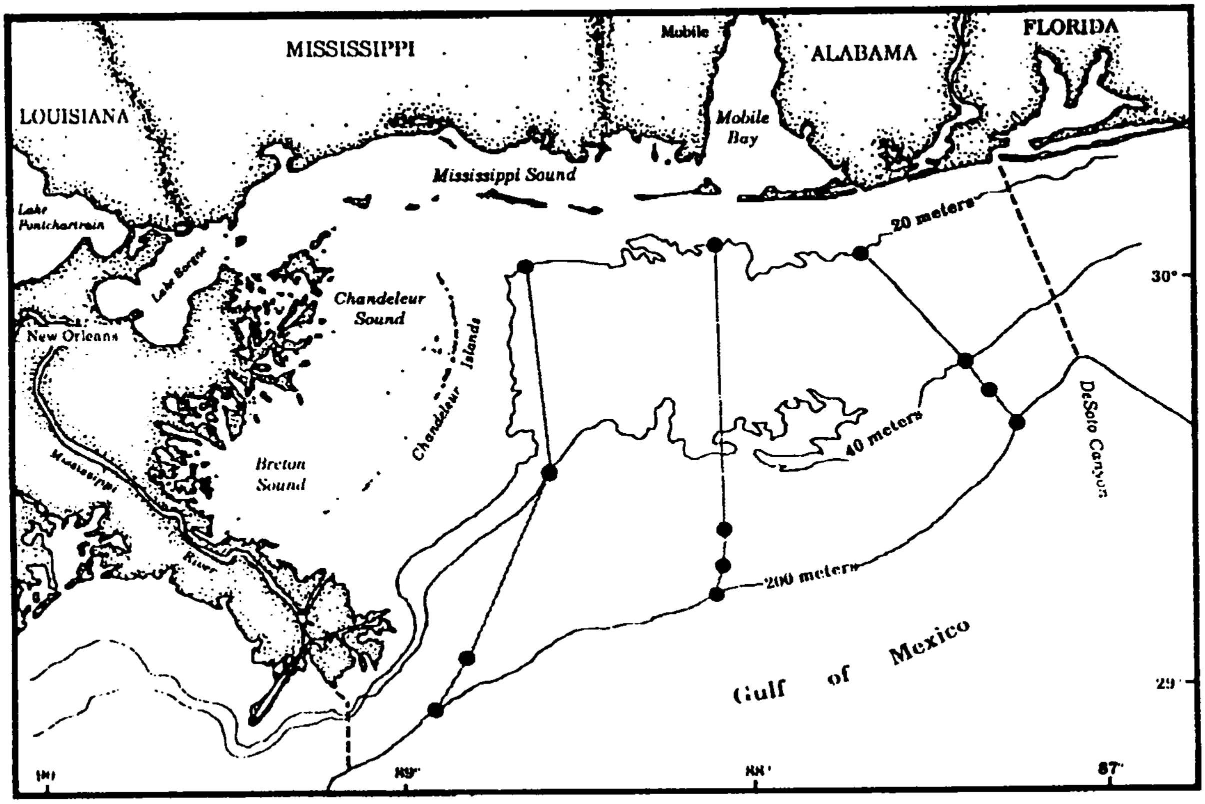
OCS Study
MMS 91-0063

Mississippi-Alabama Continental Shelf Ecosystem Study Data Summary and Synthesis

Volume II: Technical Narrative



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

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Mississippi-Alabama Continental Shelf Ecosystem Study Data Summary and Synthesis

Volume II: Technical Narrative

Editors

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1.0 Executive Summary

James M. Brooks and Rezneat M. Darnell

1.1 Introduction

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

To partially remedy this situation, the Minerals Management Service has sponsored a large multi-year and multi-disciplinary effort to examine the continental shelf ecosystem off the coast of Mississippi and Alabama. Carried out over a period of three years, the investigation has involved study of the following components at regular stations (Figure 1.1):

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

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

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

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

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

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

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

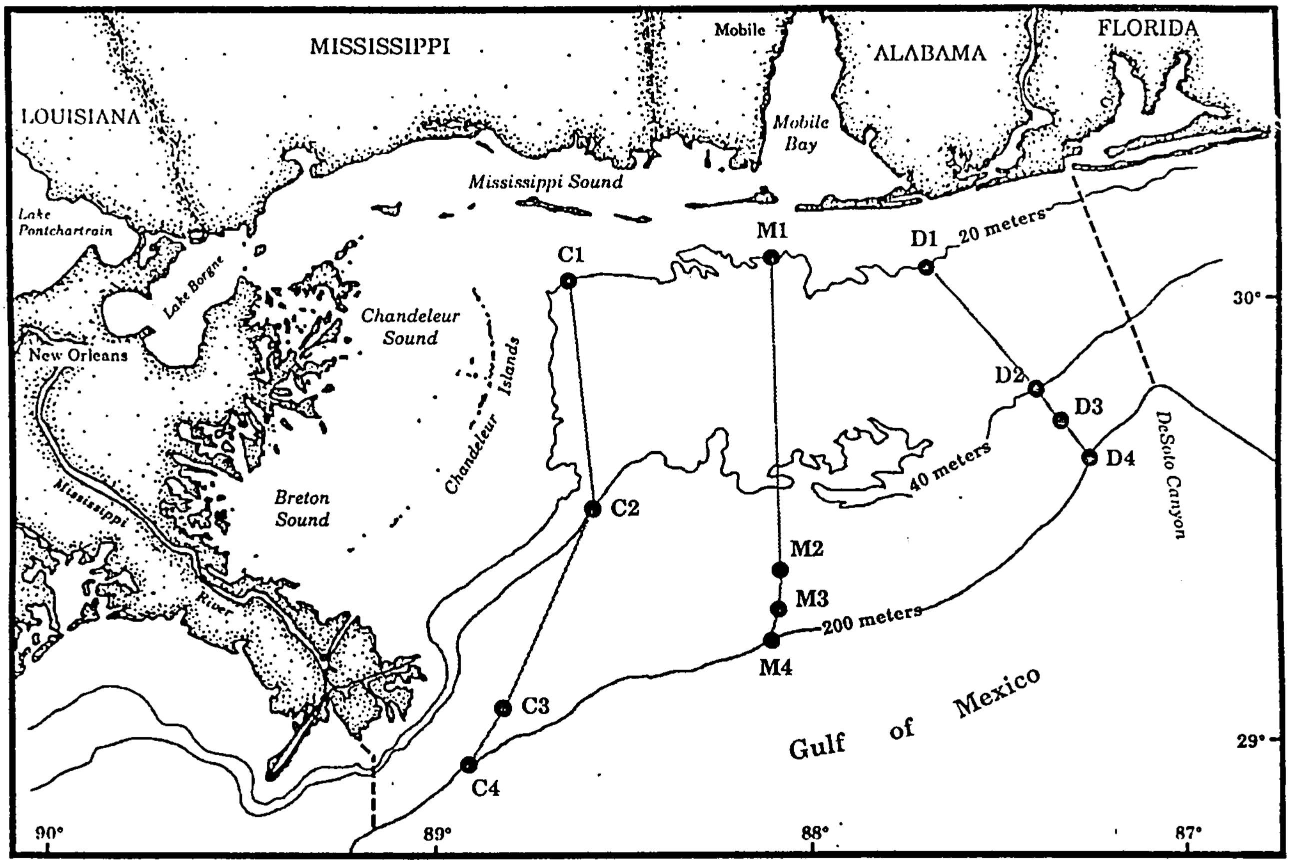

Figure 1.1 Map of the Mississippi-Alabama continental shelf and related waters. Regular semi-annual collecting stations were located along three transects (Chandeleur, Mobile, and De Soto Canyon).

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

1.2 Background

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

1.2.1 Ecological History

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

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

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

1.2.2 Natural Catastrophism

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

Cold Fronts

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

Floods

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

Major Storms

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

Hypoxic Events

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

Red Tide Outbreaks

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

1.2.3 Human Influences

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

Area 1. Mississippi River Delta through Biloxi Marshes

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

Area 2. Lake Pontchartrain through western Mississippi Sound

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

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

Area 3. Central and eastern Mississippi Sound

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

Area 4. Mobile Bay through Pensacola Bay

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

Continental Shelf

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

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

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

1.3 Physical Environment

1.3.1 Water Masses and Circulation

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

1.3.2 Temperature

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

1.3.3 Salinity

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

1.3.4 Light Transmission

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

1.3.5 Dissolved Oxygen

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

1.3.6 Dissolved Nutrients

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

1.3.7 Summary of the Physical Environment

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

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

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

1.4 Bottom Sediments

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

1.4.1 Sediment Characteristics

Clay

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

Silt

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

Sand

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

Gravel

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

Phi

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

Calcium Carbonate

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

Organic Carbon

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

Delta C-13

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

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

1.4.2 High Molecular Weight Hydrocarbons

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

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

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

1.4.3 Trace Metals

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

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

1.4.4 Topographic Features

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

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

Pinnacles - These are the deepest and apparently the oldest; ca. 105 m.
Patch reefs - These are at shallower depth and of intermediate age; ca. 65-75 m.
Ridges and scarps - These are the shallowest and youngest; ca. 60 m.

1.4.5 Summary of Bottom Sediments

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

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

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

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

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

1.5 The Biota

1.5.1 Phytoplankton and Primary Production

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

1.5.2 Zooplankton

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

1.5.3 Nekton

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

1.5.4 Macroinfauna

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

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

1.5.5 Macroepifauna

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

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

1.5.6 Demersal Fish Fauna

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

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

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

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

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

1.5.7 Demersal Fish Food Analysis

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

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

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

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

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

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

1.6 Biota of Hard Bottoms and Topographic High Features

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

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

For each community type the biota potentially consists of coralline algae, attached invertebrates, mobile invertebrates, and the fish fauna. The latter includes species which swim or hover in the water column above the reef as well as those which live on the substrate or inhabit crevices. Large bacterial colonies are associated with gas and brine seeps over a salt dome. As an aid in the visualization of the distribution of biota on the larger features, based upon the best available information, sketches have been made of submerged landscapes showing flat-top reefs (Figure 1.2) and deepwater pinnacles (Figure 1.3).

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

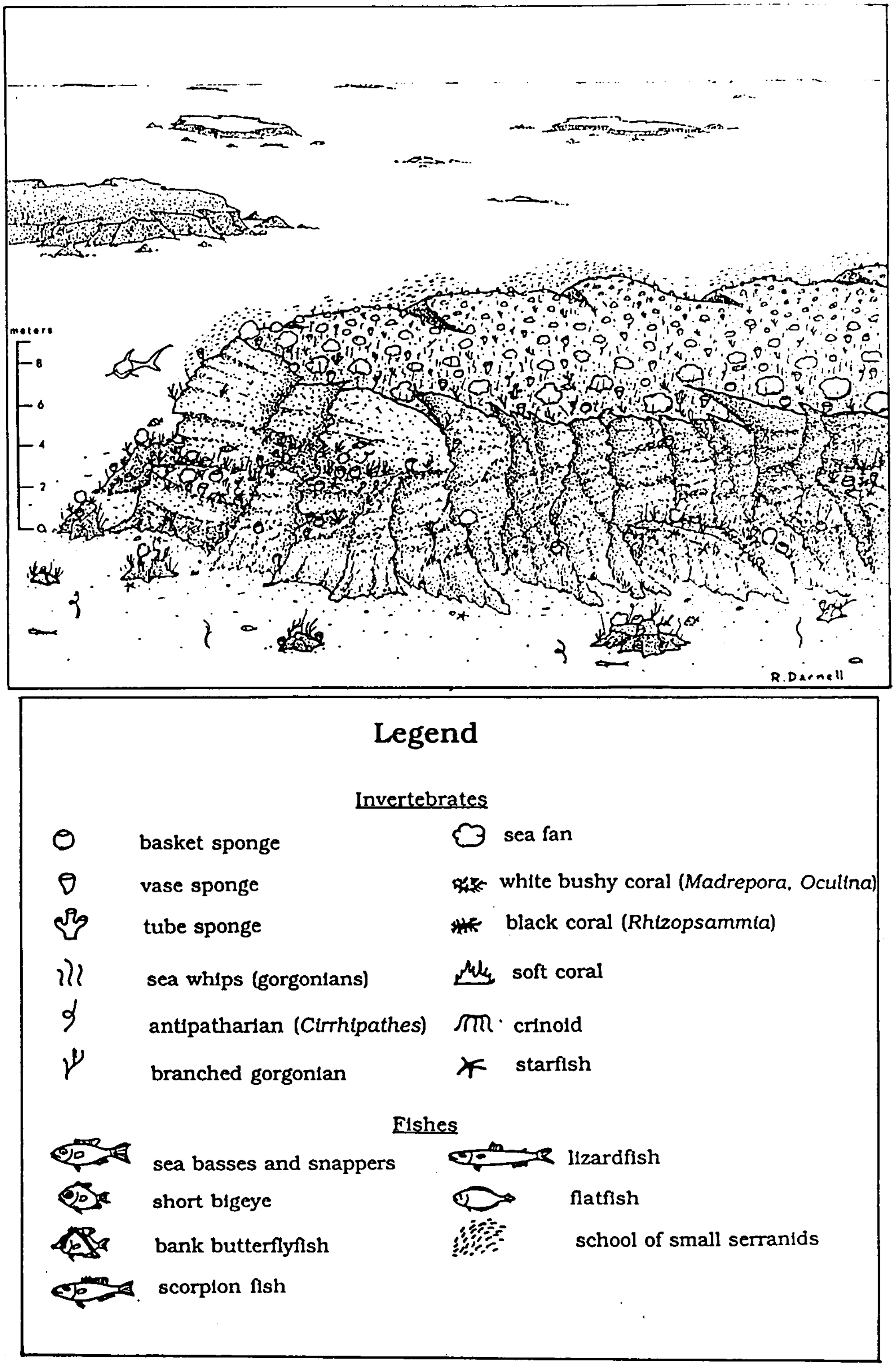

Figure 1.2 Perspective sketch of the submerged landscape of a flat-top reef province as visualized from side-scan sonar and ROV information. The biota are identified in the accompanying legend.

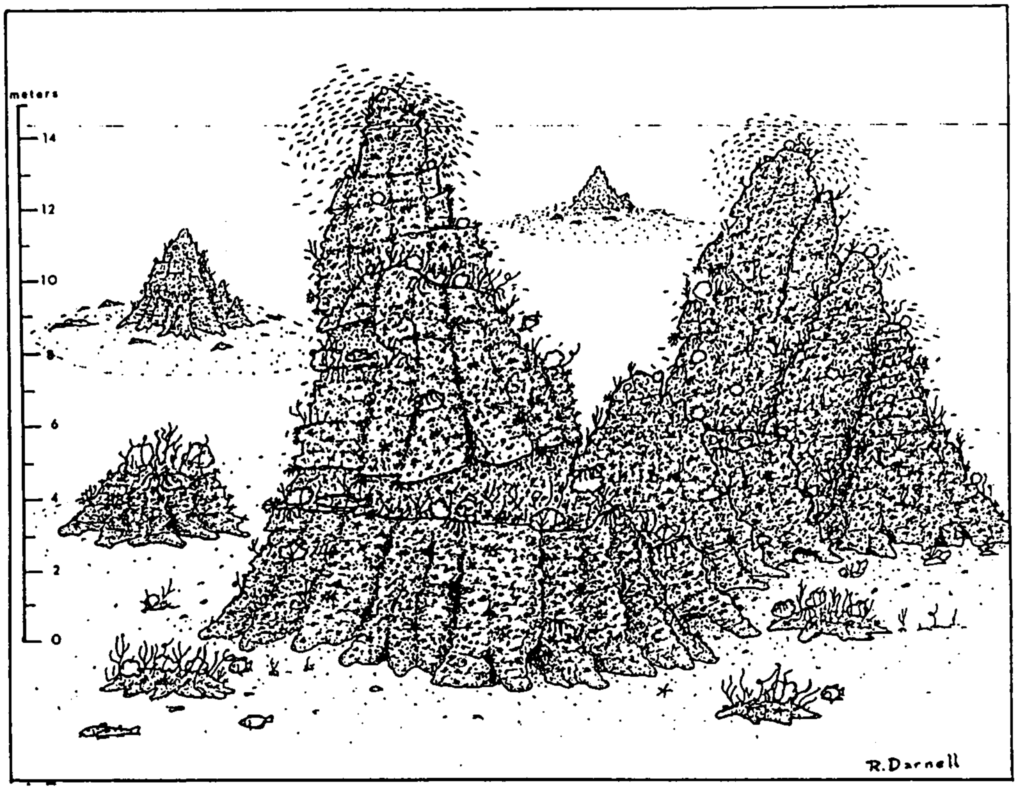

Figure 1.3 Perspective sketch of the submerged landscape of a pinnacle province as visualized from side-scan sonar and ROV information. The biota are identified in the legend accompanying Figure 2.

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

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

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

1.7 Ecosystem Synthesis

1.7.1 The Seasonal Cycle

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

1.7.2 The Benthic and Demersal Biota

1.7.2.1 Faunal Characterization

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

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

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

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

1.7.2.2 Species Assemblages

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

Macroinfauna

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

Macroepifauna

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

Demersal fishes

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

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

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

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

1.7.3 Major Episodic Events

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

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

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

- Extreme drought - reduced recruitment and survival of estuary related species;
- Major storms and hurricanes - brought heavy rainfall and induced strong currents, disrupting normal migration and distribution patterns; and
- Major Loop Current intrusions - displacing shelf waters and driving mobile species to peripheral refuges.

1.7.4 Nutrients and Trophic Relations

1.7.4.1 Nutrient Flow

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

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

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

1.7.4.2 Trophic Relations

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

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

1.7.5 Evolutionary Considerations

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

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

1.7.6 Hard Bottoms and Topographic Features

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

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

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

1.8 Management Implications

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

Normal Variation

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

Episodic Intrusion and Catastrophism

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

Biological Resiliency

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

Long-term Human-induced Pressures

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

Chemical Pollution

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

Topographic High Features - Areas of Special Concern

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

Research Needs

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

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

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

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

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

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

2.0 INTRODUCTION

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

To partially remedy this situation, the Minerals Management Service has sponsored a large multi-year and multi-disciplinary effort to examine the continental shelf ecosystem off the coast of Mississippi and Alabama. The study was designed, not as a total ecosystem effort, but rather to emphasize ecosystem components particularly susceptible to the potential impacts of OCS oil and gas activities. The present investigation represents the most complete study ever carried out on this shelf and one of the most thorough investigations ever conducted on any continental shelf of the northern Gulf of Mexico. The simultaneous measurement and sampling of many of the system elements provides an integrated network of knowledge necessary for true ecosystem synthesis.

Carried out over a period of three years, the investigation has involved study of the following components:

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

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

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

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

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

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

Results of the individual investigations are presented as various chapters of the Final Report, and raw data appear in the appendices. An additional chapter gives a summary of the various studies and, supported by historical data and meteorological records, it provides an overview and interpretation of the shelf ecosystem. Management implications are discussed. The data base and interpretations put forth in the present report should provide a firm basis for assessment of the potential effects of oil and gas development upon the physical and biological resources of this important continental shelf area.

3.0 FIELD SAMPLING AND LOGISTICS

3.1 General Sampling Overview

The field effort was directed toward characterizing biological, chemical, and physical processes which dominate the Mississippi-Alabama-Florida (MAFLA) continental shelf. To this end two summer and two winter biological/chemical characterization cruises were conducted over the contract period. In addition, two years of current meter records were obtained along two transects across the shelf, and a detailed geological characterization of topographic features central to the study area was conducted through two geological cruises and two cruises employing a Remotely Operated Vehicle (ROV).

The biological/chemical sampling array was comprised of three onshore/offshore transects, each with four sampling stations (20, 50, 100, and 200 m). The geological characterization studies were located in the center of the study region between 55 and 180 m isobaths. In the first year three current meter arrays were placed near the eastern transect in water depths of 30, 50 and 500 m. These provided two years of data. In the second study year two additional current meter moorings were deployed in the central transect, providing one year of data along this transect.

In addition to the contracted data collections described above, a biological/chemical characterization cruise was conducted at the same sampling stations in February 1987 aboard the R/V Gyre as part of GERG research activities. Although the samples were collected prior to and not as part this contract, the resultant data set was included in the analysis and interpretation for this study, since sampling sites and methodologies were the same as those used herein. Samples from that pre-award cruise are designated as from Cruise B-0.

With the exception of Cruise B-0 having been conducted on the R/V Gyre and the first geological characterization cruise having begun on the R/V Excellence II, all field work was conducted from the R/V Tommy Munro. The vessel is 29.87 m long, accommodates 12 scientists, and is fully equipped with sampling gear and laboratory space to accommodate the project requirements. The Tommy Munro is owned and operated out of

Biloxi, MS by the Gulf Coast Research Lab. The crew of the Tommy Munro and the support staff at GCRL in Ocean Springs are to be commended and acknowledged for the outstanding contribution they made to the success of the field programs through their cooperative "can do" attitudes, abilities, and efforts.

3.2 Sampling

The study area depicting the twelve sampling stations, the location of the five current meter arrays, and the area of geological characterization and topographic features study is shown in Figure 3-1.

Detailed methodologies for the field samplings are found within the report sections dealing with specific technical aspects of this study. Only a general overview is presented here, and the reader is referred to the technical sections of this document for specific sampling and analytical detail.

3.2.1 Biological/Chemical Characterization Cruises

3.2.1.1 Water Column

Water column characterization was accomplished with a CTD/transmissivity profile and six bottle water casts at each of the 12 stations on every biological/chemical cruise. This basic data set was augmented with CTD/transmissometry profiles during current meter servicing and at selected stations as the vessel transited the study area.

The CTD was a Sea-Bird Electronics Model SEACAT SBE 19, interfaced with a Sea Tech, Inc. 25 cm transmissometer. Water samples for salinity, dissolved oxygen, and nutrient determinations were collected from 1.7 l Niskin samplers. Temperatures on the CTD were confirmed with reversing thermometers on the top and bottom bottles.

Light penetration in the upper water column was measured with a Secchi disc at those stations sampled in the daylight hours.

