
	7	1448	3659	350.37	1224.51	26°10'N	96°20'W	130	426
HR	1	2159	3900	635.06	422.83	27°32'05"	96°28'19"	75	246
	2	2169	3902	644.54	416.95	27°32'46"	96°27'25"	72	237
	3	2163	3900	641.60	425.10	27°32'05"	96°27'35"	81	266
	4	2165	3905	638.40	411.18	27°33'02"	96°29'03"	76	250
SB	1	2086	3889	563.00	468.28	27°26'49"	96°31'18"	81	266
	2	2081	3889	560.95	475.80	27°26'14"	96°31'02"	82	269
	3	2074	3890	552.92	475.15	27°26'06"	96°31'47"	82	269
	4	2078	3890	551.12	472.73	27°26'14"	96°32'07"	82	269

not included in the three seasonal sampling periods. For more exact cruise dates see Groover (1977a).

Based on the initial results from 1976 it was determined both by BLM and the scientists that additional information was needed in certain study elements to meet the objectives of the investigation. Consequently, several supplemental studies were initiated in September 1977 and completed in November 1978. The results of these studies were reported to BLM in January 1979 (Griffin, 1979). In addition to these, a separate rig monitoring study was also initiated in late 1976. The objectives of this study, which included characterizing the effects of drilling muds, cuttings, and other disposals associated with exploratory drilling, was met by pre-, during-, and post-drilling surveys of the sediments, organisms and water in the immediate vicinity of an exploratory drilling rig (Groover, 1977b).

The field sampling for the third and final year of study was initiated in mid-January 1977 and was completed in mid-December 1977. Laboratoy analyses were completed by June 15, 1978. The results of these studies were reported to BLM in February 1979.

Samples were collected in 1977 during three biological-meteorological seasons from all transects and four of the bank stations. The three seasons were Winter (January-February), Spring (May-June), and Fall (September-October). In addition to the seasonal samplings, some of the study elements sampled Transect II during the six months (March, April, July, August, November, and December) not included in the three seasonal sampling periods. For more exact cruise dates see Flint and Griffin (1979).

All sample collections and measurements, except the placement and recovery of current meters, were taken aboard the University of Texas research vessel, the R/V LONGHORN. The R/V LONGHORN, designed and constructed as a coastal research vessel in 1971, is a steel-hulled 24.38 m (80 ft) by 7.42 m (24 ft), 2.13 m (7 ft) draft ship. She carries a crew of five and can accommodate a scientific party of ten. The R/V Longhorn is equipped with a stern-mounted crane, a trawling winch, side-scan sonar, radar, LORAN-A and LORAC navigational systems, and dry and wet laboratory space. Navigation and station location for water column cruises were by LORAN-A. Navigation and station location for benthic cruises were by LORAC navigational systems.

The University of Texas Marine Science Institute, Port Aransas Marine Laboratory (UTMSI/PAML) was contracted by BLM to provide overall project management, logistics, ship time, data management and certain scientific efforts. Additional scientific effort was provided by subcontracts between the University of Texas and Texas A&M University, The University of Texas at San Antonio, The University of Texas at Austin, and Rice University.

A total of 28 principal investigators participated in the three year sampling program. Table 2 lists the principal investigators with their respective institutions and scientific responsibilities. For the final year of the program, the data synthesis and integration effort, the emphasis by BLM was placed on fewer study elements than the 20 listed in Table 2. The specific study areas and variables considered in the synthesis and integration effort are listed in Table 3. It was anticipated that the analysis design developed would provide knowledge of the various living and non-living components in sufficient detail to begin to understand their relationships and enhance our ability to anticipate changes resulting from potential pollution of the STOCS ecosystem. Complete descriptions of sampling methods and laboratory analyses are included in each work element report in Volume III.

Program Management

During the field sampling phases of the STOCS environmental studies program, the program management staff consisted of a program manager, technical

TABLE 2

STOCS BIOLOGICAL, CHEMICAL AND PHYSICAL COMPONENT PARTICIPANTS BY WORK ELEMENT AND INSTITUTION

Rice University	
Microplankton and Shelled Microzoobenthon	R. E. Casey
Texas A&M University	
HMW Hydrocarbons in Macroepifauna, Demersal Fish and Macronekton	C. S. Giam, H. S. Chan, G. Neff
Trace Metals in Macroepifauna, Demersal Fish, Macronekton and Plankton	B. J. Presley, P. N. Boothe
LMW Hydrocarbons, Nutrients and Dissolved Oxygen	W. M. Sackett, J. M. Brooks, B. B. Bernard
Zooplankton	E. T. Park, P. Turk
Neuston	J. H. Wormuth, L. Pequegnat, J. McEachran
Meiofauna	W. E. Pequegnat, C. Venn
Histopathology of Macroepifauna	J. M. Neff, Valerie Ernst
Histopathology of Demersal Fishes	W. E. Haensly, Joann Eurell
Benthic Bacteriology	J. R. Schwarz, S. K. Alexander
University of Texas	
Austin:	
Water Column and Benthic Mycology	P. J. Szaniszlo, P. Powell
Marine Science Institute/Galveston Geophysical Laboratory:	
Sediment Texture	E. W. Behrens
Marine Science Institute/Port Aransas Marine Laboratory:	
Ciliated Protozoa	P. L. Johansen
Hydrography	N. P. Smith
HMW Hydrocarbons in Zooplankton, Sediment, Water	P. L. Parker, R. S. Scalan, J. K. Winters
Phytoplankton and Productivity	C. Van Baalen, D. L. Kamykowski, W. Pulich
Macroinfauna and Macroepifauna	J. S. Holland
Demersal Fishes	D. E. Wohlschlag, R. Yoshiyama
San Antonio:	
Histopathology: Gonadal Tissues of Macroepifauna and Demersal Fish	S. A. Ramirez
Water Column Bacteriology	M. N. Guentzel, H. V. Oujesky, O. W. Van Auken

TABLE 3

LIST OF STUDY AREAS AND ENVIRONMENTAL VARIABLES FOCUSED UPON DURING THE DATA SYNTHESIS AND INTEGRATION ASPECT OF THE SOUTH TEXAS OUTER CONTINENTAL SHELF PROGRAM

	Study Area	Variables
PELAGIC NON-LIVING CHARACTERISTICS	Hydrography	Temperature Salinity Depth Currents Secchi Depth Transmission
	Nutrients	Silicate Phosphate Nitrate Dissolved Oxygen
	Hydrocarbons Low-Molecular-Weight (LMW)	Methane Ethane Ethene Propene Propane
	High-Molecular-Weight (HMW)	Hexane or Benzene Fractions Retention Index w/concentrations
PELAGIC LIVING CHARACTERISTICS	Phytoplankton	Species Densities Chlorophyll (biomass) C^{14} Productivity ATP
	Microbiology (Bacteriology & Mycology)	Species Abundances Total Counts and Hydrocarbonoclastic counts
	Neuston	Species Densities Tar Ball Concentrations
	Zooplankton (Micro & Macro)	Species Densities Sample Biomass Trace Metal Body Burden HMW Hydrocarbon Body Burden
BENTHIC NON-LIVING CHARACTERISTICS	Sediment Texture	Mean Grain Size Percent Sand Percent Silt Percent Clay
	Sediment Chemistry	Organic Carbon Delta C^{13} Ethene Ethane Propene Propane Methane HMW Hydrocarbons Hexane or Benzene Fractions Retention Index w/concentrations
BENTHIC LIVING CHARACTERISTICS	Microbiology (Bacteriology & Mycology)	Species Abundances Total Counts and Hydrocarbonoclastic counts
	Meiofauna	Species Densities
	Macroinfauna	Species Densities
	Invertebrate Macroepifauna	Species Densities Trace Metal Body Burdens HMW Hydrocarbon Body Burdens Tissue Histopathology
	Demersal Fish	Species Densities Biomass Trace Metal Body Burdens HMW Hydrocarbon Body Burdens Tissue Histopathology

coordinator, data manager, program secretary, marine technician, draftsperson and ancillary data management personnel. The primary responsibilities of the program manager and staff included overall program administration, logistical coordination for field sampling, sample transmittals, lab analyses, data management, and preparation of required reports.

Meetings were held quarterly at which all principal investigators for the biological and chemical components and element leaders of other STOCS projects presented a summary of significant findings and progress reports. Following each quarterly conference a Quarterly Summary Report was submitted to BLM. To insure communication, coordination and unity of effort, an Administrative Council [consisting of the program manager, technical coordinator, data manager, the project element coordinators of other STOCS projects and the Contracting Officer's Authorized Representative (COAR)] met prior to each quarterly conference.

For the data synthesis and integration phase of the STOCS environmental studies program more emphasis was placed on the management structure to enhance the coordination required in combining the various study elements into a comprehensive description of the ecosystem. Two workshops were conducted during the period of synthesis and integration in order to follow progress of the various study elements in data analysis and plan future analysis needs of the principal investigators. Bimonthly letter reports were submitted to BLM to provide them with information on integration progress.

As indicated previously, a complete treatment of the data management component of the synthesis and integration effort is presented in Volume II. For information concerning sample quality control and archiving, the reader is referred to the annual final reports including Parker (1976), Groover (1977a), and Flint and Griffin (1979).

CHAPTER TWO

MARINE PELAGIC ENVIRONMENT OF THE SOUTH TEXAS SHELF

with contributions by:

N. P. Smith
Harbor Branch Foundation, Fort Pierce, Florida

D. L. Kamykowski
P. L. Parker
R. S. Scalan
J. K. Winters
University of Texas Marine Science Institute, Port Aransas, Texas

J. M. Brooks
Texas A&M University, College Station, Texas

Marine Meteorology

Patterns and trends in the marine environment of the northwestern Gulf of Mexico are strongly influenced by various kinds of meteorological events. Water levels along the coast change noticeably with changes in wind speed and direction. Typical circumstances for these water level changes are associated with hurricanes and the quick changes in wind directions associated with winter high pressure waves, "northers". The stress of the wind acting upon the sea surface at times other than hurricanes and "northers", however, may also be sufficient to bring about water level changes of the same magnitude as those resulting from a periodic tide-producing force. This leads to considerable deviation of the observed water level changes published in tide manuals and helps to explain the extremely unpredictable nature of water level changes along the Gulf coast.

In turn, numerous characteristics of the Gulf surface waters influence many of the weather patterns observed in the northwestern Gulf of Mexico. On a large scale, for example, the relatively high temperature of Gulf surface waters, compared to those of other waters in the same latitudes, brings about such a great warming and increase in the moisture content of the overlying air masses that weather patterns of the northwestern Gulf are markedly affected. A discussion of the extent to which the sea surface affects the overlying atmosphere is given by Jacobs (1951). He computes the average winter evaporation in the Gulf to be approximately 0.4 $g/cm^2/day$ and compares this with other ocean areas of the world. Therefore, as one would expect, there is a strong coupling between the atmospheric conditions and the sea surface conditions in the Gulf of Mexico that serve as driving forces affecting many of the dynamics of the marine environment discussed later.

The climate of south Texas is subtropical and is characterized by short, mild winters and hot summers. Significant variations in this trend do occur from north to south along the coastline. The climate of the coastal plain from the Texas-Louisiana border to Corpus Christi can be characterized as subhumid, with the area from Matagorda Bay to Corpus Christi considered more dry, subhumid than the area from the Texas-Louisiana border to Matagorda Bay (Hedgpeth, 1953). Rainfall along the Texas coast averages 25 to 125 cm/yr and decreases significantly closer to Corpus Christi. Compared to an average of 106.2 cm/yr of rainfall at Galveston, Corpus Christi receives an average of 71.9 cm/yr. Rivers in this area are small and contribute much less freshwater to the estuaries than those farther north. Air temperatures in the south Texas area are higher in the summer than along the Louisiana coast and in the winter this area may have the lowest temperatures observed for the entire Gulf coast (Parker, 1960). In this dry, subhumid portion of the coast, estuaries and lagoons commonly vary from medium to high salinities as heavy rainfall increases riverine input, or as evaporation exceeds runoff for extensive time periods.

In contrast, the coastal zone from Corpus Christi to the mouth of the Rio Grande River is classed as semiarid. No permanent rivers flow into the lagoons and estuaries resulting in hypersalinity on a permanent basis. Rainfall is frequently less than 30 to 70 cm/yr and summer air temperatures can exceed 42°C. In comparison to Corpus Christi, Brownsville receives an average rainfall of 67.9 cm/yr.

Average sea level atmospheric pressures in the Gulf of Mexico vary from 76.2 to 79.1 cm Hg. There are wide deviations from these pressures in individual synoptic circumstances such as during the development of tropical storms. Superimposed upon these general annual patterns are diel pressure variations.

During a typical 24-h period there is a lesser early morning minimum in atmospheric pressure followed by a greater late morning maximum, an evening minimum and a lesser nocturnal maximum (Leipper, 1954). The average winds vary from 6 to 8 knots in the summer, with stronger more variable winds from 10 to 12 knots in the winter. Fog is most frequent in mid-winter and occurs most often in the north central part of the Gulf. For the annual period, the average cloud cover over the northwestern Gulf of Mexico ranges from 40 to 60% of the sky obscured. The most commonly reported low type clouds are cumulus (Leipper, 1954).

The general circulation of air near the Gulf surface over the south Texas coastal region follows the sweep of the western extension of the Bermuda high pressure system throughout the year. The Bermuda pressure system becomes dominant during the spring months, as the influence of northern anticyclones (low pressure areas) causing northerly fronts disappears. Mean barometric pressure falls with a minimum mean pressure occurring in the summer as the equatorial trough migrates northward, allowing prevailing southeasterly winds to dominate. At this point the low pressure systems over Mexico deepen significantly.

Beginning in September, the equatorial trough moves southward, the Mexican low pressure system fills, and the Bermuda high pressure system decreases in strength. Accompanying this trend, continental high pressure systems to the north intensify as winter approaches. As barriers weaken to the south, the high pressure systems moving from the north reach the lower latitudes and produce maximum barometric pressures in the winter. The result of these conditions is an increase in the frequency of "northers" over the south Texas coast. The high pressure systems and their associated extratropical cyclones are responsible for the wide pressure ranges observed in winter (Berryhill, 1977).

Air temperature extremes for the south Texas area are influenced primarily by the combined effects of prevailing southeasterly winds and the large expanse of Gulf waters. Low temperatures occur when strong northerly winds associated with cold fronts penetrate the area. Freezing temperatures normally occur in coastal areas at least once each winter. The highest summer temperatures occur when the wind direction shifts from the prevailing southeast to south and southwest.

As mentioned previously, south Texas is semiarid. Peak precipitation months are May and September. Tropical cyclones may add large amounts to the monthly rainfall totals for the period of June to October and may cause normally higher saline bays to freshen drastically in a period of a few hours. Winter months have the least rainfall. Winter precipitation comes mainly from frontal activity and low stratus clouds. Because of the semiarid conditions, not only along the coast but landward for more than a hundred miles, no major streams flow to the Gulf of Mexico along the south Texas coast between Port Aransas and the Rio Grande, 135 miles to the south. This factor has a direct influence on the pattern of marine processes on the south Texas shelf.

Compared to the adjacent land area, offshore winter temperatures are higher and average wind velocities are greater. Offshore summer conditions are more similar to the onshore climate, but with some diurnal differences: the daily temperature range is smaller and the afternoon wind speed maximum is less pronounced offshore than at stations along the coast. The offshore area, unlike the coastal area, does not exhibit a season of extensive rainfall. Rain is most frequent in December and January with a secondary peak in August and September related to tropical storms and depressions. Based on rain frequency, the driest season in the offshore area is March-June with an average of less than three percent of ship's weather observations reporting rain. When rainfall was reported in the cruise reports, it was most frequently reported for mid-afternoon.

Physical Oceanography

Hydrographic features illustrate the annual progression that can occur over a shelf area such as the south Texas Gulf of Mexico. These descriptions can also provide insight concerning possible factors that influence the functioning of the ecosystem. Taken together, a number of previous studies including Jones *et al.* (1965), Rivas (1968), Armstrong (1976) and Devine (1976) provide a good overview of the hydrographic conditions of Texas shelf waters.

In the surface layer, strong cross-shelf temperature gradients during the mid-winter months disappear with seasonal heating, and surface water becomes spatially isothermal at approximately 29°C by late summer. Vertical stratification, on the other hand, is nearly absent in shelf waters during the winter months, but it is well developed in summer. Shelf salinities remain relatively high for most of the year. An exception is a short period during spring and early summer, when a plume of Mississippi River water may cover the entire shelf, lowering salinities through the uppermost 20 to 30 m.

In the open waters of the Gulf of Mexico, water mass distributions are the result of inflow through the Yucatan Channel, outflow through the Straits of Florida, surface conditioning by local air-sea exchange processes, and internal mixing. Together, these produce three well-defined water masses in layers below the surface mixed layer. The sill depth of approximately 2000 m between the Yucatan Peninsula of Mexico and the western tip of Cuba exerts a dynamically significant influence on the temperature and salinity distribution in open Gulf waters. Below the sill depth, both temperature and salinity are characterized by spatial homogeneity, due to the isolation from the deep to bottom water found in the Atlantic Ocean and the Caribbean Sea. Gulf basin water, found below the effective sill depth of approximately 1,500 m, is characterized by potential temperatures between approximately 4.2 and 4.4°C, and salinities between 34.96 and 34.98 parts per thousand (ppt).

Above the Gulf basin water, salinities decrease to a minimum of approximately 34.86 ppt between depths of 900 to 1,100 m. This salinity minimum reflects the influence of Antarctic intermediate water, which can be traced back through the Caribbean Sea, across the tropical Atlantic Ocean and into high southern latitudes to a source at the Atlantic Polar Front at 45-50° south latitude.

Both temperature and salinity increase with decreasing depth above the layer of Antarctic intermediate water. A maximum in salinity is characteristically found between approximately 100 and 300 m. This feature can also be traced back through the Caribbean Sea and upstream along the subtropical undercurrent to a source under the semi-permanent high pressure center in the Atlantic Ocean east of Bermuda (Wüst, 1964; Nowlin, 1971). Salinities are generally between 36.2 and 36.7 ppt while temperatures characteristic of this layer vary between about 18 and 26°C in open Gulf waters.

The surface mixed layer lies atop the three distinct water masses discussed above. Because of the direct contact between this layer and the overlying atmosphere, it is relatively quickly modified, or conditioned, by conductive, evaporative and radiative processes. Thus, the shelf waters exhibit not only a well defined annual cycle, but also substantial variability over shorter time scales.

Temperatures characteristic of the mixed layer over the inner Texas shelf range from approximately 11 to 13°C in late winter to 28 to 29°C in late summer. Salinity variations in nearshore waters are also variable, ranging from open Gulf surface values of about 36.4 to 20 ppt or less during the spring run-off or periods of heavy rainfall.

The extensive study and observation of south Texas shelf waters for three years has provided additional information that supports many of the above patterns. In addition, many of the observations have significantly refined our understanding of the physical dynamics of the complex Texas shelf waters. A good hydrographic summary of these waters can be obtained by examining time-depth plots of temperature and salinity for a shallow and deep station on the shelf (Figure 4). At the deeper station salinity varies minimally with the exception of lower surface salinities in the spring of the year. Temperatures indicate a greater degree of variability but there is no well-defined pattern at depth with the exception of a prevalent stratification during the summer of each year. Surface temperatures suggest a sinusoidal variation with highest temperatures occurring in August.

Hydrographic data from surface and bottom layers at the shallow site (Figure 4) show a much greater vertical homogeneity with a more clearly defined seasonal variation at both depths. The water column over the inner shelf is very nearly isothermal during the fall, winter and spring months. During mid-summer a slight stratification is sometimes present. Salinities are almost totally influenced by local rainfall and riverine input at this site.

A comparison of surface temperature at these two sites (Figure 4) provides a crude picture of cross shelf dynamics over the annual cycle. During the summer months, temperatures of slightly over 29°C are observed at both stations suggesting minimal cross shelf gradients. In contrast, lowest values of approximately 14°C over the inner shelf are well below the minimum values of 19 to 20°C found over the outer shelf during the winter, resulting in strong cross shelf gradients during these months.

Figure 5 illustrates another aspect of the hydrography that is of prime importance to many of the biological communities, especially benthic populations, that of variation in the hydrographic environment over time. There is a significant negative correlation ($P < 0.05$) between bottom water temperature and salinity deviations and depth, indicating the extreme variability of shallow waters and contrasting stability of deeper waters. A deviation from this trend is noted for several of the collection

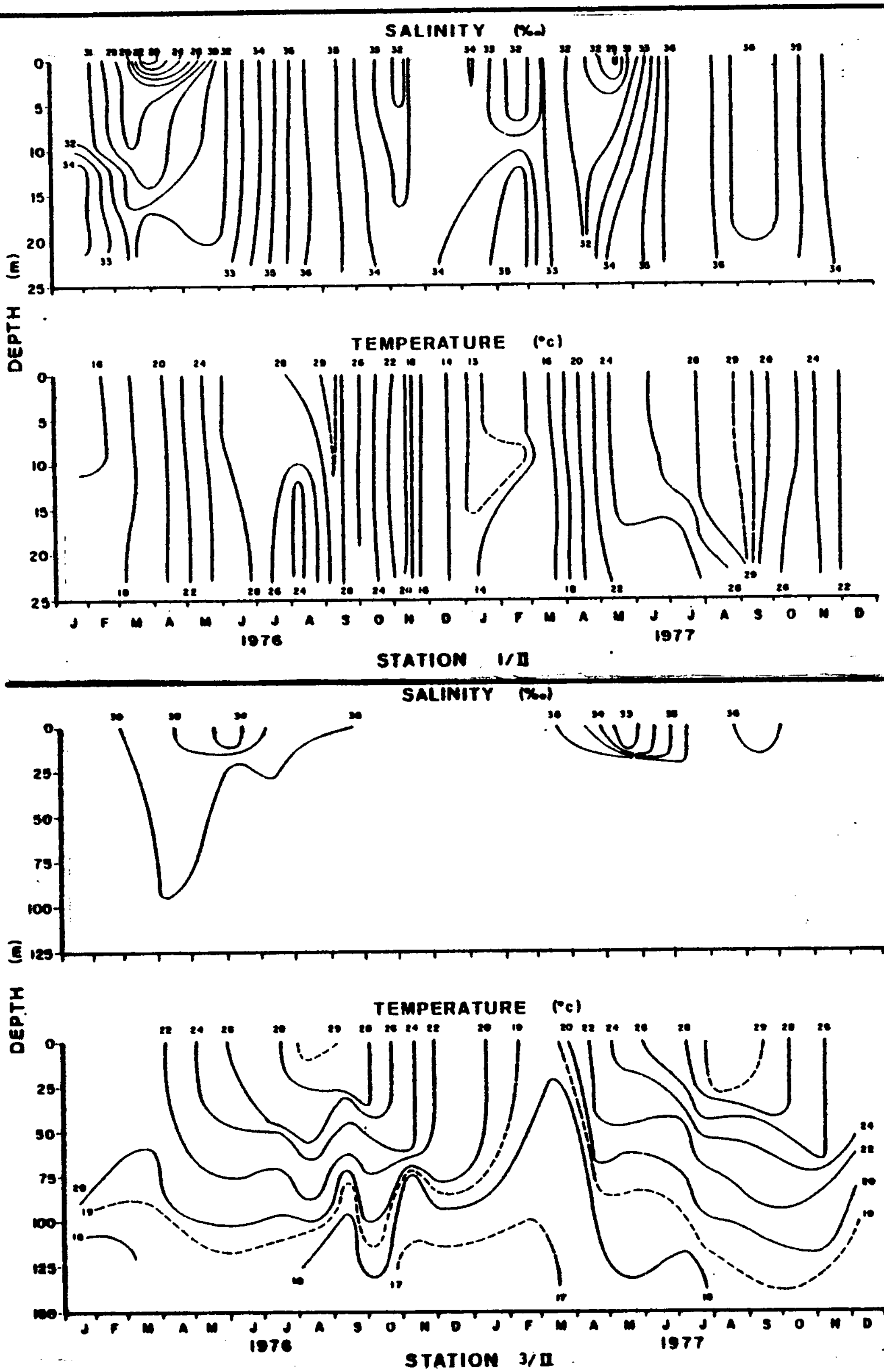

Figure 4. Time-depth plot of temperature and salinity from Transect II inner (Station 1) and outer (Station 3) shelf stations for January through December 1976 and 1977.

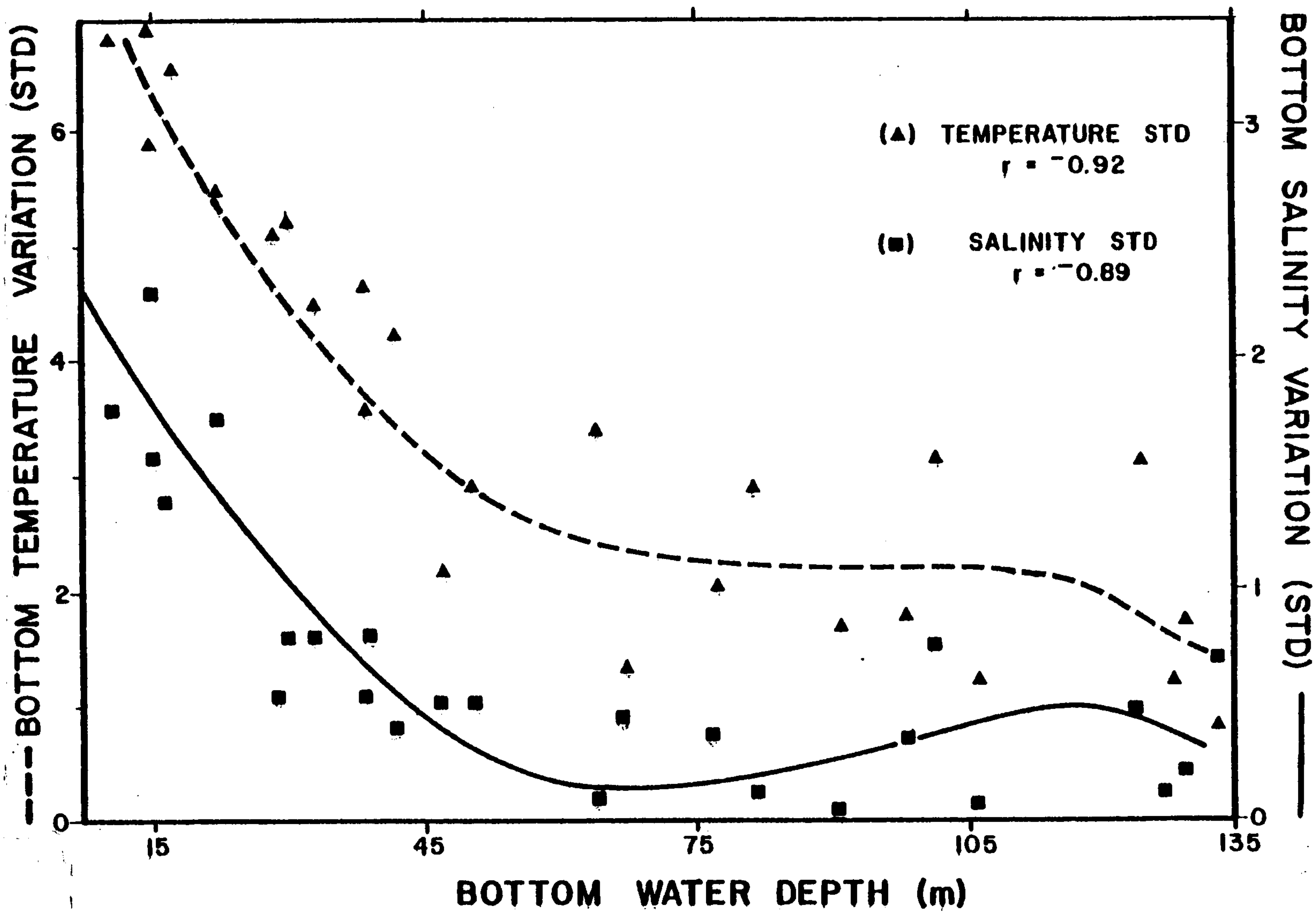

Figure 5. Plot of temperature and salinity standard deviation (STD), calculated over the study duration against water depth of each station sampled. The r values of the two polynomial curves are shown.

sites deeper than 100 m. Increases in the variance of salinity at these sites may suggest the occurrence of occasional upwelling of deep Gulf waters. This is further verified by the plot of temperature cross-section along a transect during the summer of 1977 (Figure 6). Warmest waters are found in surface layers at some distance from the coast. The onshore directed temperature gradient together with the layer of cool near-bottom water extending nearly to the coast indicate the existence of upwelling and a pattern of offshore Ekman transport of surface water with a near-bottom return flow. The summer horizontally isothermal conditions are ideal for this phenomena to occur and are the only opportunity for cross shelf currents perpendicular to the coast to occur with any regularity because of the predominant wind directions from the south-southeast.

The graphical summaries of the hydrographic data presented here are useful for quantifying the spatial, as well as the temporal variability in the hydrographic climate in Texas shelf waters. The time scales associated with the dominant local variations in temperature and salinity differ significantly between the inner and outer-shelf sites. There was a lack of stratification over the inner shelf at all depths as well as through the surface layers of the entire shelf during most of the summer months.

At greater depths, sufficiently removed from surface conditioning by air-sea exchange processes, the dominant time scales become too short to be properly resolved with the available data. If the temperature variations recorded at near-bottom levels at the outer station are associated with a vertical movement of the top of the permanent thermocline, the associated time scales would be on the order of an hour to several days. This would depend on whether these reflect internal waves or a meteorologically forced encroachment of water onto the shelf from the open Gulf.

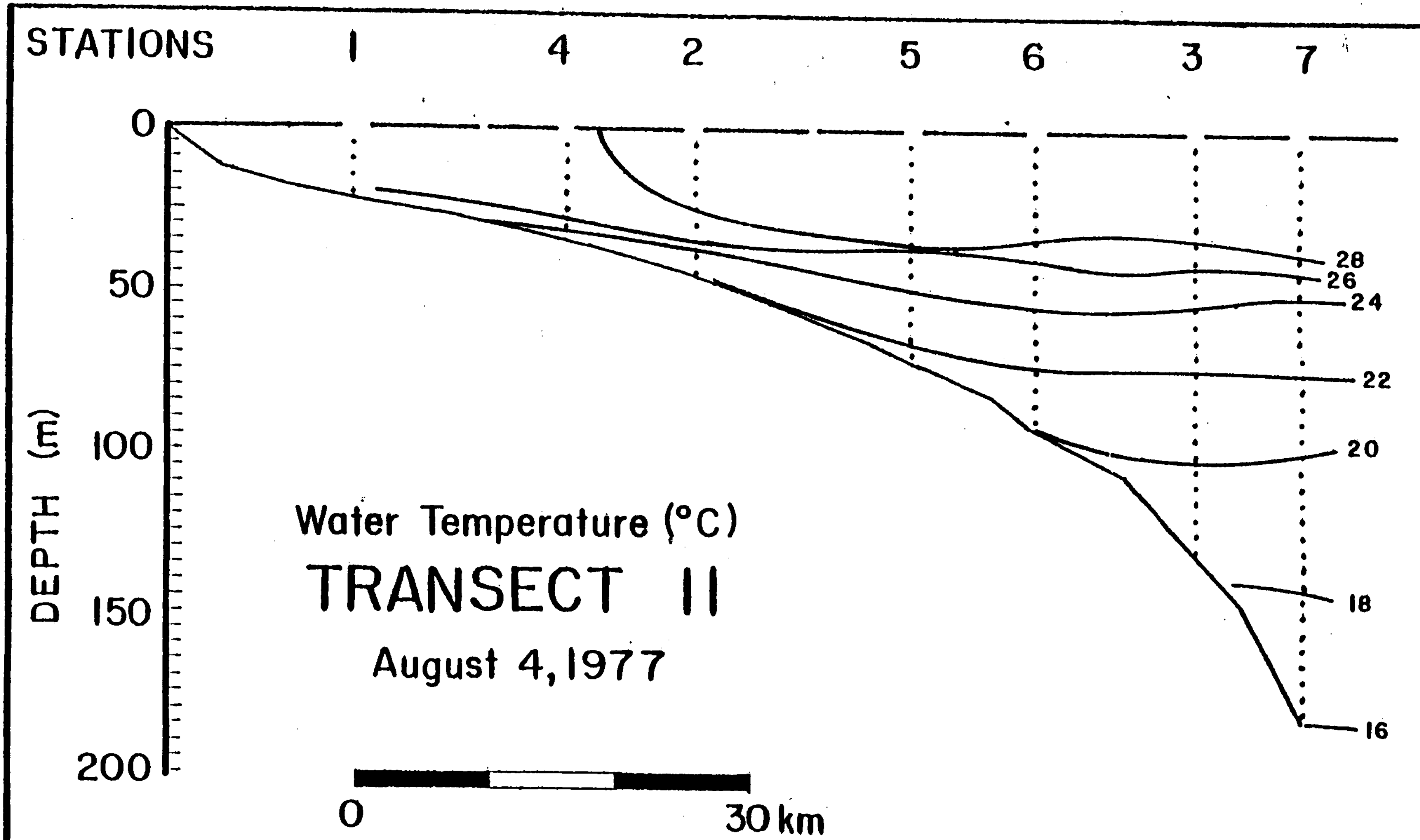

Figure 6. Temperature cross-section along Transect II, 4 August 1977.

There appear to be several significant events recurring annually and making a well-defined impression in the hydrographic data of the south Texas shelf. The plume of Mississippi River water, moving westward and southwestward along the northern rim of the Gulf of Mexico during the winter and spring months, is especially pronounced near the coast, but may at times cover the entire shelf. In addition, local rivers and estuaries potentially influence parts of the shelf, especially coastal waters, during parts of the year.

Examination of trends in a phytoplankton biomass indicator, chlorophyll a, provided additional evidence over the study period concerning different water mass influences on the Texas shelf as well as the refinement of ideas concerning general physical dynamics of the ecosystem. Of the various processes contributing to the variability of plant biomass across the shelf, freshwater discharge appeared to be most influential of those variables examined during the study. Figure 7 illustrates the relationship between salinity and particulate matter in the water column. This suggested that as salinity decreases from riverine input the particulate matter increases (decreased Secchi depth) along with possible associated nutrients and increased primary productivity. The collection of samples along the transect (II) off the Aransas Pass Inlet to approximately 90 km offshore for surface water provided an ideal picture of the relationship between lower saline waters, potentially related to freshwater inflow, and chlorophyll a concentrations (Figure 8). The highest monthly concentrations of chlorophyll a were usually associated with lower salinities, usually less than 30 ‰. This was especially apparent in the offshore waters in late winter and early spring. In contrast, the variations in temperature (Figure 8) did not appear to play an influential role in chlorophyll trends.

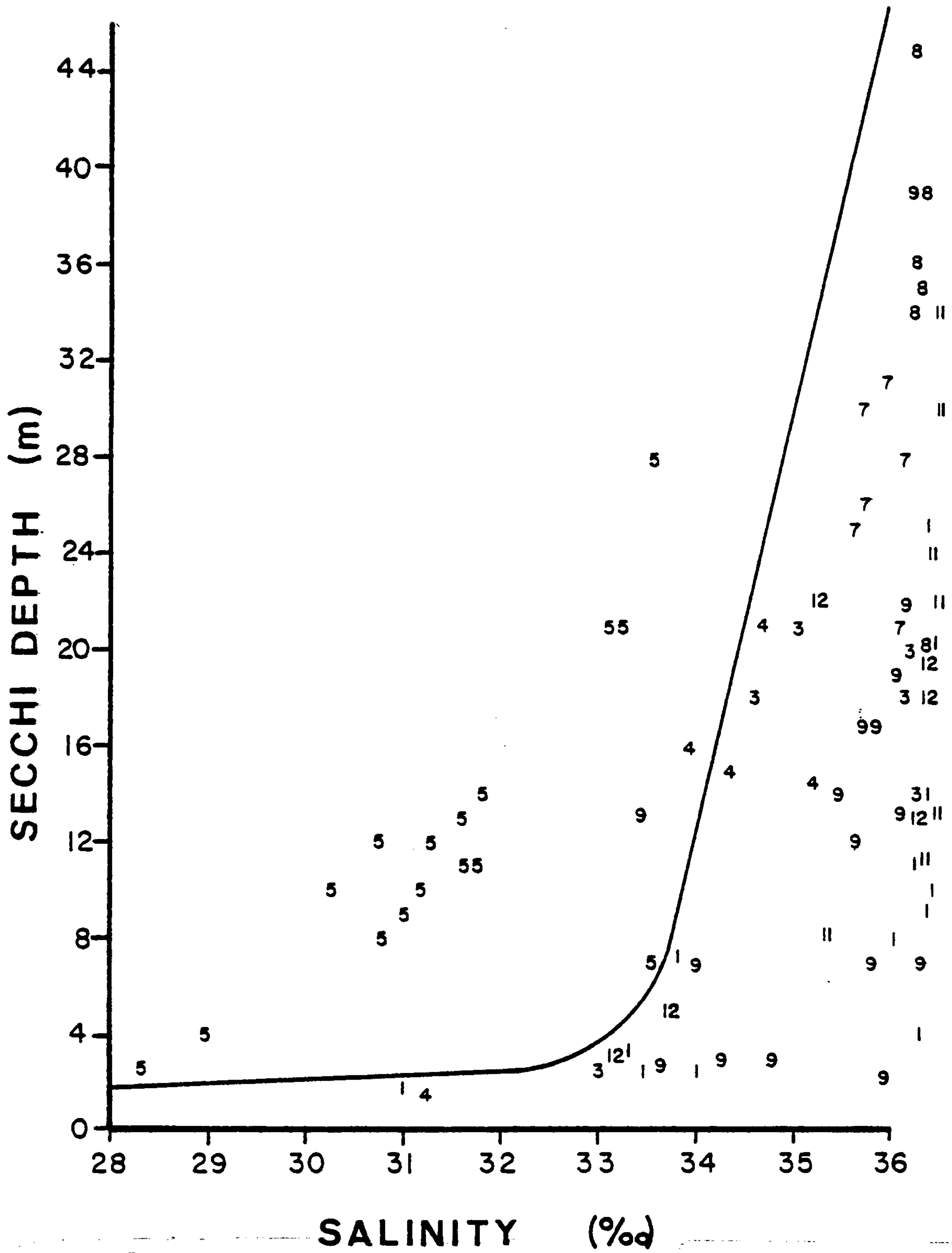

Figure 7. Relationship between salinity and secchi depth for all stations. Solid line is arbitrary curve. Numbers refer to months of year.

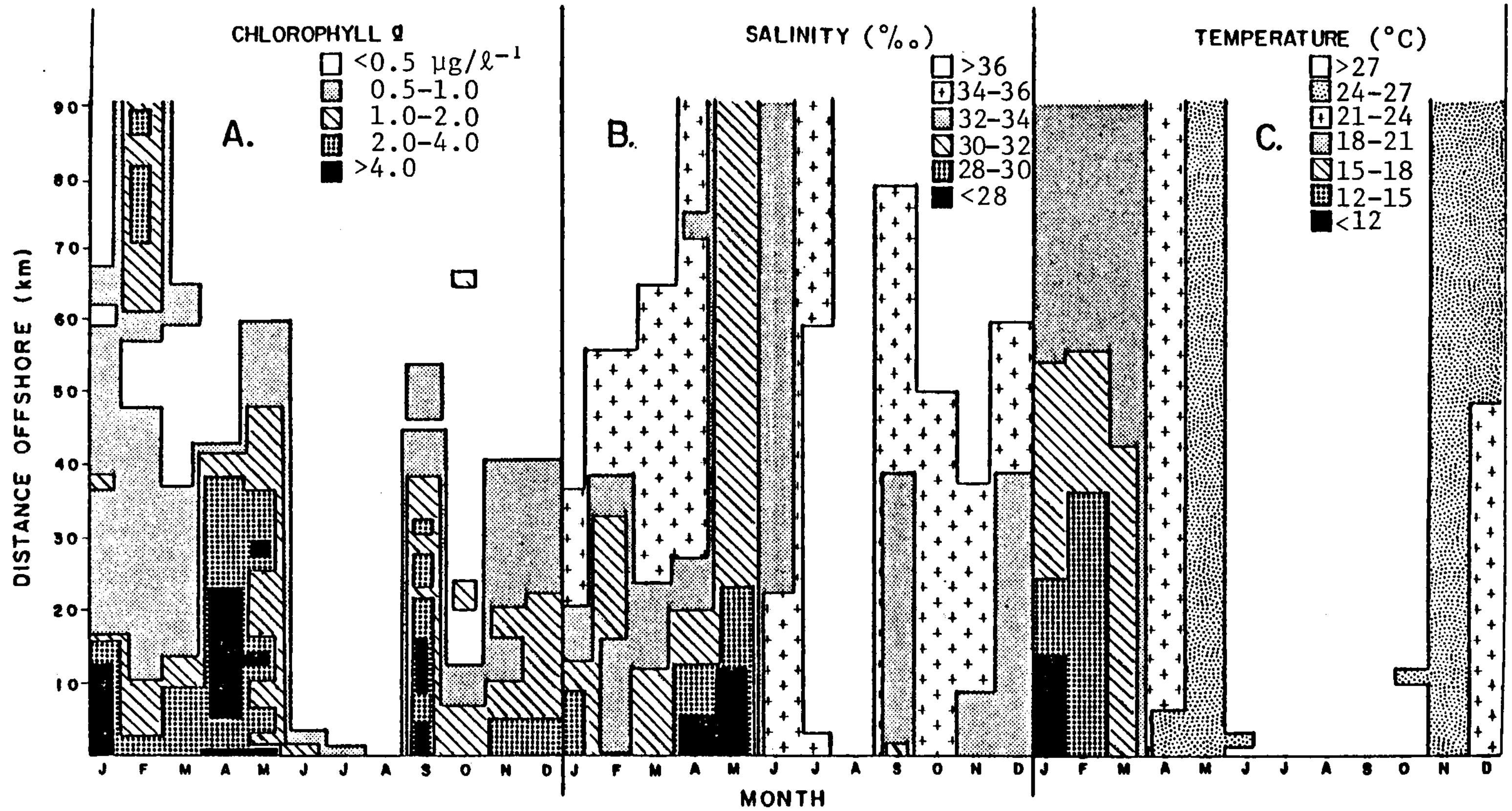

Figure 8. Contours of chlorophyll a (μg/ℓ), salinity (‰), and temperature (°C) based on data points collected every month in 1977 at each 1.85 km along a transect extending from the Port Aransas jetties to Station 3, Transect II.

Through correlational research utilizing salinity patterns, chlorophyll *a* concentrations and river flow values, it was demonstrated that the STOCS area may be influenced by different freshwater sources depending upon distance from shore on the shelf. Figure 9 summarizes the relationships among chlorophyll *a*, salinity and freshwater inflow from five point sources hypothesized as influencing the STOCS area. The upper part of the figure is a plot of correlation coefficients vs. distance offshore (km). The correlation coefficients interrelate the 12 chlorophyll *a* and salinity values available for successive 1.85 km distances offshore. The zones (marked by vertical lines) within this plot are based on the results of similar correlation coefficient vs. distance offshore plots interrelating point source discharge with either salinity or chlorophyll *a*. The zones of maximum negative correlation with salinity (bars) or of maximum positive correlation with chlorophyll *a* (dots) are shown for each point source in the lower part of Figure 9.

An inshore zone between 0-14 km offshore is characterized by a high average correlation (-0.76) between chlorophyll *a* and salinity and by the highest correlations between Texas point source discharge and salinity. Chlorophyll *a* is not well correlated with any point source discharge within this zone.

The middle zone extends from 14 - 59 km offshore. The average chlorophyll *a* - salinity correlation (-0.41) decreases in this region. Neither the Texas source discharges nor the Mississippi River discharge is well correlated with salinity throughout this zone. Texas river discharge, however, is related to salinity at the inshore side of the zone and Mississippi River discharge is highly related to salinity at the offshore side of this zone. The major correlations between point source discharge and

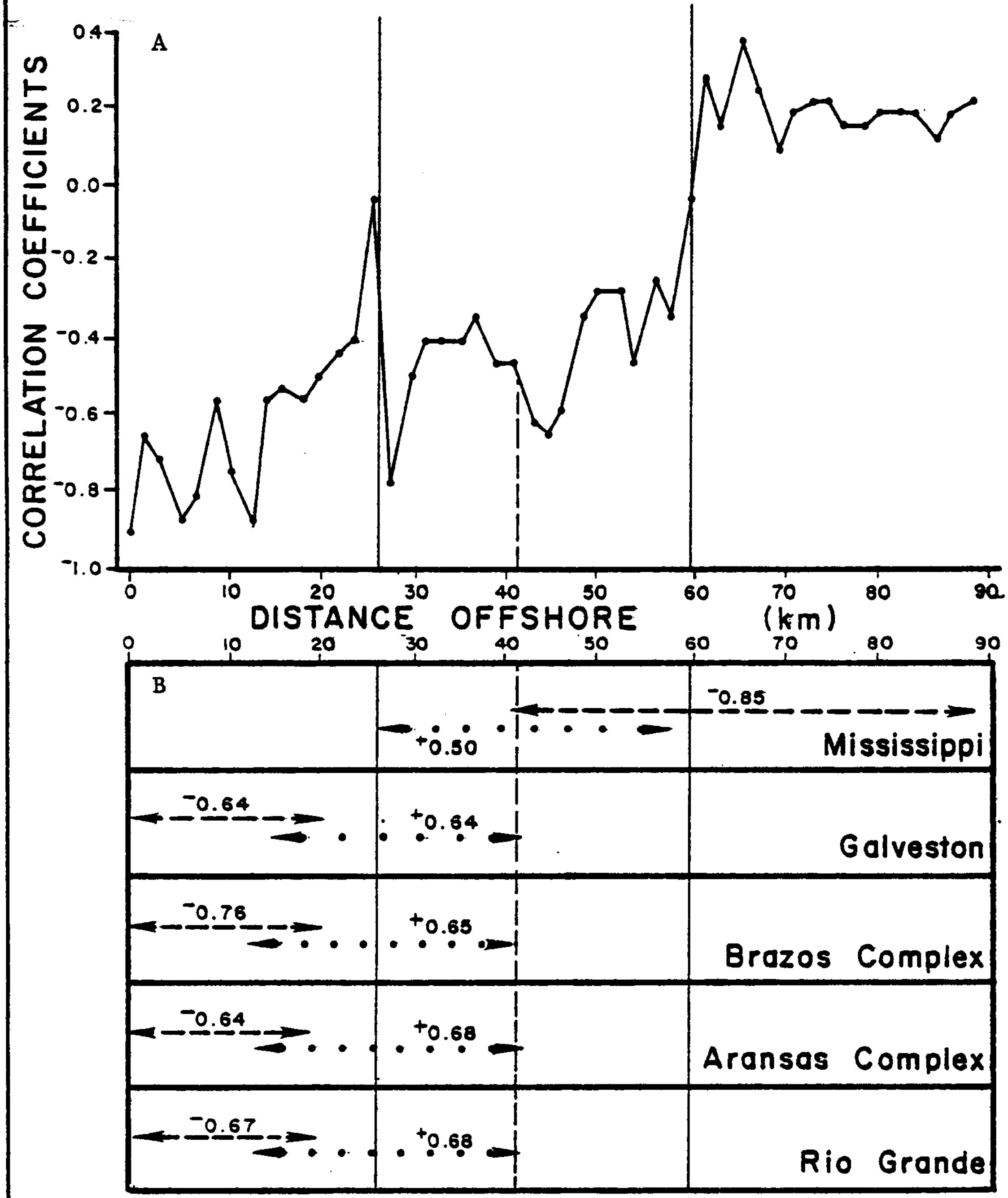

Figure 9.

A. Plot of distance offshore (km) vs. the correlation coefficients of monthly chlorophyll a and salinity (12 points) for successive km distances offshore.

B. The zones of maximum correlation between monthly point source discharge and either monthly salinity (dashes) or monthly chlorophyll a (dots) for five significant freshwater sources in the northwest Gulf of Mexico. For example, monthly Mississippi River discharge in 1977 exhibits an average correlation of -0.85 with monthly salinity readings for every 1.85km between 41-90 km offshore.

chlorophyll a almost exclusively occur in this zone. The point sources north of the sampling transect yield an interesting pattern: the farther away the point source, the farther offshore occurs the band of highest correlation. The Rio Grande exhibits its highest correlation with chlorophyll a between 39 - 50 km offshore. The Texas point sources to the north of the cross-shelf transect all abruptly end their high correlation with chlorophyll a at 41 km offshore. This feature divides the middle zone into two subzones: between 14 - 41 km offshore, chlorophyll a is best related to Texas freshwater sources; between 41 - 59 km offshore, chlorophyll a is best related to Mississippi River discharge.

The offshore zone extends from 59 km to the end of the transect (90 km). The average chlorophyll a - salinity correlation (+ 0.21) turns positive in this region suggesting fresh water does not contribute to increased chlorophyll a. In fact, chlorophyll a shows a tendency to decrease with decreasing salinity. Mississippi River discharge is highly correlated with salinity in this zone.

The preceding description provides sufficient information to develop the following model to aid in explaining the potential water mass dynamics on the Texas shelf.

1) Inshore Zone: The dominant force is freshwater from Texas riverine inputs. Salinity is inversely correlated with river discharge but chlorophyll a shows no pattern. Although chlorophyll is highly correlated with salinity, phytoplankton patchiness due to other factors (*e.g.* sediment resuspension or grazing) in this shallow, well-mixed area apparently confounds a consistent relationship between chlorophyll and river discharge.

2) Middle Zone: Texas freshwater sources as well as the Mississippi River influence both salinity and chlorophyll a. Because of mixing, freshwater discharge from the different sources shows strongest relationships with salinity at the zone boundaries. The correlations inshore of 41 km suggest a strong Texas freshwater presence while correlations beyond indicate the Mississippi River is the more significant freshwater source.

3) Offshore Zone: Mississippi River discharge dominates the shelf beyond approximately 59 km offshore. The salinity point source discharge correlation is highly negative. The point source discharge correlation with chlorophyll, however, is weak and also shows a negative response. This is intuitively proper since the transit time from source to the STOCS area is probably sufficient to deplete nutrients.

From the above described patterns it is possible to more easily understand the gradients that exist on the Texas shelf and why they exist in moving from coastal shallow waters with local influences to deeper more ocean-like waters farther out on the shelf which have very distant influential processes driving their dynamics. The conceptual model developed above suggests that many of the dynamics of the Texas shelf, such as those associated with pelagic biota, can be explained by considering topography, local river inputs, Mississippi River discharge, and climatic variables such as wind direction and velocity.

Between approximately October and March, the currents along the shelf at Aransas Pass Inlet are toward the south-southwest with a predominant longshore component. Between June and September currents over the Texas shelf are substantially weaker. The longshore component reverses over very short time scales and there are often periods of water movement across the shelf, perpendicular to the coast as described above.

Drift bottle observations from a separate study (Watson and Behrens, 1970) indicated that most of the currents directly off the barrier islands of the Texas coast were generated by local winds as measured at Corpus Christi, Texas. Nearshore currents were observed flowing in opposite directions during winter and summer, correlated to the prevailing winds. During periods of transitional weather, especially in the spring, southward surface drift was often counter to local southerly winds. Apparently the Texas coastal waters are affected by significant currents generated by winds representative of winter conditions in another, probably more northern part of the Gulf, while summer winds have begun to blow in the south Texas region.

The seasonal variation in shelf circulation has a direct and obvious effect on the spatial distribution and temporal variability of hydrographic parameters and suggests possible influential factors forcing the ecosystem dynamics. The strong and quasi-steady water flow to the south-southwest during the winter months, and especially into late spring, is responsible for the advective transport of Mississippi River water along the northwestern rim of the Gulf of Mexico at a time when discharge is at its maximum. During the summer months aperiodic near-bottom encroachment of water from depths over the outer shelf may play an important role in the ecosystem dynamics during times of relatively low riverine input. The importance of cross-shelf motion in transporting nutrients, heat, suspended solids and/or live plankton becomes quite apparent.

Water Chemistry

Nutrients

Nutrient concentrations of the Gulf waters observed during the study were representative of open Gulf surface waters in most of the water above 60 m in depth, but as illustrated in Figure 7, continental run-off influenced nearshore surface concentrations, especially in the spring. Nitrate, as the limiting nutrient to primary production, decreased to concentrations essentially below detection limits ($< 0.1\ \mu M/\ell$) after the spring and early summer phytoplankton blooms each year (Figure 10). Phosphate and silicate were substantially affected by the blooms each year but were never completely depleted during summer periods. These nutrients were generally replenished in the water column during the fall, reaching their maxima in the early to mid-winter period. Contrasts between shallow and deep sites on the shelf for surface water concentrations of these nutrients generally illustrated similar trends with the more distant station from the coastline showing proportionately lower concentrations (Figure 7). The exception to these patterns was observed for phosphate where the inshore station appeared to show a completely different trend than the deeper offshore station. The intrusion of nutrient rich 200 to 300 m western Gulf waters was often seen below 70 m as indicated by the phosphate concentration cross shelf contours from Transect II (Figure 11).

Oxygen concentrations in the upper 60 m of water varied seasonally being generally highest in the winter and lowest in the summer (Figure 7). The shallower and deeper sites again illustrated similar trends for surface water concentrations. Ratios of measured oxygen to equilibrium oxygen concentrations indicated that oxygen variations in the upper 60 m were generally controlled by physical processes (seasonal hydrographic variability) rather than pelagic productivity fluctuations. Masses of

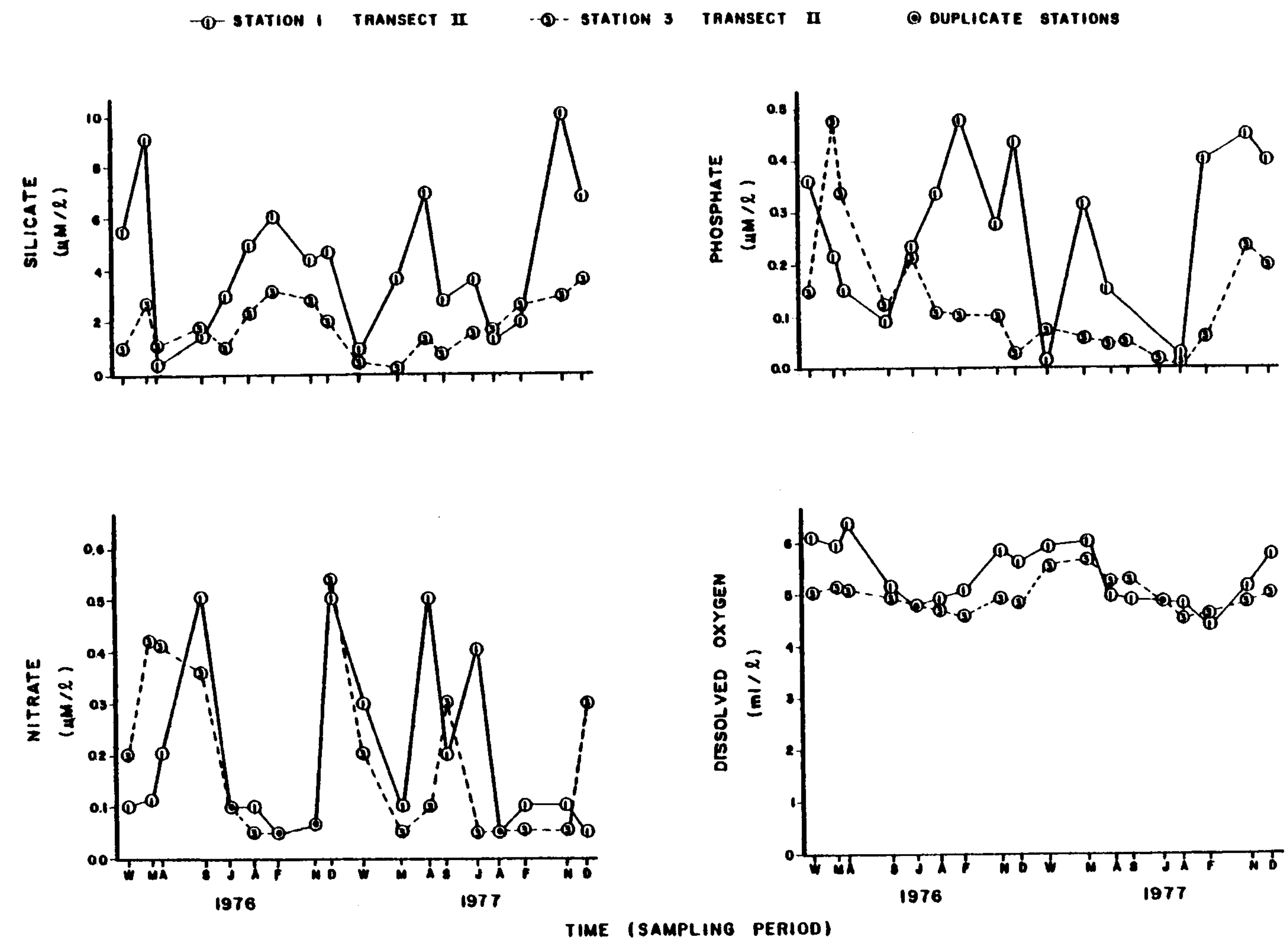

Figure 10. Plot of silicate (μM/ℓ), phosphate (μM/ℓ), nitrate (μM/ℓ), and dissolved oxygen (ml/ℓ) for the surface waters at Stations 1 and 2, Transect II for 1976 and 1977.

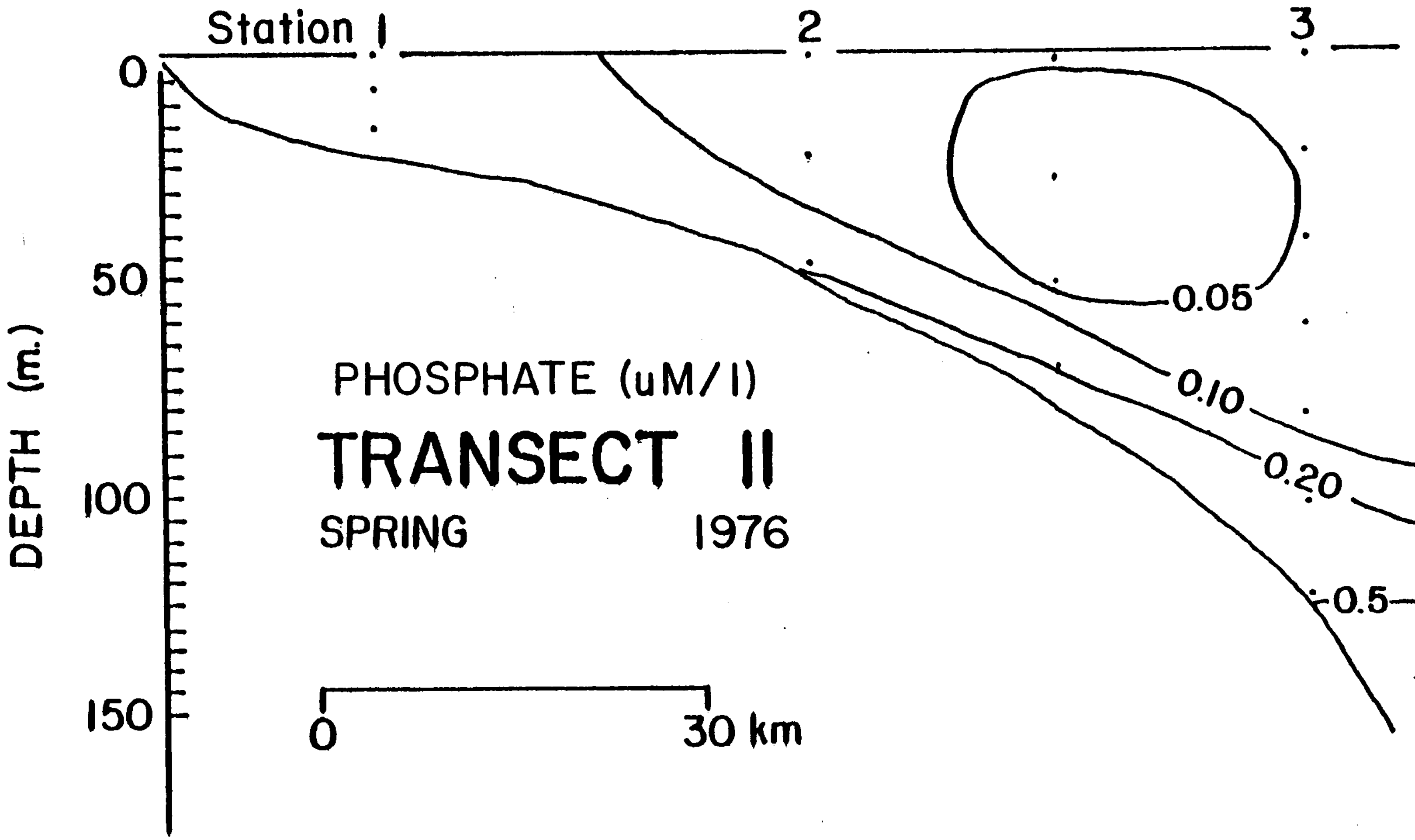

Figure 11. Phosphate (μM/ℓ) cross-sectional contours along Transect II during the spring seasonal sampling (1976).

highly oxygenated water could be traced by cross-sectional contours as they were formed nearshore in the water and displaced by warming in the spring and summer. The intrusion of oxygen-poor 200 to 300 m central Gulf water was often evident below approximately 70 m water depth. Seasonal variation of oxygen concentrations through the water column could be seen and were related to the vertical extent of mixing in deeper offshore waters. In general, bottom water oxygen concentrations observed during this study (2.58 - 5.86 ml/ℓ) appeared to be sufficient to support organisms on the Gulf seafloor.

Hydrocarbons

The STOCS ecosystem is relatively pristine with respect to hydrocarbons, with those observed during this study attributed primarily to natural sources. Numerous investigators have established that the open ocean is an important source of methane to the atmosphere. Much of the methane that fluxes at the air-water interface can be attributed to *in situ* production associated with highly active water layers, in terms of primary production and possibly bacterial production, within the water column. Other natural sources of methane plus other low-molecular-weight hydrocarbons (LMWH) include riverine and estuarine input as well as sediment seepage.

Methane in the northwestern Gulf water column exhibited considerable, seasonal and spatial variability during the study period as indicated by the ranges in Table 4. Higher surface methane values were associated with the more northern nearshore stations of the study area, probably related to more direct influences from riverine and estuarine factors. A relatively unique occurrence of higher methane concentrations was routinely observed in the deeper waters of Station 3, Transect IV during this study. These

TABLE 4

NUMBER OF OBSERVATIONS, MEAN, MINIMUM, AND MAXIMUM LOW-MOLECULAR-WEIGHT HYDROCARBON CONCENTRATIONS (nl/ℓ) AT STOCS STATIONS DURING 1976 AND 1977.

Parameter	1976			1977		
	Obs.	Mean	[Min. - Max.]	Obs.	Mean	[Min. - Max.]
Methane	299	97	[41 - 500]	328	239	[41 - 4000]
surface methane	54	73	[41 - 157]	54	112	[44 - 578]
Ethene	219	4.5	[0.1 - 25]	304	4.5	[0.1 - 21]
surface ethene	54	6.7	[0.2 - 25]	54	4.2	[1.9 - 10]
Ethane	108	0.4	[0.1 - 1.3]	273	0.7	[0.1 - 4.6]
surface ethane	53	0.4	[0.1 - 0.9]	53	0.5	[0.1 - 1.6]
Propene	107	1.0	[0.1 - 2.5]	172	1.0	[0.3 - 2.6]
surface propene	54	1.3	[0.4 - 2.5]	54	1.2	[0.4 - 2.6]
Propane	107	0.5	[0.2 - 0.8]	170	0.5	[0.2 - 1.5]
surface propane	54	0.4	[0.2 - 0.8]	53	0.4	[0.2 - 1.3]

higher concentrations were attributed to natural gas seepage across the mud-water interface at this southern point in the study area.

Although the highest near-bottom methane concentrations in the southern part of the study area were assumed to be related to natural seepage, other areas of the shelf did exhibit methane maxima. These were typically associated with a bottom nepheloid layer that is often observed, especially during the summer, on the Texas shelf (Figure 12). Although simultaneous measurements of transmissometry and LMWH were only obtained at a few stations, it appears that nepheloid layers are common especially at Stations 1 and 2 (and bank stations). Most near-bottom methane maxima in these nepheloid layers were accompanied by small increases in ethane levels. It is uncertain whether high LMWH levels in nepheloid layers resulted from resuspension of bottom sediments containing higher LMWH levels and/or from *in situ* production associated with the layer. Higher nutrient and productivity levels associated with these layers may result in high *in situ* production rates.

Table 4 lists concentrations of ethene, ethane, propene and propane during 1976 and 1977. The unsaturates dominate over their saturated analogs in most areas of STOCS, with exceptions generally occurring at water depths greater than 100 meters. Propene concentrations were almost always four times lower than ethene concentrations. There was good agreement in 1976 and 1977 between average olefin concentrations.

The level of total dissolved and particulate organic matter generally found in the Gulf of Mexico aquatic ecosystem is in the range of 0.1 to 1.0 μg/ℓ. Accurate knowledge as of the initiation of this study had not been obtained on ranges of hydrocarbon values in these same waters. Recent data collected from other systems (McAullife, 1976; Koons, 1977)

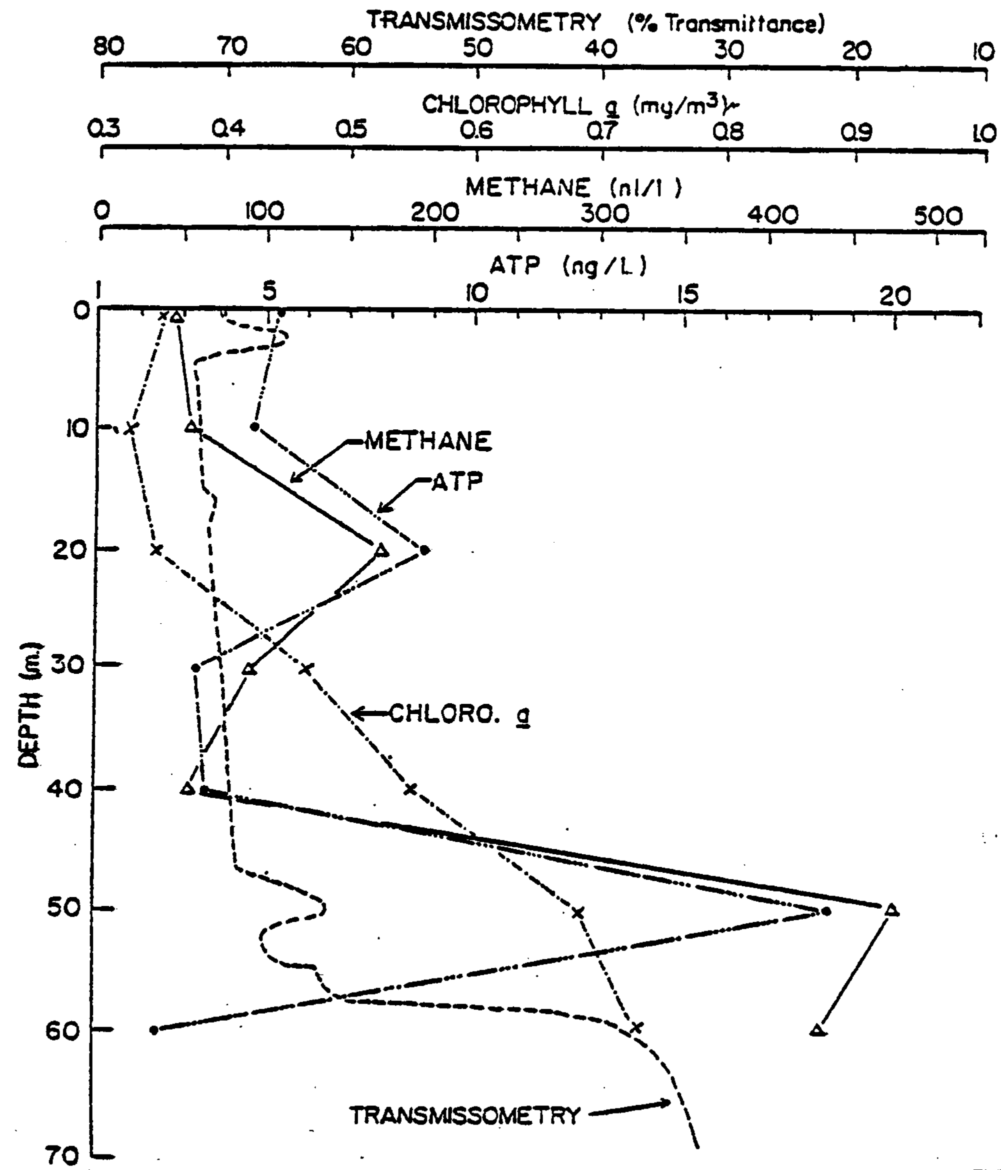

Figure 12. Depth profile of methane, ATP, chlorophyll a, and transmissometry (nl/ℓ) in the STOCS area near Station 2, Transect II for September 15, 1976.

have indicated that generally the highest concentrations of hydrocarbons are located in the surface microlayer of the water column and that these concentrations decrease rapidly within the first 10 m of water depth.

Concentrations of dissolved and particulate high-molecular-weight hydrocarbons were similar in magnitude (Table 5). Particulate hydrocarbon concentrations generally decreased with distance offshore. Higher concentrations of particulate hydrocarbons at inshore stations appeared to result from terrigeneous input through direct addition of particulates and increased primary production at shallower sites. Dissolved hydrocarbon concentrations showed less variation. Concentrations averaged higher for winter and spring than for fall samples. Proportion of dissolved and particulate hydrocarbons varied similarly. The most abundant n-alkanes were in the C_{27}–C_{33} range with a slight preference for odd carbon numbers.

TABLE 5

AVERAGE TOTAL HYDROCARBONS IN SEAWATER BY STATION (DEPTH) FOR ALL TRANSECTS

Total Hydrocarbons, Dissolved + Particulate (μg/ℓ)

	Station 1	Station 2	Station 3
1975	0.43	0.31	0.20
1976	0.34	0.25	0.21
1977	0.46	0.31	0.33
AVG.	0.41	0.29	0.25

Particulate Total Hydrocarbons (μg/ℓ)

	Station 1	Station 2	Station 3
1975*	0.11	0.10	0.05
1976	0.13	0.06	0.05
1977	0.35	0.11	0.12
AVG.	0.20	0.09	0.07

Dissolved Total Hydrocarbons (μg/ℓ)

	Station 1	Station 2	Station 3
1975*	0.16	0.11	0.15
1976	0.20	0.19	0.16
1977	0.11	0.20	0.21
AVG.	0.16	0.17	0.17

* Fall season only

CHAPTER THREE

PELAGIC BIOTA OF THE SOUTH TEXAS SHELF

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Phytoplankton

The hydrographic environment of any marine shelf ecosystem can be very complex because there are so many factors capable of influencing the dynamics of the system. The STOCS area is no exception with influences such as western land masses and associated riverine inputs, the deeper offshore Gulf waters, and possibly most important, the Mississippi River to the north. Previous work both on the Texas shelf and other shelf ecosystems has suggested that the hydrographic features and many of the biotic components, especially pelagic aspects, are strongly correlated. Hydrographic variables such as temperature, salinity, and currents presented in the preceding chapter, illustrate the annual progression that occurs over the south Texas shelf and help to suggest possible factors that influence the functioning of the ecosystem.

General patterns in phytoplankton biomass on the Texas shelf during the 1975-1977 study period are best illustrated by examining changes at the three stations on Transect II which were sampled monthly over the period 1976-1977. Figures 13 through 15 summarize the temporal and depth patterns in the nanno (a), net (b), and total (c) categories of chlorophyll a at the three stations of Transect II. Station 1/II (Figure 13) is temporally characterized by a continuous background concentration of nanno-chlorophyll a; concentration peaks occur in the April and Fall (Hurricane Anita) cruises of 1977. Net chlorophyll a is much more variable exhibiting a seasonal peak occurrence between November and May. The seasonality in total chlorophyll a concentration is dominated by the net fraction. Surprisingly, the water column is routinely inverted in chlorophyll a concentrations, *i.e.* the maximum concentration occurs in the bottom waters.

Station 2/II (Figure 14) exhibits less variability in the nanno-fraction than Station 1/II. The concentration of nanno-chlorophyll a, however, generally exceeds that of the net fraction. Two exceptions are at the surface, April 1976 and bottom, July 1977. The total chlorophyll a concentration reflects the nanno trend except during the net fraction peaks. The vertical profile of chlorophyll a again routinely exhibits an increase with depth.

Station 3/II (Figure 15) exhibits a further decrease in nanno-chlorophyll a variability. An exception occurs at the half-photic zone, winter 1977. The net fraction is extremely low except for the winter of 1977. The total chlorophyll a category reflects the even distribution of the other two categories throughout the sampling period except for the combined nanno and net peaks. This unusual concentration of chlorophyll a at all depths is related to an upwelling during February 1977. This event

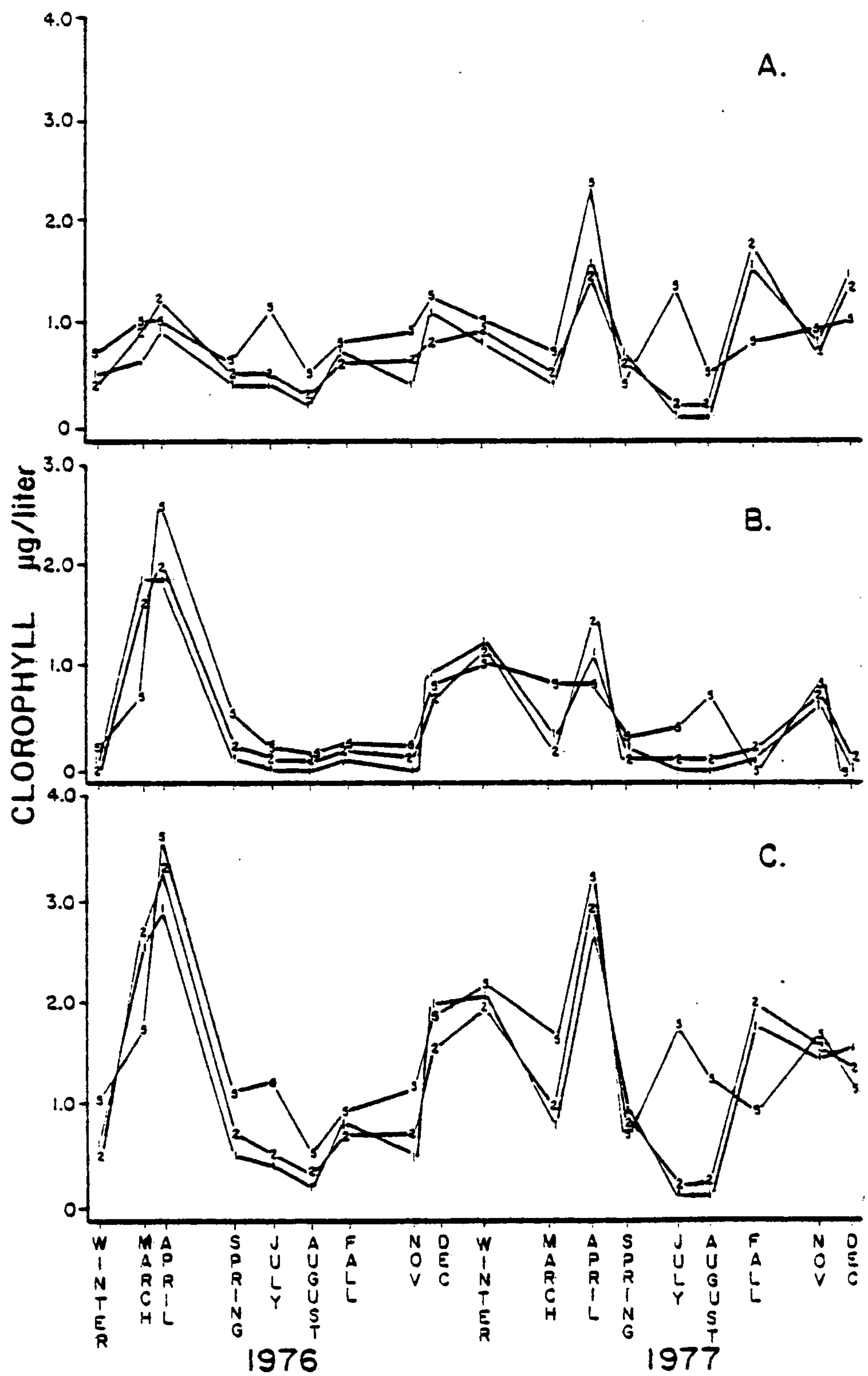

Figure 13. Station 1 chlorophyll a (µg/ℓ) at the surface (1), half the depth of the photic zone (2) and bottom (5) in the a) nanno, b) net, and c) total categories plotted against sampling period.