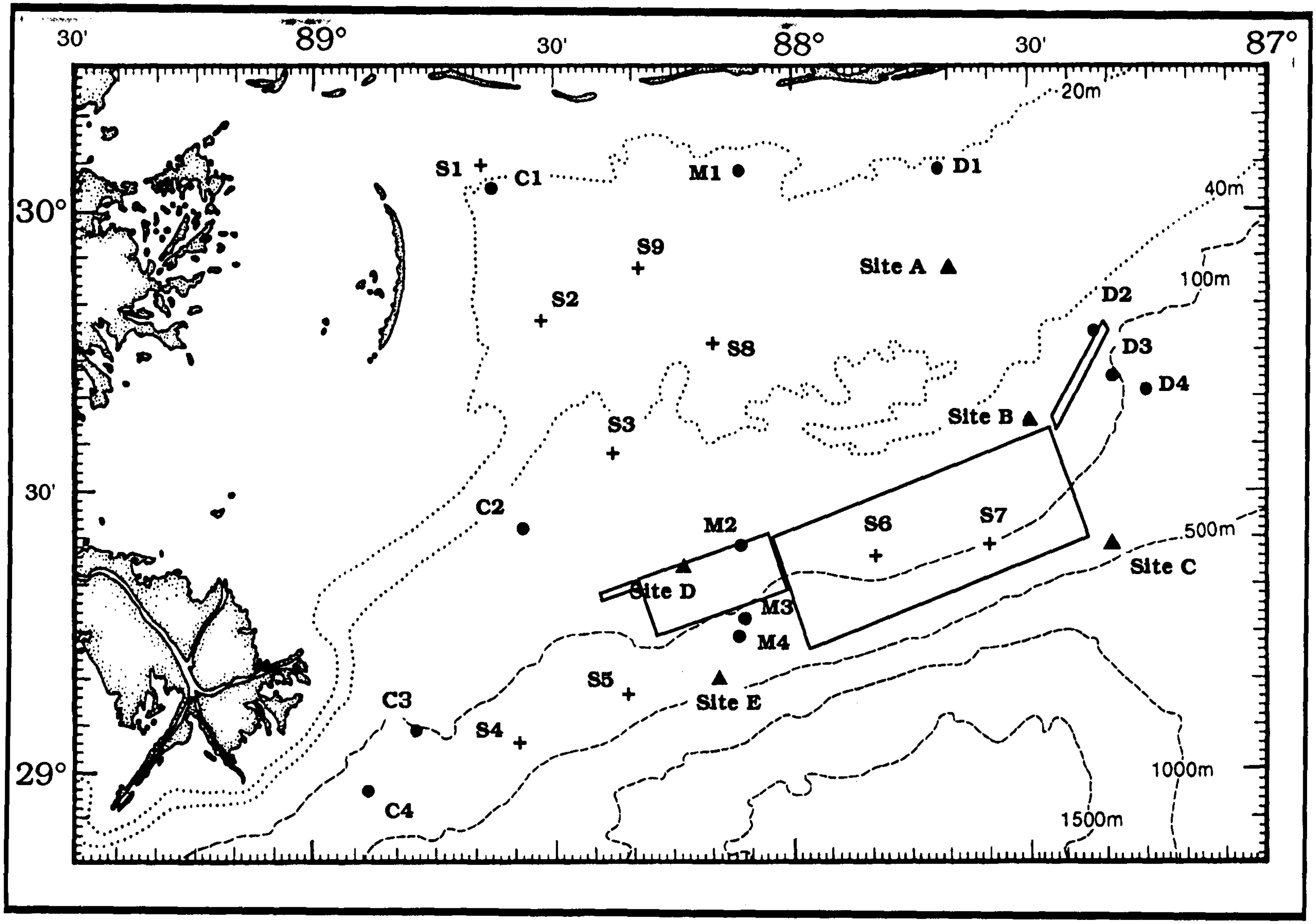

Figure 3-1. Map of the study area showing the 12 sampling stations (●), current meter mooring locations (▲), supplemental CTD stations (+), and the areas of geological characterization and topographic features study.

3.2.1.2 Sediments

Sediments were sampled using a 20 cm box corer or Smith-McIntyre grab depending on the sediment type. Six box cores were taken at each of the 12 stations for infaunal and grain size analysis. Additionally, three box cores were taken at each station and subsamples were composited from these three for analysis of sediment hydrocarbons, trace metals, and grain size.

3.2.1.3 Epifauna/Nekton

Duplicate 15 minute trawls were made at each station for epifauna and nekton collections. The trawl was a semi-balloon otter trawl with 2" stretch mesh, made by Marinovitch Trawl in Biloxi Mississippi. Steel V doors and 100' bridles were used.

3.2.1.4 Sample Inventories

From each of the biological/chemical cruises inventory of samples and/or observations were collected (Table 3-1).

3.2.2 Geological Characterization and Topographic Features

The area for detailed geological characterization in the first year is a rectangle whose corners are:

Northwest corner	29°25'19.8"N	88°02'00.8"W
Southwest corner	29°15'02.6"N	87°57'14.3"W
Southeast corner	29°26'23.2"N	87°23'41.6"W
Northeast corner	29°36'45.5"N	87°28'14.5"W

The area was surveyed with 100% bathymetric, sub-bottom profiling, and side-scan sonar coverage in order to map topographic and hard bottom features for subsequent ROV investigation. Precision navigation was provided by STARFIX and/or ARGO by John Chance & Associates. The survey required 34 southwest-northeast lines and 6 tie lines run nearly perpendicular to the 34. Approximately 1,166 NM of track line data were collected during the first characterization.

Table 3-1. Inventory of samples collected on each biological/chemical cruise.

Station	**Biological**		**Sediment**				**Water Column**				
			Replicates	Composite			Profile			Discrete	
	Infauna	Trawl	Grain Size	Gr. Sz	Tr Met	HCs	CTD	Transmiss	Dis Ox	Nutrients	Sal
C1	6	2	6	1	1	1	1	1	5	4	4
C2	6	2	6	1	1	1	1	1	5	4	2
C3	6	2	6	1	1	1	1	1	5	4	2
C4	6	2	6	1	1	1	1	1	6	6	2
M1	6	2	6	1	1	1	1	1	5	5	5
M2	6	2	6	1	1	1	1	1	6	6	2
M3	6	2	6	1	1	1	1	1	6	6	2
M4	6	2	6	1	1	1	1	1	6	6	2
D1	6	2	6	1	1	1	1	1	5	5	5
D2	6	2	6	1	1	1	1	1	6	6	6
D3	6	2	6	1	1	1	1	1	6	6	6
D4	6	2	6	1	1	1	1	1	6	6	6

In the second year of study, six survey sites were investigated. Four detailed surveys were conducted over features within the first year's study area. These were the "boulder field" patch reef area, a section of the 40 fm reef trend, a linear ridge feature, and a cluster of flat topped reefs. The remaining two surveys were of larger area and were designed to follow the 40 fm (73 m) isobath to the east and west of the original survey rectangle. The 40 fm isobath was chosen because of the discovery of large topographic features and hard bottoms associated with this depth in previous surveys. Approximately 19 NM of detailed records and 335 NM of reconnaissance data were collected in these East and West Addition surveys.

Three topographic features cruises were conducted utilizing the ROV. Two cruises were conducted in the summer of 1988 and were separated by a two month period in order to accommodate the second year geological characterization, and to allow repair and de-bugging of the ROV systems. The final ROV cruise in 1989 focused on hard bottom features discovered during the second geological mapping, investigated the "pinnacle reefs" and other features on salt domes near the Mississippi River, and conducted video surveys at six of the shallower biological sites (C2, M2, M3, D1, D2, D3). ROV surveys were carried out on each of the different type features discovered in the geological characterizations. The ROV surveys were directed at describing biotic assemblages, habitat characteristics, zonation, community condition, and environmental controls. In addition to the 35 mm color stereo photography, and color VHS recordings provided on the ROV, ancillary sampling at the sites included bottom grabs, rock dredges, and hook and line sampling of the nekton.

3.2.3 Hydrography and Current Meter Measurements

Hydrographic measurements were taken as part of the biological/chemical characterization cruises and during the current meter deployments and servicings. In the first year (December, 1987) three current meter arrays were deployed at Sites A, B, and C (Figure 3-1). CTD profiles were taken at each current meter site with each deployment/servicing, and at selected locations across the shelf while in transit on each cruise. Current meters were recovered from the moorings at sites A, B, and C in January 1988 for annual servicing. These moorings were redeployed along with two others (sites D and E) in February 1989. All meters and moorings were recovered and removed in February 1990 (see Section 3.3.3).

Coast Guard experimental drifter buoys were also deployed and tracked in the vicinity of station M4 during the second biological cruise (B2).

3.3 Field Activity Summaries

3.3.1 First Year Activities

Field activities are detailed in the Annual Reports for the respective years in which the cruises occurred. The reader is referred to the First Annual Report for details on the following cruises:

CRUISE	DESIGNATOR	VESSEL	DATES	TYPE/PURPOSE
B-0	87-G-3	GYRE	1/1-31, 1987	BIO/CHEM
B-1	87-MMS-B1	T. MUNRO	9/28-10/5, 1987	BIO/CHEM
G-1	87-MMS-G1	EXCELLENCE	10/5-11/8, 1987	GEO CHARAC
P-1	87-MMS-P1	T. MUNRO	12/20-31, 1987	CURRENTS
B-2 and P-2	88-MMS-B2	T. MUNRO	3/10-3/18, 1988	CM SERVICE
G-1A	88-MMS-G1A	T. MUNRO	4/8-17, 1988	GEO CHARAC
B-3 and P-3	88-MMS-B3	T. MUNRO	8/19-25, 1988	BIO/CHEM

3.3.2 Second Year Activities

The reader is referred to the Second Annual Report for details on the following cruises:

CRUISE	DESIGNATOR	VESSEL	DATES	TYPE/PURPOSE
B-4 and P-4	89-MMS-B4	T. MUNRO	2/11-2/18, 1989	BIO/CHEM CM Service
ROV1	88-MMS-ROV1	T. MUNRO	7/14-23, 1988	ROV,TOPO
G-2	88-MMS-G2	T. MUNRO	8/2-5, 1988	GEO CHARAC
G-2A	88-MMS-G2A	T. MUNRO	8/30-9/7, 1988	GEO CHARAC
ROV2	88-MMS-ROV2	T. MUNRO	9/21-27, 1988	ROV, TOPO
ROV3 and P-5	88-MMS-ROV3	T. MUNRO	6/18-7/3, 1989	ROV/TOPO CM SERVICE

3.3.3 Third Year Activities

In the study's third year the final two field activities were carried out. The last current meter servicing (cruise P-5) occurred in October 1989, and the current meter arrays were retrieved during cruise P-6 in February 1990.

3.3.3.1 Current Meter Servicing, Cruise P-5

Cruise 89-MMS-P5 was conducted October 22-24, 1989 aboard the R/V Tommy Munro, with Frank Kelly as Chief Scientist All five current meter moorings were serviced and the navigation light battery on witness buoy A was replaced. CTD/Transmissivity profiles were collected at the five mooring locations and at five supplemental locations along the cruise track. The instruments that were retrieved were all functioning with the exception of the the speed sensor on the top current meter of mooring E and the tide recorder at Mooring D, which was found to contain a small amount of salt water in the housing. Three of the six elastic tethers on the mooring of witness buoy B were found to be broken. A recommendation was made to MMS for their replacement during a special cruise to be staged for that purpose. The recommendation was declined, and the witness buoy remained intact until final retrieval (see section 3.3.3.2).

3.3.3.2 Current Meter Retrieval, Cruise P-6

The current meters and witness buoys were retrieved February 9 thru 12 on cruise 90-G-3 aboard the R/V GYRE in conjunction with GERG coring activities in the central Gulf. Cruise P-6 marked completion of all field work on the contract. All moored instruments, witness buoys and mooring hardware were retrieved with the exception of the mooring at site E.

Site E mooring and the data contained therein since October 1989 was lost and irretrievable. The mooring, located in 430 m of water, and a Data Sonics acoustic transponder at the top (20 m depth) and an acoustic release at the bottom. Both were functioning immediately after the mooring was last deployed on October 22, 1989. Proper functioning means that they responded to acoustic integrations from the shipboard command unit and gave slant ranges appropriate to their depth and distance from the ship. During the recovery cruise the transponder at the top of the mooring did not reply, indicating either a loss of at least the upper array or malfunction of the transponder. The acoustic release responded properly, but no part of the mooring rose to the surface. A visual search for the subsurface float was performed by divers down to a depth of 90 feet in the vicinity of the mooring, but nothing was found. The acoustic release continued to reply. The bottom portion of the mooring, consisting of the bottom current meter, the steel float above it and the acoustic release, was found floating at an unspecified location by a commercial fishing boat on October 14, 1990. The current meter was damaged and no usable data was recovered.

3.4 Geological Characterization Cruises Overview

3.4.1 Geophysical Surveys

Two different types of geophysical data, side-scan sonar records and seismic reflection profiles, were collected to characterize the submarine geology of the study area. These data were collected in 1987 and 1988 during four cruises on two vessels (Table 3-2). Precision navigation with an accuracy of better than 10 m was used for positioning on all cruises.

Table 3-2. Geophysical cruises.

Cruise	Date	Vessel	Navigation
87-MMS-G1	October 9-November 1, 1987	R/V *Excellence-II*[1]	STARFIX
88-MMS-G1A	April 8-17, 1988	R/V *Tommy Munro*[2]	ARGO
88-MMS-G2	August 2-5, 1988	R/V *Tommy Munro*[2]	STARFIX
88-MMS-G2A	August 30-September 8, 1988	R/V *Tommy Munro*[2]	STARFIX

[1] Texas A&M University
[2] Gulf Coast Research Laboratory

The survey area (Figure 3-1) is a large rectangle with extensions to the east and west. The main survey area is a rectangle with dimensions of about 11 x 32 nm (20 x 59 km), its long side parallel to the shelf break. It was surveyed during cruises 87-MMS-G1 and 88-MMS-G1A. Thirty-four ship tracks were run within this area to achieve 100% side-scan sonar coverage (Figure 3-2). Typical vessel speeds ranged from 5-8 knots. Lines 1-18, in the northern part of the main survey, were spaced 575 m apart to obtain complete side-scan coverage with a swath width of 600 m. Lines 19-34, in the southern part of the survey, were spaced 775 m apart to achieve side-scan sonar coverage with a swath width of 800 m. Six tie lines (A-F) were run in a zig-zag pattern across the preceeding lines to provide seismic reflection data oblique to the shelf break trend (Figure 3-2).

Additional geophysical data were collected in three areas: four detailed surveys within the main survey as well as reconnaissance surveys extending to the east and west (Figure 3-2). The detailed surveys (DS-1, DS-2, DS-3, and DS-4) were run to provide clearer images of interesting features observed during the original survey. The east and west extensions were done along isobaths near which topographic features were noted in the main survey. During the detailed surveys, the ship was run at 4-5 knots along track lines spaced 150 m apart. The side-scan sonar was operated with a swath width of either 200 m or 400 m to achieve coverages exceeding 100%. The east and west extension surveys used track spacings of 550 m and swath widths of 600 m. However, in the west extension, four of 24 planned lines were skipped (Figure 3-2; lines W2, W4, W6, and W8) in an area in which no seafloor features were noted. In this part of the west extension, the side-scan sonar coverage was 55%; elsewhere it was approximately 100%. The east extension consisted of only three lines (Figure 3-2; lines E4-E6). Time and weather constraints prevented completion of a larger survey program in that area.

3.4.1.1 Side-Scan Sonar and Subbottom Profiler

An EG&G model 260 side-scan sonar operating at 100 kHz was used to make acoustic images of the seafloor. From the acoustic energy returning to it from the seafloor, the sonar produced an image with a gray-scale proportional to the signal strength. These images were printed with a width of 8 inches, using an electrostatic plotter, and are corrected for vessel speed and slant-range. Additionally, a time-varying-gain (TVG) was applied to provide a consistent signal level across the image. The side-scan sonar towfish was towed behind the ship at distances varying from 100-500 m,

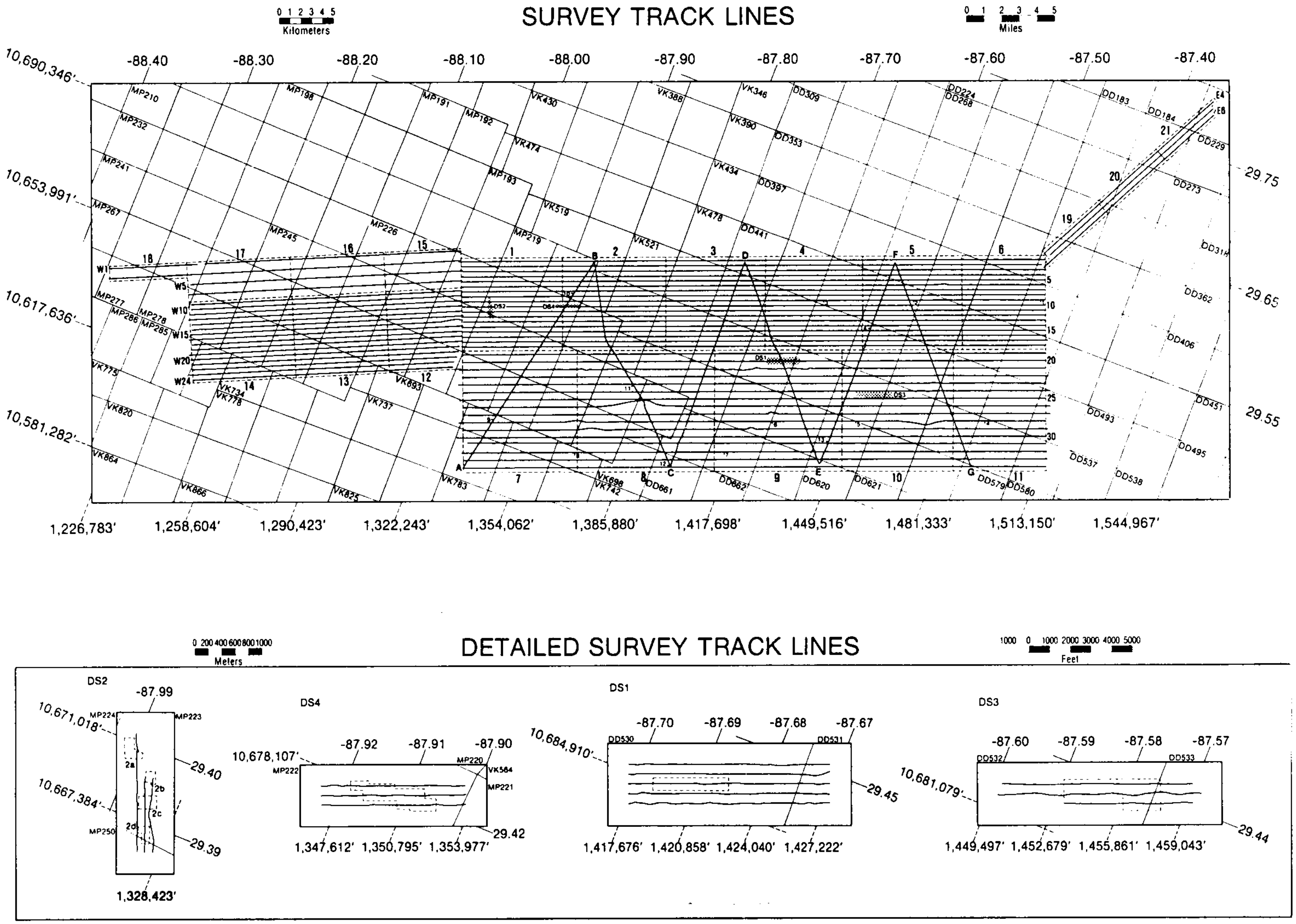

Figure 3-2. Ship tracks along which geophysical data were collected. Heavy straight lines numbered 1-34, A-F, W1-W24, and E4-E6 are the ship tracks. Shaded areas denote detailed surveys (DS1-DS4) whose ship tracks are shown at bottom. Light lines are lease block boundaries. Selected lease blocks are labelled; "MP" denotes "Main Pass", "VK" - Viosca Knoll, and "DD" - Destin Dome. Dashed lines in upper part of figure show side-scan sonar image mosaics presented in Laswell et al. (1990). Large numbers 1-21 are mosaic numbers. In bottom part of figure the dashed lines represent the parts of the detailed surveys for which mosaics are shown in Laswell et al. (1990).

depending on the depth of the seafloor and vessel speed. Typically, the towfish was maintained at an altitude above the seafloor of 5-10% of the swath-width.

Seismic reflection data were collected mainly using an EDO-Western model 515A echo-sounder with a 10 kilowatt booster amplifier operating at 4 kHz. After weather-related equipment failure, a Raytheon model PTR-105 echo-sounder using a frequency of 3.5 kHz was used for the last cruise (88-MMS-G2A). The transducers of both systems were towed directly below the stern of the vessel at a depth of 9 m. The seismic reflection data were displayed on a 20-inch electrostatic plotter using a repetition rate of 0.25 seconds in water shallower than 188 m and 0.5 seconds in deeper water.

3.4.1.2 Navigation

High resolution navigational equipment was used to position all of the geophysical tracks. Lines 1-20 in the main survey area, the detailed survey lines, and the east and west extension lines were navigated using a STARFIX satellite navigation system, leased from John E. Chance and Associates (JCA). This system receives and compares the signals from four geosynchronous satellites and converts the phase delays into a position. A new position is calculated about once every second with an accuracy of approximately 5-8 m. Lines 21-34 and A-F were navigated using an ARGO radio-triangulation system also leased from JCA. This system compares radio signals from a suite of land-based stations to determine its position. When calibrated using the known positions of objects near the survey area, this system is capable of determining positions with an accuracy near that of the STARFIX system. All positions were determined on a Clarke 1866 ellipsoid (Deetz and Adams 1969) and corresponded to the location of the navigation receiver antenna on the ship, which was amidship, approximately 9 m from the stern.

The navigation data were recorded at shotpoints along each survey line. These shotpoints were spaced 150 m apart for the reconnaissance survey lines and 60 m apart along the detailed survey lines. Shotpoints were marked on both the side-scan sonar and seismic reflection records so that they could be correlated with navigation.

4.0 SEDIMENT HYDROCARBON AND BULK ORGANIC MATTER DISTRIBUTIONS

Mahlon C. Kennicutt II

4.1 Introduction (including historical background)

Previous studies of sediment hydrocarbons in or near the study area are primarily restricted to three reports (Gearing et al. 1976; Boehm 1979; and Brooks et al. 1988). Quantitative data are difficult if not impossible to directly compare with the present study due to the widely varying analytical methods utilized. The types of data collected are also highly variable with no study collecting the same sets of data as the present study.

Gearing et al. (1976) reported the analysis of sixty sediments from the northeastern Gulf of Mexico continental shelf. Total extractable organic matter (EOM) averaged 133 ppm ±80 percent and 232 ppm ±53 percent for sediments off Florida and the Mississippi River, respectively. Aliphatic hydrocarbons were determined gravimetrically and accounted for only a small percentage of the EOM. The aliphatic hydrocarbons were dominated by a series of branched or cyclic unsaturated C_{25} isomers, n-C_{17}, high molecular weight odd carbon number n-alkanes, and an unresolved complex mixture (UCM). The relative abundances of these compounds varied regionally and represent a mixture of biological (marine and terrestrial) and petroleum hydrocarbons (UCM). Aromatic fractions exhibited sharp peaks on top of a moderate envelope of unresolved compounds (GC/FID). The large number of peaks in the aromatic fractions did not correspond to the available aromatic standards (no GC/MS confirmation was available). It was concluded that a western zone, which encompasses the present study area, extending eastward to the Alabama shelf, was dominated by terrigenous and petroleum hydrocarbon inputs from the Mississippi River and delta area.

A similar conclusion was reached by Boehm (1979) based on the analysis of sediments from the Mississippi, Alabama, Florida Outer Continental Shelf (BLM/MAFLA) baseline environmental study. A region on the Mississippi-Alabama Shelf and the more offshore areas of the Florida OCS showed strong petrogenic, anthropogenic, and terrigenous biogenic influences. Petrogenic sources were inferred from chromatograms with a double "hump" of unresolved compounds and a regular series of n-alkanes. Total hydrocarbons as estimated by gas chromatography averaged 1.6 ppm on the Mississippi-Alabama Shelf.

The most extensive sediment aromatic hydrocarbon (PAH) database in bays shoreward of the study area has recently been generated as part of NOAA's Status and Trends program. Sediments were collected at multiple sites within Gulf coast estuaries and bays and analyzed over a two year period. The data base includes samples in bays from Terrebonne Bay on the western side of the delta to Pensacola Bay in Florida on the east. Total PAHs in sediments of these bays varied below the detection limit to 4252 ppb and 44 to 5591 ppb during 1986 and 1987 samplings, respectively. Based on molecular compositions (i.e., the abundance of anthracene relative to phenanthrene) it was determined that the PAHs were predominantly pyrogenic in origin. Pyrogenic sources include fossil fuel burning, carbonization of coal, and forest fires. Unrefined petroleum did not appear to be a major source of PAHs. However, the sampling locations were intentionally selected away from known point sources of pollutants such as large urban areas and industrial complexes and the target compounds do not detect highly weathered petroleum residues, since most target compounds are removed due to microbial degradation and solution in water.

4.2 Analytical Methods

4.2.1 Bulk Parameters

Sediment is weighed (0.2-0.5 g) into disposable 5 ml polystyrene beakers and treated with concentrated HCl to remove inorganic carbon (carbonate). Acid is added dropwise until no degassing is observed. The treated samples are then dried at 50°C in a recirculating oven for 24-36 hours to remove excess acid and moisture. After drying, the sample is quantitatively transferred to a sintered crucible. Iron accelerator and tin coated copper catalyst are added and analyzed by total combustion on the Leco instrument. Organic carbon is converted to CO_2 and analyzed with a non-dispersive infrared spectrophotometer (Leco WR-12 Total Carbon

System). Blanks and standards are run on a daily basis. Leco steel ring carbon standards are commercially available. All samples are analyzed in duplicate and averaged. Periodically samples are combusted at > 800°C in a high vacuum Craig-type combustion system as a check on the combustion efficiency of the Leco System. Calcium carbonate is determined as the difference between a treated (acidified) and untreated carbon determination.

Sediment grain size analyses followed the laboratory procedure of Folk (1974). Samples are homogenized, treated with an aliquot of 30% hydrogen peroxide (H_2O_2) to oxidize organic matter, and washed with distilled water to remove soluble salts. Sodium hexametaphosphate was added to deflocculate each sample. The samples were then wet-sieved using a 62.5 micron (4.0 phi) sieve to separate gravel and sand from the silt-clay fraction.

The total gravel and sand fraction was then oven dried (40°C). Each fraction collected was examined for aggregates, disaggregated if necessary, and weighed to three significant figures.

The silt-clay fraction was analyzed for particle size distribution by the pipette (settling rate) method.

Sediment samples for carbon isotope analysis were prepared by a closed tube method. The carbon dioxide samples were analyzed on a Finnigan MAT 251 isotope ratio mass spectrometer with triple collector. Measurements were made relative to several working standards. All values are reported in the ‰ notation relative to the Pee Dee Belemnite carbonate standard.

4.2.2 Hydrocarbons

Sediment samples from six replicate box cores were combined and analyzed for the compounds listed in Table 4-1. The following analytical procedures provide quantitative hydrocarbon concentrations in sediments from the study area. The Quality Assurance protocol as described in GERG's manual for "Analytical and Quality Assurance Procedures for the Measurement of Trace Organic Compounds" are strictly adhered to and provide data that meet the precision, accuracy, and completeness objectives

Table 4-1. Hydrocarbons determined by the analytical methodologies.

Aliphatic Compounds	Aromatic Compounds	
n-C_{11} to n-C_{32}	Naphthalene	Methyl phenanthrenes
pristane	Methylnaphthalenes	Pyrene
phytane	Dimethylnaphthalenes	Benzanthracene
	Trimethylnaphthalenes	Chrysene
	Fluorene	Benzo(b) fluoranthene*
	Fluoranthene	Benzo(k) fluoranthene*
	Acenaphthene	Benzo(e) pyrene
	Acenaphthylene	Benzo(a) pyrene
	Phenanthrene	Dibenzanthracene
	Anthracene	Benzo (g,h,i)perylene
		Indenoperylene

* These two isomers are resolved under the given conditions but other more complex mixtures of benzofluoranthenes may not be fully resolved.

Table 4-2. Summary of precision, accuracy and completeness objectives.

Measurement Parameter	Precision Std. Dev.	Accuracy	Completeness
Aliphatic Hydrocarbons (AHs)	± 20%	± 30%	90%
Polynuclear Aromatic Hydrocarbons (PAHs)	± 20%	± 30%	90%

outlined in Table 4-2. The lower limit of reporting is 10 ppb for all analytes and exceeds the method detection limit by at least a factor of five.

Sample Preparation

All glassware is precleaned by washing in Micro cleaning solution, rinsing with distilled water and combustion at 400°C for four hours. All solvents are glass-distilled, nanograde purity (e.g., Burdick and Jackson Laboratories, Inc.). Solvent purity is checked by concentration of each solvent 10-fold greater than the concentration factor required in the analytical methodology. The concentrated solvent is tested by the same analytical and detection systems as samples and all analytes of interest in the blank analysis must be lower than the limit of quantitation (LOQ) for the solvents to be acceptable for sample processing.

Each set of samples (10-20 samples) is accompanied by a "system blank" and a "spiked blank" which are carried through the entire analytical scheme in a manner identical to samples. "System blanks" and "spiked blanks" are evaluated by gas chromatography with appropriate detectors. "System blanks" include all reagents, solvents, and internal standards. "System blanks" are acceptable if all of the analytes of interest are below the LOQ, otherwise corrective action is taken. No samples are processed until an acceptable "system blank" is obtained. "Spiked blanks" are "system blanks" plus known amounts of all analytes. Standard reference materials (in the appropriate matrix) are analyzed as additional quality assurance checks when available.

Surrogates are added to all samples immediately before extraction. The aliphatic surrogates are d_{26}-dodecane, d_{42}-n-eicosane, d_{50}-tetracosane and d_{62}-triacontane. The aromatic surrogates are d_4-1,4-dichlorobenzene, d_8-naphthalene, d_{10}-acenaphthene, d_{10}-phenanthrene, d_{12}-chrysene, and d_{12}-perylene. Surrogates are added at a concentration similar to that expected for the analytes of interest. All surrogates are fully resolved from, and do not interfere with, naturally occurring substances under the described analytical conditions. All data is corrected for surrogate recoveries.

Approximately 25 g of freeze-dried sediment is ground, surrogates added, and Soxhlet extracted for 12 hours with 250 ml of methylene chloride. The organic phase is concentrated to ~ 10-15 ml in a round bottom flask equipped with a three-ball Snyder condenser. Activated copper is added to the extract during the extraction and concentration steps to remove elemental sulfur. The extract is concentrated further in a 25 ml Kuderna-Danish (KD) receiver in a water bath (60°C). Extracts are stored refrigerated (-4°C).

Extractable organic matter (EOM) content is determined by weighing an aliquot of the solvent extract. Ten µl of the extract is transferred to a preweighed filter pad on a Cahn Electrobalance and the solvent is allowed to evaporate. The lipid content is determined from the residual weight and reported as a percent of the total dry weight of sediment.

Aliphatic Hydrocarbons (AHs) - GC/FID

Component separation of the aliphatic fraction (f_1) is accomplished using 25 m fused silica capillary columns coated with DB-5 (J&W Scientific Inc.). Interior diameter of the column is 0.25 mm, film thickness 0.32 µ, and flow (He) through the column is 2-3 ml/min. Dilutions and injection sizes are appropriately adjusted to be within the detectors linear range. Two HP 5880A and two HP 5790A gas chromatographs equipped with HP 7571A autosamplers and flame ionization detectors are used for the analyses. Samples are injected on the capillary column at 60°C, the GC oven is then temperature programmed to 300°C (12°C/min) and held at 300°C for 10 minutes. Total analysis time is 30 minutes. Baseline separation on n-C_{17} and pristane and n-C_{18} and phytane is maintained or the capillary column is replaced.

A quantitative alkane standard (including pristane and phytane) from n-C_{11} to n-C_{34} containing all of the internal standards is prepared twice yearly (Alltech Assoc. and MSD Isotopes). The new standard is calibrated against the previous standard.

Initial calibration and determination of linearity of the gas chromatographic flame ionization detector (GC/FID) is accomplished with the injection of quantitative standards at three concentrations. The response is assumed to be linear and the R of the calibration points must exceed 0.99 for a first degree fit of the data for the instrument to be in calibration. Concentrations of identified compounds are calculated from the average response factor for the three quantitative standard injections. An unresolved complex mixture (UCM) concentration is calculated using a computer-based method. An electronic baseline generated from the daily solvent blank injection is subtracted from each sample analysis and an aliphatic UCM is calculated exclusive of any resolved peaks. An average response factor for n-alkanes over the retention time range of the UCM is used to calculate a pseudo-concentration.

A calibration check is run twice daily (per ~10 sample analyses) and calculated values must predict the known value by ±20 percent on average for all analytes and ±30 percent for any single analyte or remedial action is taken. No further samples are analyzed until the instrument is in calibration. A "blank" and "spiked blank" are included in each set (~10) of samples. "Spiked blanks" and/or SRMs must calculate within ±30 percent of the known concentration on average for all analytes and within ±35 percent for individual analytes or analyses are halted. Duplicate samples are analyzed at a frequency of five percent. At least ten percent of the aliphatic hydrocarbon fractions are analyzed by GC/MS to confirm peak identity and to investigate unidentified peaks.

Polynuclear Aromatic Hydrocarbon (PAHs) - GC/MS/SIM

PAHs are quantitatively analyzed by GC/MS in a selected ion mode (SIM) utilizing molecular and secondary analyte ions. Typical operating conditions are summarized in Table 4-3. Total analysis time is 36 minutes.

The mass spectrometer is calibrated daily to the standard Hewlett-Packard autotune parameters using perfluorotributylamine (PFTBA). The GC/MS is initially calibrated and detector linearity is determined by duplicate injection of standards (including all internal standards) at three concentrations (usually 0.5 ng/µl, 2.5 ng/µl, and 5.0 ng/µl). A linear relationship between concentration and response is assumed and an R of better than 0.99 for a first degree fit of the data must be obtained before analysis of samples is initiated. Sample components are quantified from the average response of the standard injections. Peak identity is confirmed by

Table 4-3. GC/MS/SIM operating conditions for PAH analysis.

INSTRUMENTS:
- GC/MS HP 5996 linked with an HP 1000 (RPN) data system
- GC/MSD HP 5970 Mass Selectie Detector interfaced to an HP 5890 gas chromatograph linked with an HP 1000 (RPN) data system

One HP 5996 GC/MS and two HP 5970 GC/MSD's are available

TYPICAL MS SETTINGS:

Ion Source: 250°C
Transfer Line: 290°C
Analyzer: 250°C
Run Time: 36 min.
Scan Start Time: 5 min.
Electron Energy: 70 ev
X-Ray: 44V

Multiplier Voltage: 1600V
Entrance Lens: 50 mV/AMU
Repeller: 9.8V
Ion Focus: 0
Axis Gain: -63
Axis Offset: -6
AMU Gain: 149

SELECTED ION MONITORING:

GROUP I IONS   Start Time: 5 min   Stop time: 14 min.

Quantitation Ion (m/z)	Dwell Time (msec)	Secondary Ion (m/z)	Dwell Time (msec)	Compounds Detected
128	50	127	50	naphthalene
136	50	-----	----	*-$d_8$naphthalene
142	50	141	50	methyl-naphthalene
152	50	151	50	acenaphthylene
154	50	153	50	diphenyl, acenaphthene
156	50	141	50	dimethyl-naphthalenes
162	50	-----	----	**hexamethyl-benzene
164	50	-----	----	*d_{10}-acenaphthene
166	50	165	50	fluorene
170	50	155	50	trimethyl naphthalenes

Total Dwell time : 600 m sec

Table 4-3. Continued

GROUP II IONS Start time: 14 min Stop time: 22 min.

Quantitation Ion (m/z)	Dwell Time (msec)	Secondary Ion (m/z)	Dwell Time (msec)	Compounds Detected
178	100	179	100	phenanthrene, anthracene
188	100	-----	100	d_{10} plenanthrenes
192	100	191	100	methylphenanthrene methyl anthracene
202	100	226	100	benzanthracene, chrysene
240	100	-----	-----	*d_{12}-chrysene

Total dwell time: 800 msec

GROUP III IONS Start time: 22 min Stop time: 36 min.

Quantitation Ion (m/z)	Dwell Time (msec)	Secondary Ion (m/z)	Dwell Time (msec)	Compounds Detected
252	150	253	150	benzopyrenes, perylene, benzofluoranthenes
264	150	-----	-----	*d_{12}-perylene
276	150	138	150	indenopyrenes, benzoperylenes
278	150	139	150	dibenzanthracenes

Total dwell time 1050 msec

Table 4-3. Continued

GAS CHROMATOGRAPHY:

Injector: 300°C, splitless mode
Total Run Time: 36 min.
Column: 25m, DB-5

Temp 1	40°C	Temp 2	300°C
Time 1	0 min.	Time 2	10 min.
Rate	10°C/min.		

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* - internal standards (IS)

** - gas chromatography internal standards (GCIS) their molecular ion, the ratio of the primary (base) ion to the secondary ion, and retention time. At a minimum, calibration checks are analyzed daily. "Spiked blanks" and "system blanks" are analyzed with each set of samples. Calibration checks are routinely analyzed twice daily (per ~10 sample analyses). The GC/MS is considered to be in calibration if the average percent difference between the calculated value and the known value for the calibration check is on average less than ±20 percent for all analytes and less than ±30 percent for individual analytes. Duplicate samples are run at a frequency of 5 percent. The "spiked blank" and/or SRM is considered acceptable if the percent difference between the calculated and the known value is less than ±30 percent on average for all analytes and individual analytes are than less than ±35 percent. An internal standard (IS) (hexamethylbenzene or d_{10}-fluoranthene) is added just prior to the GC/MS/SIM analysis. The sample analyte concentrations are calculated using the appropriate internal standard area and the average response factor from the six standard injections. The GCIS recoveries are used to estimate absolute recoveries in order to evaluate analyte losses during the analytical procedure. Data are corrected for surrogate recoveries.

4.3 Results

4.3.1 Sediment Bulk Parameters

Sediment total organic carbon content (TOC) varied from < 0.1% to 3.1% and averaged 0.8% (Table 4-4). The highest TOC concentrations were along the Chandeleur Sound transect (C) and at the deepest stations of the Mobile (M) and Desoto Canyon (D) transects in water depths of 100-200 meters. The central portion of the study area was consistently low in TOC. Organic carbon content was highly variable between samplings with certain locations increasing (Station D3 after Cruise 0) and others decreasing (Stations C1, D1, D2) with time (Figure 4-1). Other locations contained relatively constant organic carbon contents (transect M) while a few varied regularly, exhibiting maximum values at various sampling times (i.e. Stations C2, C3, and C4).

Table 4-4. Summary of sediment bulk parameters on three transects during five sampling times. (C-Chandeleur, M-Mobile, D-Destin Dome).

PARAMETER	TRANSECT-STATION											
CRUISE	C-1	C-2	C-3	C-4	M-1	M-2	M-3	M-4	D-1	D-2	D-3	D-4
Total Organic Carbon (%)												
Cruise MMS-0	1.3	0.3	1.3	0.1	0.1	0.2	0.1	0.8	**	0.1	0.9	1.7
Cruise MMS-1	0.7	0.7	1.7	0.8	0.4	0.2	0.6	1.7	0.3	0.3	0.2	2.0
Cruise MMS-2	0.6	1.5	1.2	1.4	0.3	0.3	0.5	1.3	0.1	0.4	0.9	3.1
Cruise MMS-3	0.3	0.9	1.3	1.9	0.1	< 0.1	0.6	1.5	<0.1	0.2	1.1	1.8
Cruise MMS-4	0.2	1.0	1.3	1.5	0.5	< 0.1	0.2	1.7	<0.1	< 0.4	2.6	2.9
Carbonate Content (%CaCO3)												
Cruise MMS-0	8.2	7.1	1.5	2.1	2.4	3.6	14.7	17.6	**	54.0	60.9	43.3
Cruise MMS-1	7.0	2.5	3.2	2.9	1.4	6.6	16.0	11.0	0.7	2.5	58.0	53.5
Cruise MMS-2	5.6	6.8	2.9	3.0	2.9	5.2	22.5	2.0	1.2	2.1	53.3	25.9
Cruise MMS-3	7.4	11.4	4.0	12.3	0.1	7.1	30.7	1.1	0.1	45.2	78.1	72.0
Cruise MMS-4	4.8	8.7	6.3	5.2	6.1	6.2	9.9	20.4	0.2	2.4	80.0	84.8
Total Extractable Matter (ppm)												
Cruise MMS-0	44.8	16.0	129.6	134.4	10.4	14.4	4.8	145.2	**	8.0	51.2	102.0
Cruise MMS-1	38.1	87.5	70.1	123.6	10.4	18.4	55.0	86.6	19.7	7.3	7.7	188.1
Cruise MMS-2	41.5	70.3	49.5	262.1	32.9	128.0	119.2	8.0	24.8	24.8	81.5	12.0
Cruise MMS-3	63.3	68.4	179.2	135.9	41.8	25.2	53.2	64.0	31.8	16.8	56.8	98.1
Cruise MMS-4	53.6	81.5	104.8	130.4	68.0	38.3	59.3	97.7	33.5	46.3	28.0	100.8
del 13C (per mil)												
Cruise MMS-0	-21.3	-20.4	-21.2	-20.4	-25.1	-24.0	-21.5	-20.4	**	-19.1	-21.5	-21.0
Cruise MMS-1	-23.4	-23.7	-23.4	-23.3	-24.8	-20.5	-23.3	-23.3	-22.9	-23.3	-22.3	-22.7
Cruise MMS-2	-21.4	-23.5	-23.0	-22.7	-24.9	-23.3	-21.3	-21.7	-24.2	-20.6	-23.2	-22.2
Cruise MMS-3	-22.6	-21.7	-21.2	-22.1	-21.5	-20.5	-21.3	-20.9	-20.5	-21.9	-20.7	-22.3
Cruise MMS-4	-21.3	-21.3	-21.1	-21.6	-21.5	-20.7	-20.8	-21.1	-19.0	-21.2	-20.4	-20.4

** = Samples not taken during first cruise

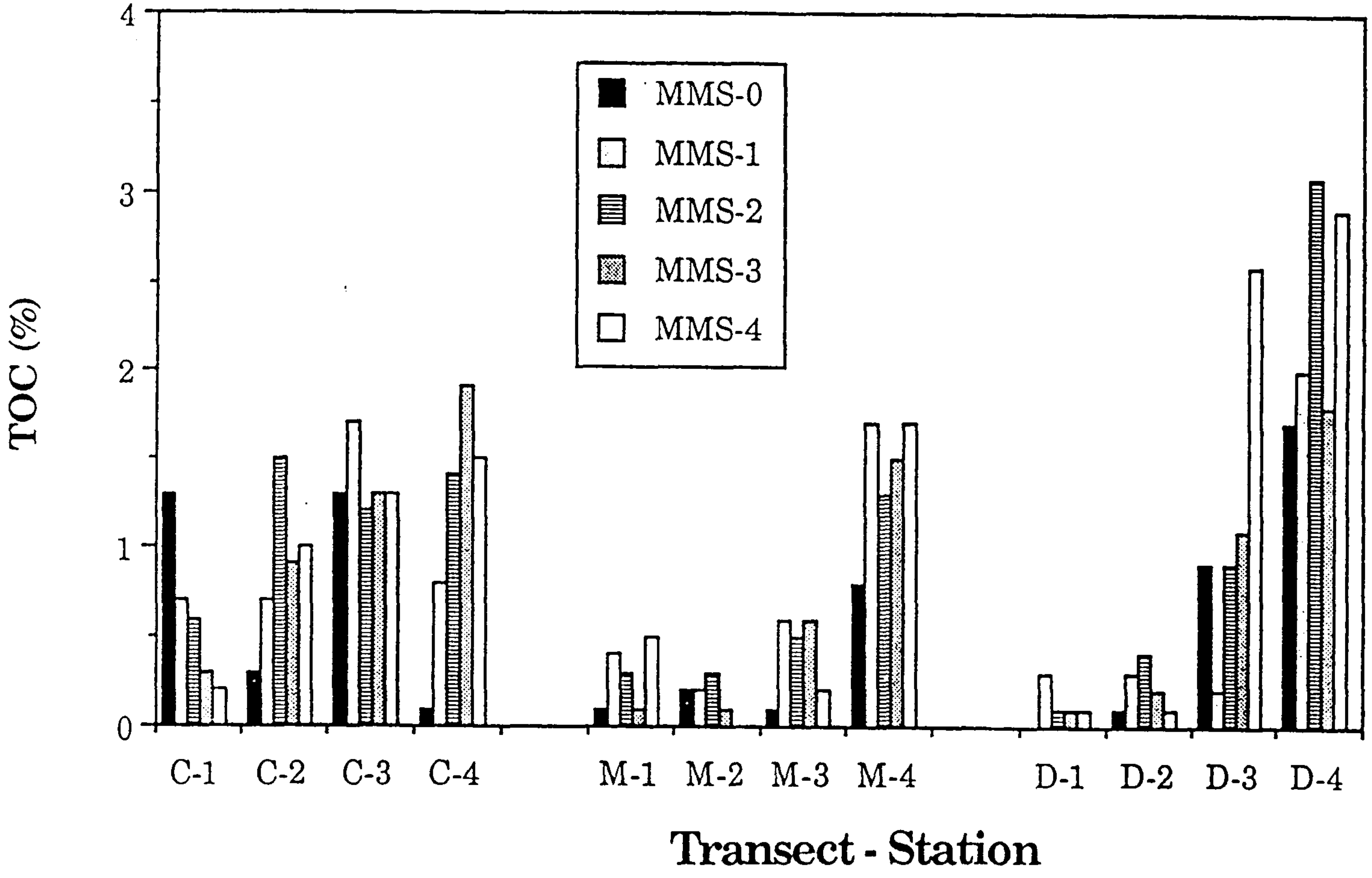


Figure 4-1. Summary of total organic carbon content (%) of sediment from the study area.