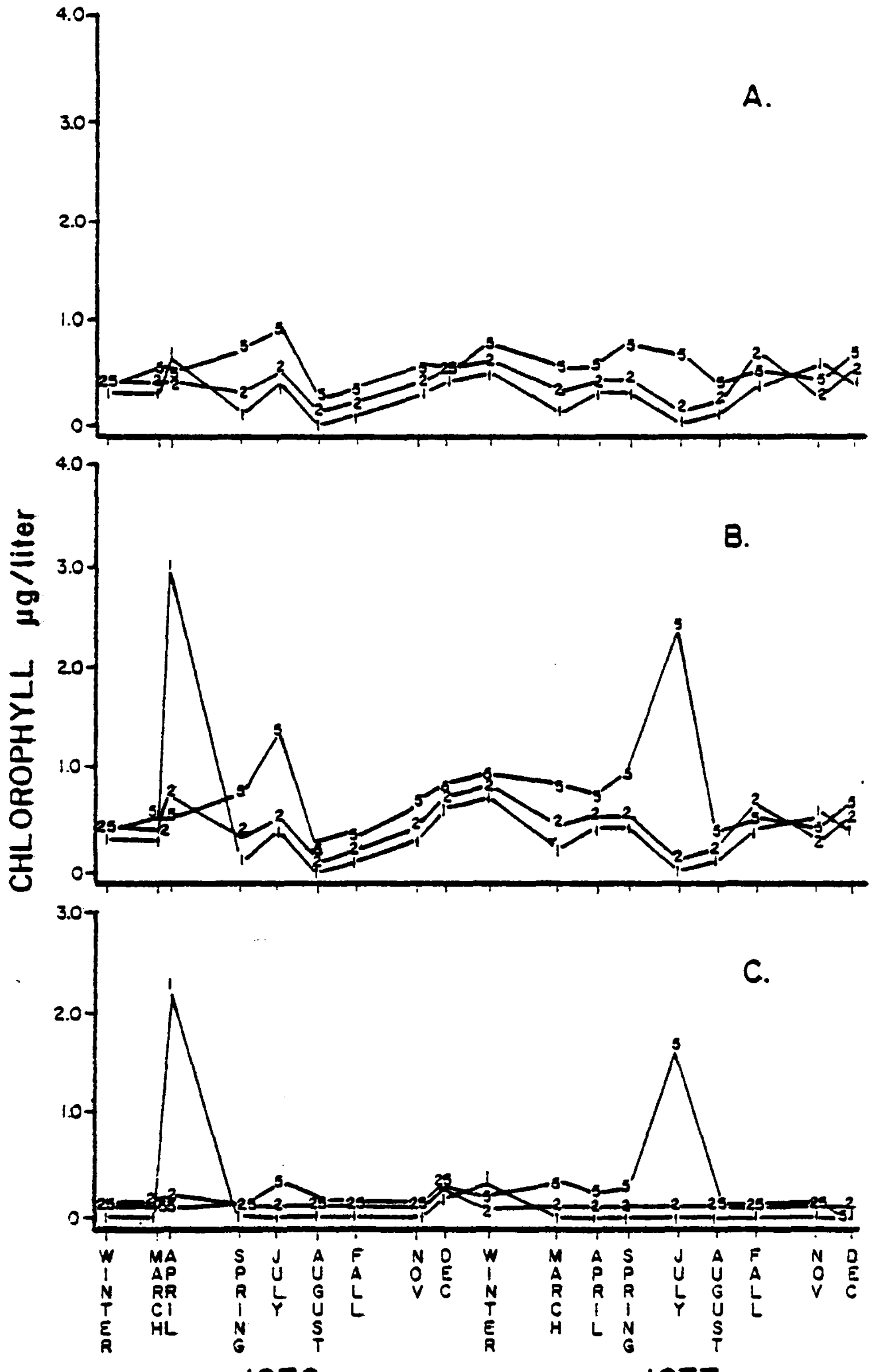

Figure 14. Station 2 chlorophyll a (µg/ℓ) at the surface (1), half the depth of the photic zone (2), and bottom (5), in the a) nanno, b) net, and c) total categories plotted against sampling period.

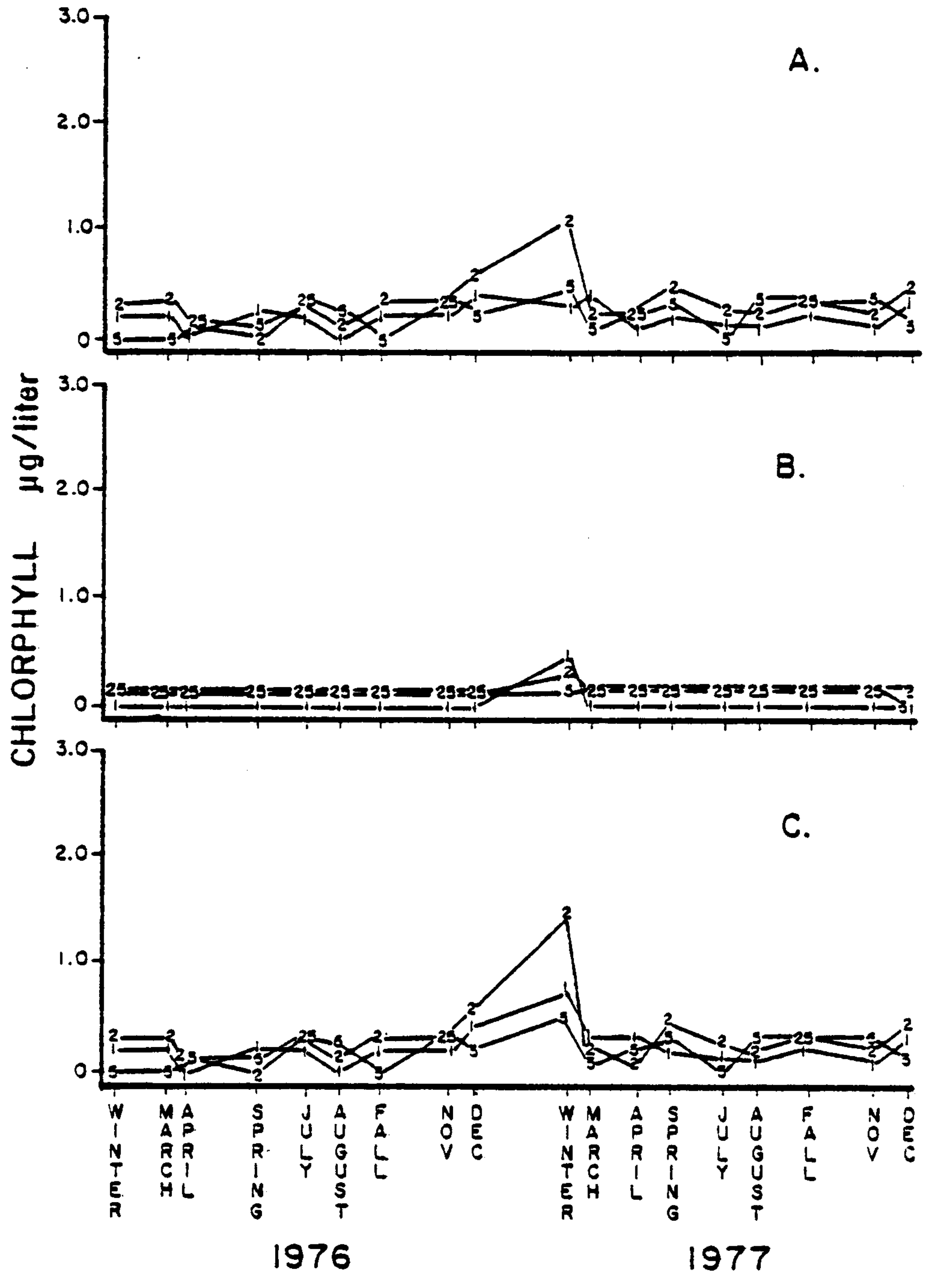

Figure 15. Station 3 chlorophyll a (µg/ℓ) at the surface (1), half the depth of the photic zone (2), and bottom (5), in the a) nanno, b) net, and c) total categories plotted against sampling period.

may occur every year but may be easily missed in most sampling programs because of its probable short duration.

Analysis of variance (ANOVA) results of the general chlorophyll a trends illustrated above showed that the cross-shelf gradient was statistically significant ($P < 0.05$) for all components of chlorophyll at all depths. The bottom samples, however, exhibited a slightly different pattern from the surface or half the depth of the photic zone collections within these general trends. The latter showed that Station 1 was significantly different from Stations 2 and 3. For bottom water concentrations, on the other hand, the nanno and total chlorophyll categories were similar at Stations 1 and 2 while both these collection sites differed from Station 3.

There was also a north-south chlorophyll gradient observed on the shelf although it was not as strong as the cross-shelf gradient. The northern part of the STOCS was significantly ($P < 0.05$) higher in chlorophyll a both at the surface and half the depth of the photic zone than the southern part of the shelf. Measures of chlorophyll in the bottom waters, however, did not show a north-south gradient. These patterns may reflect Mississippi River influences on the shelf which significantly decrease in their impact on the southern collection sites. That the bottom waters do not show the same patterns illustrates lack of mixing on the outer shelf.

Figure 16 summarizes the temporal patterns in the nanno (a), net (b), and total (c) categories of carbon 14 uptake at the three stations of Transect II during 1977. Stations 2 and 3 dominate the winter nanno activity; Station 1 is dominant over the majority of the rest of the year. The inshore peaks in nanno activity occur in spring and fall. Station 1 dominates the net activity during the spring and November; Station 3 domi-

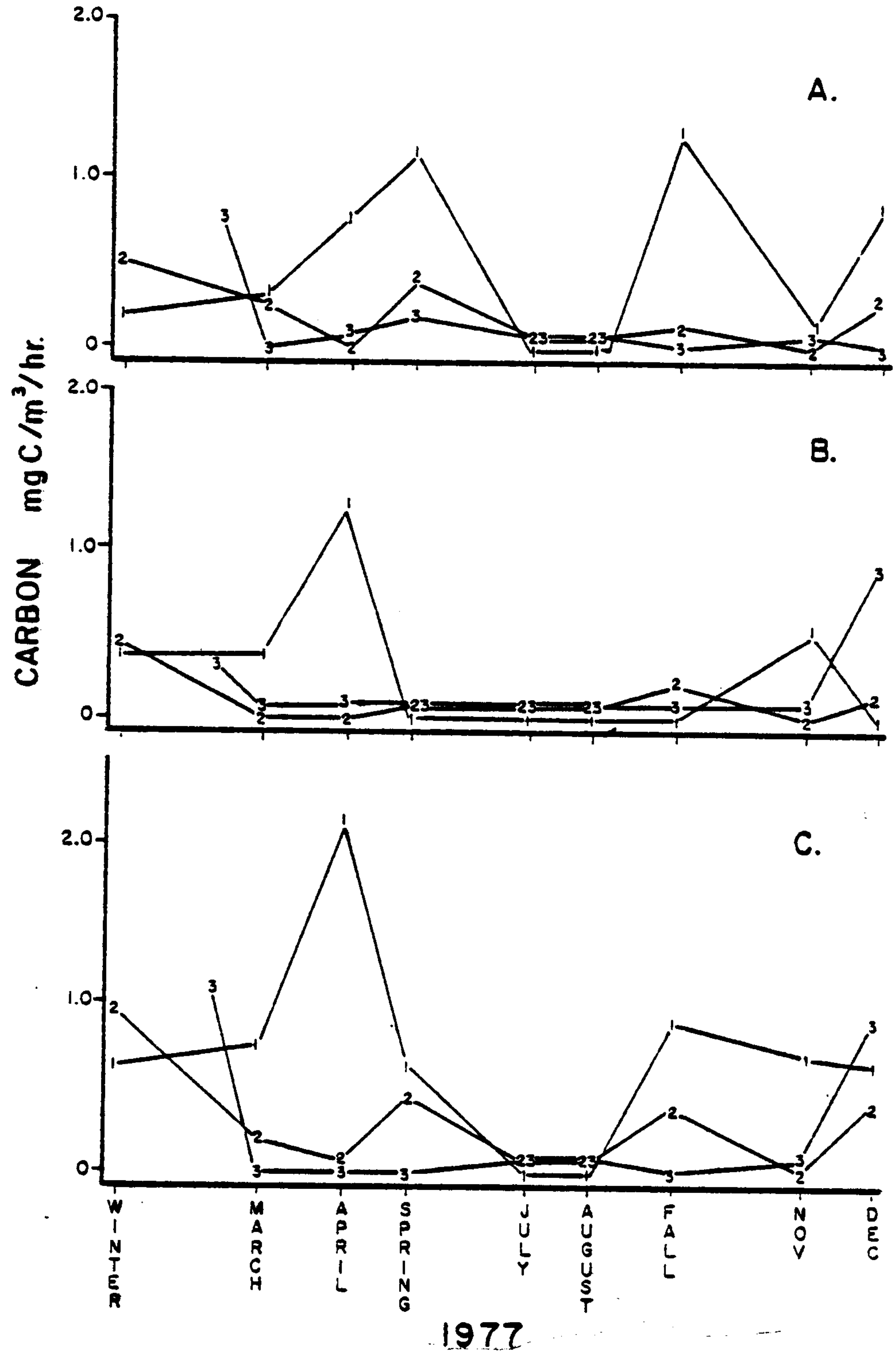

Figure 16. Stations 1, 2 and 3 surface carbon 14 uptake (mg $C/m^3/hr$) in the a) nanno, b) net, and c) total categories plotted against sampling period.

nates during December. The peaks in net activity are in April and November. The net peak precedes the nanno peak in the spring bloom and follows it during the fall bloom. The total category presents the composite of the size fractions and provides a picture of classic temperate zone phytoplankton activity.

The chlorophyll concentrations observed during this study, especially in the shallower shelf waters plus the phytoplankton activity represented by Figure 16 suggested that the Texas shelf may be extremely productive in terms of primary producer biomass. Utilizing a technique developed by Ryther and Yentsch (1957), which estimates primary production based upon chlorophyll a measures and light transmittance through the water column, a two-year production curve was developed for Station 1 of Transect II (Figure 17). Primary production for Texas inner shelf waters (Figure 17) is somewhat bimodal annually with peaks in the spring and fall. Annual estimates of production, based upon the chlorophyll a measures converted to carbon equivalents, indicated that these waters produced a mean of approximately 103 g $C/m^2/yr$. In contrast, estimates of primary production for coastal waters of other continental shelves that support substantial fisheries, as the STOCS does, such as the North Sea (Steele, 1974), indicate an annual production of 70 to 90 g $C/m^2/yr$. It appears that the Texas shelf can be considered an extremely productive ecosystem in terms of plant biomass.

In terms of species composition, the phytoplankton community structure of the STOCS area is complex but relatively consistent with respect to different water masses that occur on the shelf over the annual cycle. In general, the progression of community structure through the seasons occurs at different rates at different locations on the shelf. The results of

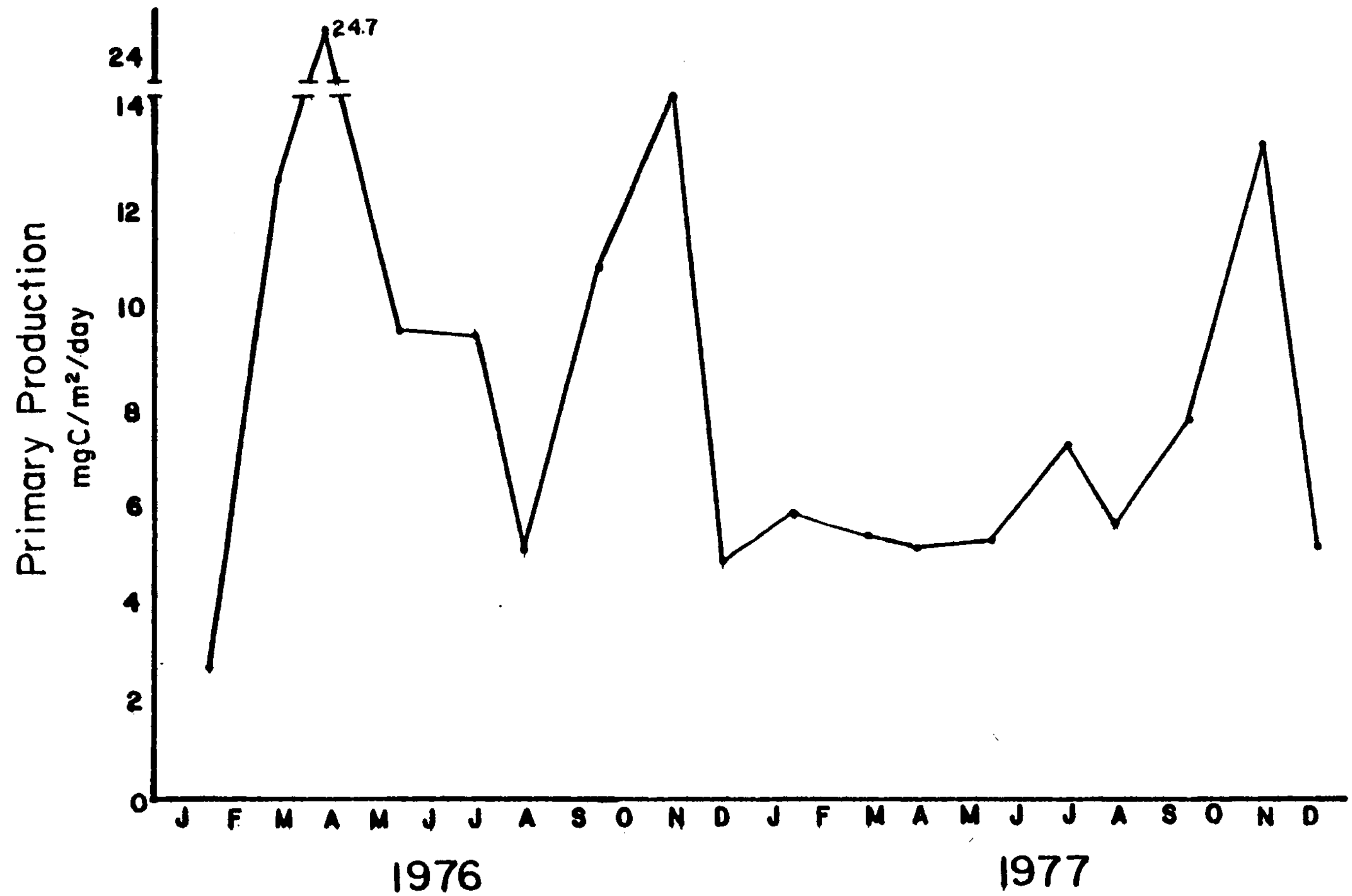

Figure 17. The two year cycle of primary production (carbon fixation) for Texas coastal waters between 1976 and 1977. Carbon fixation estimated from chlorophyll measures according to technique of Ryther and Yentsch (1957).

cluster analyses have indicated that the temporal changes in community structure of the phytoplankton are related to light intensity, day length, temperature, salinity, stratification, wind and nutrient sources. The patterns observed over the study period demonstrate the complexity of phytoplankton response to conditions on the Texas shelf.

Species groupings derived from the cluster analysis of phytoplankton are less informative than the station groupings. This results from both technical and biological reasons. Technically, the phytoplankton counts are generally limited to the size fraction above 20 μ. Since this fraction is dominant only between December and April, the species groupings represent successions only within this time period. The cruises were not sufficiently frequent to adequately distinguish community changes within this limited period. Information on summer community structure was also limited by the fact that the greatest concentration of phytoplankton occurred near bottom where species composition samples were not available. The biological reasons are related to the low sampling frequency compared to the rate of change of phytoplankton species composition. The species lists are usually very different from one cruise to the next. Considering these problems, Figure 18 depicts the seasonal patterns of the phytoplankton classes and Figure 19 depicts the seasonal pattern of selected phytoplankton species or genera from the net phytoplankton observed at the surface along Transect II during 1976 and 1977. The graphs are ordered by decreasing numerical abundance.

Diatoms, dinoflagellates, and silicoflagellates are generally most abundant between the November and Spring cruises through the winter months (Figure 18). The remaining time interval is represented by a minor dinoflagellate peak, coccolithophorids and blue-green algae.

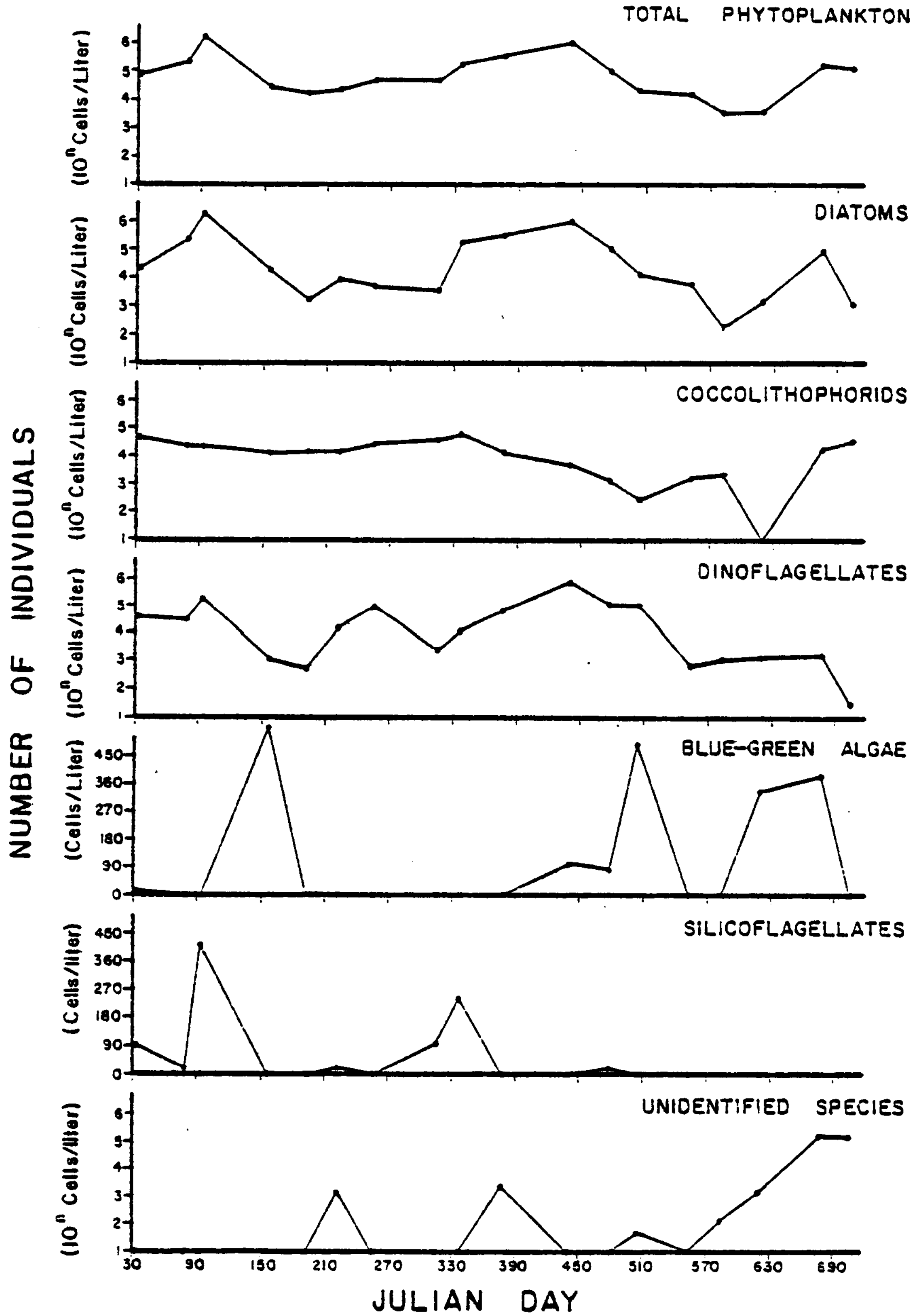

Figure 18. Comparison of seasonal abundances of the different classes of phytoplankton observed along Transect II during 1976 and 1977. Each point represents the sum of the surface abundances at Stations 1/II, 2/II and 3/II within a sample period. Number of individuals (cells/ℓ) are plotted against Julian Day. The graphs are ordered by decreasing abundance.

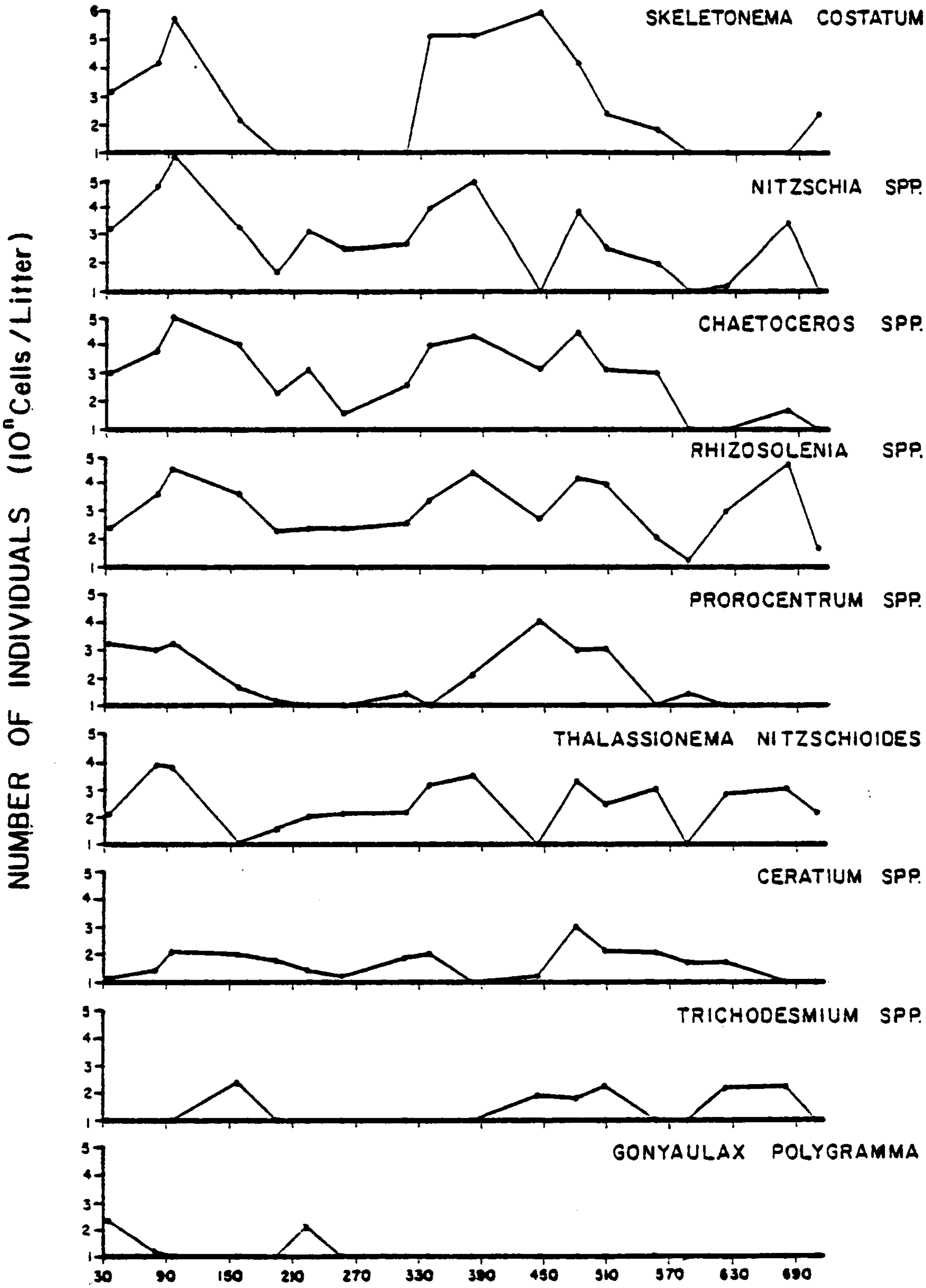

Figure 19. Comparison of seasonal abundances of different species or genera of phytoplankton observed along Transect II during 1976 and 1977. Each point represents the sum of the surface abundances at Station 1/II, 2/II and 3/II within a sample period. Number of individuals (cells/ℓ) are plotted against Julian Day. The graphs are ordered by decreasing abundance.

Figure 19 demonstrates the seasonal preference of selected taxa. The two years are different in the order of species appearance. In 1976, a relatively clear succession occurs: Winter - *Gonyaulax polygramma* and *Prorocentrum micans*; March - *Thalassionema nitzschioides*; April - *Skeletonema costatum, Nitzschia* spp., *Chaetoceros* spp.; Spring - *Trichodesmium* spp.; August - *Gonyaulax polygramma* and *Thalassionema nitzschioides*. In 1977, more co-occurrence is evident: Pre-March - *Chaetoceros* spp., *Rhizosolenia* spp., *Thalassionema nitzschioides, Ceratium* spp. and *Trichodesmium* spp.; November - *Rhizosolenia* spp.

The patterns present a confused picture of the phytoplankton community. This probably results from the complex hydrography in the STOCS area. Better information on the specific dynamics according to shelf-influencing factors may be obtained by eliminating geographic stations and relating species assemblages in similar water masses as was done with the chlorophyll a observations presented above.

Nepheloid Layer

As stated previously, the highest concentrations of chlorophyll a were often observed in the bottom waters of the shelf (Figure 13) especially at the shallow stations on the shelf. The bottom water is also characterized by a pervasive nepheloid layer (Berryhill, 1977) at least during part of the annual cycle. Data from several cruises in 1978, to examine nepheloid layer dynamics, not only demonstrated prevalent nepheloid levels (Figure 20), but also illustrated the presence of peak chlorophyll layers in the bottom waters, as well as peaks in nitrogen represented by ammonia. These peaks of primary producer biomass as well as greater than 1% light transmissions at these depths suggested the possibility of photosynthesis taking place. Carbon 14 experiments confirmed this (Kamykowski

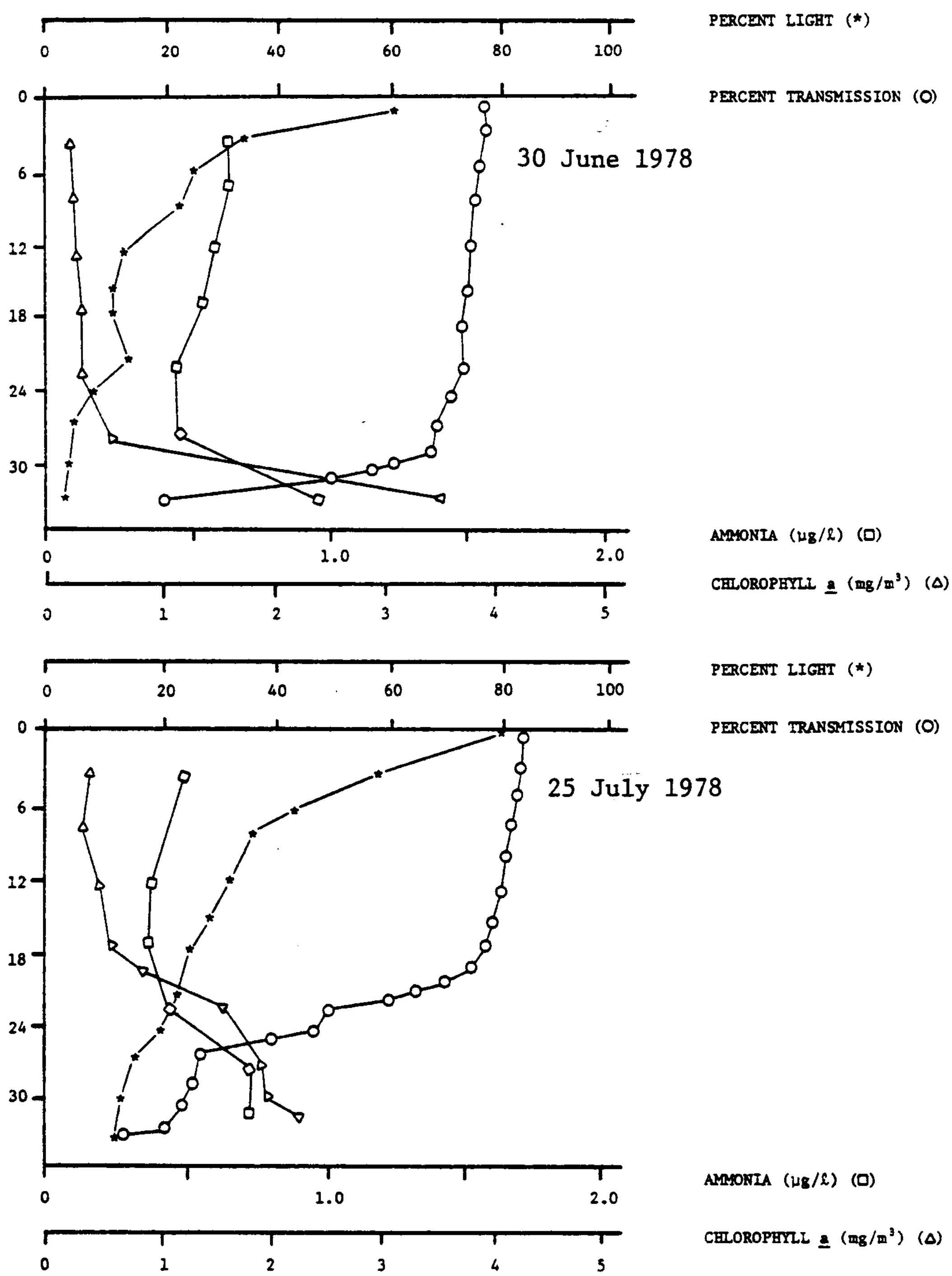

Figure 20. Depth profiles of percent light, transmissometry, chlorophyll a and ammonia nitrogen concentrations for two cruises off the Texas coast (33 m water depth) during 1978 near Station 4, Transect II.

and Batterton, 1979). In addition to the primary producer biomass in bottom waters there appeared to be a considerable amount of nutrient regeneration as illustrated by the ammonia concentrations (Figure 20).

The basic conclusions drawn from the study of the nepheloid layer during four diel sampling cruises in 1978 were:

1) The nepheloid layer was present throughout the 24-hr sampling period and fluctuated in thickness and density within this period;
2) Phytoplankton are concentrated in the nepheloid layer during the summer months in the STOCS area. Active carbon fixation can occur since 10% surface radiation may often reach the sediment interface in the zone within 50 km of shore;
3) Since nutrients are probably supplied to the layer at least partly from benthic diffusion, the phytoplankton dynamics of the layer may be affected by perturbations of the benthos caused by oil-related activities;
4) The overall impact of this effect depends on organism sensitivity, the area perturbed, exchange intensity and the trophic significance.

Neuston

The neuston is defined as plants and animals that live on or just beneath the surface film of marine waters. Sargassum mats are usually associated with this surface component of the Texas shelf waters as well as some freshwater plants such as water hyacinth which enters the system through riverine inflow, especially farther south near the U.S.-Mexico border. Very diverse communities of fauna are normally associated with these floating mats. The focus of the STOCS study, however, was concerned with the more free-living fauna that inhabit this surface zone. It is felt that many potential pollutants that enter the marine system do so through the surface waters (*e.g.* petroleum hydrocarbons) and any biological impact from these pollutants may first manifest itself in changes to the neuston.

Although the neuston defies a strict biological definition in terms of species, there are certain taxonomic groups which are commonly found in the upper 15 to 20 cm of the water column during significant portions of each day. There is considerable variability not only in the abundance of neuston, either as total numbers of organisms or dry weight, as well as taxonomic composition. This is due, in part, to diel vertical migration, but also to various types of environmental heterogeneity. Day-night sampling helps to minimize the former variation, but the latter source of variability is not generally monitored.

The number of organisms and densities of these organisms collected from all stations for each season varied widely both within taxa and temporally (Table 6). Neuston biomass was also highly variable during the study interval. Most taxa showed distinct seasonal cycles with peaks occurring during the spring and summer sampling periods. In contrast, a few late fall-winter species were found. These general trends showed good year-to-year reproducibility. Onshore-offshore variation was observed in the distribution of some taxa, particularly the larval decapod crustaceans.

The neuston decapod fauna was studied in great detail during 1976 and 1977. A total of 104 decapod taxa were identified consisting of 88 larval taxa and 16 non-larval taxa. Decapod larvae accounted for 53% of the mean concentration of total decapods and 6% of the total neuston.

TABLE 6

MEAN ABUNDANCES OF SELECTED TAXA BY CRUISE AND TIME OF DAY. NUMBERS ARE GIVEN IN NUMBER/10^3m^3. UPPER (u) AND LOWER (ℓ) 95% CONFIDENCE LIMITS ARE GIVEN ONLY WHEN THEY DID NOT CROSS ZERO. NUMBER OF OBSERVATIONS ARE GIVEN UNDER THE COLUMN HEADED N

			Hyperidae			*Lucifer faxoni*			Brachyuran megalopa			Brachyuran zoea			*Calanopia americana* females			*Centropages velificatus* females		
CRUISE		N	u	$\bar{x}$	ℓ	u	$\bar{x}$	ℓ	u	$\bar{x}$	ℓ	u	$\bar{x}$	ℓ	u	$\bar{x}$	ℓ	u	$\bar{x}$	ℓ
WINTER	Day	12	-	413	-	-	3988	-	-	447	-	255	152	48	-	58	-	-	480	-
	Twilight	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Night	12	31905	17176	2447	4381	2874	1367	-	11897	-	6650	3962	1273	2068	1331	594	2513	1537	560
MARCH	Day	3	-	84	-	-	125	-	-	165	-	-	551	-	-	0	-	-	478	-
	Twilight	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Night	3	-	31349	-	-	5844	-	-	13620	-	-	11593	-	-	1661	-	-	2155	-
APRIL	Day	3	-	343	-	-	230	-	-	23	-	-	327	-	-	27	-	-	108	-
	Twilight	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Night	3	-	14443	-	-	9684	-	-	1584	-	-	12903	-	-	3317	-	10563	5808	1052
SPRING	Day	6	-	805	-	-	2609	-	-	696	-	-	1494	-	-	11	-	-	29311	-
	Twilight	7	-	36624	-	115152	60424	5695	-	430	-	-	6159	-	-	4165	-	-	59366	-
	Night	11	151055	85268	19480	19761	13132	6502	22427	12698	2968	18182	12021	5859	-	930	-	72905	41955	11004
JULY	Day	1	-	-	-	-	35	-	-	105	-	-	738	-	-	-	-	-	1265	-
	Twilight	3	-	99	-	-	9285	-	-	2768	-	-	426	-	-	-	-	-	114	-
	Night	2	-	4554	-	-	3638	-	-	8129	-	-	2737	-	-	123	-	-	1294	-
AUGUST	Day	2	-	75	-	-	101362	-	-	1659	-	-	3127	-	-	-	-	-	3319	-
	Twilight	1	-	89	-	-	757	-	-	-	-	-	178	-	-	445	-	-	757	-
	Night	3	-	29355	-	-	6426	-	-	11105	-	-	9214	-	-	5215	-	-	3885	-
FALL	Day	11	-	2653	-	5634	3130	625	-	325	-	-	-	-	-	24	-	-	1491	-
	Twilight	1	-	636	-	-	29771	-	-	14808	-	-	-	-	-	159	-	-	955	-
	Night	12	53563	28495	3877	5528	3502	1475	10800	6169	1538	4931	2775	619	-	4529	-	11929	6517	1105
NOVEMBER	Day	2	-	2411	-	-	15637	-	-	1269	-	-	379	-	-	677	-	-	5068	-
	Twilight	1	-	5451	-	-	1777	-	-	7229	-	-	355	-	-	829	-	-	177	-
	Night	3	-	6184	-	-	1874	-	-	4001	-	-	701	-	-	4507	-	-	8144	-
DECEMBER	Day	2	-	817	-	-	22024	-	-	815	-	-	1838	-	-	3071	-	-	2405	-
	Twilight	1	-	41	-	-	57	-	-	-	-	-	131	-	-	8	-	-	1748	-
	Night	3	-	1898	-	-	1385	-	-	4452	-	-	2824	-	-	22433	-	-	11549	-

TABLE 6 CONT.'D

Nannocalanus Minor			Temora stylifera			Anomolocera ornata immatures			Labidocera immatures			Pontellopsis villosa males			Chaetognaths			Fish larvae			Fish eggs		
u	$\bar{x}$	ℓ	u	$\bar{x}$	ℓ	u	$\bar{x}$	ℓ	u	$\bar{x}$	ℓ	u	$\bar{x}$	ℓ	u	$\bar{x}$	ℓ	u	$\bar{x}$	ℓ	u	$\bar{x}$	ℓ
-	616	-	-	1592	-	20370	11782	3193	-	-	-	-	177	-	2998	1804	609	809	427	44	-	14767	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14691	8520	2349	3131	1904	676	9567	4793	19	-	347	-	-	40	-	11878	8776	5674	852	577	302	13663		472
-	358	-	-	1638	-	-	8264	-	-	1207	-	-	16	-	-	3130	-	-	430	-	-	9118	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	21792	-	6726	6542	6357	-	13792	-	-	3169	-	-	110	-	-	21746	-	-	3068	-	-	6951	-
-	40	-	-	218	-	-	966	-	-	13743	-	-	-	-	-	309	-	-	233	-	-	2171	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	16428	-	-	17273	-	-	9233	-	-	100612	-	-	145	-	10388	7731	5073	1061	722	382	-	5307	-
-	-	-	6817	3836	854	-	-	-	-	184046	-	3849	2367	884	7431	3821	210	-	341	-	-	4114	-
-	1071	-	179432	97112	14792	-	-	-	-	26664	-	-	61450	-	18362	12468	6573	-	543	-	-	7182	-
4082	2176	269	77722	47760	17797	-	-	-	-	5360	-	-	989	-	34078	22998	11917	2597	1601	604	6348	3507	-
-	-	-	-	4219	-	-	-	-	-	984	-	-	35	-	-	1336	-	-	8	-	-	1371	-
-	990	-	-	518	-	-	-	-	-	8089	-	-	516	-	-	2306	-	-	205	-	-	1497	-
-	1265	-	-	6027	-	-	-	-	-	7006	-	-	24	-	-	4539	-	-	2555	-	-	6247	-
-	-	-	-	671	-	-	-	-	-	113	-	-	2428	-	-	720	-	-	79	-	-	1706	-
-	133	-	-	3208	-	-	-	-	-	44	-	-	222	-	-	2718	-	-	133	-	-	757	-
-	240	-	-	1579	-	-	-	-	-	232	-	-	3714	-	-	4575	-	-	3584	-	-	5299	-
-	9	-	1408	780	151	-	-	-	995	599	202	2861	2184	1506	-	2111	-	136	72	7	-	741	-
-	-	-	-	159	-	-	-	-	-	159	-	-	636	-	-	477	-	-	62	-	-	159	-
-	526	-	-	1311	-	-	-	-	2372	1393	414	-	2036	-	13456	8733	4009	1656	961	265	965	534	102
-	-	-	-	507	-	-	20098	-	-	590	-	-	1943	-	-	5443	-	-	357	-	-	866	-
-	2666	-	-	118	-	-	-	-	-	237	-	-	-	-	-	1777	-	-	125	-	-	59	-
-	489	-	-	365	-	-	2068	-	-	189	-	-	474	-	-	5412	-	-	424	-	-	429	-
-	-	-	-	1514	-	-	-	-	-	-	-	-	2968	-	-	5440	-	-	3859	-	-	477	-
-	-	-	-	41	-	-	-	-	-	41	-	-	90	-	-	362	-	-	113	-	-	-	-
-	2554	-	-	3360	-	-	-	-	-	517	-	-	297	-	-	11350	-	-	1405	-	-	700	-

Decapod larval species diversity was greater in spring and fall than in winter and greater at nearshore stations than at offshore stations. The decrease in larval diversity with distance from shore could be expected since decapod larval input into the surface waters is greatest over inshore areas where benthic decapod adult populations are more diverse and there is the direct influence of estuarine input to the system. Nearly all of the dominant decapod larvae reached greatest concentrations during the spring.

A large number of fish taxa occur in the neuston off south Texas for at least part of their life span; most have distinct seasonal, diel and horizontal distribution cycles. The neuston fauna consisted of a cold water component, present either from fall through winter, or from winter through early spring; a warm water component, present either from late spring through summer or entirely during the summer; and a ubiquitous component present in high abundance most of the year. Within each of the seasonal components, taxa were generally distributed either inshore or offshore and were present in the neuston zone either nocturnally or diurnally.

Diversity of fish taxa, when computed for each of the sampling years, was relatively high (H' = 2.72 for 1976; H' = 2.58 for 1977). In 1976, the most abundant taxa (those which individually represented 2.5% or more of the total) were: *Antennarius* sp. (22.6%), *Harengula jaguana* (11.9%), *Mugil cephalus* (8.6%), Mullidae (8.1%), *Opisthonema oglinum* (4.4%), *Cynoscion* sp. (4.2%), Gerreidae (3.8%), *Engraulus eurystole* (3.0%), *Micropogon undulatus* (2.9%), and *Citharichthys spilopterus* (2.5%). With the exception of *Antennarius* sp. which was captured at only three stations, these taxa were widely distributed over the survey area during at least one of the sampling seasons (winter, spring-summer, fall).

In 1977 the most abundant taxa, representing 2.5% or more of the total, were: Mullidae (18.1%), *Etrumeus teres* (12.9%), *Harengula jaguana* (8.5%), Gerreidae (4.7%), *Trachurus lathami* (4.6%), *Rachycentron canadum* (4.0%), *Mugil curema* (3.3%), *Prionotus* spp. (3.2%), *Mugil cephalus* (2.6%), and *Menticirrhus* sp. (2.6%). All of these taxa, with the exception of *Rachycentron canadum*, were widely distributed over the survey area during at least one of the sampling seasons (winter, spring-summer, fall). The Gerreidae, *Prionotus* spp. and *Menticirrhus* spp. were each represented by several species in the survey area.

Analysis of variance of tar concentrations collected in neuston tows showed significant differences according to season and transect but not station or time. To illustrate this, tar concentrations were highest during March and September-November. In part this was due to single high values which shifted the means upward. Figure 21 shows variations on tar ball concentrations with transect in the STOCS area. Highest averages were observed on Transect I and II with dramatic decreases on Transects III and IV. It should be noted that Transect II was sampled more consistently (monthly) during the study period which may account for the higher mean concentrations. The trends suggest, however, that presently the surface concentrations of hydrocarbons may be related to ship traffic in the Aransas Pass Inlet and other points in the northern Gulf and extensive petroleum activities in the waters off Louisiana, north of the STOCS study area.

The only significant correlation for neuston biomass observed during this study was with the amount of tar obtained in the same samples. Two theories may possibly explain this phenomenon. One concerns surface circulation which creates convection cells, *i.e.* Langmuir cells (Pollard, 1977). If tar is considered to be a passively floating object, then it

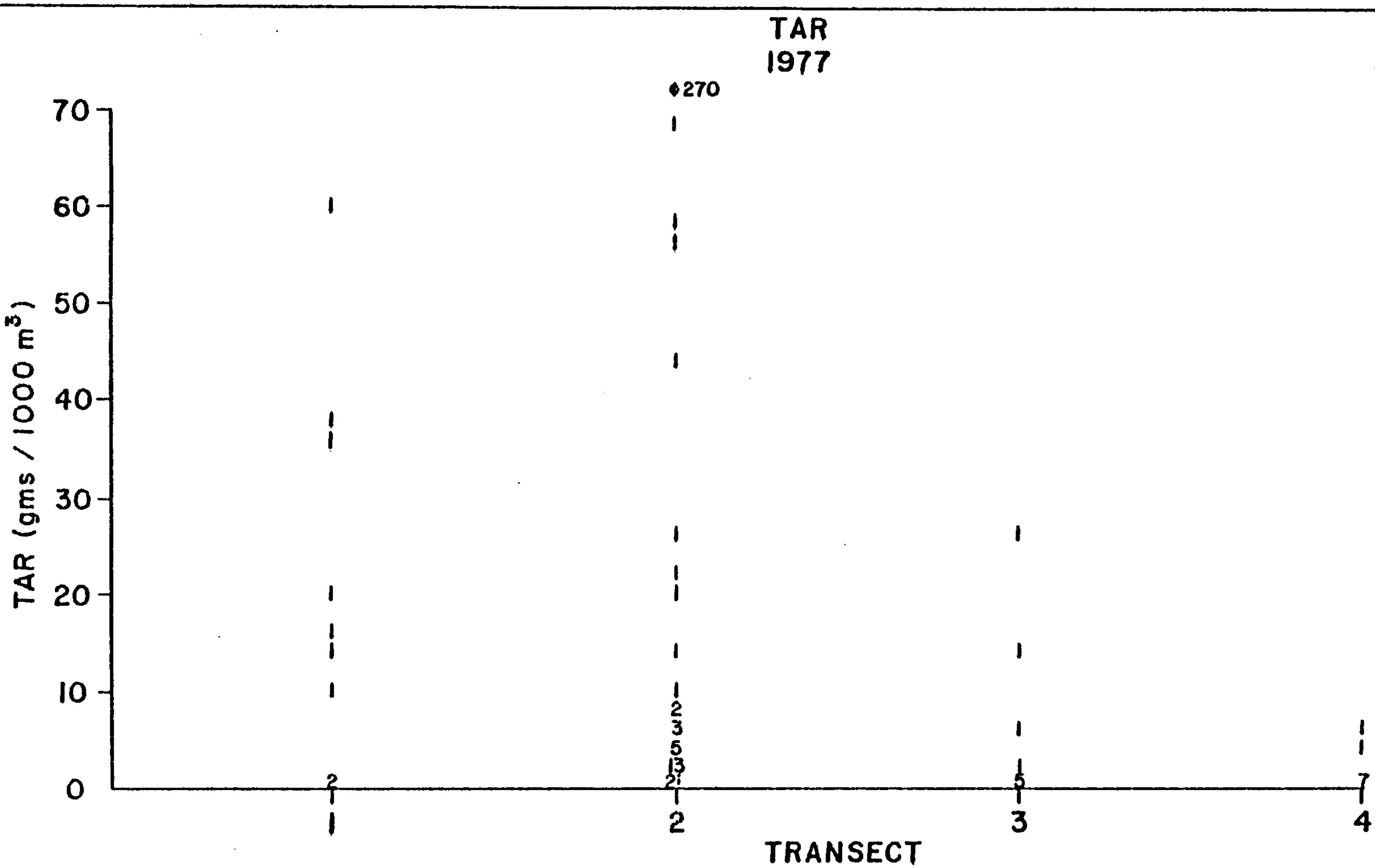

Figure 21. The variation in tar concentration by transect. The numbers represent the number of coincident points.

would be expected to be concentrated by this type of circulation into windrows. The positive correlation then may suggest that neuston, in general, are also concentrated in windrows to some extent.

An alternative explanation may be related to the nutrition of neuston. It has often been observed in Gulf waters that small fish and larger crustaceans (*i.e.* crabs) are frequently associated with small floating pancakes of mousse and tar balls. These reports have included observations of the fauna feeding off the tar and mousse. There is a very good likelihood that well-weathered petroleum products floating in the Gulf surface waters develop growths of epiphytes and other colonial forms normally associated with hard surfaces. These growths on the floating tar could possibly be providing a food source to many surface-oriented species including neuston.

Neuston cluster grouping results showed patterns consistent with water temperature trends. Thus it could be concluded that the dynamics of the neuston may be controlled by temperature, which is the influential factor related to spawning of many of the temporary populations found in the neuston.

In general, the faunal composition of the neuston differed from that of the water column below the neuston zone. Finucane (1976, 1977) reported on the ichthyoplankton captured in the water column from the same stations sampled in this study and found a number of differences between the species composition of the two. Fishes of the neuston zone can be classified as facultative neustonic taxa or euneustonic taxa. Those of the former category are found in the neuston during the larval stage while those of the latter category spend their entire life history in the neuston. Facultative forms dominate the neuston and a majority of these spend their juvenile and adult stages in the estuaries and inshore waters of the northwestern Gulf of Mexico.

Diel variability played a large role in influencing the dynamics of the STOCS neuston. In addition, distance from shore played a role for many taxa, particularly the decapods, probably due in large part to the benthic distribution patterns of the adult species and estuarine influences.

Zooplankton

Zooplankton biomass, total density, and female copepod density decreased with distance offshore. When only the means were considered (Figures 22 and 23), biomass weights not only decreased seaward but varied most consistently between seasons at the shallow stations. Mean total zooplankton densities varied similarly in a seaward decrease, but seasonal fluctuations by depth were poorly patterned. Mean densities of female copepods changed with the total zooplankton, decreasing with depth. Species diversities followed the same patterns of change with depth and season that were observed in the number of species. The mean equitabilities, however, showed almost no pattern of change related to depth or season. The relatively low mean values obtained for equitability at each depth, indicated that a few species accounted for most of the zooplankton density across the shelf.

The dominant female copepod species observed during this study are illustrated in Figure 24 along with their frequency of occurrence at stations along Transect II. Copepod species formed five species groups which were generally related with water depth (station location) on the transect. The first group was generally considered ubiquitous in nature. Group 2 was confined to the shallower waters on the shelf, Group 3 to mid-depths, and Groups 4 and 5 to the deeper waters. In addition to the general trends

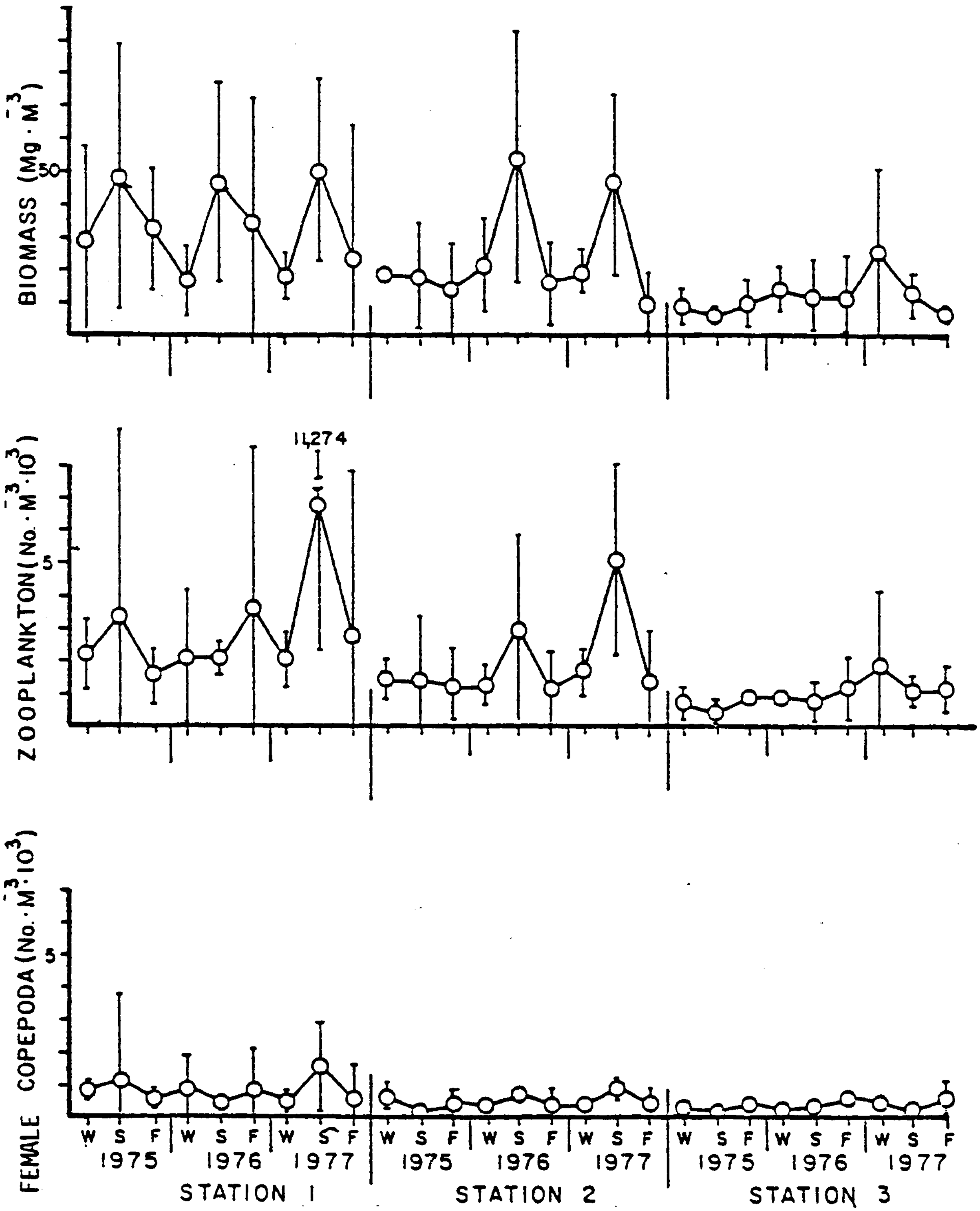

Figure 22. The mean (circles) and 95% confidence interval (bars) for representative zooplankton variables (average of four transects for each station and season).

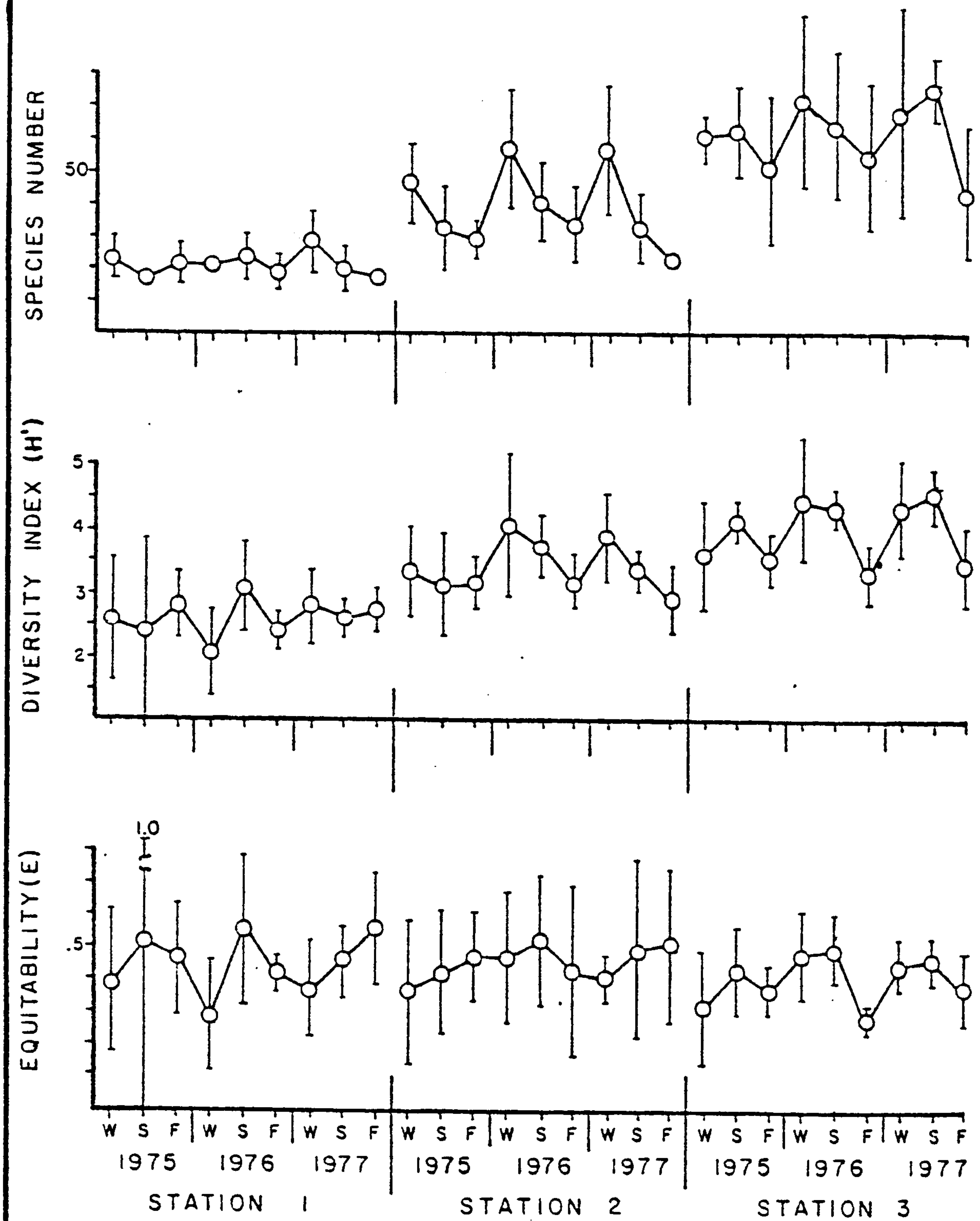

Figure 23. The mean (circles) and 95% confidence intervals (bars) for representative zooplankton variables (average of four transects for each station and season).

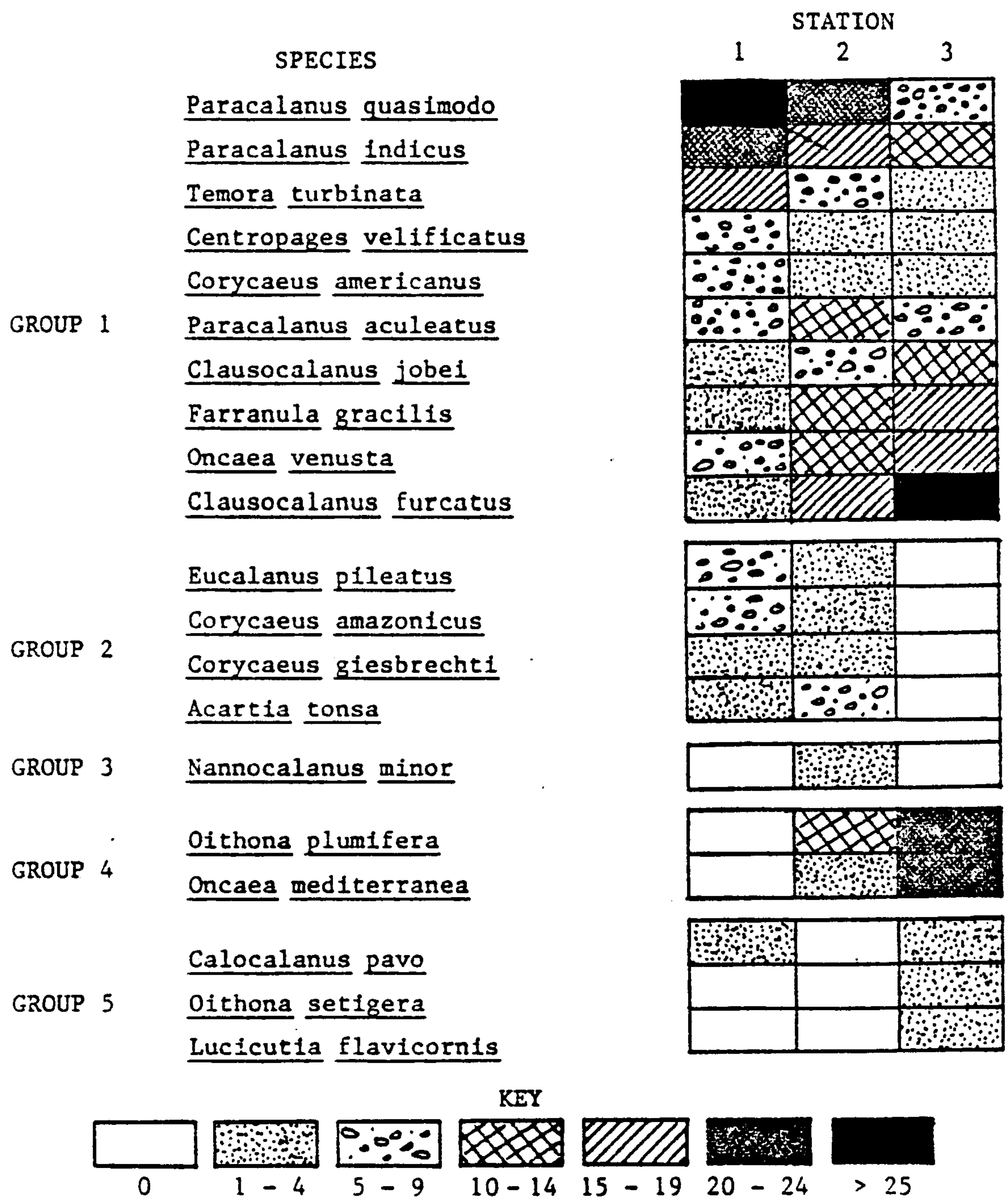

Figure 24. The frequency of occurrence of female copepod species used in cluster analysis for each bottom depth (= station 1-3 in order of increasing depths). Maximum number of occurrences = 36.

observed in Figure 24, the dominant species at both the shallow and mid-depth stations on the Texas shelf usually differed during the semi-annual periods from December-June and July-November.

The results of representative zooplankton variables such as biomass, total zooplankton density and female copepod density revealed considerable variation in zooplankton distribution along bottom-depth contours from transect to transect during each of the nine seasonal cruises. The variability suggested the occurrence of pulsing inputs to the systems which encouraged zooplankton production but which were so limited that the entire length of the study area was not uniformly affected. For example, the calanoid species *Acartia tonsa*, *Paracalanus indicus*, *Paracalanus quasimodo*, and *Clausocalanus furcatus* were often found in dense patches on one or two transects in the spring. Cladocerans, *Penilia* spp., appeared in a highly regionalized dense patch at Station 1, Transect II in the spring of 1977 and in August 1976. Ostracods, primarily *Euconchoecia chierchiae*, were found in dense patches at various stations throughout the study.

It is possible that the patchy distribution of the zooplankton in the study area was related to pulses of low salinity input from bay systems. Evidence for estuarine influence in the STOCS area may be found in the composition of copepod species. *Acartia tonsa* is a calanoid copepod which is almost always reported among the most abundant copepod species inhabiting bays and estuaries in the Gulf of Mexico and along the Atlantic coast from Florida to Cape Hatteras (Breuer, 1962; Cuzon du Rest, 1963; Bowman, 1971). In the STOCS area *Acartia tonsa* appeared in large numbers in 1975 at the nearshore and mid-depth stations on Transects I and II in the spring. In all three years *Acartia tonsa* was most abundant in the spring when salinities were low and the largest abundances in other typically estuarine copepod species (*Centropages hamatus, Labidocera aestiva, Oithona nana* and *Paracalanus crassirostris*) were also most abundant.

Multiple regression analysis identified possible relationships between zooplankton densities and physical, nutrient and phytoplankton variables. A number of expected, or at least plausible, relationships were indicated; however, occasional relationships between trophically separated entities (*i.e.* phosphates and copepods) suggested that some of the relationships may be deceptive. At the shallow stations, changes in ichthyoplankton more frequently related to the variation in zooplankton variables than any of the other independent (physical or phytoplankton) variables. This may indicate that ichthyoplankton populations were possibly responding to changes in zooplankton density. It is generally accepted that some species of planktonic fish take advantage of the zooplankton as a food source (*e.g.* Peters and Kjelson, 1975).

Salinity, although related to several zooplankton community characteristics at the shallow stations, was more often highly correlated with these at the mid-depth stations. The implied relationships between zooplankton variables and salinity at the mid-depth stations may indirectly reflect a response of the zooplankton to changes in primary production which have been shown to be commonly associated with salinity changes in neritic waters.

The number of associations between zooplankton and phytoplankton variables increased seaward. At the deep stations, phytoplankton density generally accounted for the largest percentages of explained variation in zooplankton variables. The implied direct relationship of zooplankton to phytoplankton at the deep stations reflects a close dependence of zooplankton on phytoplankton which is generally reported for oceanic, subtropical or tropical areas of marine waters (Menzel and Ryther, 1961; Sander and Moore, 1978). The combined results from the three depth contours suggested that offshore zooplankton populations may be controlled by food availability while nearshore zooplankton populations may be controlled by predation.

Results from studies of microzooplankton on the Texas shelf indicated that protozoa reached a maximum in abundance in early spring (March-April). A second protozoan abundance peak was noted in September 1977 but this peak was thought to be atypical and a result of Hurricane Anita which passed through the area at that time. Oligotrichs were the dominant protozoan group on the STOCS, both spatially and temporally. The other protozoan groups tended to be more restricted both in space and time. Species diversity was high during most of the year and varied erratically. Protozoan biomass ranged from 1 to 348% of the macrozooplankton biomass, indicating that protozoa are a significant component of the zooplankton community.

Zooplankton Body Burdens

Hydrocarbons

Approximately 50% of the zooplankton hydrocarbon samples taken in 1977 showed the possible presence of petroleum-like organic matter. This was slightly more than was observed for samples in 1976 (30%) and considerably higher than observed in 1975 (7%). This apparent increase may be a reflection of the increased import activities for crude oils during this time interval.

The criteria for presence of petroleum-like organic matter are smooth distribution of n-alkanes in the region of molecular size greater than

C_{21} and odd/even preference (OEP) values close to unity. In the case of samples analyzed by gas chromatography/mass spectrometry (GC/MS) techniques, the presence of aromatic compounds is usually indicative of petroleum-like material.

Seven zooplankton samples were investigated by GC/MS analyses in 1977. One sample, 3/IV, spring, contained polynuclear aromatic hydrocarbons (PAH) in quantities such that they were readily identified even though the quantities were too inadequate for the components to be observable in the gas chromatographic analysis. Four samples (1/II, spring; 2/III, spring; 3/II, spring; 1/IV, spring), showed possible trace quantities of PAH by GC/MS analysis, though quantities were inadequate to permit certain identification. Two samples (2/IV, winter; 1/III, fall) showed no indication of the presence of PAH. All seven of these samples met the n-alkanes distribution criterion as possibly having petroleum-like organic matter present.

Although relatively high OEP values were observed for particulate hydrocarbons in the water column, these values were considerably lower than values found for zooplankton in this study. Zooplankton average OEP values for nine seasonal sampling periods ranged from 2.0 to 15.4 with an average of 5.8. The comparatively low values of OEP for particulate hydrocarbons (0.9 - 1.6) suggested that the majority of these hydrocarbons were not synthesized by zooplankton or higher plants. The higher zooplankton values observed could have reflected the bioaccumulation and concentrating tendencies of zooplankton for pelagic particulate matter in general during their feeding activities. It is well documented (Conover, 1971) that zooplankton will ingest micro-tarballs and other petroleum forms from the water column and pass them through their systems without digesting them. This is also a mechanism for input of petroleum hydrocarbons to the benthos via zooplankton fecal pellets.

The usual range of total hydrocarbon concentration in zooplankton was 50 to 500 μg/g. Total hydrocarbons did not show either temporal or spatial variations that were significant. None of the isoprenoid parameters were shown to vary in a statistically significant manner.

Seasonal averages of zooplankton hydrocarbon concentrations in the region of C_{25}-C_{32} (which represent the sum of highest carbon ranges of high molecular weight hydrocarbons) as well as the seasonal average OEP values are plotted in Figure 25A. Since both parameters were estimates of the quantity of petroleum hydrocarbons, they were considered as a single data set from which a curve was constructed. The large standard deviation associated with both parameters results from the "patchiness" of zooplankton and petroleum hydrocarbons likely present as micro-tarballs. In view of the difficulty in obtaining representative samples composed of two components each having its own unequal distribution, the fit of points to the curve is rather good. The data (Figure 25A) suggested a significant increase in the contribution of petroleum hydrocarbons to zooplankton samples during the three-year study period.

Exploration and drilling activities in the study area probably were not a major source of petroleum residues found in the zooplankton samples. A much more likely source would be the oil tankers which delivered increased quantities of crude oil to Texas ports during the study period. The quantity of crude oil imported to the Port of Corpus Christi and Harbor Island from 1975 through 1977 has been plotted in Figure 25B. The curve generated by the data of Figure 25A has been included in Figure 25B for comparison, and the two show a good correlation suggesting potential causes of hydrocarbon increases.

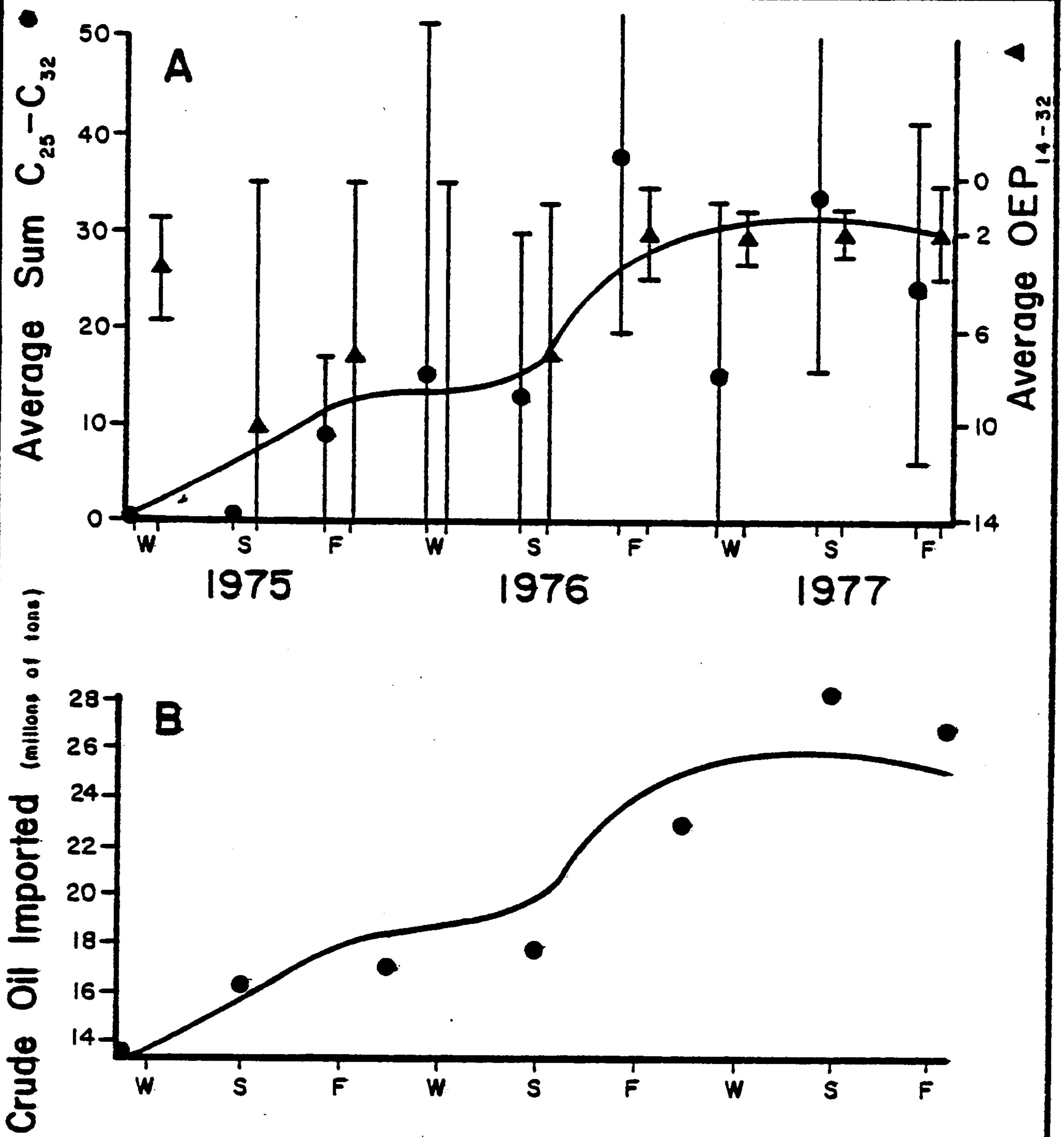

Figure 25. A. Average Sum Hi (C_{25}-C_{32}) and average OEP of zooplankton samples 1975-1977.