Sediment calcium carbonate content varied from less than 1% to greater than 80% and averaged 17.4% (Table 4-4). The greatest variability in carbonate content, as well as the highest values, was observed at Stations D3 and D4 (Figure 4-2). Carbonate content was relatively constant and low along transects C and M and Station D1 during the study period.

Extractable organic matter content varied from 4.8 to 262.1 ppm and averaged 66.2 ppm. As with TOC distributions the highest values were in sediments from transect C and at the deepest stations of transects M and D (Figure 4-3). At a few locations EOM appeared to vary in a cyclical fashion (C3, D3, D4) whereas other locations had relatively constant EOM values or the concentrations varied randomly.

The stable carbon isotope composition of sedimentary organic matter ($\delta^{13}C_{om}$) varied widely within a sampling and between samplings at a given location (Table 4-4; Figure 4-4). In general the entire study area had more negative $\delta^{13}C_{om}$ values during the August 1987 sampling suggesting a significant influx of land-derived materials. Stations closest to Mobile Bay were consistently more negative than the deeper water stations during the first three cruises. During the fourth and fifth cruise all locations had stable isotope compositions more typical of planktonic debris.

Reflective of these trends, sediments in the central portion of the study area were predominantly sand (> 60%; stations M1, M2, M3, D1, D2, D3). Stations on deeper water were predominantly silt/clay (C3, C4, M4, D4). One notable event was a large influx of silt material before the August 1987 sampling that significantly changed grain size distributions at several stations (C2, C3, C4, M3, M4 and D4). This increased silt content was apparent at least through the third sampling.

4.3.2 Hydrocarbons

Aliphatic hydrocarbons were ubiquitous throughout the study area. Total n-alkanes varied from 100 to 3157 ppb and averaged 860 ppm (Table 4-5). Molecular compositions were highly variable and were found in highest concentrations along transect C and at the deepest stations of transects M and D (Figure 4-5). Lowest values were found in the central portion of the study area corresponding to the low organic carbon, high sand

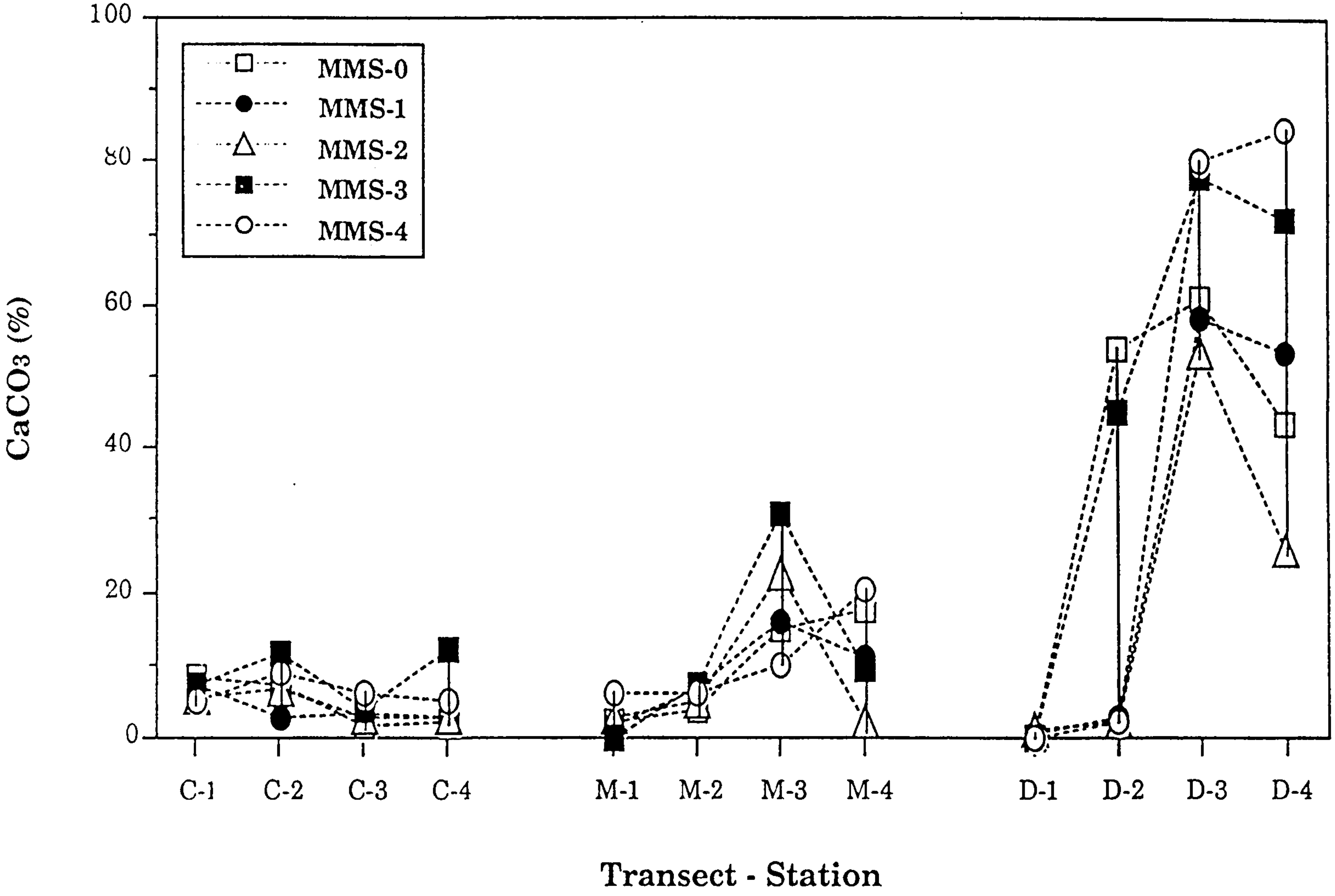


Figure 4-2. Summary of the calcium carbonate content (%) of sediments from the study area.

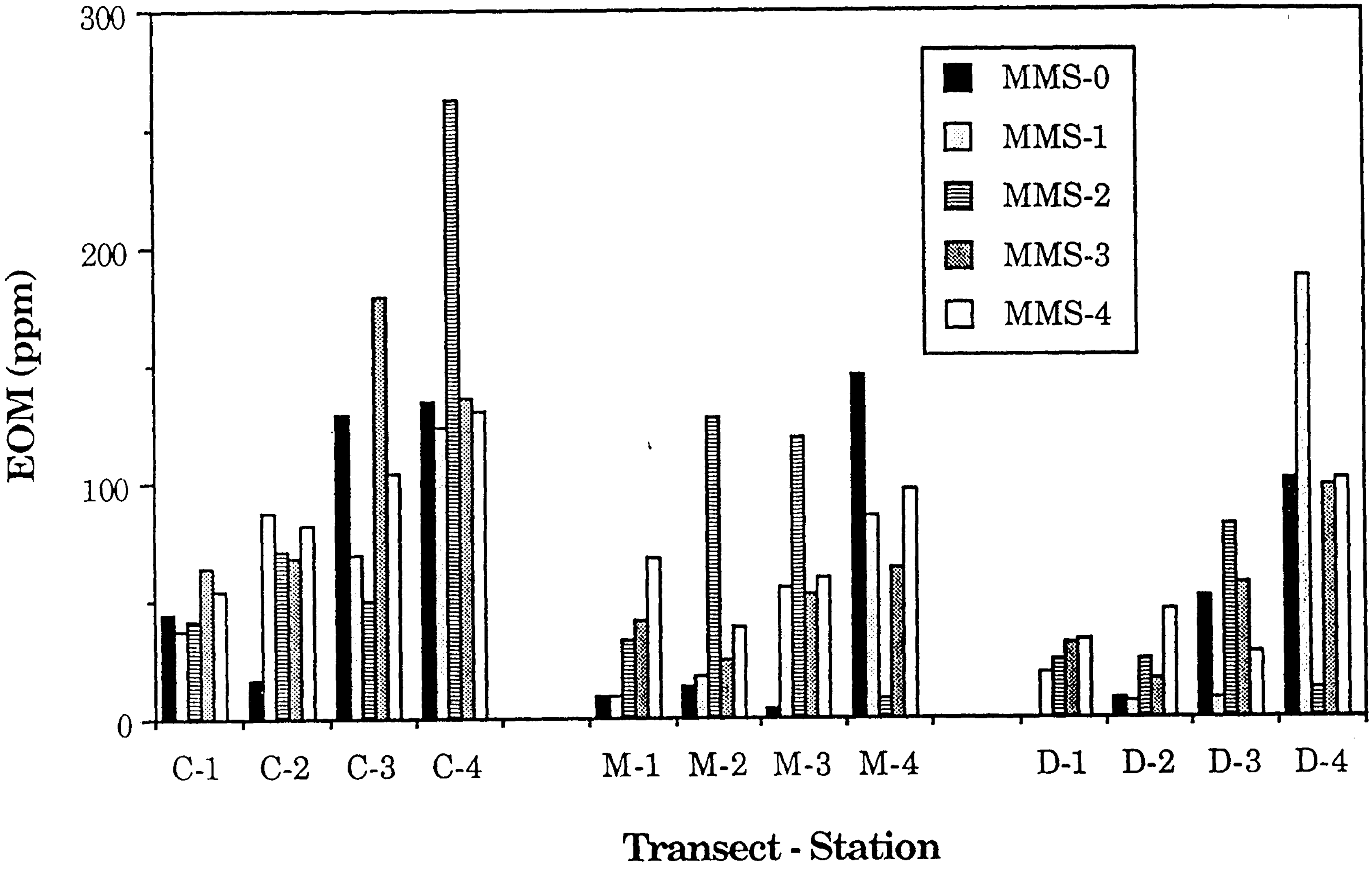


Figure 4-3. Summary of the extractable organic matter (EOM) content (ppm) of sediments from the study area.

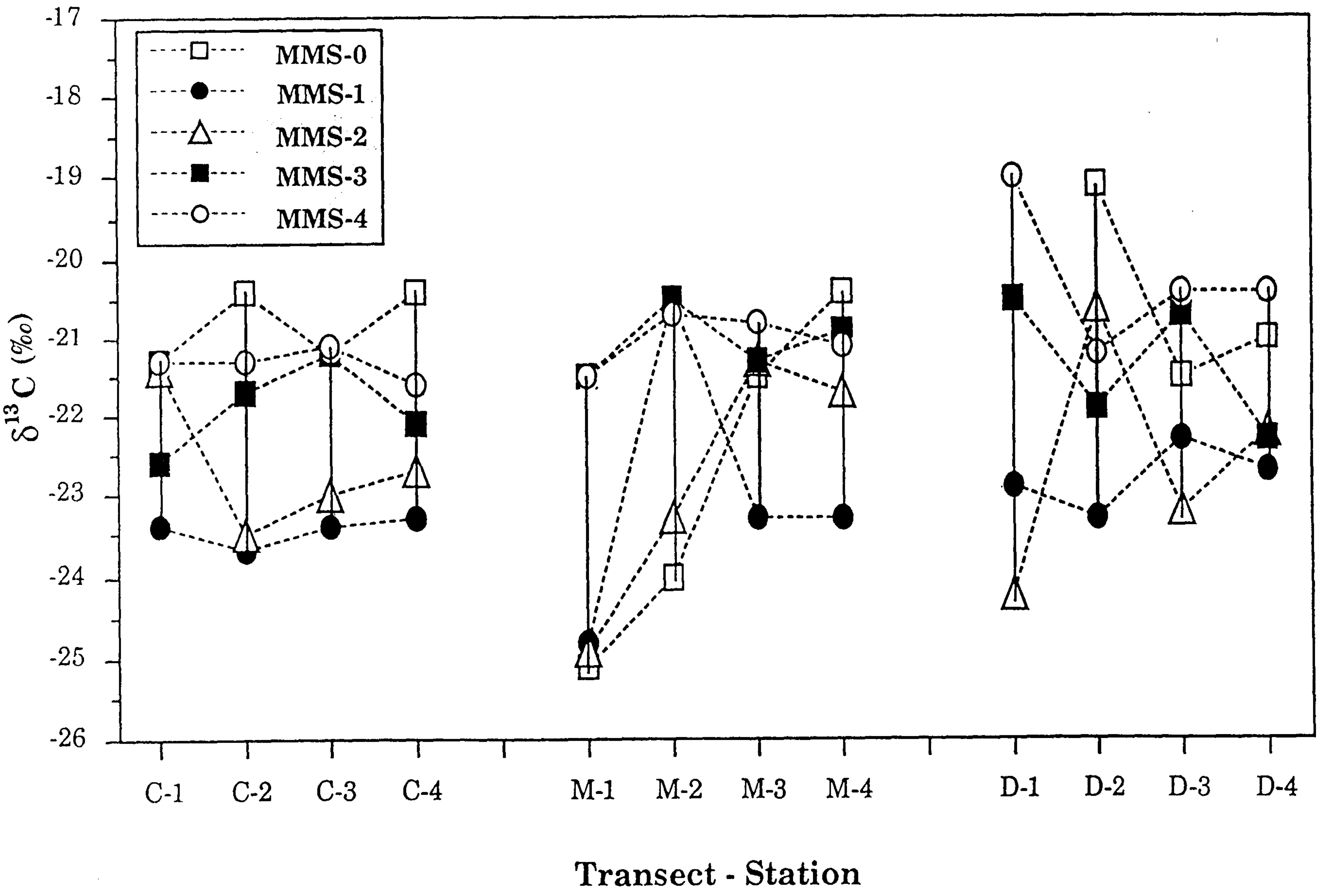


Figure 4-4. Summary of the stable carbon isotope compositions of organic matter in sediments from the study area.

Table 4-5. Summary of sediment aliphatic hydrocarbon data for the study period.

PARAMETER	TRANSECT-STATION											
CRUISE	C-1	C-2	C-3	C-4	M-1	M-2	M-3	M-4	D-1	D-2	D-3	D-4
Total n-Alkanes (ppb)												
Cruise MMS-0	330	156	499	1592	184	128	626	525	**	215	254	312
Cruise MMS-1	1777	1402	2091	1810	461	511	1440	1893	271	343	635	656
Cruise MMS-2	482	738	528	1905	573	773	289	365	322	299	735	431
Cruise MMS-3	487	1397	1150	1946	517	244	1531	953	100	199	482	1294
Cruise MMS-4	857	2089	2411	3157	1724	633	420	1995	133	355	243	895
Total UCM (ppm)												
Cruise MMS-0	4	3	23	42	2	1	6	12	**	2	3	11
Cruise MMS-1	5	14	12	17	3	3	6	12	2	2	4	14
Cruise MMS-2	9	22	14	46	9	24	3	4	13	10	24	8
Cruise MMS-3	19	35	52	66	17	7	23	22	8	6	21	29
Cruise MMS-4	35	65	104	131	76	19	23	92	13	7	20	45
CPI > n-C23												
Cruise MMS-0	3.30	1.60	3.55	5.78	16.00	13.67	2.37	3.23	**	0.78	11.58	1.99
Cruise MMS-1	8.89	8.19	5.55	9.66	8.00	19.73	3.06	7.83	42.40	43.20	6.36	3.98
Cruise MMS-2	4.65	3.84	3.74	6.65	4.01	5.47	6.22	9.59	2.23	4.43	4.11	1.29
Cruise MMS-3	4.86	5.25	4.80	4.40	4.91	2.74	1.87	3.62	5.25	2.64	3.55	7.09
Cruise MMS-4	5.45	4.03	5.02	5.28	6.09	13.73	4.12	5.48	1.91	13.42	2.41	5.55
Pristane/Phytane												
Cruise MMS-0	*	2.20	1.67	3.24	*	*	1.10	2.00	**	0.73	1.56	2.00
Cruise MMS-1	0.77	0.59	0.65	0.73	0.83	0.81	0.90	0.82	*	0.55	1.00	3.38
Cruise MMS-2	0.50	0.70	0.80	0.96	1.14	1.70	*	1.40	2.80	1.00	1.63	1.00
Cruise MMS-3	*	3.14	1.39	2.13	*	*	1.36	1.67	*	*	*	*
Cruise MMS-4	2.03	0.23	1.56	1.60	2.02	*	1.23	*	0.74	*	*	*

* = Not determined due to one or more peaks less than the limit of quantification.

** = Samples not taken during first cruise

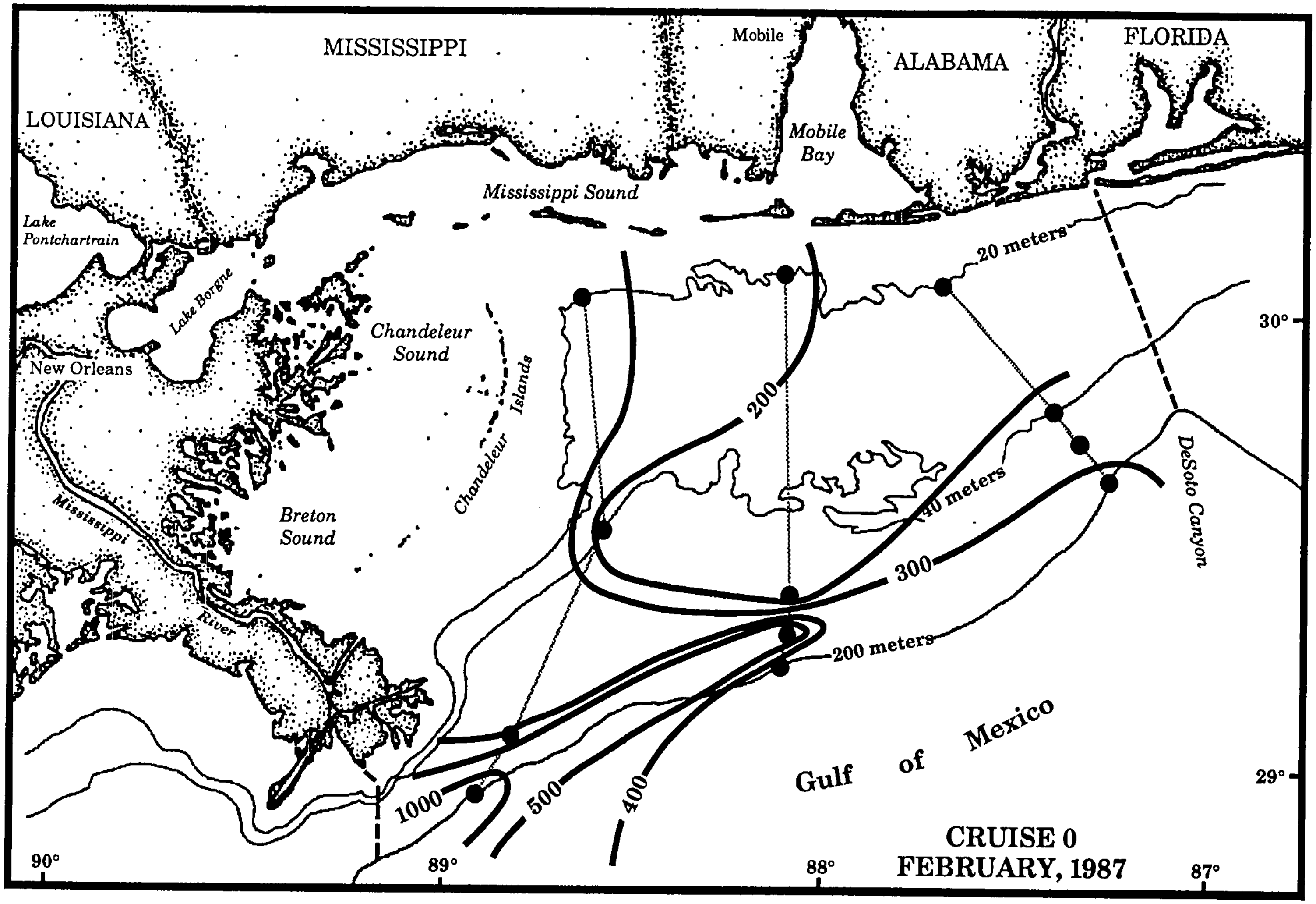


Figure 4-5. Geographic distributions of total n-alkanes concentrations during five samplings.

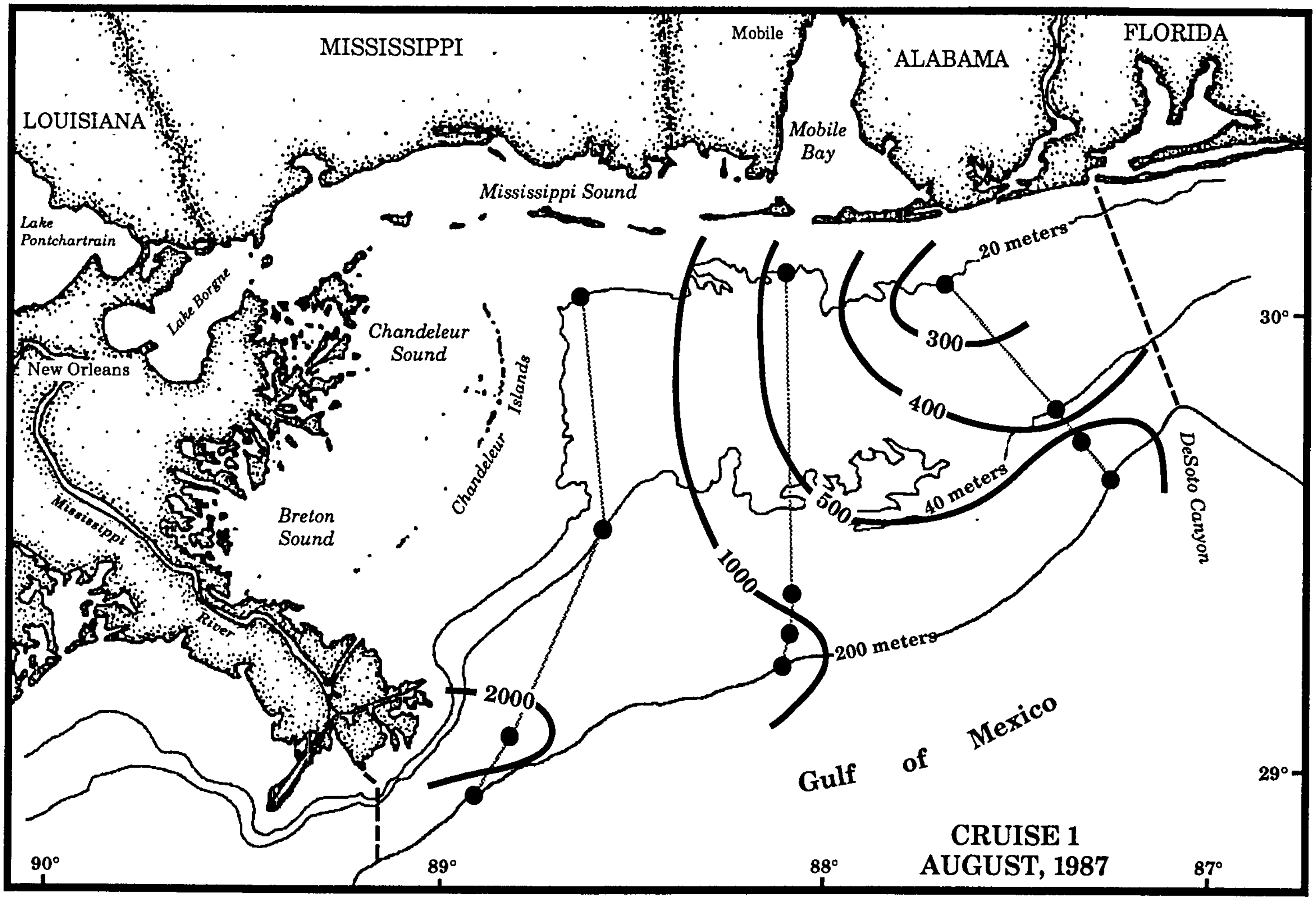


Figure 4-5. Continued.

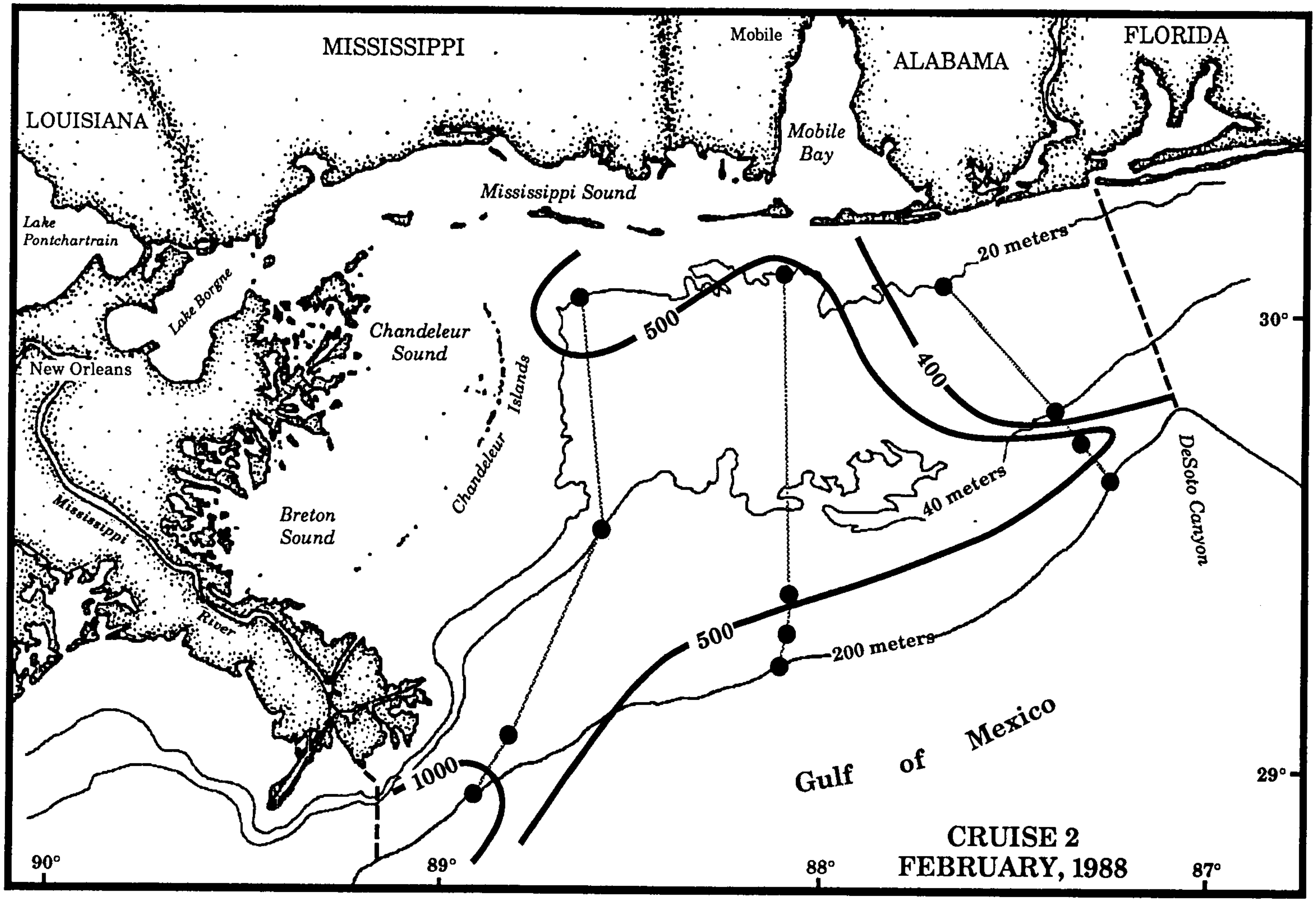


Figure 4-5. Continued.

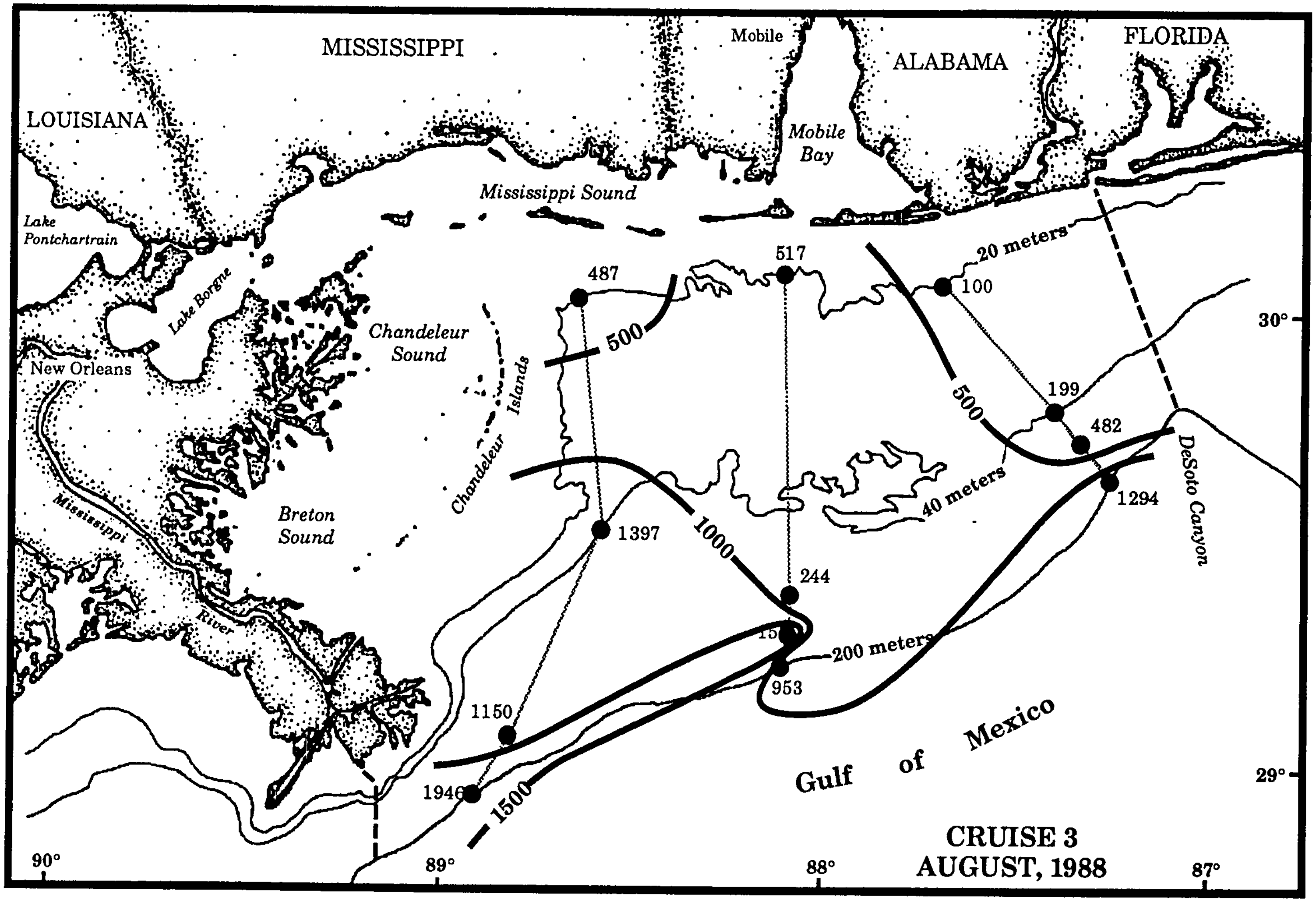


Figure 4-5. Continued.

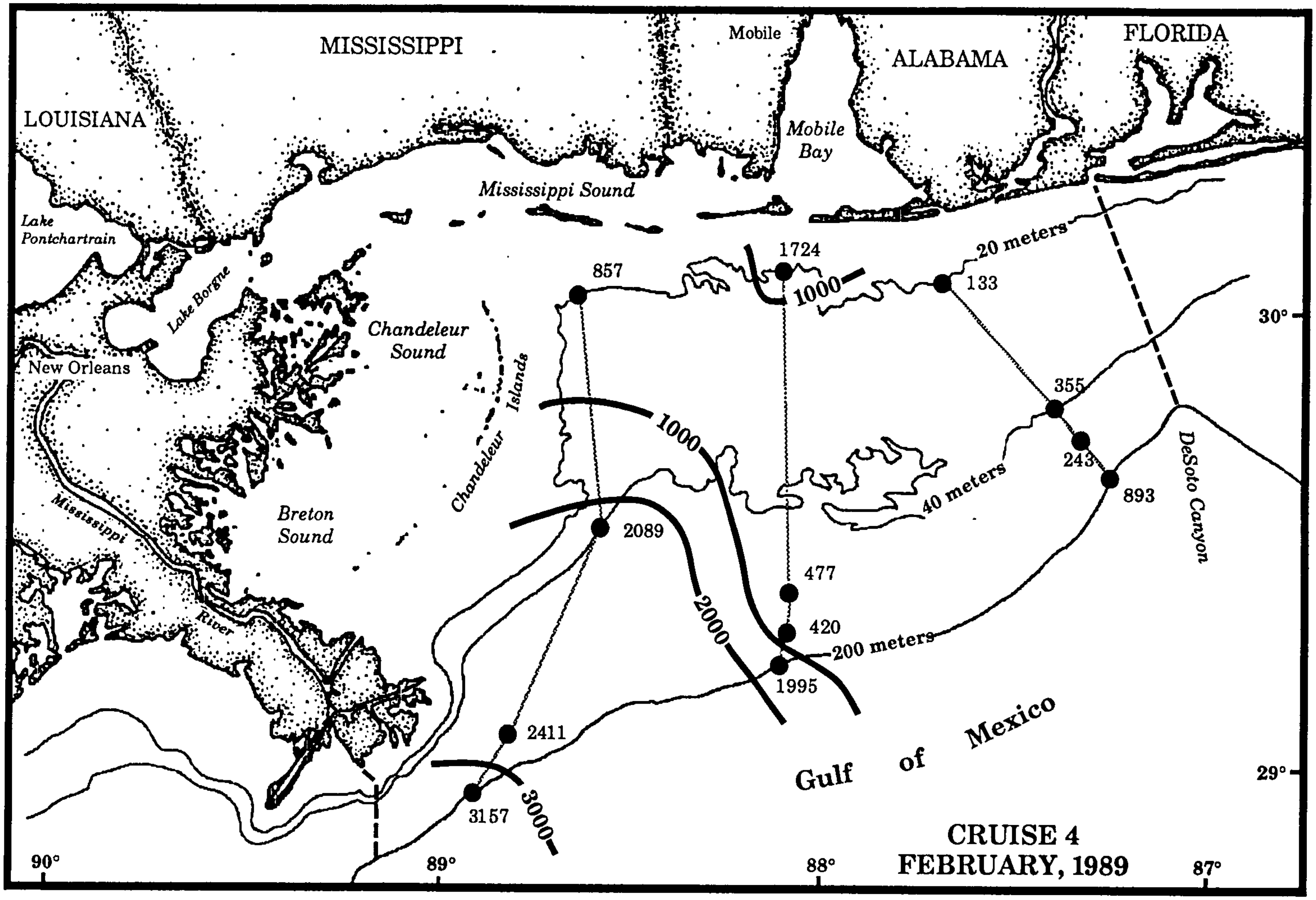


Figure 4-5. Concluded.

content sites. On occasion the station directly offshore of Mobile Bay had elevated concentrations of aliphatic hydrocarbons (M1). Odd n-alkanes appeared to continuously increase during the sampling period on transects C and M (Figure 4-6). The unresolved complex mixture varied from 1 to 32 ppm, averaged 11 ppm and generally parallels EOM distributions.

Aromatic hydrocarbons were present at low levels and varied from less than the detection limit to 673 ppb and averaged 158 ppb. Two to five ring aromatic hydrocarbons were detected (Table 4-6). Molecular compositions were highly variable and anthracene was only sporadically detected (Table 4-6). The highest PAH values were along transect C and at the deepest stations of transects M and D (Figure 4-7). PAH concentrations appear to vary in a cyclic manner over the sampling period, but at varying rates dependent on location (Figure 4-8).

4.4 Discussion

4.4.1 Bulk Parameters

Total organic carbon (TOC) contents, in general, were typical for continental shelf sediments. TOC values in excess of 2% are somewhat anomalous and most likely reflect periodic inputs of large amounts of organic matter as well as enhanced preservation in the sediment. Calcium carbonate content was also highly variable throughout the study area. The deepest water stations of transect D were dominated by shell hash. Station M3 and D2 also exhibited occasional high carbonate contents probably reflecting the variable and heterogeneous nature of sediments in the area. Extractable organic matter (EOM) can have both a biological and an anthropogenic source. In general the EOM was highly variable between locations within a single sampling and between samplings at a single location. High organic carbon, high extractable organic matter, and low carbonate contents were concentrated along transect C, nearest to the Mississippi Delta. The deepest water stations were consistently highest in organic carbon content for all three transects suggesting a concentration of clay rich sediments along the 100 to 200 meter isobath.

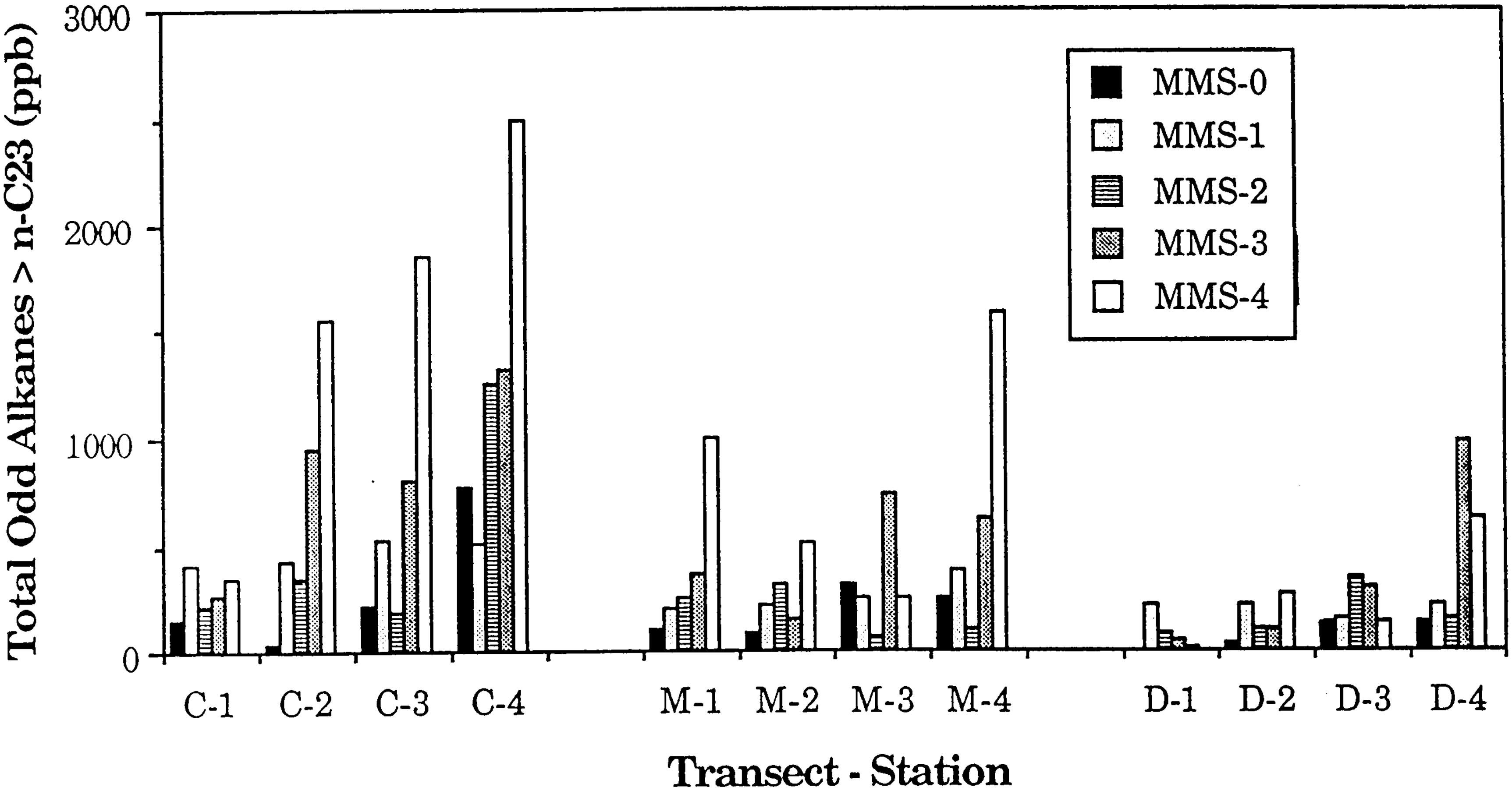


Figure 4-6. Summary of the total concentrations odd-carbon-numbered n-alkanes with 23 to 31 carbons in sediments from the study area.

Table 4-6. Summary of the polycyclic aromatic hydrocarbon data for the study period.

PARAMETER	TRANSECT-STATION											
CRUISE	C-1	C-2	C-3	C-4	M-1	M-2	M-3	M-4	D-1	D-2	D-3	D-4
Total Aromatics (ppb)												
Cruise MMS-0	16	6	174	348	*	*	7	112	**	5	6	63
Cruise MMS-1	76	263	288	514	*	6	97	279	6	*	45	192
Cruise MMS-2	14	269	35	331	10	*	147	*	*	*	47	*
Cruise MMS-3	113	243	496	673	*	*	130	280	32	*	68	118
Cruise MMS-4	68	176	296	567	138	18	19	194	*	*	28	114
2-3 Rings (%)												
Cruise MMS-0	32.6	*	23.2	30.9	*	*	*	31.4	**	*	*	72.6
Cruise MMS-1	64.0	52.9	57.3	45.4	*	*	72.5	58.9	*	*	56.0	82.0
Cruise MMS-2	0.0	58.2	20.5	22.2	*	*	18.2	*	*	*	0.0	*
Cruise MMS-3	62.3	25.9	35.6	25.4	*	*	71.2	36.3	*	*	39.2	42.0
Cruise MMS-4	69.4	11.2	24.2	23.7	82.1	*	*	8.3	*	*	51.4	9.1
4-5 Rings (%)												
Cruise MMS-0	67.4	*	76.8	69.1	*	*	*	68.6	**	*	*	27.4
Cruise MMS-1	36.0	47.1	42.7	54.6	*	*	27.5	41.1	*	*	44.0	18.0
Cruise MMS-2	100.0	41.8	79.5	77.8	*	*	81.8	*	*	*	100.0	*
Cruise MMS-3	37.7	74.1	64.4	74.6	*	*	28.8	63.7	*	*	60.8	58.0
Cruise MMS-4	30.6	88.8	75.8	76.3	17.9	*	*	91.7	*	*	48.6	90.9
4-5 Rings/2-3 Rings												
Cruise MMS-0	2.07	*	3.32	2.23	*	*	*	2.19	**	*	*	0.38
Cruise MMS-1	0.56	0.89	0.75	1.20	*	*	0.38	0.70	*	*	0.78	0.22
Cruise MMS-2	*	0.72	3.88	3.50	*	*	4.50	*	*	*	*	*
Cruise MMS-3	0.61	2.86	1.81	2.94	*	*	0.41	1.75	*	*	1.55	1.38
Cruise MMS-4	0.44	7.91	3.13	3.22	0.22	*	*	11.11	*	*	0.95	9.99
Phenanthrene/Anthracene												
Cruise MMS-0	*	*	*	*	*	*	*	*	**	*	*	*
Cruise MMS-1	*	*	*	*	*	*	*	*	*	*	*	*
Cruise MMS-2	*	4.12	*	2.72	*	*	*	*	*	*	*	*
Cruise MMS-3	2.55	*	5.35	5.20	*	*	*	*	1.47	*	*	*
Cruise MMS-4	*	*	*	*	*	*	*	*	*	*	*	*

* = Not determined due to one or more peaks less than the limit of quantitation.