B. Crude oil imported to the Port of Corpus Christi and Harbor Island 1975-1977.

Curve from A has been included in B for comparison.

Trace Metals

Table 7 summarizes the three years of zooplankton trace element data by station and transect sampled. The only truly meaningful spatial effect observed in zooplankton was an increase in Cd concentrations offshore. The reason for this trend is not clear. The trend does not suggest any significant anthropogenic input of Cd to the nearshore environment. Secchi depth, however, was strongly correlated with Cd levels (r^2 = .30). This parameter is a measure of turbidity and suggested that zooplankton Cd levels were influenced in some way by the amount of suspended particulate matter in the water column.

Table 8 summarizes the average seasonal concentrations of trace metals in zooplankton observed during this three-year study. Aluminum, Fe and Ni exhibited significant seasonal trends. Elevated levels of Al and Fe in zooplankton samples are generally interpreted as incorporation of clay particles by the zooplankters (Martin and Knauer, 1973). Considerable evidence suggested that this process is responsible for the seasonal trends observed here. The concentrations of Al and Fe in suspended matter from the Gulf of Mexico were approximately 9% and 5%, respectively (Trefry and Presley, 1976a). The Fe/Al ratio in such particulates was 0.56. Aluminum and Fe levels in zooplankton samples from this study were strongly correlated (r^2 = .81) and the average Fe/Al ratio was 0.52. In addition, the trend in zooplankton Al and Fe concentrations (Table 8) corresponded well with the observed seasonal fluctuations in suspended matter concentrations in STOCS surface waters. Suspended particulate concentrations are generally highest in the fall and lowest in the spring (Berryhill, 1978). Also Al and Fe levels in zooplankton decreased with increasing distance from shore. These geographical trends for zooplankton were

TABLE 7

AVERAGE CONCENTRATIONS OF TRACE ELEMENTS IN ZOOPLANKTON FROM THE STOCS STUDY

Transect	Station	Number of Samples	Concentration in ppm dry weight (95% confidence interval observed around mean)									
			Cd	Cr	Cu	Fe	Ni	Pb	V	Zn	Al	Ca
I	1	18	1.4 (0.65-3.0)	6.0 (0.10-22)	14 (5.0-23)	4500 (400-13000)	8.5 (0.60-20)	22 (1.8-160)	21 (4.0-45)	120 (9.0- 500)	7000 (1900-19000)	35000 (14000-40000)
	2	20	3.0 (1.6 -6.0)	4.5 (0.35-14)	21 (6.0-90)	1900 (100- 5000)	6.0 (2.0 -11)	13 (1.4- 75)	9.5 (1.2-20)	125 (6.0- 210)	2500 (140- 6500)	30000 (4500-60000)
	3	12	5.0 (3.0 -7.0)	2.5 (0.40-6.0)	24 (9.5-70)	1200 (130- 3900)	8.0 (3.0 -15)	7.0 (1.3- 13)	7.0 (1.4-25)	130 (95- 160)	2200 (100-10000)	35000 (22000-65000)
II	1	16	2.4 (0.95-5.5)	4.0 (0.70-14)	20 (2.5-75)	3000 (35-13000)	5.0 (2.2 -16)	11 (1.3- 70)	16 (0.4-70)	130 (25- 250)	5500 (12-25000)	30000 (16000-45000)
	2	20	3.5 (1.8 -5.5)	3.5 (0.50-9.0)	190 (5 -2500)	2100 (20- 8500)	7.0 (1.9 -30)	11 (1.0- 70)	16 (2.2-65)	180 (22- 500)	4000 (75-14000)	65000 (8000-140000)
	3	12	5.0 (3.5 -7.0)	2.5 (0.10-7.5)	21 (7.0- 90)	1600 (40- 8000)	6.5 (2.0 -18)	12 (0.6- 65)	14 (2.0-25)	110 (40- 190)	2500 (95-12000)	30000 (16000-50000)
III	1	18	2.0 (0.65-4.0)	4.5 (0.60-13)	16 (5.5- 60)	3000 (240-17000)	5.5 (0.95-30)	15 (0.60-45)	25 (4.0-60)	130 (30- 270)	7000 (850-30000)	60000 (18000-100000)
	2	20	3.5 (1.5 -5.5)	4.5 (0.30-10)	14 (8.0- 20)	3000 (550- 6600)	7.0 (3.0 -18)	10 (0.80-40)	15 (3.0-70)	140 (35- 500)	6000 (1300-30000)	50000 (25000-80000)
	3	12	4.5 (1.8 -6.0)	3.5 (0.75-8.0)	13 (6.0- 30)	2500 (350-11000)	7.0 (2.0 -17)	8.5 (0.80-30)	10 (3.5-35)	220 (75-1300)	4500 (300-17000)	30000 (25000-35000)
IV	1	16	3.0 (0.80-4.5)	3.0 (0.45-8.5)	13 (6.0- 35)	3000 (200-12000)	6.0 (2.0 -16)	7.0 (0.80-40)	13 (4.5-50)	170 (75- 500)	4500 (550-20000)	25000 (9500-35000)
	2	18	3.0 (0.60-4.5)	5.5 (0.11-16)	50 (8.0- 300)	5000 (24-15000)	10 (2.0 -40)	23 (0.55-140)	24 (2.3-85)	350 (9.0-2000)	9000 (80-25000)	40000 (10000-70000)
	3	12	4.0 (2.5 -6.0)	4.0 (0.10-11)	17 (7.5- 55)	550 (70- 1600)	5.5 (3.0 -8.0)	12 (0.60- 40)	13 (5.0-25)	180 (80-1000)	1500 (200- 3000)	4000 (35000-50000)
Transect [1]			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Station [1]			.001	NS	NS	.005	NS	NS	NS	NS	.008	NS

[1] ANOVA results: metals for which the main effect indicated was significant at level shown. NS means not significant ($p > .05$)

TABLE 8

AVERAGE SEASONAL CONCENTRATIONS OF TRACE ELEMENTS IN ZOOPLANKTON FROM THE STOCS STUDY

Season[1]	Number of Samples	Concentration in ppm dry weight (95% confidence interval observed around mean)									
		Cd	Cr	Cu	Fe	Ni	Pb	V	Zn	Al	Ca
Winter	56	3.0 (0.85-5.0)	4.0 (0.60-8.5)	15 (4.5-45)	2300 (120-6000)	5.5 (2.0-9.5)	15 (1.5 -45)	13 (4.0-40)	160 (25- 500)	4500 (250-13000)	30000 (9500-50000)
Spring	70	3.5 (1.1 -6.0)	3.5 (0.10-10)	16 (6.0-38)	950 (23-3500)	6.0 (1.9-18)	7.5 (0.60-45)	13 (1.3-65)	130 (40- 200)	1300 (75- 5000)	45000 (16000-90000)
Fall	68	3.0 (0.65-6.0)	5.5 (0.15-14)	70 (5.5-210)	5500 (30-15000)	9.5 (1.6-25)	14 (0.65-80)	25 (4.0-45)	220 (9.0-1000)	11000 (100-25000)	50000 (16000-95000)
Season[2]		.022	NS	NS	.001*	.001*	NS	NS	NS	.001*	.005

1 Seasons: Winter = Jan.-Feb.; Spring = May-June; Fall = Sept.-Oct.

2 ANOVA Results: metals for which season main effect was significant at the level shown. NS means not significant ($p > .05$). Asterisk (*) indicates season main effect was significant in both 2-way ANOVA tests made which included that effect.

TQ

significant in only one of the two ANOVA tests conducted involving station effect. As a result they could not be considered completely clear cut. Still, they were consistent and followed suspended matter concentrations which also decreased offshore (Berryhill, 1978).

CHAPTER FOUR

MARINE BENTHIC ENVIRONMENT OF THE SOUTH TEXAS SHELF

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General Features

The primary topographic features of the STOCS are the deltaic bulge seaward of the Rio Grande, the comparable outline of an ancestral delta near the shelf edge seaward of Matagorda Bay, the Colorado-Brazos, and the broad ramp-like indentation on the outer shelf between the two deltaic bulges. Second order topographic features are the north-to-northeastward trending low ridges, terraces and low scarps over the ancestral Rio Grande delta, the series of small enclosures associated with a band of irregular topography (*e.g.* Hospital Rock, Southern Bank) along the ramp between water depths of 64 to 91 m and the terrace-like area along the outer shelf beginning at the 91 m isobath.

In general, the remainder of the sea floor is characterized by sand-sized sediments on the inner shelf which decrease in abundance seaward. The surficial and near-surface bottom sediments are typically relatively soft and not suitable for bearing heavy structures at shallow depths

(Berryhill, 1977). Some slumping of the seafloor sediments has been indicated along the periphery of the ancestral Rio Grande delta. Where firm relict sand and soft mud are locally adjacent, seafloor stability is highly variable over short distances. Rapid rates of local sediment deposition or scour have not been observed for this area.

According to results of the 1975 study on STOCS summarized by Berryhill (1977), sand is being transported seaward from the high energy zone of the innermost shelf. The presence of thin, discrete sand layers in the subsurface sediments to a distance of at least 18 km offshore suggests that transport of sand occurs over a relatively short time and is influenced by short-lived events. The encroachment of sand particles into the Texas shelf from the north suggests a regional southward movement of sediment.

A feature peculiar to the outer continental shelf of the northwestern Gulf of Mexico is the series of pinnacle-like banks or topographic highs rising abruptly from the generally smooth, sediment-covered bottom (Parker and Curray, 1956). Two of these, Hospital Rock and Southern Bank, were studied in conjunction with the STOCS survey. In addition, a series of inshore irregularities between 26° and 27°N latitude (near Transects III and IV, respectively) include scattered rock, shell and sand banks at 20 to 30 m and 50 to 80 m and a series of inshore elongated troughs and ridges from 10 to 18 m (Mattison, 1948). Some of these features have been determined to be of lacustrine origin (Thayer *et al.*, 1974) as well as remains of an earlier more northerly extension of the Rio Grande delta system. STOCS study transects did not incorporate any of these features.

<u>Sediment Structure</u>

The 25 transect stations sampled during 1975-1977 on the south Texas shelf included a wide range of sediment textures from silty clays to muddy sands. Stations varied enough so that each could be treated as having unique characteristics. More efficient or meaningful comparisons with other data could be obtained, however, if generalizations were based on groups or gradients of textural data.

The most distinctive group was the outer shelf clays. These graded from finest, best-sorted, and least variable texture for the outermost stations (7/IV, 6/III, 3/III, and 3/II) to slightly less well-sorted, siltier, more variable stations (2/III, 5/III, 5/II, 6/II and 3/I). These deepest stations generally displayed mean grain sizes of 8.5 to 9.6 ∅ and averaged only 5% sand and 33% silt. Station 5/I was very similar to this group but was more variable. Station 6/I was similar in variability but slightly coarser and less well-sorted with a mean grain size of 7.7 ∅ and 18.5% sand.

Station 4/III was most characteristic of the outer margin (shoreface) of the barrier island sand body where variability was low, probably because wave action could constantly maintain a fairly well-sorted texture. Slightly seaward of this zone, sand usually remained predominant but was mixed with considerable amounts (20 to 50%) of shelf mud (Stations 1/I, 4/I, 1/IV, and 4/IV). The stations on Transect I had fine to very fine sand as the coarse fraction while those from Transect IV had much coarser sand and some gravel in the coarse fraction.

The rest of the stations on Transect IV (3, 4, 5 and 6) were characteristically very poorly sorted, variable mixtures of fine gravel to fine clay. High sample variability suggested that bottom conditions were least uniform in this environment with abundant patches of both very clayey and coarse, sandy sediment.

In addition to being related to physical energy intensity and variability, sediment texture variability is also related to variety of source material. Thus, where older sediments are being reworked into more recent material on the Rio Grande delta, there is relatively high variability. The highly variable Station 5, Transect I may be similarly related to the ancestral Colorado-Brazos delta sediments at the northern margin of the study area.

Maximum variability was characteristic of a zone just seaward of the boundary of shoreface sands (Stations 1/II and 1/III). Fine sand constituted between 10% and 40% of the sediment and was apparently distributed very heterogeneously on scales from centimeters to tens of meters. Adequate statistical sampling in this zone and on the Rio Grande delta would require the largest number of replicates, probably more than has been used in the BLM studies.

The last group of Stations (2/I, 2/II and 4/II) represented mid-shelf muds of moderate variability. Although the means for these stations were generally in the silt range, silt was almost never predominant, and relative amounts of sand, silt, and clay were extremely variable with each ranging from 20% to 40%. Consequently, sorting was poor with a mean of 3.5 ± 0.3 ∅.

The degree of in-station variability did not correlate closely with significant seasonal textural changes. In fact, significant seasonal changes tended to occur in regions which had the most uniform sorting. This suggested that seasonal changes were due to active processes rather than to variability of repositioning stations on successive sampling cruises.

Four stations (1/II, 2/III, 5/IV, and 6/IV) showed significant seasonal changes in sediment texture. The change was an increase in coarseness during the spring accomplished by both an increase in sand and a decrease in clay with little change in silt content. This may have resulted from winnowing of clays and some fine silts during the spring when seasonal winds were at a maximum. The high spatial variability of the Rio Grande delta and the high probability of at least one navigational error having occurred in this region (Station 6/IV) however, made navigational variance a slightly more plausible explanation in this case. Station 6/IV was among the group with a high percentage increase in sorting with the addition of possible seasonal effects, but no other indicators suggested a real temporal change at this station, and none was believed to be significant.

The remaining five stations that showed significant seasonal changes were 1/I, 2/I, 3/I, 3/II, and 4/II. The seasonal changes at Station 3/II followed the most widespread, significant seasonal changes observed in 1976. Those were spring coarsenings at the outer shelf, clayey stations accomplished by reduction in the quantity of finest clays (> 10 Ø). Stations 6/I, 4/II, 5/II and 6/II, also followed this trend, but most of these stations lacked the precision LORAC navigation on the spring cruise when coarsening was observed. Furthermore, the spring coarsening was caused by complex variations in sand, silt, and clay contents rather than just loss of fine clays. Many stations (3/I, 3/III, 5/III, 6/III and 7/IV) in the outer-shelf group showed no pattern or opposite seasonal trends. Consequently the trend apparent in the 1976 data of spring coarsening on the outer shelf by winnowing of the finest clays had little support from the 1977 data.

In contrast to the outer-shelf stations, the inner-shelf stations with high sand contents (30 to 80%) showed similar coarsening trends throughout 1977. Although changes at Station 4/III were relatively small, the small intrastation variance made them significant. Coarsening occurred throughout the year, whereas in 1976 spring coarsening was followed by fall fining at this station. Significant spring coarsening also occurred at Station 1/I. All coarsening at inner-shelf stations accompanied increases in sand content and decreases in mud content, resulting possibly from sand deposition, mud erosion, or both. If sand deposition occurred, it would imply a general offshore movement of sand from the barrier shoreface. This and mud erosion may have resulted from an increase in wave climate. The coarsening effects apparent in the fall seasonal samples may have been related to such an increase resulting from the passage of a hurricane just south of the study area in August preceding the fall sampling cruises. The effectiveness of this event was supported by some fall coarsening at all inner-shelf stations, although Stations 4/I, 1/IV and 4/IV did not pass tests of significance.

Station 2/I varied similarly to the inner-shelf stations during 1977 in that an increase in sandiness caused the spring texture to be significantly coarser than the texture for the winter samples. There was no significant change, however, between spring and fall at this station.

On the other hand, Station 3/I showed spring fining and fall coarsening. These changes apparently resulted from clay deposition in the spring and silt deposition in the fall. These events represented the deeper water equivalents to coarser particle deposition at the inner-shelf stations.

The preceding description of the south Texas shelf sediment structure can be summarized by reference to several sediment variables listed in Table 9 and illustrated geographically in Figure 26. These variables are categorized according to station groupings similar to those listed above but also represent major biotic zones of the benthos which are described in detail in the next chapter. The textural gradients offshore

TABLE 9

THE MEAN AND STANDARD DEVIATION () FOR SEVERAL SEDIMENT VARIABLES FOR THE STATION GROUPINGS DEFINED BOTH FROM COMMUNITY ORDINATION OF BENTHIC SPECIES LISTS AND DISCRIMINANT ANALYSIS. ANALYSIS OF VARIANCE INDICATED SIGNIFICANT DIFFERENCES (P < 0.01) BETWEEN ALL GROUPS. LEAST SIGNIFICANT DIFFERENCE RESULTS FOR INDIVIDUAL GROUPS NOT SIGNIFICANTLY DIFFERENT FROM EACH OTHER (P < 0.05) ARE INDICATED BY OVERLAPPING HORIZONTAL LINES OR SIMILAR SUPERSCRIPTS

Variable	Group 1	Group 2	Group 3	Group 4	Transition Stations	Group 5
Depth	15.0 (8.8)	18.5 (0.0)	33.6 (10.2)	67.7 (18.6)	84.6 (13.3)	125.0 (10.3)
Mean Grain Size	4.10 (0.51)	4.90 (0.42)	7.47 (0.98)	6.68 (1.57)	8.74 (0.70)	9.45 (0.23)
Grain Size Deviation	2.60 (0.48)	3.57 (0.27)	3.46 (0.27)	3.86 (0.43)	3.15 (0.26)	2.90 (0.15)
Grain Size Skewness	2.56 (0.84)	1.28 (0.32)	0.37 (0.31)	0.38 (0.46)	-0.03 (0.22)	-0.27 (0.10)
Percent Sand	79.2 (5.1)	65.4 (6.5)	22.1 (14.6)	40.3 (21.5)	8.3 (6.1)	3.2 (2.4)
Percent Silt	9.8 (3.0)	13.3 (3.1)	35.6* (8.2)	19.5 (7.5)	34.8* (5.3)	30.3 (2.1)
Percent Clay	11.0 (4.4)	21.3 (4.5)	42.3 (9.8)	40.2 (14.1)	56.8 (9.2)	66.5 (3.0)
Sand/Mud Ratio	4.66 (1.2)	2.14 (0.7)	0.36 (0.3)	0.90 (0.6)	0.10 (0.08)	0.04 (0.04)
Silt/Clay Ratio	1.25 (1.02)	0.65*[a] (0.19)	0.89 (0.25)	0.49*[a] (0.04)	0.65* (0.18)	0.46[a] (0.05)

*a - Similar superscripts indicate no significant differences between groups according to LSD test.

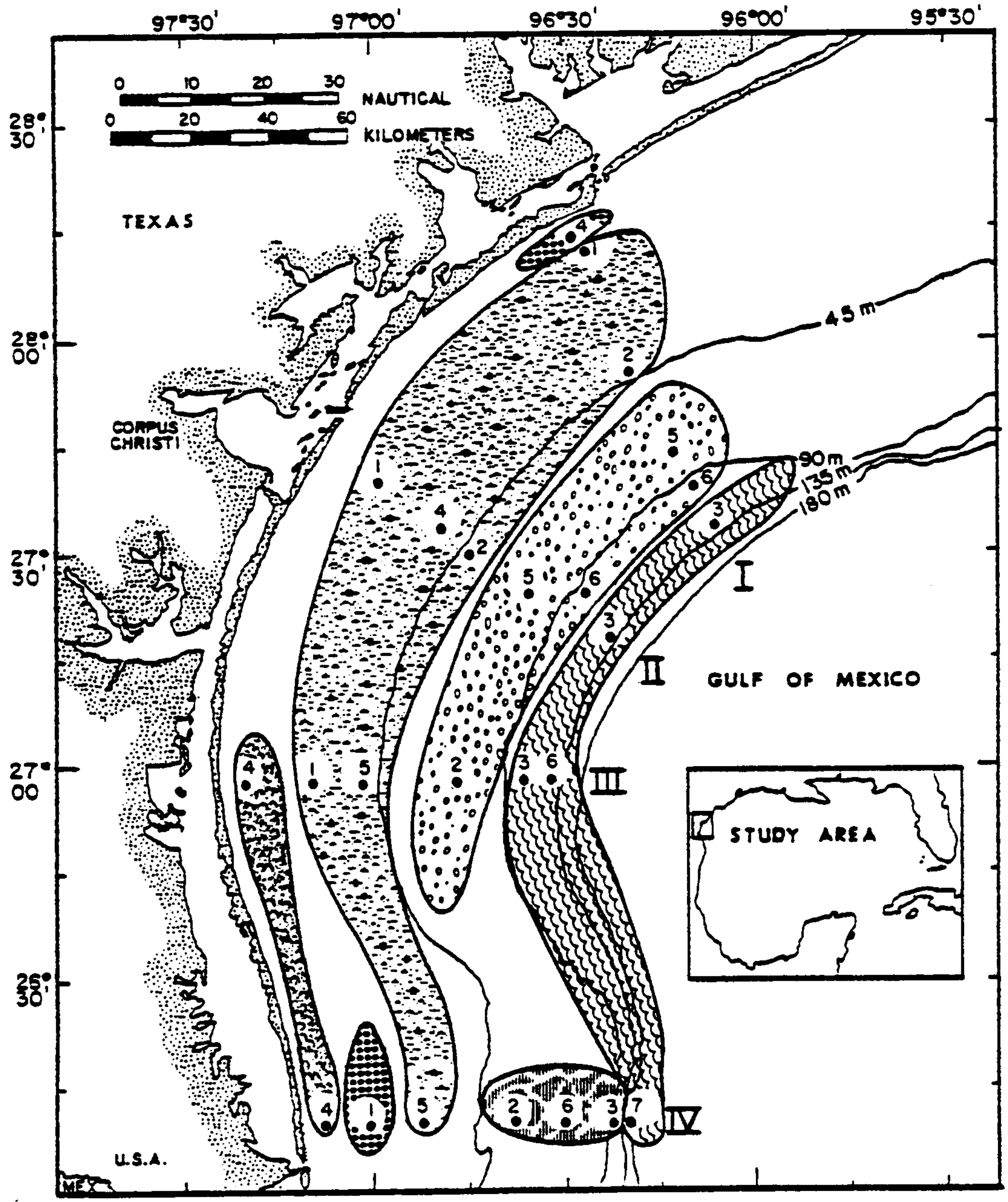

Figure 26. Geographical representation of different shelf zones where sediment characteristics are relatively similar within the zone on the south Texas shelf. Each shaded area represents a station group which has the depth and sediment characteristics listed on Table 9.

towards land were as follows. There was a silty (30%) clay of very uniform texture from sample to sample as indicated by mean grain size and its standard deviation (Table 9) which sometimes showed a seasonal tendency to coarsen by winnowing of finest clays during the early spring at Stations 3/I, 3/II, 3/III, 6/III, and 7/IV. A slightly coarser, more variable silty clay occurred at Stations 5/I, 6/I, 5/II, 6/II, and 2/III. These were transition stations (Table 9) between deeper clayey sediments and the silty sediments of the mid shelf (Figure 26). There was quite a variable sand-silt-clay, mid-shelf mixture at Stations 2/I, 2/II and 4/II in the northern part of the study area and further landward the most variable inner-shelf, sandy muds occurred at Stations 1/I, 1/II, 1/III, 5/III, and 5/IV. These comprised Station Group 3 on Table 9. A similar group of stations with somewhat more variability at least partly because of a much coarser sand (Table 9) mode with some gravel included Stations 2/IV, 3/IV, and 6/IV on the Rio Grande delta (Station Group 4). Stations 4/I and 1/IV (Group 2) had moderately variable muddy sands near the barrier shoreface sand-offshore mud boundary, while Stations 4/III and 4/IV (Group I) were within the shoreface sands where variability became as low as at the outermost stations due to the efficiency of wave action constantly sorting the bottom sediments in shallow water (Table 9). At the inner-shelf stations there was also a suggestion of seasonal coarsening in early spring and a year-long coarsening in 1977 perhaps related to hurricane generated waves between spring and fall sampling.

Sediment Chemistry

The results of the Delta ^{13}C and total organic carbon analyses for the shelf sediments are summarized in Table 10. There was a very clear trend of increasing total organic carbon with distance from shore (P=.001).

TABLE 10

SUMMARY OF SEDIMENT DELTA ^{13}C AND
PERCENT TOTAL ORGANIC CARBON (IN PARENTHESES) DATA

Transect I	Nearshore	Mid Shelf	Offshore	Line Average
Winter	-19.92(.72)	-20.40(.88)	-20.24(1.02)	-20.18(.87)
Spring	-19.58(.47)	-20.50(1.06)	-20.46(1.04)	-20.18(.86)
Fall	-19.24(.58)	-19.68(.94)	-19.89(.56)	-19.60(.69)
Yearly	-19.58(.58)	-20.20(.96)	-20.20(.88)	-19.99(.81)
Transect II				
Winter	-20.35(.70)	-20.35(.88)	-20.50(1.12)	-20.40(.90)
Spring	-20.17(.93)	-20.38(.89)	-20.36(1.13)	-20.30(.98)
Fall	-19.43(.82)	-19.65(1.02)	-20.24(1.28)	-19.77(1.04)
Yearly	-19.98(.82)	-20.12(.93)	-20.36(1.18)	-20.17(.97)
Transect III				
Winter	-19.75(.94)	-19.90(1.02)	-20.10(.84)	-19.92(.94)
Spring	-19.54(.44)	-19.95(.97)	-20.32(1.12)	-19.94(.84)
Fall	-18.94(.42)	-19.98(1.01)	-19.88(1.30)	-19.60(.91)
Yearly	-19.40(.60)	-19.94(1.00)	-20.10(1.08)	-19.82(.90)
Transect IV				
Winter	-19.40(.73)	-20.10(.77)	-20.30(1.10)	-19.99(.90)
Spring	-19.18(.28)	-19.75(.79)	-19.91(.79)	-19.61(.62)
Fall	-19.32(.21)	-19.99(1.75)	-20.26(.86)	-19.86(.94)
Yearly	-19.30(.50)	-19.94(.82)	-20.16(.52)	-19.82(.82)

BANK STATIONS

	SB	HR	Bank Average
Winter	-20.35(1.01)	-20.30(.70)	-20.32(.86)
Spring	-20.26(1.04)	-20.38(1.12)	-20.32(1.08)
Fall	-20.32(1.03)	-20.19(1.22)	-20.26(1.12)
Yearly	-20.31(1.03)	-20.29(1.04)	-20.30(1.04)

	Transect I	Transect II	Transect III	Transect IV
Nearshore	4,1	1,4	4,1	4,1
Mid Shelf	2,5	2,5	5,2	5,2
Offshore	6,3	6,3	3,6	6,3,7

This trend correlated with the percent clay in the samples (correlation coefficient = .76). There was also a significant change (P = .001) in Delta ^{13}C with more positive (^{13}C enriched) values nearer shore. Delta ^{13}C is a measure of carbon^{-13} enrichment or depletion. A negative value under these circumstances represents an enrichment of ^{13}C and depletion of ^{12}C in respect to a standard with a value of 0. Seagrasses are more ^{13}C enriched than plankton (Calder, 1977; Fry, 1977) and this trend may represent the export of seagrasses from the estuary to the shelf. The bank stations were very uniform.

The rather uniform pattern of Delta ^{13}C and the low values of total organic carbon suggest that petroleum pollution at a fairly gross level could be detected by Delta ^{13}C shifts. If oil of Delta C^{13} equal to -30 is added to sediment at a level to shift the total organic carbon level from 0.5 to 1.0, then Delta ^{13}C will shift to a value between -20 and -25. Such a total organic carbon shift could go undetected but such a Delta ^{13}C shift would be easily noted. Even if the oil lost its chemical identity as a hydrocarbon, due to partial oxidation and incorporation into cells, the Delta ^{13}C shift would persist.

Statistical analyses provided only weak evidence for temporal and spatial variation of sediment total hydrocarbons. The data suggested sediments contained slightly higher total hydrocarbons in fall, intermediate values in winter and lower values in spring. Transect III stations had highest concentrations; Transect II had mid to high values; and Transects I and IV had the lowest values.

Statistically significant seasonal effects were noted for the sum of the hydrocarbons between C_{14}-C_{18} (SUM LOW) in 1975 and 1976 data. Seasonal changes in SUM LOW may reflect biological activity and molecular dynamics which take place within the sediment. The high spring and fall values for SUM LOW could result from increased production of these compounds in the water column or at the sediment-water interface. Microorganisms within the sediment consume the added organic matter including lower molecular weight hydrocarbons and produce their own characteristic hydrocarbon distribution which contains a larger percentage of higher carbon number alkanes. Sediment SUM LOW therefore decreases as primary production of lower molecular weight hydrocarbons decreases.

Long-term temporal changes in sediments were also observed for mid range hydrocarbons between C_{19}-C_{24}(SUM MID) and the higher ranged hydrocarbons between C_{20}-C_{32}(SUM HI). The data presented in Figure 27 indicates a significant increase in SUM HI (P = .001) and concommitant decrease in SUM MID (P = .001) over the three-year study.

No significant change in OEP HI (C_{25}-C_{32}) was observed over the study period despite the tremendous increase in SUM HI (C_{25}-C_{32}). OEP MID (C_{19}-C_{24}) did, however, show a significant change (P = .001) as a result of the decrease in SUM MID (C_{19}-C_{24}). The lack of change in OEP HI and the changes which did occur in SUM MID and OEP MID suggest that the increase in SUM HI during the study period was due to natural processes rather than the direct addition of petroleum hydrocarbons.

The lack of evidence for the presence of aromatic hydrocarbons in sediments suggested minimal petroleum pollution of STOCS sediments. Petroleum pollution in the form of micro-tarballs observed in the water column (zooplankton samples) apparently did not contribute a sufficient quantity of petroleum hydrocarbons to sediments to significantly change sediment OEP HI or permit detection of aromatics.

Concentrations of low-molecular-weight hydrocarbons in the top few

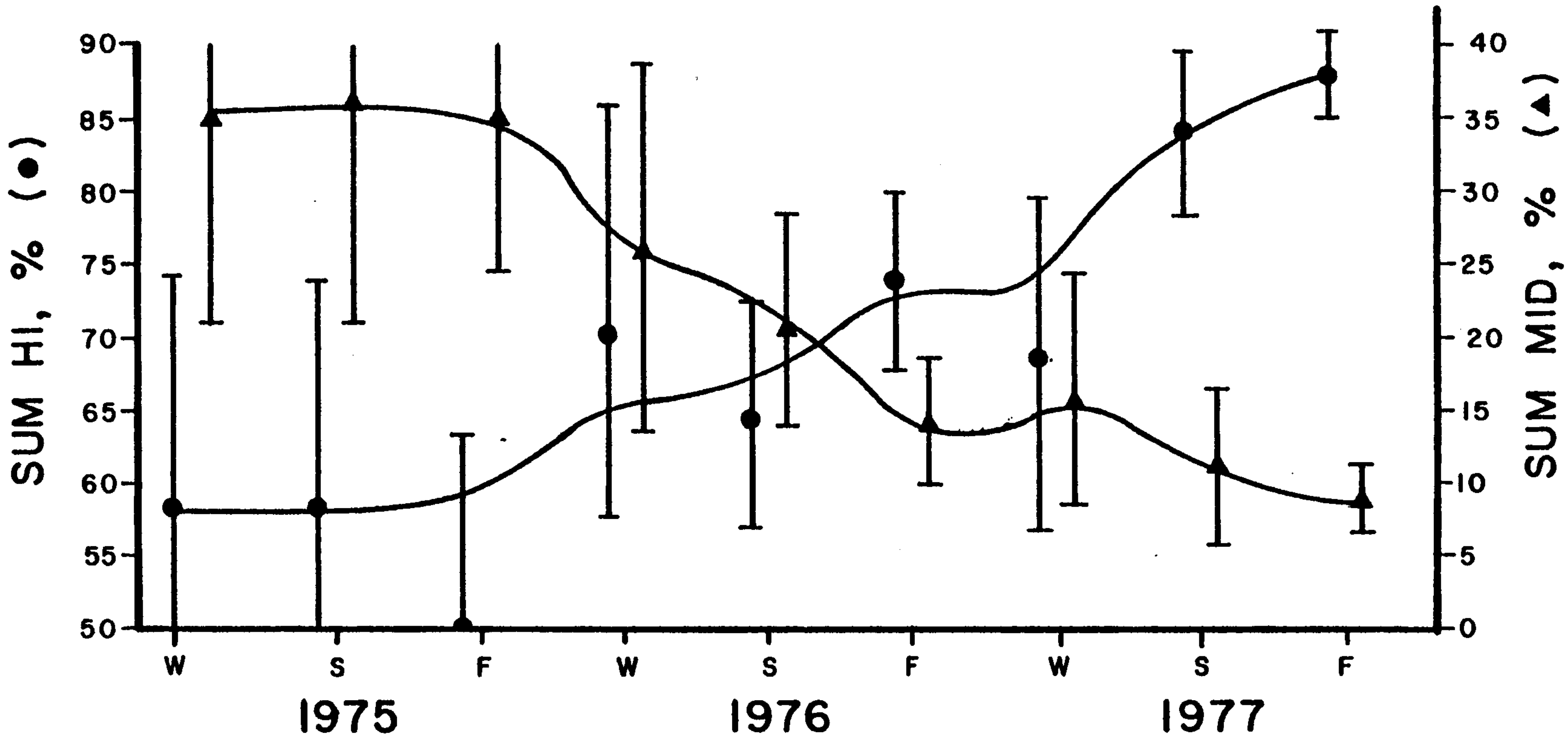

Figure 27. Percentage of sediment n-alkanes in the Sum Mid (C_{19}-C_{24}) and Sum Hi (C_{25}-C_{32}) ranges.

meters of STOCS sediment was generally of microbial origin, as evidenced by the existence of anomalously high methane concentrations in the top sediment layers. Apparently, bacterial production of methane is not restricted to the sulfate-free zone, but also occurs within microenvironments in sediments having near-seawater interstitial sulfate concentrations.

Two meter vertical methane profiles in nearshore sediments exhibited maxima ranging from 100 to 500 $\mu\ell/\ell$ (pore water). Figure 28 is a schematic representation of interstitial methane in the upper four meters of sediment based on samples taken in the STOCS area as compared to slope and abyssal sediments examined independently. The diagram illustrates the disappearance of the maxima as well as the trend of decreasing interstitial methane in an offshore direction. These trends were associated with variations in temperature and microbial activity.

Interstitial concentrations of ethene, ethane, propene, and propane decreased progressively from 160 to 60 $n\ell/\ell$ (pore water) in nearshore sediments, to fairly uniform levels of 80 to 25 $n\ell/\ell$ downslope, respectively. These trends are illustrated in Figure 29, which shows average concentrations of the four hydrocarbons throughout the cores of Transect I stations which were sampled independently for comparison of shelf and slope low-molecular-weight hydrocarbons.

The trends of the C_2 and C_3 hydrocarbons with distance from shore were similar to the behavior of methane. These patterns suggest that the concentrations of C_2 and C_3 in the top few meters of shelf and slope sediments were microbially supported. Like methane, concentrations of the C_2 and C_3 hydrocarbons are probably controlled by biological oxidation and diffusion into the overlying waters.

The concentrations illustrated in Figure 29 generally represent

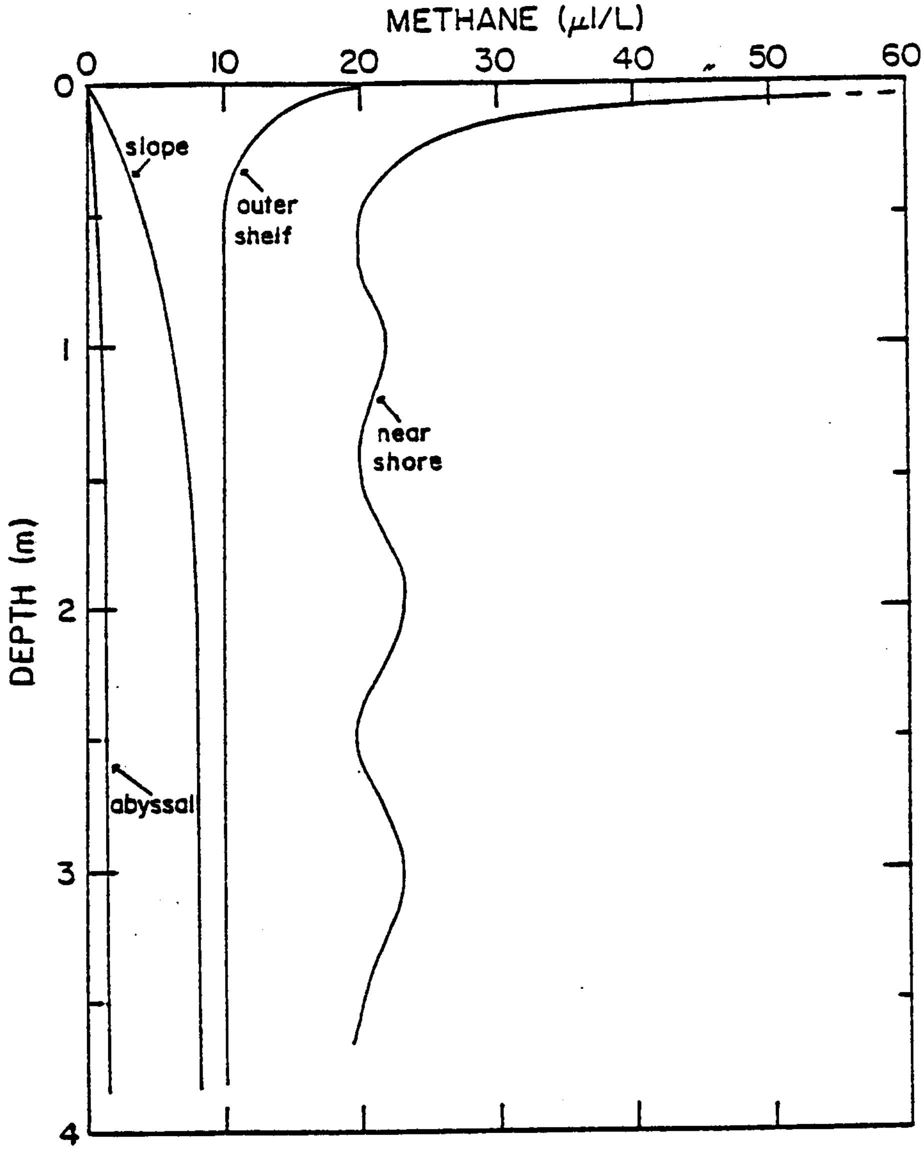

Figure 28. Schematic diagram of methane variations in the upper four meters of sediment.

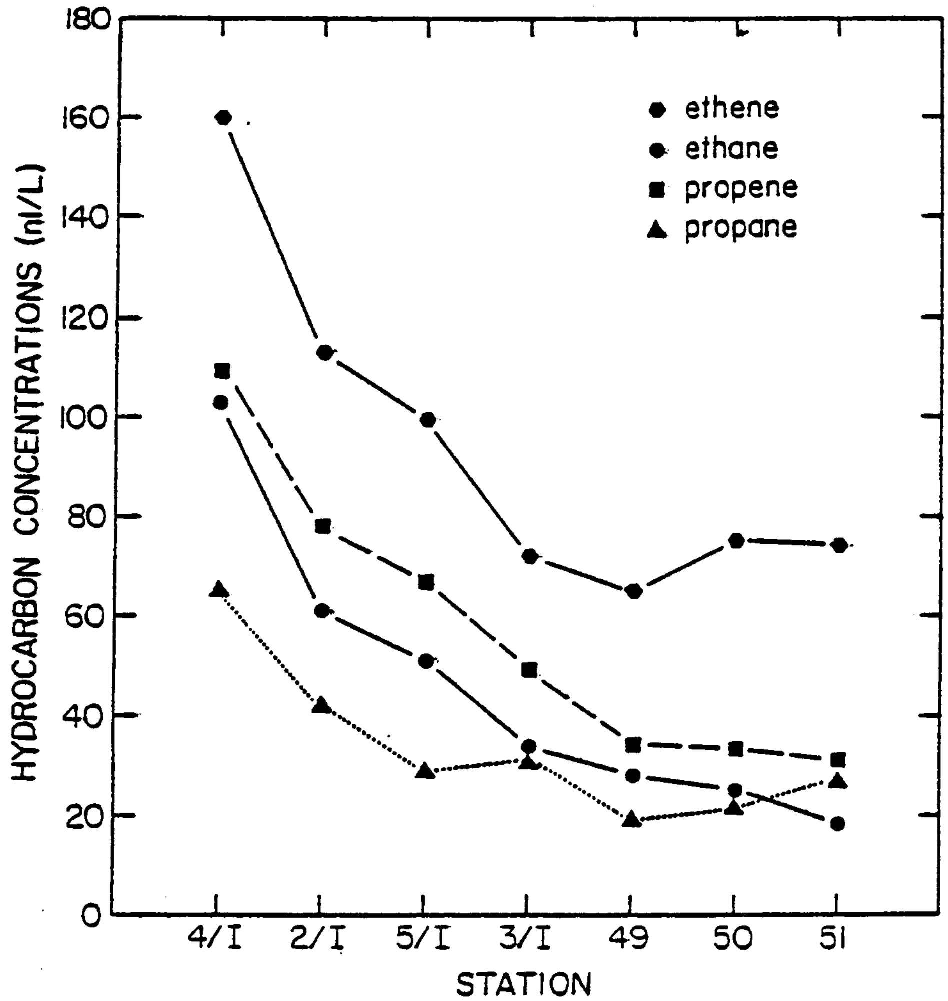

Figure 29. Average concentrations of the C_2 and C_3 hydrocarbons at Transect I stations, Note that stations 49-51 were sampled independent of this study and the data are presented for comparison of shelf and slope sediments.

"baseline values" of the low-molecular-weight hydrocarbons on the Texas shelf. One area of anomalously high ethane and propane was found, however, suggesting an input of thermocatalytic gas from the subsurface. Figures 30 and 31 show ethane and propane concentrations with sediment depth at the Transect IV stations as compared to Transect III stations. Corresponding to the seepage observed in the water column at Transect IV (pg. 44, Chapter 2), sediment low-molecular-weight hydrocarbon showed anomalously high concentrations at Stations 4, 6, 3 and 7 along this transect. The stations along Transect III were typical of the normal distribution of low-molecular-weight hydrocarbons from biogenic sources in the shelf sediments. Interstitial ethane and propane concentrations varied between 20 and 40 nℓ/ℓ in this area. Ethane and propane concentrations along Transect III (Figure 30 and 31) tended to decrease in an offshore direction with ethane levels generally slightly higher than propane, in a manner very similar to Transect I (Figure 29).

The northwestern Gulf of Mexico, including the STOCS area, appears to be free of any significant sediment trace element contamination. Metal pollution has been observed in sediments from Corpus Christi Bay (Neff *et al.*, 1978; Holmes *et al.*, 1974), the Houston Ship Channel-Galveston Bay area (Hann and Slowey, 1972), the Mississippi River delta (Trefry and Presley, 1976a) and a few inland waterways (Slowey *et al.*, 1973). There is no evidence of large scale offshore transport of these contaminants to the outer continental shelf and thus little contamination in shelf sediments (Trefry and Presley, 1976b). This situation is not unexpected, especially for the STOCS area, which is not highly industrialized.

Anthropogenic trace elements, along with other materials are transported to the ocean from continents by freshwater discharges (*e.g.* sewage outfalls, storm runoff and river discharge) and atmospheric processes.

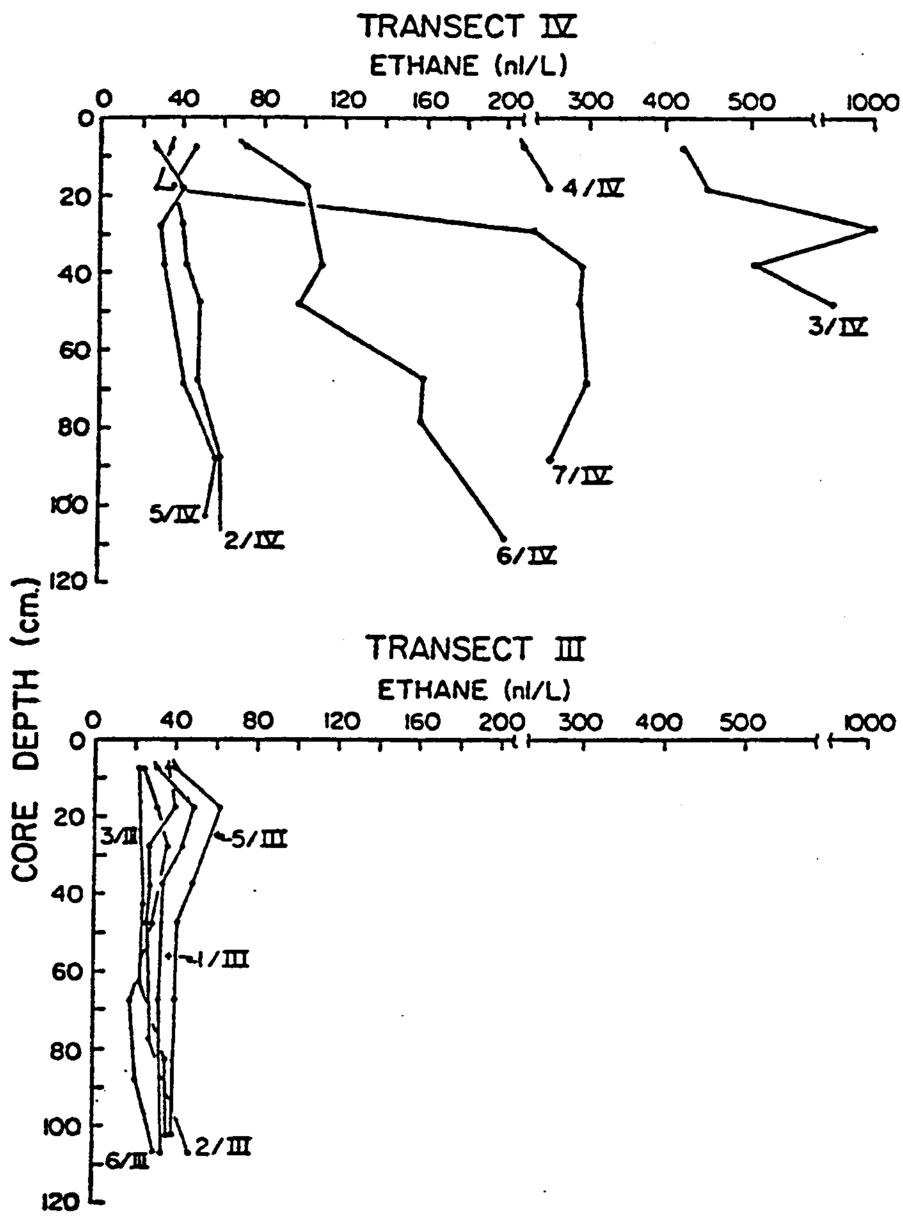

Figure 30. Interstitial ethane concetrations (nl/ℓ pore water) at stations along Transects III and IV.

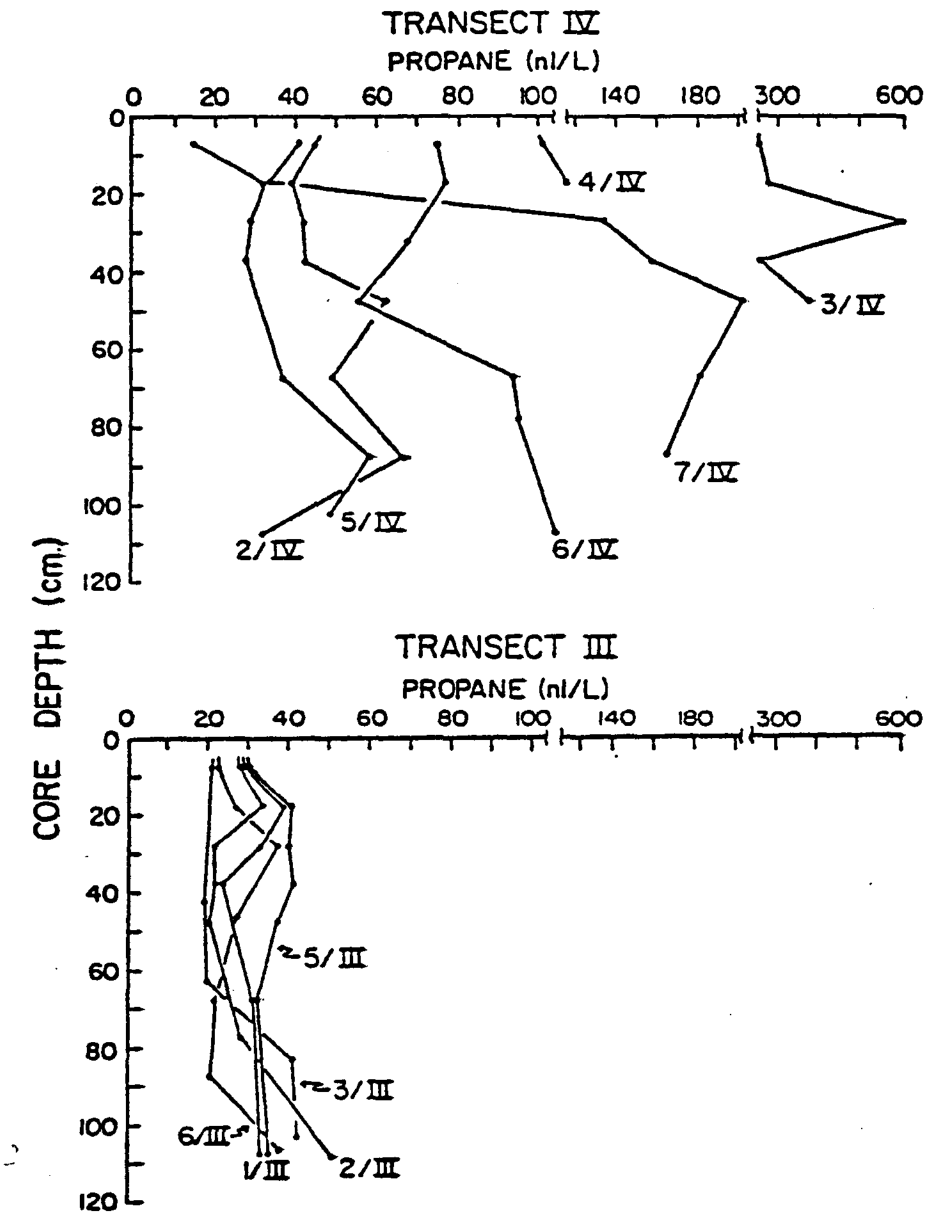

Figure 31. Interstitial propane concentrations (nl/ℓ pore water) at stations along Transects III and IV.

Direct freshwater discharge into the STOCS region is minimal. The Mississippi and Atchafalaya rivers account for more than 95% of the fresh water entering the northwest Gulf (Berryhill, 1977). The discharge points of these rivers are located at approximately 700 and 500 km, respectively, from the study area. In addition, all rivers on the south Texas coast (except the Rio Grande) discharge into bays and estuaries which are separated from the Gulf by barrier islands.

Without the major industrial areas on the coast and the lack of any direct local riverine impacts to the south Texas shelf, high trace metal concentrations in the shelf sediments would not be expected. In general, these trends have been verified by previous work in the northwestern Gulf (Berryhill, 1977). Any localized concentration of trace metals in the sediments along the edge of the shelf were attributed to suspected natural gas seepage. Offshore gradients of very low trace metal levels were also shown to be directly related to increases in clay content of these sediments.

CHAPTER FIVE

BENTHIC BIOTA OF THE SOUTH TEXAS SHELF

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One of the major focuses of this multidisciplinary study on the south Texas shelf was characterization of the subtidal benthic habitat from near-shore to the shelf slope. As stated by the International Council for the Exploration of the Sea (ICES Cooperative Research Report #75, 1978), "a large number of field studies are documented that have as their basis the identification and enumeration of the species occurring in a community, many of which are concerned with the relatively sedentary benthos on the basis that these species will be unable to avoid adverse conditions. Thus, the status of such populations at any point in time is likely to reflect the conditions that prevailed over a relatively long preceding period".

The benthos represents an important component of any aquatic ecosystem.

Unlike pelagic water masses and associated biota, which are in continual motion, the benthos is relatively stationary and as such serves as a barometer reflecting changes that occur in localized areas within the ecosystem. Except for the species with obvious commercial importance, however, the benthos has not received the attention necessary to completely explain the natural variation or to follow the transfer of materials through the communities to which these species belong. It is believed that benthos serves as one of the essential links in the trophic dynamics of many of our more important fisheries such as the Gulf of Mexico shrimp fishery.

Microbiology

Marine Fungi

Fungi are ubiquitous in both terrestrial and aquatic environments. It is somewhat surprising, however, that the predominant genera and species found in sublittoral marine sediments are the same saprobic members of the Fungi Imperfecti that are commonly found in terrestrial habitats (Steele, 1967). Despite their documented abundance and the fact that they occur in sediments as viable mycelial filaments (Johnson and Sparrow, 1961), the free-living higher fungi have been largely ignored by marine mycologists who have directed their attention to yeasts and less abundant, but uniquely marine, groups of algal parasites and wood rotting fungi (Jones, 1976). The ability of fungi to degrade alkane (Markovetz *et al.*, 1968) and aromatics (Cerniglia *et al.*, 1978) hydrocarbons is well documented, but the factors controlling the fungal degradation of crude oil in marine sediments are as yet largely unknown. The study of sediment fungi on the south Texas outer continental shelf is timely because of the rapid increase in petroleum development and production activities in the area.

Marine fungi on the Texas shelf were isolated from sediment samples in 1977. Population densities ranged from a low of five Colony Forming Units per ml (CFU/ml) in winter samples from Station 3/I to a high of 1600 CFU/ml in the fall samples from 3/II (Table 11). The average for the year in the study area was 236 CFU/ml sediment. There was a progression toward larger fungal populations beginning with the late-winter low and ending with a significant ($P < 0.03$) increase in the fall. An exception to this trend was seen at the deep station on Transect I where fungal abundance was much greater in the spring than in the fall. The annual pattern of increasing numbers of fungi through the fall period was paralleled by an increase in generic richness, an index of community diversity (Table 11).

When the abundance of fungi capable of degrading petroleum products, as measured by assaying the growth of pure isolates on crude oil, was compared to that of non-hydrocarbon degraders, 52% of the total 83 benthic isolates tested were observed as capable of assimilating crude oil (Table 12). It was clear that a greater proportion of fungi from the shallow stations than those from intermediate depth stations were capable of degrading oil (Table 12). Oil degradation potential decreased offshore.

Crude oil stimulated the growth of benthic fungi (Figure 32). The addition of South Louisiana Crude Oil (SLCO) to fall benthic sediment samples resulted, after 45 days, in an average 7-fold increase in fungal abundance at the 0.5% (volume/volume) oil level and a 3.6-fold increase at the 0.1% oil level relative to the control. There was, however, an initial inhibition of the natural mixed fungal populations in the 0.5% treatment. This initial toxicity was also seen in experiments with pure cultures of *Candida diddensii* in which pre-starved inoculum and low nutrient conditions duplicated as nearly as possible STOCS ecosystem conditions.

TABLE 11

FUNGAL ABUNDANCE (CFU/ml)* AND GENERIC RICHNESS IN STOCS SURFICIAL SEDIMENTS
BY BOTTOM DEPTH AND SEASON**

Depth	Station/ Transect	SEASON Winter	Spring	Fall	Mean
Shallow	1/II	110	33	200	98
	1/IV	16	30	200	
Intermediate	2/II	11	20	910	248
	2/III	12	83	450	
Deep	3/I	5	350	160	359
	3/II	21	15	1600	
Season Mean		29 ± 40	89 ± 130	587 ± 571	
Generic Richness Avg. No. Genera/Station		5.8	7.0	10.3	

*Colony Forming Units/ml wet sediment
**One-way ANOVA with season as independent variable
F= 4.8331, df = 2,13, P= 0.024.

TABLE 12

GROWTH OF FUNGAL ISOLATES* IN CRUDE OIL
BY STATION AND DEPTH

Depth	Station/Transect	Growth	No Growth
Shallow	1/II	11	6
	1/IV	13	9
Intermediate	2/II	5	9
	2/III	3	7
Deep	3/I	3	3
	3/II	8	6

By depth $X^2 = 4.916$
$0.05 < P < 0.1$
D.F. = 2

*Isolated from benthic sediments on nonselective medium

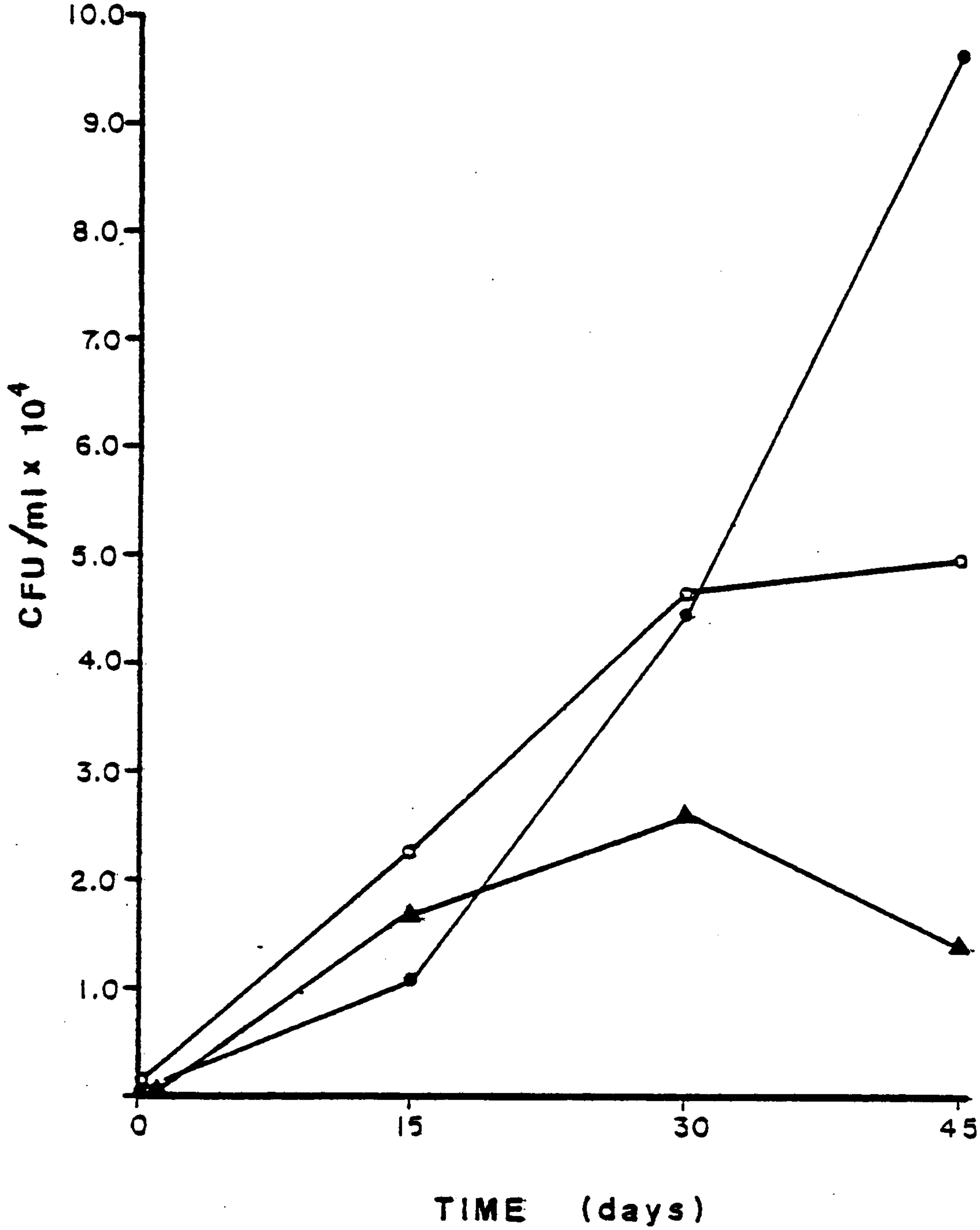

Figure 32. Effect of crude oil concentration on fungal growth in natural mixed cultures of STOCS benthic sediments diluted (1:5) with artificial seawater. The numbers are the mean values for all samples from the fall 1977. (●) - 0.5% oil (SLCO); (○) - 0.1% oil (SLCO); (▼) - control to which no oil was added.

Severe toxicity was observed in all cases with early survival rates ranging from 0 to 3% of the no-oil control. Maximum toxicity occurred between the third and sixth days with recovery and significant stimulation taking place by the 22nd day.

The abundance of fungi in the STOCS benthic system appears to be controlled by two factors: 1) the replenishment of inoculum from the water column, a seasonal phenomena; and 2) the availability of organic carbon, a site specific parameter. In general the genera of fungi observed during the study were those whose spores are usually most abundant in the air over the adjacent land masses. The species most frequently encountered in sediment samples during this study were *Cladosporium cladosporioides* (Freson.) deVries, *Penicillium citrinum* Thom, *Aspergillus flavus* var. *columnaris* Raper and Fennel, *Aspergillus sydowi* (Bain and Sart.) Thom and Church, *Fusarium ventricosum* Appel and Wollenweber and *F. moniliforme* var. *subglutanans* Wr. and Reink. The terrestrial origin of these genera was also suggested by higher abundances observed in the nearshore stations (Table 11).

The large increase in benthic fungi isolated in the fall can be explained by the early fall arrival in the sediments of spores suspended throughout the summer at the thermocline/pycnocline following their deposition in the water column during late winter and spring. As the atmospheric spore load in Texas is reaching its annual maximum (Chapman, 1979), the last continental air masses of spring are moving out over the Gulf of Mexico off Corpus Christi in late April or early May (Orton, 1964). Until fall the area is covered by maritime air masses. These conditions are reflected in the abundance of fungi in STOCS near-surface waters (Szaniszlo, 1979). During March and April of 1977 fungi were uniformly very abundant with monthly averages of 40,000 and 16,000 CFU/ℓ compared to only 13 CFU/ℓ in July, 4 CFU/ℓ in August, 21 CFU/ℓ in November and 4 CFU/ℓ in December.

The number of colony forming units of benthic marine fungi observed in the fall samples was directly correlated with the total organic carbon concentrations of these sediments ($r = 0.843$). Indirect evidence also existed from the observations of this study suggesting that fungal mineralization of the organic material during winter, spring and summer controlled the peak abundance of fungi observed during the fall. Fungi appeared to be short-lived in the STOCS sediments where available carbon was the limiting factor. Over half of the benthic fungi tested were able to assimilate South Louisiana crude oil to overcome carbon limitation.

Since organic carbon, and not nitrogen or phosphorus, limited fungal abundance in the STOCS ecosystem, it is reasonable to presume that at least some fungal oxidation of intrusive petroleum would occur anywhere in the area. Greater activity, however, would be expected inshore in coarse sediments subject to high nutrient freshwater outwash.

Marine Bacteria

Aerobic heterotrophic bacteria ranged from 4.6×10^4 to 1.3×10^6/ml wet sediment. Analysis of variance indicated a significant ($P < 0.01$) seasonal difference in benthic bacterial populations with highest numbers during spring and lowest during winter (Table 13). There was no significant difference between transects. There was, however, a significant difference between stations, with highest populations at Station 1, decreasing with increasing depth (Figure 33). Mean populations of benthic bacteria at Stations 1, 2 and 3 (all transects and seasons) were 7.9, 4.3 and 2.2×10^5/ml wet sediment, respectively. The variation by station accounted for 47% of the total variance in benthic bacteria. The only deviation from this distribution was on Transect IV,

TABLE 13

SUMMARY OF BENTHIC BACTERIAL POPULATIONS OF THE SOUTH TEXAS OUTER CONTINENTAL SHELF DURING 1977

Type	Season	Number of Samples	Mean $\pm$ 1S.D.
Aerobic heterotrophic bacteria (number/ml wet sediment)	Winter	24	$40.2 \pm 28.0 \times 10^4$
	Spring	24	$55.4 \pm 41.6 \times 10^4$
	Fall	24	$47.8 \pm 31.2 \times 10^4$
Hydrocarbon degrading bacteria (number/ml wet sediment)	Winter	24	$2.7 \pm 3.8 \times 10^3$
	Spring	24	$3.1 \pm 5.1 \times 10^3$
	Fall	24	$23.5 \pm 35.8 \times 10^3$
Percent hydrocarbon degrading bacteria	Winter	24	0.6 ± 0.5
	Spring	24	0.5 ± 0.4
	Fall	24	4.8 ± 6.1

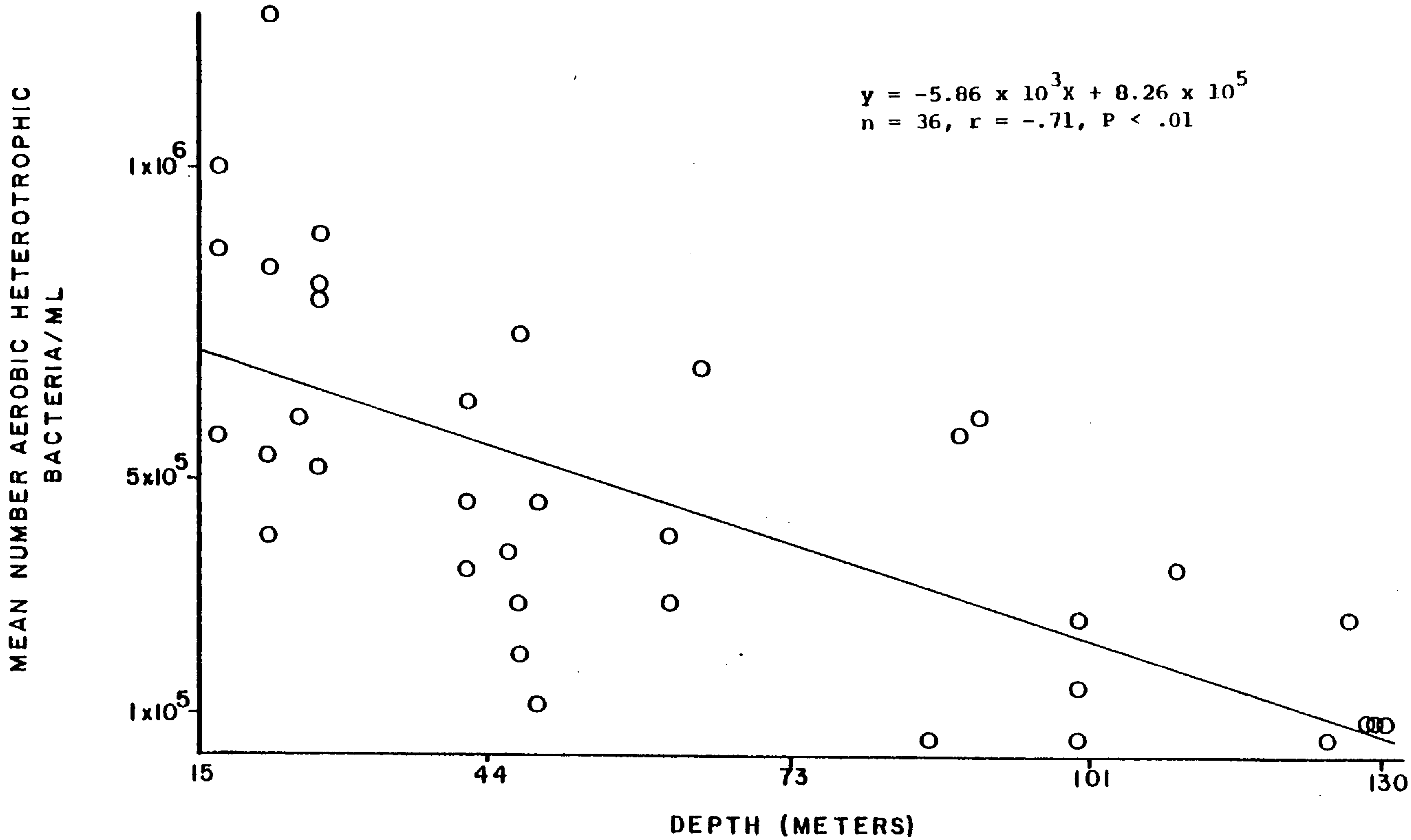

Figure 33. Relation between aerobic heterotrophic bacteria of sediment and bottom depth.

where Station 3 contained an unusually high number of bacteria during the spring and fall.

Rates of organic carbon input to the sediments during the spring are expected to be greater than at any other time during the year because of peak productivity measures in the overlying water column. Benthic bacteria appear to have responded to this high input during the spring, since this is the period of maximal populations. Temperature may also effect the seasonal distribution of benthic bacteria. Benthic bacterial populations were lowest during the winter, corresponding to seasonal low sediment temperatures.

Hydrocarbon degrading bacteria were isolated from all 72 samples collected during the study. Populations ranged from 8.0×10^1 to 1.1×10^5/ml sediment and were significantly correlated with total alkanes of the sediment (Figure 34). Analysis of variance demonstrated a significant ($P < 0.01$) seasonal variation in the number of hydrocarbon degrading bacteria, with highest populations during fall and lowest during winter (Table 13). There was a significant ($P < 0.01$) difference between transects, with greatest concentrations on Transect I during winter and spring, and on Transect IV during fall. Hydrocarbon degrading bacteria were also significantly ($P < 0.01$) greater at Station 1, decreasing with increasing depth. The mean number of hydrocarbon degrading bacteria at Stations 1, 2 and 3 (all transects and seasons) was 17.3, 9.3, and 2.6×10^3/ml wet sediment, respectively.

Benthic bacteria are capable of degrading all n-alkanes from C_{14} to C_{32}, but exhibit a preference for the lower ranged high-molecular-weight hydrocarbons (C_{14} to C_{20}). Spatial variations in biodegradation of oil were examined for each season. No significant spatial variations occurred

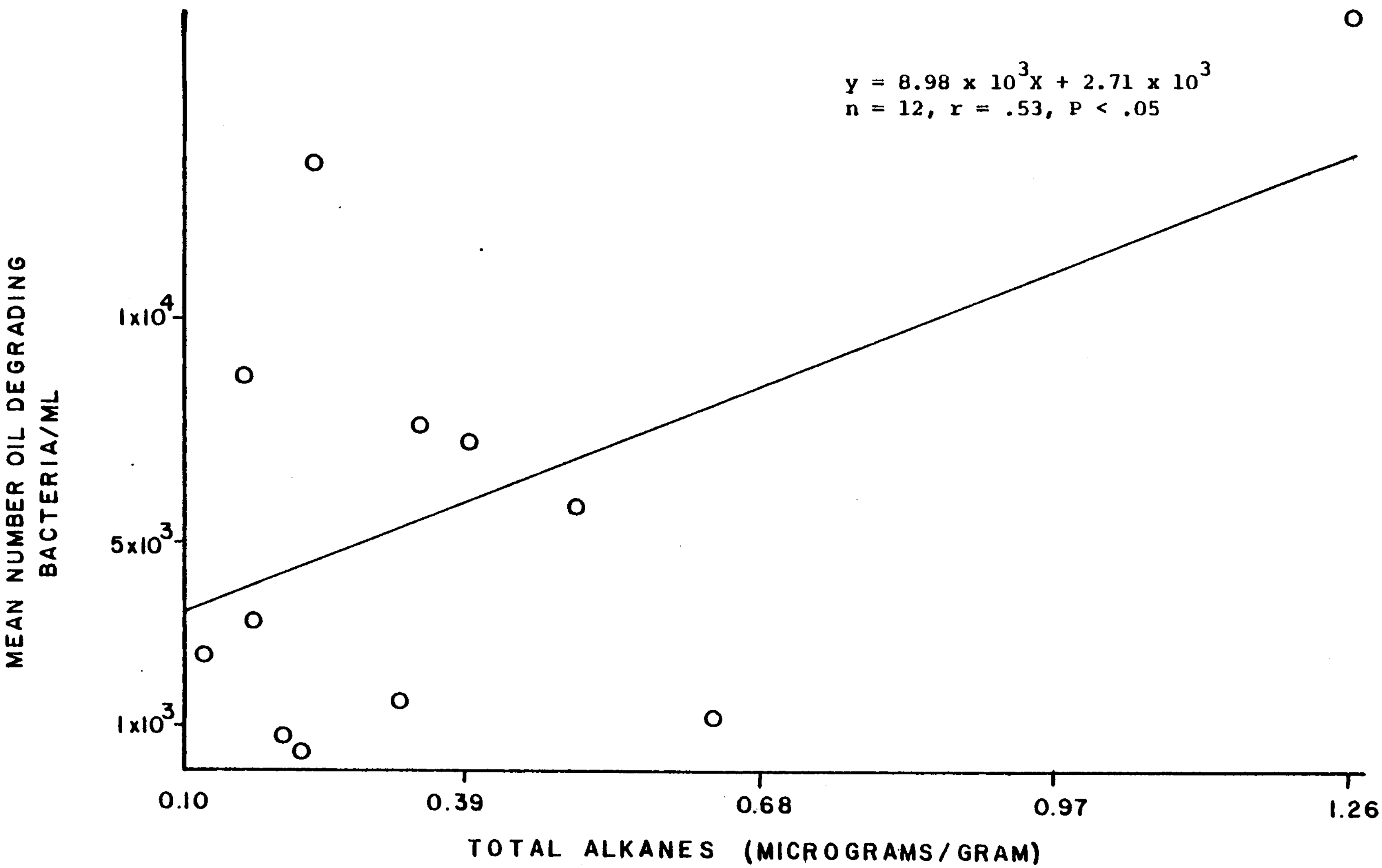

Figure 34. Relation between number of oil degrading bacteria of sediment and total alkanes.

in the winter, probably due to consistently low rates of biodegradation (from 0 to 16.78%). During the spring, there were significantly ($P < 0.01$) higher biodegradation potentials at Station 1, decreasing with increasing station number, or increasing depth. There was also a significant ($P < 0.05$) difference between transects, with lowest potentials on Transect III. During the fall, there was no significant spatial variations in biodegradation potential. The mean percent biodegradation of oil during the spring and fall was significantly correlated with the mean number of hydrocarbon degrading bacteria ($r = 0.66$ and $4 = 0.73$, respectively).

Oil significantly ($P < 0.01$) stimulated the growth of total aerobic heterotrophic bacteria at the majority of stations during the three seasons. Growth stimulation by SLCO occurred after one week and continued through eight weeks. Significant growth inhibition by oil was not observed. The number of hydrocarbon degrading bacteria of sediment was also significantly ($P < 0.05$) increased by the addition of oil. Stimulation of hydrocarbon degrading bacteria by oil was recorded after two days and continued through eight weeks.

In conclusion, two study findings suggest that hydrocarbon degrading bacteria may be a useful indicator of sediment hydrocarbons in the STOCS area: 1) the number and percent hydrocarbon degrading bacteria were significantly correlated with total alkanes of the sediment; and 2) the addition of oil to the sediment increased the number and percent hydrocarbon degrading bacteria after two days.