** = Samples not taken during first cruise.

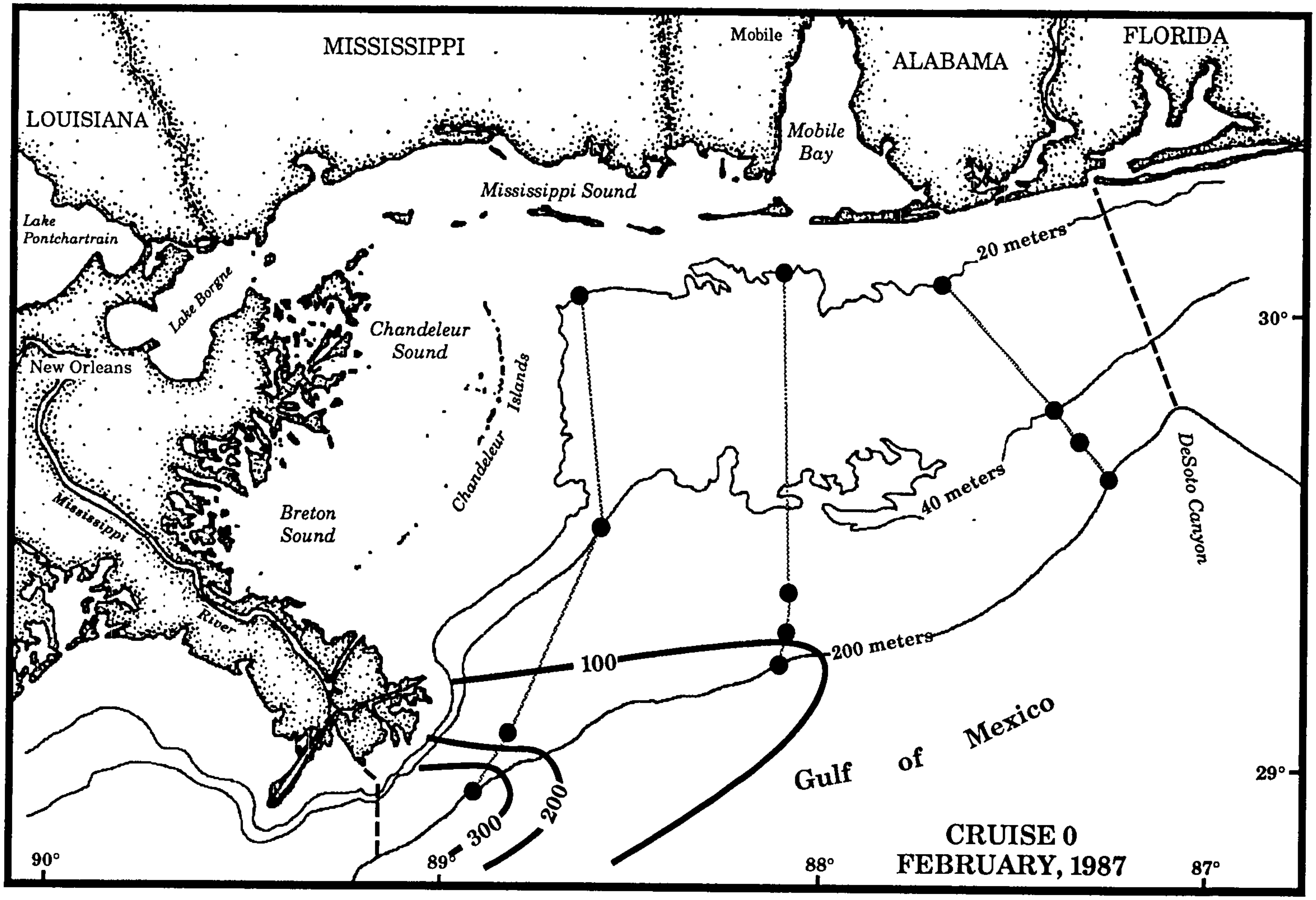


Figure 4-7. Geographic distributions of the total concentration of measured polycyclic aromatic hydrocarbons (PAHs) during five samplings.

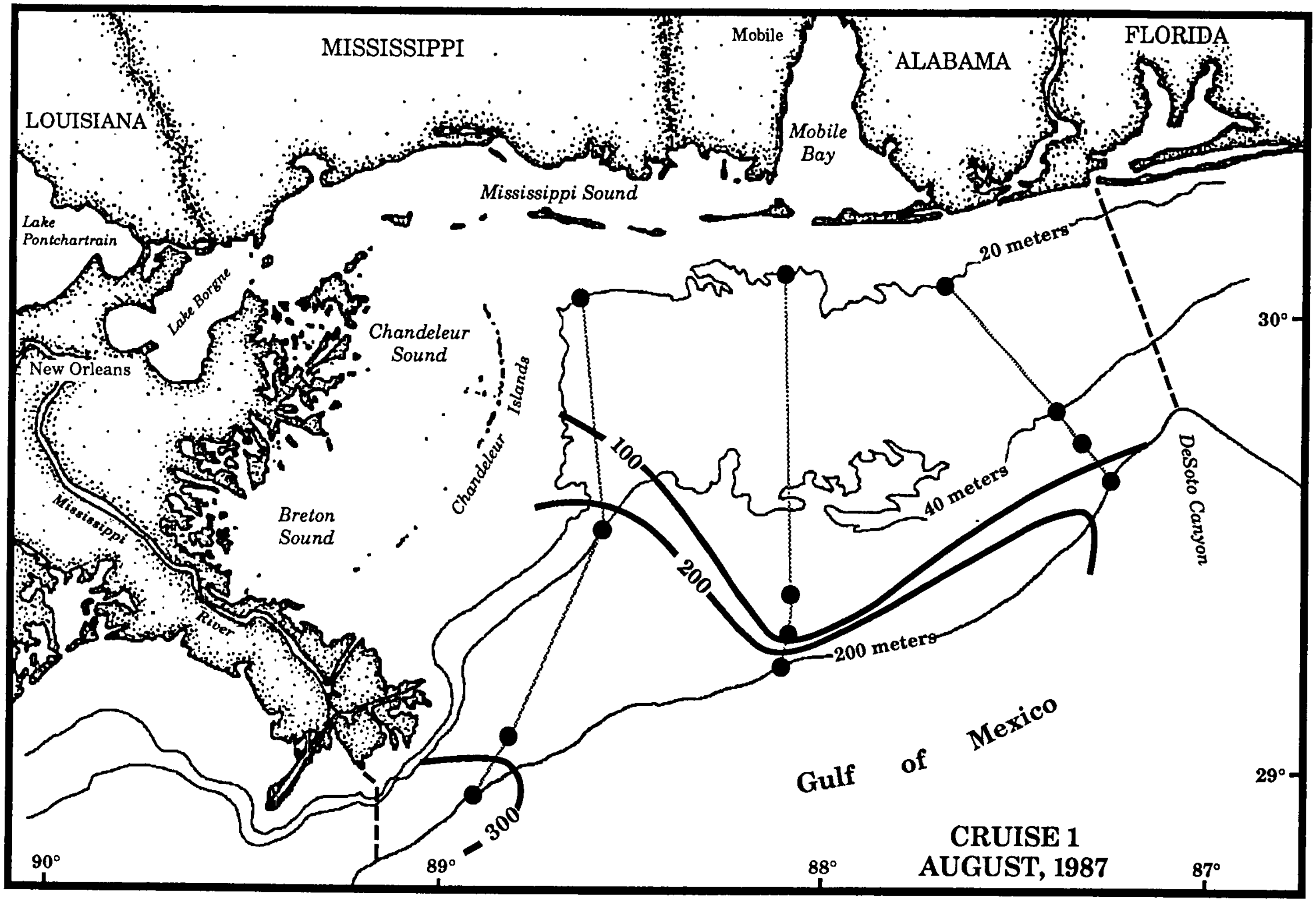


Figure 4-7. Continued.

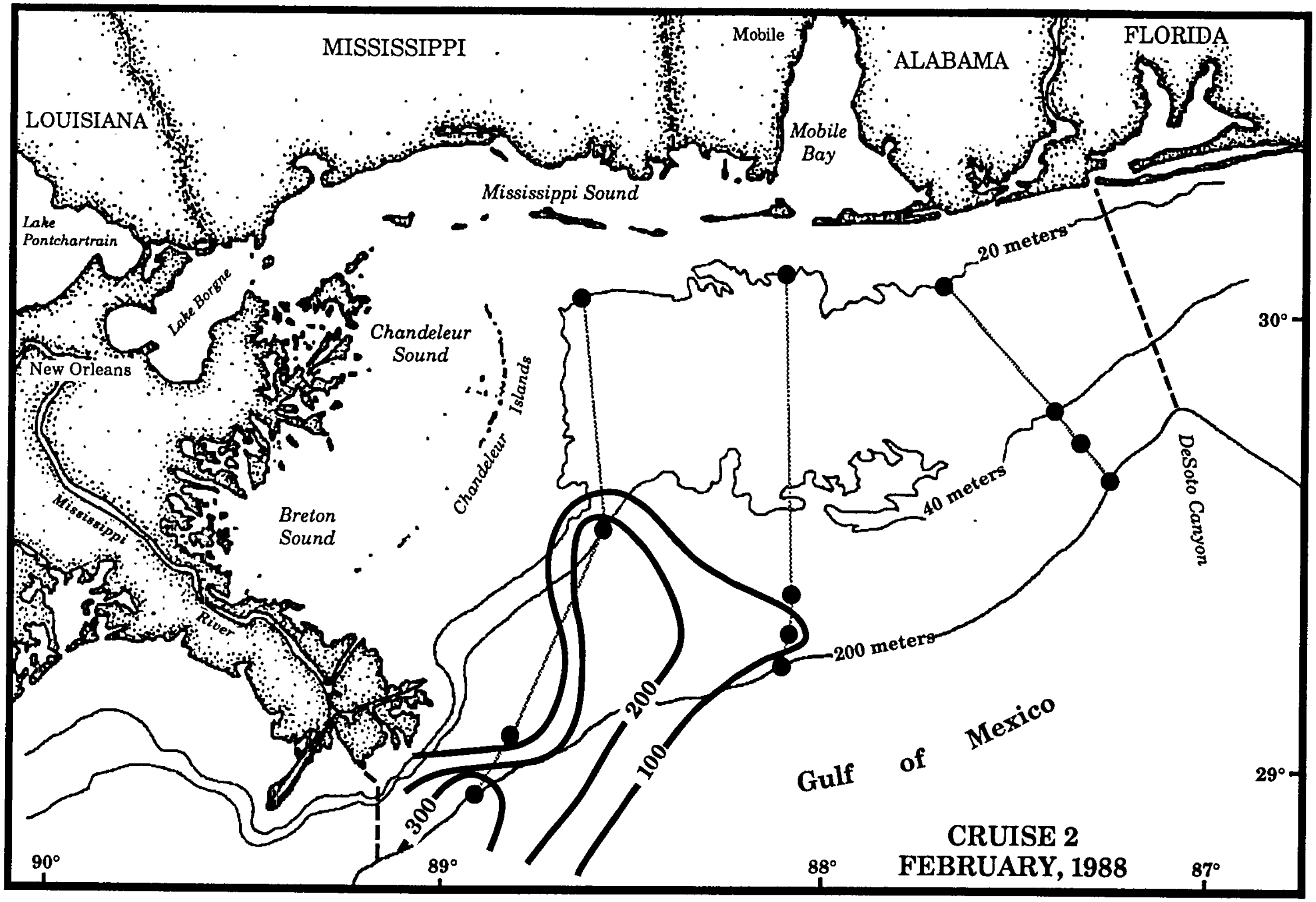
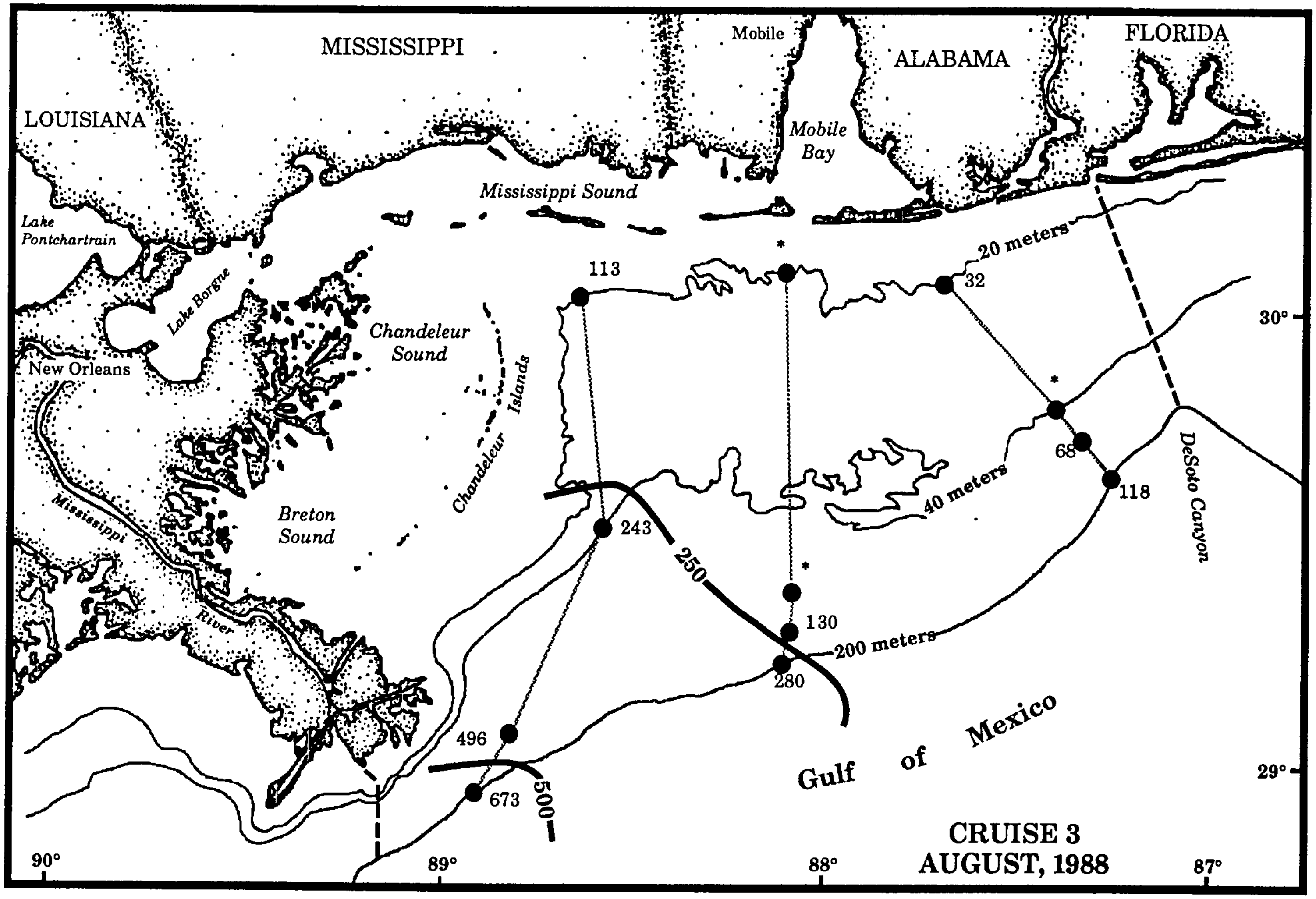


Figure 4-7. Continued.



CRUISE 3
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Figure 4-7. Continued.

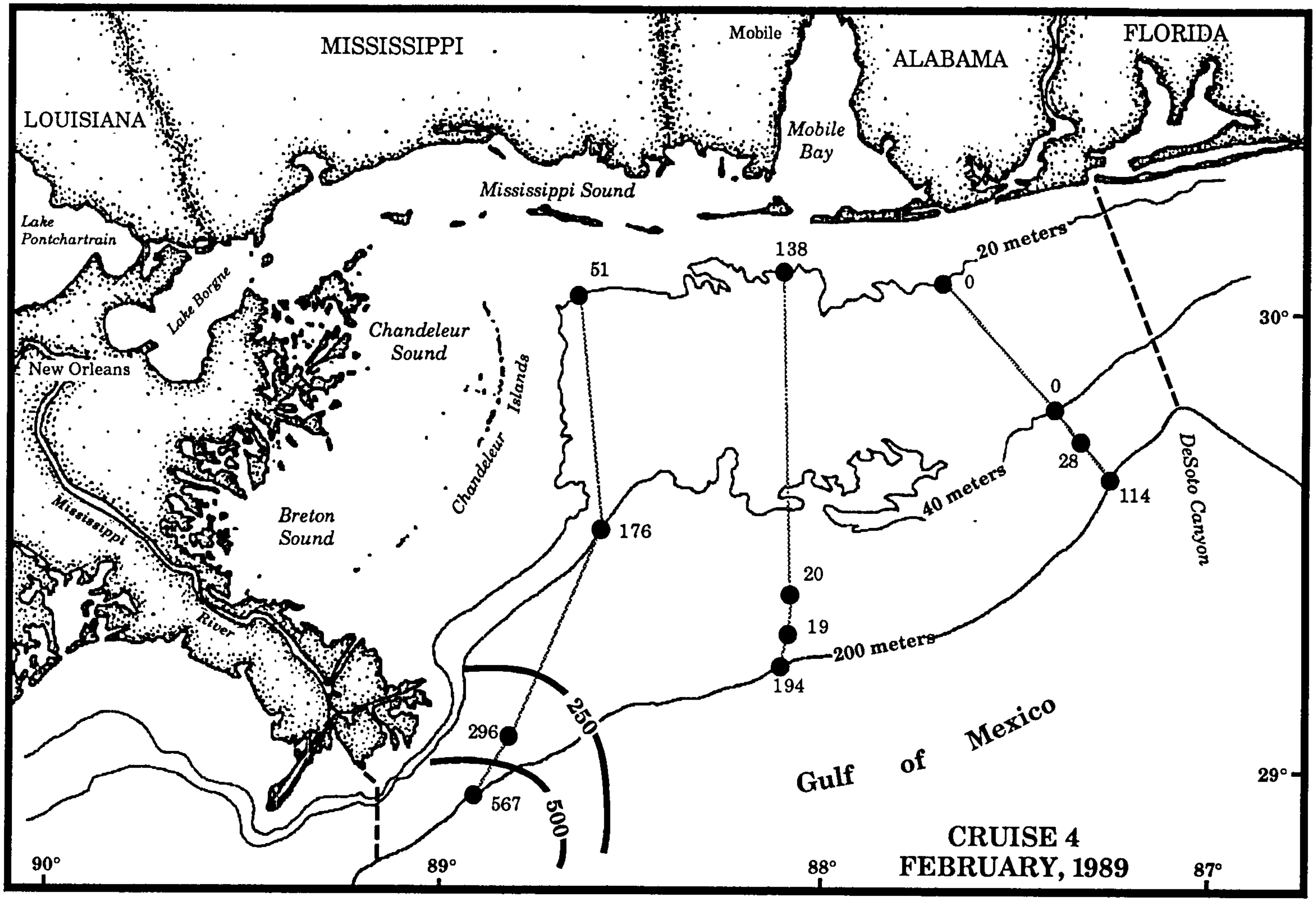


Figure 4-7. Concluded.

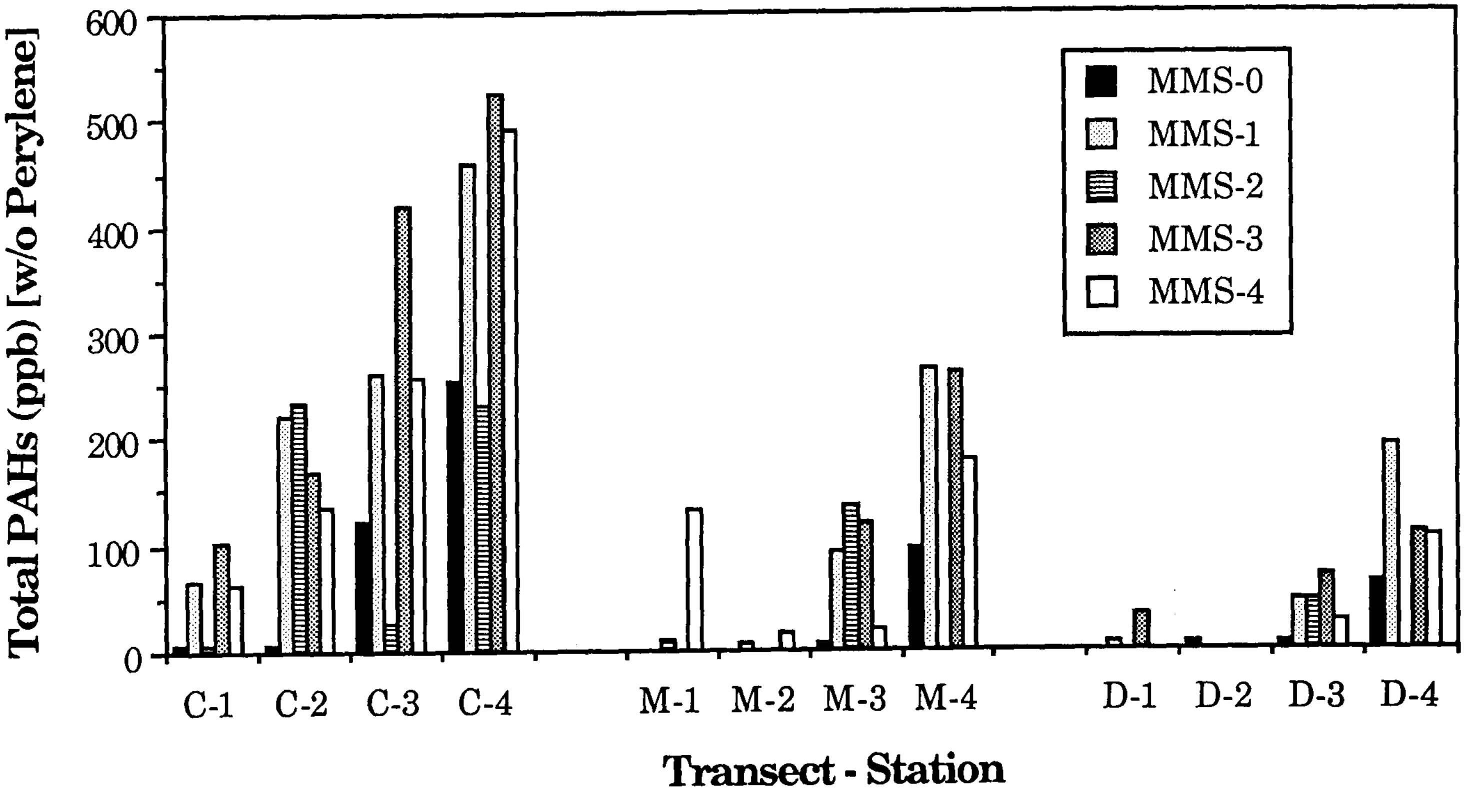


Figure 4-8. Summary of the distribution of total concentrations of PAHs in sediments from the study area.