Meiofauna

The meiofauna has been largely ignored until the last three decades. The importance of the economic aspects of macrobenthos to fisheries and the function of microorganisms in converting organic material into usable energy in a food chain have received the majority of research attention, the former to a considerable extent. Meiobenthic work has, until recently, been confined to species composition, diversity and density studies, or on detailed examination of a particular group. In the last ten years increasing attention has been focused on the ecology of the marine meiobenthos and its trophic interactions.

"Meiobenthos" was first used by Mare (1942) to characterize benthic fauna of intermediate size, such as small crustacea, small polychaetes and lamellibranchs, nematodes and foraminifera. The distinction was to separate the intermediate-sized metazoans from larger macrofauna of the bottom and the microbenthos--protozoa (excluding foraminifera), diatoms, and bacteria. This arbitrary size definition, usually accepted as animals which pass through a 0.5 mm sieve but are retained on a sieve with mesh smaller than 0.1 mm (Coull, 1973), may include representatives of the young of the macrofauna (temporary meiobenthos) but are more commonly accepted only in terms of species which even at the adult stage fit into the stated size and fit certain taxonomic categories, the permanent meiobenthos (McIntyre, 1969).

The meiobenthos designation is considered purely statistical (McIntyre, 1969) with no clear cut distinction between the macro- and meiofaunal components. Further delineation as "permanent" however, provides a more operational definition in terms of sampling methods and a natural grouping with certain biological characteristics (McIntyre, 1969). McIntyre (1969) further defined meiofauna as an "assemblage of small metazoans which differ from their larger counterparts (macrofauna) in their reproductive capacity and general metabolism, as well as in the ecological niche they fill." It has been suggested that the two components may: 1) compete with each other for resources (McIntyre, 1964; 1969); 2) lack significant interaction between each other; or 3) operate independently of each other while being controlled by different environmental factors (McIntyre, 1974). Study into the trophic relations and microecology of meiofauna indicates that they are as intricately entrenched in the integrated marine food web as the macrofauna and differ in activities and requirements.

During both 1976 and 1977 meiofaunal populations diminished with increasing depth on the Texas shelf (Figure 35A-D). Consistently Transect IV supported the highest populations inshore and Transect II the lowest. Populations of the deepest station of Transect II were almost as great as those of the shallowest station. In contrast, for the other three transects, populations of the deepest stations were only a small percentage of those of the shallowest stations.

Pequegnat and Sikora (1977) reported that sampling on a monthly basis was necessary to define temporal variability of meiofaunal populations. This was best shown by nematodes on Transect II, which was the only transect sampled more than three times during the year (Figure 36). There were population peaks in March, July-August, and November. Population peaks were much greater inshore than offshore. Figure 36 also shows that the March 1976 inshore population was very small and November was large, followed by a very large March 1977 population and a reduced November population.

Nematodes were the most abundant meiofaunal taxa observed averaging 92.6% of the total abundance of the permanent meiofauna (Table 14). Transect II for the year 1976, averaged 86.9% nematodes and was the only case of a transect averaging less than 90% in the two years. The numerically dominant nematodes are listed in Table 14. *Sabatieria* occurred

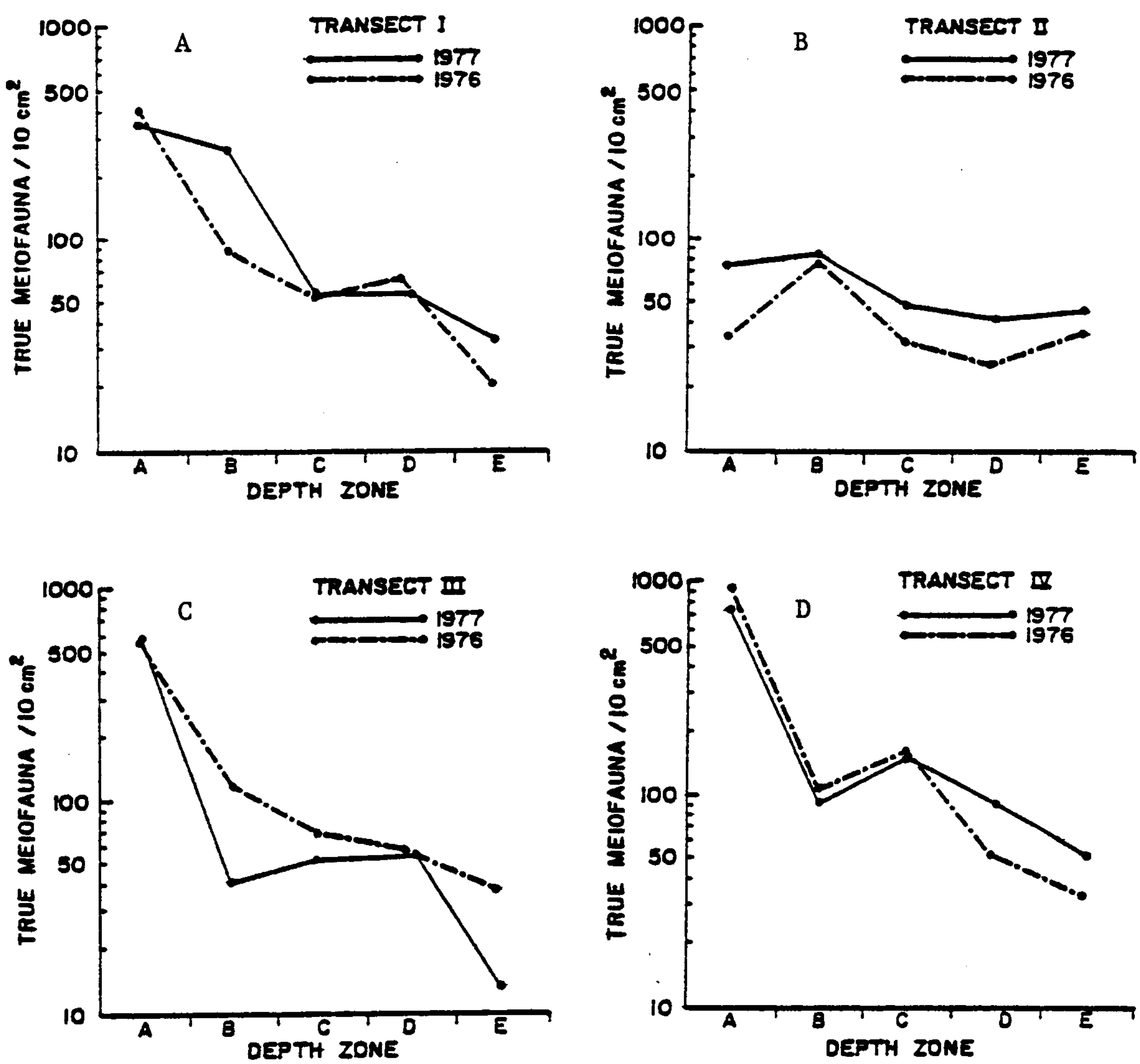

Figure 35. Distribution of permanent meiofauna on Transects I through IV during the winter, spring and fall sampling periods by depth zone for 1976 and 1977. Points are means of populations for three seasonal sampling periods plotted logarithmically. Depth zones are: A (0-30 m); B (30-60 m); C (60-90 m); D (90-120 m); E (> 120 m).

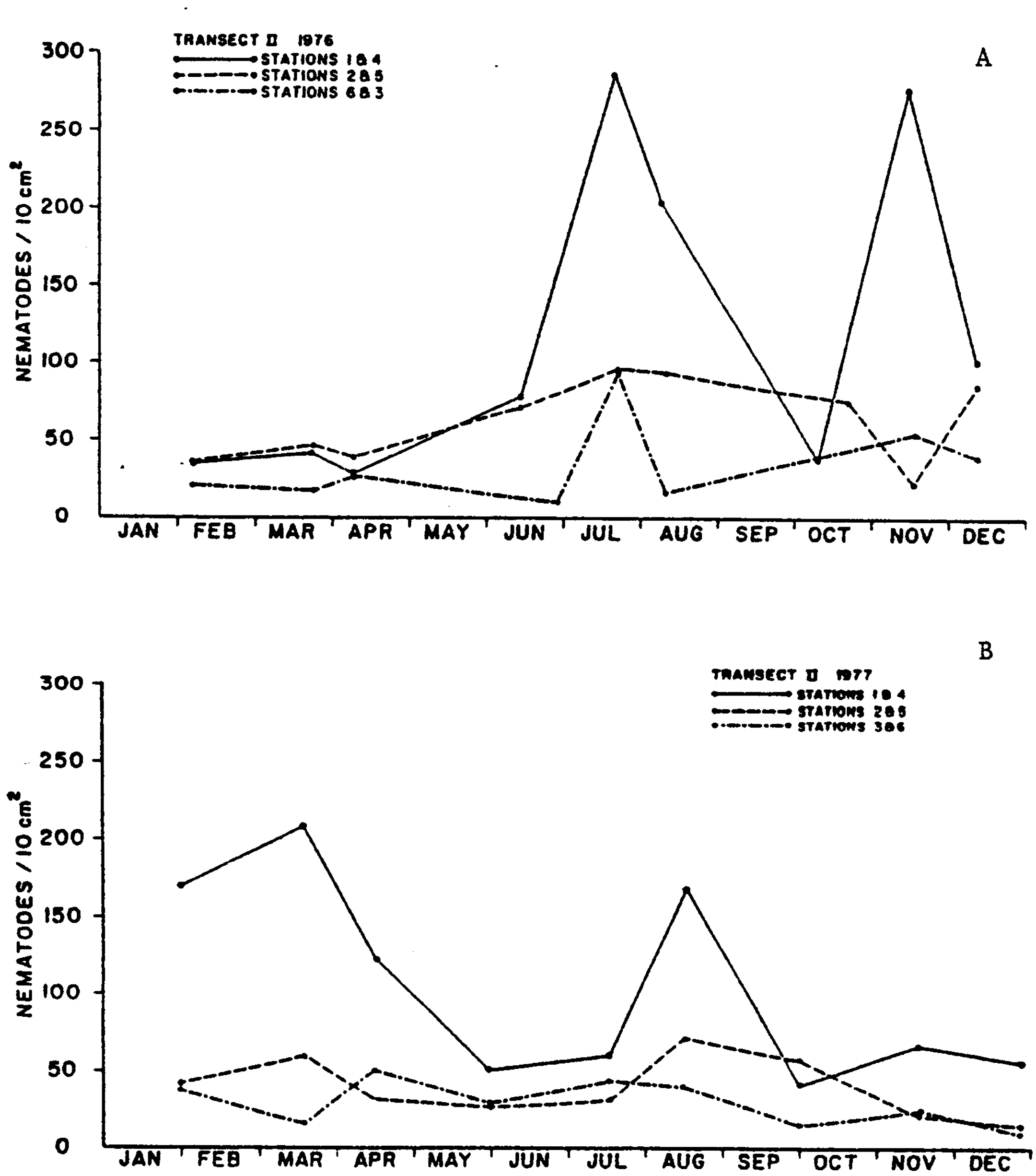

Figure 36. Monthly distribution of Nematoda at inshore stations (1 and 4), mid-depth stations (2 and 5) and offshore stations (6 and 3) of Transect II during 1976 (A) and 1977 (B).

TABLE 14

MAJOR TAXA OF THE MEIOBENTHOS - NUMBERS SHOWN ARE MEAN PERCENT OF THE TRUE MEIOFAUNA AT ALL STATIONS EXCEPT FOR THE POLYCHAETA, WHERE THE PERCENTAGE SHOWN IS OF TOTAL MEIOFAUNA. PERCENTAGES AND RANGES FOR BOTH BANKS ARE FOR 1976 AND 1977 COMBINED. GENERA ARE LISTED IN ORDER OF NUMERICAL ABUNDANCE.

Transects	Nematoda	Harpacticoid	Kinorhyncha	Polychaeta
1976 - Mean (%)	94.5	3.1	0.4	4.6
Range (%)	100.0 - 61.6	25.7 - 0.0	3.1 - 0.0	25.0 - 0.0
1977 - Mean (%)	90.7	4.1	0.6	4.1
Range (%)	100.0 - 55.9	15.4 - 0.0	7.3 - 0.0	16.3 - 0.0
Both Years				
Mean (%)	92.6	3.6	0.5	4.3
Genera or Species	*Sabatieria*	*Haloschizopera*	*Echinoderes*	*Paraonis gracilis*
	Theristus	*Enhydrosoma*	*Pycnophyes*	*Tharyx setigera*
	Halalaimus	*Pseudobradya*	*Semnoderes*	*Mediomastus californiensis*
	Dorylaimopsis	*Ameira*	*Trachydemus*	*Aedicira belgicae*
	Neotonchus	*Ectinosoma*	*Centroderes*	*Protodorvillea* sp. A
	Terschellingia	*Typhlamphiascus*		*Cossura delta*
	Synonchiella	*Robertgurneya*		*Aricidea cerruti*
	Viscosia	*Halectinosoma*		*Sigambra tentaculata*
	Laimella	*Thompsonula*		*Prionospio cristata*
	Ptycholaimellus	*Apodopsyllus*		
		Leptopsyllus		
		Stenhelia		
Banks (Both Years)				
Mean (%)	84.1	8.5	0.6	5.4
Range (%)	100.0 - 40.9	36.0 - 0.0	3.3 - 0.0	16.7 - 0.0

*Percentages are of Total Meiofauna excluding Foraminiferida and Protozoa very commonly in sandy silts and muds, regardless of water depth. *Laimella* also occurred primarily in sandier sediments. There was a marked increase in nematodes when the sand content of the sediment was 60% or more by weight. The high percentage of nematodes in the samples was comparable to that found in muddy continental shelf areas in the Kerguelen Islands (deBovee and Soyer, 1977), off Massachusetts (Wigley and McIntyre, 1964) and also to Wieser's (1960) 18 m mud station in Buzzards' Bay, Massachusetts.

The second most abundant taxon in the STOCS study was Harpacticoida. Harpacticoid populations were proportionately much smaller than those of the nematodes (Table 14). Inversely to that of the nematodes, the proportion of harpacticoids was somewhat higher at Hospital Rock and Southern Bank, averaging 8.5% of the permanent meiofauna for both banks together over 1976 and 1977. The high percentage of harpacticoids may have been more a result of very reduced total meiofauna populations at those stations, thereby increasing the proportional effect of an occasional occurrence, rather than a true indication of increased harpacticoid abundance. Numbers of harpacticoids taken at the transect stations ranged from 0 to 97.4 individuals per 10 cm^2 in 1976 and from 0 to 59.3 individuals per 10 cm^2 in 1977. The mean for all stations was 662.0 individuals in 1976 and 458.7 individuals in 1977.

Kinorhyncha were not very abundant averaging about 0.5% of the taxa over all transect stations for both years (Table 14). They were even less abundant at the two bank stations with a total of 27 kinorhynchs from all stations and sampling periods in 1976 and 24 in 1977.

Polychaeta was the second most abundant taxon of the total meiofauna (excluding the Foraminiferida and Protozoa) on Transects I through IV (Table 14), totaling 3593 individuals collected over the two years of the study. As with the nematodes and the mean permanent meiofauna, the Polychaeta highest abundances were in the shallow zone (0 to 30 meters), with numbers decreasing at the offshore stations. Abundances ranged from 0 to 115.9 individuals per 10 cm^2 with a mean of 7.0 individuals per 10 cm^2 in 1976 and from 0 to 47.6 individuals per 10 cm^2 with a mean of 5.8 per 10 cm^2 in 1977. Numbers of polychaetes averaged less for the bank stations than for the transects.

Meiofauna in general are similar to macrofauna in that they are not a homogeneous group. They employ many of the same varied feeding mechanisms as the heterotrophic macrofauna: subsurface specialized deposit feeders, microbial consumers, non-selective subsurface deposit feeders, and predators (Gerlach, 1978; McIntyre, 1964). Still others are highly specialized and physiologically adapted, such as in a sulfide community where the dominant forms are ciliates and a few metazoans capable of existing in a reducing environment by employing surface existence or a very narrow vertical range (Coull, 1973).

Meiofauna share similar habitats with macrofauna, both being found in all marine ecosystems, estuaries, sandy beaches, subtidal muds and the deep sea. Macrofauna show a pattern of distribution similar to that of the meiofauna influenced primarily by sediment parameters (Wieser, 1960) with preference for sandy or silty sediment. In contrast, life histories of meiobenthos are very diversified, probably not less than in different macrofauna (Gerlach, 1971). With constant numbers spawning all year in some habitats and not restricted by season, the resultant productivity may equal or excel that of macrofauna (McIntyre, 1964).

Macrofauna

Infauna

Since Petersen (1913, 1918), investigators have delineated benthic communities in relation to environmental parameters such as hydrological variables (Molander, 1928), physical properties of the bottom sediments (Jones, 1950) and biological adaptations derived from species interactions in relatively stable environments (Sanders, 1968). Community distributions have been examined in a number of different aquatic environments in recent years. These studies have found that the benthos varies considerably in space due to the general heterogeneity of aquatic systems and the tendency towards patchiness in the benthic fauna.

The development of a large multidisciplinary research program in a little studied subtropical area of the Gulf of Mexico off the south Texas coast provided the opportunity to contrast benthic community structure and factors influencing this structure with other continental shelf ecosystems. The south Texas shelf is comprised of much siltier, less stable sediments than other shelves such as the Middle Atlantic region which is characterized by sandier sediments out to greater depths on the shelf (Boesch, 1978). The outer Texas shelf can also be considered a true soft-bottom environment because unlike other shelves of the eastern and southern Gulf, south Atlantic or Pacific, there are very few reef areas or extensive banks with their influential biogeographic effects, *i.e.* "islands in a sea of mud". Additionally, with pressure of extensive energy exploitation slated for the near future on the south Texas shelf, it is imperative to document the species assemblages of the benthos in a relatively pristine habitat. Although pristine, this habitat is one which would probably be most directly impacted should a major environmental disturbance occur (*e.g.* oil well blowout) and one which is a direct supportive element to many of the regional fisheries such as shrimp.

Ordination analysis of the infaunal species composition for each of the 25 collection sites indicated that 73% of the total variation between sites was accounted for by the first and second coordinates. The third coordinate only accounted for an additional 4% variation and showed no meaningful trends. Therefore, all emphasis was placed on the first two coordinates (X and Y axes).

In order to objectively define community differences within the collection sites and station scores from community ordination were evaluated by the Least Significant Difference (LSD) multiple range test. Both coordinate mean scores of the six collection periods were compared for each station. The results showed that the first ordination coordinate was able to significantly delineate ($P < 0.05$) four station groupings, Groups I, II, III and V (Figure 37). Station Group I consisted of Stations 4/I and 1/IV while Group II was composed of collections from Stations 4/III and 4/IV.

Station Group III (Figure 37) was defined by the largest number of collection sites and included mid-depth stations. According to the LSD results for the second ordination coordinate three collection sites on Transect IV significantly ($P < 0.05$) differed from the other sites in Station Group III and were thus considered a group within themselves (Station Group IV). Station Group V was comprised of the five deepest stations that showed consistently low scores for both the first and second ordination coordinates (Figures 37). A group of five stations including 5/I, 6/I, 5/II, 6/II, 2/III did not show a significant difference from most sites in Station Group III or V according to first coordinate mean and were not further differentiated by the second coordinate. Therefore,

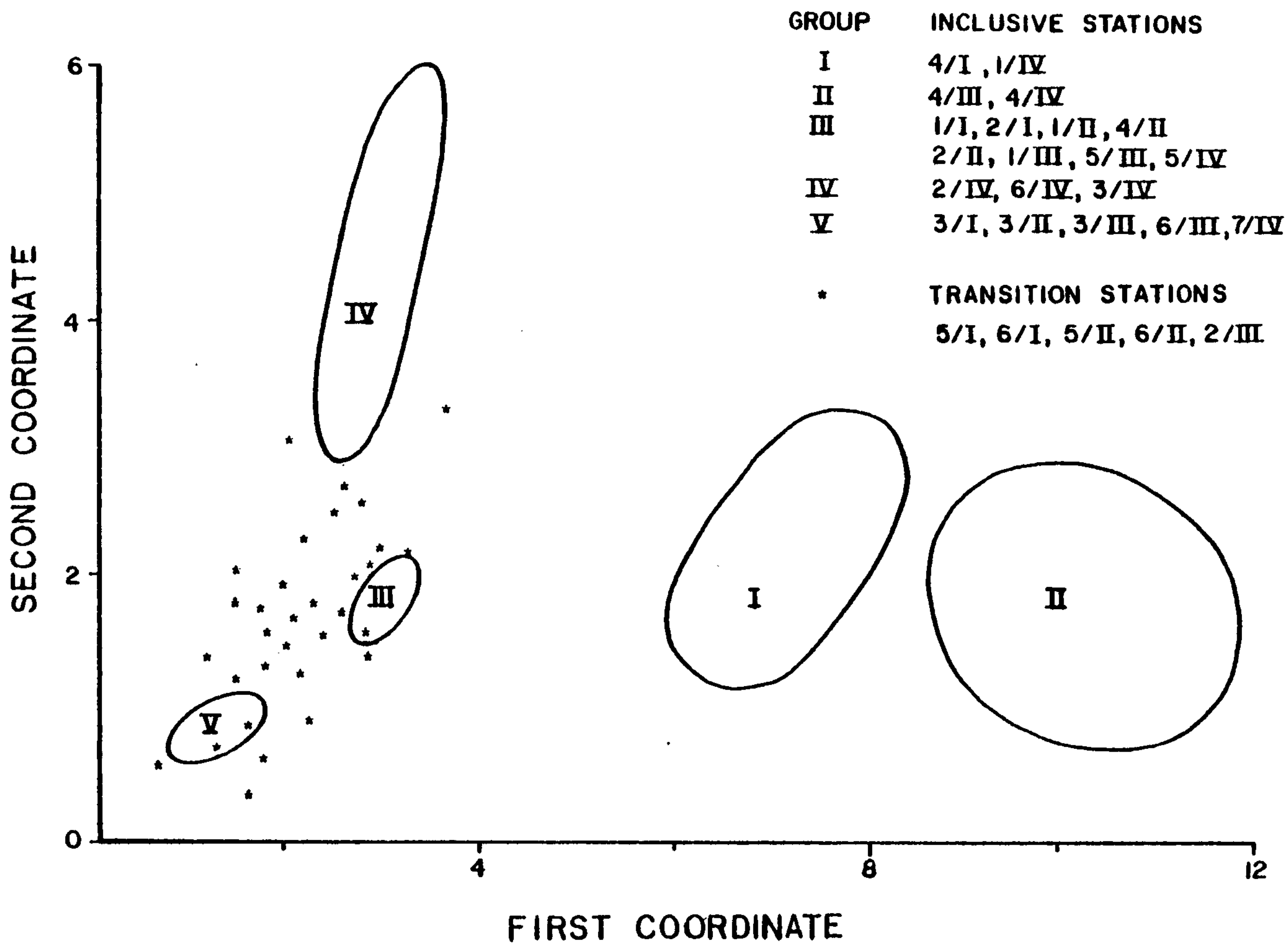

Figure 37. Results of benthic infauna community ordination. The group 95% confidence ellipses are shown for the first and second coordinate from ordination. Asterisks represent transition stations.

these stations were defined as a transition zone between the mid-shelf communities (Station Group III) and the deep water communities (Station Group V). Cluster analyses on the same data showed similar results. These station groupings are also illustrated in Figure 26 (pg. 92, Chapter 4) which suggests that the infaunal station groupings and benthic habitat environmental variables showed similar trends.

The community variables of species numbers, infauna density, species diversity, and equitability exhibited trends (Figure 38) that were consistent with the community ordination results for the station groups. The number of species (Figure 38) was consistently the highest at the shallow stations (Groups I and II) with a sufficient drop for Group III sites. Organism density was also greatest for the shallowest sites with decreases in deeper waters on the shelf. High species numbers and infaunal densities resulted in high species diversity for the shallow stations (Groups I and II). The highest diversities, however, were measured for Station Group IV. Equitability showed an increase in the offshore direction indicating that although the shallow collection sites were high in species numbers and densities, these sites were characterized by a few dominant fauna, in contrast to more evenly distributed population densities for the offshore species assemblages (Groups IV and V). Results of one-way ANOVA indicated there was a general significant difference ($P < 0.01$) between station groups for all four community structure measures. LSD range tests, however, showed no difference between the transition zone and at least one of the station groups bordering this zone (III or V) for each of the four variables presented in Figure 38, emphasizing the transitional nature of these fauna.

Inverse community ordination (R mode), identifying the species characteristic of collection sites, aided in the interpretation of specific

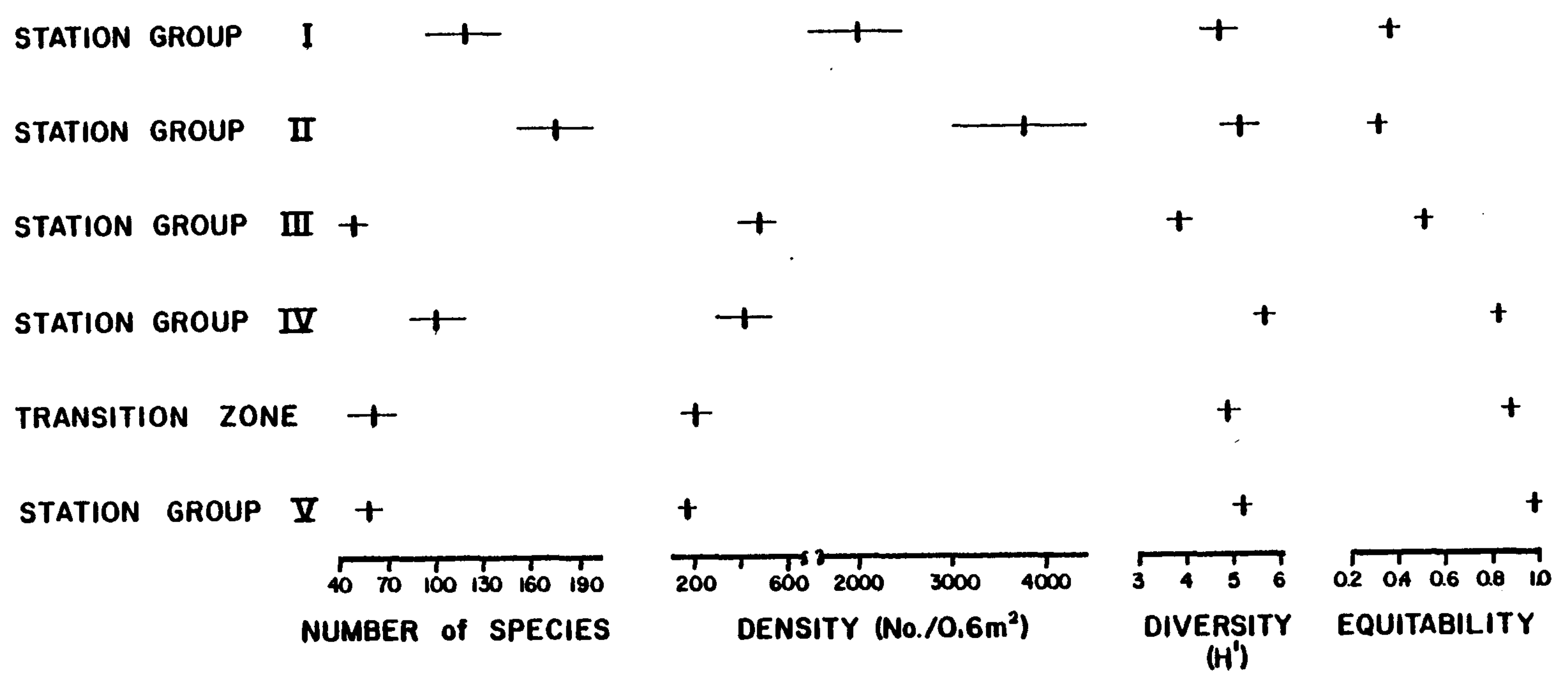

Figure 38. Plots of station group means for infaunal community characteristics. Station groups defined from Figure 37. Bars represent 95% confidence intervals.

faunal assemblages that described the shelf station groups highlighted above. Fifty-eight (58) infaunal species which showed a minimum of at least one percent abundance at a station over the study period were identified by this ordination analysis (Figure 39). These 58 species comprised six groups that were coincident with one or more of the station groups. Species Group I represented shallow water fauna, while Species Groups II and III consisted of infauna showing shallow to mid-shelf distributions. Species Group IV was comprised almost exclusively of deep water infauna. Groups V and VI were composed of infaunal species relatively ubiquitous over the south Texas shelf. Most major taxonomic classes (*i.e.* polychaetes, molluscs, crustaceans) were represented by these faunal groupings, but polychaetes were by far the dominant taxa of the shelf benthos. As illustrated by monthly sampling on Transect II (Table 15) there was a decrease in polychaete domination in the offshore direction but they still comprised the majority of the community at all stations.

The transition stations again illustrated why they were called such, showing the abundance of species characteristic of both mid-shelf stations and deep stations (Figure 39). The frequency of species occurrences within Station Group IV suggested that this area may be unique on the Texas shelf. Although in deeper water, these sites supported fauna characteristic of shallower stations (*e.g. Prionospio pinnata* and *Ceratocephale oculata*) as well as fauna representative of collection sites within their depth range. Figure 39 further illustrates two points stressed in Figure 38. First, the occurrence of more species in Station Group IV contributed to the high species diversity of this group on the shelf. Secondly, the proportionately more species with higher frequencies of occurrence at the shallower stations hinted to the dominance of some of these organisms in

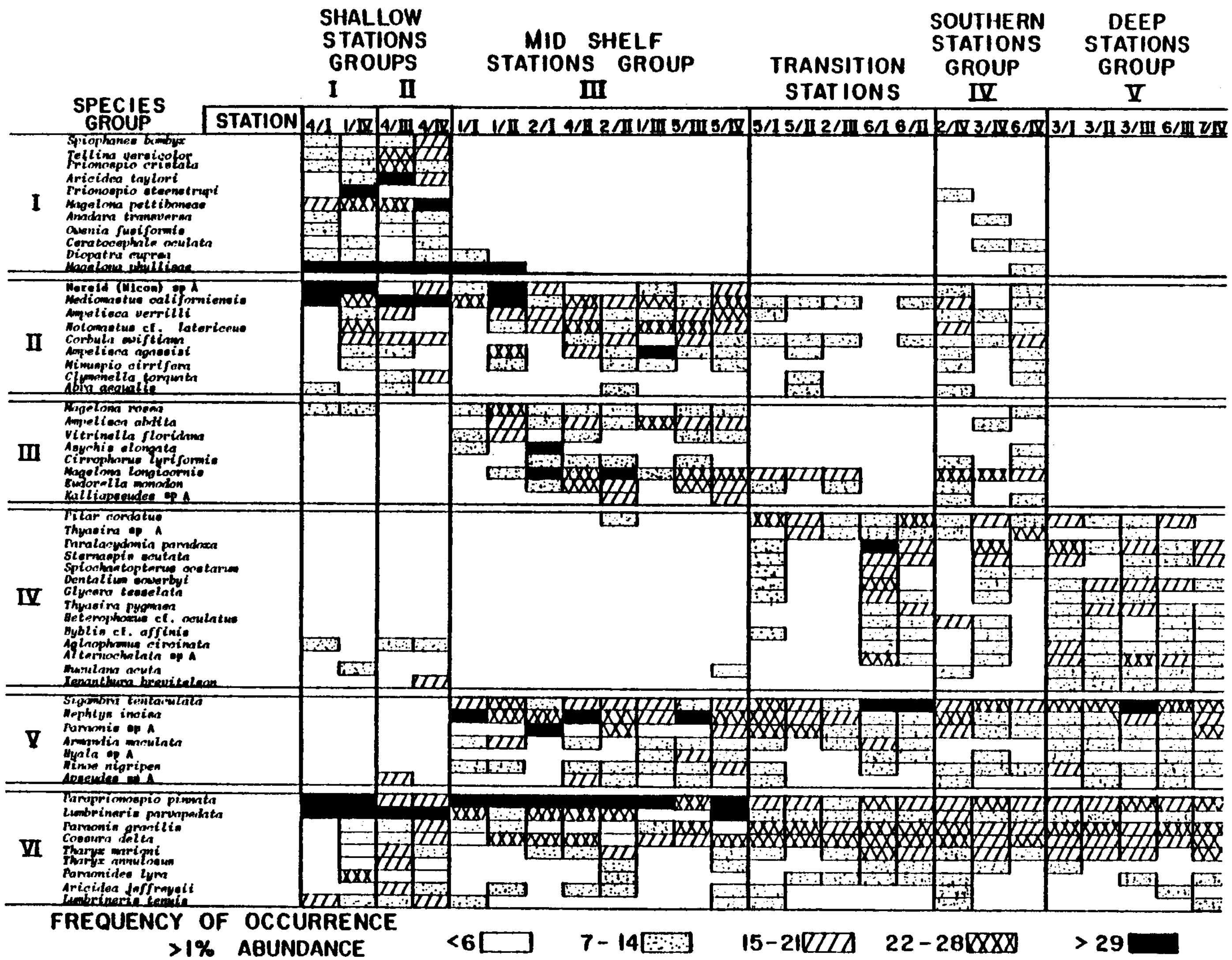

Figure 39. Infaunal species frequency of occurrence for the STOCS sampling stations presented according to station group defined from Figure 37. Species groups are also indicated by Roman numerals.

TABLE 15

MEAN PERCENT COMPOSITIONS OF MAJOR FAUNAL GROUPS AT SIX OUTER CONTINENTAL SHELF STATIONS ON TRANSECT II OVER STUDY DURATION

Faunal Groups	Stations	1	2	3	4	5	6
Polychaeta		81.6	67.7	67.4	49.6	53.2	52.6
Mollusca		2.3	6.0	10.2	34.2	20.0	14.4
Gastropoda		1.9	2.9	2.3	3.5	2.9	1.9
Pelecypoda		0.3	3.1	7.7	29.1	15.1	9.0
Crustacea		10.6	19.7	14.3	8.4	16.0	21.5
Ostracoda		-	-	0.1	0.4	1.6	8.0
Isopoda		-	-	-	0.3	5.2	3.0
Amphipoda		9.1	10.7	6.2	3.7	6.7	5.6

the shallower shelf waters (*i.e. Magelona phyllisae, Paraprionospio pinnata,* and *Lumbrineris parvapedata*).

Assemblages of organisms are rarely present as discrete groups with clear-cut boundaries as evidenced by the need for a transition community in the observations presented above. Groupings of organisms into communities must therefore be inferred from consideration of the interactions of the fauna with various environmental factors. This is also evident in the similar patterns observed between the infaunal station groupings (Figure 37) and the station groupings for the sediment characteristics (Chapter 4, Figure 26 and Table 9). Multivariate discriminant analysis was used to aid in identifying discriminating environmental variables for the infaunal station groupings and also to test the null hypothesis that there was no difference environmentally between these groups.

Figure 40 illustrates the position of station group mean discriminant function scores with their 95% confidence ellipses in a two-dimensional space defined by the first and second functions (Figure 40A) and the first and third functions (Figure 40B). Also indicated on each plot are the individual transition station scores for each collection period. From a suite of 13 original environmental variables four variables proved to be good discriminators of the infaunal station groupings (Figure 41).

The first and second discriminant functions accounted for 94.7% of the variation between station groups and were both significant ($P < 0.01$) in discriminating between groups as indicated by their chi-square values (Figure 40A). Approximately 80% of the variation in the first function was accounted for by the environmental variable of water depth. The sediment parameter, sand/mud ratio, accounted for an additional 18.7% of the first function's variation. Figure 41 illustrates that water depth was able to significantly differentiate the shallow stations (Groups I and II)

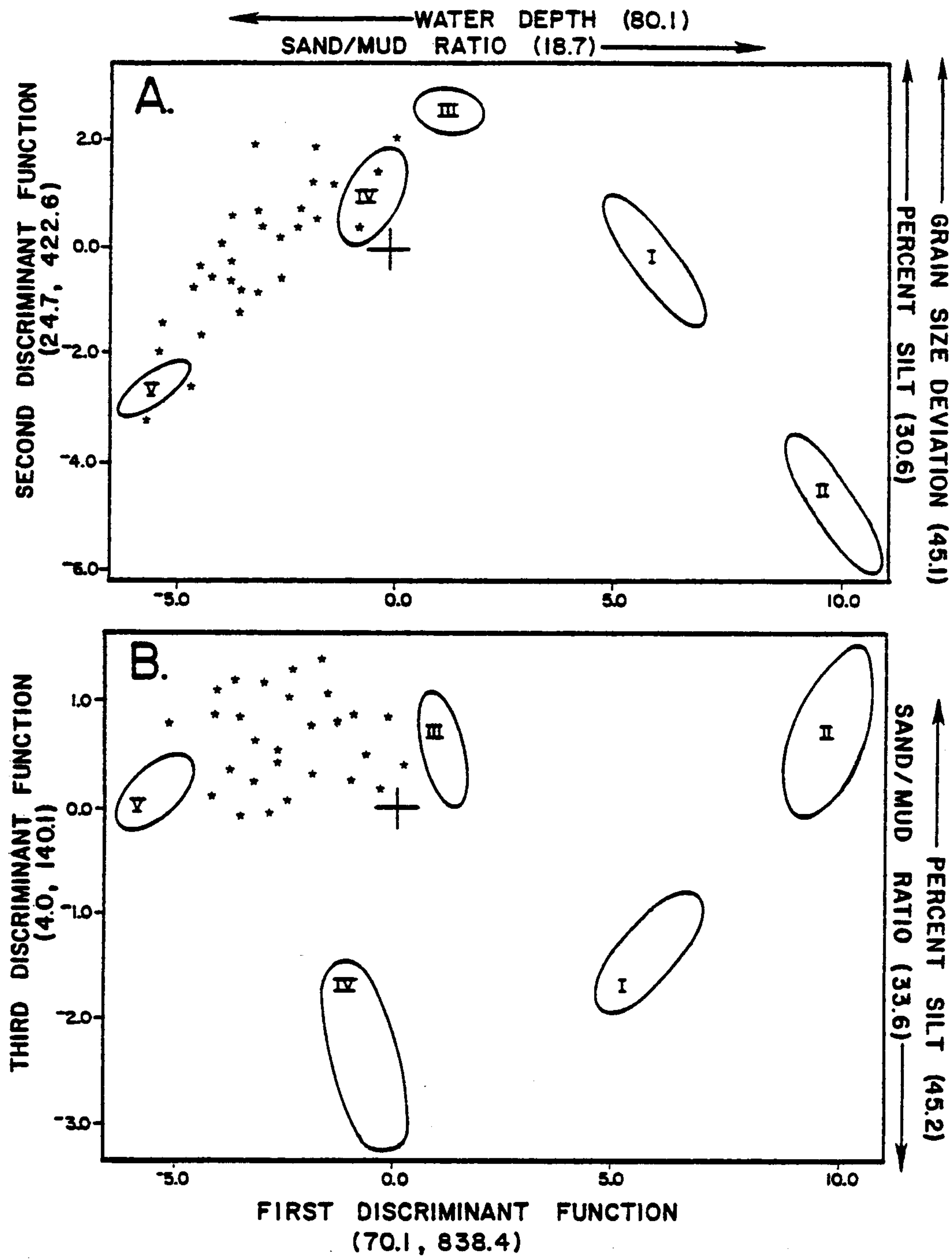

Figure 40. Results from discriminant analysis of environmental variables according to infaunal station groupings (Figure 37). The 95% confidence ellipses for each group plus the individual points for the transition station (asterisk) are plotted for the first and second (A) and first and third (B) discriminant scores. Environmental variables responsible for group separation are shown with their percent explained variation.

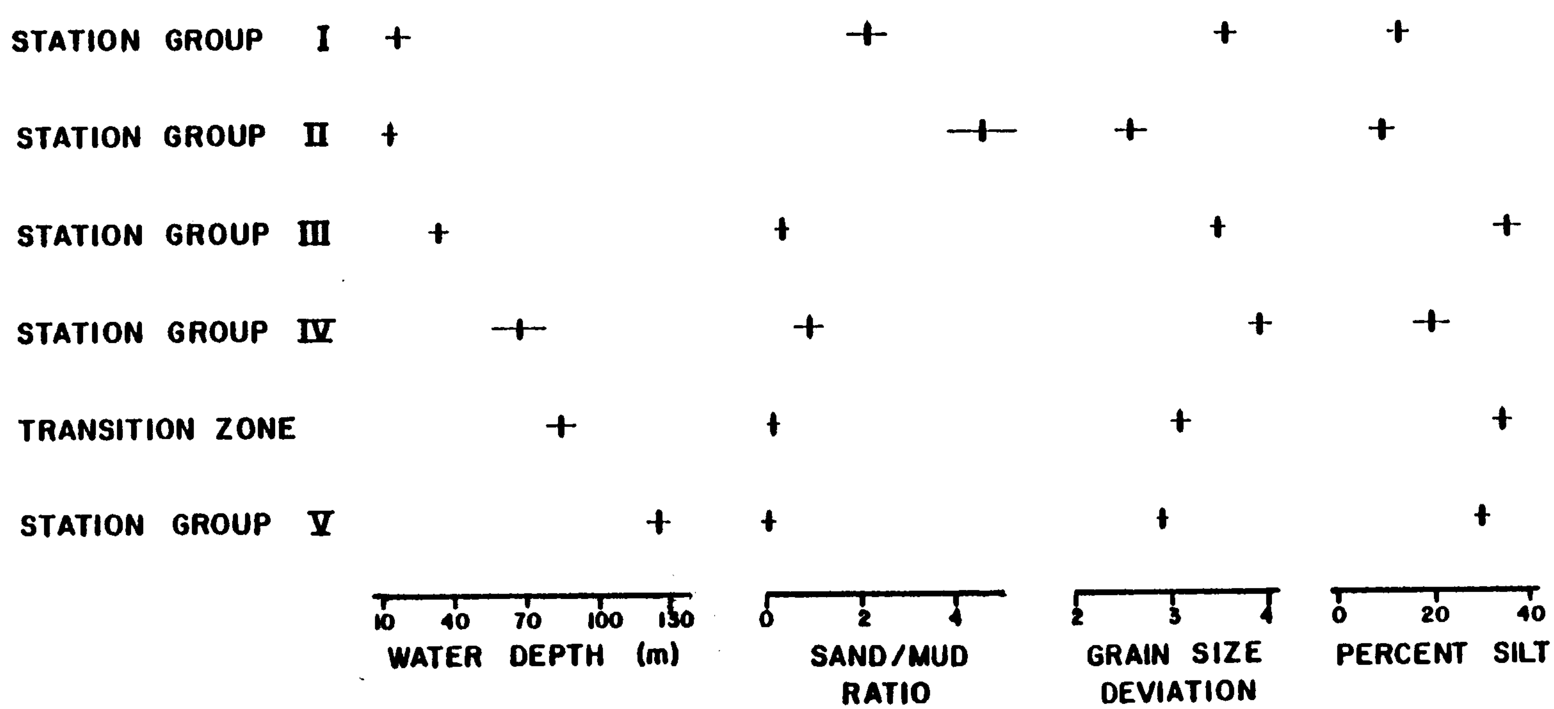

Figure 41. Station group mean and 95% confidence limits for environmental variables responsible for station group separation in Figure 40.

from the mid-shelf stations (Groups III and IV) and the mid-shelf stations from the deep stations (Groups V). The sand/mud ratio was further able to differentiate Station Groups I and II from each other.

On the second discriminant function (Figure 40A) sediment grain size deviation further distinguished differences between Groups I and II (Figure 41) as well as showing a more subtle but significant split between Groups III and IV. The sediment variable, percent silt, however, showed the strongest differentiation between the latter groups.

The third discriminant function (Figure 40B) was also significant ($P < 0.05$) and accounted for an additional four percent in variation between station groups. This function further illustrated the discriminating power of percent silt in not only differentiating Groups III and IV but also Group IV from the transition stations which were in the same general depth range (Figure 41).

The overall chi-square derived from the general Mahalanobis distance squared was 640.9 for the discriminant analysis of station groups according to environmental variables. This chi-square was highly significant ($P < 0.001$) and suggested that the null hypothesis of no environmental difference between groups be rejected. It was assumed, therefore, that there was very little probability the station groups could have been formed by chance but that the separation between them was real. These results confirmed the biological model and suggested some of the variables potentially influential in structuring the infaunal communities along the shelf depth gradient.

Sediment properties appeared to be relatively important in terms of community structure patterns according to Figures 40 and 41. Although these properties are mildly correlated with water depth, the most powerful discriminating variable observed, there are other factors also related to water depth which must be considered in the interpretation of results from the study. These factors include the degree of food availability to the benthos and bottom water environmental variability along the depth gradient as characterized by surface chlorophyll a concentrations and the standard deviation measure of temperature and salinity. Data presented in previous chapters indicate that these variables decrease with increasing water depth on the shelf. Chlorophyll a concentrations were highest and also most variable in shallower waters (Chapter 3) where highest densities of infauna were observed. Lower concentrations of primary producers, whose abundances were less variable throughout the study interval at deeper stations, were associated with lower densities of infauna and more evenly distributed population numbers (equitability) within these assemblages (Figure 38).

Temperature and salinity were both most variable at the shallower collection sites, with decreasing variability as water depth increased (Chapter 2). This implied that the shallower benthic habitat was much more variable and less predictable in terms of environmental changes and, therefore, conducive to dominance by a few fauna. This variability of the shallow shelf was further verified by the fluctuations of chlorophyll a representing a food source to the benthos through the detrital pool. In addition to the influential effects of certain sediment characteristics on benthic community structure, gradational features of a food source to the benthos and variability in the bottom water environment were also suspect in potentially causing the different faunal patterns observed.

Other benthic marine systems investigated have been shown to be typically gradational in space with respect to sediment and other environmental variables (*e.g.* Day *et al.*, 1971; Field, 1971; Boesch, 1973;

Glemarec, 1973). Closely correlated with these environmental changes are changes in macroinfaunal communities. According to the observations presented above, sediment structure plays an important role in structuring the benthos. Superimposed on the mechanics that the substrate pose on the benthic infauna, however, are factors involved in producing variability both to a food source of the benthos and the overlying hydrologic environment. These environmental aspects couple together to produce a very complex association between the Gulf of Mexico benthos and the habitat in which they live.

According to Glemarec (1973), nature of the sediments is of prime importance for the settlement of most invertebrate larvae and the resultant composition of communities. He extends his definition of spatial stages of the benthos, however, to include the effects of variations in bottom water temperature and cites examples from Jones (1950) and Lie (1967). Glemarec concludes that the environmental properties which permit a distinction between faunal assemblages are different depending upon whether the assemblages are in shallow or deep water.

Significant variability in shallow waters combines with coarse ill-sorted sediments to provide an unstable habitat. This habitat is characterized by many different fauna with few exhibiting dominant abundance (low evenness). In contrast, another habitat also with coarse sediments (Station Group IV) exhibits the most diverse fauna observed during the study period. These sites, in addition to having a very heterogenous sediment structure, are characterized by very stable hydrologic variables as well as a more predictable food source.

As Sanders (1968) and McCall (1977) illustrated, in a marine habitat subjected to continual local disturbances and harshness of environmental variables as found in Texas inner-shelf waters, a few highly specialized species, opportunists according to Grassle and Grassle (1974), are present in large numbers. These species are able to invade new areas voided of fauna by a local disturbance (*i.e.* currents) and maintain their large population sizes because of the abundant food sources and unpredictability of the bottom water environment including occasional disturbance from storm currents. In contrast, deeper shelf habitats exhibit less bottom water variability, and sediment characteristics become the key to faunal distribution. This is evident in the faunal changes between the mid-depth stations (Group III) where the silt content is high and the deep water stations where clay is the more dominant sediment component.

There was a variable sand/silt/clay mid-shelf mixture observed at most stations between water depths of 20 and 50 m (Station Group III) with silt representing the dominant component. These stations generally showed a sand/mud ratio of 0.3 to 0.5, much lower than the shallow study sites. Percent silt was also a major discriminating variable separating Station Groups III and IV (Figure 41). Group III exhibited the lowest number of infaunal species on the shelf while supporting population densities second only to the shallow sites. Associated with these community parameters were low measures for both species diversity and equitability suggesting that these species assemblages were dominated by a few fauna with high densities.

Rhoads (1974) stated that siltier sediments present a difficult environment to which fewer species can adapt. Not only are the ecological niches decreased by a more homogenous substrata (Ward, 1975) but the stability of particle sizes to bottom water currents is less. This can produce a relatively unstable substrate for infauna inhabitants. A good example of the instability of this particular area is the sediment resuspension associated with the nepheloid layer that occurs frequently during the year (Kamykowski *et al.*, 1977).

Although the results of this investigation were similar to other studies cited above in that a gradational nature was defined for the Texas shelf benthos related to several environmental variables, differences between some of these variables in this and other studies was the key. As stated earlier, the Texas shelf differs from other shelf ecosystems because of the silty nature of its sediments. The infaunal-environmental relationships observed here suggest that these siltier sediments may be responsible for a difference in dominant taxa on the Texas shelf compared to other shelves such as the Middle Atlantic.

Polychaetes were the dominant taxa observed in this study. The majority of their feeding strategies, according to comparisons with the fauna discussed by Fauchald and Jumars (in press), involved deposit feeding modes. These strategies are much more conducive to silty, unstable bottom habitats (Sanders, 1960; Saila, 1976). In contrast, the dominant fauna observed on the Middle Atlantic shelf were amphipods (Boesch, 1978). This shelf is characterized by sandier sediments than the Texas shelf. Amphipods derive their nutrition primarily by suspension feeding, which according to Sanders (1960) and Levinton (1972), is a more appropriate feeding strategy for sandier more stable sediments.

It was concluded that the subtropical Texas shelf showed infaunal patterns consistent with other shelf ecosystems in terms of environmental gradation (Day *et al.*, 1971) and shallow water variability as found in temperate marine systems (Sanders, 1968). The Texas shelf differed, however, from at least one other shelf extensively studied (Boesch, 1978) in that a different taxa dominated the infauna and this difference was possibly related to the sediment structure differences of the mid-shelf habitat between the two areas.

Epifauna

Northern Gulf of Mexico epifauna are considered by many investigators as an extension of the Carolinian province with faunal divisions at the Mexican border and just east of the Mississippi delta (Hedgpeth, 1953). The STOCS study area falls within the Texas to Mississippi delta region, but by virtue of the southernmost stations, is influenced by Caribbean fauna. Distribution of any species is based on a complex of environmental factors. Temperature and salinity control the range of benthic species, but within that range, more subtle factors determine faunal distribution. Depth was the most apparent factor controlling epifaunal distribution in this study.

The results of cluster analysis, which were used to define community changes for epifauna on the Texas shelf, were relatively similar for both 1976 and 1977. The analyses divided the shelf into two major regions based on depth and/or distance from shore (Figure 42). All stations within 10 to 45 m depth (plus 2/II at 49 m) and located less than 30 miles offshore were grouped together (A). Stations with depths greater than 45 m and located at least 30 miles offshore formed the other major group (B). The two regions varied in other physical variables. Bottom water temperatures (10 to 29°C) and salinity (30 to 37 ppt) varied widely throughout the year in Group A. Group B stations were characterized by a more stable temperature (15 to 25°C) and salinity (35 to 37 ppt) regime. There was considerable overlap of sediment types between the two regions but the sandiest sediments were found at shallow, nearshore stations and the highest clay content was in sediments from the deep offshore stations.

Subdivisions from cluster analysis divided the study area into six groups of stations (Figure 42). These minor divisions generally corresponded to shallow (10 to 15 m), shallow-intermediate (22 to 45 m), deep-intermediate (47 to 100 m), and deep (106 to 134 m) stations. Stations

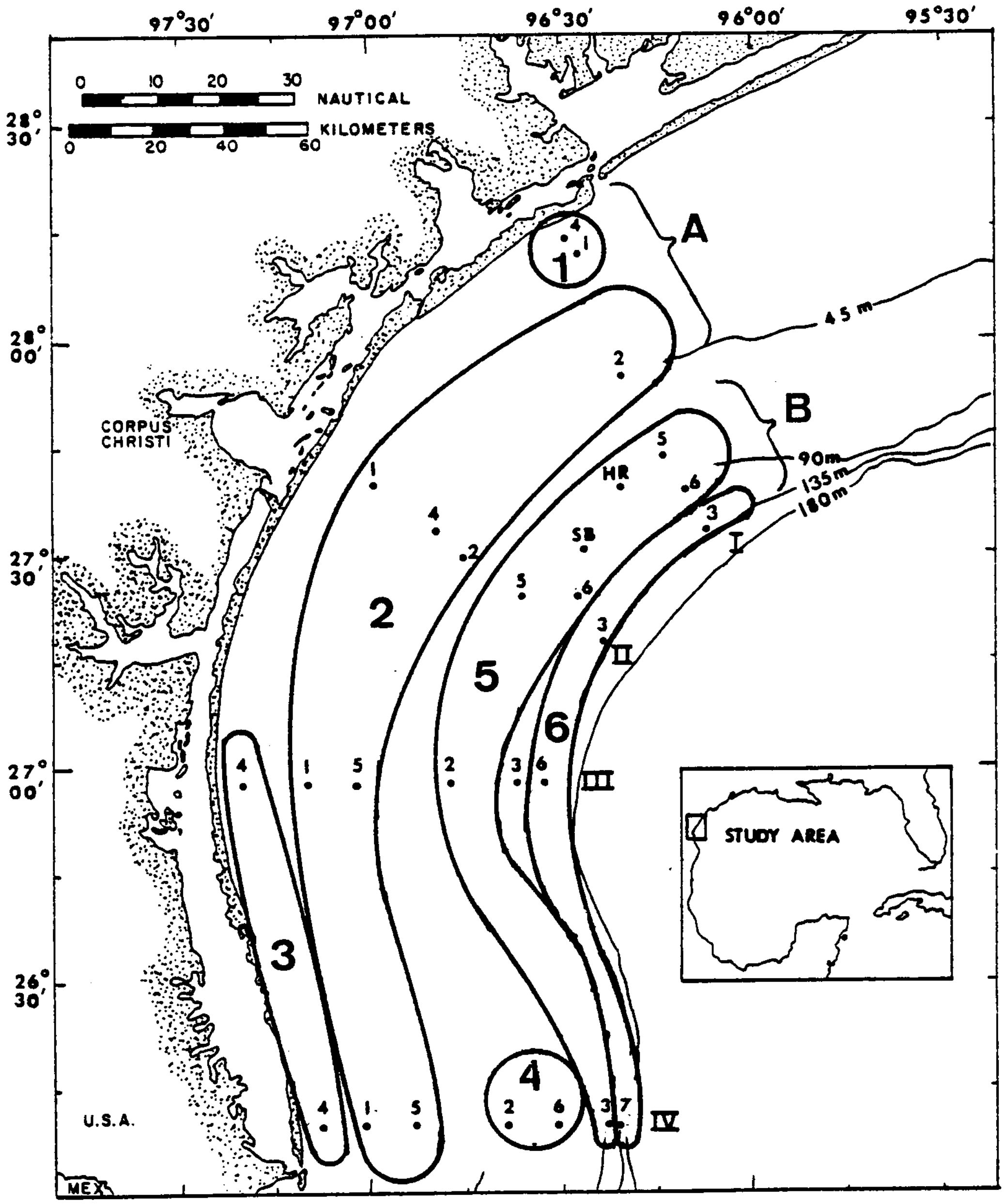

Figure 42. Location of station groups from cluster analysis of seasonal epifaunal data.

which clustered together two out of three seasons were considered to be a group. Seasonal changes in abundance and the mobility of epifaunal organisms precluded clean distinctions of station groups consistent throughout the year.

Station groups were also defined by the species found there. Clustering by species or inverse analysis resulted in eight species groups (Figure 43). The first three groups of species were collected only at stations with greater than 45 m depth; Species Group IV was taken most consistently at the same stations. Group V species were collected at intermediate depth stations but not at shallow or deep stations. Species in Groups VI and VII were most often collected at stations less than 45 m in depth. Group VIII species were collected at all but the deepest stations. Although a species group was relatively constant to a station group, most individual species responded in a unique way to the physical environment common to the stations.

For example, many of the species most characteristic of the shallow shelf are motile decapods found in inlets, bays and shoal areas in summer and early fall. Copeland (1965) collected large numbers of *Trachypenaeus similis* and *Squilla empusa* in Aransas Pass Inlet in late summer and early fall. Large numbers of *Penaeus setiferus* are found in the bays in fall and support a sizable bay fishery. Seasonal changes in population may be related to the annual temperature (14 to 29°C in 1976) and salinity (31 to 36 ppt in 1976) extremes at inner-shelf stations. In contrast, large numbers of species with low abundance characterize the outer-shelf assemblage. High equitability and species richness of this area reflect the relatively stable environment conditions characteristic of the area.

Similar to the general community structure differences on the Texas

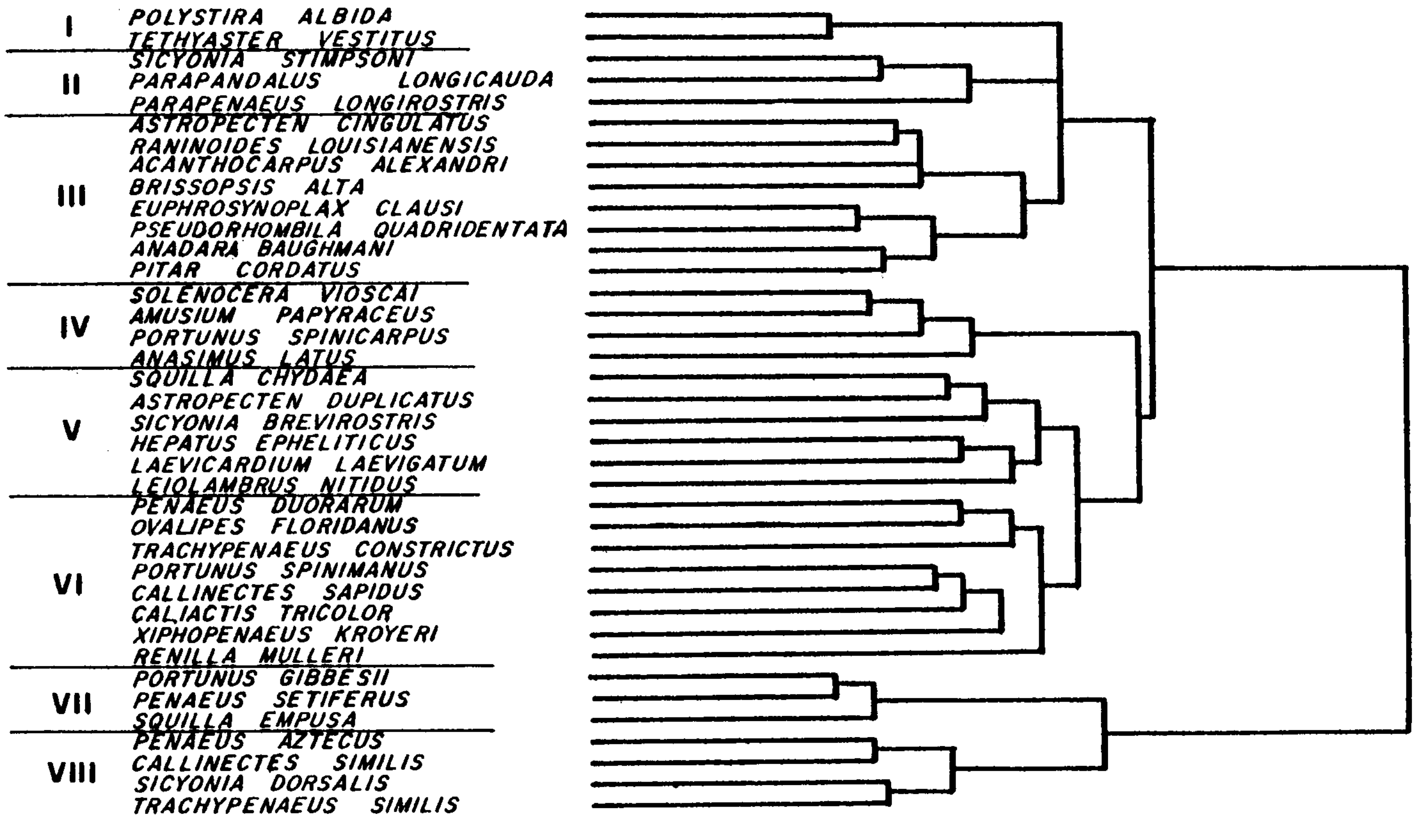

Figure 43. Species dendrogram from inverse analysis of seasonal epifaunal data. Roman numerals refer to species-groups.

shelf being relatively consistent over two years of study, specific community variables such as number of species, density, diversity and equitability showed similar trends across the shelf between years (Figures 44 through 46). Number of epifaunal species collected per station presented no consistent general pattern. The numbers collected were much smaller than in the infaunal collections. Along Transect I, epifaunal species numbers were fairly evenly distributed during each collection period. Differences between seasons were apparent. The winter sampling showed fewer species collected on this transect. The number of species collected at 5/I was somewhat depressed at all collection times. Transect II showed a varying pattern of species abundance spatially and temporally. The winter collection had a peak species abundance at 6/II suggesting an increase with depth. There were species abundance peaks at Station 2/II in both spring and fall collections so that the abundance of species was greatest at mid-depth and decreased shoreward and offshore. On Transect III, there was a slight winter increase in species richness with depth. Spring collections at the deepest two stations (3 and 6) were extremely depressed. Minor peaks in species abundance occurred at Stations 1/III and 2/III in the fall. Transect IV epifaunal species richness varied widely with season. The winter collection showed a strong decrease in species richness with depth. In spring numbers of species were somewhat evenly distributed along the transect with Station 6/IV somewhat depressed. The fall collection exhibited a strong positive correlation of species richness with water depth.

The number of individual epifaunal organisms collected at each station generally peaked at mid-depth or shallow-intermediate depths and decreased shoreward and offshore (Figures 44 through 46). Transect I

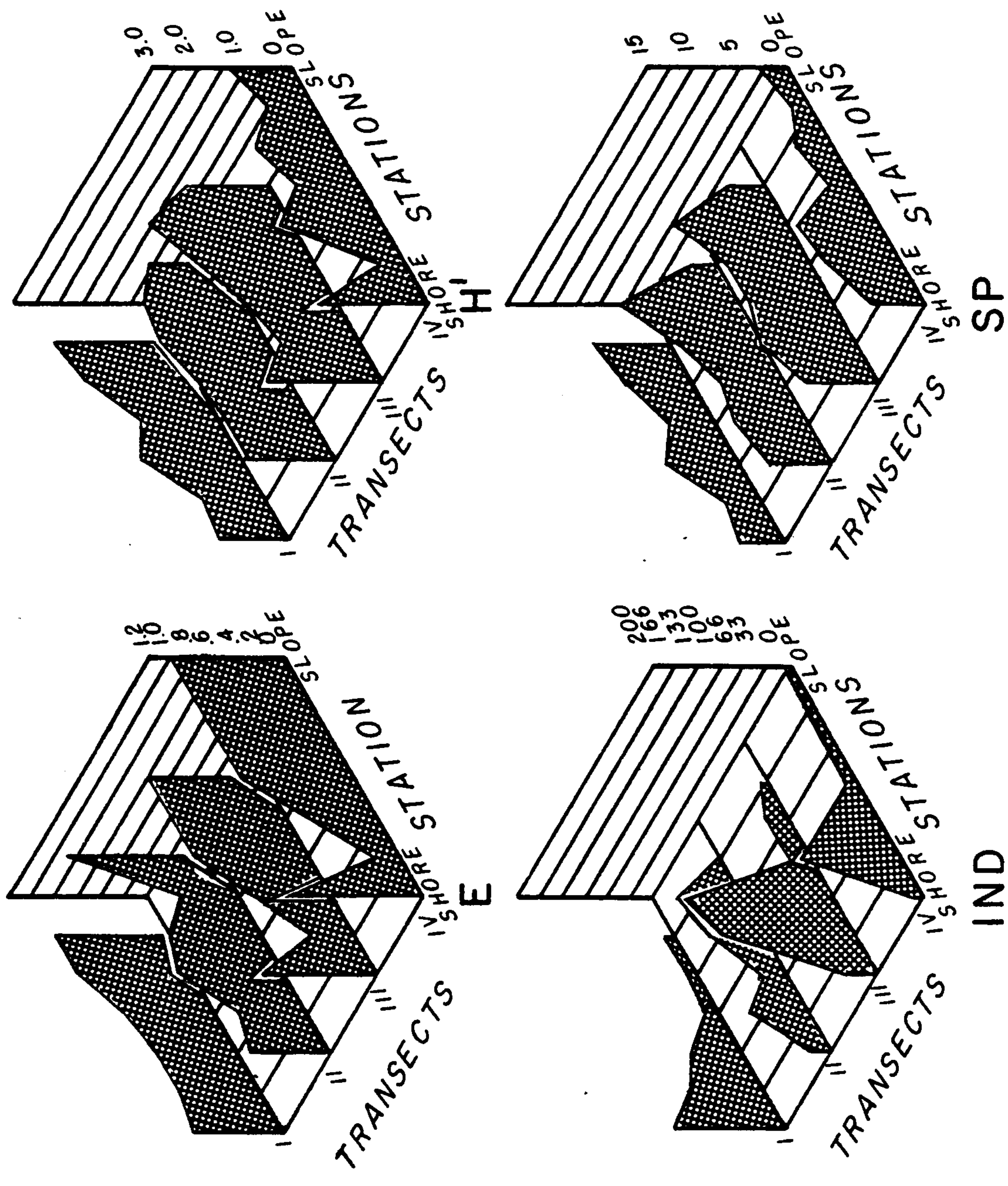

Figure 44. Shannon diversity values - H", equitability - E, number of species and number of individuals for winter 1977 epifaunal data.

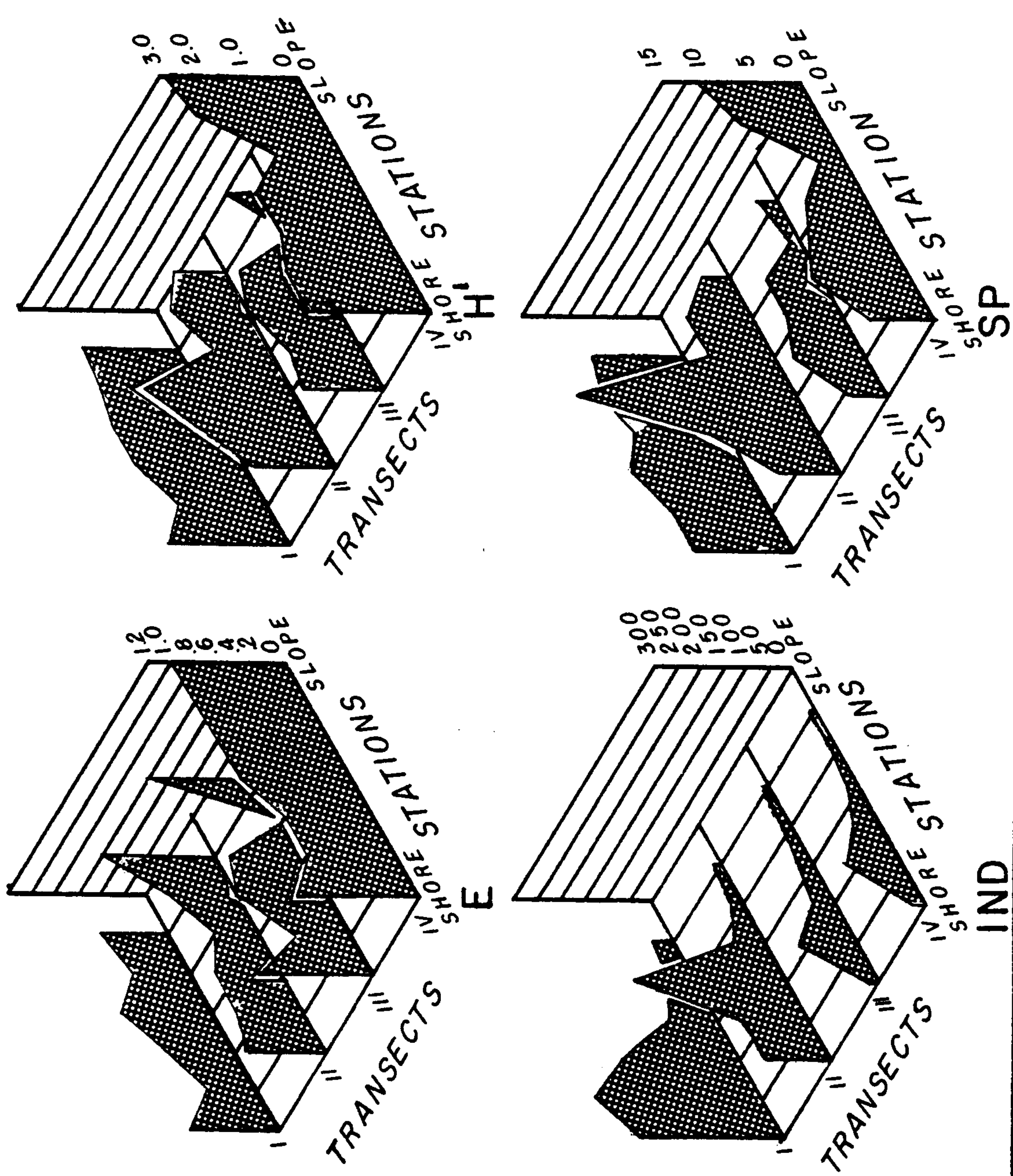

Figure 45. Shannon diversity values - H", equitability - E, number of species and number of individuals for spring 1977 epifaunal data.

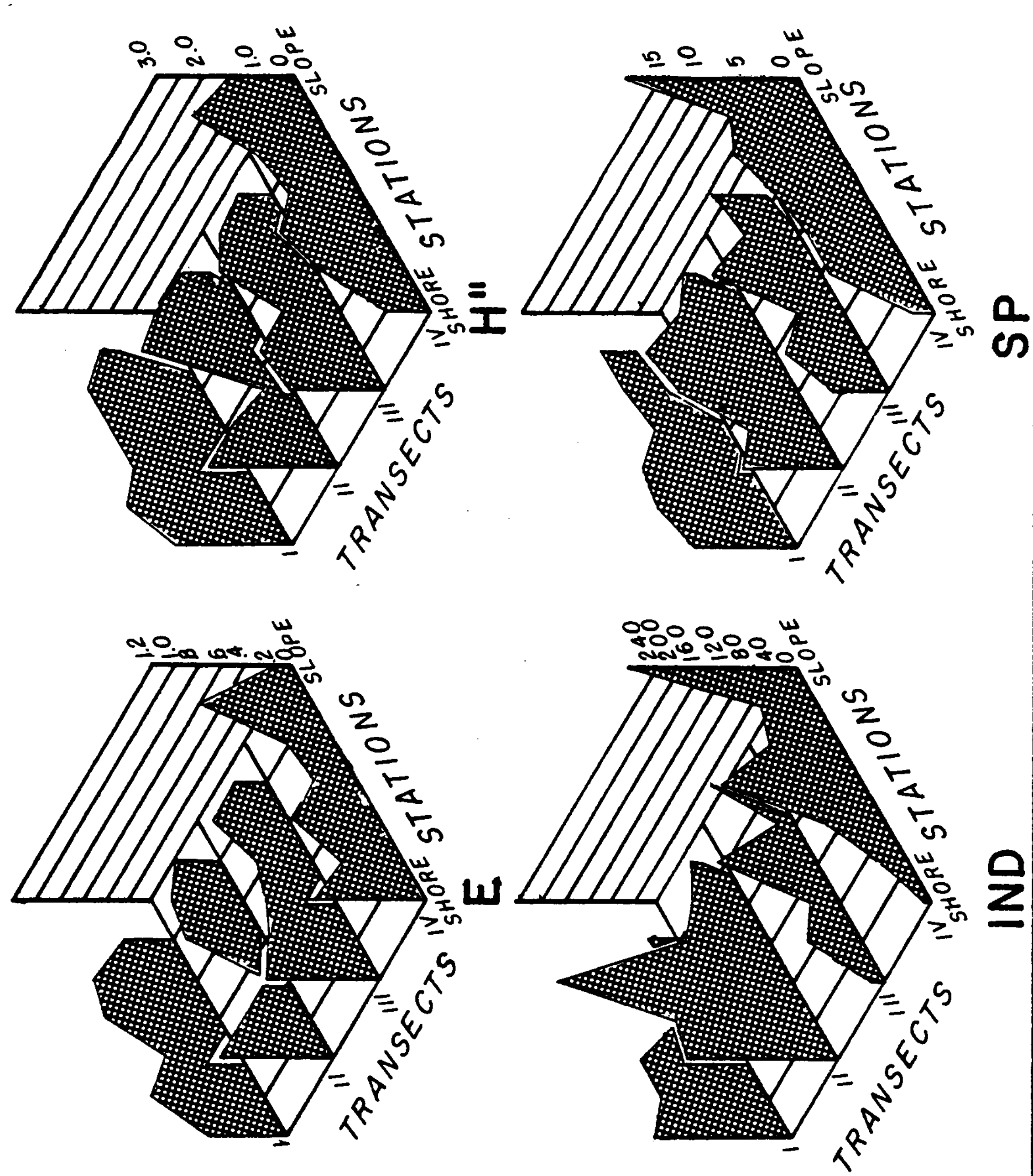

Figure 46. Shannon diversity values - H", equitability - E, number of species and number of individuals for fall 1977 epifaunal data.

epifaunal density distributions followed the same general pattern but with maximal numbers of individuals at inshore sites, more so than other transects. A highly varied pattern of density was seen on Transect II. Winter collections were small and similar in numbers of individuals across the shelf. A major peak in density occurred in the spring collection at Station 2/II with numbers of individuals decreasing shoreward and offshore. The fall collection on this transect displayed the densest epifaunal communities observed for the entire year, particularly at the four shallowest stations. The number of epifaunal organisms collected on Transect II varied widely through the year. Dense populations on the inner half of the study area occurred in the winter collection. Densities along this transect were low during the spring collection period. Fall collections indicated peaks of abundances at Stations 1, 2 and 6. Epifaunal density patterns on Transect IV were similar to Transect III with the winter onshore collections slightly diminished and the fall collections generally increased.

Epifaunal diversity (H') was generally lower than that exhibited by infaunal collections (Figures 44 through 46). No general pattern of diversity across all transects was observed. Relatively high densities were consistent across the shelf for Transect I with some tendency to increase with depth in the winter with a major peak at Station 2/II in the spring and a major decline at Station 3/II in the fall. Transect III exhibited a fairly high winter diversity with a minimum at Station 1/III. Increases in this variable with depth were observed, except at the deepest site where there was a decrease in diversity. A major decrease in diversity was observed at 3/III in the spring collection. Diversity on Transect III in the spring was fairly uniform with decreases at Stations 5 and 6. There were relatively low diversities on Transect IV in the winter, uniformly high values in spring with the exception of Station 3/IV and a tendency of H' values to increase with depth in the fall.

Epifaunal equitability values showed no pattern consistent to all transects (Figures 44 through 46). There was a trend toward greater equitability inshore and offshore with mid-depth areas being depressed. A smooth pattern of increasing equitability with depth in the winter was evident on Transect I. Spring and fall values were more diverse with low equitability at Stations 1 and 6 in the spring and Stations 4, 2, and 3 in the fall. Transect II exhibited increased equitability at the deepest site (Station 3) in winter and spring which decreased sharply in fall concommitant with an increase in equitability at the nearshore stations. Transects III and IV were very similar in the winter with high equitability at all except the shallow mid-depth stations. Equitability on Transect III showed peaks shallow and deep with variable levels between in the spring while Transect IV values remained almost uniformly high. Fall collections on Transects III and IV indicated the trend toward greater equitability inshore and offshore with decreased values at mid-depths.

As illustrated above, epifaunal community structure parameters showed no general trends or spatial patterns. Variation in temporal and spatial abundances of dominant species in 1976 was due to recruitment of young age classes at shallow to shallow-intermediate stations, as well as to migration of the adult population, accompanied by reduction in abundance, to the deeper stations. The same pattern was observed in 1977 except that there was a stronger tendency for the abundance to be concentrated at stations along Transects I and II.

Because epifaunal species differ in physical and biological needs and some are capable of moving considerable distances, analysis of individual species distributions may be the best method for interpreting the

STOCS data. An important aspect of this study was the evaluation of the shelf ecosystem in terms of numbers and kinds of species. Further information that can be derived from the data includes an understanding of the distribution of species important to man (directly or indirectly) and the identification of species with narrow or critical tolerances to environmental change.

Demersal Fish

Patterns of distribution and abundance of outer continental shelf fishes off the Texas coast have been examined by a number of workers (*e.g.* Hildebrand, 1954; Chittenden and Moore, 1977), but ecological aspects of this ichthyofauna (particularly regarding factors which affect these patterns) remain poorly understood. Although distributions of certain species off Texas and in other parts of the Gulf of Mexico have been related in a broad manner to a few obvious factors such as depth, sediment and temperature (Dawson, 1964; Chittenden and McEachran, 1976; Lewis and Yerger, 1976), a more detailed exposition of the relationship between fish populations and the ecological factors which affect them is desirable. The need for statistical evaluations of these fish-environment relationships has been specifically pointed out (Chittenden and Moore, 1977).

The numerical analyses of the demersal fish data are presented in Figure 47 and show three distinct station groups aligned with depth on the shelf. The following general conclusions were apparent from the analyses: 1) zonation appeared to be depth related, with temperature-related seasonal migration patterns influencing the species associations; 2) the shallow-shelf turbulent zone exhibited low species diversity throughout the year, with especially high numbers of individuals in winter and spring; 3) the nearshore faunal associations dissipated during the late

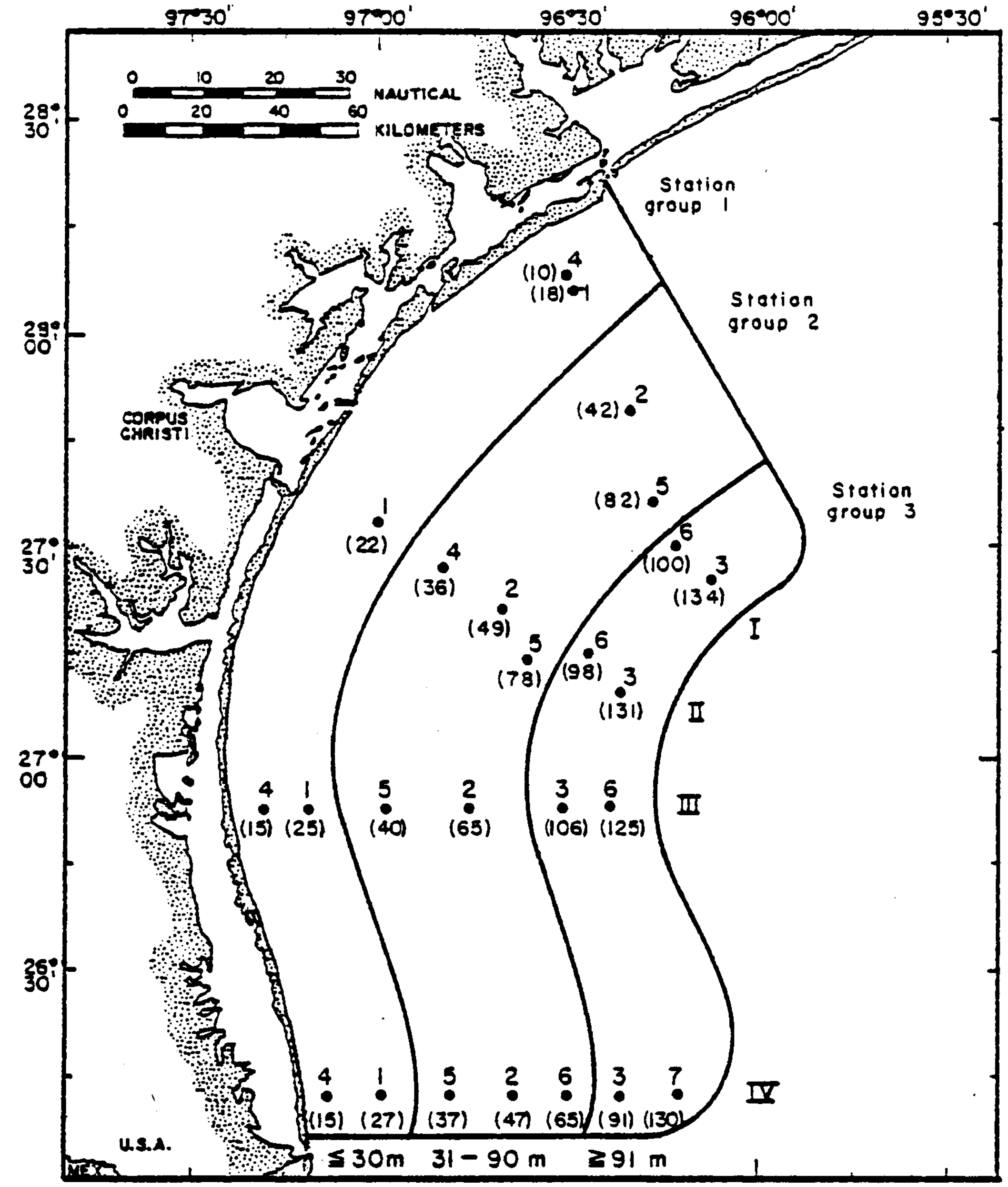

Figure 47. Station groupings for demersal fish according to cluster analysis. Numbers in parentheses are depths in meters.

summer or autumn when shallow water temperatures were highest; 4) mid- and deep-water associations were somewhat more stable throughout the year with the mid-shelf groups of species having the highest diversity; 5) north-south gradients were minimal except during autumn when weak species associations developed to show that the northern two transects were slightly different from the southern two transects; and 6) there was evidence of considerable species "shuffling" during the year in all faunal zones, which suggested that Petersen-type, species-dominated communities did not persist in the shelf areas that were studied.

Over 160 fish species were captured during the three years of sampling, but only 57 species were captured in excess of 100 individuals and 22 species in excess of 1000. The most common species are listed in Table 16, and their frequencies of occurrence among the ten most abundant species for each season and station group (defined by Figure 47) are given in Tables 17 and 18. Most of the common species were dominant elements (*i.e.* among the top ten species) of the ichthyofauna in only one or two station groups (*e.g. Syacium gunteri, Diplectrum bivittatum* in Station Groups 1 and 2; *Serranus atrobranchus* in Station Groups 2 and 3), reflecting the spatial (depthwise) differences in the fish assemblages found over the study area. The notable exception was *Trachurus lathami*, which was dominant at roughly equal frequencies in all three station groups. Seasonal changes in the extent to which species dominated the ichthyofauna also occurred (*e.g. Syacium gunteri* was predominant mainly in winter and fall), although a number of species showed no variation (*e.g. Stenotomus caprinus, Serranus atrobranchus*; Table 17).

A greater number of species were caught in night trawls than in day trawls during the seasonal sampling cruises. Part of this difference was

TABLE 16

TOTAL ABUNDANCE AND NUMBER OF OCCURRENCES
(NUMBER OF TRAWLS IN WHICH TAKEN)
OF THE MOST ABUNDANT FISHES CAPTURED DURING THE
SAMPLING PROGRAM, 1974-1977

Species	Number of Individuals	Number of Occurrences
Trachurus lathami	8612	243
Serranus atrobranchus	8406	365
Micropogon undulatus	7767	140
Peprilus burti	6656	169
Cynoscion nothus	5952	123
Syacium gunteri	4465	263
Stenotomus caprinus	3905	327
Pristipomoides aquilonaris	3534	312
Prionotus paralatus	2608	235
Polydactylus octonemus	2392	65
Saurida brasiliensis	2162	194
Anchoa hepsetus	1987	59
Chloroscombrus chrysurus	1945	65
Sphoeroides parvus	1724	163
Upeneus parvus	1724	217
Centropristis philadelphica	1705	297
Prionotus stearnsi	1635	187
Cynoscion arenarius	1431	130
Prionotus rubio	1429	217
Trichopsetta ventralis	1390	193
Synodus foetens	1186	308
Diplectrum bivittatum	1072	133
Porichthys porosissimus	957	189
Pontinus longispinis	548	73
Synodus poeyi	512	112
Bollmannia communis	507	112
Lepophidium graellsi	455	149

TABLE 17

FREQUENCY OF OCCURRENCE OF COMMON FISHES AMONG THE TEN MOST ABUNDANT SPECIES DURING EACH SEASON. EACH OCCURRENCE CORRESPONDED TO A SINGLE SAMPLING SERIES (E.G. STATION GROUP 1-DAY-1977). A TOTAL OF 12 OCCURRENCES (SAMPLING SERIES) PER SEASON WAS POSSIBLE. SAMPLING SERIES INCLUDED: STATION GROUPS 1, 2, 3/DAY,NIGHT/1976, 1977 (DATA FROM WOHLSCHLAG 1977, 1978).

Species	Number of Occurrences Among Top Ten Species		
	WINTER	SPRING	FALL
Anchoa hepsetus	2	3	1
Cynoscion nothus	3	3	3
Micropogon undulatus	3	4	6
Peprilus burti	3	6	3
Syacium gunteri	8	3	7
Cynoscion arenarius	4	3	1
Sphoeroides parvus	4	3	4
Trachurus lathami	2	8	6
Polydactylus octonemus	-	4	6
Chloroscombrus chrysurus	-	3	3
Upeneus parvus	4	7	4
Stenotomus caprinus	8	8	9
Diplectrum bivittatum	2	1	6
Saurida brasiliensis	3	2	2
Serranus atrobranchus	8	8	8
Synodus foetens	2	3	1
Prionotus stearnsi	2	3	5
Pristipomoides aquilonaris	6	7	6
Prionotus paralatus	4	5	5
Trichopsetta ventralis	5	3	4
Halieutichthys aculeatus	2	1	3
Pontinus longispinis	I	2	4
Prionotus rubio	4	1	3
Centropristis philadelphica	3	3	3

TABLE 18

FREQUENCY OF OCCURRENCE OF COMMON FISHES AMONG THE TEN MOST ABUNDANT SPECIES IN EACH DEFINED STATION GROUP.
EACH OCCURRENCE CORRESPONDED TO A SINGLE SAMPLING PERIOD (E.G. WINTER-DAY 1977). A TOTAL OF 12 OCCURRENCES (SAMPLING PERIODS) PER STATION GROUP WAS POSSIBLE.
SAMPLING PERIODS INCLUDED: WINTER, SPRING, FALL/DAY, NIGHT/1976, 1977
(DATA FROM WOHLSCHLAG 1977, 1978)

Species	Number of Occurrences Among Top Ten Species		
	Station Group 1	Station Group 2	Station Group 3
Anchoa hepsetus	6	-	-
Cynoscion nothus	8	1	-
Micropogon undulatus	11	2	-
Peprilus burti	7	4	1
Syacium gunteri	9	8	1
Cynoscion arenarius	7	1	-
Sphoeroides parvus	7	4	-
Trachurus lathami	5	6	5
Polydactylus octonemus	7	3	-
Chloroscombrus chrysurus	5	1	-
Upeneus parvus	2	5	8
Stenotomus caprinus	2	12	11
Diplectrum bivittatum	4	5	-
Saurida brasiliensis	-	5	2
Serranus atrobranchus	-	12	12
Synodus foetens	-	5	1
Prionotus stearnsi	-	8	2
Pristipomoides aquilonaris	-	7	12
Prionotus paralatus	-	2	12
Trichopsetta ventralis	-	2	10
Halieutichthys aculeatus	-	1	5
Pontinus longispinis	-	-	7
Prionotus rubio	4	2	2
Centropristis philadelphica	2	7	-

attributed to the greater sampling effort expended during the night cruises. However, the differences between the numbers of night and day trawls taken during the seasonal cruises were rather small, and it appeared reasonable to conclude that some biological reason existed for the observation that night trawls yielded greater numbers of species than did day trawls during both 1976 and 1977.

In terms of day *vs.* night collections of demersal fishes, parameters such as biomass, number of species and individuals as well as measures of diversity differed throughout the year. Fish taken predominantly during day collections were commonly schooling species while predominantly nocturnal species were solitary in nature. Numbers of species were low in fall and high in the spring.

General catch statistics illustrated that highest densities of demersal fish occurred during the day in spring and during the night in fall. The lowest catches occurred in winter for both day and night. The lowest biomasses were taken during the winter for both day and night. Highest seasonal biomasses were observed during the night in fall. Spring and fall daytime collections yielded much higher biomasses than did winter.

There were no obvious trends in biomass correlated with depth. The relationships between abundances of selected fish species and some physical variables were examined by plotting abundance of these species against values of a particular variable. From this exercise it was apparent that within a given species different sizes of fish may respond differently to some environmental variables. The implication is that further studies should consider the possible effects of individual size on the relations of the fish to environmental conditions.

The diversity of demersal fishes was low at shallow stations and increased with depth to about 85 m. As with the epifauna, seasonal changes in fish populations appeared to be related to depth, temperature, and movements into and out of the estuaries.

Discriminant analysis, using the defined demersal fish station groups in Figure 47, was applied to data on STOCS bottom water and sediment physical variables to investigate relationships between the fish communities and their habitat. Physical variables used were bottom water temperature (°C) and salinity (‰), sediment mean grain size (Ø units), standard deviation and skewness of the sediment grain size distribution, and percent silt composition of the sediment.

The analysis yielded two discriminant functions. Values for the standardized coefficients indicated that mean grain size, salinity and percent silt were the most important variables on the first discriminant function. These three variables served most to discriminate between demersal fish station groupings on the shelf with respect to the first discriminant function. Mean grain size, skewness and standard deviation of the grain size distribution served most to separate demersal fish station groups with respect to the second discriminant function.

The discriminant scores of the data cases for the three fish station groupings are plotted with respect to the first and second discriminant functions in Figure 48. Each of these groups was found to be significantly different from one another. Interpreting the patterns in terms of the original physical variables, the demersal fish group represented by Station Group 1 was characterized (relatively) by *a combination* of large mean grain size, low salinity and high percent silt composition. Station Group 3 had the opposite characteristics, while Station Group 2 could be characterized as intermediate between Station Groups 1 and 3. Station

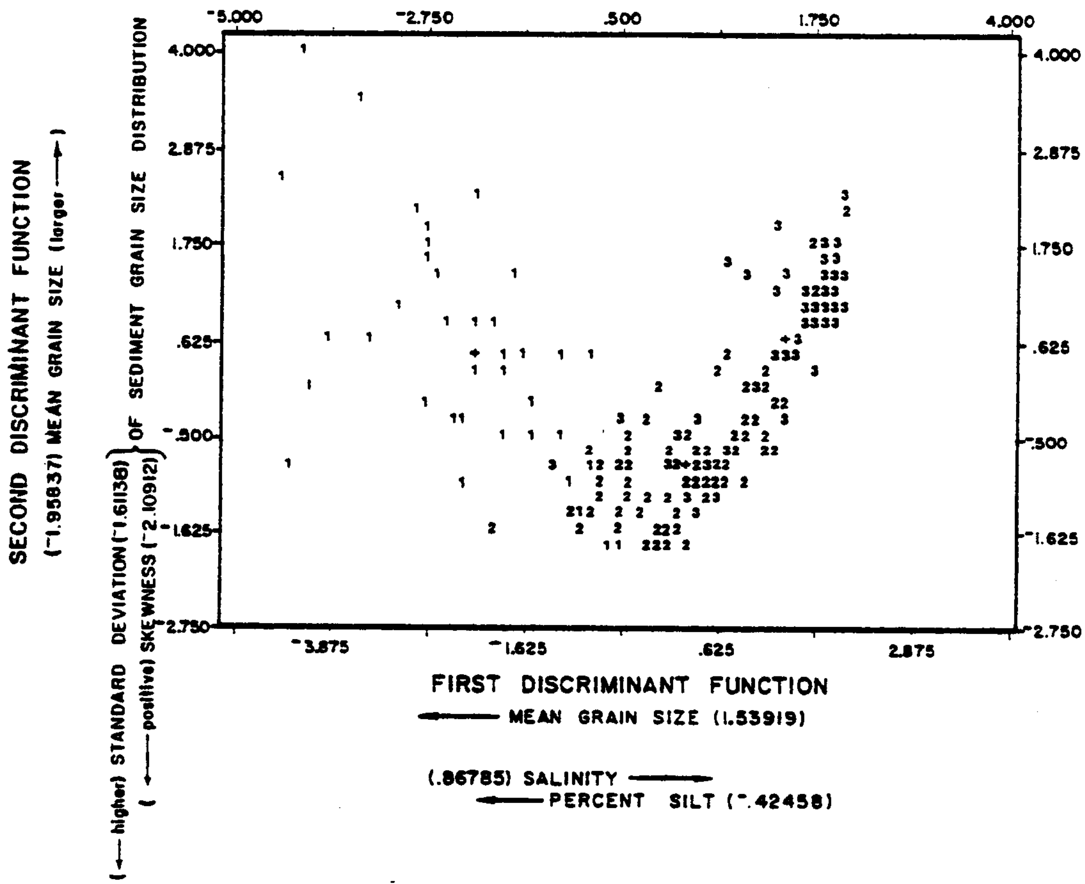

Figure 48. Discriminant space based on analysis of physical variables. Each number represents a sampling episode (sampling station for a given time period; *e.g.* Station 1/I, day-winter) with value equal to station group identification. Symbol (+) denotes a group centroid. Values in parentheses by discriminating variables are standardized discriminant function coefficients (weights).

Groups 3 and 2 had the highest and lowest mean values, respectively, on the second discriminant function. In terms of physical variables, the demersal fish inhabitating Station Group 3 were related to a relatively small mean sediment grain size, low variation (standard deviation) in the sediment grain size distribution, and a negative skewness in this distribution. Fish occurring at Station Group 2 were related to the opposite characteristics, and Station Group 1 demersal fish chose a range of values for these physical variables intermediate between the other two groups.

Discriminant analysis using fish abundances (from all sampling episodes over three years) as discriminating variables yielded two discriminant functions, with the first approximately twice as important as the second in separating station groups. Standardized coefficients showed the following species to contribute most to the first discriminant function: *Cynoscion nothus*, *Pristipomoides aquilonaris*, *Sphoeroides parvus*, *Syacium gunteri*, *Trichopsetta ventralis*, and to a lesser degree, *Chloroscombrus chrysurus*, *Micropogon undulatus*, *Peprilus burti*, and *Prionotus paralatus*. *Bollmannia communis*, *Syacium gunteri*, *Synodus foetens*, *Synodus poeyi* and *Trichopsetta ventralis* were the most important species for the second discriminant function.

A discriminant plot of the demersal fish station groups (Figure 49) showed Group 1 to generally have the highest scores and Group 3 the lowest on the first discriminant function. Group 1 could therefore be viewed as having, in combination, relatively high abundances of *Cynoscion nothus*, *Sphoeroides* and *Syacium* and low abundances of *Pristipomoides* and *Trichopsetta*, while Group 3 had the opposite characteristics. Groups 1 and 3 had roughly equal mean scores (with Group 1 slightly higher) and

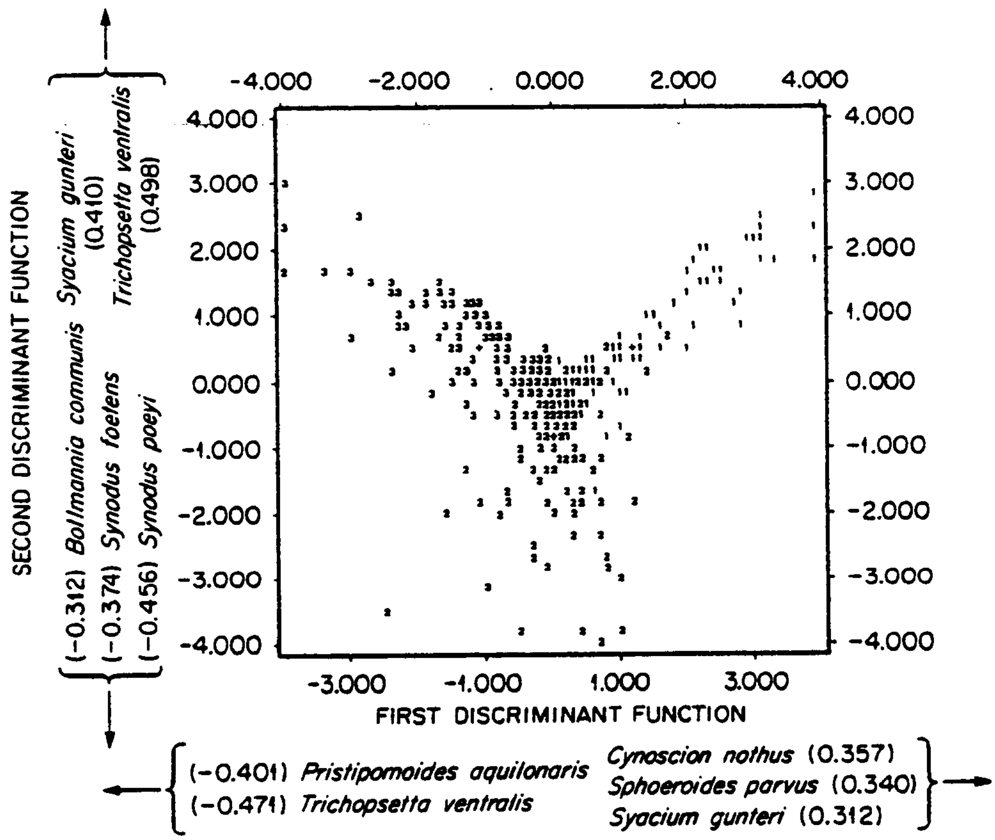

Figure 49. Discriminant space based on analysis of fish abundance. Fish number represents a sampling episode (sampling station for a given time period; *e.g.* Station 1/I, day-winter) with value equal to station group identification. Symbol (+) denotes a group centroid. Values in parentheses by discriminating variables are standardized discriminant function coefficient (weights).

Groups 2 had the lowest on the second discriminant function. Groups 1 and 3 thus could be characterized as having a combination of relatively high abundances of *Syacium* and *Trichopsetta* and low abundances of *Bollmannia* and the two *Synodus* species. Group 2 showed converse features. Pairwise statistical comparisons of the group centroids (using F-values on Mahalonobis distances between groups) revealed significant differences between all groups ($P < 0.001$).

Although the discriminant analysis using fish abundance data was aimed toward obtaining descriptions of the defined station groups with respect to the common fishes, it also provided a test of the growth of the groupings (as did the analysis using physical variables). The statistically significant differences between the groups ($P < 0.001$) and the moderately high proportion (0.758) of data cases correctly classified in the discriminant analysis indicated that the defined demersal fish station groups (Figure 47) could be satisfactorily differentiated on the basis of abundances of common fishes while being explained in terms of their relation to environmental factors of the benthic habitat.

The work described above on demersal fishes serves to identify major components of the outer continental shelf benthic ichthyofauna and describes the more obvious spatial and temporal patterns in abundance of species. The characterization of major depth zones using common fishes by discriminant analysis as well as by straightforward descriptions of the fauna should be particularly useful for the assessment of man-induced impacts on this environment.

Benthic Biota Body Burdens

Hydrocarbons

The majority of the studies regarding petroleum pollution have centered on the immediate and long term effects of catastrophic events such as oil spills. This emphasis is partly due to the identifiably apparent impact of large amounts of oil in an area and partly due to the relative ease of identifying and quantifying some petroleum compounds in spill situations. The effects of low level and chronic inputs of petroleum have been less intensively studied and information on background levels of hydrocarbons in unpolluted environments is scarce. Although identifying and quantifying trace quantities of petroleum hydrocarbons have been major deterrents to low level studies, methods are rapidly being developed for hydrocarbon trace analyses.

One of the major problems associated with quantifying trace levels of petroleum in the environment is differentiating petrolic compounds from biogenic hydrocarbons. This differentiation is complicated by the effects of weathering or environmental degradation on the hydrocarbon composition of petroleums. Unlike the case of an oil spill, where a single source of petroleum generally provides a very characteristic hydrocarbon pattern, trace levels of petroleum may be from a number of sources, such as petroleum production, or shipping and waste disposal, which further complicates hydrocarbon patterns and thus detection and quantification.

The use of a number of parameters has been suggested to aid the analyst in distinguishing sources of hydrocarbons in environmental samples. One of these is the measurement of ratios of concentrations of individual hydrocarbons, such as the ratio of n-heptadecane (C_{17})/ pristane and of pristane/phytane (Ehrhardt and Blumer, 1972). These ratios have been suggested as aids in the detection of a single source of petroleum contamination as they are generally characteristic of an oil.

One study of importance (Gilfillan *et al.*, 1977) indicated that concentrations of hydrocarbons in clams collected from various areas did not correlate with those in the sediments. Concentrations of hydrocarbons in clams were found to range from 8.5 to 11 μg/g body weight, while concentrations in sediments ranged from 9 to 228 μg/g. Benthic organisms collected from unpolluted deep sea areas had hydrocarbon distributions quite different from those distributions found in surrounding sediments (Teal, 1976). These reports indicate that the effect of sediment-adsorbed hydrocarbons on the hydrocarbons of benthic epifauna is quite difficult to predict. It is probable that hydrocarbons in water, including those from sediment desorption in interstitial water, have a greater effect on the hydrocarbon content of benthic organisms than those adsorbed directly from sediment. Uptake from food is also probably a more important source of hydrocarbons than from sediment.

Information on mechanisms of hydrocarbon transport in the marine environment, such as food chain transfer and uptake from water and sediment is important for assessing the probable effects of petroleum hydrocarbons. Few studies of hydrocarbon distributions and transport, particularly in benthic organisms and the benthic environment, have been reported.

Approximately 400 faunal samples from the benthic habitat, representing 48 species, were analyzed for high-molecular-weight hydrocarbons. The mean and standard deviations of selected parameters from the analyses of the six most frequently occurring species are given in Table 19. Overall, total hydrocarbon concentrations ranged from less than 0.01 μg/g (ppm) to 54.47 μg/g dry weight with the majority of samples containing less than 1 μg/g. Pentadecane (C_{15}) and heptadecane (C_{17}) were the

TABLE 19

MEANS AND STANDARD DEVIATIONS FOR SELECTED PARAMETERS FROM HEAVY MOLECULAR WEIGHT HYDROCARBON ANALYSES OF MACROEPIFAUNA AND MACRONEKTON

Species (Number Analyzed)	Total Alkanes (μg/g)	Sum of Alkanes (%)			Pristane/Phytane	Pristane/C_{17}	Phytane/C_{18}	CPI_{14-20}	CPI_{20-32}
		C_{14}-C_{18}	C_{19}-C_{24}	C_{25}-C_{32}					
Loligo spp. (45)	1.89±3.32 (45)	60.9±34.0 (42)	16.5±18.6 (42)	22.7±28.5 (42)	166.5±172.9 (2)	9.3±13.4 (34)	2.7±3.2 (2)	18.6±10.4 (23)	3.7±4.2 (27)
Penaeus aztecus (48)	0.14±0.28 (48)	39.7±7.2 (34)	9.1±12.7 (34)	51.1±39.1 (34)	44.0±58.0 (2)	2.0±1.7 (17)	0.2±0.1 (2)	1.6±0.6 (5)	6.8±10.1 (22)
Pristipomoides aquilonaris (38)	2.98±4.28 (38)	82.7±26.3 (38)	7.1±10.3 (38)	10.2±3.2 (38)	46.7±20.5 (5)	2.6±2.4 (34)	0.6±0.1 (5)	16.0±7.2 (28)	6.7±18.3 (18)
Serranus atrobranchus (27)	0.19±0.20 (27)	69.4±32.7 (21)	9.7±11.8 (21)	20.9±28.8 (21)	13.0±5.6 (2)	3.6±6.0 (18)	1.0±0.7 (2)	6.2±3.5 (8)	1.4±0.8 (8)
Stenotomus caprinus (27)	1.02±1.83 (27)	55.2±31.4 (26)	13.3±18.1 (26)	31.5±26.3 (26)	32.8±25.3 (6)	5.9±3.9 (25)	0.9±0.2 (5)	5.6±3.3 (16)	10.1±21.8 (17)
Trachurus lathami (25)	8.58±12.00 (25)	69.0±36.3 (25)	13.5±17.7 (25)	17.5±23.7 (25)	132.0±65.9 (10)	33.4±37.0 (18)	2.1±0.8 (10)	19.3±6.9 (15)	6.2±8.6 (17)

dominant n-alkanes, frequently constituting 70% or more of the alkanes. Pristane was found in almost all samples at relatively high levels. Phytane was found in approximately 20% of the samples, generally at less than 0.05 μg/g. The pristane/phytane, pristane/heptadecane and phytane/octadecane ratios ranged widely and did not appear to be indicative of a common source of petroleum in the study area. The Carbon Preference Index (CPI) ratio illustrating odd-carbon dominance especially for the CPI_{14-20} and CPI_{20-32} ratios also were not indicative of petroleum contamination. Squalene was frequently the only compound detected in the aromatic fraction. Aromatic compounds were rarely detected and were usually at 0.005 μg/g or lower concentrations. The distribution of aromatics was not suggestive of petroleum origins. Unresolved complex mixture (UCM) peaks were also rarely detected in the gas chromographs and were very low when present. The distribution of phytane in the samples appeared to yield a spatial trend. Phytane was found most frequently at Stations 1 and 2, Transects III and IV. Stations 1 and 2, Transects I and II also had a higher frequency of phytane occurrence than Station 3 of all transects.

Analyses of variance, testing for spatial and temporal differences, indicated three correlations for brown shrimp (*Penaeus aztecus*) that appeared to be good indicators of seasonal changes in hydrocarbon distributions. As can be seen in Figure 50 the hydrocarbon distribution changes with season, causing significant changes in the low and high sums of hydrocarbons ($p = 0.02$) and the CPI_2 ($p = 0.01$).

The dominant hydrocarbons observed were pristane, pentadecane and heptadecane. These hydrocarbons probably reflect dietary sources since pristane is the major hydrocarbon in zooplankton (Blumer *et al.*, 1964)

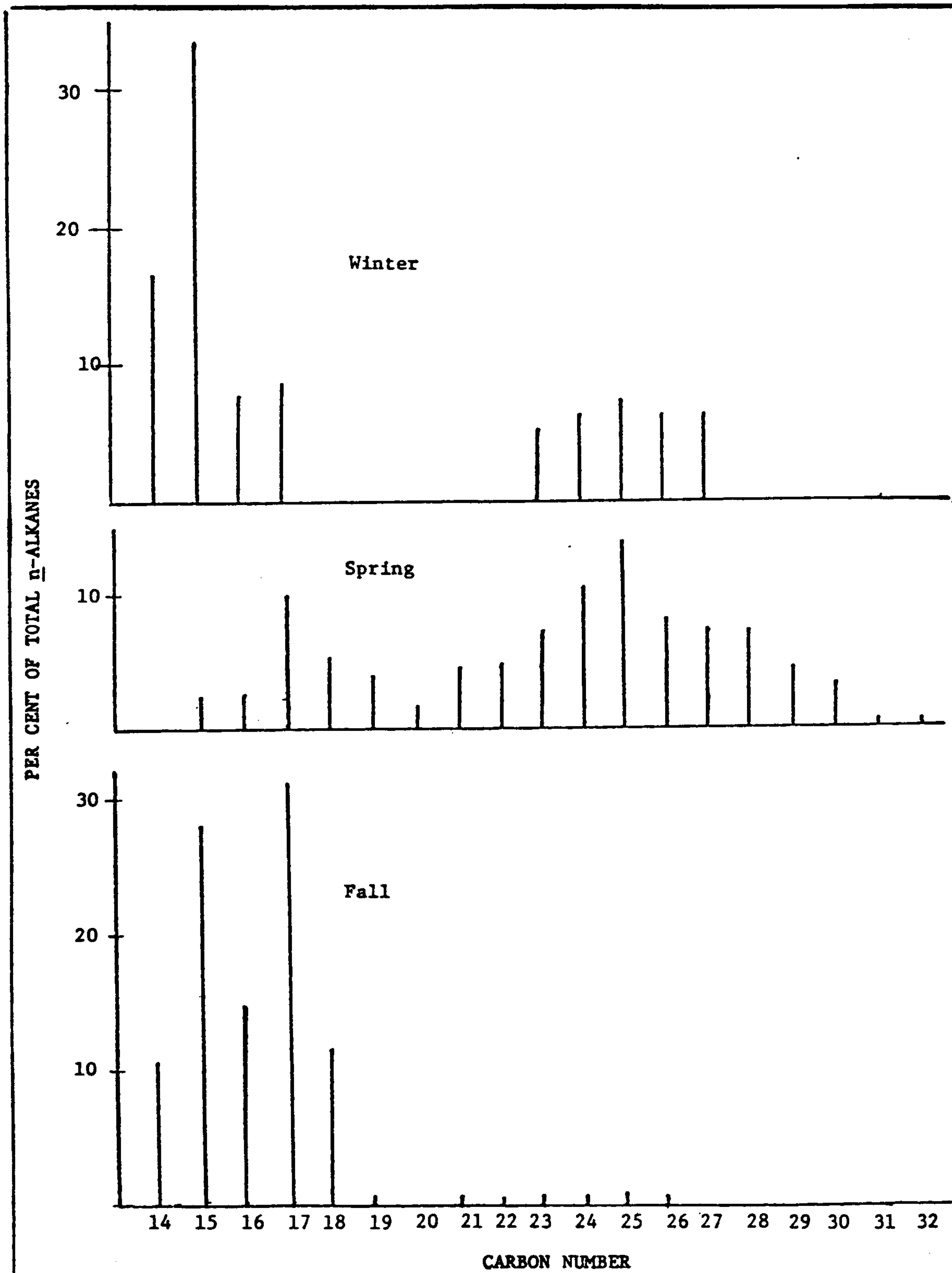

Figure 50. Percent distribution of n-alkanes in *Penaeus aztecus* (brown shrimp).

and pentadecane and heptadecane are the major hydrocarbons in unpolluted algae (Clark and Blumer, 1967). The overall concentration of hydrocarbons in the samples were generally quite low (less than 1 μg/g dry weight in in many samples) and the hydrocarbon distributions found were not suggestive of petroleum. The CPI ratios showed the high odd-carbon dominance characteristic of biogenic hydrocarbons (Clark, 1974; Clark and Finley, 1973; Cooper and Bray, 1963) although shrimp tended to have CPI_{14-20} values close to 1.

Phytane was the only potential indicator of petroleum (Farrington *et al.*, 1972; Blumer and Synder, 1965) found with any frequency in the samples. It was found most often in samples from Stations 1 and 2 of all transects. This may indicate some petroleum contamination from onshore or shipping activities or may reflect species variation and mobility, as the species collected at Stations 1 and 2 were generally different from those at Stations 3.

The distribution of aromatics, when present, was not suggestive of petroleum sources. Thus, petroleum contamination of the benthic organisms of the study was not significant during the study period and the data obtained should provide an excellent data base for future studies of petroleum pollution. The data synthesis efforts have concentrated on maximizing the utility of the data for characterization purposes.

The significant results for brown shrimp are indicative of a change in hydrocarbon distribution that occurs in shrimp in spring, possibly due to spawning activities or to dietary effects (Figure 50). The hydrocarbon levels in shrimp were also lower in winter and fall (0.04 and 0.06 μg/g, respectively) than in spring (0.33 μg/g), although the differences were not significantly different at $p = 0.05$ level.

From the results of this study, shrimp appear to be excellent organisms for monitoring the presence of petroleum hydrocarbons. Shrimp demonstrate significant changes in hydrocarbon distribution with season, but these changes are relatively consistent and quantifiable. The low levels of hydrocarbons present in shrimp may also simplify the detection of pollutant hydrocarbons. A post-drilling rig monitoring sample obtained in winter had 0.6 μg/g total hydrocarbons compared to 0.04 μg/g found for the winter samples in this study. This sample also had very low CPI's (CPI_{14-20}=1.1, CPI_{20-32}=0.6) and a distribution of hydrocarbons suggestive of petroleum, especially when compared to the patterns found for shrimp in this study, as shown in Figure 51. In contrast, shrimp from an oil producing area of the Gulf had higher hydrocarbon levels (0.53 to 2.45 μg/g) than found in this study (Middleditch and Basile, 1978).

Of the approximately 140 macronekton analyses performed, 120 were for two species, the red and vermilion snappers (*Lutjanus campechanus* and *Rhomboplites aurorubens*). Approximately 20 samples were obtained for each species over the two years of this study. Each sample yielded three tissue analyses: muscle, liver, gill in 1976, and gonad in 1977, which were each analyzed separately. The ranges and means of total hydrocarbon concentrations found for the macronekton are summarized in Table 20. The means of several of the parameters measured in muscle and liver are shown in Table 21. The alkanes, n-pentadecane (C_{15}) and n-heptadecane (C_{17}), and pristane were the major aliphatic hydrocarbons in all samples. In red snapper muscle, the C_{15} plus the C_{17} n-alkanes totaled 23 to 100% of the n-alkanes; the total was less than 75% in only 3 of the 20 samples. One of these samples had the C_{27} n-alkanes as the major n-alkane while the other two had a wide range of hydrocarbons. In

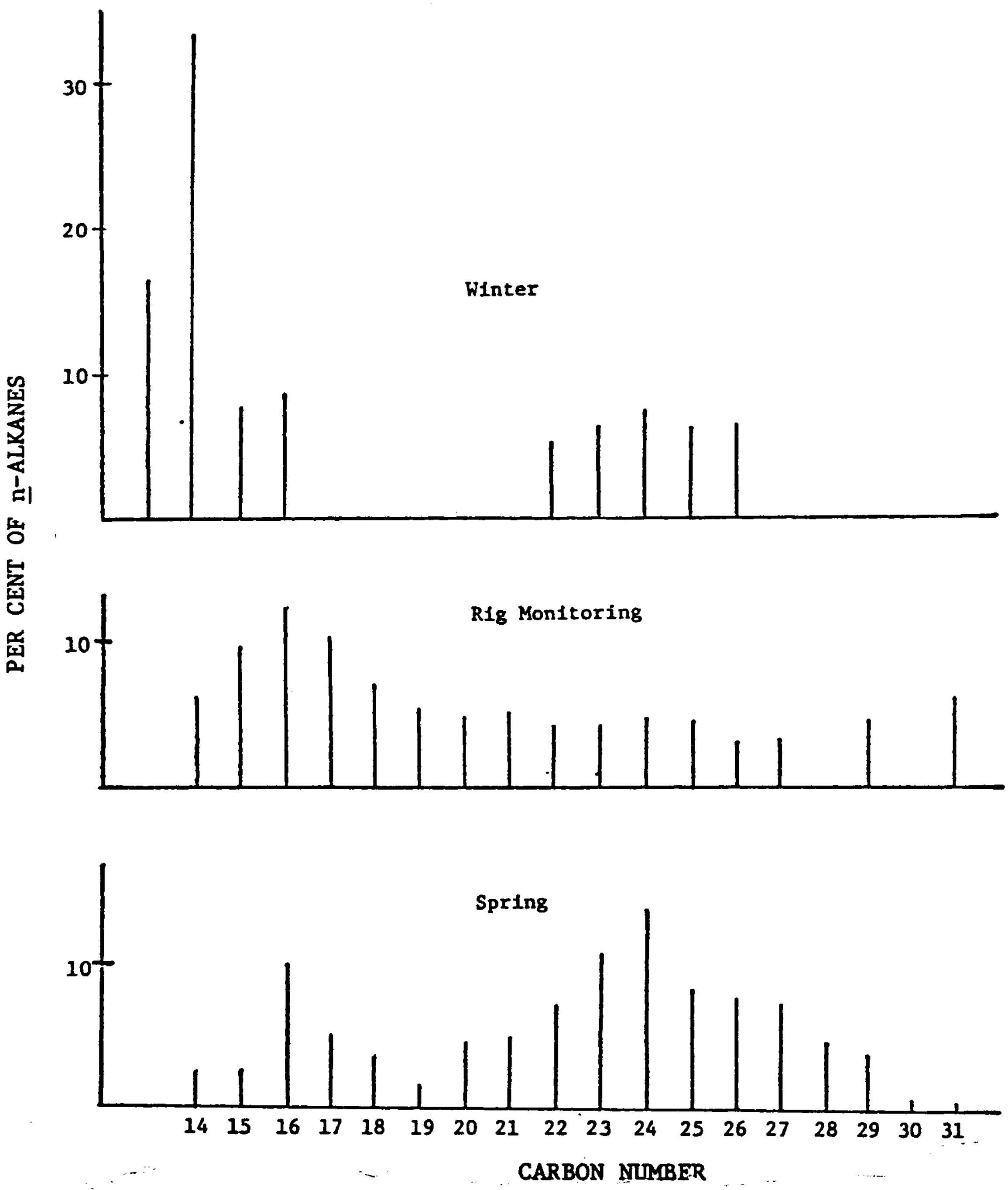

Figure 51 Comparison of rig monitoring and seasonal hydrocarbon distribution in *Penaeus aztecus* (brown shrimp).

TABLE 20

RANGES OF TOTAL HYDROCARBON CONCENTRATIONS
FOR MACRONEKTON

Species	Concentration (μg/g, dry weight)			
	Muscle	Liver	Gill	Gonad
Red Snapper (*Lutjanus campechanus*)				
Range	0.03-7.4	1.1-43.8	0.1-20.0	1.7-55.1
Mean ± 1 S.D.	0.7±1.6	8.7±9.6	4.7±6.1	36.8±31.8
Vermilion snapper (*Rhomboplites aurorubens*)				
Range	0.02-4.3	0.6-35.8	0.0-30.6	2.3-25.3
Mean ± 1 S.D.	1.4±1.3	13.6±9.8	7.0±9.4	6.8±7.2

TABLE 21

MEANS AND STANDARD DEVIATIONS FOR SELECTED PARAMETERS FROM HEAVY MOLECULAR WEIGHT HYDROCARBON ANALYSES OF MACRONEKTON

	Species and Organ			
	Lutjanus campechanus		*Rhomboplites aurorubens*	
	Muscle	Liver	Muscle	Liver
$\Sigma\ C_{14-18}$	87.9±25.6	83.4±19.5	91.2±12.5	80.3±22.9
$\Sigma\ C_{19-24}$	4.5±10.2	6.6±7.8	5.0±8.3	8.6±11.4
$\Sigma\ C_{25-32}$	7.6±19.6	10.0±15.1	3.8±8.9	11.0±13.2
$\frac{\text{Pristane}}{\text{Phytane}}$	13.5±4.8	30.0±24.1	87.7±38.5	81.4±59.1
$\frac{\text{Pristane}}{C_{17}}$	1.9±1.5	2.5±1.5	16.3±29.0	10.7±9.9
$\frac{\text{Phytane}}{C_{18}}$	0.6±0.2	0.9±0.9	1.3±0.8	0.7±0.5
CPI_{14-20}	16.7±9.7	12.7±10.5	22.6±14.3	25.4±35.7
CPI_{20-32}	1.0±0.1	2.0±2.2	1.5±0.4	2.9±4.1

vermilion snapper muscle, C_{15} plus C_{17} ranged from 42% to 100% of the n-alkanes. The C_{19} or C_{23} alkanes had relatively high concentrations in the two samples with the lowest C_{15} plus C_{17} concentrations.

A wider range of hydrocarbons, as well as higher concentrations of the C_{18}-C_{30} n-alkanes, appeared to be present in the spring samples relative to the fall and winter samples, but the differences were not statistically significant ($P < 0.05$). The liver, gill and gonad samples also had pentadecane, heptadecane and pristane as the major hydrocarbons with non-significant seasonal changes similar to those found in muscle. Phytane was found in 10% of the muscle samples, in more than 50% of the liver samples and in all of the gonad samples, generally at low concentrations. Small, generally unquantifiable, unresolved complexes were detected in many of the chromatograms. Aromatic compounds were rarely detected and, when found, were generally at the limits of detection (0.005 μg/g).

The high-molecular-weight hydrocarbon analysis of macroepifauna and macronekton samples from the STOCS indicated little, if any, petroleum contamination of the study area. No significant spatial trends and few seasonal trends were present in the data, suggesting relative stability in the hydrocarbon pools of the organisms studied. Of the species studied, the brown shrimp, *Penaeus aztecus* appears to be the best indicator organism for monitoring purposes.

Trace Metals

Ten trace elements were analyzed in benthic biota including cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), nickel (Ni), lead (Pb), vanadium (V), zinc (Zn), aluminum (Al), and calcium (Ca). Nickel and V were selected because they are present in large concentrations in some oil and tars. Cadmium and Pb, two very toxic metals, are frequently observed to be above natural levels near industrial centers. Copper and Zn are essential trace metals which can reach toxic levels as a result of man's activities. Iron is also an essential trace element in biological systems (Dulka and Risby, 1976; Brooks, 1977). Iron and Al, because of their abundance in the environment, are important in making geochemical comparisons among trace elements (Trefrey and Presley, 1976b). Finally, Ca is important in identifying potentially severe matrix interferences in our analytical procedures.

Table 22 summarizes trace element data for the four selected species of demersal fish in terms of transect sampled. The levels of several trace metals (*i.e.* Cd, Cr. Ni, Pb, V) in fish muscle were at or below the detection limits of our analytical procedures. For these metals it was obviously not possible to distinguish any spatial or temporal trends. Still, even for elements present in detectable amounts, none of the species exhibited any significant geographical patterns in muscle tissue trace element levels. *Trachurus lathami* was the only species to show any significant seasonal trends in trace metal concentrations.

Aluminum levels in demersal fish exhibited the same seasonal pattern as did zooplankton. Aluminum and Fe in *Trachurus* muscle were strongly correlated ($r^2 = .41$). Also *Trachurus* was the only demersal fish species collected predominantly at nearshore stations. Almost 90% of the samples came from Stations 1 and 2. These facts suggest that the temporal trend in Al levels was a reflection of the more variable nearshore environment which is characterized by sizable seasonal fluctuations in the amount of suspended aluminosilicate particulate matter. The other three species of fish had generally similar concentrations of Al (Table 22), but no seasonal trends were observed. These species were collected predominantly from

TABLE 22

AVERAGE CONCENTRATIONS OF TRACE ELEMENTS IN MUSCLE OF DEMERSAL FISH FROM THE STOCS STUDY

Transect	Species	Number of Samples	Concentration in ppm dry weight (95% confidence interval observed around mean)									
			Cd	Cr	Cu	Fe	Ni	Pb	V	Zn	Al	Ca
I	*Pristipomoides aquilonaris*	7	<0.05	<0.05	1.3 (0.70-3.0)	4.5 (2.0-6.0)	<0.07	<0.04	<0.10	13 (11-16)	25 (19-30)	700 (400- 950)
	Serranus atrobranchus	4	<0.02	<0.05	0.95 (0.50-1.6)	3.5 (2.0-5.0)	<0.09	<0.03	<0.10	10 (6.0-12)	30 (24-32)	1100 (900-1300)
	Stenotomus caprinus	7	<0.06	<0.05	1.0 (0.70-1.3)	5.5 (4.0-6.0)	<0.10	<0.08	<0.20	14 (11-17)	20 (15-25)	700 (400-1200)
	Trachurus lathami	2	<0.04	<0.03	2.4	9.5	<0.08	<0.05	<0.15	24	19	800
II	*Pristipomoides aquilonaris*	23	<0.03	<0.04	1.4 (0.70-1.9)	4.0 (1.0-7.0)	<0.08	<0.04	<0.30	8.5 (1.0-17)	30 (16-45)	700 (350- 850)
	Serranus atrobranchus	8	<0.03	<0.05	0.90 (0.60-2.0)	3.0 (1.0-5.0)	<0.08	<0.05	<0.40	10 (6.0-14)	30 (25-40)	1900 (700-4500)
	Stenotomus caprinus	11	<0.05	<0.05	1.1 (0.70-1.7)	5.0 (2.0-8.0)	<0.08	<0.06	<0.10	13 (6.0-25)	25 (12-55)	700 (400-1400)
	Trachurus lathami	8	0.10 (0.01-0.25)	<0.05	2.3 (1.7 -3.0)	15 (8.0-20)	<0.10	<0.06	<0.10	24 (12-35)	30 (15-40)	750 (550-1000)
III	*Pristipomoides aquilonaris*	7	<0.03	<0.04	1.0 (0.60-1.6)	4.0 (2.0-7.0)	<0.07	<0.05	<0.10	10 (2.0-16)	22 (16-30)	500 (300- 600)
	Serranus atrobranchus	9	<0.02	<0.04	1.3 (0.50-3.5)	3.0 (2.0-4.0)	<0.09	<0.05	<0.10	10 (2.0-17)	20 (14-30)	1300 (750-2000)
	Stenotomus caprinus	8	<0.06	<0.05	0.90 (0.60-1.1)	4.5 (4.0-5.0)	<0.08	<0.06	<0.10	13 (10-18)	13 (10-20)	600 (350- 850)
	Trachurus lathami	9	0.12 (0.01-0.30)	<0.10	2.5 (1.7 -3.5)	15 (7.0-25)	<0.10	<0.10	<0.15	24 (15-40)	25 (10-50)	1000 (300-2500)
IV	*Pristipomoides aquilonaris*	12	<0.05	<0.07	1.1 (0.60-2.0)	4.0 (1.8-6.0)	<0.08	<0.07	<0.10	14 (10-20)	18 (15-25)	600 (300-1100)
	Serranus atrobranchus	5	<0.02	<0.07	0.80 (0.50-1.6)	5.5 (4.0-6.0)	<0.10	<0.05	<0.15	12 (11-16)	17 (14-30)	1800 (750-3500)
	Stenotomus caprinus	7	<0.05	<0.05	1.1 (0.60-1.5)	4.0 (3.0-6.0)	<0.08	<0.04	<0.10	12 (6.0-15)	23 (20-25)	1200 (750-1600)
	Trachurus lathami	9	0.04 (0.01-0.09)	<0.07	2.2 (0.50-3.0)	15 (6.0-25)	<0.09	<0.09	<0.10	19 (13-25)	17 (12-30)	800 (550-1200)

offshore stations (*i.e.* 80% of the samples from Station 3) which are characterized by lower concentrations of organic-rich suspended matter.

Trace element data for penaeid shrimp muscle are summarized in Table 23 in terms of station/transect sampled. No significant spatial trends in the data were detected for either species. *Penaeus setiferus* was only collected from the inshore stations on each transect. *Penaeus aztecus*, however, was consistently collected from 10 of the 12 stations sampled during this three-year study. Flesh trace element concentrations were not significantly different between the two species (*i.e.* paired t statistic, $p < 0.05$). No strong correlations were observed between these data and corresponding sediment trace metal or potential prey organism variables. Aluminum and Fe levels in *P. aztecus* muscle were strongly correlated ($r^2 = 0.72$) and both metals exhibited significant correlations ($r^2 = 0.36$) with certain sediment texture parameters. These results suggest that shrimp were assimilating sediment derived Al and Fe into their muscle tissue.

Zinc levels in *P. aztecus* did exhibit a significant seasonal effect with a fall maximum. The reason for this relationship is not clear. The trend was not related to differences in the size (age) of shrimp analyzed among seasons. The seasonal fluctuations could have been a result of environmental changes which reflected physiological changes in the shrimp. Although no strong correlations ($r^2 < 0.20$) were observed between Zn levels and corresponding temperature, salinity or dissolved oxygen conditions at the sampling sites, these parameters were strongly correlated ($r^2 > .32$) with Zn concentrations in the hepatopancreas of the same shrimp.

One of the most striking aspects of this organismal trace element data set is the general lack of any significant spatial trends. This situation may in part be a result of the generally small number of data cases for

TABLE 23

AVERAGE CONCENTRATIONS OF TRACE ELEMENTS IN FLESH OF PENAEID SHRIMP FROM THE STOCS STUDY

				Concentration in ppm dry weight (95% confidence interval observed around mean)									
Transect	Station	Species	Number of Samples	Cd	Cr	Cu	Fe	Ni	Pb	V	Zn	Al	Ca
I	1	*Penaeus aztecus*	3	0.13 (0.10-0.20)	<0.05	25 (20-30)	3.0	<0.10	<0.05	<0.07	45 (20-60)	18	1200
		Penaeus setiferus	3	0.05 (0.01-0.10)	<0.05	21 (19-22)	3.5 (2.0-5.0)	<0.10	<0.10	<0.05	50 (45-60)	20 (17-25)	950 (750-1100)
	2	*Penaeus aztecus*	7	0.08 (0.01-0.20)	<0.05	25 (20-35)	4.5 (1.0-10)	<0.10	<0.07	<0.20	50 (40-55)	20 (8.0-30)	1100 (750-1900)
	3	*Penaeus aztecus*	2	0.15 (0.13-0.17)	—	25 (20-30)	--	--	--	--	50 (40-65)	--	--
II	1	*Penaeus aztecus*	5	0.08 (0.02-0.12)	<0.05	24 (19-30)	3.5 (3.0-4.0)	<0.15	<0.15	0.30	55 (50-65)	36	2500
		Penaeus setiferus	8	0.05 (0.01-0.12)	<0.05	24 (19-30)	2.5 (0.50-5.0)	<0.10	<0.10	<0.05	60 (50-70)	25 (15-35)	1500 (450-2500
	2	*Penaeus aztecus*	6	0.11 (0.02-0.25)	<0.05	25 (20-30)	6.5 (4.0-12)	<0.10	<0.10	<0.10	50 (40-60)	24 (14-34)	950 (800-1100)
III	1	*Penaeus aztecus*	4	0.07 (0.01-0.11)	<0.05	25 (25-30)	4.5 (3.0-6.0)	<0.10	<0.05	<0.06	60 (55-65)	13	1100
	2	*Penaeus aztecus*	5	0.10 (0.01-0.25)	<0.05	25 (18-35)	2.5 (2.0-3.0)	<0.08	<0.10	<0.10	60 (50-70)	20 (17-25)	1100 (850-1500)
	3	*Penaeus aztecus*	4	0.18 (0.04-0.35)	<0.05	24 (18-35)	2.0	0.10	0.08	0.12	50 (40-55)	20	1400
IV	1	*Penaeus aztecus*	4	0.06 (0.01-0.16)	<0.05	24 (20-28)	2.0 (1.0-3.0)	<0.08	<0.03	<0.10	55 (45-70)	22 (16-25)	700 (550- 900)
		Penaeus setiferus	1	0.01	<0.05	17	1.0	<0.10	<0.10	<0.05	30	60	400
	2	*Penaeus aztecus*	6	0.08 (0.01-0.13)	<0.10	24 (18-30)	13 (3.0-30)	<0.30	<0.15	<0.40	50 (45-60)	45 (13-90)	2000 (450-3500)
	3	*Penaeus aztecus*	5	0.18 (0.11-0.25)	<0.10	25 (20-30)	4.0	<0.30	<0.06	<0.20	50 (45-60)	24 (18-30)	1000

C/T

many species which made the detection of actual differences difficult. This absence of geographical trends, however, could be the result of at least two other factors. First, all of the species discussed here are quite mobile. Although the extent of their movements is generally not well documented, it certainly could be significant. This mobility would tend to integrate trace metal exposures at many sites and dampen any differences between them. Second, geographical trends in trace metal levels within the STOCS resulting from man's activities are probably minimal. Any significant input of trace metals into the STOCS area is most likely to be from diffuse (atmospheric) sources. Due to the relatively small amount of industrialization in the adjacent coastal areas, this atmospheric input is probably quite low and generally similar for all parts of the STOCS region.

It is worth noting that all of the significant seasonal trends observed for demersal fauna appeared to be linked to the more changeable nearshore environment. Only species which were collected consistently at nearshore stations exhibited any significant seasonality in trace metal levels. Species collected only at offshore stations showed no seasonal trends. This observation suggests that in any future monitoring, it should be easier to detect changes in the levels of bioavailable trace elements at offshore stations than at nearshore ones.

CHAPTER SIX

SOUTH TEXAS OUTER ECOSYSTEM CHARACTERISTICS

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General Trends

The three-year multidisciplinary study of the south Texas outer continental shelf resulted in the development of an extensive data base depicting the physical, chemical and biological characteristics of an extremely important marine subtidal area in terms of natural resources. The Texas shelf can be described as a very dynamic system driven by a complex aggregation of meteorological and oceanographical events, including diverse wind and current structures. Superimposed upon these phenomena are influences to the system both from local rivers and estuaries as well as distant factors such as the Mississippi River and deep ocean waters of the Gulf basin.

The ecosystem represents a typical ocean environment in terms of nutrient concentrations and associated annual dynamics. The Texas shelf is relatively pristine in respect to the pollutants monitored during this study, such as hydrocarbons and trace metal concentrations, with the majority of hydrocarbon observations related to natural phenomena, during the study period.

The shelf supports relatively high phytoplantkon biomasses with extremely high annual production especially in the inner-shelf waters. Many of the phytoplankton characteristics are strongly related to salinity and incident solar radiation as well as possible nutrient regeneration. Most of the marine biota observed in this study show strong geographical trends, usually related to water depth or distance from shore, as illustrated in Figure 52. The plankton are most abundant along the inner-shelf. Their numbers are predictably large in the spring, correlated with riverine inputs and nutrient maxima.

The inner-shelf maxima for phytoplankton were also reflected in zooplankton (Figure 52). Peaks in zooplankton biomass were observed at shallow sites with decreases occurring in an offshore direction. Both infaunal and epifaunal (as represented by *Penaeus aztecus* densities) organisms were more numerous along the inner shelf where general productivity was greater in response to increased food supplies. An additional factor potentially controlling the infaunal and epifaunal organisms appeared to be the coarser-grained sediments at the shallow sites. These may provide a more suitable habitat than the finer silts and clays of the outer shelf environment.

The larger and more mobile fauna, such as the demersal fish, showed less spatial patterning in their distributions on the shelf. The ichthyoplankton, however, which were strongly correlated with zooplankton, were far more abundant on the Texas inner shelf. It appears reasonable to conclude that the shallower areas of the south Texas shelf are biologically a more critical part of this marine ecosystem.

The changes in fauna observed suggest that the inner-shelf region is a much more dynamic area than the waters near the shelf break. In addition, much of the riverine input to the south Texas shelf enters through well-developed estuaries. These estuaries undoubtedly have an important impact on the shelf which may be manifested in some of the gradients illustrated in Figure 52.

The presence of isothermal conditions from the surface waters to the

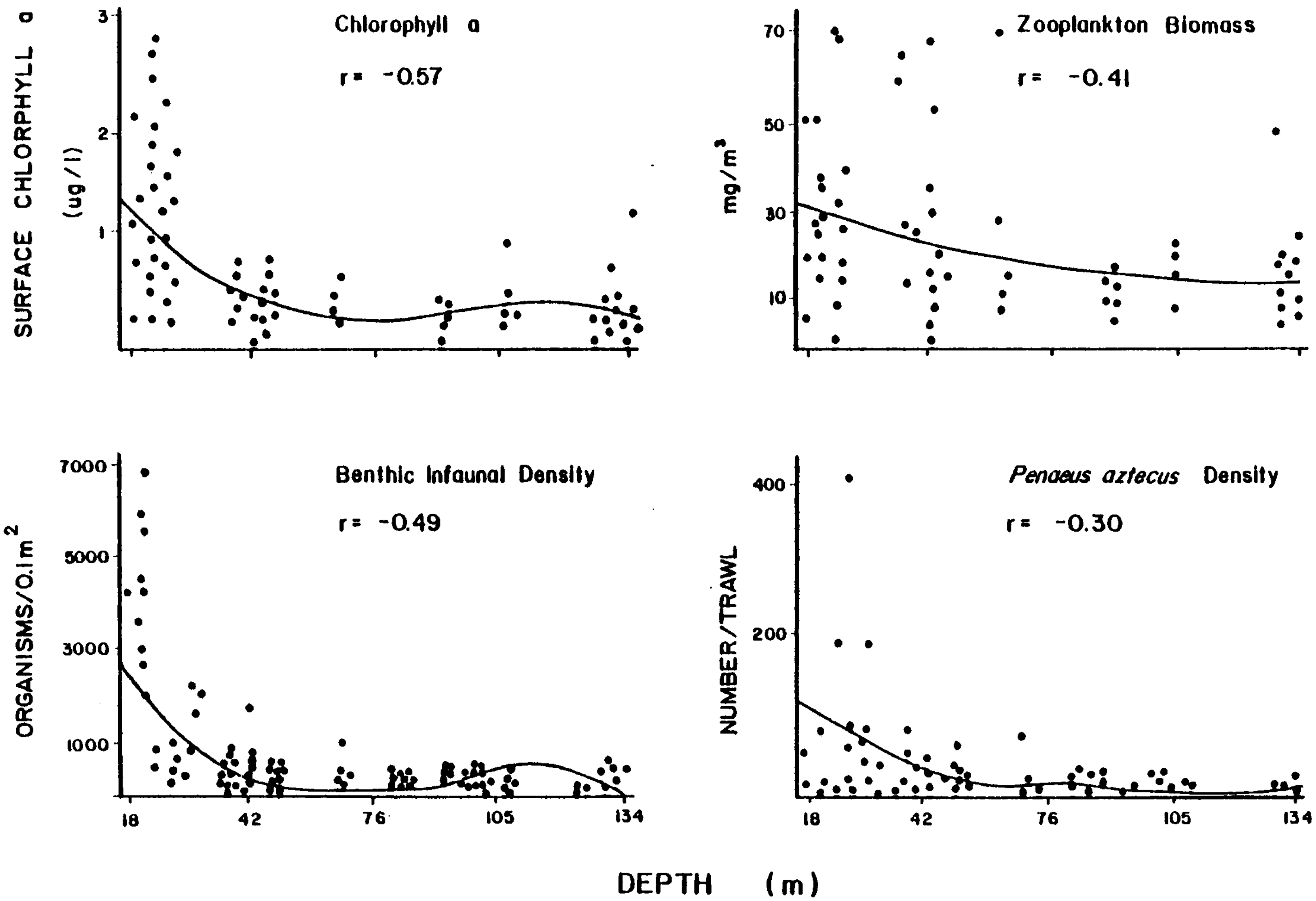

Figure 52. Relationships of chlorophyll a, zooplankton biomass, benthic infaunal density, and *Penaeus aztecus* (brown shrimp) density with water depth (m) for the south Texas outer continental shelf. Correlation coefficients (r) are indicated for each plot.

sea-floor during much of the year allows for considerable interaction between two dynamic communities in the inner-shelf region of the Texas coast: 1) a benthic community consisting of those organisms living in or on the sediment or near the sediment-water interface; and 2) a pelagic community consisting of those organisms drifting, floating, or swimming in the overlying waters. Because of their interactions, the boundaries of these two communities are not clear. Many nekton organisms, for example, deposit eggs which become part of the benthic community while the larvae and adults are members of the pelagic community. Conversely, numerous benthic species produce eggs which float in the water column, hatch into planktonic larvae and become dispersed by currents before settling permanently to the bottom. In addition to the above interactions, demersal fishes swim into the pelagic zone to feed on plankton while the benthos depends upon the continual "rain" of materials (*e.g.* algae, fecal pellets) from the overlying waters for nourishment.

Nutrient Regeneration

Evidence from the three-year study indicates that the Texas shelf waters, especially inner-shelf waters, are extremely productive in plant biomass. Further evidence for this high production comes from the fact that several important commercial fisheries are supported in these same waters. Rowe *et al.* (1975) recently contended that nutrient regeneration in sediments is the major factor responsible for the relatively high rate of primary carbon fixation in continental shelf waters. They indicated that the lack of bottom sediment contributions of nutrients such as ammonia would cause the loss of an important "feedback" to the system, which would leave the pelagic primary producers dependent solely on water column sources of nutrients. They speculated that if this were the case, shelf primary production would be reduced to rates observed beyond the shelf break.

The conclusions stated above (Rowe *et al.*, 1975) were based primarily on two observations. First, they observed gradients of decreasing ammonium (NH_4^+) concentrations between the benthos and overlying water column. Secondly, they estimated potential releases of ammonia by the sediments from measurements of respiration, assuming the oxidation of organic matter, including infaunal metabolism, would result in ammonia release.

More recently Carpenter and McCarthy (1978) attempted to shed doubt on the hypothesis of Rowe *et al.* (1975) by contending that on the continental shelf the sediments play a minor role in cycling nitrogenous nutrients for primary producers. Part of the basis for their contention was that primary producers in the water column of a shelf habitat do not have enough of their energy diverted to the benthos to cause rates of ammonia regeneration by the sediments as reported by Rowe *et al.* (1975), because much of their energy is utilized by zooplankton and nekton on the shelf. Carpenter and McCarthy (1978) felt that for regeneration rates as reported by Rowe *et al.* (1975) to be occurring, the sediments would have to receive supplemental supplies of allochthonous organic materials. As will be illustrated later in this chapter, data collected on the Texas shelf indicate that the majority of phytoplankton biomass produced on the STOCS inner-shelf waters does not go as energy to pelagic components of the system but rather is diverted directly to the benthos.

Data collected during several special cruises in the STOCS study, which were intended to trace the nepheloid layer dynamics on the Texas shelf, lend support to the original hypothesis put forth by Rowe and his colleagues. Figure 53 illustrates diel ammonium (NH_4^+) profiles through the

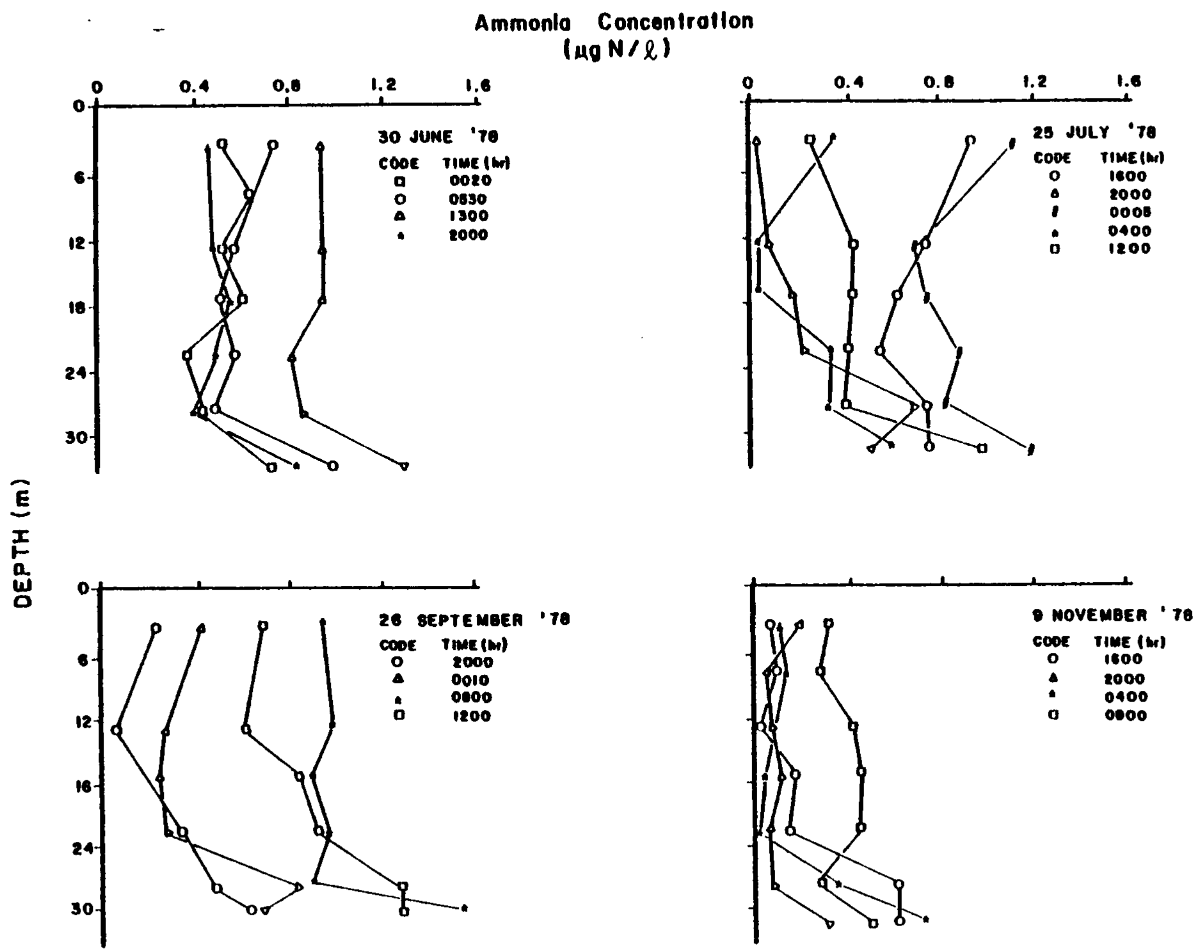

Figure 53. Temporal (by hour) profiles for ammonia nitrogen concentrations with depth during the sampling periods indicated at a sampling location near Station 4, Transect II.

water column at a station of approximately 33 m water depth on the Texas shelf during four periods in 1978. Almost every profile illustrates a gradient in ammonia through the water column with increases in concentration near the mud-water interface. These data were collected during both conditions of water column stratification and non-stratification and showed similar trends during both. In addition, results presented in Chapter 3 (Figure 20) indicate that the peaks in bottom water nitrogen were often associated with chlorophyll peaks. In conjunction with these peaks, photosynthesis was shown to be occurring, suggesting that the nutrient concentrations are being utilized by primary producers.

Given the observations by Rowe *et al.* (1975) plus the experiences cited above for Texas shelf waters, there appears to be sufficient evidence to support the idea of sediment nutrient regeneration being at least partially responsible for higher rates of primary production in shelf waters. Under circumstances like these the bottom may serve as a nutrient reservoir and may dampen the effects of surface productivity cycles. Furthermore, the occurrence of this phenomena on the south Texas shelf emphasizes the importance of several other ecosystem mechanisms that should be briefly mentioned.

As stated above, the sediments of the STOCS ecosystem may act as a reservoir for nitrogenous compounds such as ammonia that are potentially usable for primary producers. Besides the apparent flux of ammonia out of the sediments, generated by gradients between the sediments and overlying water, there is another possible mechanism for nutrient release on the Texas shelf which is directly related to the consistent occurrence of the nepheloid layer. As suggested in Chapter 3, the nepheloid layer is the result of sediment resuspension. The silty-mud nature of Texas shelf sediments help to perpetuate the presence of a nepheloid layer in these bottom waters. The benthic fauna, as well as macroepifaunal species which may disturb and otherwise bioturbate the bottom sediments, potentially serve as other influencing factors in the maintenance of this nepheloid layer with its associated nutrients, plant biomass and detritus. The biological dynamics of the fauna in and on the sediments potentially provide aeration to the interstitial water and sediments as well as different degrees of substrate coherence and stability, dependent upon the type of biological function that occurs.

The recycling and release of nutrients as well as sediment detritus to the water column depend largely on the ease with which the muddy seafloor can be resuspended. Bioturbation and current turbulence control this process (Rhoads *et al.*, 1974). Knowledge of the overall extent of biogenic activity is a key to partially predicting the consistency of nepheloid layer occurrence over various parts of the shelf. Furthermore, it is likely that the bioturbation activities of the benthic fauna play a role not only in the dynamics of the nepheloid layer but also in the general mechanisms responsible for nutrient regeneration across the mud-water interface. According to the evidence cited above and by Rowe *et al.* (1975), these nutrient regeneration dynamics of the Texas shelf could serve as a major force driving the ecosystem and responsible for some of the extremely productive fisheries supported by this shelf.

Trophic Coupling

For many years immense amounts of information have been accumulating on primary production, zooplankton abundance and the distribution of benthic organisms in important fishing areas. Despite these data bases it is very difficult to describe quantitatively the links between primary production and fish yields. A few plausible attempts to quantify these links have been provided by Steele (1974) for the North Sea ecosystem and by Mills and Fournier (in press) for the Scotian Shelf system. Even without complete data bases, the comparison of regions like the North Sea, the Scotian shelf, and for example, the northwestern Gulf of Mexico shelf, should offer insight into the general structure of marine ecosystems and pinpoint deficiencies in our understanding of them. Of most concern here is the need to take a hard look at the hypothesis that, despite geographical differences, most coastal ecosystems with productive fisheries have similarly constructed food webs (Dickie, 1972; Mills, 1975).

The importance of understanding the functioning of an ecosystem, especially with respect to an important fishery, cannot be overemphasized. For example, to demonstrate the effect on an ecosystem from perturbation such as an oil spill and to relate that directly to an impact on man, the effect to a natural resource such as a refinery must be cited. This effect on fishery productivity as reflected by commercial catch statistics is extremely risky at best. There are several shortcomings in fishery catch statistics. They do not represent precise reporting because they fail to take into account the changing effort and technological advances of fisheries. They also are generally not available for the localized areas in which the perturbation may be intense.

Based on these shortcomings and the desire to better understand the components of an important resource to the Texas shelf, we decided to use both the STOCS data base as well as bibliographical information to derive a conceptual model of the trophic relations involved in the shrimp fishery on the shelf. Through correlation research, relationships were sought between different components of the STOCS data base that intuitively made biological sense. The results of this search were the development of a conceptual model, based on correlation coefficients, that suggested relationships between the water column, benthos and shrimp that could serve as the basis upon which to create a food web hypothesis.

These relationships are depicted in Figure 54. Only significant correlation coefficients ($P < 0.05$) are illustrated. The model emphasizes several patterns. There is a relationship between the water column fauna, in this case zooplankton, and the sediment detrital pool, illustrated by the correlations between zooplankton nickel body burdens and sediment nickel concentrations as well as several zooplankton hydrocarbon body burden variables and hydrocarbons observed in the sediment. The hypothesis that could be derived from these results is that zooplankton fecal pellets serve as a major input to marine sediment detrital pools. This has been verified by numerous studies (Steele, 1974).

In addition to zooplankton inputs to the benthos, the data indicate that primary producer biomass, as represented by bottom water chlorophyll concentrations, is related to densities of benthic infauna and bacteria, potentially through the detrital pool (Figure 54). Furthermore, the relationships depicted by the model suggest the suspended relation between sediment hydrocarbon concentrations and bacteria with the former serving as a potential food source.