Based on the difference of the average carbon isotopic composition of terrestrial and marine plants, the relative input of terrestrial and marine organic matter into marine sediments has been inferred (Wickman, 1952; Craig, 1953; Sackett, 1964). This original interpretation is complicated by: (1) the overlap of the isotopic composition of marine and terrestrial plants; (2) the effects of water temperature on the fractionation of carbon in plankton; (3) the alteration of organic matter isotopic composition during bacterial degradation and diagenesis; (4) migration of thermogenic hydrocarbons from deeper reservoirs to shallow sediments; (5) anomalous isotopic compositions produced in localized (closed) environments; and (6) the incorporation of recycled organic matter into recent sediments. Given these limitations and assumptions the relative importance of land versus plankton derived organic matter can be estimated.

In this particular model the planktonic $\delta^{13}C$ end-member is considered to be between -19 and -21‰ and land plant associated organic matter is assumed to be between -26 and -28‰. The maximum and minimum values are calculated and reported in Table 4-7. In general the study area was dominated by planktonic debris during Cruises 0, 3 and 4. Cruises 2 and especially 1 showed significant enhancement in terrestrially derived organic matter. This same sampling coincides with the greatly enhanced silt contents noted in the grain size analysis. High silt content directly corresponds with $\delta^{13}C$ values and the relationship persisted through Cruise 2. Several transects showed a decreasing land plant influence with increasing distance offshore (Cruise 0, transect M; Cruise 1, transect M; Cruise 2, transects M and D). Though the definition of end-members composition is only approximate, this model does demonstrate that significant variations in the relative importance of various organic matter inputs were observed over the 2-1/2 year study period.

4.4.2 Aliphatic Hydrocarbons

Aliphatic hydrocarbon compositions have been extensively used to estimate the relative importance of hydrocarbon sources. The use of aliphatic hydrocarbons as indicator compounds is based on the premise that recognizable assemblages of normal and branched alkanes can be associated with specific sources. In nature, however, few unique aliphatic end-

Table 4-7. Summary of the maximum and minimum inputs of terrestrial and planktonic derived organic matter modeled on stable carbon isotopic compositions.

CRUISE		TRANSECT-STATION											
PARAMETER		C-1	C-2	C-3	C-4	M-1	M-2	M-3	M-4	D-1	D-2	D-3	D-4
Cruise MMS-0													
del 13C (per mil)		-21.3	-20.4	-21.2	-20.4	-25.1	-24.0	-21.5	-20.4	**	-19.1	-21.5	-21.0
Planktonic	Minimum	67.1%	80.0%	68.6%	80.0%	12.9%	28.6%	64.3%	80.0%	**	98.6%	64.3%	71.4%
	Maximum	95.7%	100.0%	97.1%	100.0%	41.4%	57.1%	92.9%	100.0%	**	100.0%	92.9%	100.0%
Terrestrial	Minimum	4.3%	0.0%	2.9%	0.0%	58.6%	42.9%	7.1%	0.0%	**	0.0%	7.1%	0.0%
	Maximum	32.9%	20.0%	31.4%	20.0%	87.1%	71.4%	35.7%	20.0%	**	1.4%	35.7%	28.6%
Cruise MMS-1													
del 13C (per mil)		-23.4	-23.7	-23.4	-23.3	-24.8	-20.5	-23.3	-23.3	-22.9	-23.3	-22.3	-22.7
Planktonic	Minimum	37.1%	32.9%	37.1%	38.6%	17.1%	78.6%	38.6%	38.6%	44.3%	38.6%	52.9%	47.1%
	Maximum	65.7%	61.4%	65.7%	67.1%	45.7%	100.0%	67.1%	67.1%	72.9%	67.1%	81.4%	75.7%
Terrestrial	Minimum	34.3%	38.6%	34.3%	32.9%	54.3%	0.0%	32.9%	32.9%	27.1%	32.9%	18.6%	24.3%
	Maximum	62.9%	67.1%	62.9%	61.4%	82.9%	21.4%	61.4%	61.4%	55.7%	61.4%	47.1%	52.9%
Cruise MMS-2													
del 13C (per mil)		-21.4	-23.5	-23.0	-22.7	-24.9	-23.3	-21.3	-21.7	-24.2	-20.6	-23.2	-22.2
Planktonic	Minimum	65.7%	35.7%	42.9%	47.1%	15.7%	38.6%	67.1%	61.4%	25.7%	77.1%	40.0%	54.3%
	Maximum	94.3%	64.3%	71.4%	75.7%	44.3%	67.1%	95.7%	90.0%	54.3%	100.0%	68.6%	82.9%
Terrestrial	Minimum	5.7%	35.7%	28.6%	24.3%	55.7%	32.9%	4.3%	10.0%	45.7%	0.0%	31.4%	17.1%
	Maximum	34.3%	64.3%	57.1%	52.9%	84.3%	61.4%	32.9%	38.6%	74.3%	22.9%	60.0%	45.7%
Cruise MMS-3													
del 13C (per mil)		-22.6	-21.7	-21.2	-22.1	-21.5	-20.5	-21.3	-20.9	-20.5	-21.9	-20.7	-22.3
Planktonic	Minimum	48.6%	61.4%	68.6%	55.7%	64.3%	78.6%	67.1%	72.9%	78.6%	58.6%	75.7%	52.9%
	Maximum	77.1%	90.0%	97.1%	84.3%	92.9%	100.0%	95.7%	100.0%	100.0%	87.1%	100.0%	81.4%
Terrestrial	Minimum	22.9%	10.0%	2.9%	15.7%	7.1%	0.0%	4.3%	0.0%	0.0%	12.9%	0.0%	18.6%
	Maximum	51.4%	38.6%	31.4%	44.3%	35.7%	21.4%	32.9%	27.1%	21.4%	41.4%	24.3%	47.1%
Cruise MMS-4													
del 13C (per mil)		-21.3	-21.3	-21.1	-21.6	-21.5	-20.7	-20.8	-21.1	-19.0	-21.2	-20.4	-20.4
Planktonic	Minimum	67.1%	67.1%	70.0%	62.9%	64.3%	75.7%	74.3%	70.0%	100.0%	68.6%	80.0%	80.0%
	Maximum	95.7%	95.7%	98.6%	91.4%	92.9%	100.0%	100.0%	98.6%	100.0%	97.1%	100.0%	100.0%
Terrestrial	Minimum	4.3%	4.3%	1.4%	8.6%	7.1%	0.0%	0.0%	1.4%	0.0%	2.9%	0.0%	0.0%
	Maximum	32.9%	32.9%	30.0%	37.1%	35.7%	24.3%	25.7%	30.0%	0.0%	31.4%	20.0%	20.0%

** = Samples not taken during first cruise

members occur. A review of alkane hydrocarbon distributions and their significance has been provided by Brassell et al. (1978), Philp (1985) and Kennicutt and Comet (1990). Plankton generally produce simple mixtures of hydrocarbons dominated by n-$C_{15,17,19}$ and pristane (Clark and Blumer, 1967; Blumer et al., 1970; Goutx and Saliot, 1980; Table 4-8). Petroleum also contains these compounds but usually contains nearly equal amounts of n-$C_{16,18,20}$ and phytane as well (Farrington and Tripp, 1977; Farrington et al., 1973). Straight chain biowaxes with 25,27,29 and 31 carbons have been used extensively as indicators of terrestrial or land-derived organic matter (Philp, 1985 and references therein). Wax-derived normal alkanes are also found in petroleum but are accompanied by near equal amounts of n-$C_{24,26,28,30}$. Immature sediments also contain these hydrocarbons but exhibit a significant odd carbon preference, similar to the original input.

In general the presence of petroleum is suggested by an unresolved complex mixture in the gas chromatographic analysis. In general aliphatic hydrocarbons (normal and isoprenoid) have overlapping distributions and cannot always be unambiguously resolved. A complete homologous series of *n*-alkanes up to n-C_{40} of near equal abundance is thought to be specific to petroleum. This interpretation is complicated by the presence of fungal and bacterial contributions which can also have a smooth distribution or in some cases show a strong even carbon preference (Nishimura and Baker, 1986). Unless the contributing factors can be fully resolved some doubt always remains in the interpretation of n-alkane environmental data though useful assumptions can be applied.

The UCM is believed to be primarily due to petroleum though in non-purified extracts a portion of the UCM may be biological in origin. The dominant alkanes were the odd carbon number alkanes with 23 to 31 carbons presumably due to terrigenous plant biowaxes. Significant amounts of n-alkanes with 15 to 21 carbons were also present and have a dual source in petroleum and marine plankton. Marine planktonic inputs were difficult to identify.

Table 4-8. Summary of the major sources of normal and branched alkanes in the geosphere (after Brassell *et al.*, 1978).

Dominant Compounds	Carbon No. Range	Organism
Biological alkanes		
n-C_{17}, n-C_{15}	14-29	photosynthetic bacteria (C_{26}); non-photosynthetic bacteria (17-20); algae, (blue-green, brown red);
n-C_{18} + n-C_{24}	18-34 or 20-28	zooplankton
n-$C_{27,29,31}$	15-37	higher plants (terrestrial)
Monomethyl alkanes	C_{25-31} C_{18}	bacteria, higher plants blue-green algae
Isoprenoids	i-C_{19} i-C_{20}	algae, zooplankton, bacteria
C_{17} cyclopropane		marine benthic algae
Petroleum Related Alkanes		
variable	C_1-C_{35}^+ normal	ancient sediments, shales,
variable	C_4-C_{35}^+ branched	coals, oil seeps,
	C_9-C_{22}^+ isoprenoid	anthropogenic inputs
an unresolved complex mixture	cycloalkanes	

4.4.3 Aromatic Hydrocarbons

Aromatic hydrocarbons are widely used as an indicator of petroleum contamination in environmental samples. In general, environmental studies consider polyaromatic hydrocarbons consisting of condensed rings and simple alkylations (i.e. naphthalenes, phenanthrenes, fluoranthenes, chrysenes, etc.). Aromatics are ubiquitous in sedimentary environments and can have multiple sources in petroleum, biosynthesis, early diagenesis, coal, combustion and immature/mature sediments (Table 4-9). Molecular compositions have been extensively documented so that these various sources can be recognized based on parent and alkylated homologues and ring number distributions. These basic concepts have been extensively reviewed elsewhere and will not be repeated here (Hites et al., 1980; La Flamme and Hites, 1978; Wakeham et al., 1980a,b; and references therein).

A clear association between petroleum and condensed aromatic compounds (PAH) is evident. The abundance and composition of polynuclear aromatic hydrocarbons are a good indication of petroleum related hydrocarbons. The presence of apparently mature hydrocarbons, as evidenced by a complex mixture of aromatic compounds, in an immature sedimentary sequence can be due to anthropogenic influences, migration from a deeper source, *in situ* formation (unlikely if the section is judged thermally immature), recycling of mature sediments from the continent (exposed source rocks or oil seepage), and/or contamination during sample collection or preparation. Few aromatic hydrocarbons are synthesized by organisms and the complex mixture of alkylated homologues present in petroleum are only formed at elevated temperatures.

PAHs are a major constituent of petroleum and have little or no source in biological materials. The aromatic compounds were evenly distributed among 2, 3, 4 and 5 ring aromatics typical of unprocessed petroleum as compared to adjacent bay samples with predominantly pyrogenic PAHs (Figure 4-9). This interpretation is confirmed by the absence of anthracene at most sites, a constituent of pyrogenic hydrocarbons. Unprocessed petroleum can result from natural seepage, urban runoff, industrial complexes, offshore oil production, and shipping or tanker activities.

Table 4-9. Summary of sources of aromatic hydrocarbons in the geosphere.

Source	Composition
Petroleum	- 1 to 6 or larger rings with zero to 5 or more carbon alkylation - aromatized steranes (primarily mono and triaromatics) - aromatic sulfur compounds - porphyrins
Organism (biosynthetic or early diagentic products in recent sediments)	retene, perylene, octahydrochrysenes, alkyl chrysenes, picene, pimanthrene, tetra and pentacyclic PAH* (see Wakeham *et al.*, 1980a,b)
Immature/Mature Sediments	monoaromatized and triaromatized steranes (as well as the same as petroleum for mature sediments)
Pyrogenic (combustion, forest fires)	parent aromatic compounds are enriched (see Laflamme and Hites, 1978; Hites *et al.*, 1980).

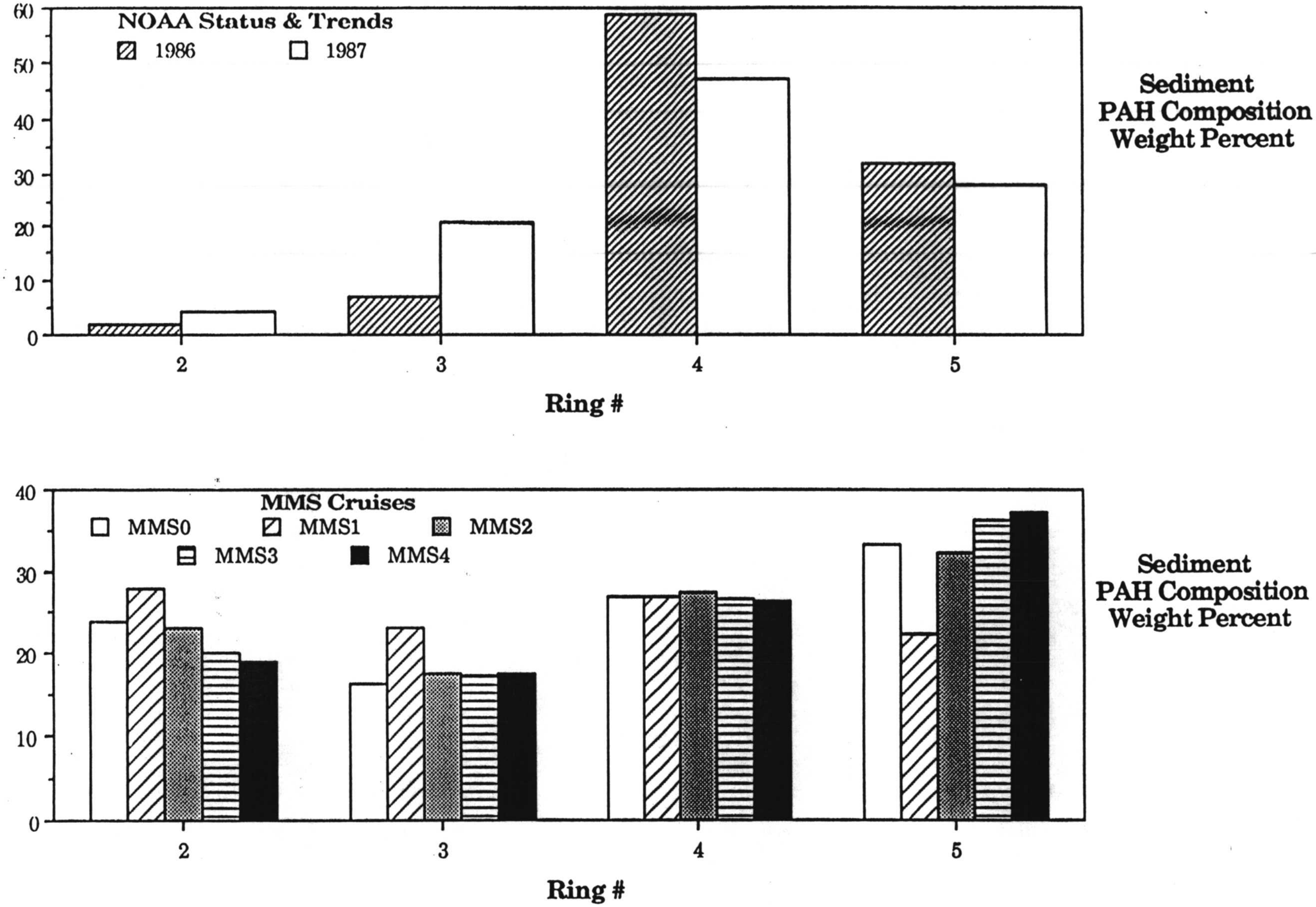


Figure 4-9. Comparison of PAH compositions between sediments in the study area and adjacent bays and estuaries.

The association between sediment texture, trace metal content and PAHs lends clues to the origin of the petroleum related PAH detected. In general high PAH levels are associated with sediments containing low amounts of sand (Figure 4-10). PAH levels below 200-300 ppb appear to represent a diffuse chronic background contamination of indeterminate origin distributed throughout the study area. Molecular compositions suggest a petroleum source with a minor combustion input possible. This is in contrast to PAH contamination in adjacent bays suggesting little if any flux of sediment contaminants onto the shelf from behind the barrier islands. The association of PAH with fine particulates suggests that river transported material is a significant source of sedimentary PAH (Figure 4-10).

The highest PAH levels correlate with enhanced barium concentrations indicating an association with drilling mud discharges (Figure 4-11). This correlation could be due to two scenarios. First the PAH contamination localized along the seaward portion of transect M and the deeper water stations is due to point source inputs from drilling operations on the face of the delta. A second scenario is that the co-occurrence is due to a riverine PAH input that acquired an enhanced barium content as it was transported across the shelf to its present site of deposition. In general PAH contamination is restricted to within tens of meters of a drilling platform (Brooks et al. 1989). The geographical extent of the enhanced PAH contamination suggests that the sediments have been effected by a more generalized input than represented by localized offshore oil exploration activities. Although localized inputs cannot be ruled out, a river related input of PAH appears likely. Land derived alkane hydrocarbon distributions and the similarity between sediment and Mississippi River suspended particulate trace metal chemistry suggests a significant riverine association for contaminants.

4.5 Summary

Sediments in the study area contain a mixture of biological and petroleum hydrocarbons. Biological hydrocarbons are predominantly plant biowaxes (n-C_{23} - n-C_{33}) with a minor planktonic input (n-C_{15} - n-C_{19}) possible. Petroleum hydrocarbons are present as polynuclear aromatic

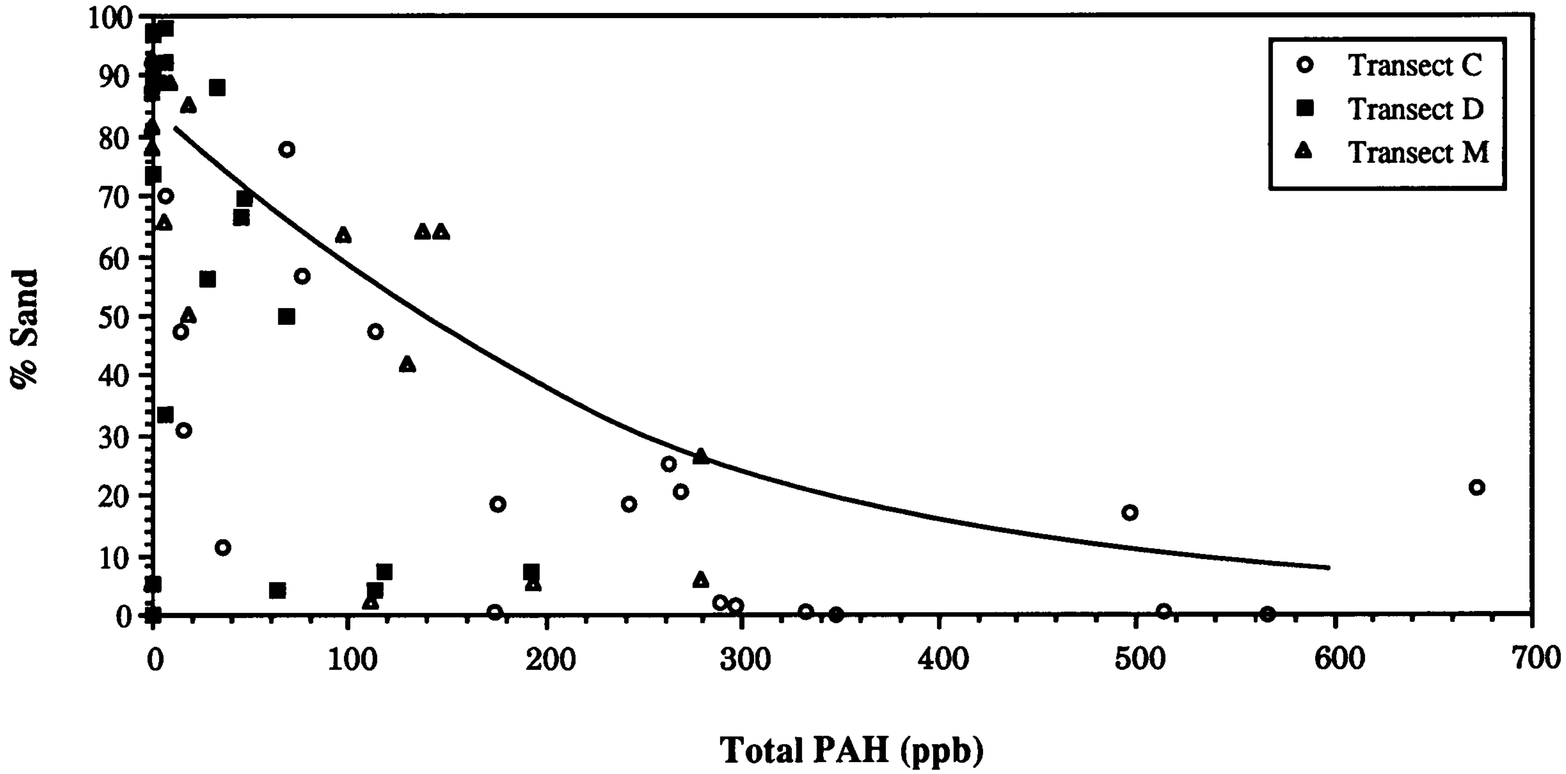


Figure 4-10. The relationship between sediment sand content and PAH contamination.