The interrelationships that are suggested in Figure 54 for the various faunal size categories living within the sediments (bacteria, meiofauna, and macrofauna) are relatively strong and provide further insight into the functioning of the Texas shelf benthos. The constant ratio of benthic animals to bacteria, and not organic carbon, indicates that benthic animals are more related to bacteria than to organic carbon. This relationship suggests that benthic animals utilize bacteria as a food source and not organic carbon. Bacteria are considered a major food

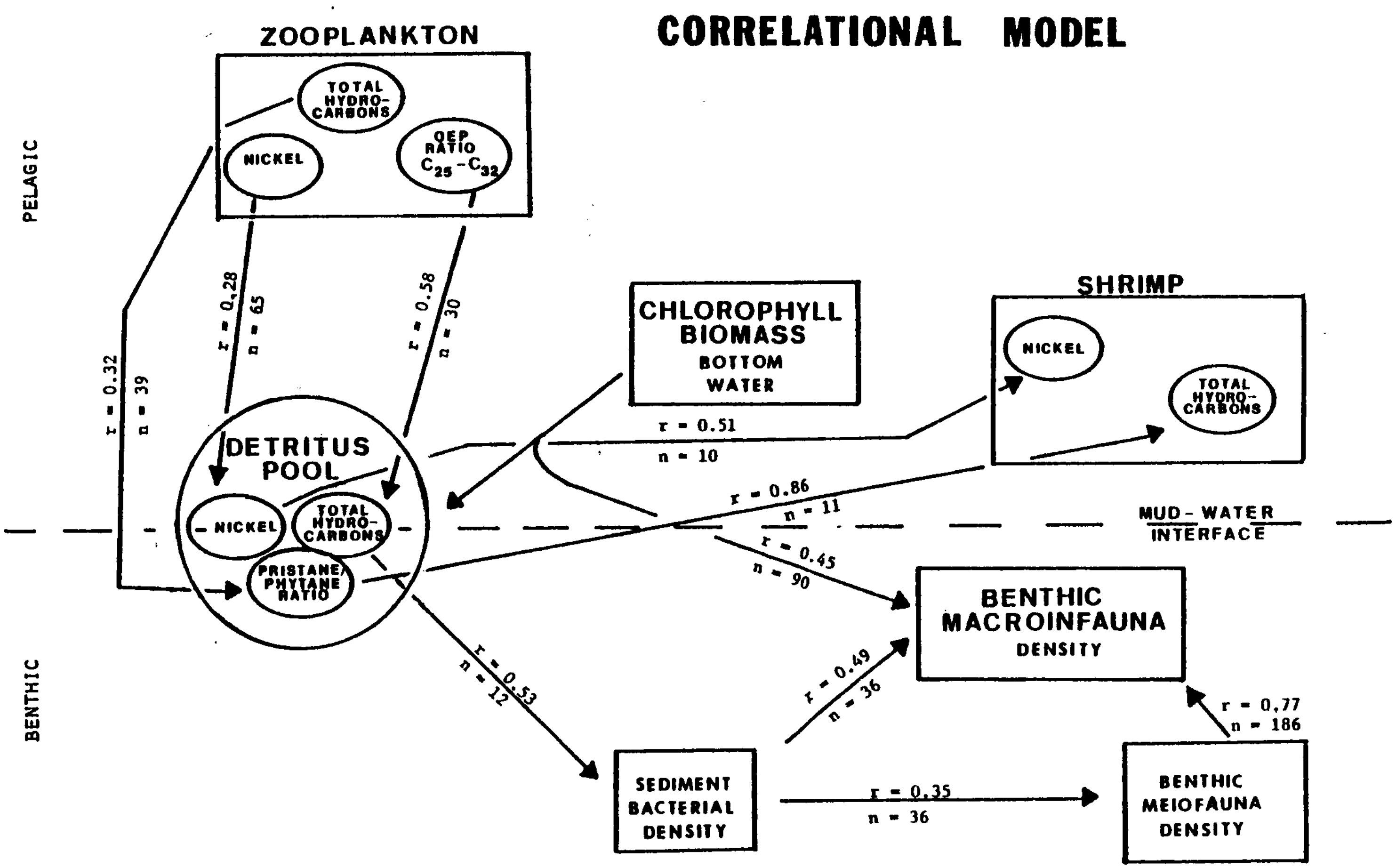

Figure 54. Schematic representation of significant ($P < 0.01$) correlations found between the STOCS variables indicated. The correlation coefficients (r) and number of cases (n) are also shown.

item for a wide variety of meiofauna (Coull, 1973) and macrofauna (Zobell and Feltham, 1938; Newell, 1965; Chua and Brinkhurst, 1973).

There are some indications that the meiofauna may contribute more to the matter and energy cycles of the sea than was envisaged by earlier investigators (Perkins, 1958; McIntyre, 1969). Recent caging experiments (Bell and Coull, 1978; Rubright, 1978; Buzas, 1978) have shown that meiofaunal populations, particularly the Nematoda, the Foraminiferida and the Polychaeta, are substantially reduced by predation and, therefore, probably represent an important food source. Buzas (1978) performed predator exclusion experiments in which foraminiferal biomass inside meiofaunal cages were 3 to 12 g/m^2 higher than outside the cages. This suggested foraminiferal densities were significantly reduced by predation. Another study by Bell and Coull (1978) indicated that *Palaemonetes* (grass shrimp) predation/disturbance significantly lowered total meiofaunal densities and that the shrimp randomly fed on the available nematodes in proportion to their abundance.

Macrofauna acting as surface deposit feeders can shift to subsurface deposit feeding when high quality sedimentated food following a spring phytoplankton bloom diminishes. Others are exclusively subsurface deposit feeders. Much meiofaunal predation may be incidental to non-selective subsurface deposit feeding. In the sediment, the organic food is more refractive and the energy source available to macro- and meiofauna is via bacteria and organic fractions which can be digested (Gerlach, 1971).

Gerlach (1978) further stated that although the estimates of meiofaunal contribution to the organic content of sediment utilized by subsurface deposit feeders was considered low, the bacterial biomass was not very much higher than meiofaunal biomass. He further stated that meiofauna must be considered an important food source if the concept of non-selective feeding is valid.

Similar complex feeding modes are found within the meiofauna. With increased study on the life histories of meiofauna, as has been the case with the macrofauna, the classical consensus that meiofauna are detrital feeders or indiscriminant feeders on benthic diatoms and bacteria (Wieser, 1960) has been replaced with the idea that they show as varied a feeding mode and diet as exists in the sediments (Coull, 1973). Some meiofauna are active predators. Many feed on bacteria and protozoa in competition with macrofauna, and others assimilate dissolved organic matter directly.

The primary function of meiobenthos in trophic relationships has traditionally been the assistance of recycling nutrients at a low trophic level (McIntyre, 1969). However, added importance is now being attributed to meiofauna in the enhancement of microbiota environment (growth) on detritus. Growth of an associated microbiota is enhanced when the detrital feeder mechanically breaks down the particle and increases the surface to volume size, thus furthering the microbial growth and decomposition (Coull, 1973). There is little doubt that particulate organic detritus is consumed in great quantities by the meiofauna. Gerlach (1978) stated that *in situ* sediment bacterial production is far below potential rates and somewhat stationary. Furthermore, he found that faunal activities may be beneficial for bacterial growth in marine sediments and may stimulate the rate of detritus decomposition. This statement applies to micro- as well as meiofauna, which would place both categories back into the same complex food web. Meiofauna may be more efficient, however, in utilizing organic substrates than macrofauna (Gerlach, 1978).

Gerlach (1978) reported more specific relationships between meiofauna and sediment bacteria. In microcosm experiments, the breakdown of ^{14}C-labelled *Zostera* detritus was greater when meiofauna was present than when there were only polychaetes. Nematodes may share with protozoa a major role in benthic nutrient regeneration and prevent bacteria from reaching self-limiting numbers. More specific interactions between meiofauna and bacteria were also reported by Gerlach (1978) in which the cuticle of certain nematodes were covered with a sheet of densely packed bacteria which they fed on and "gardened" by providing favorable environmental conditions; for example, by migrating up and down between aerobic and sulfide layers of the sediments. Other simple associations such as "mucus traps" on nematodes to which organic particles adhere resulting in a subsequent bacterial growth may be more widely distributed in marine sediments than is now known.

Finally, Figure 54 depicts a relationship that potentially ties the density of shrimp on the Texas shelf to the functioning of other major components of the ecosystem. There are strong correlations shown for shrimp body burdens of nickel and total hydrocarbons with sediment nickel concentrations and a hydrocarbon variable, suggesting that shrimp may derive their nutrition from the benthos. More important, however, are the relationships that are portrayed for nickel concentrations throughout the model depicted in Figure 54 (zooplankton →sediment →shrimp). These correlations make it possible to propose a trophic coupling hypothesis for shrimp which includes both pelagic and benthic components. It is quite clear than in inner-shelf waters, where mixing occurs, resulting in a relatively homogeneous water column, the discrimination between pelagic and benthic components is very obscure and the potential for trophic coupling between the two becomes very important.

The nearshore subtidal region of the Texas coast with its many interacting communities is the site of several major fisheries including penaeid shrimp. As a result of the south Texas shelf correlational model detailed in Figure 54, we feel it is imperative to examine some of the trophic interactions of this region and relate them to a fishery of immense economic importance, in order to delineate the deficiencies in our understanding.

Outside the bays and estuaries, the shrimp fishery extends to approximately 80 m depth on the shelf, with maximums in yield obtained well inside this range. Annual shrimp landing reports (NOAA/NMFS Gulf Coast Shrimp Data, Annual Summaries) indicate that for the reporting area (Statistical Area #20) similar to STOCS stations monitored during 1975-1977 (Figure 55), an annual average of 5.7 x 10^6 kg of shrimp were landed for the years 1975-1976. This represented a mean value of 18 million dollars for that period to the commercial fishery.

For purposes of developing a conceptual model, a single station centered in the middle of the fishery reporting area described above, which was monitored on almost a monthly basis for the period 1976-1977 will be emphasized. This station, Station 1/II (reference station, Figure 55) was located off Aransas Pass Inlet in approximately 22 m water depth.

Primary production for Texas inner-shelf waters as characterized by the above station was somewhat bimodal on an annual basis with peaks in the spring and fall (Chapter 3, Figure 17). Annual estimates of production based upon chlorophyll a measures converted to carbon equivalents according to methods of Ryther and Yentsch (1957) indicated that these waters produced a mean of approximately 103 g $C/m^2/yr$ (Figure 56).

Macrozooplankton biomass on the Texas shelf averaged approximately 3.566 g/m^2 wet weight over the sampling interval. Assuming a turn-over ratio of 7 (Steele, 1974), annual production of the macrozooplankton was estimated to be 25 $g/m^2/yr$. Since the water column was usually fairly

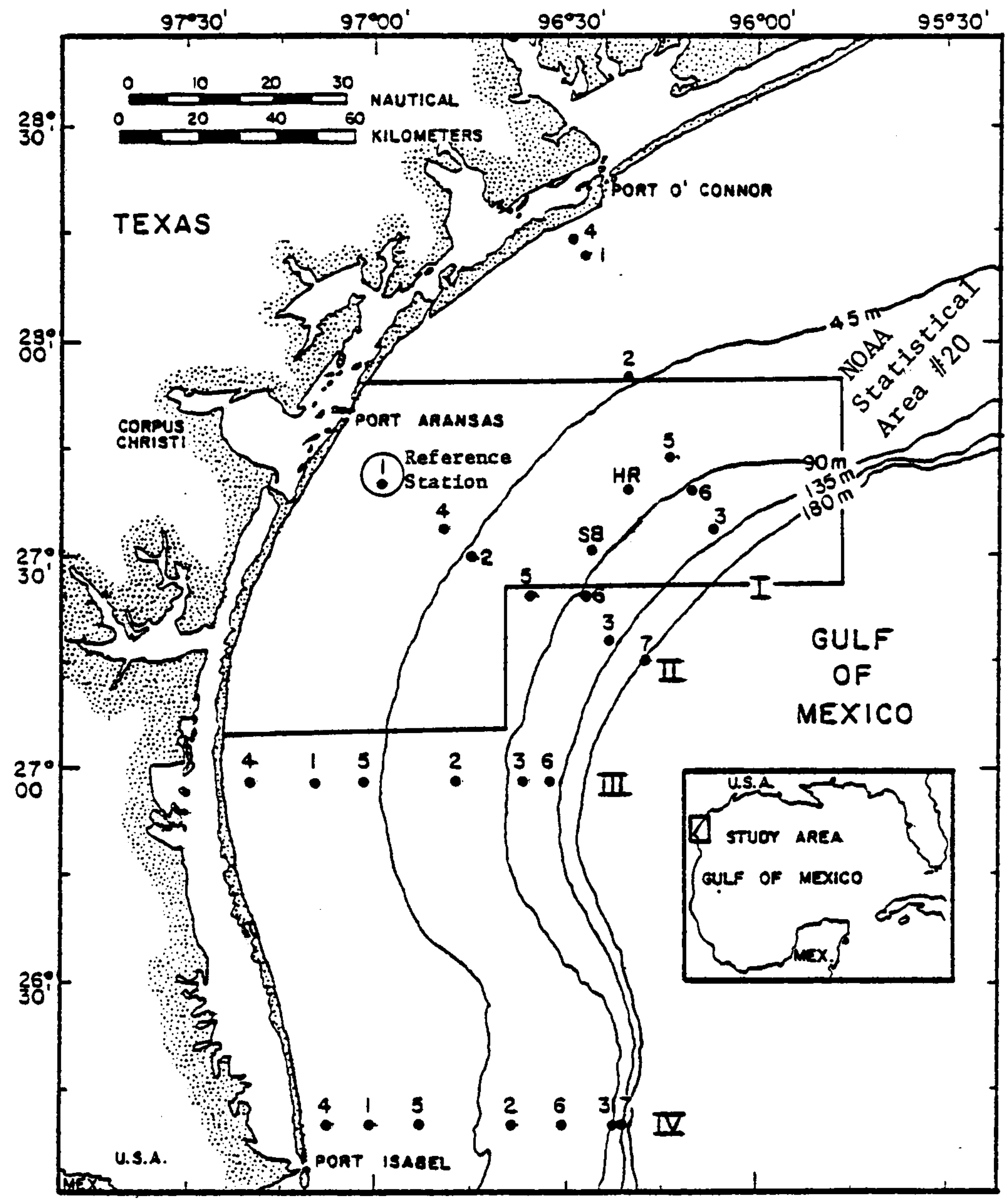

Figure 55. Location of the reference station focused upon in the NOAA statistical reporting area (rectangular boxed area) for the development of a trophic model for shrimp.

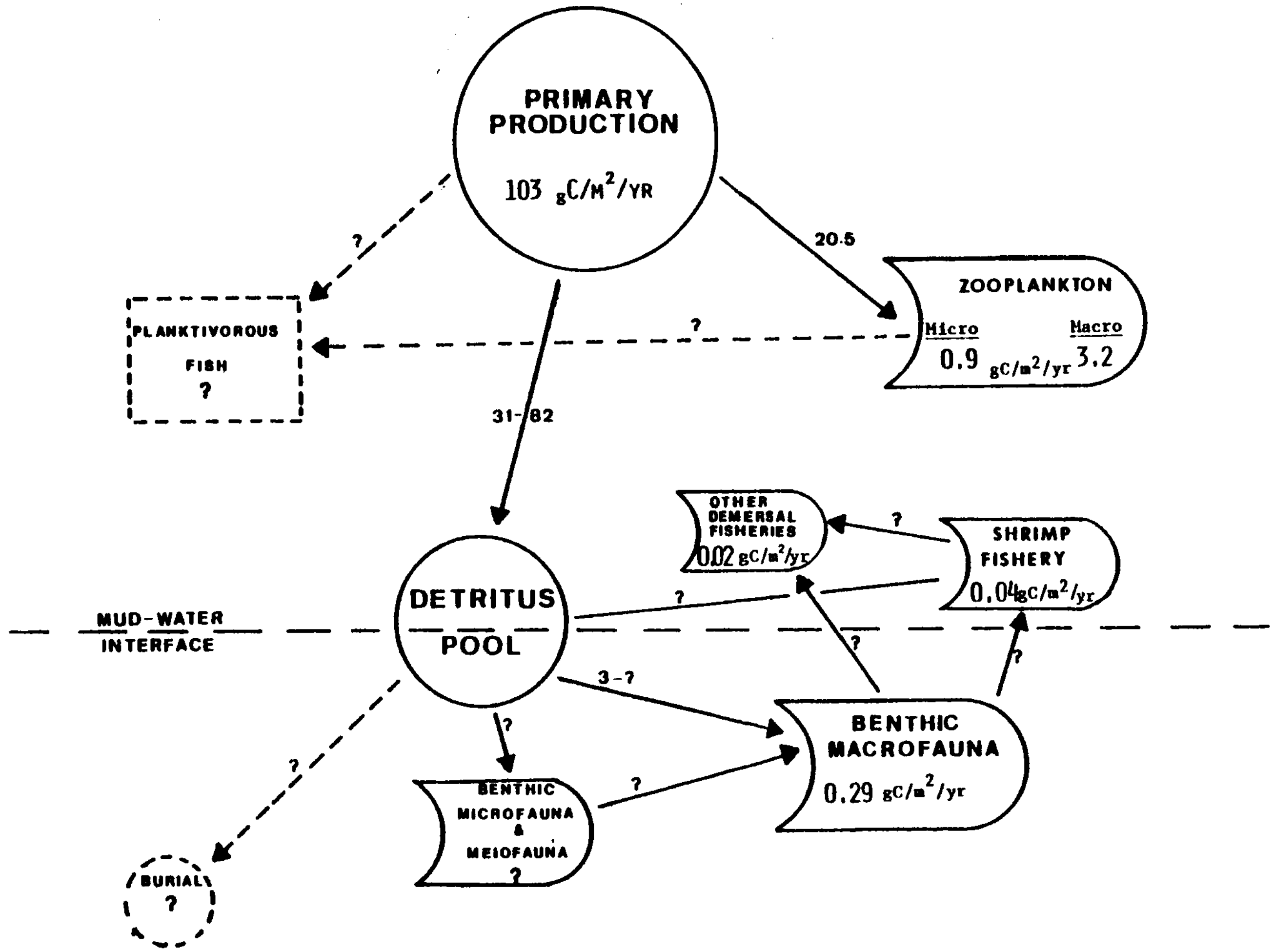

Figure 56. Conceptual trophic model for the brown shrimp fishery. Material transfers indicated are also in $gC/m^2/yr$.

homogeneous and the zooplankton tows often did not reach the bottom, plus sampling bias from net clogging, it is likely that the number for production estimate should be doubled to 50 $g/m^2/yr$ for purposes of this model. Assuming approximately a 6% conversion between wet weight and carbon content of metazoans (Rowe, personal communication) the carbon equivalent of zooplankton production was estimated to be 3 g $C/m^2/yr$ (Figure 56).

Information on the neuston component of the planktonic community indicated that an additional 0.21 g $C/m^2/yr$ could be assumed for the macroplankton production from these surface animals. Standing crop of microplankton was calculated to be 465 mg/m^2 wet weight. Annual production was estimated as 10 times the standing crop because of larger expected turnover ratios for the microplankton. With the conversion to carbon content mentioned above this resulted in approximately 0.9 g $C/m^2/yr$. Therefore, the total production estimate for the zooplankton component of the food web on the Texas inner shelf is approximately 4.1 g $C/m^2/yr$ (Figure 56).

If we assume a minimum transfer efficiency of 20% (very conservative) between primary producers and the zooplankton, then 20.5 g $C/m^2/yr$ (Figure 56) would be required to support the zooplankton. This transfer of carbon results in approximately 82 g $C/m^2/yr$ of primary production remaining. Mills and Fournier (in press) indicated that, contrasted with the North Sea ecosystem (Steele, 1974), for the coastal ecosystem on the Scotian Shelf the majority of primary production was diverted to the demersal fisheries. This may very well be the case for the Gulf coastal ecosystem also. The bottom waters appear to support greater amounts of primary producers than the surface or mid depths during the majority of the time (Chapter 3, Figure 13).

The amount of pelagic fisheries biomass that is directly supported by primary producers on the Texas inner shelf is unknown. From the amount of zooplankton production observed, however, one would have to assume that the pelagic fisheries is small. Therefore, the Texas inner-shelf ecosystem is probably characterized as a system where the majority of primary production is input directly to the bottom waters and benthos.

Information from Steele (1974) indicated that 30% of the primary production is transported to the benthos in the North Sea ecosystem. From the above facts, plus if we assume there are no other major links to pelagic fisheries other than through zooplankton, it would appear that almost 80% of this production reaches the benthos in the Texas coastal waters. This is probably an over-estimation but the real number is certainly greater than the 30% estimated for the North Sea.

To further illustrate the input to the bottom, data from several cruises to examine nepheloid layer dynamics, which were detailed in Chapter 3, substantiate the presence of peak chlorophyll layers in these bottom waters. The carbon production at depth plus the direct input to the benthos of detritus, both from the nepheloid layer and the upper portions of the water column, presumably can provide a sizable nutritional source for demersal-oriented trophic links.

Estimates of benthic infaunal biomass in this region of the Texas inner shelf range between 0.5 g/m^2 (STOCS study) and 2.5 g/m^2 (Rowe *et al.*, 1974; Table 24). Assuming a turnover ratio of approximately 4.5 (Nichols, 1978), an average of 0.29 g $C/m^2/yr$ are produced by the infaunal benthos (Figure 56).

Shrimp fisheries yields (NOAA/NMFS Gulf Coast Shrimp Data, Annual

TABLE 24

COMPARISON OF ABUNDANCE AND BIOMASS OF MACROBENTHOS FROM THE NORTHWESTERN ATLANTIC OCEAN AND NORTHWESTERN GULF OF MEXICO

Atlantic Ocean[1]			Gulf of Mexico				
Depth (m)	Density (#/m^2)	Wet Weight (g/m^2)	Depth (m)	Density[1] (#/m^2)	Wet Weight[1] (g/m^2)	Density[2] (#/m^2)	Wet Weight[3] (g/m^2)
30	26,060	7.69	12			1,536	0.63
40	7,390	2.44	16	1,373	0.74		
			30	14,623	4.09	675	0.28
Average	16,725	5.07		7,998	2.42	1,106	0.46

[1]Measures from Rowe *et al.* (1974).

[2]Measures from the South Texas Outer Continental Shelf Study, 1975-1977.

[3]Wet weight calculated from densities of organisms using the density to wet weight ratio of the respective values from Rowe *et al.* (1974).

Summaries) were used to estimate the production of shrimp on an annual basis for the inner-shelf waters. Utilizing the suggested conversions to obtain the heads-on weight and assuming a turnover ratio of approximately 0.8 (Caillouet, NMFS, personal communication), the commercial fishery catch represented approximately 0.03 g C/m^2/yr of shrimp production. According to the hypothesized survival curve presented in Figure 57 this estimate of shrimp production was for approximately 78% of the shelf population in statistical area #20 (Figure 55). Therefore, adding the other 22% of the population, annual production was estimated to be 0.04 g C/m^2/yr (Figure 56).

Data from the STOCS study indicated that an additional 0.02 g C/m^2/yr of other demersal species was produced on the inner shelf. The combination of this data with the shrimp production estimates illustrated that approximately 0.06 g C/m^2/yr was produced by the fauna living in these bottom waters of the Texas shelf. Comparing this trophic level to the infaunal production and assuming a standard 10% transfer efficiency, it would appear that benthic biomass is an insufficient food source to solely support the demersal component of the inner-shelf food web. These figures do not include meiofaunal production, but even if this component were known, there probably would still not be enough biomass to directly support the demersal fisheries. Furthermore, as illustrated in Table 24, there appears to be much less benthic infaunal production in the northwestern Gulf of Mexico contrasted to other continental shelf regions such as the northwestern Atlantic. This is surprising considering the extensive fishery supported on the Gulf continental shelf.

The alternative to an infaunal-demersal fishery trophic link is a detrital based trophic web for many of the commercially important species,

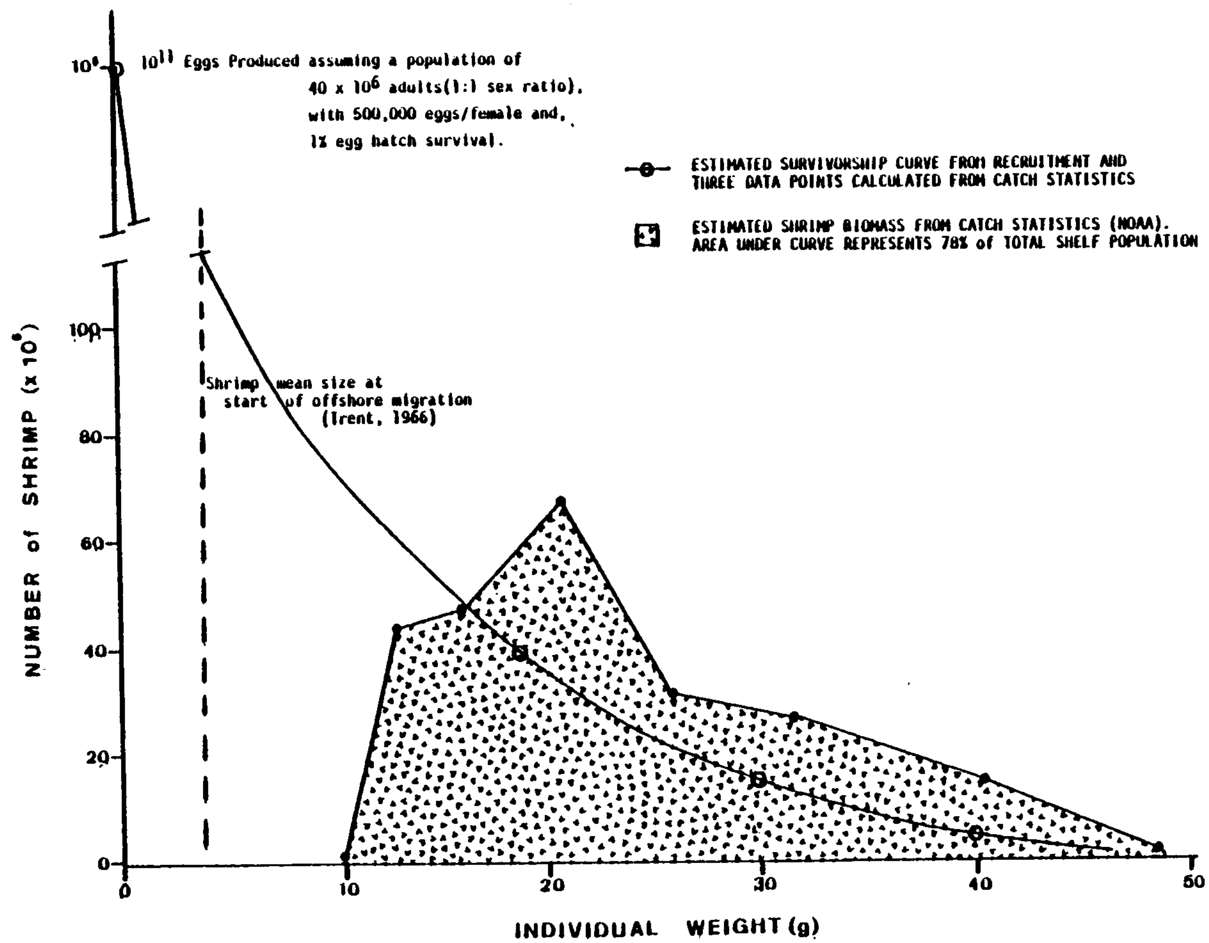

Figure 57. Plot of the reported shrimp fishery yield (shaded area) according to size range along with an estimated survivorship curve (solid line) for the south Texas shelf brown shrimp population.

including the shrimp. The data on primary production plus the peak concentrations of chlorophyll in the bottom waters along with a relatively small amount of pelagic secondary production would tend to support this conclusion.

If the Texas inner shelf trophically revolves around a detrital food web, one of several questions to ask concerns where the benthos fit into this trophic scheme; especially since they do not appear to have the biomass to alone support the observed production at higher trophic levels. A possible hypothesis for the role of the benthos takes into account the dynamics of the nepheloid layer. Rhoads *et al.* (1974) pointed out that the concentration of suspended solids in many estuaries and coastal waters is higher in the bottom waters than at the surface, especially where the water column passes over muds that have undergone intensive bioturbation.

As stated previously, the recycling of materials, such as detritus, from the sediment, to the bottom waters depends largely on the ease with which the muddy sea floor can be resuspended. Bioturbation by infauna and current scour control this process (Rhoads *et al.*, 1974). Primary productivity in turn provides plankters to the bottom waters through surface sedimentation. Both living and dead plankters plus associated microorganisms produce detrital food for demersal consumers including shrimp populations. Thus, benthic infauna do not necessarily provide all of the direct food sources for an important fishery such as shrimp, but rather supplement the demersal consumer's diet and indirectly provide alternative nutritional sources through their bioturbation activities and the maintenance of a very productive zone in the near-shelf bottom waters.

In turn, the extremely high densities of shrimp on the Gulf of Mexico shelf, as indicated by the successful fishery, probably have a direct effect on the smaller benthic infaunal biomasses observed for these waters as contrasted to the Atlantic coastal waters (Table 24). The predation pressure of the shrimp plus their physical feeding activities may serve as influential factors in maintaining infaunal organisms at relatively smaller sizes with possibly higher turnover ratios than even assumed here.

From the preceding exercise it is obvious that the coastal waters of the Gulf of Mexico are extremely productive and that this production is influenced by many factors. It is suggested that much of this production is diverted directly to the benthos and that the major regional fisheries, such as shrimp, receive much of their nutrition from a detrital food web. Determining the mechanisms of this food web and the exact role of such components as the benthos is an extremely important task for future research. It would appear that this ecosystem, and its food webs leading to major commercial fisheries, is certainly different in structure than, for example, the system described by Steele (1974) for the North Sea. This points to the need for detailed regional studies before generalizations and models to predict effects from such factors as environmental disturbance can be constructed for important fisheries.

Environmental Disturbance

In the state of Texas, one-third of the population resides in the coastal zone. A total population of 3.5 million was recorded for the state in 1975 with the population projected to increase to 5 million by 1980. Such dynamic growth in Texas and throughout the United States implies parallel expansion in the coastal zone with increased demands for manufacturing, petroleum and natural gas exploration, production, and refining, increased marine transportation, commercial use of natural resources, and recreation and tourism.

The pressures imposed by a rapidly increasing population demand intelligent control and management of coastal regions. The nearshore coastal waters make up less than one percent of the world's oceans, yet it is in this fringe that are found the most productive ecosystems in the world. The different water masses influencing the Texas shelf, in particular freshwater discharge, suggest that as salinity decreases from riverine input the particulate matter increases along with possible associated nutrients and primary productivity. The effects of this scheme are felt throughout the south Texas shelf. Thus, the outer continental shelf system is not just a product of the dynamics of Gulf waters but a reflection of many processes in nearshore coastal waters as well. Our continued multiplicity of demands upon the complex coastal environments make it imperative that their functioning and ecological values be understood. This knowledge is essential for decision makers to properly manage coastal environments while maintaining the best possible conditions for the continued productive uses of natural resources.

Healthy, naturally functioning ecosystems are one of the principal resources in the northwestern Gulf of Mexico that are susceptible to environmental disturbance, such as oil spills. The benefits we reap from these systems include multi-million dollar commercial fisheries, both shellfish and finfish, and particularly penaeid shrimp. The health of the general public can be threatened by contaminated foodstuff passing through the fishery markets. A sizable sports fishery also harvests these resources. An important segment of our coastal economy is based on recreation and tourism which in turn are dependent upon the natural resources. Additionally, segments of the shelf ecosystem provide habitats for endangered and threatened species, such as sea turtles. Billions of dollars per year are contributed to our economy from the northwestern Gulf of Mexico as a result of all these fish and wildlife populations.

In addition, the Gulf coastal zone must be considered one of the most critical nonliving resources. Population centers naturally develop along the coast and serve as focal points for national and international commerce as well as recreation. Wastes of various kinds normally enter Gulf waters by direct discharge from coastal municipalities and industries or through tributary streams that serve as transmission media for waters from larger areas. Included in this waste are raw and partially treated municipal sewage, industrial wastes including petroleum products, and sediment loads from soil erosion. In an era of increased energy demands, the coastal zone is an area which may be affected by oil and gas exploration and production, oil spills, increased marine transportation, and manufacturing and industrialization. A potential exists for increased sources and amounts of pollutants to enter the system. Impacts to these areas from an environmental disturbance may include loss of income from decreased fisheries, tourism and/or recreation, health dangers, and damage to natural resources.

The objectives of the three-year study of the south Texas outer continental shelf were to describe the physical, chemical and biological components of the system and their interactions, against which subsequent changes or impacts could be compared, particularly in light of the effects of outer continental shelf oil and gas development activities. The synthesis and integration of this data was designed to develop an encompassing description of the study area, identifying the temporal and spatial trends that best represented the ecosystem along with mathematical descriptions for unique relationships that would serve as "fingerprints" for future comparisons.

The study results indicate that a major step has been taken toward reaching this objective. Our analyses have shown the south Texas shelf to be an extremely productive and complex system. Meaningful relationships have been found between the physical, chemical and biological components studied, and naturally inherent variability has been quantified. Potential, implicative, or biologically intuitive relationships have been hypothesized which describe some of the forcing dynamics of this system, but these exercises only serve to point out the need for detailed studies before overall generalizations and predictive models can be constructed.

Evidence from the study indicates that the south Texas shelf bottom environment is relatively pristine with respect to those chemicals monitored during the study period. There is minimal petroleum pollution of sediments (lack of aromatic hydrocarbons), and these appear to be free of any significant trace metal contamination. Likewise, the water column is relatively pristine with respect to the hydrocarbons studied, with those observations during the study attributed primarily to natural sources such as suspected natural gas seeps along the edge of the shelf. Because of the tremendous quantities of available dilution water from local and Mississippi riverine input, pollution wastes originating in the coastal area have, to date, had minimal effects upon either water quality or resources in the Gulf of Mexico. There is, however, increasing pressure to further develop many of the energy resources in the Gulf which can severely threaten the pristine nature of the waters, especially in terms of hydrocarbons.

The ecological effects of oil pollution on the Texas shelf environment are an important consideration in energy policy decisions directed at this area, primarily because of economic consideration such as the extensive commercial fisheries. At present, assessment of the environmental impact of energy resource development must be made somewhat in ignorance and uncertainty because of large knowledge gaps and conflicting opinions. The only remedy for our uncomfortable lack of knowledge are programs such as the one detailed in this presentation. It is hoped that the ecosystem description presented here will begin to fill the large information gaps that exist. As we have seen, the Texas shelf is a complex collection of many components, all interrelated and dependent upon its parts for the well-being, health and productivity of the whole system. Although a beginning, we are still a long way from the level of commitment required to completely understand the Gulf ecosystem and the impact to the environment from unnatural impacts resulting from oil and gas exploration and production.

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APPENDIX A

OVERALL BASELINE RESULTS

DISTRIBUTIONAL CHARACTERISTICS OF SELECTED IMPORTANT VARIABLES

PREFACE[1]

The purpose of this appendix is to present baseline information for the South Texas Outer Continental Shelf (STOCS) for the period 1975-1977. Presented are the distributional characteristics (*i.e.* mean, standard deviation, skewness, kurtosis and confidence intervals) for parameters selected from each of the study areas of the STOCS study integration effort. Also presented is information concerning significant temporal and spatial variation for these parameters.

The actual numerical results are presented in Table A-10 at the end of this appendix. Preceding Table A-10 are several explanatory sections: 1) a section describing the format and use of Table A-10; 2) an overview of the sampling scheme of the STOCS study; 3) a methodology section describing the selection of variables and the statistical methods used; 4) a section discussing the comparison of the present baseline results to future monitoring results; 5) a section discussing the number of samples needed in future monitoring efforts; and 6) an index of study areas for Table A-10. No attempt has been made in this appendix to discuss the scientific meaning or implications of the various numerical results. Such discussion has already been presented in the main text of this volume and in Volume III. It is hoped that the present appendix will allow future workers to efficiently locate desired baseline results and to quickly compare these results to values from future monitoring efforts.

Format and Use of Table A-10

Table A-10 has been organized to present several different types of results and the format is somewhat complicated. A set of hypothetical

[1]Text of appendix by R. Godbout, STOCS Data Manager

results is presented in Table A-1 which will serve to illustrate the general format of Table A-10. These column titles in the table refer to the distribution statistics presented for each variable; STD DEV-standard deviation; SKEW-skewness; KURT-kurtosis; 95% EMPIR CI-95% empirical confidence interval; and N-the number of data cases involved. The actual methods used to calculate the different distribution statistics are spelled out in the methodology section of this appendix.

In Table A-1, "High-Molecular-Weight Hydrocarbons in Epifauna", indicates the study area for the variables which follow. In parentheses after the study area title are the years for which data are being considered, 1976 to 1977 in this example. Note that the variables which follow are relevant to a specific species (*Rhomboplites aurorubens*) and a specific tissue (liver). The first for this species-tissue combination is "Total Hydrocarbons". This variable is the sum of the normal alkanes involving from 14 to 32 carbon atoms ($n\text{-}C_{14}$ to $n\text{-}C_{32}$) and the units for this variable are micrograms per gram. There was a total of 50 cases considered for the Total Hydrocarbon variable and the overall mean was 13.60; the overall standard deviation, 9.78; etc. Note that "Total Hydrocarbons" is then broken down by station and then by year. For example, the 20 data cases for Station 1 had a mean of 13.04 and a standard deviation of 8.79; while the 15 data cases for 1976 had a mean of 10.68 and a standard deviation of 9.63.

The fact that breakdowns by station and by year are presented for "Total Hydrocarbons" signifies that valid significant differences (beyond the 0.05 level of significance) were found among the three stations and also between the two years. In general, a series of analyses of variance[2]

[2]The actual analyses performed and the rationale for these analyses are presented in the methodology section of this appendix.

TABLE A-1

HYPOTHETICAL RESULTS ILLUSTRATING TABLE A-10 FORMAT

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
HIGH-MOLECULAR-WEIGHT HYDROCARBONS						
EPIFAUNA (1976-1977)						
Rhomboplites aurorubens Liver						
TOTAL HYDROCARBONS ($n-C_{14}$ to $n-C_{32}$) (micrograms/gm)	13.60	9.78	0.84	0.08	0.57 - 35.80	50
Station 1	13.04	8.79	0.73	0.01	0.57 - 32.91	20
Station 2	15.96	9.30	0.74	-0.05	2.98 - 35.80	20
Station 3	11.26	10.64	0.92	0.18	6.29 - 28.76	10
1976	10.68	9.63	0.80	0.07	5.43 - 29.78	15
1977	14.91	9.43	0.85	0.08	0.57 - 28.76	35
PRISTANE/PHYTANE	81.41	59.10	0.79	-1.34	17.27 - 171.60	40
PRISTANE/$n-C_{17}$	10.67	9.92	1.65	2.02	1.85 - 36.00	42
Winter	7.03				7.03 - 7.03	1

TABLE A-1 CONT.'D

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
March	6.31	2.98	-0.49		3.85 - 8.22	3
April	14.97	7.63	2.91	1.42	5.94 - 36.00	5
Spring	20.60	10.42	3.41	2.12	6.92 - 28.72	5
July	5.78	10.80	1.56	1.92	1.85 - 16.92	14
August	5.29	6.99	1.72	1.62	4.93 - 6.77	4
Fall	8.46	9.67	1.82	2.60	6.91 - 10.32	5
November	2.18	9.56	1.84	2.11	7.12 - 11.92	4
December	1.85				1.85 - 1.85	1
PHYTANE/n-C_{18}	0.68	0.52	0.46	-1.60	0.17 - 1.50	46

were performed to test each variable for significant temporal and spatial differences--differences due to transect, station, collection period (month or season) and year. If an effect (*e.g.* transect) was consistently significant for a variable (*i.e.* significant in all analyses involving that effect), and if that effect was general (*i.e.* there were no significant interactions involving that effect); then valid significance was accorded that effect and a breakdown of the effect has been included in the table. This system for selecting valid significant results is quite conservative and has limited the significant temporal and spatial effects reported in Table A-10 to those which are general and unambiguous. Further details are presented in the methodology section.

Again consider the hypothetical results in Table A-1. Note that collection period and transect are not broken down for "Total Hydrocarbons", indicating that valid significant differences were not found for these two effects. The second variable in Table A-1 is the pristane to phytane ratio ("Pristane/Phytane"). The lack of breakdowns for this variable indicates that no valid significant temporal or spatial differences were found. Note that no units of measurement are presented for "Pristane/Phytane" since it is a unitless ratio.

The third variable in Table A-1 is the pristane to n-heptadecane ratio ("Pristane/n-C_{17}"). Collection period has been broken down for "Pristane/n-C_{17}" indicating valid significant differences for that effect. Note that standard deviation, skewness and kurtosis values are not present for winter or December. These statistics were not calculable because there was only one data case for each of these two periods. Also note that no kurtosis value is presented for the spring. There were only three data cases in the spring and a minimum of four data cases is required for the calculation of kurtosis. In general, blank values indicate that the statistic could not be calculated.

In the 95% EMPIR CI column in Table A-1, there are two values separated by a dash. The value preceding the dash is the lower limit of the confidence interval, and the value following the dash is the upper limit of the confidence interval. Note that the lower limit of the 95% empirical confidence interval corresponds to the 2.5 percentile of the observed distribution while the upper limit of the confidence interval corresponds to the 97.5 percentile. Such an empirically defined 95% confidence interval can be quite different from the theoretically defined 95% confidence interval (mean ± 1.96 x standard deviation) so familiar in the literature. The theoretically defined confidence interval is based on the assumption of an underlying normal distribution. Such an assumption of normality is not valid for a large number of the variables presented, thereby obviating the general use of the theoretical confidence interval. Further discussion of both empirical and theoretical confidence intervals is presented in the methodology section of this appendix. This concludes consideration of Table A-1.

Overview of the Sampling Scheme

The variables presented in Table A-10 represent several different sampling schemes. For most variables, data were collected for all three years of study (1975-1977). There are exceptions, however, with data being collected in only one or two years for some variables. In some cases, the Principal Investigator for a study area had questions about the validity or reliability of a variable for a particular year. In such cases, those data for the year in question have not been considered in the construction of Table A-10.

Two different sampling schemes were employed for collection periods.

Some variables were sampled three times a year (winter, spring, fall); this scheme being referred to as seasonal sampling. Other variables were sampled nine times a year (Winter, March, April, Spring, July, August, Fall, November, December); this scheme being referred to as monthly sampling. Spring collections occurred in May and June. Fall collections usually occurred in September and October. (One of four fall cruises in 1975 was made in August.) Winter collections usually occurred in January and February. (Two of six cruises for 1975 were made in December 1974, and one of seven winter cruises for 1976 was made in March 1976.) Table A-2 summarizes the sampling schemes with regard to collection period.

Spatially (geographically) three different sampling schemes were employed for the total study area as shown in Figure A-1: a) a 12 station scheme involving Transects I through IV, primarily for water column (pelagic) sampling; b) a 25 station scheme involving Transects I through IV, primarily for benthic sampling[1]; c) a two station scheme involving one station on the Southern Bank (SB) and one station on Hospital Rock (HR).[1] For the 12 station scheme, stations were classified into one of three groups on the basis of depth (Table A-3). Variables collected according to the 12 station scheme were analyzed for two spatial effects—station group (1-3) and transect (I-IV). For the 25 station scheme, stations were classified into 1 of 6 groups on the basis of depth (Table A-4). Variables collected according to the 25 station scheme were analyzed for two spatial effects--station group (1-6) and transect (I-IV). Variables collected according to the two station scheme were analyzed for a single spatial effect, SB vs. HR.

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[1]These station schemes did not begin until 1976. Consequently, this scheme only covers the 1976 and 1977 sampling years.

TABLE A-2

COLLECTION PERIODS

Seasonal Sampling Scheme	Monthly Sampling Scheme
Winter	Winter
Spring	March
Fall	April
	Spring
	July
	August
	Fall
	November
	December

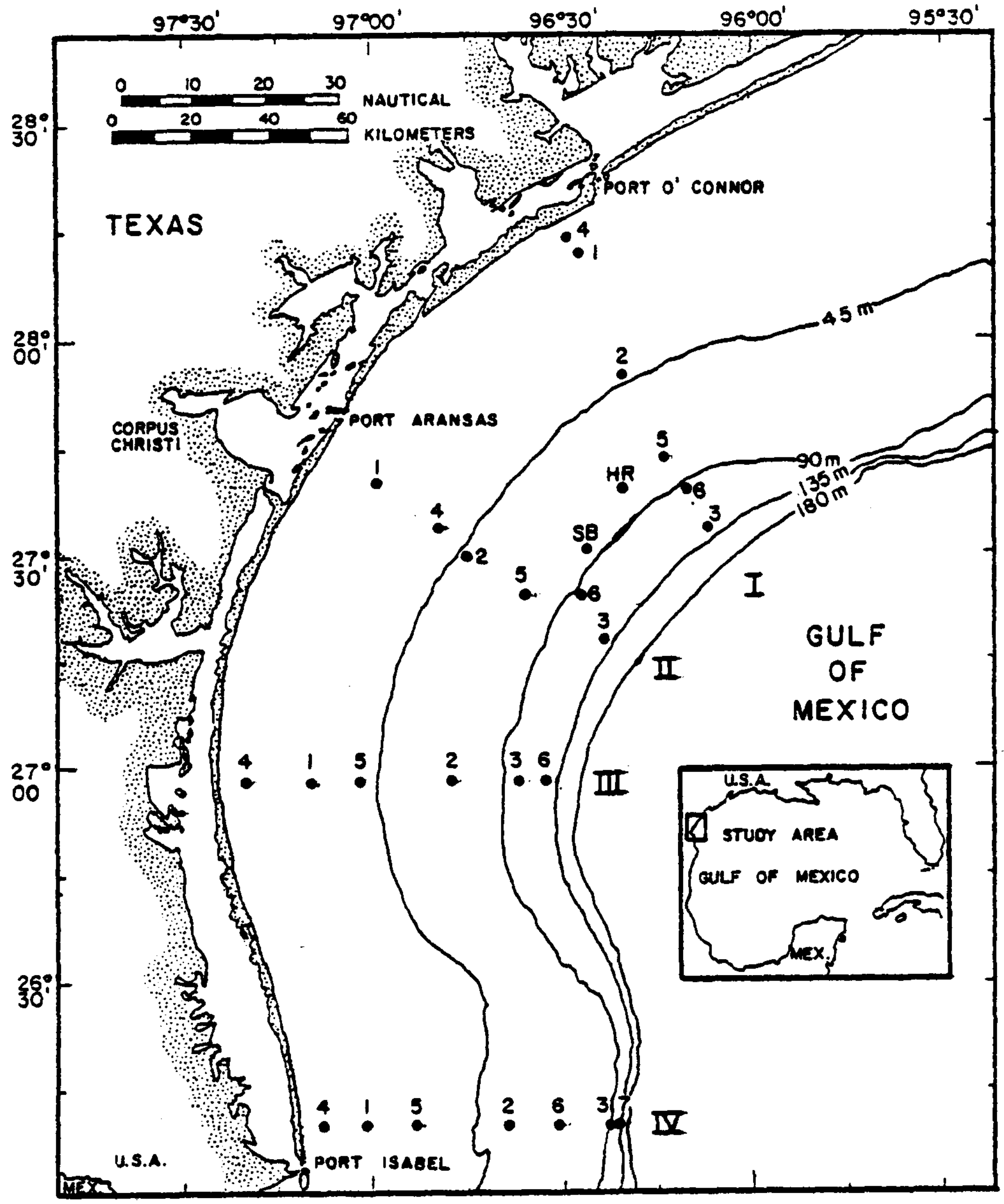

Figure A-1. Sampling sites for the STOCS study. The 12 station (pelagic) scheme involved Stations 1, 2, and 3 on Transects I through IV. The 25 station (benthic) scheme involved all stations on Transects I through IV. The single station marked HR refers to Hospital Rock; the station marked SB refers to Southern Bank.

TABLE A-3

STATIONS GROUPED BY DEPTH FOR THE 12 STATION SAMPLING SCHEME

Station Group	Depth Range (m)	Transect	Station	Depth (m)
1	18-27	I	1	18
		II	1	22
		III	1	25
		IV	1	27
2	42-65	I	2	42
		IV	2	47
		II	2	49
		III	2	65
3	91-134	IV	3	91
		III	3	106
		II	3	131
		I	3	134

TABLE A-4

STATIONS GROUPED BY DEPTH FOR THE 25 STATION SAMPLING SCHEME

Station Group	Depth Range (m)	Transect	Station	Depth (m)
1	10–18	I	4	10
		III	4	15
		IV	4	15
		I	1	18
2	22–27	II	1	22
		III	1	24
		IV	1	27
3	36–49	II	4	36
		IV	5	37
		III	5	40
		I	2	42
		IV	2	47
		II	2	49
4	65–82	IV	6	65
		III	2	65
		II	5	78
		I	5	82
5	91–106	IV	3	91
		II	6	98
		I	6	100
		III	3	106
6	125–134	III	6	125
		IV	7	130
		II	3	131
		I	3	134

Methodology Used in Constructing Table A-10

Selection of Variables

A variable was selected for inclusion in Table A-10 if a) the Principal Investigator for the study area in question recommended it as an important baseline characteristic, or b) that variable was found to have significant temporal or spatial variation. That a variable demonstrated temporal or spatial differences indicated that it is sensitive to environmental changes and thus a possible candidate for future monitoring.

Descriptive Statistics

For many variables, replicate[3] samples were not taken consistently and were therefore scattered over the different sampling sites and times. To allow a uniform approach to all variables, data from replicate samples were averaged to arrive at a single mean data case for each site-period-year combination. The number of data cases (N) in Table A-10 refers to the number of such mean values and all descriptive statistics were calculated on the basis of these mean values. The mean ($\bar{X}$) is self-explanatory, indicating the normal arithmetic average. The standard deviation (STD DEV) presented in Table A-10 is the unbiased estimate of a population value given by the following expression:

$$\text{STD DEV} = \left[\frac{\sum_{i=1}^{N} (X_i - \bar{X})^2}{N-1}\right]^{\frac{1}{2}}$$

In the above expression, N refers to the number of data cases and X_i refers to the value for the ith data case.

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[3]Replicate samples here refer to different samples taken at the same site, collection period, and year.

A basic characteristic of a distribution is skewness (SKEW). Skewness is a measure of the extent to which a distribution is symmetric about its mean. The measure of skewness presented in Table A-10 is calculated according to the following expression:

$$\text{SKEW} = \frac{\sum_{i=1}^{N} (X_i - \overline{X})^3}{N(\text{STD DEV})^3}$$

If the skewness value is 0, then the distribution is symmetric. If the value is positive, then the tail to the right of the mean is drawn out relative to the tail to the left. The converse is true for negative skewness values; the tail to the left is drawn out relative to the tail to the right. An important use of a measure of skewness is to determine if a distribution is normal in shape or not. A normally distributed population will have a skewness value equal to 0, and samples drawn from that population will have skewness values close to 0. Table A-5, adapted from Snedecor and Cochran (1967), can be used to test whether an obtained skewness value is significantly different from θ. If the absolute value of an obtained skewness exceeds the tabled value for the appropriate sample size and desired significance level, then that skewness is significantly different from 0.

Another characteristic of a distribution is kurtosis (KURT). Kurtosis is a measure of the relative peakedness or flatness of a distribution. The measure of kurtosis presented in Table A-10 is based on the following expression:

$$\text{KURT} = \frac{\sum_{i=1}^{N} (X_i - \overline{X})^4}{N(\text{STD DEV})^4} - 3$$

TABLE A-5

TABLE OF CRITICAL VALUES FOR TESTING SKEWNESS[1]
TABLED VALUES ARE MINIMUM ABSOLUTE VALUES OF THE SKEWNESS MEASURES
REQUIRED FOR A SIGNIFICANT DIFFERENCE FROM 0

Size of Sample	Level of Significance[2]	
N	.05	.01
25	0.711	1.061
30	0.662	0.986
35	0.621	0.923
40	0.587	0.870
45	0.558	0.825
50	0.534	0.787
60	0.492	0.726
70	0.459	0.673
80	0.432	0.631
90	0.409	0.596
100	0.389	0.567
125	0.350	0.508
150	0.321	0.464
175	0.298	0.430
200	0.280	0.403
250	0.251	0.360
300	0.230	0.329
350	0.213	0.305
400	0.200	0.285
450	0.188	0.269
500	0.179	0.255

[1]This table has been adapted from Table A6 on page 552 of Snedecor and Cochran (1967).

[2]Significance levels are for a one-tailed test. For a two-tailed test, the significance levels become .10 instead of .05 and .02 instead of .01.

A normal distribution will have a kurtosis of 0. If the kurtosis is positive then the distribution is more peaked (narrow) than would be true for a normal distribution, while a negative value means that it is flatter. Table A-6, adapted from Snedecor and Cochran (1967), can also be used to test whether an obtained kurtosis value is significantly different from 0 (*i.e.* whether the distribution deviates from normality). To test kurtosis, simply enter Table A-6 with the appropriate sample size and the desired level of significance. An obtained negative kurtosis value is significantly different from 0 if it is less than the tabled negative kurtosis value. An obtained positive kurtosis is significantly different from 0 if it exceeds the tabled positive kurtosis value.

The confidence intervals presented in Table A-10 are 95% empirical confidence intervals (95% EMPIR CI). The empirical confidence intervals were determined as follows. The distribution of values for a variable was inspected and the largest value not exceeding more than 2.5% of the distribution was selected as the lower limit of the 95% confidence interval. The smallest value exceeded by 2.5% or less of the distribution was selected as the upper limit of the 95% confidence interval. When there were fewer than 40 data cases in the distribution, the 95% empirical confidence interval (as here defined) was identical to the range of values. When there were 40 or more data cases, the range and empirical confidence interval need not necessarily coincide.

The confidence interval usually reported is a theoretical confidence interval based on the assumption of an underlying normal distribution. The 95% normal distribution confidence interval (95% NORMAL CI) is given by the following expression:

$$95\% \text{ NORMAL CI} = \overline{X} \pm 1.96 \text{ (STD DEV)}.$$

TABLE A-6

TABLE OF CRITICAL VALUES FOR TESTING KURTOSIS[1]

Size of Sample N	Level of Significance 0.05 Negative Kurtosis	0.05 Positive Kurtosis	0.01 Negative Kurtosis	0.01 Positive Kurtosis
50	-0.85	0.99	-1.05	1.88
75	-0.73	0.87	-0.92	1.59
100	-0.65	0.77	-0.82	1.39
125	-0.60	0.71	-0.76	1.24
150	-0.55	0.65	-0.71	1.13
200	-0.49	0.57	-0.63	0.98
250	-0.45	0.52	-0.58	0.87
300	-0.41	0.47	-0.54	0.79
350	-0.38	0.44	-0.50	0.72
400	-0.36	0.41	-0.48	0.67
450	-0.34	0.39	-0.45	0.63
500	-0.33	0.37	-0.43	0.60

[1]This table has been adapted from Table A6 on page 552 of Snedecor and Cochran (1967).

Two considerations led us to report empirical confidence intervals rather than normal distribution confidence intervals. First, the normal distribution confidence interval can be easily computed given the mean and standard deviation. In this report, reporting the normal distribution confidence interval is redundant to reporting the mean and standard deviation. In contrast an empirical confidence interval cannot be determined from distributional characteristics (such as the mean and standard deviation). Rather, an empirical confidence interval must be determined from the actual frequency distribution of the data cases. Second, the normal distribution confidence interval is valid only if the distribution is approximately normal. The distribution for many of the variables presented in Table A-10 are far from normal. It would therefore have been misleading to report normal curve confidence intervals for all variables.

Consider an example where both types of confidence interval have been determined for a variable with a non-normal distribution. Figure A-2 presents the frequency distribution and the overall distribution statistics for the pristane and phytane ratio in sediments. Note that the distribution is skewed to the right (SKEW = 2.336) and is more peaked than a normal distribution (KURT = 6.869). The skewness and kurtosis values differ from 0 at the 0.01 level of significance (Tables A-5 and A-6). Both the empirical and normal distribution confidence intervals have been drawn above the frequency distribution. Note that the two confidence intervals are quite different. Problems with the normal distribution confidence interval can readily be seen. The lower bound is -1.5, an impossible value for the pristane by phytane ratio. The upper bound of 6.6 is exceeded by almost 6% of the data values and this upper bound probably severely underestimates the true value for the underlying

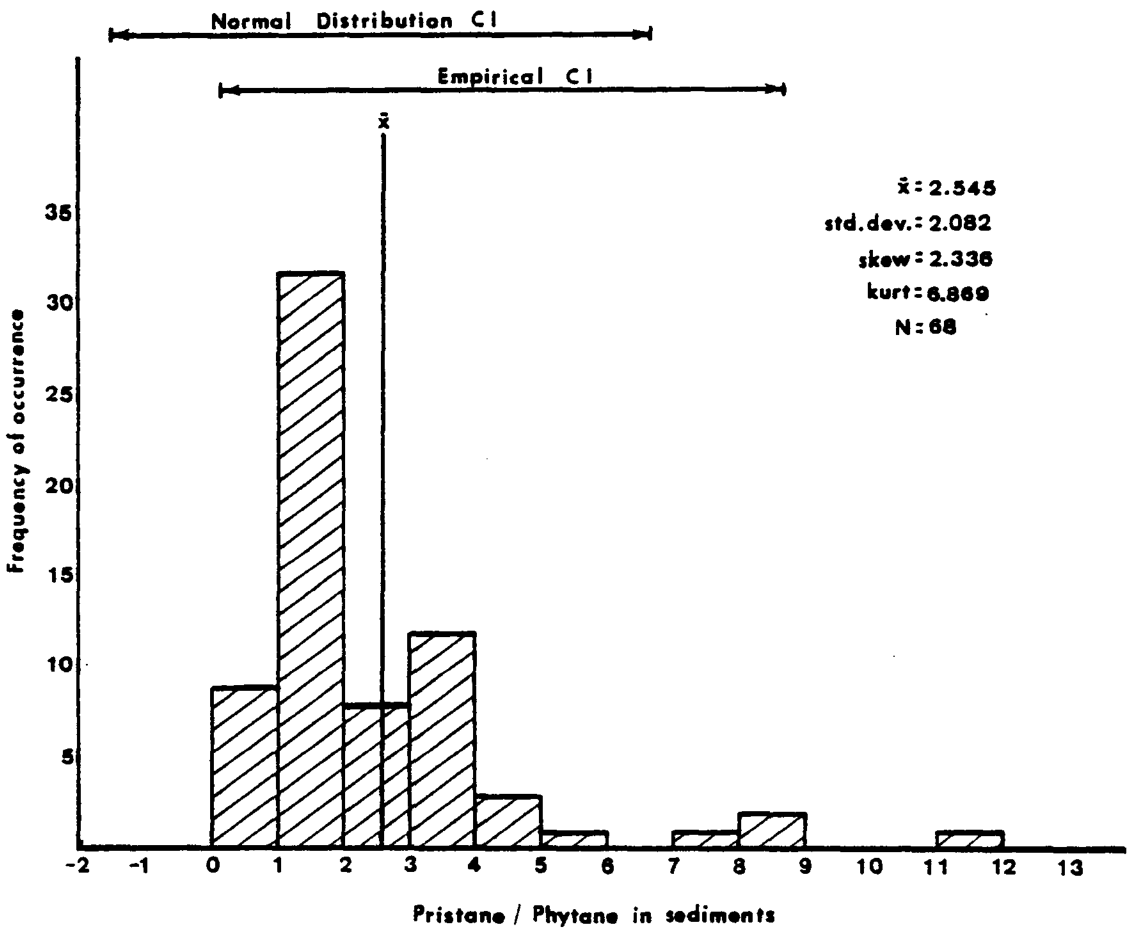

Figure A-2. Example comparison of empirical and normal curve confidence intervals.

population of values.

While empirical confidence intervals are generally applicable they should be interpreted with some caution. The empirical confidence interval is most greatly influenced by the extreme values in a distribution. Extreme values are most subject to sampling error, and therefore the empirical confidence interval can be greatly influenced by sampling error. In contrast, the normal distribution confidence interval will be less of a function of sampling error since it is not so dependent upon the extreme and most errorful values in a distribution.

All of these considerations about confidence intervals suggest the following recommendations for a user of Table A-10. Inspect the skewness and kurtosis values for a parameter. If neither are significantly different from 0, then assume that the distribution is normal. The normal distribution confidence interval should then be calculated and used to best describe that variable. If either skewness or kurtosis is significantly different from 0, then assume that the distribution is not normal. In this case, the empirical confidence interval should best describe that variable.

Analysis of Spatial and Temporal Effects

Each variable in Table A-10 was analyzed with regard to temporal and spatial variation. The analysis procedures employed were more complicated than one might anticipate. The complexity arose for two types of reasons. First, from a statistical point of view, several aspects of the design of the STOCS study were quite haphazard. The purpose of the study evolved from year to year with corresponding design changes occurring from year to year. Replicate samples (a series of samples taken for each collection period and site combination) were taken inconsistently, thereby precluding use of the most straight forward statistical designs. Missing data further aggravated our problems. Second, time constraints ruled out the use of different analysis approaches for different variables. It was necessary to arrive at an automated system which could uniformly be applied to all variables. Such a uniform approach further sacrificed analytic simplicity.

The temporal effects analyzed were collection period and year while the spatial effects analyzed were station and transect. For many variables replicate samples (different samples taken at the same time, collection period and year) were not taken consistently and were therefore scattered over the different sampling sites and times. To allow a uniform approach to all variables, data from replicate samples were averaged to arrive at a single mean data case for each site-period-year combination. These mean values were then analyzed for temporal and spatial variation.

For study elements involving body burdens, desired samples were often not obtained due to failure to catch the species in question. For other study elements (*e.g.* high-molecular-weight hydrocarbons in sediment), the contracted samples involved one set of sites during one collection period but a different set of sites during other collection periods. Thus, for several variables the data were scattered over the range of possible data cases. Even when samples were obtained, it was often the case that particular variables were uncalculable or unmeasurable. For example, variables involving hydrocarbon ratios (*e.g.* pristane/phytane) were uncalculable if the concentration in the denominator was 0. Trace metal concentrations were sometimes unmeasurable due to detection limit problems.

When data cases were scattered over the possible collection sites and times or when there were missing data for some data cases, analyses for temporal and spatial variation involved unbalanced data (*i.e.* unequal cell frequencies). Standard analysis of variance (ANOVA) calculation techniques (involving simple comparison of means) are not useful with unbalanced data. When data are unbalanced, all effects (both main effects and interactions) are confounded (Kerlinger and Pedhazur, 1973; Rao, 1965; Searle, 1971). Consider the following example:

Design 1

		Season 1	Season 2
Transect	I	10	10
	II	10	10

Design 2

		Season 1	Season 2
Transect	I	2	10
	II	8	10

Numbers within the cells are numbers of data cases. Design 1 involves balanced data (equal cell frequencies) while Design 2 involves unbalanced data (unequal cell frequencies). The standard ANOVA technique for assessing the season effect in such designs involves comparisons of the mean value for Season 1 with the mean value for Season 2. For Design 1, the Season 1 mean involves data cases which are equally divided between Transect I and II, and the same is true for the Season 2 mean. Therefore, the difference between the Season 1 mean and the Season 2 mean is balanced with regard to transect. In Design 1, effects are unconfounded, and the standard ANOVA procedure of comparing row means and comparing column means is appropriate. For Design 2, the Season 1 mean involves data cases from Transect I 20% of the time and data cases from Transect II 80% of the time. The Season 2 mean for this design involves equal numbers of Transect I and Transect II data cases. If transect does indeed have an effect, then this differential effect due to the two transects will produce a difference between the Season 1 mean and the Season 2 mean, regardless of whether the two seasons have differential effects or not. In Design 2, all the effects (transect, season, and transect by season interaction) are confounded and standard ANOVA procedures are not valid.

Multiple linear regression analysis is the technique suggested for analysis of unbalanced data (Kerlinger and Pedhazur, 1973; Rao, 1965; Searle, 1971). For the present data, multiple linear regression analysis was used to assess the effect of a factor with all other factors in the design covaried (statistically controlled). For example, for a two-way analysis involving transect and season, the transect effect was assessed with the season effect and the transect by season interaction covaried, the season effect was assessed with the transect effect and the transect by season interaction covaried, and the transect by season interaction was assessed with the transect effect and the season effect covaried. All regression analyses were calculated by using the "Regression Option" of subprogram ANOVA from the Statistical Package for the Social Sciences (Nie *et al.*, 1975).

Regression analysis with covaried effects was applied to all the variables reported in Table A-10 whether the data for those variables were balanced or unbalanced. Such a uniform approach to all data was quite satisfactory. For variables with unbalanced data, regression analysis with covaried effects was necessary for meaningful interpretation of results. For variables with balanced data, regression analysis with covaried effects produced exactly the same results and conclusions as standard ANOVA procedures would have (Searle, 1971).

For most variables, there was an insufficient number of data cases to attempt a full four factor design simultaneously incorporating all four effects of interest (transect, station group, collection period, and year). To allow a uniform approach to all parameters, a series of two factor analyses were performed for each variable. Table A-7 presents the two factor analyses performed for those variables sampled according to the 12 station scheme, for those sampled according to the 25 station scheme, and for those sampled according to the 2 station scheme. For the 12 station scheme, all possible two factor analyses were performed. For the 25 station scheme, 5 of the 6 possible two factor analyses were performed. The transect by station analysis was not attempted for the 25 station sampling scheme. A glance at Table A-4 will demonstrate the difficulty in performing a transect by station analysis for the 25 station sampling scheme. The transects are haphazardly represented in the first three station depth groups. Note that there is no easy redefinition of these three station groups which would yield groups containing an equal number of representatives from each transect. Given this situation, the results of a transect by station analysis would have been quite difficult to interpret. For the two station sampling period, only three two-factor analyses were performed. For the two station scheme, there was only one spatial effect (transect). This one spatial effect with the two temporal effects (period and year) produced three possible two-factor analyses.

Note that a significance level of $P \leq 0.05$ was employed in all analyses for spatial and temporal effects. The following procedure was employed in order to lessen the probability of accepting a chance-produced significant result as a valid result. The overall F ratio for each two-factor analysis was examined. These overall F's are analogous to the overall between-groups F's in standard ANOVA; they provide a single test of all effects (main effects and interaction) pooled together. If the overall F for a specific two-factor analysis was not significant ($P \leq 0.05$ level), then the entire set of results for that analysis was

TABLE A-7

TWO FACTOR ANALYSES STRATEGY PERFORMED FOR VARIABLES SAMPLED ACCORDING TO DIFFERENT SAMPLING SCHEMES

Sampling Scheme	Analyses Performed
12 station scheme	Transect (I-IV) by Station Group (1-3)
	Transect (I-IV) by Period (1-9)
	Transect (I-IV) by Year (1975-1977)
	Station Group (1-3) by Period (1-9)
	Station Group (1-3) by Year (1975-1977)
	Period (1-9) by Year (1975-1977)
25 station scheme	Transect (I-IV) by Period (1-9)
	Transect (I-IV) by Year (1976-1977)
	Station Group (1-6) by Period (1-9)
	Station Group (1-6) by Year (1976-1977)
	Period (1-9) by Year (1976-1977)
2 station scheme	Transect (HR - SB) by Period (1-9)
	Transect (HR - SB) by Year (1976-1977)
	Period (1-9) by Year (1976-1977)

discarded as chance produced. If the overall F was significant, then significant main effects from that analysis were accepted as valid significant results. In other words, a significant main effect was accepted as valid only if the corresponding overall F was also significant.

The entire set of two-factor analyses for a given variable was then inspected. Only if a given effect (*e.g.* year) was significant in every two-factor analyses involving that effect, was that effect accepted as a clear source of significant variation. For example, consider a variable collected under the 12 station sampling scheme. Six two-factor analyses would be involved in this case and the year effect would be analyzed in three of the six analyses. If year were found to be significant in each of the three analyses, then year would be accepted as clearly significant. That is, year is significant when period is covaried, when station is covaried and when transect is covaried. If year were found to be significant in only one or two of the three analyses, then the picture is unclear. The significant year effects in one or two of the analyses do indicate significant variation, but clear identification of the source of this significant variation is not possible due to confounded effects.

If a main effect was accepted as being clearly significant for a particular variable, then all interactions involving that main effect were inspected for significance. A significant interaction involving a main effect indicated that the main effect may not be general. For example, consider a case where the main effect of station is significant and the station by transect interaction is also significant. The significant station main effect indicates that stations differ on the average. The significant station by transect interaction indicates that the difference among stations varies for the different transects. It is quite possible that stations are different on Transects I and II but not on Transects III and IV. That is, the station effect may not be general with regard to transect. Because of such possibilities, significant main effects have been reported in Table A-10 only when there were no significant interactions involving those main effects.

A few comments are necessary concerning these procedures for selection of spatial and temporal effects. For some variables, a limited number of data cases resulted in two-factor designs with empty cells. In these cases it was impossible to evaluate the two-way interaction. Also, for some trace metal body burden variables, data were not available for an entire spatial category (*e.g.* Transect II or Station Group 3) or any entire temporal category (*e.g.* spring). In such cases, these categories were omitted from analysis.

In summary a spatial or temporal result was included in Table A-10 only if the answer to all of the following questions was yes.

1) Is the overall F significant for every two-factor analysis involving the main effect in question?
2) Is the main effect significant in each of the relevant two-factor analyses?
3) Are the interactions involving the main effect all insignificant?

This procedure for selecting the temporal and spatial results for inclusion in Table A-10 served to limit the reported effects to those which were clear, general, and had the least probability of being chance produced.

Comparison of the Present Baseline Results to Future Monitoring Results

The t-test presents a simple method for comparing the present baseline results to the results obtained in future monitoring. Given a mean and standard deviation from the present baseline results and a mean and standard deviation from future monitoring, a t value can be computed as follows.

$$\underline{t} = \frac{\overline{X}_M - \overline{X}_B}{\text{STD ERR}} \qquad [1]$$

In expression [1], $\overline{X}_M$ indicates the mean value for future monitoring; $\overline{X}_B$ indicates the mean baseline value; and STD ERR indicates the appropriate standard error. The standard error in expression [1] is the standard error of the difference between the two means and this standard error is given as follows.

$$\text{STD ERR} = \left[\left(\frac{SS_B + SS_M}{N_B + N_M - 2}\right)\left(\frac{1}{N_B} + \frac{1}{N_M}\right)\right]^{\frac{1}{2}} \qquad [2]$$

The terms in expression [2] are as follows: SS_B indicates the sum of squares for the baseline results; SS_M indicates the sum of squares for the monitoring results; N_B indicates the number of data cases for the baseline results; and N_M indicates the number of data cases for the monitoring results. The monitoring sum of squares is defined as follows.

$$SS_M = \sum_{i=1}^{N_M} (\overline{X}_{M_i} - \overline{X}_M)^2$$

The baseline sum of squares can be obtained from the standard deviation (STD DEV) in Table A-10 as follows.

$$SS_B = (\text{STD DEV})(N_B - 1)$$

The t value in expression [1] is associated with a number of degrees of freedom (df) equal to $N_B + N_M - 2$. The significance of an obtained t can then be determined by reference to a t-table with the obtained t value and the degree of freedom. For convenience, a t-table has been reproduced here as Table A-8.

Comparison of baseline and monitoring results is quite straightforward when the baseline results (Table A-10) do not include significant temporal and/or spatial variation. In this case, the t-test can be based upon the overall monitoring results. When the baseline results for a variable indicate significant temporal and/or spatial differences, then determination of baseline vs. monitoring differences is more complicated. If there is significant baseline variation due to collection period (*i.e.* month or season), then baseline vs. monitoring comparisons should be performed separately for each collection period involved. If there is significant baseline variation due to collection site (*i.e.* station depth, group or transect), then separate comparisons should be made for each relevant spatial category.

Determination of the Number of Samples Needed in Future Monitoring

Suppose one wishes to determine if the value for a variable has changed significantly from the baseline value. How many monitoring samples (data cases) would be required? This "number of samples" issue falls within the realm of statistical power analysis. The power of a statistical test is the probability that it will yield significant results when a difference actually exists in nature. That is, statistical power is the probability of detecting a population difference in a statistical

TABLE A-8

THE DISTRIBUTION OF t (2-Tailed Test)*

Degrees of Freedom	Probability of a Larger Value, Sign Ignored								
	0.500	0.400	0.200	0.100	0.050	0.025	0.010	0.005	0.001
1	1.000	1.376	3.078	6.314	12.706	25.452	63.657		
2	0.816	1.061	1.886	2.920	4.303	6.205	9.925	14.089	31.598
3	.765	0.978	1.638	2.353	3.182	4.176	5.841	7.453	12.941
4	.741	.941	1.533	2.132	2.776	3.495	4.604	5.598	8.610
5	.727	.920	1.476	2.015	2.571	3.163	4.032	4.773	6.859
6	.718	.906	1.440	1.943	2.447	2.969	3.707	4.317	5.959
7	.711	.896	1.415	1.895	2.365	2.841	3.499	4.029	5.405
8	.706	.889	1.397	1.860	2.306	2.752	3.355	3.832	5.041
9	.703	.883	1.383	1.833	2.262	2.685	3.250	3.690	4.781
10	.700	.879	1.372	1.812	2.228	2.634	3.169	3.581	4.587
11	.697	.876	1.363	1.796	2.201	2.593	3.106	3.497	4.437
12	.695	.873	1.356	1.782	2.179	2.560	3.055	3.428	4.318
13	.694	.870	1.350	1.771	2.160	2.533	3.012	3.372	4.221
14	.692	.868	1.345	1.761	2.145	2.510	2.977	3.326	4.140
15	.691	.866	1.341	1.753	2.131	2.490	2.947	3.286	4.073
16	.690	.865	1.337	1.746	2.120	2.473	2.921	3.252	4.015
17	.689	.863	1.333	1.740	2.110	2.458	2.898	3.222	3.965
18	.688	.862	1.330	1.734	2.101	2.445	2.878	3.197	3.922
19	.688	.861	1.328	1.729	2.093	2.433	2.861	3.174	3.883
20	.687	.860	1.325	1.725	2.086	2.423	2.845	3.153	3.850
21	.686	.859	1.323	1.721	2.080	2.414	2.831	3.135	3.819
22	.686	.858	1.321	1.717	2.074	2.406	2.819	3.119	3.792
23	.685	.858	1.319	1.714	2.069	2.398	2.807	3.104	3.767
24	.685	.857	1.318	1.711	2.064	2.391	2.797	3.090	3.745
25	.684	.856	1.316	1.708	2.060	2.385	2.787	3.078	3.725
26	.684	.856	1.315	1.706	2.056	2.379	2.779	3.067	3.707
27	.684	.855	1.314	1.703	2.052	2.373	2.771	3.056	3.690
28	.683	.855	1.313	1.701	2.048	2.368	2.763	3.047	3.674
29	.683	.854	1.311	1.699	2.045	2.364	2.756	3.038	3.659
30	.683	.854	1.310	1.697	2.042	2.360	2.750	3.030	3.646
35	.682	.852	1.306	1.690	2.030	2.342	2.724	2.996	3.591
40	.681	.851	1.303	1.684	2.021	2.329	2.704	2.971	3.551
45	.680	.850	1.301	1.680	2.014	2.319	2.690	2.952	3.520
50	.680	.849	1.299	1.676	2.008	2.310	2.678	2.937	3.496
55	.679	.849	1.297	1.673	2.004	2.304	2.669	2.925	3.476
60	.679	.848	1.296	1.671	2.000	2.299	2.660	2.915	3.460
70	.678	.847	1.294	1.667	1.994	2.290	2.648	2.899	3.435
80	.678	.847	1.293	1.665	1.989	2.284	2.638	2.887	3.416
90	.678	.846	1.291	1.662	1.986	2.279	2.631	2.878	3.402
100	.677	.846	1.290	1.661	1.982	2.276	2.635	2.871	3.390
120	.677	.845	1.289	1.658	1.980	2.270	2.617	2.860	3.373
∞	.6745	.8416	1.2816	1.6448	1.9600	2.2414	2.5758	2.8070	3.2905

*Adapted from Snedecor and Cochran (1967, Table A-4, p 549).

analysis of samples drawn from that population. For the present purposes, we are concerned with the power of the t-test for means. The statistical power of the t-test is a complex function of the difference between the population means, the level of significance chosen, the sample size (number of data cases), and the measurement error.

Consider the basic formula for the t-test.

$$\underline{t} = \frac{\overline{X}_1 - \overline{X}_2}{SN^{-\frac{1}{2}}} \qquad [3]$$

In expression [3], $\overline{X}_1$ and $\overline{X}_2$ refer to the means of the two groups, S is the pooled within groups standard deviation, and N is the sample size (number of data cases per group). The obtained value of t is significant if it exceeds a tabled critical value. The power of the t-test will increase if the calculated value of t increases or if the critical value decreases. Increasing the significance level (*i.e.* from 0.05 to 0.10) will decrease the tabled critical value. Thus, the power of the t-test is a positive function of significance level.

Note in expression [3] that the obtained t value is positively related to the obtained mean difference ($\overline{X}_1 - \overline{X}_2$). The larger the difference in population means between the two groups, the larger the obtained mean difference will tend to be. Thus, the power of the t-test is a positive function of the population mean difference. The value of S in [3] is a positive function of measurement error. The obtained t in turn is inversely related to S. Therefore, the power of the t-test is a negative function of measurement error. The sample size (N) is directly related to the obtained t in expression [3]. The power of the t-test is therefore positively related to the sample size.

For present purposes, it will be convenient to define the effect size (EF) as follows.

$$EF = \frac{\overline{X}_1 - \overline{\overline{X}}}{S} - \frac{\overline{X}_2 - \overline{\overline{X}}}{S} . \qquad [4]$$

In expression [4], $\overline{\overline{X}}$ refers to the overall grand mean. The effect size in [4] is a measure of the standardized (normal deviate) difference between the two group means. The convenience of such an effect size is that it is independent of the specific units of measurement. Such an effect size can be used in constructing general tables which are applicable to any variable regardless of units of measurement. Expression [4] can be simplified as follows.

$$EF = \frac{\overline{X}_1 - \overline{X}_2}{S} . \qquad [5]$$

Expression [5] can then be substituted into expression [3] yielding:

$$\underline{t} = (EF)(N)^{\frac{1}{2}} . \qquad [6]$$

Note in expression [6] that the obtained t-value is a positive function of the effect size. Thus, the power of the t-test is a positive function of effect size.

Sufficient background has been provided to now consider a table of sample sizes based upon statistical power. Table A-9 presents the sample sizes required to obtain a significant difference with a given probability (power) for a given effect size (EF). To use Table A-9, one must choose a desired effect size, power, and level of significance. The level of

TABLE A-9

SAMPLE SIZE TO DETECT EFFECT SIZE (EF) AT A GIVEN LEVEL OF POWER AND A GIVEN LEVEL OF SIGNIFICANCE*

$a_1 = .01$ $(a_2 = .02)$**

	EF										
Power	.10	.20	.30	.40	.50	.60	.70	.80	1.00	1.20	1.40
.25	547	138	62	36	24	17	13	10	7	5	4
.50	1083	272	122	69	45	31	24	18	12	9	7
.60	1332	334	149	85	55	38	29	22	15	11	8
2/3	1552	382	170	97	62	44	33	25	17	12	9
.70	1627	408	182	103	66	47	35	27	18	13	10
.75	1803	452	202	114	74	52	38	30	20	14	11
.80	2009	503	224	127	82	57	42	33	22	15	12
.85	2263	567	253	143	92	64	48	37	24	17	13
.90	2605	652	290	164	105	74	55	42	27	20	15
.95	3155	790	352	198	128	89	60	51	33	23	18
.99	4330	1084	482	272	175	122	90	69	45	31	23

$a_1 = .05$ $(a_2 = .10)$

	EF										
Power	.10	.20	.30	.40	.50	.60	.70	.80	1.00	1.20	1.40
.25	189	48	21	12	8	6	5	4	3	2	2
.50	542	136	61	35	22	16	12	9	6	5	4
.60	721	181	81	46	30	21	15	12	8	6	5
2/3	862	216	96	55	35	25	18	14	9	7	5
.70	942	236	105	60	38	27	20	15	10	7	6
.75	1076	270	120	68	44	31	23	18	11	8	6
.80	1237	310	138	78	50	35	26	20	13	9	7
.85	1438	360	160	91	58	41	30	23	15	11	8
.90	1713	429	191	108	69	48	36	27	18	13	10
.95	2165	542	241	136	87	61	45	35	22	16	12
.99	3155	789	351	198	127	88	65	50	32	23	17

*Adapted from Cohen, 1969, Table 2.4.1, pp 52-53

**a_1 is the one-tailed level of significance; a_2 is the two-tailed level of significance

TABLE A-9 CONT.'D

a_1 = .10 (a_2 = .20)

Power	EF .10	.20	.30	.40	.50	.60	.70	.80	1.00	1.20	1.40
.25	74	19	9	5	3	3	2	2	2	2	2
.50	329	82	37	21	14	10	7	5	4	3	2
.60	471	118	53	30	19	14	10	8	5	4	3
2/3	586	147	65	37	24	17	12	10	6	4	3
.70	653	163	73	41	27	19	14	11	7	5	4
.75	766	192	85	48	31	22	16	13	8	6	4
.80	902	226	100	57	36	26	19	14	10	7	5
.85	1075	269	120	67	43	30	22	17	11	8	6
.90	1314	329	146	82	53	37	27	21	14	10	7
.95	1713	428	191	107	69	48	35	27	18	12	9
.99	2604	651	290	163	104	73	53	41	26	18	14

a_1 = .005 (a_2 = .01)

Power	EF .10	.20	.30	.40	.50	.60	.70	.80	1.00	1.20	1.40
.25	725	183	82	47	31	22	17	13	9	7	6
.50	1329	333	149	85	55	39	29	22	15	11	9
.60	1603	402	180	102	66	46	34	27	18	13	10
2/3	1810	454	203	115	74	52	39	30	20	14	11
.70	1924	482	215	122	79	55	41	32	21	15	12
.75	2108	528	236	134	86	60	45	35	23	17	13
.80	2338	586	259	148	95	67	49	38	25	18	14
.85	2611	654	292	165	106	74	55	43	28	20	15
.90	2978	746	332	188	120	84	62	48	31	22	17
.95	3564	892	398	224	144	101	74	57	37	26	20
.99	4808	1203	536	302	194	136	100	77	50	35	26

a_1 = .025 (a_2 = .05)

Power	EF .10	.20	.30	.40	.50	.60	.70	.80	1.00	1.20	1.40
.25	332	84	38	22	14	10	8	6	5	4	3
.50	769	193	86	49	32	22	17	13	9	7	5
.60	981	246	110	62	40	28	21	16	11	8	6
2/3	1144	287	128	73	47	33	24	19	12	9	7
.70	1235	310	138	78	50	35	26	20	13	10	7
.75	1389	348	155	88	57	40	29	23	15	11	8
.80	1571	393	175	99	64	45	33	26	17	12	9
.85	1797	450	201	113	73	51	38	29	19	14	10
.90	2102	526	234	132	85	59	44	34	22	16	12
.95	2600	651	290	163	105	73	54	42	27	19	14
.99	3675	920	409	231	148	103	76	58	38	27	20

significance is the probability of finding a difference by chance when one does not exist. Selection of significance level is straightforward and needs no discussion. Selection of effect size and power are more difficult and need to be considered in detail.

The effect size of interest in the present appendix is based upon a difference between known baseline results and the unknown results of future monitoring. For this case, expression [5] can be rewritten as follows.

$$EF = \left| \frac{\overline{X}_M - \overline{X}_B}{S_B} \right| \qquad [7]$$

In expression [7], $\overline{X}_M$ and $\overline{X}_B$ are the monitoring and baseline means, while S_B is the baseline standard deviation. Note that before monitoring S_B is the best guess as to the value of the pooled within groups standard deviation calculable after monitoring. Before monitoring, $\overline{X}_M$ is the only unknown value on the right side of expression [7]. If one can select a mean for monitoring ($\overline{X}_M$) which is a critical value to detect, then this value can be substituted into [7] thereby yielding the desired effect size for entry into Table A-9. For example, the $\overline{X}_M$ chosen may be the critical value of a trace metal beyond which this metal is toxic in the aquatic environment. Another choice of a critical value for the $\overline{X}_M$ may be one or two standard deviations below the $\overline{X}_B$ to use for example for benthos infaunal density or demersal fish density. One must then specify the level of confidence (power) for detecting a value as extreme as the critical value of $\overline{X}_M$. This level of confidence is the probability of finding a difference when one exists and usually is greater than 0.80. Entry into Table A-9 with this confidence level (power) and effect size will then yield the required sample size (number of data cases) in the body of the table.

Therefore, when selecting a sample size, the rule of thumb is to have a significance level as low as possible and a power as high as possible. The meeting of these two criteria, however, depends upon the economics of obtaining the information since by meeting the criteria you will dramatically increase your sample size.

Unfortunately, one difficulty remains in using the sample size value obtained from Table A-9. The sample size values in this table are for a t-test involving two groups of equal size. Construction of sample size tables allowing unequal group sizes involves too much additional complexity. The present sample size table can be adopted, however, to use with unequal group sizes in the manner suggested by Cohen (1969). For unequal sized groups, the same size values in Table A-9 should equal the harmonic mean of the two group sizes. The harmonic mean ($\overline{N}_h$) of the two group sizes (N_1 and N_2) is given by:

$$\overline{N}_h = \frac{2N_1N_2}{N_1 + N_2}$$

For our case involving baseline and monitoring results, this expression becomes:

$$\overline{N}_h = \frac{2N_B\ N_M}{N_B + N_M} \qquad [8]$$

Now $\overline{N}_h$ is the value from Table A-9 and N_B is the baseline sample size, a known value. Therefore, N_M is the only unknown in [8] and this expression can be solved for N_M with the following result.

$$N_M = \frac{\overline{N}_h \ N_B}{2N_B - \overline{N}_h} \qquad [9]$$

Expression [9] can then be used to estimate the required number of monitoring samples, given the value from Table A-9 ($\overline{N}_h$) and the known number of baseline data cases (N_B). One caution must be considered concerning the use of expression [9]. Note that the calculated value of N_M will be negative if the quantity, $2N_B-\overline{N}_h$, is less than zero. In this case, there is no possible value for N_M and there is no way to detect the chosen effect size with the desired power. The only solution is to decrease the effect size of interest and/or decrease the power desired. Such difficulties arise because the number of baseline data cases is fixed and this number imposes limits on the achievable level of power for a given effect size.

In conclusion, statistical power analysis affords a method for estimating the number of samples needed in future monitoring. While the methods are complex and require the user to make subjective judgements about effect size and confidence, they do provide guidelines to assist in monitoring planning. No viable alternative exists.

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INDEX OF VARIABLES FOR TABLE A-10*

INDEX CONT.'D

INDEX CONT.'D

INDEX CONT.'D

INDEX CONT.'D

INDEX CONT.'D

*The analytic methods used to determine the values for the variables presented in Table A-10 are detailed in Volume III.

PELAGIC NON-LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
HYDROGRAPHY (1976-1977)						
SECCHI DEPTH (meters)	15.93	9.59	0.47	-0.46	2.00 - 36.00	108
Station Group 1	6.83	5.10	1.49	1.77	2.00 - 21.00	24
Station Group 2	16.13	7.83	0.85	-0.03	5.00 - 34.00	24
Station Group 3	22.71	7.39	0.20	0.24	9.00 - 39.00	24
1976	18.42	9.24	0.05	-1.03	5.00 - 35.00	36
1977	12.03	8.60	1.06	1.28	2.00 - 39.00	36
NUTRIENTS (1976-1977)						
SILICATE (surface) (micromoles/liter)	2.32	1.68	1.66	3.46	0.16 - 6.80	108
Station Group 1	2.47	1.38	0.68	0.59	0.16 - 6.00	24
Station Group 2	2.07	1.25	0.92	-0.07	0.70 - 4.80	24
Station Group 3	1.43	0.66	0.32	-0.59	0.40 - 2.80	24

PELAGIC NON-LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
NUTRIENTS (cont.'d)						
PHOSPHATE (surface) (micromoles/liter)	0.19	0.16	0.93	-0.15	0.01 - 0.56	105
NITRATE (surface) (micromoles/liter)	0.29	0.51	4.98	29.94	0.05 - 1.90	108
DISSOLVED OXYGEN (surface) (milliliters/liter)	5.10	0.53	1.15	1.33	4.26 - 6.36	108
LOW-MOLECULAR-WEIGHT HYDROCARBONS						
DISSOLVED (1975-1977)						
METHANE (surface) (nannoliters/liter)	89.47	64.96	4.33	25.30	41.00 - 275.00	144
Winter	106.86	77.73	2.12	4.27	40.00 - 377.00	36
Spring	73.14	41.63	3.03	11.28	37.00 - 260.00	36
Fall	81.28	36.20	2.70	9.86	45.00 - 240.00	36
1975	78.11	36.17	2.83	10.93	37.00 - 240.00	36
1976	68.42	24.79	1.89	4.08	41.00 - 157.00	36

PELAGIC NON-LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
LOW-MOLECULAR-WEIGHT HYDROCARBONS (cont.'d)						
1977	114.75	81.07	1.77	2.69	44.0 - 377.0	36
ETHENE (surface) (nannoliters/liter)	7.08	7.46	3.64	17.99	1.5 - 25.3	144
Winter	3.33	1.65	0.67	0.01	0.2 - 7.5	36
Spring	10.62	11.87	2.60	7.31	2.3 - 58.3	36
Fall	9.50	5.50	0.96	0.46	2.9 - 25.0	36
1975	12.02	12.06	2.18	5.53	1.5 - 58.3	36
1976	7.27	4.99	0.77	-0.27	0.2 - 19.1	36
1977	4.15	1.72	1.64	3.51	1.9 - 10.0	36
ETHANE (surface) (nannoliters/liter)	0.56	0.51	2.56	8.92	0.1 - 1.8	130
Winter	0.95	0.74	1.54	2.83	0.1 - 3.5	35
Spring	0.34	0.07	0.73	1.04	0.2 - 0.5	23
Fall	0.39	0.36	1.91	3.59	0.1 - 1.6	36

PELAGIC NON-LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
LOW-MOLECULAR-WEIGHT HYDROCARBONS (cont.'d)						
1975	1.13	0.90	0.52	0.35	0.1 - 3.5	24
1976	0.35	0.14	1.07	1.41	0.1 - 0.7	35
1977	0.44	0.20	0.52	-0.30	0.1 - 0.9	35
PROPENE (surface) (nannoliters/liter)	1.43	0.88	2.02	5.77	0.4 - 4.3	141
Station 1	1.74	1.15	1.99	3.75	0.5 - 5.7	36
Station 2	1.41	0.80	1.47	3.26	0.5 - 4.2	35
Station 3	1.31	0.85	1.85	5.72	0.2 - 4.6	34
Winter	0.83	0.41	0.84	-0.04	0.2 - 1.8	35
Spring	1.87	1.06	2.22	5.06	0.9 - 5.7	36
Fall	1.77	0.91	1.66	2.45	0.8 - 4.4	34
1975	2.14	1.39	0.74	-0.05	0.2 - 5.7	33
1976	1.35	0.42	-0.71	-0.46	0.4 - 1.9	36
1977	1.03	0.38	0.24	-0.04	0.4 - 2.0	36

PELAGIC NON-LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
LOW-MOLECULAR-WEIGHT HYDROCARBONS (cont.'d)						
PROPANE (surface) (nannoliters/liter)	0.72	0.80	2.90	8.80	0.1 - 3.2	138
Winter	0.83	0.73	2.97	11.22	0.3 - 4.1	35
Spring	0.47	0.26	1.52	3.07	0.1 - 1.3	32
Fall	1.14	1.26	1.38	0.73	0.2 - 4.7	35
1975	1.73	1.23	0.74	-0.07	0.1 - 4.7	31
1976	0.42	0.12	1.32	3.27	0.2 - 0.8	36
1977	0.43	0.13	0.24	0.05	0.2 - 0.7	35
NUTRIENTS (1976-1977)						
SILICATE (half-photic zone) (micromoles/liter)	2.18	1.60	1.71	3.36	0.15 - 6.80	108
Station Group 1	2.50	1.42	0.73	0.74	0.15 - 6.20	24
Station Group 2	1.85	0.85	0.32	-0.96	0.70 - 3.40	24
Station Group 3	1.27	0.58	0.90	0.12	0.50 - 2.60	24

PELAGIC NON-LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
NUTRIENTS (cont.'d)						
Winter	1.85	1.08	0.81	0.30	0.15 - 4.50	24
Spring	1.37	0.59	0.66	-0.94	0.80 - 2.50	24
Fall	2.40	1.33	0.99	1.74	0.50 - 6.20	24
PHOSPHATE (half-photic zone) (micromoles/liter)	0.17	0.19	2.32	8.03	0.01 - 0.67	107
NITRATE (half-photic zone) (micromoles/liter)	0.24	0.46	5.50	34.46	0.05 - 1.80	108
DISSOLVED OXYGEN (half-photic zone) (milliliters/liter)	5.10	0.46	1.47	2.82	4.47 - 6.35	96
LOW-MOLECULAR-WEIGHT HYDROCARBONS						
DISSOLVED (1975-1977)						
METHANE (half photic zone) (nannoliters/liter)	155.56	473.90	8.44	75.52	42.00 - 393.00	114
ETHENE (half photic zone) (nannoliters/liter)	6.16	4.86	2.46	7.40	1.70 - 22.20	107

PELAGIC NON-LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
LOW-MOLECULAR-WEIGHT HYDROCARBONS (cont.'d)						
Winter	3.65	2.09	2.74	10.02	1.3 - 11.8	24
Spring	7.10	4.53	1.47	2.17	1.7 - 22.2	36
Fall	8.24	7.23	1.95	3.38	2.3 - 30.0	24
1975	8.98	6.85	1.43	1.75	1.3 - 30.0	36
1976	5.86	2.90	0.42	-1.15	1.7 - 11.0	12
1977	4.10	1.93	1.94	4.93	1.9 - 11.0	36
ETHANE (half photic zone) (nannoliters/liter)	0.72	0.61	1.43	1.70	0.1 - 2.2	80
Winter	1.17	0.62	1.04	1.50	0.5 - 3.0	24
Spring	0.44	0.18	0.99	0.00	0.2 - 0.8	12
Fall	0.55	0.67	1.79	2.00	0.1 - 2.2	24
PROPENE (half photic zone) (nannoliters/liter)	1.30	0.89	1.80	3.79	0.2 - 3.7	89
PROPANE (half photic zone) (nannoliters/liter)	0.98	1.08	1.89	2.72	0.01 - 4.0	88

PELAGIC NON-LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
LOW-MOLECULAR-WEIGHT HYDROCARBONS (cont.'d)						
Winter	1.08	0.93	2.81	9.96	0.4 - 4.7	24
Spring	0.49	0.31	0.88	1.35	0.01 - 1.3	21
Fall	1.77	1.51	0.31	-1.66	0.2 - 4.2	24
HIGH-MOLECULAR-WEIGHT HYDROCARBONS						
DISSOLVED (1975-1977)						
TOTAL HYDROCARBONS ($n-C_{14}$ to $n-C_{32}$) (micrograms/gram)	0.22	0.53	7.82	72.75	0.00 - 0.91	125
PRISTANE vs. PHYTANE	2.73	4.34	5.33	31.10	0.12 - 7.17	40
Winter	10.04	12.18	1.81	3.27	2.00 - 28.00	4
Spring	2.12	1.50	1.73	4.50	0.12 - 6.75	18
Fall	1.72	1.00	0.10	-0.97	0.31 - 3.50	14
PARTICULATE (1975-1977)						
TOTAL HYDROCARBONS ($n-C_{14}$ to $n-C_{32}$) (micrograms/gram)	0.18	0.36	3.34	10.80	0.00 - 1.61	103

PELAGIC NON-LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
HIGH-MOLECULAR-WEIGHT HYDROCARBONS (cont.'d)						
PHYTANE vs. n-C_{18}	0.83	2.21	5.75	34.88	0.03 - 2.41	40
1975	0.08	0.02	1.72	0.00	0.07 - 0.10	3
1976	0.18	0.13	1.26	0.54	0.03 - 0.45	17
1977	0.83	0.67	1.26	1.04	0.09 - 2.41	16
SUM MID (n-C_{19} to n-C_{24}) (relative percent)	22.91	21.71	1.30	0.80	0.00 - 75.80	101
Winter	32.80	19.60	0.02	-1.14	0.00 - 65.54	24
Spring	19.94	22.70	2.19	4.25	0.00 - 88.38	26
Fall	14.03	13.70	2.80	10.21	0.00 - 73.33	35
NUTRIENTS (1976-1977)						
SILICATE (bottom) (micromoles/liter)	3.70	2.06	0.61	-0.23	0.40 - 7.60	90
Station Group 1	2.24	1.58	0.63	-0.54	0.30 - 4.63	6
Station Group 2	3.63	2.10	0.30	-1.51	0.80 - 6.70	18

PELAGIC NON-LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
NUTRIENTS (cont.'d)						
Station Group 3	3.57	2.28	1.42	2.33	0.80 - 9.98	18
Station Group 4	3.66	2.25	0.98	1.26	1.33 - 7.54	6
Station Group 5	2.64	1.17	-0.26	-0.59	0.40 - 4.20	12
Station Group 6	5.48	1.72	0.15	-1.76	3.30 - 7.80	12
Transect I	4.00	2.26	-0.09	-1.07	0.30 - 7.60	18
Transect II	4.60	2.45	0.60	-0.58	1.60 - 9.98	18
Transect III	3.49	1.77	0.68	0.17	0.97 - 7.54	18
Transect IV	2.50	1.30	0.78	1.13	0.40 - 5.81	18
PHOSPHATE (bottom) (micromoles/liter)	0.48	0.62	4.40	26.30	0.03 - 1.88	89
Station Group 1	0.28	0.14	-0.11	-2.52	0.11 - 0.43	6
Station Group 2	0.38	0.30	2.17	6.09	0.03 - 1.34	17
Station Group 3	0.25	0.17	1.21	0.96	0.03 - 0.67	18
Station Group 4	0.23	0.12	0.57	-2.01	0.10 - 0.38	6
Station Group 5	0.30	0.31	2.36	6.55	0.02 - 1.19	12
Station Group 6	1.16	1.23	2.58	7.53	0.17 - 4.74	12

PELAGIC NON-LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
NUTRIENTS (cont.'d)						
NITRATE (bottom) (micromoles/liter)	3.64	5.48	1.75	2.01	0.10 - 17.10	81
DISSOLVED OXYGEN (bottom) (milliliters/liter)	4.43	0.95	-0.50	-0.78	2.58 - 5.86	90
Station Group 1	4.53	1.35	-0.99	-0.18	2.32 - 5.86	6
Station Group 2	4.75	0.82	-0.24	-0.66	3.06 - 6.00	18
Station Group 3	4.83	0.57	-0.14	-0.37	3.70 - 5.83	18
Station Group 4	4.71	0.52	0.12	-0.61	3.98 - 5.43	6
Station Group 5	4.21	0.91	-0.52	-0.81	2.58 - 5.37	12
Station Group 6	3.58	0.96	0.95	-0.07	2.66 - 5.61	12
Winter	4.98	1.00	-1.35	0.60	2.80 - 6.00	24
Spring	4.24	0.82	-0.84	0.01	2.32 - 5.43	24
Fall	4.17	0.75	-0.71	-0.02	2.58 - 5.47	24
1976	4.16	1.01	-0.36	-1.25	2.32 - 5.71	36
1977	4.76	0.73	-0.05	-1.00	3.37 - 6.00	36

PELAGIC NON-LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
LOW-MOLECULAR-WEIGHT HYDROCARBONS						
DISSOLVED (1975-1977)						
METHANE (bottom) (nannoliters/liter)	190.40	150.89	1.87	3.85	45.0 - 589.0	88
ETHENE (bottom) (nannoliters/liter)	3.25	2.63	2.98	13.63	0.1 - 10.5	89
Station Group 1	4.36	2.33	1.05	-0.73	2.4 - 8.1	6
Station Group 2	4.19	2.29	2.41	7.01	1.9 - 11.8	18
Station Group 3	4.49	4.11	2.77	8.53	0.7 - 18.6	18
Station Group 4	3.61	1.11	1.06	2.86	2.2 - 5.6	6
Station Group 5	2.58	1.53	1.72	3.17	1.0 - 6.5	12
Station Group 6	1.09	0.51	-0.07	-0.18	0.1 - 1.9	12
Winter	2.12	1.04	0.08	-0.48	0.1 - 4.0	24
Spring	3.21	1.29	0.08	0.79	0.7 - 6.4	24
Fall	5.01	4.08	1.89	4.38	0.8 - 18.6	24

PELAGIC NON-LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
LOW-MOLECULAR-WEIGHT HYDROCARBONS (cont.'d)						
ETHANE (bottom) (nannoliters/liter)	0.54	0.25	1.26	3.11	0.1 - 1.0	89
PROPENE (bottom) (nannoliters/liter)	0.65	0.35	0.84	-0.15	0.2 - 1.5	88
Station Group 1	1.16	0.38	-0.93	-0.28	0.6 - 1.5	6
Station Group 2	1.01	0.30	-0.17	-0.78	0.5 - 1.5	18
Station Group 3	0.62	0.18	0.46	0.26	0.3 - 1.0	17
Station Group 4	0.51	0.13	-0.48	-0.97	0.3 - 0.7	6
Station Group 5	0.48	0.13	1.61	3.09	0.3 - 0.8	12
Station Group 6	0.32	0.06	-0.64	-0.11	0.2 - 0.4	12
PROPANE (bottom) (nannoliters/liter)	0.52	0.17	1.40	2.71	0.3 - 1.0	88

PELAGIC LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
PHYTOPLANKTON (1976-1977)						
PHYTOPLANKTON SPECIES (surface) (number of species/liter)	28.94	15.94	0.69	0.04	5.00 - 67.00	107
PHYTOPLANKTON DENSITY (surface) (number of cells/liter)	83613.38	261934.61	6.63	50.57	400.00 - 963392.00	107
Chaetoceros spp. (surface) (cells/liter)	5283.28	20848.99	7.52	63.51	0.00 - 30200.00	107
Transect I	7147.24	10107.56	1.48	1.27	0.00 - 30200.00	17
Transect II	3052.33	6590.06	3.10	10.51	0.00 - 26720.00	18
Transect III	1157.39	2119.01	2.63	6.76	0.00 - 8017.00	18
Transect IV	1509.11	3583.39	2.73	6.62	0.00 - 127400.00	18
NANNO C^{14} (surface) (milligrams^{C}/m^{3}/hr)	3.20	3.33	1.25	1.28	0.00 - 11.71	51
NET C^{14} (surface) (milligrams^{C}/m^{3}/hr)	2.38	3.52	1.66	1.80	0.00 - 11.89	51

PELAGIC LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI		N
PHYTOPLANKTON (cont.'d)							
TOTAL C^{14} (surface) (milligrams^{C}/m^3/hr)	4.99	5.37	1.21	1.09	0.00 -	19.06	53
NANNO CHLOROPHYLL (surface) (micrograms/liter)	0.45	0.35	1.84	4.41	0.00 -	1.59	107
NET CHLOROPHYLL (surface) (micrograms/liter)	0.19	0.42	3.32	11.82	0.00 -	1.93	107
Station Group 1	0.33	0.37	1.58	1.81	0.00 -	1.26	24
Station Group 2	0.05	0.08	1.87	3.60	0.00 -	0.28	24
Station Group 3	0.04	0.12	3.10	8.44	0.00 -	0.41	23
TOTAL CHLOROPHYLL (surface) (micrograms/liter)	0.64	0.66	1.95	3.43	0.00 -	2.77	107
Winter	0.80	0.57	1.39	1.06	0.25 -	2.20	24
Spring	0.43	0.35	1.36	2.31	0.00 -	2.00	24
Fall	0.58	0.58	1.82	2.85	0.15 -	2.31	23

PELAGIC LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI		N
PHYTOPLANKTON (cont.'d)							
NANNO PHAEOPHYTIN (surface) (micrograms/liter)	1.20	0.34	-2.72	7.69	0.00 -	1.47	107
Station Group 1	1.35	0.15	2.55	9.29	1.18 -	1.93	24
Station Group 2	1.21	0.28	-3.80	16.63	0.00 -	1.42	24
Station Group 3	1.13	0.37	-2.76	7.09	0.00 -	1.44	23
Winter	1.31	0.09	-0.80	0.81	1.06 -	1.44	24
Spring	1.11	0.44	-2.27	3.77	0.00 -	1.45	24
Fall	1.26	0.19	2.14	6.80	1.06 -	1.93	23
1976	1.13	0.36	-2.72	6.72	0.00 -	1.44	36
1977	1.33	0.14	2.39	10.48	1.11 -	1.93	35
NET PHAEOPHYTIN (surface) (micrograms/liter)	0.66	0.75	0.29	-1.85	0.00 -	1.67	107
Station Group 1	1.20	0.65	-1.27	0.04	0.00 -	2.00	24
Station Group 2	0.66	0.74	0.25	-2.02	0.00 -	1.67	24
Station Group 3	0.20	0.54	2.36	3.89	0.00 -	1.60	23

PELAGIC LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
PHYTOPLANKTON (cont.'d)						
1976	0.37	0.66	1.35	0.05	0.00 - 2.00	36
1977	1.03	0.72	-0.76	-1.41	0.00 - 1.75	35
TOTAL PHAEOPHYTIN (surface) (micrograms/liter)	1.22	0.35	-2.67	7.27	0.00 - 1.52	107
1976	1.15	0.37	-2.61	6.29	0.00 - 1.47	36
1977	1.36	0.13	1.15	4.27	1.11 - 1.85	35
PHYTOPLANKTON SPECIES (half photic zone) (number of species/liter)	28.18	14.82	0.71	0.37	3.00 - 68.00	108
1976	34.67	13.81	0.70	0.18	13.00 - 73.00	36
1977	23.14	11.87	0.12	-0.78	2.00 - 45.00	36
PHYTOPLANKTON DENSITY (half photic zone) (cells/liter)	71671.67	177591.70	4.44	20.94	60.00 -478729.00	108
Winter	73766.33	102835.75	2.95	10.40	5660.00 -478729.00	24
Spring	19573.38	25451.93	3.42	13.46	2260.00 -125105.00	24
Fall	30797.75	82587.35	4.50	21.08	60.00 -407685.00	24

PELAGIC LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI		N
PHYTOPLANKTON (cont.'d)							
NANNO CHLOROPHYLL (half photic zone) (micrograms/liter)	0.46	0.38	2.07	6.52	0.00 -	1.51	108
NET CHLOROPHYLL (half photic zone) (micrograms/liter)	0.17	0.36	3.15	10.62	0.00 -	1.46	108
TOTAL CHLOROPHYLL (half photic zone) (micrograms/liter)	0.63	0.67	2.09	4.45	0.00 -	2.75	108
NANNO PHAEOPHYTIN (half photic zone) (micrograms/liter)	1.16	0.38	-2.54	5.17	0.00 -	1.46	108
NET PHAEOPHYTIN (half photic zone) (micrograms/liter)	0.65	0.77	0.42	-1.63	0.00 -	1.80	108
Station Group 1	1.14	0.68	-1.15	-0.62	0.00 -	1.67	24
Station Group 2	0.54	0.80	1.04	-0.40	0.00 -	2.50	24
Station Group 3	0.33	0.66	1.67	1.11	0.00 -	2.00	24
1976	0.33	0.63	1.42	0.07	0.00 -	1.60	36
1977	1.00	0.79	-0.34	-1.47	0.00 -	2.50	36

PELAGIC LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI		N
PHYTOPLANKTON (cont.'d)							
TOTAL PHAEOPHYTIN (half photic zone) (micrograms/liter)	1.20	0.36	-2.76	6.87	0.00 -	1.51	108
TOTAL CHLOROPHYLL (bottom) (micrograms/liter)	0.75	0.65	1.65	4.03	0.00 -	2.18	90
Station Group 1	1.29	0.73	-0.52	-1.38	0.23 -	2.12	6
Station Group 2	1.21	0.59	0.88	0.78	0.24 -	2.63	18
Station Group 3	0.70	0.35	0.33	-0.86	0.11 -	1.32	18
Station Group 4	0.62	0.24	0.84	0.74	0.38 -	1.02	6
Station Group 5	0.32	0.17	-0.10	0.12	0.00 -	0.58	12
Station Group 6	0.18	0.19	0.75	0.08	0.00 -	0.59	12
TOTAL PHAEOPHYTIN (bottom) (micrograms/liter)	1.19	0.39	-2.53	5.38	0.00 -	1.50	90
ZOOPLANKTON (1975-1977)							
COPEPOD SPECIES NUMBER (number of species/m^3)	41.03	20.47	0.57	-0.85	15.00 -	83.00	144

PELAGIC LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
ZOOPLANKTON (cont.'d)						
COPEPOD TOTAL DENSITY (number of individuals/m^3)	535.94	470.40	3.28	15.62	91.30 - 1768.10	144
Station Group 1	816.54	742.39	2.18	5.58	47.00 - 3594.10	36
Station Group 2	478.14	273.77	0.69	0.01	56.40 - 1230.10	36
Station Group 3	331.37	176.03	1.63	4.07	107.40 - 977.60	36
ICHTHYOPLANKTON DENSITY (number of larvae/1000 m^3)	2091.28	1741.02	1.33	1.92	75.00 - 6209.00	144
Winter	1000.29	1044.07	1.90	5.20	32.00 - 5056.50	36
Spring	2254.28	1694.90	0.99	-0.25	329.50 - 5975.00	36
Fall	2829.04	1804.82	1.34	2.82	361.00 - 8932.00	36
TOTAL ZOOPLANKTON BIOMASS (grams/m^3)	21.84	16.83	1.64	2.33	3.30 - 70.60	144
Farranula gracilis (individuals/m^3)	17.38	34.78	3.84	18.84	0.00 - 105.60	144
Station Group 1	4.94	21.49	5.87	34.87	0.00 - 129.40	36
Station Group 2	18.59	27.14	1.63	1.59	0.00 - 97.90	36
Station Group 3	22.52	42.78	4.48	23.32	0.00 - 248.70	36

PELAGIC LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI		N
ZOOPLANKTON (cont.'d)							
Winter	2.54	4.53	2.46	5.98	0.00 -	19.85	36
Spring	8.61	15.08	3.42	13.74	0.00 -	79.15	36
Fall	34.91	48.44	2.79	10.34	0.00 -	248.70	36
Clausocalanus jobei (individuals/m^3)	16.28	42.77	5.59	37.44	0.00 -	85.50	144
1975	5.81	15.63	3.59	13.30	0.00 -	76.05	36
1976	11.92	22.18	2.19	3.68	0.00 -	75.95	36
1977	40.09	76.31	3.13	10.16	0.00 -	342.55	36
Nannocalanus minor (individuals/m^3)	3.51	4.90	1.90	3.86	0.00 -	16.75	144
Station Group 1	1.16	2.67	3.00	9.49	0.00 -	12.30	36
Station Group 2	3.75	4.46	1.61	2.28	0.00 -	17.05	36
Station Group 3	5.73	6.40	1.54	2.08	0.00 -	26.15	36
Winter	5.39	5.55	1.15	0.56	0.00 -	20.60	36
Spring	2.37	3.12	1.76	2.72	0.00 -	12.30	36
Fall	2.88	5.73	2.74	7.95	0.00 -	26.15	36

PELAGIC LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI		N
ZOOPLANKTON (cont.'d)							
Oncaea mediterranea (individuals/m^3)	15.45	21.11	2.20	6.51	0.00 -	65.65	144
Station Group 1	1.88	3.88	3.31	13.23	0.00 -	19.90	36
Station Group 2	14.48	19.38	2.74	10.49	0.00 -	100.75	36
Station Group 3	32.48	25.70	1.62	3.81	1.55 -	121.90	36
Paracalanus aculeatus (individuals/m^3)	23.19	31.78	3.32	14.79	0.00 -	122.65	144
Winter	16.47	14.03	1.18	0.89	0.65 -	57.85	36
Spring	11.79	14.07	2.74	9.96	0.50 -	73.35	36
Fall	38.88	47.15	2.54	7.43	0.00 -	219.05	36
Temora turbinata (individuals/m^3)	34.59	86.90	5.18	31.26	0.00 -	316.00	144
Station Group 1	83.48	145.84	3.11	10.11	0.00 -	689.90	36
Station Group 2	20.33	34.74	3.35	12.17	0.00 -	172.45	36
Station Group 3	5.93	10.71	2.82	8.21	0.00 -	47.40	36
Paracalanus indicus (individuals/m^3)	81.44	157.24	3.32	12.92	0.00 -	634.50	144

PELAGIC LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
ZOOPLANKTON (cont.'d)						
Station Group 1	169.81	215.82	1.29	0.39	0.00 - 688.45	36
Station Group 2	55.83	54.07	0.91	-0.06	0.00 - 192.60	36
Station Group 3	14.60	34.37	5.03	27.67	0.15 - 203.35	36
Winter	124.55	149.73	2.09	4.99	0.80 - 674.25	36
Spring	85.54	160.64	2.67	6.60	0.00 - 688.45	36
Fall	30.14	105.48	5.68	33.28	0.00 - 634.50	36
Paracalanus quasimodo (individuals/m^3)	77.01	161.39	5.97	47.32	0.00 - 486.45	144
Station Group 1	137.13	139.48	1.20	0.76	0.00 - 490.35	36
Station Group 2	48.51	43.18	0.98	0.14	1.05 - 160.25	36
Station Group 3	11.64	20.84	3.58	13.15	0.00 - 102.30	36
Centropages velificatus (individuals/m^3)	13.83	34.66	4.63	22.85	0.00 - 150.65	144
Station Group 1	27.19	43.98	2.87	8.68	0.00 - 206.05	36
Station Group 2	17.94	49.21	3.88	14.28	0.00 - 220.50	36
Station Group 3	2.89	5.73	3.11	10.11	0.00 - 27.30	36

PELAGIC LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI		N
ZOOPLANKTON (cont.'d)							
TOTAL CALANOIDS (individuals/m^3)	607.18	667.47	3.60	18.24	61.20 -	2860.20	144
Station Group 1	1055.78	1050.89	2.42	6.60	55.85 -	5211.85	36
Station Group 2	534.76	343.48	0.90	0.51	61.20 -	1411.05	36
Station Group 3	258.78	189.90	2.43	7.72	67.75 -	1040.20	36
LARVACEA (individuals/m^3)	49.22	53.45	2.16	5.90	1.75 -	196.30	144
1975	23.25	23.45	2.34	7.52	1.20 -	119.65	36
1976	51.49	55.16	2.29	7.11	2.25 -	277.35	36
1977	45.69	40.83	1.30	1.63	2.05 -	176.35	36
TOTAL CLADOCERA (individuals/m^3)	28.84	70.35	4.30	23.51	0.00 -	232.45	144
Station Group 1	56.00	113.48	3.00	10.20	0.00 -	545.20	36
Station Group 2	27.58	60.33	2.57	5.94	0.00 -	249.85	36
Station Group 3	5.45	8.94	2.44	6.15	0.00 -	37.60	36

PELAGIC LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI		N
HIGH-MOLECULAR-WEIGHT HYDROCARBONS							
ZOOPLANKTON (1975-1977)							
TOTAL HYDROCARBONS ($n-C_{14}$ to $n-C_{32}$) (micrograms/gram)	134.94	422.68	9.21	93.12	0.58 -	436.59	124
PRISTANE vs. PHYTANE	351.40	753.79	4.51	24.16	2.66 -	101.69	84
PRISTANE vs. $n-C_{17}$	7.80	14.32	4.03	17.44	0.08 -	75.12	119
PHYTANE vs. $n-C_{18}$	1.06	5.02	8.03	67.94	0.01 -	3.10	85
(Pr + Ph)/n-ALKANES	2.30	5.18	6.86	56.68	0.05 -	9.91	121
SUM LOW ($n-C_{14}$ to $n-C_{18}$) (relative percent)	56.97	26.10	-0.15	-0.68	0.00 -	100.00	123

PELAGIC LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
HIGH-MOLECULAR-WEIGHT HYDROCARBONS (cont.'d)						
SUM MID ($n-C_{19}$ to $n-C_{24}$) (relative percent)	26.49	18.67	0.85	1.08	0.00 - 61.36	123
SUM HIGH ($n-C_{25}$ to $n-C_{32}$) (relative percent)	16.55	20.94	1.37	1.46	0.00 - 66.14	123
AVERAGE OEP ($n-C_{14}$ to $n-C_{32}$)	5.37	8.41	3.35	12.10	0.69 - 36.74	103
TRACE METALS						
ZOOPLANKTON (1976-1977)						
IRON (ppm dry weight)	2750.45	3716.53	1.99	3.68	27.3 - 13333.3	72
CALCIUM (ppm dry weight)	38044.09	20582.30	1.47	3.24	8200.0 - 90000.0	62
VANADIUM (ppm dry weight)	18.08	19.99	2.68	9.90	1.3 - 70.0	105

PELAGIC LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI		N
TRACE METALS (cont.'d)							
ZINC (ppm dry weight)	157.06	183.80	5.48	34.30	32.00 -	500.00	141
ALUMINUM (ppm dry weight)	5280.86	7319.55	1.90	3.00	90.00 -	29000.00	67
LEAD (ppm dry weight)	12.60	19.73	4.61	27.67	0.60 -	64.00	136
NICKEL (ppm dry weight)	7.03	5.35	2.85	12.11	2.00 -	20.00	144
COPPER (ppm dry weight)	26.34	95.09	11.12	128.73	5.50 -	75.00	143
CHROMIUM (ppm dry weight)	3.99	3.08	0.98	0.50	0.10 -	11.10	140
CADMIUM (ppm dry weight)	3.32	1.54	0.26	-0.62	0.80 -	6.50	144

BENTHIC NON-LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
SEDIMENT TEXTURE (1976-1977)						
SEDIMENT MEAN GRAIN SIZE (Ø units)	7.70	1.72	-0.75	-0.47	3.69 - 9.79	186
Station Group 1	4.85	0.96	0.27	-1.05	3.44 - 6.46	24
Station Group 2	6.79	1.63	-0.49	-1.55	4.38 - 8.69	18
Station Group 3	7.65	1.07	-0.25	-0.48	5.40 - 9.23	36
Station Group 4	8.12	1.44	-1.02	-0.17	4.97 - 10.08	24
Station Group 5	8.20	1.56	-0.82	-0.68	5.01 - 9.85	24
Station Group 6	9.47	0.26	-0.20	-0.74	8.98 - 9.95	24
Transect I	7.50	1.59	-0.23	-1.08	4.55 - 10.08	36
Transect II	8.32	0.94	0.04	-1.27	6.63 - 9.85	36
Transect III	8.23	1.87	-1.62	1.18	3.69 - 9.83	36
Transect IV	6.37	2.00	0.54	-0.98	3.44 - 9.78	42
SEDIMENT GRAIN SIZE STANDARD DEVIATION (Ø units)	3.26	0.43	-0.04	1.69	2.47 - 4.22	186
Station Group 1	3.09	0.61	-1.01	1.05	1.38 - 3.78	24
Station Group 2	3.44	0.24	1.26	1.02	3.14 - 4.00	18
Station Group 3	3.49	0.33	1.04	0.42	2.94 - 4.28	36

BENTHIC NON-LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
SEDIMENT TEXTURE (cont.'d)						
Station Group 4	3.37	0.49	0.80	-0.50	2.61 - 4.34	24
Station Group 5	3.28	0.49	0.72	-0.60	2.71 - 4.38	24
Station Group 6	2.89	0.17	0.04	-0.88	2.58 - 3.21	24
Transect I	3.34	0.28	-0.59	-0.05	2.61 - 3.78	36
Transect II	3.22	0.25	-0.68	-0.68	2.71 - 3.59	36
Transect III	2.93	0.39	-2.03	6.33	1.38 - 3.40	36
Transect IV	3.54	0.58	-0.27	-1.47	2.58 - 4.34	42
PERCENT SAND	22.86	24.44	1.17	0.05	1.03 - 81.78	186
Station Group 1	67.1	14.9	-0.5	-1.1	39.7 - 87.3	24
Station Group 2	32.3	26.5	0.7	-1.5	4.5 - 74.2	18
Station Group 3	20.5	14.6	0.8	-0.3	2.5 - 55.3	36
Station Group 4	18.1	20.6	1.2	-0.3	2.2 - 61.6	24
Station Group 5	17.4	20.9	1.2	-0.1	1.0 - 60.9	24
Station Group 6	3.5	2.5	0.7	-0.6	0.4 - 9.3	24
Transect I	27.2	21.8	0.7	-0.9	2.2 - 74.4	36
Transect II	11.5	8.0	0.5	-0.6	1.0 - 30.6	36
Transect III	17.0	28.8	1.8	1.6	0.9 - 87.3	36
Transect IV	44.3	26.8	-0.5	-1.1	0.4 - 81.8	42

BENTHIC NON-LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
SEDIMENT TEXTURE (cont.'d)						
PERCENT SILT	30.37	10.66	-0.58	-0.54	8.64 - 47.55	186
Station Group 1	14.7	6.9	0.7	-0.8	6.9 - 27.8	24
Station Group 2	30.7	14.3	-0.6	-1.6	9.6 - 49.0	18
Station Group 3	34.4	8.7	-0.4	-0.4	14.6 - 48.8	36
Station Group 4	29.8	10.2	-0.6	-1.2	11.9 - 43.1	24
Station Group 5	29.9	8.7	-1.0	-0.3	13.3 - 40.2	24
Station Group 6	29.6	1.8	0.6	-0.0	26.3 - 33.7	24
Transect I	28.7	8.6	-0.5	-0.5	8.7 - 41.8	36
Transect II	37.1	6.2	0.3	-0.7	26.3 - 49.0	36
Transect III	31.5	10.5	-1.2	0.5	8.6 - 44.3	36
Transect IV	18.6	8.0	0.3	-1.3	6.9 - 31.4	42
PERCENT CLAY	46.77	17.42	-0.44	-0.69	8.87 - 71.61	186
Station Group 1	18.2	8.8	0.1	-1.2	2.9 - 32.9	24
Station Group 2	37.5	13.6	-0.3	-1.4	15.3 - 55.1	18
Station Group 3	45.1	10.6	0.5	-1.1	30.1 - 62.8	36
Station Group 4	52.1	10.2	-0.6	-1.2	26.5 - 74.8	24
Station Group 5	52.6	15.0	-0.4	-1.4	25.8 - 72.2	24

BENTHIC NON-LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
SEDIMENT TEXTURE (cont.'d)						
Station Group 6	67.0	3.3	-0.3	-0.5	60.3 - 73.3	24
Transect I	44.2	17.0	0.2	-1.2	16.4 - 74.8	36
Transect II	51.4	12.1	0.1	-1.3	32.3 - 72.2	36
Transect III	51.5	20.5	-1.5	0.8	2.9 - 70.3	36
Transect IV	37.1	19.3	0.6	-0.9	9.8 - 71.6	42
SEDIMENT CHEMISTRY (1977)						
SEDIMENT TOTAL ORGANIC CARBON (% organic carbon/dry weight sediment)	0.85	0.32	-0.43	0.08	0.10 - 1.32	75
Station Group 1	0.48	0.34	0.12	-1.57	0.08 - 1.04	12
Station Group 2	0.62	0.18	-0.72	-0.19	0.30 - 0.85	9
Station Group 3	0.88	0.18	-0.51	-0.30	0.50 - 1.19	18
Station Group 4	0.94	0.22	-0.38	-0.67	0.54 - 1.25	12
Station Group 5	0.93	0.25	0.14	-0.98	0.56 - 1.32	12
Station Group 6	1.17	0.26	-1.05	2.75	0.55 - 1.62	12
SEDIMENT DELTA C^{13} (per mil deviations from the PDB standard)	-19.95	0.45	0.82	0.49	(-20.60)- (-18.90)	75

BENTHIC NON-LIVING CHARACTERSITICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
SEDIMENT CHEMISTRY (cont.'d)						
Station Group 1	-19.34	0.46	0.28	-0.21	(-19.93)- (-18.44)	12
Station Group 2	-19.69	0.37	-0.74	0.10	(-20.40)- (-19.19)	9
Station Group 3	-19.99	0.31	0.26	-1.43	(-20.42)- (-19.50)	18
Station Group 4	-20.19	0.26	0.17	-0.82	(-20.58)- (-19.73)	12
Station Group 5	-20.11	0.36	0.53	-1.09	(-20.55)- (-19.52)	12
Station Group 6	-20.29	0.22	-0.43	-0.27	(-20.70)- (-19.93)	12
Winter	-20.12	0.33	1.02	1.18	(-20.60)- (-19.20)	25
Spring	-20.01	0.46	0.87	-0.01	(-20.58)- (-18.90)	25
Fall	-19.73	0.48	0.48	1.02	(-20.70)- (-18.44)	25
Transect I	-19.99	0.46	0.48	-1.13	(-20.58)- (-19.15)	18
Transect II	-20.16	0.41	0.95	0.20	(-20.70)- (-19.19)	18
Transect III	-19.82	0.45	1.86	4.37	(-20.40)- (-18.44)	18
Transect IV	-19.85	0.44	0.65	-0.58	(-20.50)- (-18.90)	21
HIGH-MOLECULAR-WEIGHT HYDROCARBONS						
SEDIMENT (1975-1977)						
TOTAL HYDROCARBONS ($n-C_{14}$ to $n-C_{32}$) (micrograms/gram)	0.49	0.38	1.72	4.37	0.04 - 1.45	85

BENTHIC NON-LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
SEDIMENT CHEMISTRY (cont.'d)						
PRISTANE vs. PHYTANE	2.55	2.08	2.34	6.87	0.15 - 8.62	68
PRISTANE vs. n-C_{17}	0.55	0.32	2.06	5.41	0.18 - 1.50	73
PHYTANE vs. n-C_{18}	0.31	0.21	1.48	3.32	0.04 - 0.77	68
(Pr + Ph)/n-ALKANES	0.02	0.01	1.02	0.86	0.00 - 0.06	73
SUM LOW (n-C_{14} to n-C_{18}) (relative percent)	9.78	8.34	1.77	6.54	0.00 - 29.62	119
Winter	4.76	5.26	1.28	1.58	0.00 - 21.15	35
Spring	11.86	7.93	0.78	1.01	0.00 - 35.85	35
Fall	13.22	9.30	2.64	10.63	0.00 - 54.86	37
SUM MID (n-C_{19} to n-C_{24}) (relative percent)	23.79	12.97	1.05	0.67	6.72 - 57.10	119
1975	35.39	12.90	0.52	-0.43	15.69 - 66.92	34
1976	20.32	9.76	1.40	2.44	7.55 - 47.14	73

BENTHIC NON-LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
SEDIMENT CHEMISTRY (cont.'d)						
SUM HIGH (n-C_{25} to n-C_{32}) (relative percent)	66.43	14.96	-0.75	0.65	20.15 - 90.82	119
1975	55.36	15.67	-0.10	-0.42	19.91 - 83.30	34
1976	69.32	11.66	-1.13	3.76	20.15 - 90.82	73

BENTHIC LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
MICROBIOLOGY (1977)						
FUNGAL COUNTS	237.50	408.10	2.68	7.49	34.56 - 440.44	18
FUNGAL OIL DEGRADERS	157.22	249.39	2.01	4.33	33.20 - 281.24	18
TOTAL BACTERIA	477986.11	322844.14	0.51	-0.26		36
Station 1	788083.33	257882.45	-0.06	0.43	402000.0 - 1310000.0	12
Station 2	430083.33	194982.73	0.32	-0.54	115000.0 - 758400.0	12
Station 3	215791.67	211454.58	1.17	0.14	46300.0 - 632000.0	12
BACTERIA OIL DEGRADERS	9725.83	21808.65	3.84	15.17		36
Winter	2665.83	2971.58	1.15	0.33	80.0 - 9100.0	12
Spring	3070.00	3830.13	1.92	3.64	130.0 - 13000.0	12
Fall	23441.67	34379.76	2.05	3.41	1300.0 - 110000.0	12
MEIOFAUNA (1976-1977)						
TOTAL MEIOFAUNA SPECIES (number of species/10 cm^2)	4.65	1.67	0.74	0.53	2.0 - 8.5	186

BENTHIC LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
MEIOFAUNA (cont.'d)						
Station Group 1	6.7	1.7	0.2	-0.03	3.5 - 10.5	24
Station Group 2	5.5	1.8	0.6	0.21	2.5 - 9.5	18
Station Group 3	4.4	1.1	1.1	1.61	2.5 - 7.0	36
Station Group 4	4.1	1.2	0.8	1.26	2.0 - 7.5	24
Station Group 5	4.2	1.4	0.4	-0.56	2.0 - 7.3	24
Station Group 6	4.0	1.3	0.4	-0.42	1.5 - 6.8	24
TOTAL MEIOFAUNA DENSITY (number of individuals/10 cm^2)	202.86	311.04	2.50	6.09	8.8 - 1153.3	186
Station Group 1	710.3	408.7	0.2	-1.1	77.8 - 1447.0	24
Station Group 2	347.5	432.7	1.9	4.3	19.5 - 1682.5	18
Station Group 3	140.5	193.6	4.0	19.2	23.5 - 1118.0	36
Station Group 4	91.0	81.4	1.8	3.2	11.5 - 339.3	24
Station Group 5	60.7	38.9	0.8	-0.4	8.5 - 139.5	24
Station Group 6	42.0	26.7	1.0	0.7	8.8 - 112.7	24
Transect I	211.1	264.5	1.9	3.3	8.5 - 1118.0	36
Transect II	69.0	10.2	2.1	4.4	12.5 - 283.8	36
Transect III	248.8	412.6	2.1	3.1	8.8 - 1447.0	36
Transect IV	336.9	402.6	1.6	2.0	14.3 - 1213.0	42

BENTHIC LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
MEIOFAUNA (cont.'d)						
NEMATODE DENSITY (number of individuals/10 cm^2)	152.17	246.83	2.60	6.70	4.5 - 903.5	186
Station Group 1	578.6	338.1	0.1	-0.8	26.5 - 1267.5	24
Station Group 2	268.5	348.4	1.8	3.6	7.8 - 1313.5	18
Station Group 3	91.4	109.8	3.1	11.3	8.0 - 580.5	36
Station Group 4	66.9	55.8	1.6	2.7	8.3 - 238.0	24
Station Group 5	46.4	32.2	0.8	-0.5	3.3 - 109.5	24
Station Group 6	26.7	19.6	1.1	0.4	4.5 - 75.5	24
Transect I	158.6	200.5	1.5	1.2	3.3 - 731.0	36
Transect II	45.5	41.4	2.7	9.7	4.5 - 226.0	36
Transect III	189.1	329.7	2.2	3.8	6.5 - 1267.5	36
Transect IV	267.1	331.1	1.5	1.5	8.5 - 992.5	42
HARPACTICOID DENSITY (number of individuals/10 cm^2)	6.35	15.26	4.92	29.75	0.0 - 56.0	186
Station Group 1	24.5	30.3	2.1	5.5	0.0 - 130.0	24
Station Group 2	8.3	11.4	3.0	10.6	0.0 - 49.5	18
Station Group 3	2.7	4.8	3.5	12.5	0.0 - 23.3	36
Station Group 4	2.5	5.1	3.9	16.1	0.0 - 24.5	24
Station Group 5	1.9	2.5	2.9	10.7	0.0 - 11.8	24

BENTHIC LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
MEIOFAUNA (cont.'d)						
Station Group 6	1.5	1.8	1.4	0.8	0.0 - 6.0	24
Transect I	4.2	7.3	3.2	11.2	0.0 - 36.3	36
Transect II	1.9	1.8	1.3	1.6	0.0 - 7.5	36
Transect III	11.8	25.7	3.4	12.9	0.0 - 130.0	36
Transect IV	7.9	13.7	2.9	9.3	0.0 - 49.5	42
MACROINVERTEBRATES (1976-1977)						
INFAUNA SPECIES (number of species/0.1 m^2)	70.63	41.82	1.72	2.63	26.0 - 201.0	186
Station Group 1	129.9	61.6	-0.01	-1.51	38.0 - 226.0	24
Station Group 2	73.5	46.9	0.98	-0.81	32.0 - 161.0	18
Station Group 3	56.6	20.2	0.81	0.53	26.0 - 115.0	36
Station Group 4	68.6	39.5	1.30	1.21	20.0 - 169.0	24
Station Group 5	76.5	31.7	0.39	-0.87	29.0 - 133.0	24
Station Group 6	57.1	17.4	-0.27	1.11	14.0 - 91.0	24
Transect I	73.4	26.3	1.02	1.58	34.0 - 156.0	36
Transect II	51.2	18.7	1.20	1.24	27.0 - 107.0	36
Transect III	67.6	50.3	1.96	2.62	20.0 - 207.0	36

BENTHIC LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
MACROINVERTEBRATES (cont.'d)						
Transect IV	105.1	52.5	0.48	-0.56	14.0 - 206.0	42
INFAUNA DENSITY (number of individuals/0.1 m^2)	667.53	1077.35	3.36	12.40	47.0 - 4475.0	186
Station Group 1	2726.3	1834.9	0.64	-0.36	491.0 - 6770.0	24
Station Group 2	922.3	582.1	1.08	-0.12	323.0 - 2249.0	18
Station Group 3	404.9	332.8	2.75	10.34	62.0 - 1877.0	36
Station Group 4	255.0	259.8	2.37	5.46	43.0 - 1063.0	24
Station Group 5	290.8	160.9	0.48	-0.77	58.0 - 639.0	24
Station Group 6	167.3	71.2	0.18	0.27	37.0 - 324.0	24
Transect I	801.5	959.2	2.14	4.61	69.0 - 4303.0	36
Transect II	281.4	181.3	1.22	2.09	37.0 - 884.0	36
Transect III	1043.4	1886.6	2.17	3.35	50.0 - 6772.0	36
Transect IV	885.2	952.5	1.49	1.31	37.0 - 3084.0	42
EPIFAUNA SPECIES (number of species/trawl)	8.58	4.43	0.99	2.38	1.0 - 19.0	185
EPIFAUNA DENSITY (number of individuals/trawl)	136.34	218.06	3.78	18.97	2.0 - 823.0	185

BENTHIC LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
DEMERSAL FISHES (1976-1977)						
FISH SPECIES (number of species/trawl)	14.30	5.64	0.52	0.22	4.0 - 27.0	185
FISH DENSITY (number of individuals/trawl)	126.69	167.82	4.20	24.11	8.0 - 566.0	185
FISH BIOMASS (grams/trawl)	2708.76	2630.03	3.18	18.10	175.1 - 8142.7	185
HIGH-MOLECULAR-WEIGHT HYDROCARBONS (1975-1977)						
Penaeus aztecus						
TOTAL HYDROCARBONS ($n-C_{14}$ to $n-C_{32}$) (micrograms/gram)	0.15	0.28	4.70	25.95	0.0 - 1.77	46
Lutjanus campechanus-gonad						
TOTAL HYDROCARBONS ($n-C_{14}$ to $n-C_{32}$) (micrograms/gram)	36.79	31.76	0.95	0.20	1.74 - 98.56	9

BENTHIC LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
HIGH-MOLECULAR-WEIGHT HYDROCARBONS (cont.'d)						
Lutjanus campechanus-gill						
TOTAL HYDROCARBONS (n-C_{14} to n-C_{32}) (micrograms/gram)	4.67	6.06	1.87	3.72	0.00 - 20.01	11
Lutjanus campechanus-liver						
TOTAL HYDROCARBONS (n-C_{14} to n-C_{32}) (micrograms/gram)	8.68	9.55	2.90	9.88	1.13 - 43.80	20
SUM MID (n-C_{19} to n-C_{24}) (relative percent)	6.58	7.77	1.09	0.12	0.00 - 24.10	20
1976	0.90	1.48	2.10	4.79	0.00 - 4.80	11
1977	13.51	6.51	0.59	-1.09	6.00 - 24.10	9
AVERAGE OEP (n-C_{14} to n-C_{32})	6.59	6.35	0.67	-1.70	1.13 - 15.83	14
1976	14.70	1.25	-1.04	-0.35	12.81 - 15.83	5
1977	2.09	0.87	0.69	-1.62	1.13 - 3.31	9

BENTHIC LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
HIGH-MOLECULAR-WEIGHT HYDROCARBONS (cont.'d)						
Lutjanus campechanus-muscle						
TOTAL HYDROCARBONS ($n-C_{14}$ to $n-C_{32}$) (micrograms/gram)	0.68	1.58	4.19	18.43	0.0 - 7.40	21
Rhomboplites aurorubens-gill						
TOTAL HYDROCARBONS ($n-C_{14}$ to $n-C_{32}$) (micrograms/gram)	6.95	9.41	2.10	4.68	0.0 - 30.62	10
Rhomboplites aurorubens-gonad						
TOTAL HYDROCARBONS ($n-C_{14}$ to $n-C_{32}$) (micrograms/gram)	6.85	7.24	2.56	6.89	2.32 - 25.31	9
Rhomboplites aurorubens-muscle						
TOTAL HYDROCARBONS ($n-C_{14}$ to $n-C_{32}$) (micrograms/gram)	1.37	1.30	1.17	0.59	0.02 - 4.38	20
Rhomboplites aurorubens-liver						
TOTAL HYDROCARBONS ($n-C_{14}$ to $n-C_{32}$) (micrograms/gram)	13.60	9.78	0.84	0.08	0.57 - 35.85	18

BENTHIC LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
HIGH-MOLECULAR-WEIGHT HYDROCARBONS (cont.'d)						
PRISTANE vs. n-C_{17}	10.67	9.92	1.65	2.02	1.85 - 36.00	15
Winter	7.03	0.00	0.00	0.00	7.03 - 7.03	1
March	6.31	0.00	0.00	0.00	6.31 - 6.31	1
April	36.00	0.00	0.00	0.00	36.00 - 36.00	1
Spring	20.60	7.22	-1.42	0.00	12.55 - 26.08	3
July	5.78	1.41	-0.68	0.00	4.27 - 7.07	3
August	5.29	2.33	0.00	0.00	3.64 - 6.94	2
Fall	8.46	2.65	0.00	0.00	6.59 - 10.34	2
November	2.18	0.00	0.00	0.00	2.18 - 2.18	1
December	1.85	0.00	0.00	0.00	1.85 - 1.85	1
Trachurus lathami						
TOTAL HYDROCARBONS (n-C_{14} to n-C_{32}) (micrograms/gram)	8.58	12.00	2.47	6.60	0.03 - 51.32	25
Stenotomus caprinus						
TOTAL HYDROCARBONS (n-C_{14} to n-C_{32}) (micrograms/gram)	1.05	1.85	3.32	11.70	0.02 - 8.58	26

BENTHIC LIVING CHCARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
HIGH-MOLECULAR-WEIGHT HYDROCARBONS (cont.'d)						
Loligo pealei						
TOTAL HYDROCARBONS ($n-C_{14}$ to $n-C_{32}$) (micrograms/gram)	1.93	3.35	2.58	6.30	0.00 - 14.09	44
Serranus atrobranchus						
TOTAL HYDROCARBONS ($n-C_{14}$ to $n-C_{32}$) (micrograms/gram)	0.19	0.21	0.88	-0.47	0.00 - 0.68	26
Pristipomoides aquilonaris						
TOTAL HYDROCARBONS ($n-C_{14}$ to $n-C_{32}$) (micrograms/gram)	3.04	4.33	2.01	3.27	0.12 - 15.80	37
TRACE METALS						
BODY BURDENS (1975-1977)						
Penaeus aztecus-flesh						
ZINC (ppm dry weight)	52.90	8.79	-0.83	2.73	20.00 - 68.00	51

BENTHIC LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
TRACE METALS (cont.'d)						
CADMIUM (ppm dry weight)	0.11	0.08	0.83	0.36	0.01 - 0.25	51
Trachurus lathami-flesh						
CADMIUM (ppm dry weight)	0.09	0.09	1.20	0.33	0.01 - 0.30	24
CALCIUM (ppm dry weight)	882.5	498.97	2.37	7.61	310.00 - 2500.00	16
ALUMINUM (ppm dry weight)	22.75	11.20	1.11	0.84	10.00 - 50.00	16
Serranus atrobranchus-flesh						
ZINC (ppm dry weight)	10.88	3.28	-0.72	1.46	2.00 - 17.00	24
Stenotomus caprinus-flesh						
CADMIUM (ppm dry weight)	0.08	0.05	0.45	-0.82	0.02 - 0.16	17

BENTHIC LIVING CHARACTERISTICS

	MEAN	STD DEV	SKEW	KURT	95% EMPIR CI	N
TRACE METALS (cont.'d)						
Lutjanus campechanus-gill						
VANADIUM (ppm dry weight)	0.39	0.26	0.55	-3.10	0.15 - 0.70	5

APPENDIX B

VARIABLE GEOGRAPHIC DISTRIBUTIONAL MAPS

PREFACE

The purpose of this appendix is to present a quick reference to the distributional characteristics of those environmental variables measured during the south Texas outer continental shelf (STOCS) study that showed significant ($P < 0.05$) spatial variation over the study area. Presented are the mean and 95% normal confidence interval statistics for every station on the Texas shelf sampled over the study period (1975-1977). The intention of this presentation is to provide decision-makers and environmental managers with a quick reference to the study area in respect to those variables included, so that he/she can make a decision concerning the management of the ecosystem or develop criteria for further monitoring of the system.

Sampling Scheme

The variables presented represent several different sampling schemes. For some variables, data were collected for all three years of the study (1975-1977). Others collected data in only one or two years of study. For further reference concerning extent of sampling, the reader should see the specific scientific section concerning a certain variable in Volume III. The means and confidence intervals presented in the distributional maps of this appendix represent data collected during the three meteorological seasons of each year only; winter, spring and fall.

Spatially, two different sampling schemes are presented in the maps: a) a 12 station scheme involving Stations 1-3, Transects I-IV, primarily for pelagic sampling (Figure B-1); and b) a 25 station scheme involving Stations 1-6, Transects I-III and Stations 1-7, Transect IV, primarily for benthic sampling (Figure B-1). Table B-1 lists the LORAN and LORAC coordinates, as well as latitude, longitude and water depth of each site represented by one of the two sampling schemes described above.

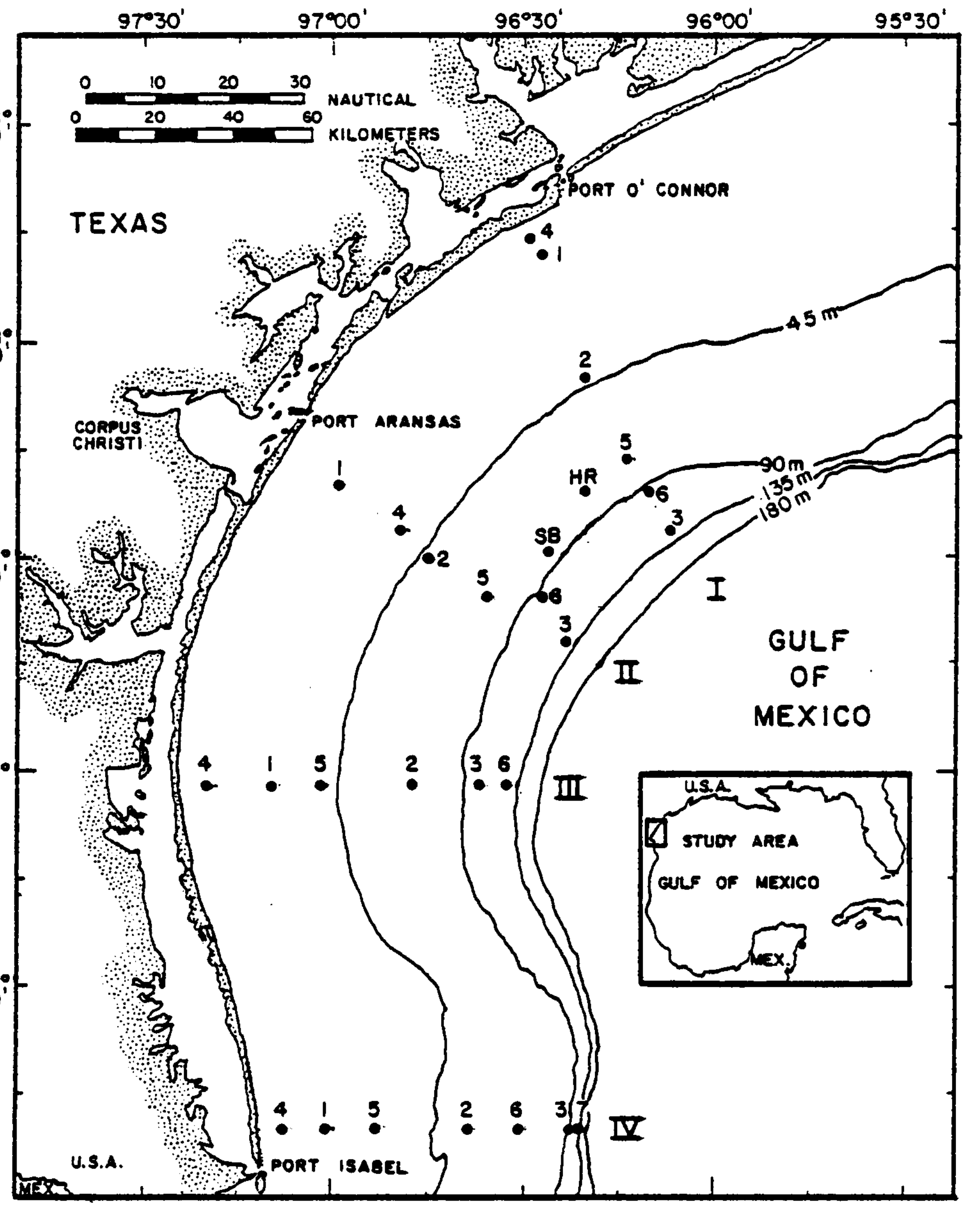


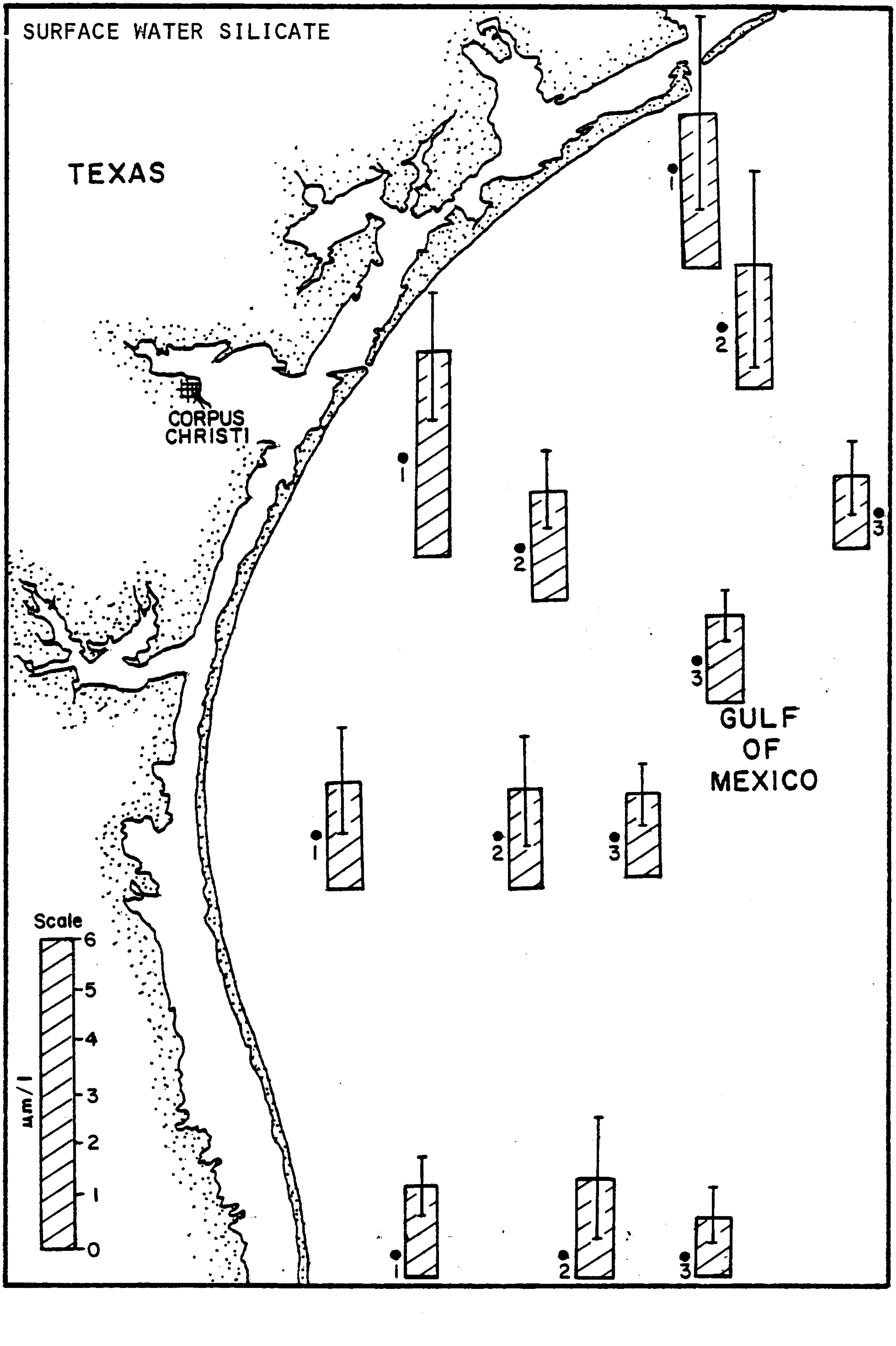
Figure B-1. Map showing the south Texas outer continental shelf bathymetry and location of sampling sites.

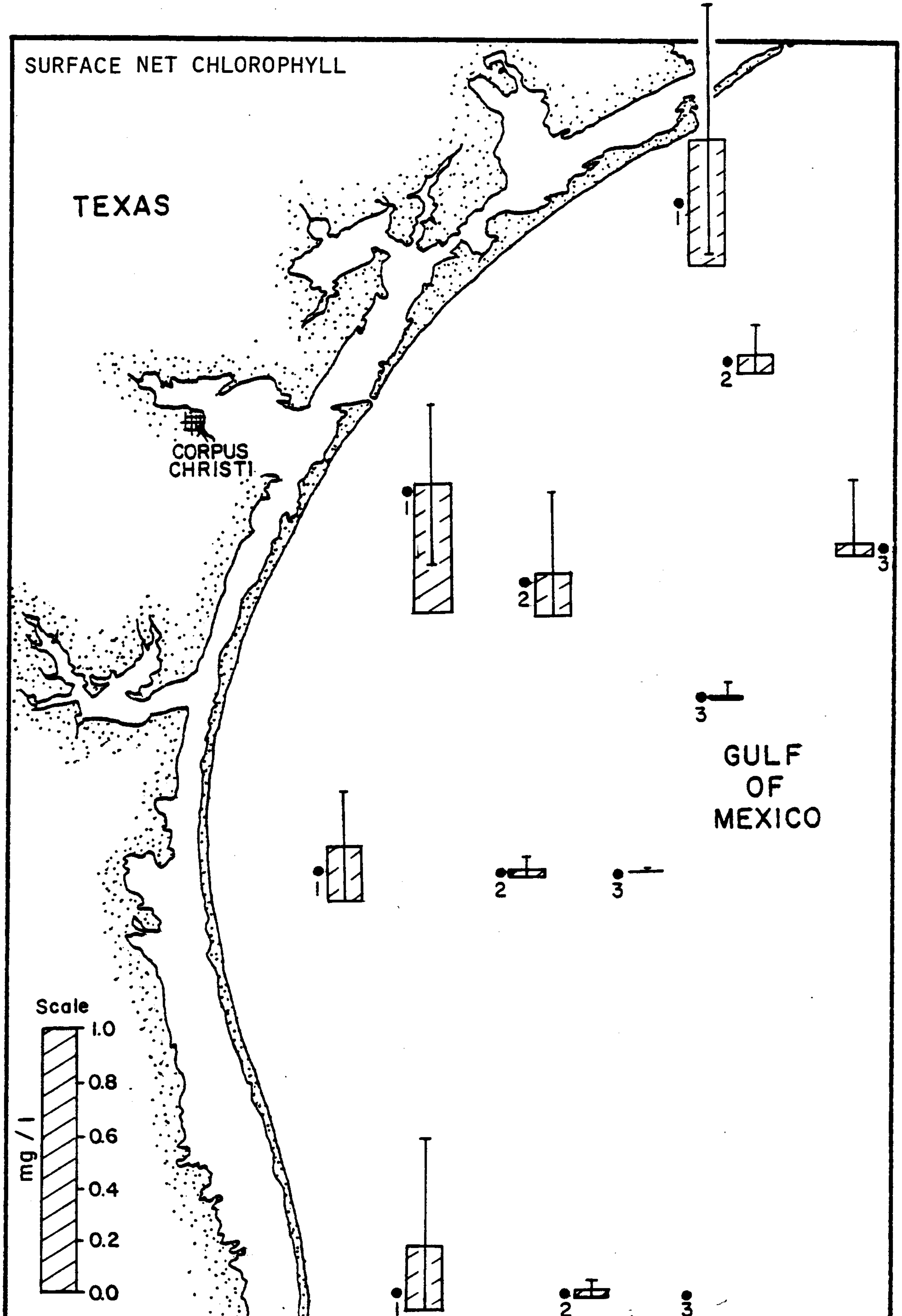
TABLE B-1

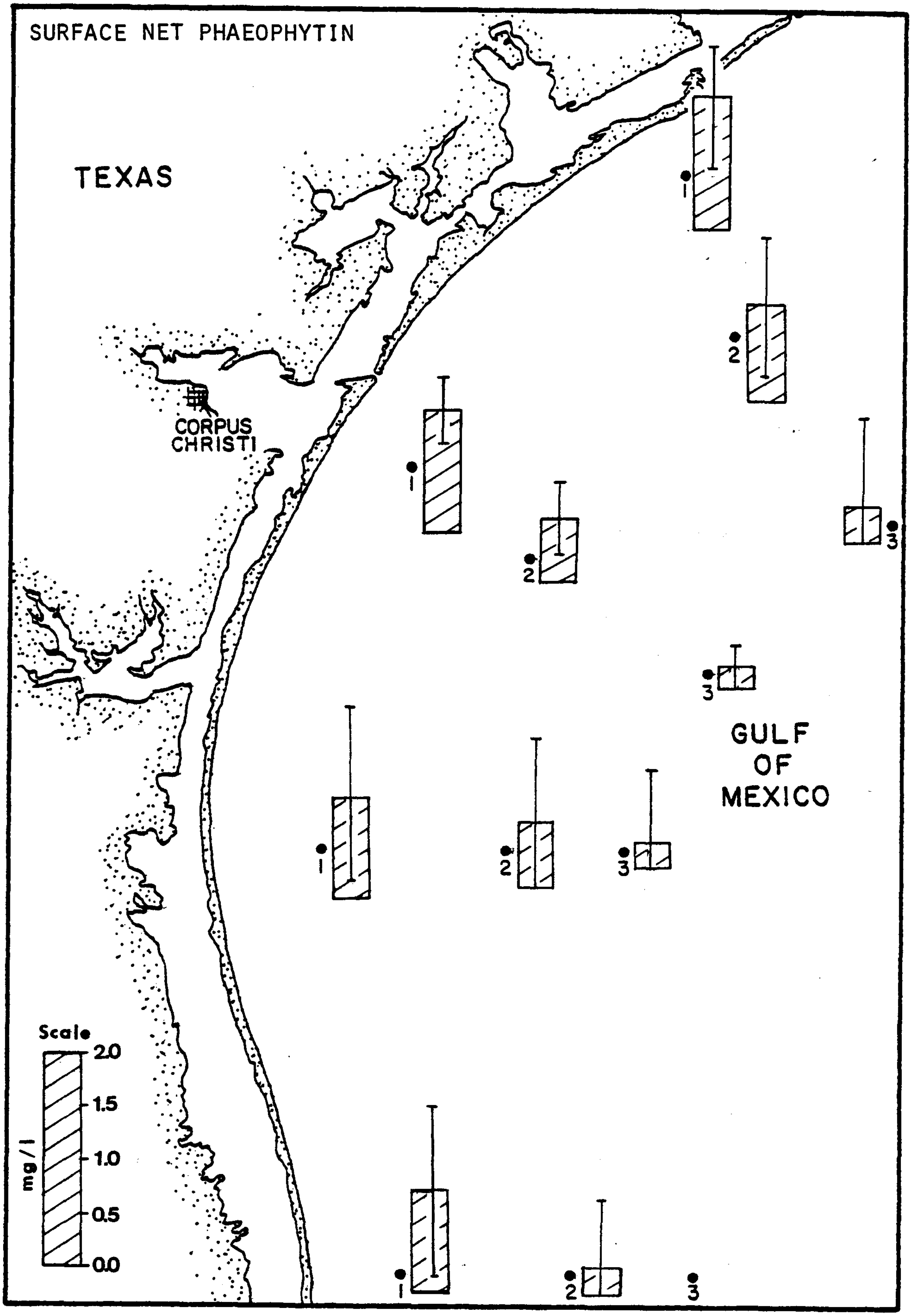
BLM STOCS MONITORING STUDY STATION LOCATIONS

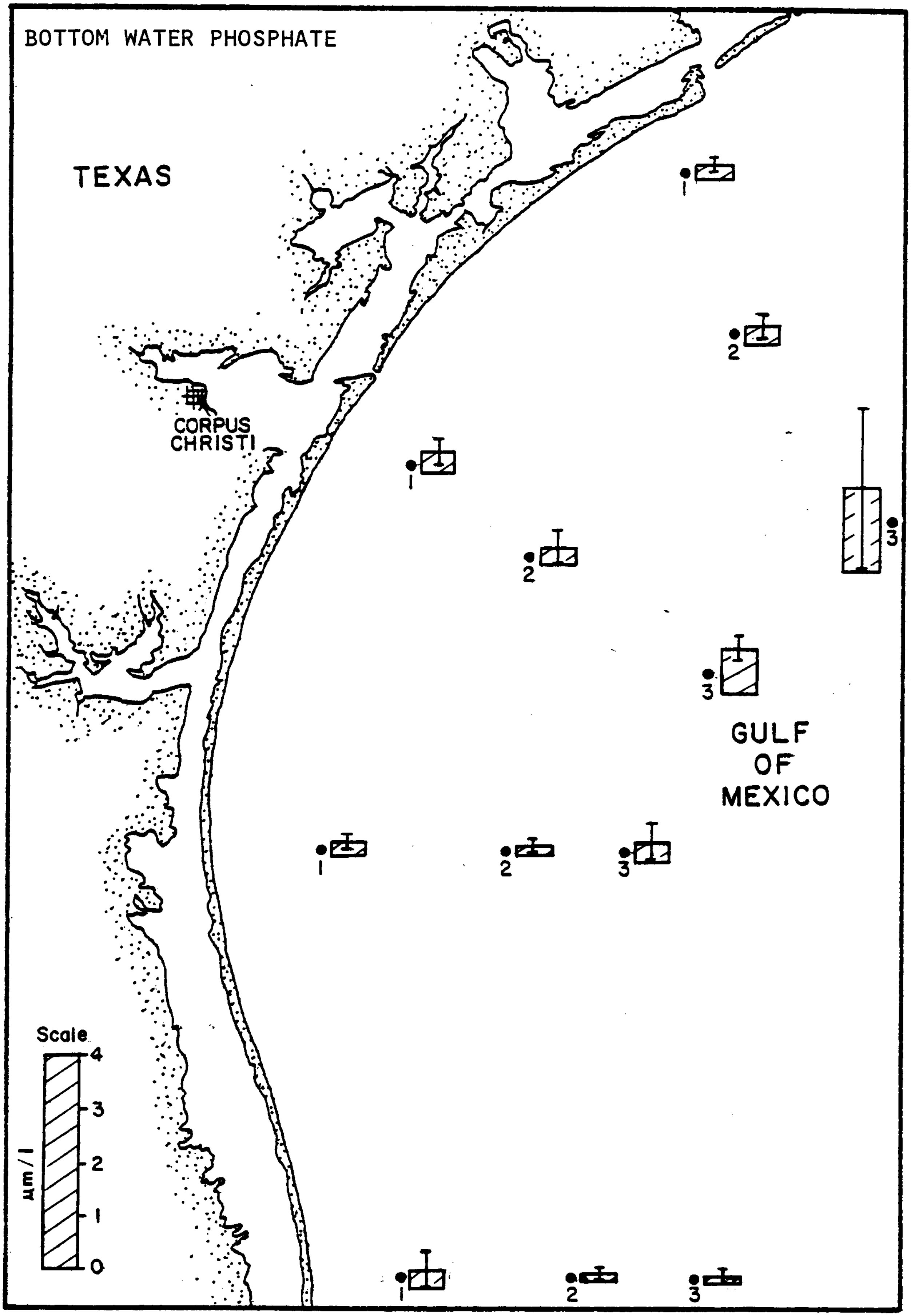
TRAN.	STA.	LORAN		LORAC		LATITUDE	LONGITUDE	DEPTH	
		3H3	3H2	LG	LR			METERS	FEET
I	1	2575	4003	1180.07	171.46	28°12'N	96°27'W	18	59
	2	2440	3950	961.49	275.71	27°55'N	96°20'W	42	138
	3	2300	3863	799.45	466.07	27°34'N	96°07'W	134	439
	4	2583	4015	1206.53	157.92	28°14'N	96°29'W	10	33
	5	2360	3910	861.09	369.08	27°44'N	96°14'W	82	269
	6	2330	3892	819.72	412.96	27°39'N	96°12'W	100	328
II	1	2078	3962	373.62	192.04	27°40'N	96°59'W	22	72
	2	2050	3918	454.46	382.00	27°30'N	96°45'W	49	161
	3	2040	3850	564.67	585.52	27°18'N	96°23'W	131	430
	4	2058	3936	431.26	310.30	27°34'N	96°50'W	36	112
	5	2032	3992	498.85	487.62	27°24'N	96°36'W	78	256
	6	2068	3878	560.54	506.34	27°24'N	96°29'W	98	322
	7	2045	3835			27°15'N	96°18.5'W	182	600
III	1	1585	3880	139.13	909.98	26°58'N	97°11'W	25	82
	2	1683	3841	286.38	855.91	26°58'N	96°48'W	65	213
	3	1775	3812	391.06	829.02	26°58'N	96°33'W	106	348
	4	1552	3885	95.64	928.13	26°58'N	97°20'W	15	49
	5	1623	3867	192.19	888.06	26°58'N	97°02'W	40	131
	6	1790	3808	411.48	824.57	26°58'N	96°30'W	125	410
IV	1	1130	3747	187.50	1423.50	26°10'N	97°01'W	27	88
	2	1300	3700	271.99	1310.61	26°10'N	96°39'W	47	154
	3	1425	3663	333.77	1241.34	26°10'N	96°24'W	91	298
	4	1073	3763	163.42	1456.90	26°10'N	97°08'W	15	49
	5	1170	3738	213.13	1387.45	26°10'N	96°54'W	37	121
	6	1355	3685	304.76	1272.48	26°10'N	96°31'W	65	213
	7	1448	3659	350.37	1224.51	26°10'N	96°20'W	130	426
HR	1	2159	3900	635.06	422.83	27°32'05"	96°28'19"	75	246
	2	2169	3902	644.54	416.95	27°32'46"	96°27'25"	72	237
	3	2163	3900	641.60	425.10	27°32'05"	96°27'35"	81	266
	4	2165	3905	638.40	411.18	27°33'02"	96°29'03"	76	250
SB	1	2086	3889	563.00	468.28	27°26'49"	96°31'18"	81	266
	2	2081	3889	560.95	475.80	27°26'14"	96°31'02"	82	269
	3	2074	3890	552.92	475.15	27°26'06"	96°31'47"	82	269
	4	2078	3890	551.12	472.73	27°26'14"	96°32'07"	82	269

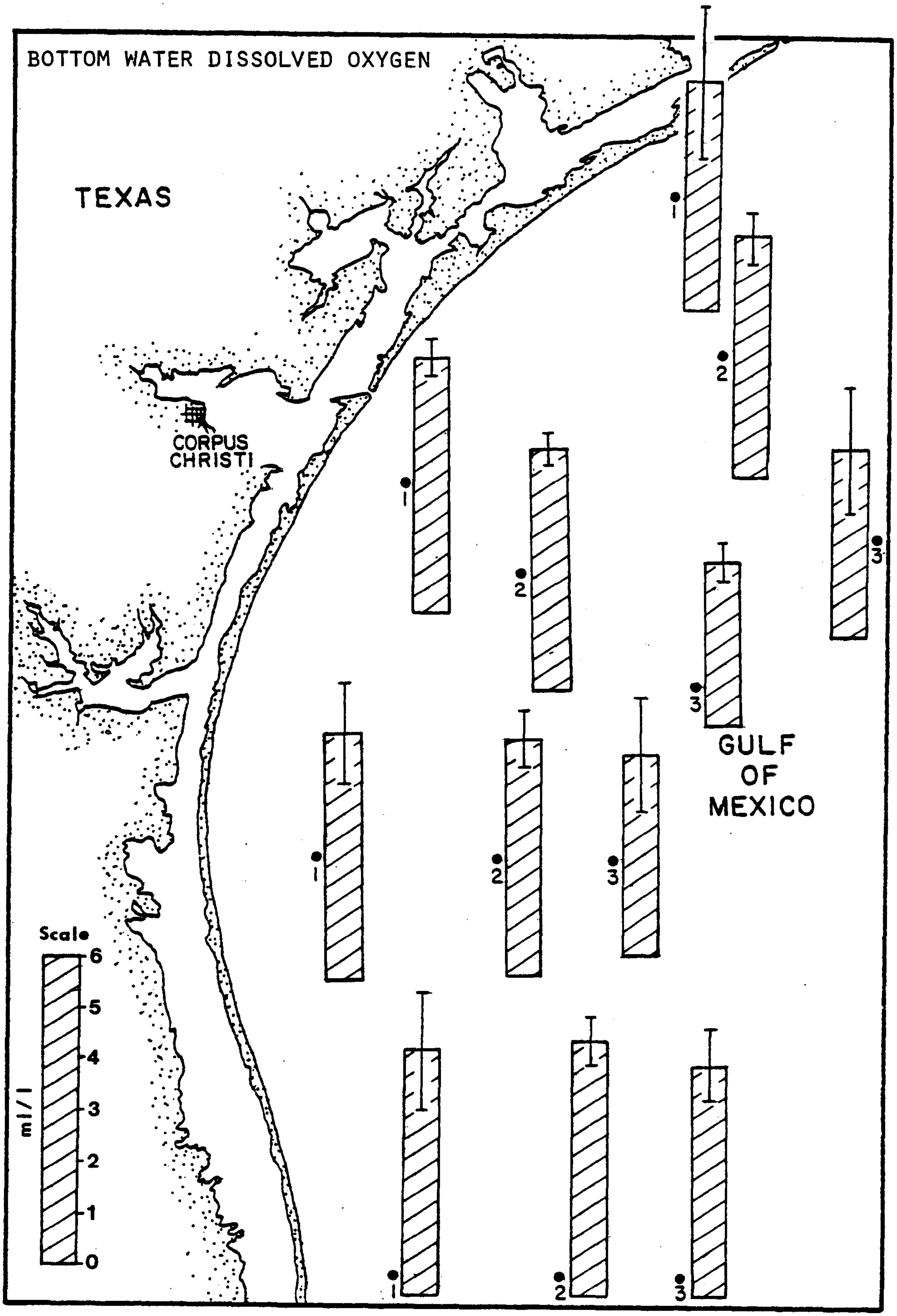
INDEX TO VARIABLE DISTRIBUTIONAL MAPS

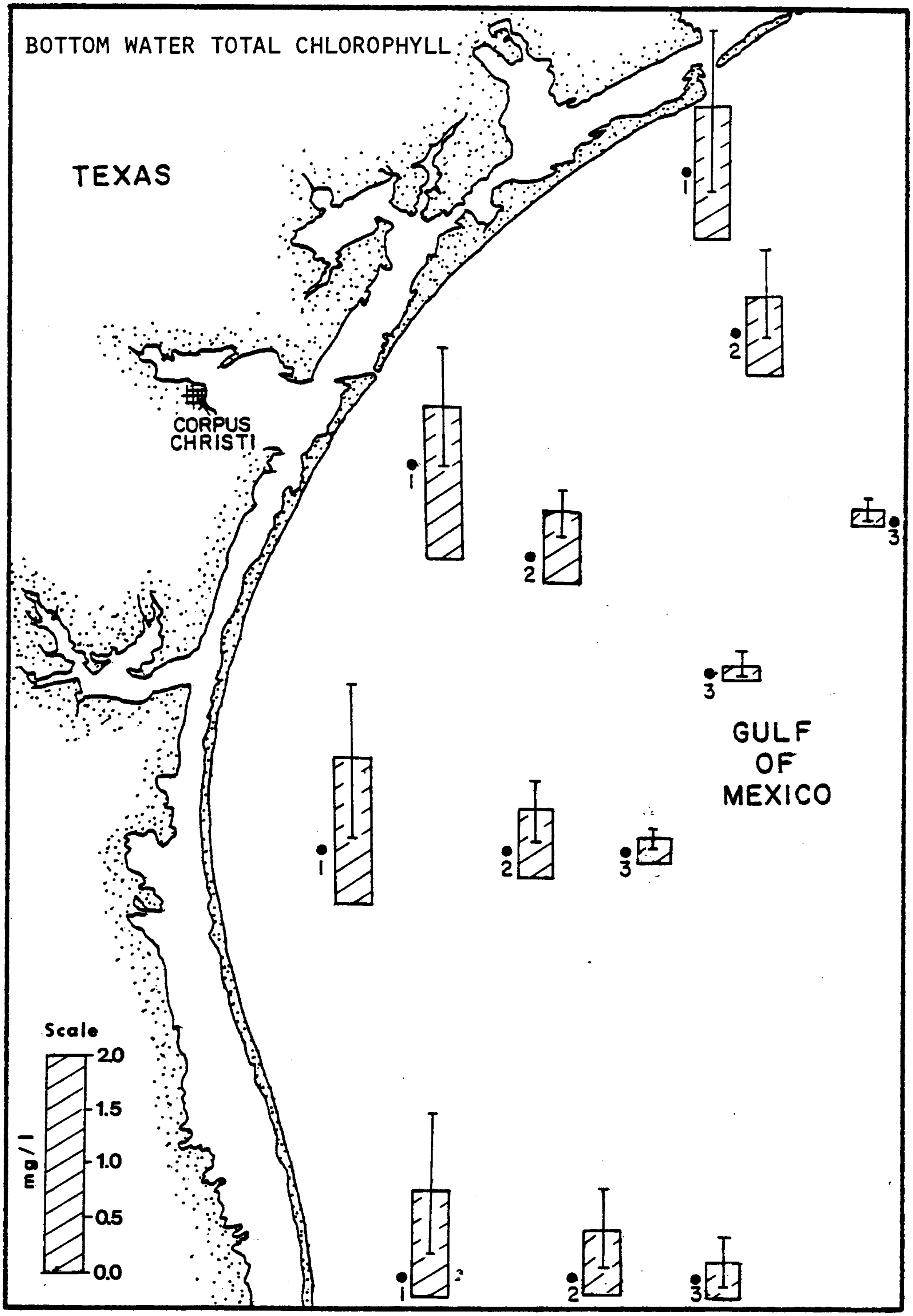

SURFACE WATER SILICATE
TEXAS
CORPUS
CHRISTI
GULF
OF
MEXICO
Scale
6
5
4
3
2
1
0
µm/l
1
2
3

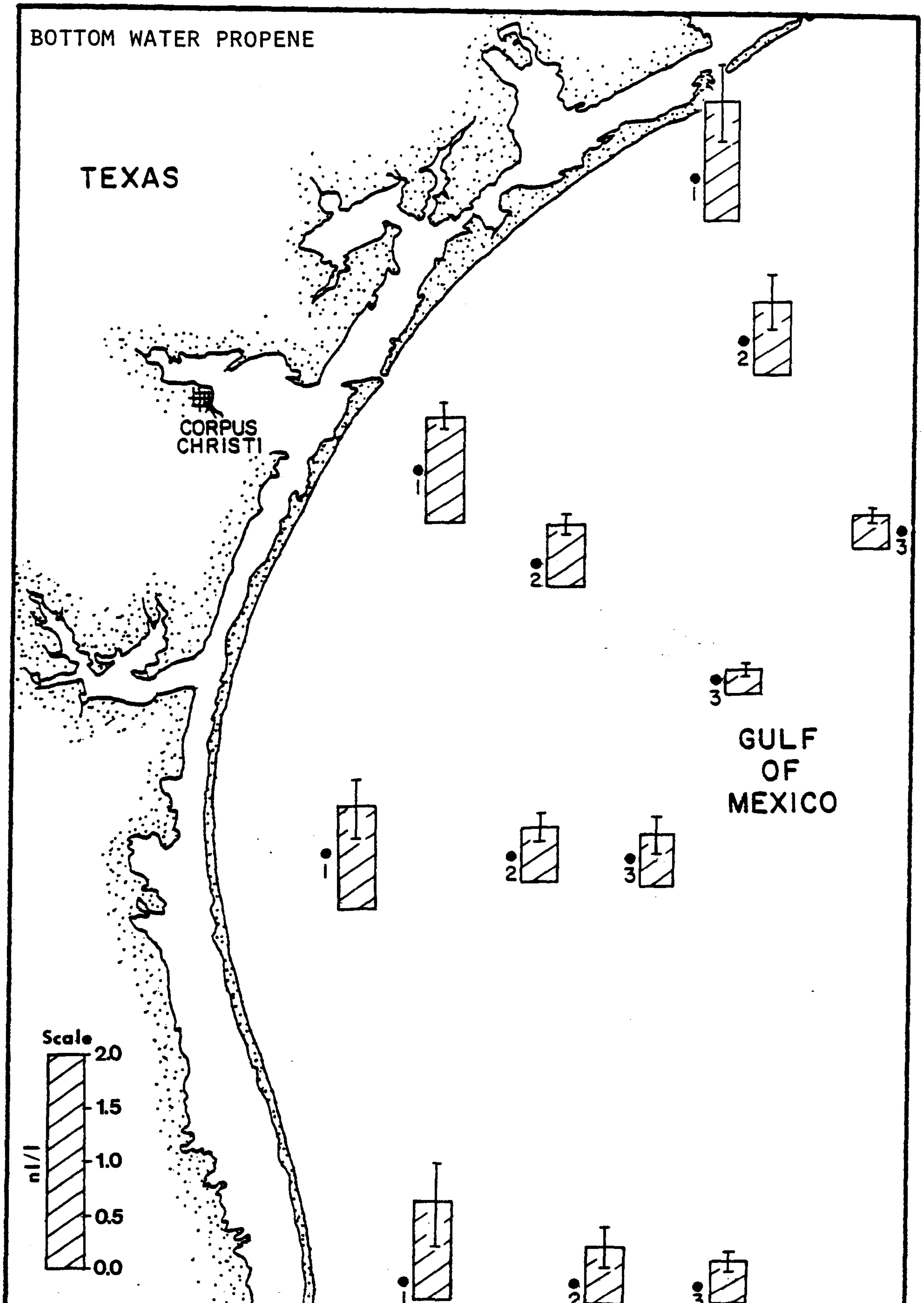

SURFACE NET CHLOROPHYLL
TEXAS
CORPUS
CHRISTI
GULF
OF
MEXICO
Scale
mg / l
1.0
0.8
0.6
0.4
0.2
0.0
1
2
3


SURFACE NET PHAEOPHYTIN
TEXAS
CORPUS CHRISTI
GULF OF MEXICO
Scale
mg/l
2.0
1.5
1.0
0.5
0.0
1
2
3
1
2
3
1
2
3
1
2
3
1
2
3

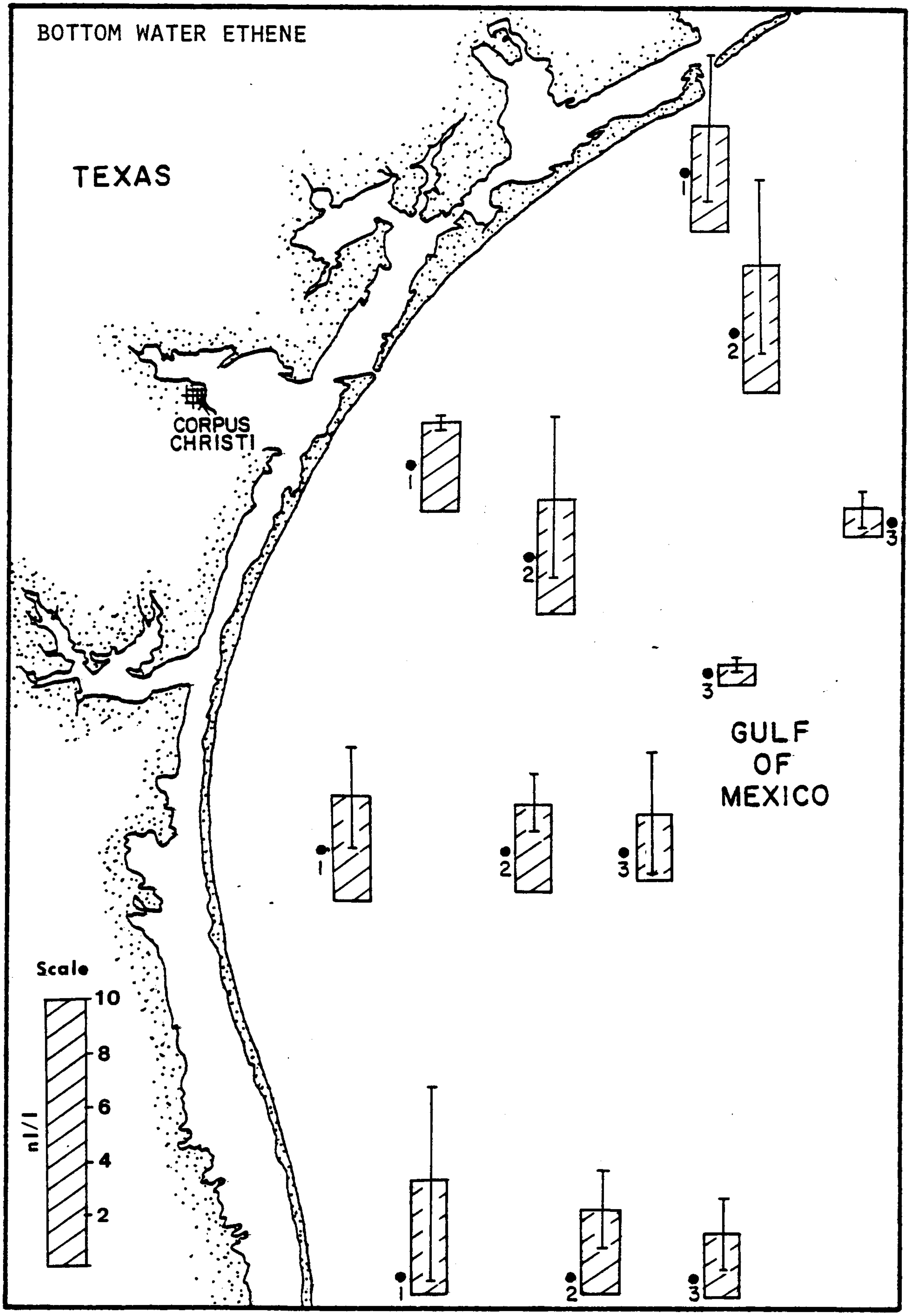

BOTTOM WATER PHOSPHATE
TEXAS
CORPUS CHRISTI
GULF OF MEXICO
Scale
4
3
2
1
0
μm/l
1
2
3
1
2
3
1
2
3
1
2
3

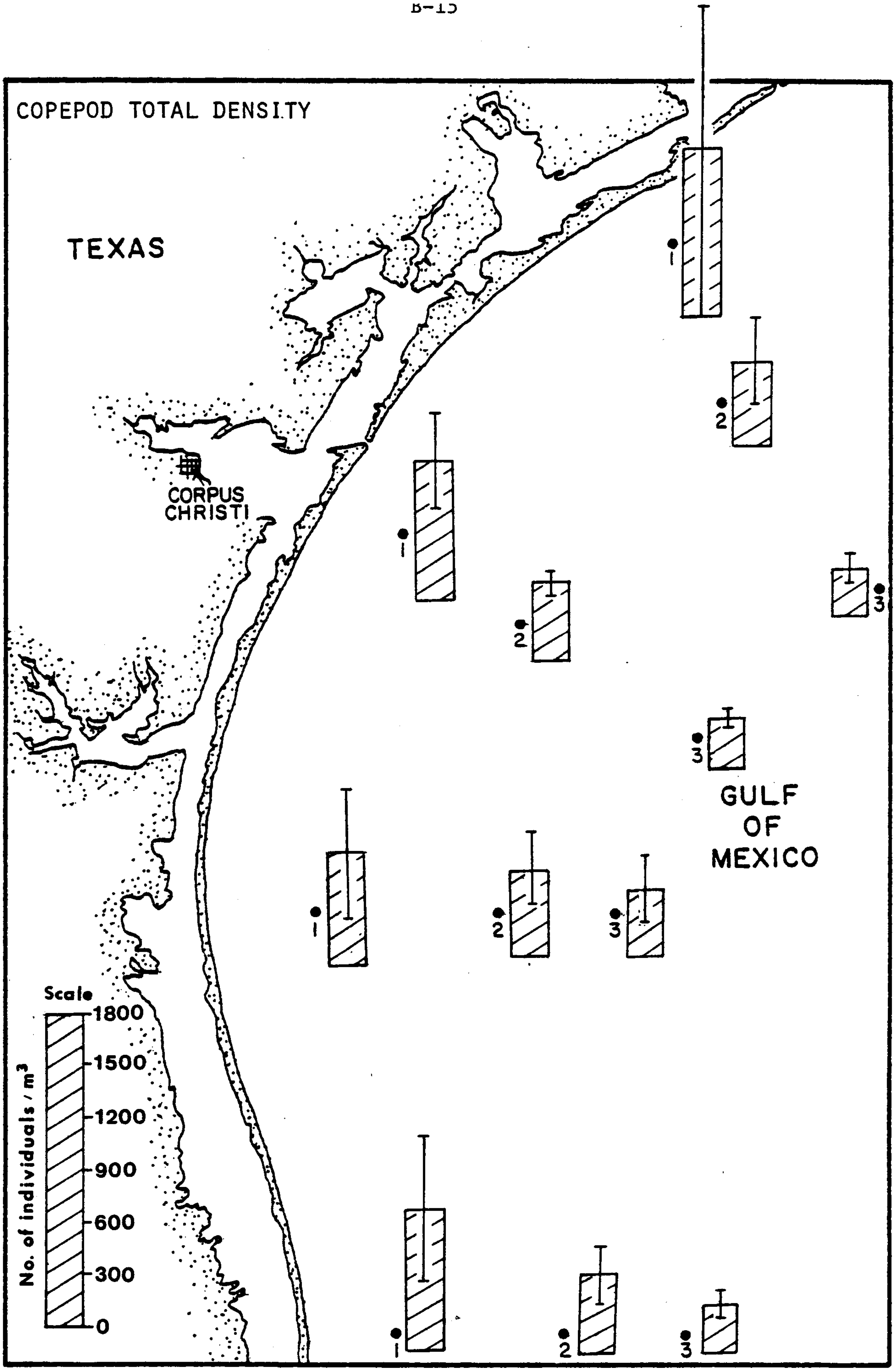

BOTTOM WATER DISSOLVED OXYGEN
TEXAS
CORPUS CHRISTI
GULF OF MEXICO
Scale
ml/l
6
5
4
3
2
1
0
1
2
3

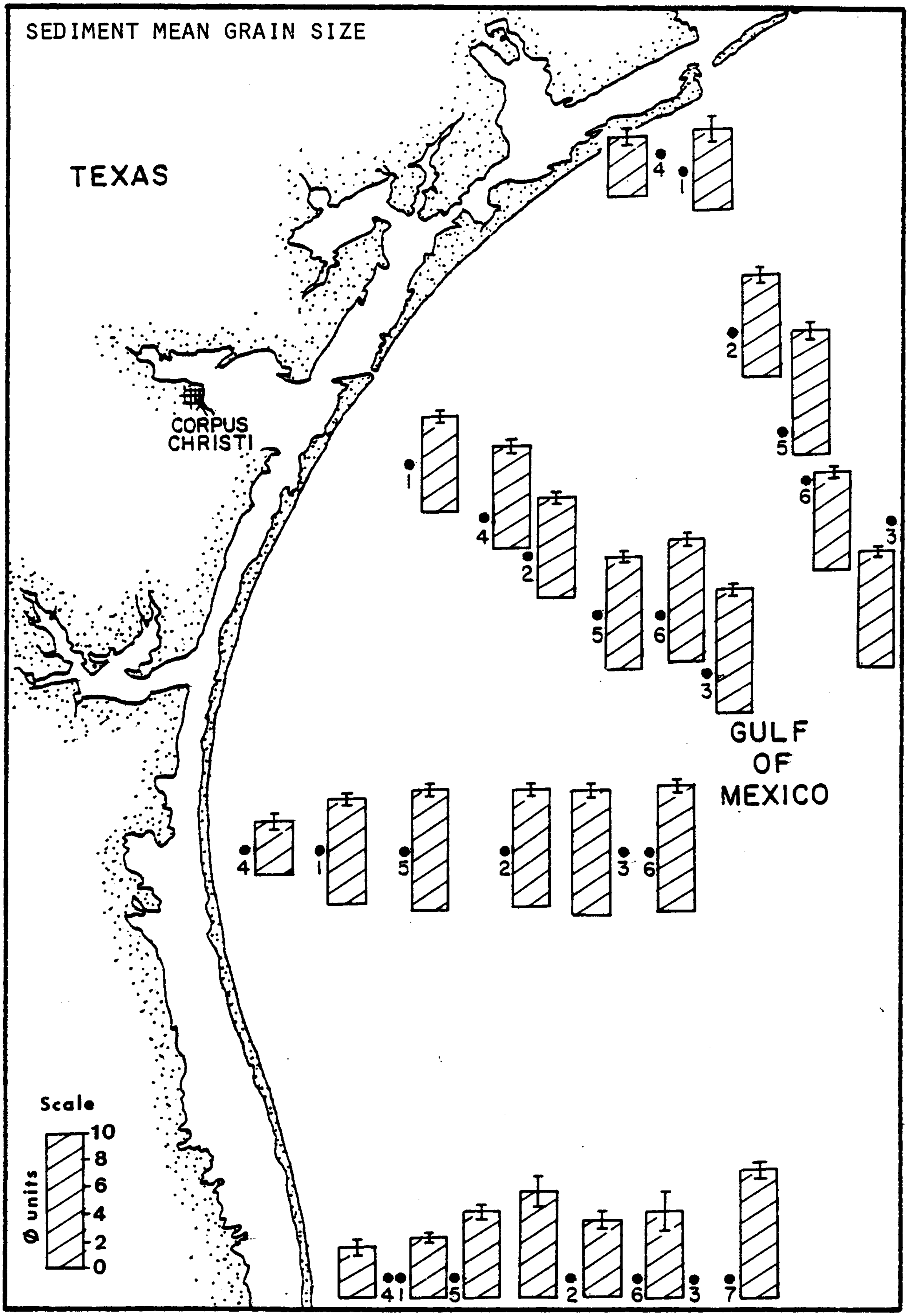

BOTTOM WATER TOTAL CHLOROPHYLL
TEXAS
CORPUS CHRISTI
GULF OF MEXICO
Scale
mg/l
2.0
1.5
1.0
0.5
0.0
1
2
3

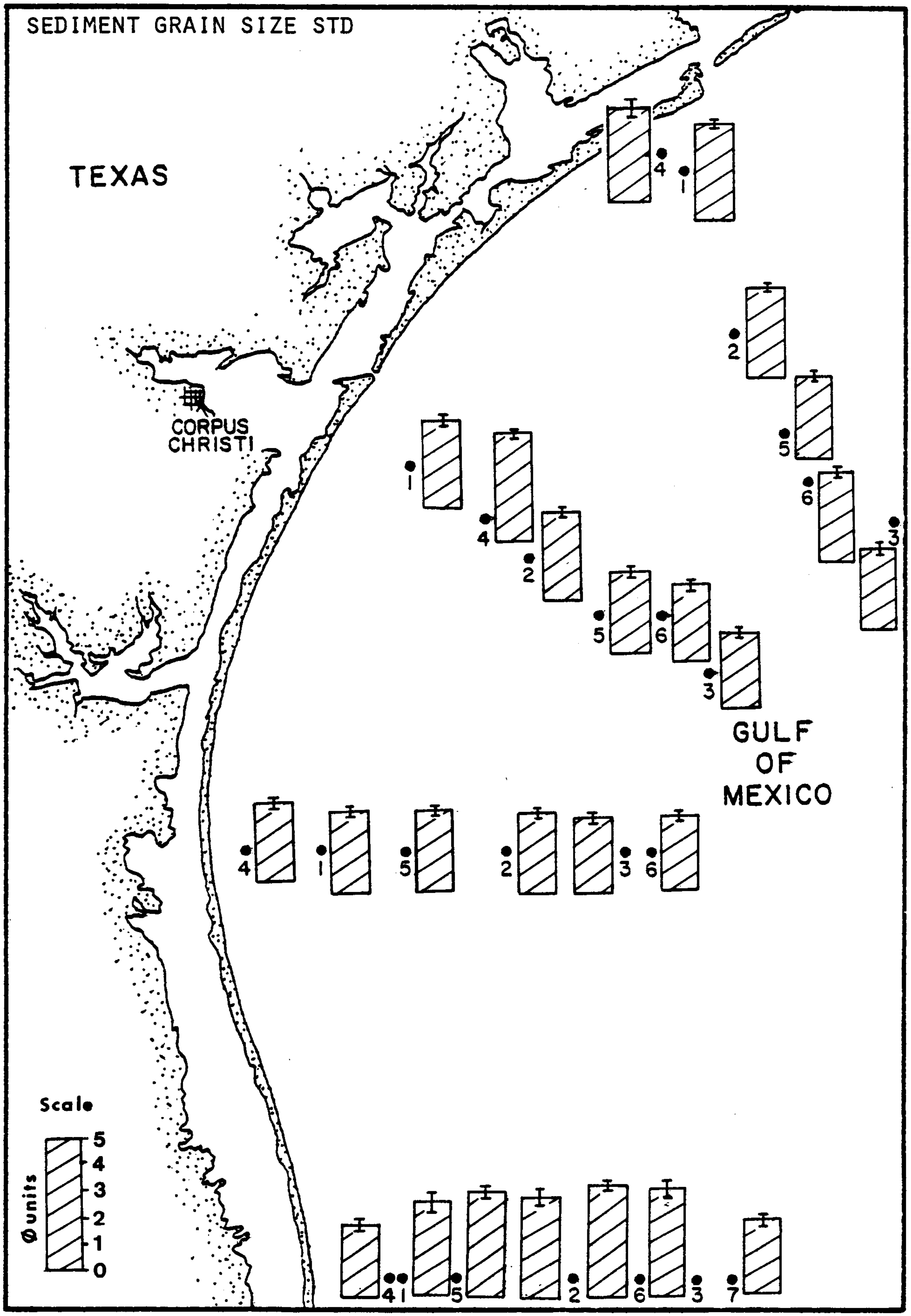


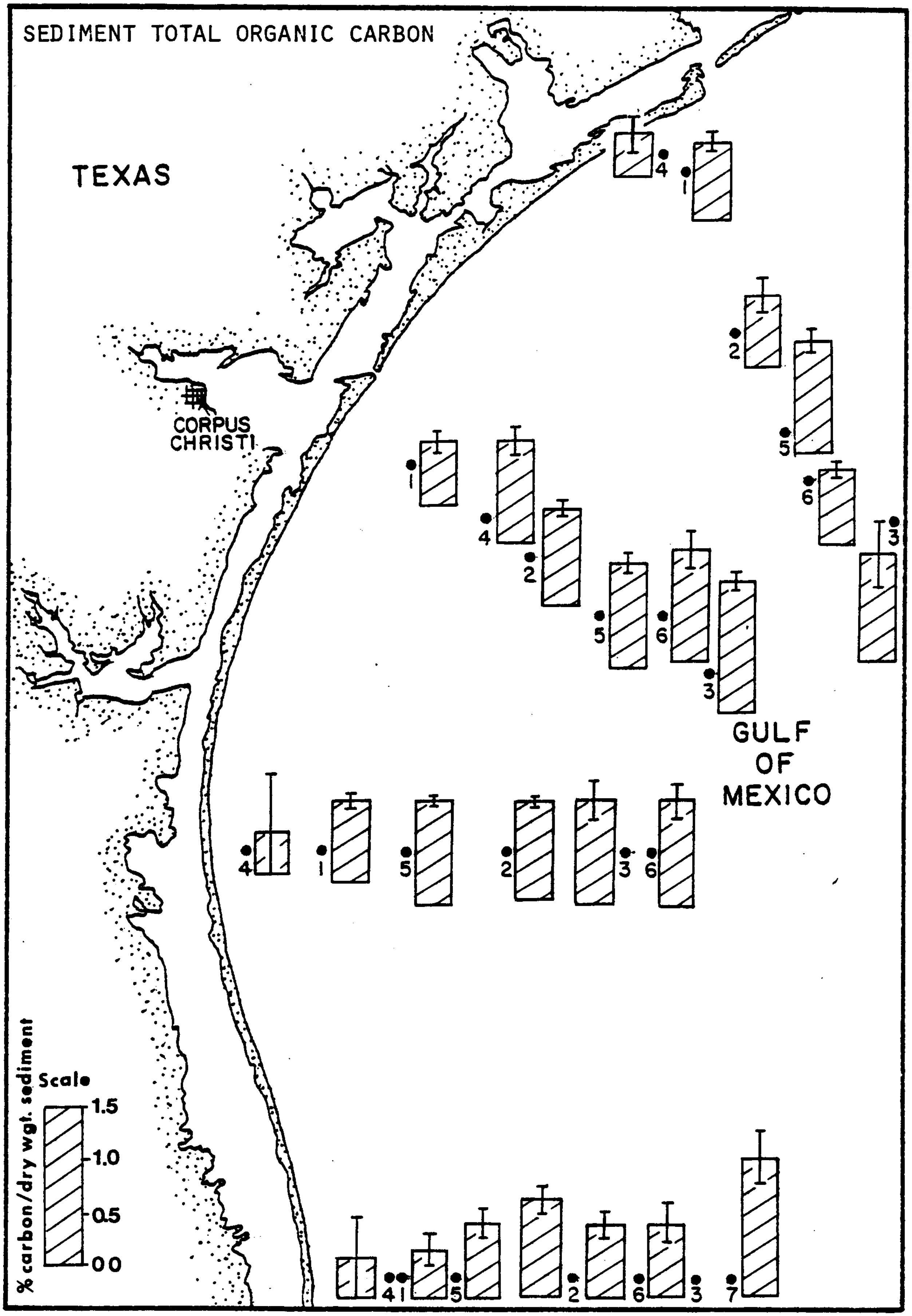
BOTTOM WATER PROPENE
TEXAS
CORPUS CHRISTI
GULF OF MEXICO
Scale
2.0
1.5
1.0
0.5
0.0
nl/l
1
2
3
1
2
3
1
2
3
1
2
3

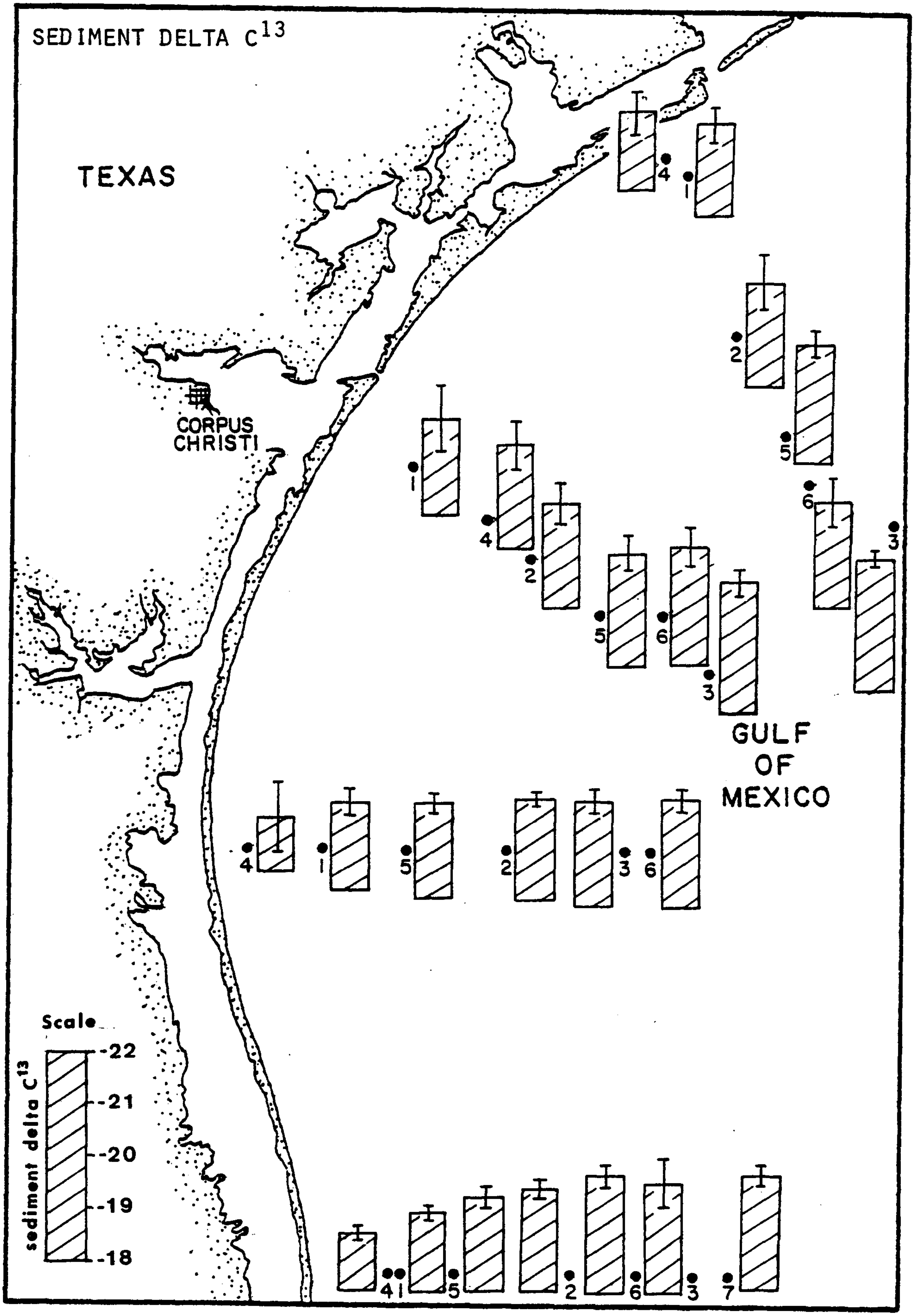

BOTTOM WATER ETHENE
TEXAS
CORPUS CHRISTI
GULF OF MEXICO
Scale
10
8
6
4
2
nl/l
1
2
3
1
2
3
1
2
3
1
2
3

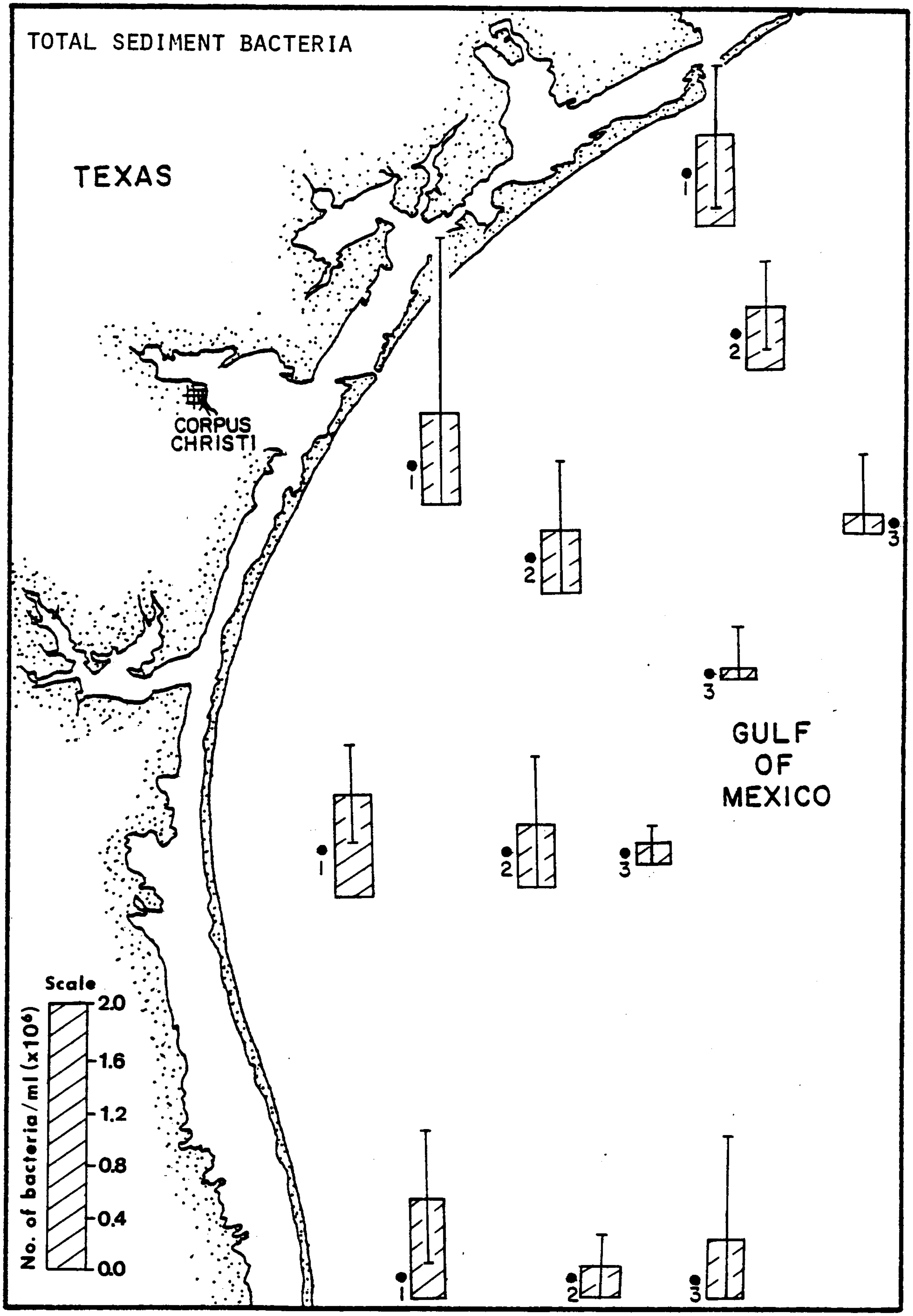

COPEPOD TOTAL DENSITY
TEXAS
CORPUS CHRISTI
GULF OF MEXICO
Scale
1800
1500
1200
900
600
300
0
No. of individuals / m³
1
2
3

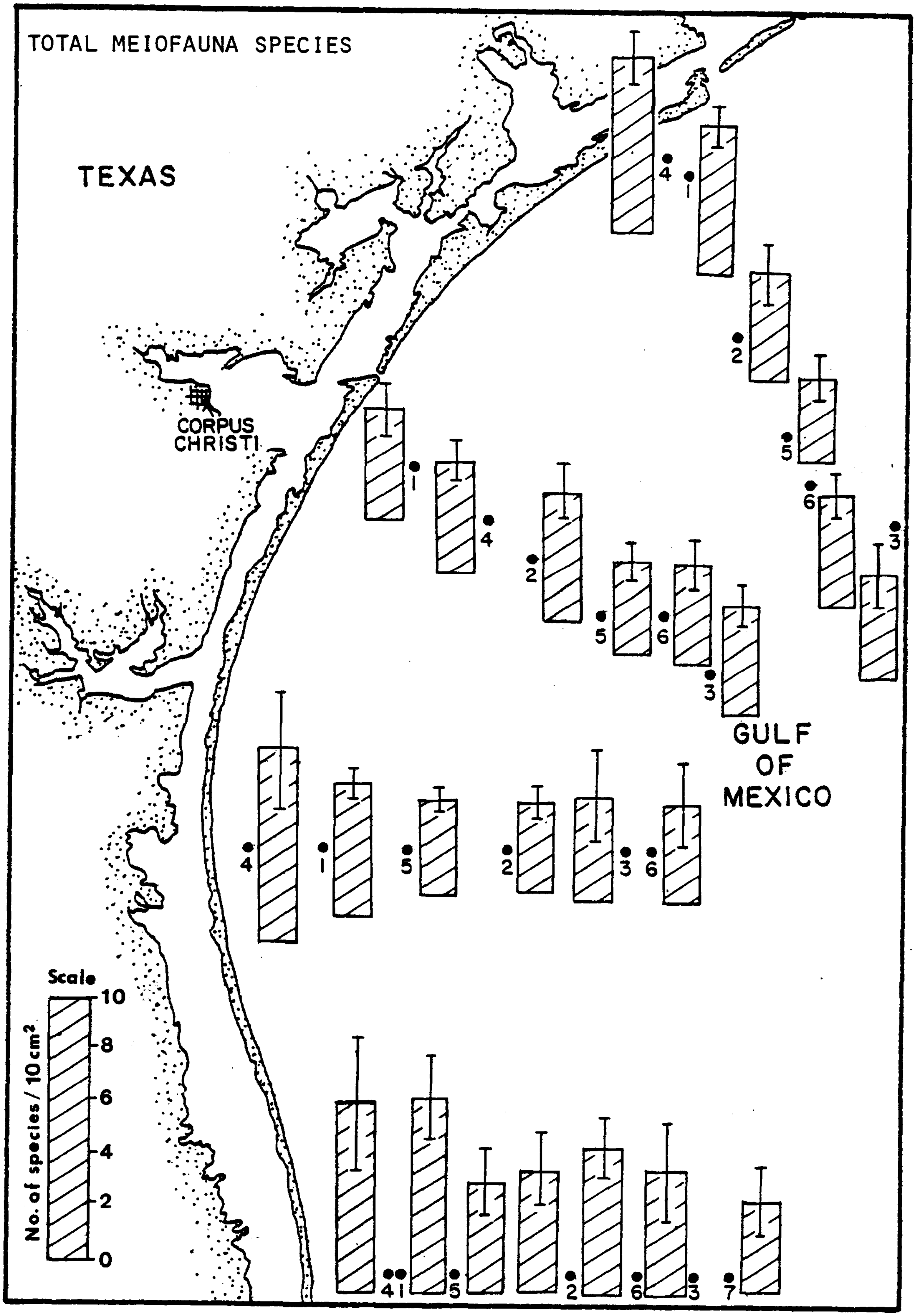

SEDIMENT MEAN GRAIN SIZE
TEXAS
CORPUS CHRISTI
GULF OF MEXICO
Scale
Ø units
10
8
6
4
2
0

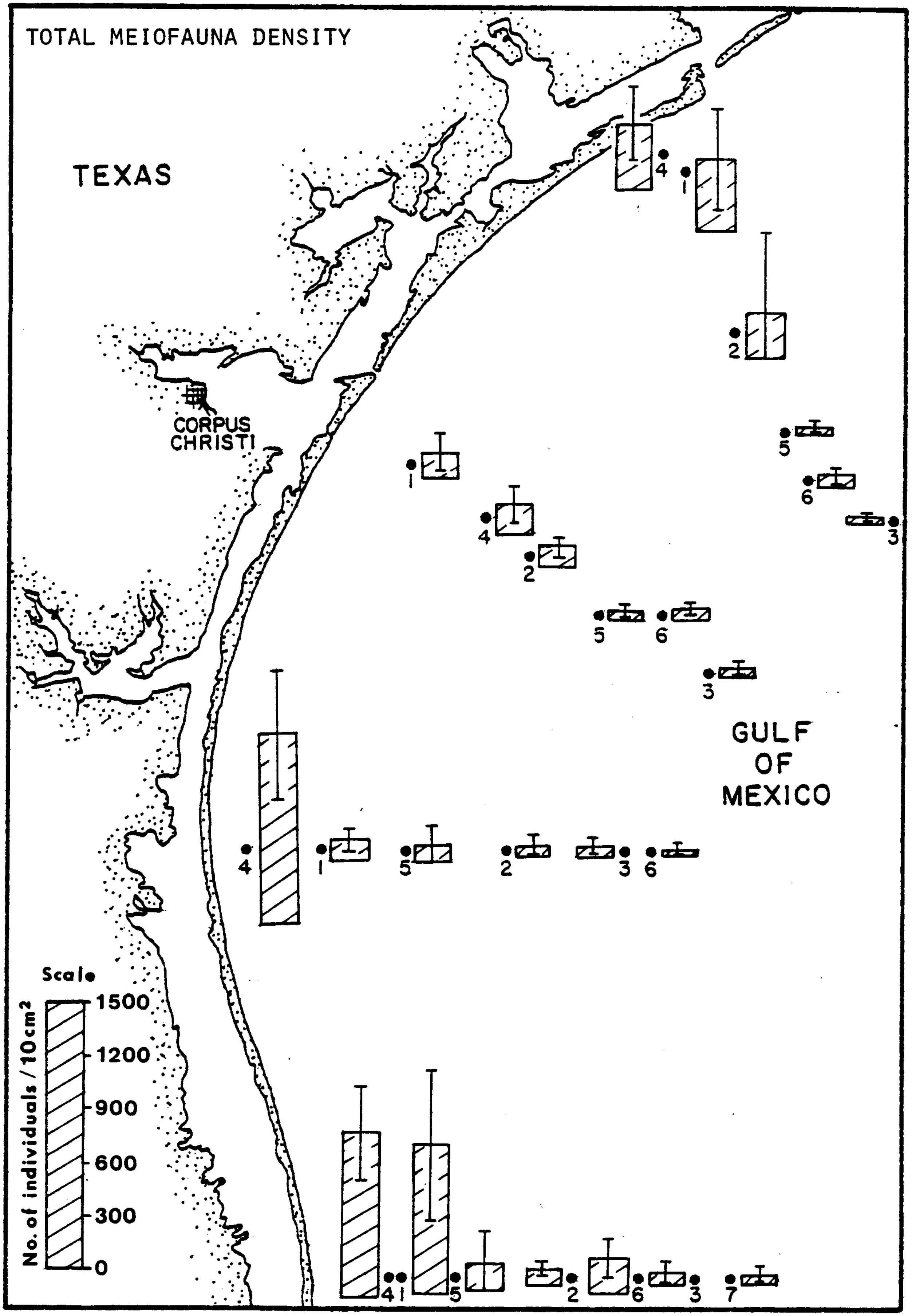

SEDIMENT GRAIN SIZE STD
TEXAS
CORPUS CHRISTI
GULF OF MEXICO
Scale
Ø units
0
1
2
3
4
5

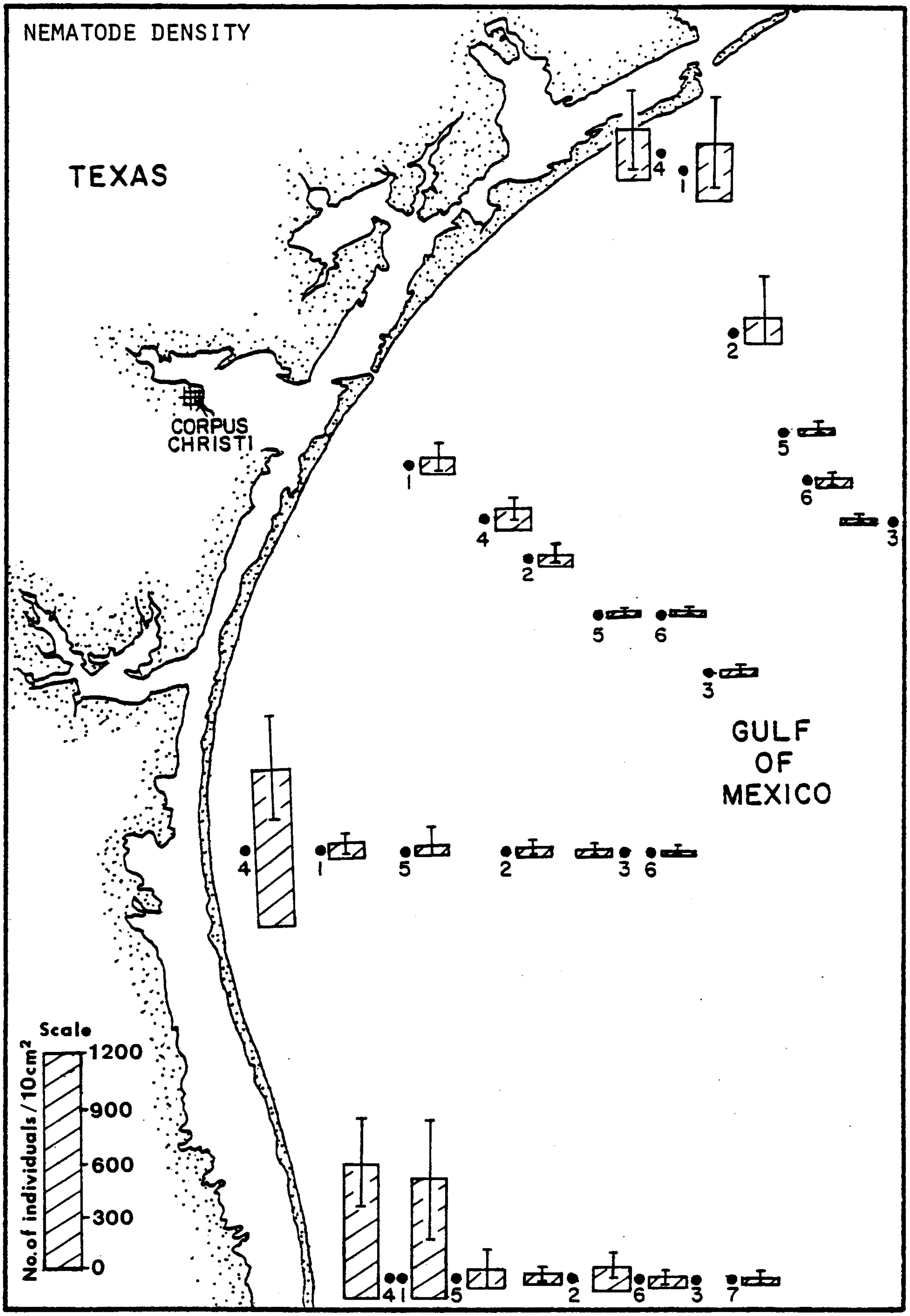

SEDIMENT TOTAL ORGANIC CARBON
TEXAS
CORPUS CHRISTI
GULF OF MEXICO
Scale
% carbon/dry wgt. sediment
1.5
1.0
0.5
0.0

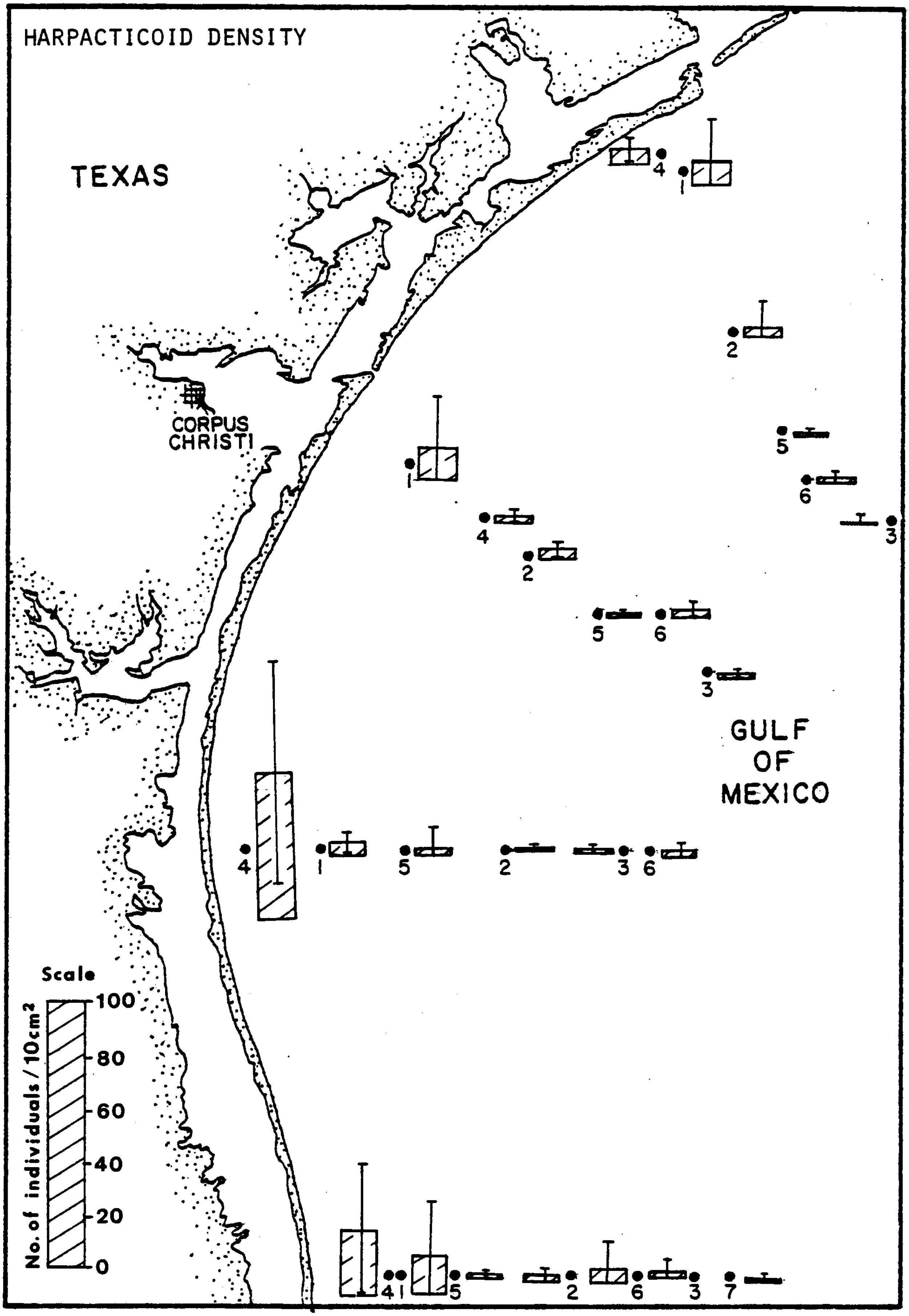

SEDIMENT DELTA C13
TEXAS
CORPUS CHRISTI
GULF OF MEXICO
Scale
sediment delta C13
-22
-21
-20
-19
-18

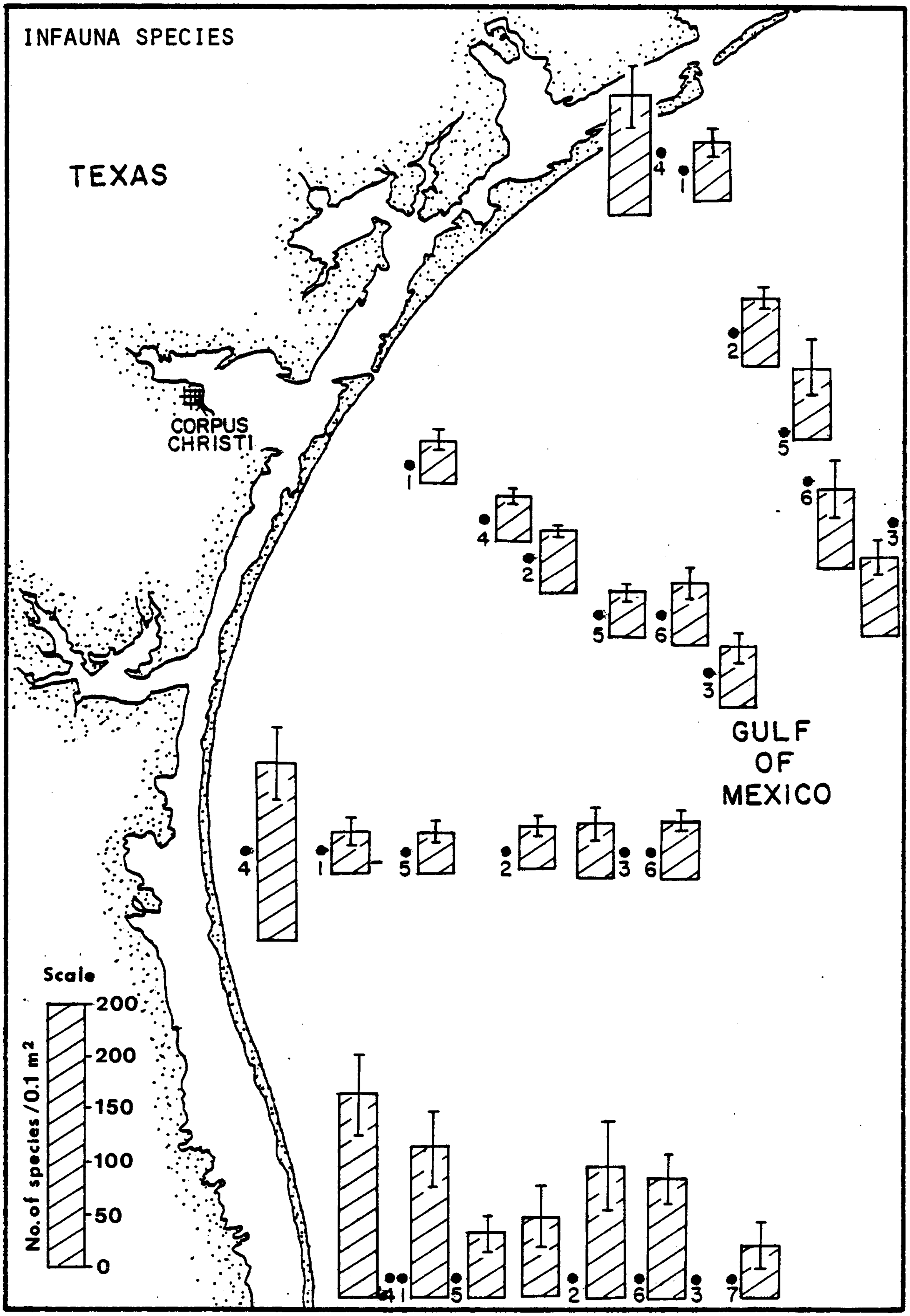

TOTAL SEDIMENT BACTERIA
TEXAS
CORPUS
CHRISTI
GULF
OF
MEXICO
Scale
No. of bacteria/ml (x10⁶)
2.0
1.6
1.2
0.8
0.4
0.0
1
2
3

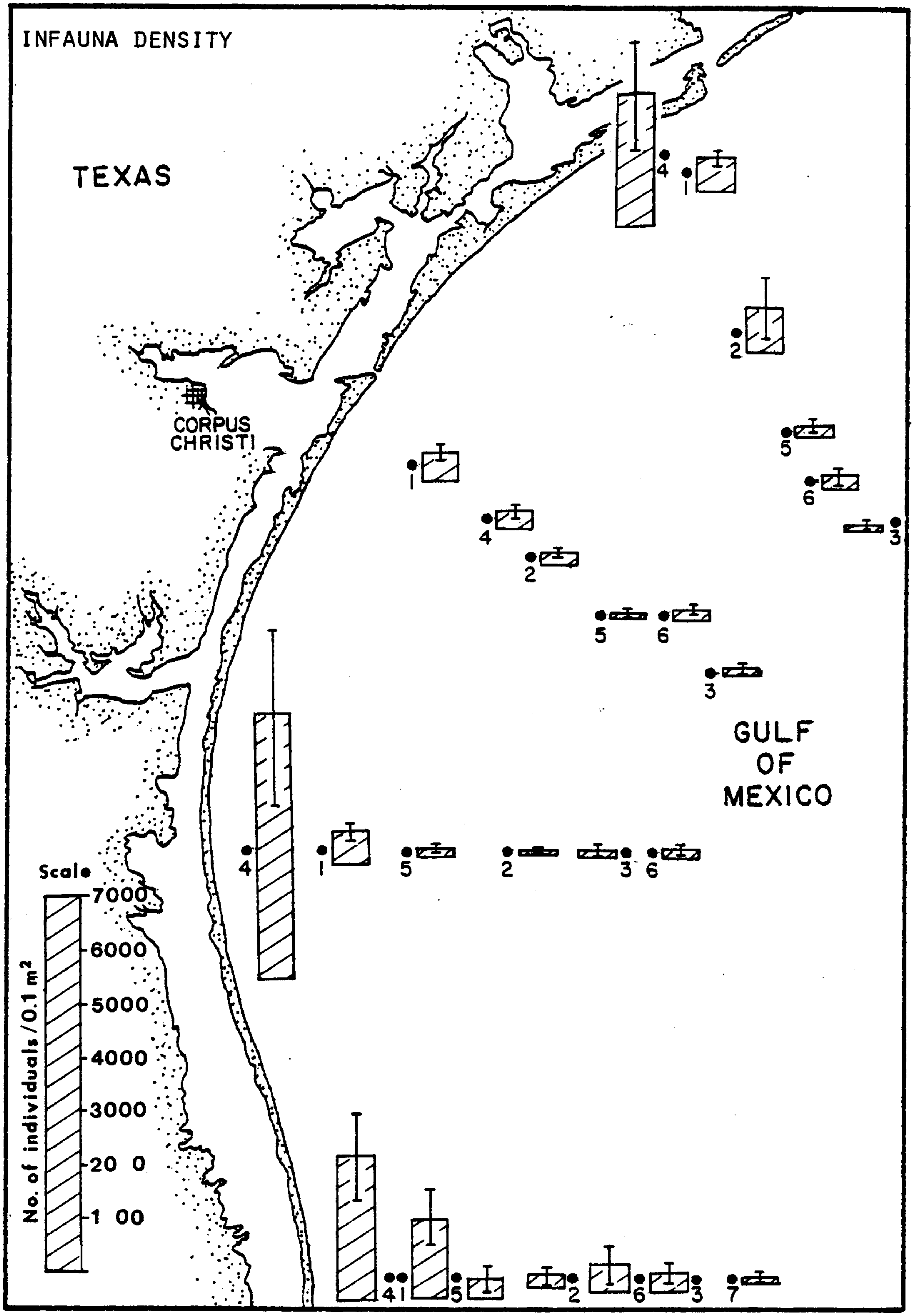

TOTAL MEIOFAUNA SPECIES
TEXAS
CORPUS CHRISTI
GULF OF MEXICO
Scale
No. of species / 10 cm²
0
2
4
6
8
10
4
1
2
5
6
3
7


TOTAL MEIOFAUNA DENSITY
TEXAS
CORPUS CHRISTI
GULF OF MEXICO
Scale
No. of individuals / 10cm²
1500
1200
900
600
300
0
4
1
2
5
6
3
7


NEMATODE DENSITY
TEXAS
CORPUS CHRISTI
GULF OF MEXICO
Scale
No. of individuals / 10cm²
1200
900
600
300
0
4
1
2
5
6
3
1
4
2
5
6
3
4
1
5
2
3
6
4
1
5
2
6
3
7


HARPACTICOID DENSITY
TEXAS
CORPUS CHRISTI
GULF OF MEXICO
Scale
No. of individuals / 10cm²
100
80
60
40
20
0
1
2
3
4
5
6
7


INFAUNA SPECIES
TEXAS
CORPUS CHRISTI
GULF OF MEXICO
Scale
No. of species /0.1 m²
200
200
150
100
50
0
4
1
2
5
6
3
1
4
2
5
6
3
4
1
5
2
3
6
4
1
5
2
6
3
7


INFAUNA DENSITY
TEXAS
CORPUS CHRISTI
GULF OF MEXICO
Scale
7000
6000
5000
4000
3000
20 0
1 00
No. of individuals /0.1 m²
4
1
2
5
6
3
7

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Minerals Revenue Management** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.