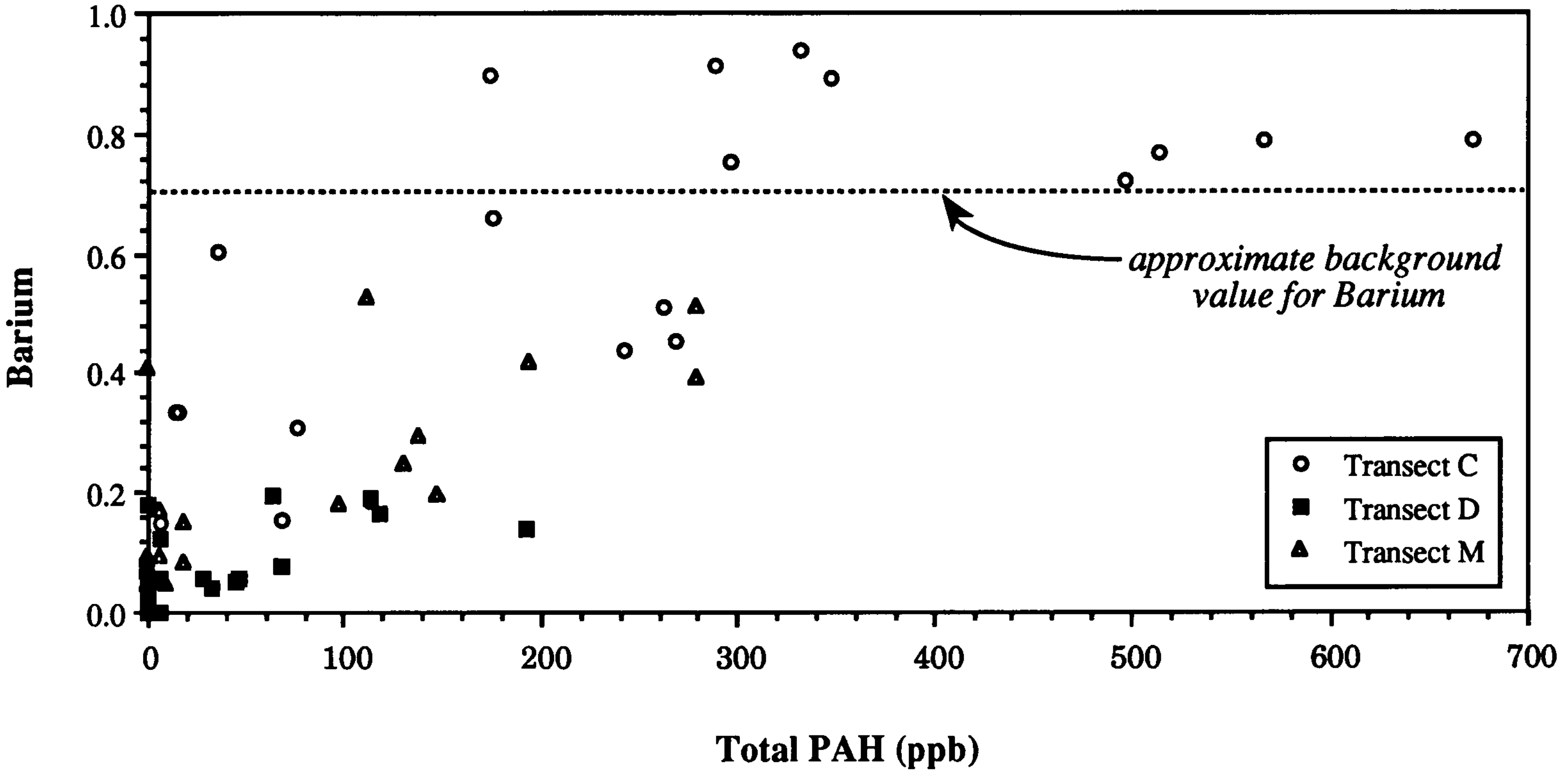


Figure 4-11. The relationship between sediment barium concentrations and PAH contamination.

compounds (PAH), a complete suite of n-alkanes, and an unresolved complex mixture. Sediment PAHs on the shelf average six times lower than PAHs analyzed in sediments in adjacent bays. High hydrocarbon concentrations are generally at the seaward ends of the transects between the 100 and 200 m isobaths with the stations closest to the delta containing the highest concentration of hydrocarbons. Large variations in sediment chemistry were observed between samplings, apparently related to the influx of riverine material. One possible scenario is a large episodic influx of riverine material followed by slow biological mixing (bioturbation) diluting the input. It is also possible that active currents on the shelf scour the organic matter out of the sediments, transport it offshore, and deposit the organic rich material in a band along the shelf break. Shelf sediment PAHs are typical of unprocessed petroleum as contrasted to adjacent bay sediment PAHs which are predominantly of a pyrogenic origin. Pyrogenic sources include fossil fuel combustion, carbonization of coal, and forest fires. The bay sediments were intentionally sampled away from point sources of pollution such as large urban areas and industrial complexes. In general, higher hydrocarbon concentrations are associated with fine grained sediments. Sediment PAHs are characterized by a low level diffuse PAH (200-300 ppb) contamination distributed throughout the study area and an input of enhanced PAHs along transect M and near-delta deep water stations. This higher sediment PAH contaminant loading (300-700 ppb) may result from localized point sources due to offshore oil exploration activities and/or river related transport of sediments. Elevated PAH concentrations co-occur with sand poor, barium rich sediments.

The temporal variations in sediment properties in the study area can be explained by various scenarios. Individual sediment components vary independently and are subject to a variety of different processes. These scenarios are as follows:

(1) <u>cyclic</u> - on time frames of 6 months, one year, two years and possibly longer. This can be explained by either regular inputs (such as seasonal variations) being balanced by either removal processes or dilution events (i.e., aromatic and aliphatic hydrocarbons).

(2) steadily increasing - in this scenario input continues overtime with no efficient (or active) removal process. The episodic occurrence of mass movement of sediments only redistributes components within the system. Another possible explanation is input exceeds removal processes thus leading to a build-up (i.e., the unresolved complex mixture - residual petroleum).

(3) random variation - episodic perturbation due to one-time or infrequent events such as major storm events (i.e., extractable organic matter).

(4) no change - could reflect input equal to removal rate with a relatively constant rate of input or the timeframe of change is greatly in excess of the two years monitored in this study (i.e., carbonate content at some locations).

Sediments on the Mississippi-Alabama shelf are very dynamic and change on time scales varying from less than six months to more than two years. Inputs are complex and often independently driven. Removal processes are complex, constituent-dependent and vary independently. Sediment properties vary by an order of magnitude or more over the two years of the study. Many of these variations can be directly related to variations in land derived inputs that are mediated by river outflow from the Mississippi River/Delta system as well as other rivers in the area. Hydrocarbon pollutant loading to sediments is primarily derived from fresh, unrefined petroleum closely associated with fine particulates derived from riverine transport. Aeolian transport and outflow from coastal bays appear to be minor influences.

In contrast to the view of sediments as relatively stable repositories of particulate matter, very dynamic interactions are apparent. Clearly if sediments are to be characterized, temporal as well as spatial variations need to be considered. As an intimate part of the benthos as well as an interface with the overlying water column, these dramatic variations in sediment composition and character need to be assessed in light of ecological assessments of man's potential impact on these areas.

5.0 TRACE METALS DISTRIBUTIONS

Bobby J. Presley

5.1 Introduction

Trace metal concentrations in the environment can be increased as a result of petroleum exploration and production, and this can potentially have harmful effects on marine organisms. To assess present day background levels of trace metals in the offshore Mississippi-Alabama area, sediment samples collected on each of the cruises have been analyzed. The twelve stations shown in Figure 3-1 were sampled on each cruise; however, no sample was obtained at Station D1 on the first cruise. At each station three different box cores were taken and the upper 5 cm of all three were used to make a composite sample for analysis.

The composite samples were analyzed for all the elements except aluminum currently being determined on the NOAA Status and Trends Program using the method employed on that program (Brooks et al. 1988). This method has been shown to produce high quality data through a series of intercalibration exercises and its use here allows the MMS data to be compared to the large data set on northwest Gulf of Mexico sediments produced by Status and Trends. In addition, all samples were analyzed for barium, chromium and iron by neutron activation analysis, a method shown to produce high quality data (Boothe and James 1985).

5.2 Methods

5.2.1 Sample Preparation and Digestion

Sediment samples were frozen in plastic containers in the field. In the laboratory, the sediment samples were freeze-dried and finely ground before analysis. The major analytical technique used was atomic absorption spectrometry (AAS), flame for those elements in high enough concentration and flameless or cold vapor when necessary. This technique made it necessary to dissolve the samples before analysis. To prepare samples for AAS, digestions were conducted in closed all-teflon "bombs" (Savillex Corp.)

of 50 ml capacity. Accurately weighed aliquots of about 200 mg of sediment were digested at 130°C for eight hours in a mixture of nitric, perchloric and hydrofluoric acids. A saturated boric acid solution was then added to complete dissolution of the sediment and the digest was brought to a known volume. Various dilutions were made on the clear digest solutions to bring them into the working range for AAS. Standard reference materials and blanks were digested with every batch of samples. A more complete outline of the preparation methods is given in Table 5-1, and Table 5-2 gives details on cleaning the digestion equipment to avoid contamination of the samples.

5.2.2 Instrumental Analysis

As mentioned above, the primary analytical method used in our laboratory was atomic absorption spectrometry. This technique has good sensitivity but requires the sample to be in solution for analysis. If not done correctly, dissolving the sample can result in either losses or gains in the trace metal content. When possible, therefore, we also analyzed the samples by neutron activation analysis, a method which uses the untreated solid sample. Unfortunately, only a few of the elements were in high enough concentration in the sediment to be determined by neutron activation, but where an element was determined by both methods (e.g., Fe) agreement was good, indicating good recovery by the digestion method used.

5.2.3 Atomic Absorption Spectrometry (AAS)

Three different AAS techniques were used on the sample digests. Due to the great speed and relative freedom from matrix interference Flame AAS, this technique was used when concentrations were high enough . For sediment samples, only aluminum, iron, manganese and zinc were in consistently high enough concentrations to be determined by flame AAS. Other elements, for example chromium, copper, and lead, were high enough to be determined by flame AAS on the clay-rich samples, but many of the samples were sandy and thereby low in trace metals. The flame AAS iron and aluminum values were judged to be less reliable than INAA values for these elements; therefore, the INAA values are given in the data tables. Most of the other elements were determined by graphite furnace AAS.

Table 5-1. Outline of sediment digestion methods for trace metal analysis.

Reagents:

4:1 mixture of nitric:perchloric, both vycor distilled and stored in teflon bottles.

Baker reagent grade Hydrofluoric Acid.

2.5% solution of Baker Ultrex Boric Acid - 50 g boric acid in 2L of distilled-deionized water.

1. Weight out 200 mg ground, dry sediment and add to a preweighed, acid cleaned teflon bomb. Be as careful as possible to pour the sediment to the bottom of the bomb. Static electricity will cause the sediment particles to adhere to the inside walls of the bomb.
2. Add 1 ml of 4:1 HNO_3NClO_4. Try to carefully wash the inside walls of the bomb with acid. Tighten the bombs with wrenches and place in 130°C oven for 4 hours.
3. Remove bombs and let cool. Add 3 ml HF, retighten bombs and return to oven ~8 to 12 hours (overnight).
4. Remove bombs and let cool. Add 20 ml of 2.5% H_3BO_3, tighten bombs and return to oven ~8 hours.
5. Let bombs cool and weigh. Calculate the solution volume using a density of 1.05 g/ml.
6. Transfer the solutions to 30 ml acid cleaned polybottles.
7. Remove 0.5 ml of solution and dilute it to 20:1 with dilute HNO_3 (the exact composition of the diluting solution changes). This can be done in a new 5-dram snap cap vial. This dilution is used for Fe, Al, and Si analyses.
8. Reagent blanks - run 2 for each batch. Follow steps 2-7.

Each batch of sediments and oysters digested included two to four of the reference standards listed below.

Sediments:

NOAA Intercalibration Standards, A,B,C,&D
NBS River Sediment Standard #1645
USGS Geochemical Exploration Sample #5
NBS Estuarine Sediment Standard #1646
TAMU House Standard #1
TAMU House Standard #2

Table 5-2. Bomb cleaning procedures for trace metals after sediment digestion.

Bomb Cleaning After Sediment Digestions:

1. Wipe inside of bombs with a paper towel and diluted Micro™ cleaning solution, then place bombs in a dilute Micro™ bath* for 24 hours.
2. Rinse with house distilled water and then with deionized water. Place rinsed bombs into nitric bath** for 24 hours.
3. Rinse with deionized water and set the bombs out to dry in the clean room.

*Change these baths after each batch.
**Change the nitric bath one a week.

The flame AAS work was conducted on a Perkin-Elmer Corp. Model 306 instrument, essentially following the manufacturer's recommendations. An air-acetylene flame was used, except for aluminum where a N_2O-acetylene flame was employed. Working curves were constructed from commercial standards and resulting concentrations were verified by analyzing NBS and other standard materials with every batch of samples (see Table 5-1).

Graphite furnace AAS is much more of an "art" than is flame AAS. The Perkin-Elmer Zeeman 3030 used was equipped with a HGA 600 furnace and ASA-60 autosampler. The furnace is capable of an almost infinite number of temperatures, holding times and ramp times and, in addition, samples can be placed either on a platform or directly on the furnace tube wall. A number of different matrix modifiers can also be used. Therefore, in the early stages of this program, a great deal of time was spent working out the best combination of conditions for analyzing each element. The conditions are stored in the computer memory of the instrument and can be recalled and printed out on command. The conditions currently used will be supplied on request, but it should be noted that the conditions must be changed slightly from time to time, especially as a graphite tube ages, to maximize sensitivity and minimize interferences.

5.2.4 Instrumental Neutron Activation Analysis (INAA)

A dozen or more metals can be determined on coastal sediments by instrumental neutron activation analysis using a single irradiation and a single counting. Barium can be determined following an 8- to 16-hr irradiation and a 10- to 15-day "cooling" period. Barium is an element of interest because of the widespread use of $BaSO_4$ in oil well drilling mud. We, therefore, analyzed many of the sediment samples under conditions optimized for determining barium. Under these conditions several of the rare earth elements, as well as Cr, Co, Fe, Sb and Th are also detected. The INAA data for Ba, Cr and Fe is included in the data tables but the other INAA data has not been reduced and tabulated as it did not seem relevant to the present project.

Irradiations for INAA were done at the one megawatt TRIGA reactor at Texas A&M, which produces a flux of about 10^{13} neutrons/cm^2/sec. After a cooling period (usually 10 days), to allow Na, Cl and other interfering isotopes to decay to non-interfering levels, the samples were counted. Counting was done using a Ge (Li) detector coupled to a Nuclear Data Corp. Model 66 pulse height analyzer and computer data acquisition system. Concentrations were obtained by comparing counts for each sample with counts for standard rock powders of accurately known concentration which were irridiated and counted under conditions identical to those used for samples. The INAA technique we used is described in detail by Boothe and James (1985) who also discuss analysis of standard reference materials and other aspects of the technique.

5.2.5 Procedure for Mercury

Mercury was determined by cold vapor AAS on an aliquot of the same digest used to determine other trace elements. The method used was a "head space" sampling procedure in contrast to the more common "stripping" procedure; therefore, the "head space" procedure will be described here. One ml of sample or standard (more if needed) was put into a 25-ml Erlenmeyer flask and the flask was closed with a rubber serum stopper. The flask was injected with 0.5 ml of a 10 percent $SnCl_2$ solution from a syringe. The sample and $SnCl_2$ was shaken for 30 seconds to reduce Hg to the metal and allow it to transfer into the air space in the flask. A syringe needle connected to the mercury analyzer by a short piece of tygon tubing was next pushed through the serum stopper. Finally, a syringe needle connected to a water reservoir by tygon tubing was pushed through the serum stopper. Water was allowed to flow into the flask at a rate that filled it in about 10 seconds. The water forced air from the flask, with its Hg, into the Hg analyzer where it was measured. A Laboratory Data Control Corp. UV monitor with a 30 cm path length cell was used for Hg detection.

5.3 Results

A composite sample, made by combining aliquots from the upper 5 cm of three box cores taken at each station sampled during the Mississippi-Alabama Marine Ecosystem Study (MAMES) was analyzed for silver (Ag), arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), manganese (Mn), nickel (Ni), lead (Pb), selenium (Se), tin (Sn), and zinc (Zn). The data are given in Table 5-3, where the cruises are designated as Cruise 0, 1, 2, 3 and 4, respectively.

As the data show, there was considerable station to station variation in the trace metal concentrations in the samples. There was also considerable variation from cruise to cruise, especially at the shallow water stations. This latter observation results from the heterogeneous nature of shallow water sediments and the difficulty of sampling in exactly the same place on each cruise. It is also likely that the surface-most sediments in this shallow water area are somewhat mobile and shift with changing currents, as has been suggested by Dinnell (1988). These two phenomenon cause not only a temporal variablilty in the trace element concentration of the sediment, but also changes in $CaCO_3$ and organic carbon. The basic character of the sediment thus varies with time. The most drastic change from cruise to cruise was the result of deliberately slightly changing the location of Station C2 after Cruise 0. This was done in order to sample sediment more characteristic of the station location. The Cruise 0 sample from Station C2 was generally two to five times lower in trace metals than the samples from

Table 5-3. Trace metals in sediments from MMS Cruises 0, 1, 2, 3, 4.

Cruise - 0

Sample	Ag (ppb)	As (ppm)	Ba (ppm)	Cd (ppb)	Cr (ppm)	Cu (ppm)	Fe (%)	Hg (ppb)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Se (ppm)	Sn (ppm)	Zn (ppm)
I-C-1	49	12	333	49	47	8	2.20	66	346	8	15	<0.5	1.9	55
I-C-2	18	1	150	19	15	2	0.66	15	141	3	5	<0.5	0.4	20
I-C-3	92	15	895	130	84	22	4.20	83	1239	27	33	<0.5	3.3	126
I-C-4	118	14	890	204	84	23	4.20	96	664	31	34	0.6	2.9	124
I-M-1	11	3	70	13	7	1	0.32	8	65	1	2	<0.5	0.4	11
I-M-2	11	2	44	4	6	1	0.26	8	40	1	2	<0.5	<0.1	8
I-M-3	39	6	170	50	30	6	2.34	24	367	10	10	<0.5	1.4	55
I-M-4	56	8	525	143	76	23	3.58	70	329	31	33	0.6	4.4	71
I-D-1														
I-D-2	22	7	<18	90	13	1	1.13	28	202	4	2	<0.5	0.1	10
I-D-3	12	5	125	83	35	8	2.47	22	264	14	5	0.9	0.1	42
I-D-4	49	4	195	148	52	17	1.79	41	371	23	11	1.2	1.3	56

Cruise - 1

Sample	Ag (ppb)	As (ppm)	Ba (ppm)	Cd (ppb)	Cr (ppm)	Cu (ppm)	Fe (%)	Hg (ppb)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Se (ppm)	Sn (ppm)	Zn (ppm)
II-C-1	47	12	310	52	45	8	2.02	27	334	15	15	<0.5	1.0	48
II-C-2	53	10	510	70	62	11	2.80	47	481	18	24	<0.5	1.4	90
II-C-3	76	9	910	140	79	23	3.80	63	433	28	30	<0.5	2.2	137
II-C-4	112	10	770	179	86	22	4.10	81	148	39	40	0.6	2.2	154
II-M-1	19	1	75	4	15	1	0.35	<5	47	1	< 1	<0.5	0.1	2
II-M-2	<10	2	95	11	14	1	0.49	8	74	1	1	<0.5	0.1	7
II-M-3	<10	5	180	54	36	12	2.40	22	271	15	11	<0.5	0.9	59
II-M-4	99	8	510	126	72	19	3.38	85	200	43	32	0.8	1.6	79
II-D 1	<10	2	55	4	16	1	0.20	7	12	4	2	<0.5	<0.1	<2
II-D-2	<10	1	10	4	5	1	0.13	7	20	1	< 1	<0.5	0.3	<2
II-D-3	<10	10	50	59	23	15	2.39	16	484	9	9	1.2	0.4	25
II-D-4	21	3	140	162	48	19	1.64	44	302	20	9	1.1	0.8	55

Cruise - 2

Sample	Ag (ppb)	As (ppm)	Ba (ppm)	Cd (ppb)	Cr (ppm)	Cu (ppm)	Fe (%)	Hg (ppb)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Se (ppm)	Sn (ppm)	Zn (ppm)
III-C-1	12	15	335	23	36	5	1.61	66	201	11	14	<0.5	0.3	50
III-C-2	35	17	455	64	66	13	3.04	43	495	22	21	<0.5	1.5	97
III-C-3	23	6	605	50	47	10	2.06	39	168	13	18	<0.5	1.2	73
III-C-4	157	15	940	99	79	23	3.9	113	324	24	38	0.8	2.0	134
III-M-1	<10	4	45	21	5	1	0.21	<5	52	5	2	<0.5	<0.1	8
III-M-2	45	2	95	11	10	1	0.48	49	38	7	3	<0.5	0.7	11

Table 5-3. Trace metals in sediments from MMS Cruises 0, 1, 2, 3, 4 (continued).

Sample	Ag (ppb)	As (ppm)	Ba (ppm)	Cd (ppb)	Cr (ppm)	Cu (ppm)	Fe (%)	Hg (ppb)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Se (ppm)	Sn (ppm)	Zn (ppm)
Cruise - 2 cont'd														
III-M-3	36	4	195	48	42	6	2.37	21	325	14	12	<0.5	1.8	58
III-M-4	90	8	405	101	74	18	3.40	93	480	27	29	0.7	2.6	97
III-D-1	11	5	39	8	5	1	0.01	30	17	<1	1	<0.5	<0.1	6
III-D-2	<10	3	24	11	5	1	0.18	<5.	23	<1	2	<0.5	<0.1	7
III-D-3	<10	12	55	31	19	2	1.72	44	349	11	8	1.6	0.2	27
III-D-4	48	5	180	105	51	15	1.64	20	312	22	16	0.8	0.4	59
Cruise - 3														
IV-C-1	33	5	185	16	25	3	0.90	20	180	5	8	0.2	0.6	37.8
IV-C-2	65	13	440	65	64	12	2.93	47	515	22	20	0.3	2.0	105.4
IV-C-3	80	14	720	115	78	22	3.77	70	345	25	23	0.2	2.4	124.7
IV-C-4	95	10	790	175	84	18	4.02	85	430	27	29	0.1	2.8	150.0
IV-M-1	11	2	90	43	9	1	0.38	14	40	2	1	<0.10	<0.20	18.5
IV-M-2	5	<1.0	65	15	12	1	0.36	6	65	3	3	<0.10	0.3	17.5
IV-M-3	29	6	250	50	42	6	2.45	20	340	14	13	0.2	0.9	80.0
IV-M-4	65	7	390	120	72	16	3.34	50	390	30	24	0.3	2.2	125.0
IV-D-1	12	<1.0	42	<10.	7	1	0.088	6	11	1	1	<0.10	0.6	11.4
IV-D-2	<10	7	31	41	10	1	0.75	11	145	3	4	<0.10	<0.20	19.8
IV-D-3	26	13	75	105	26	3	1.80	20	395	10	10	0.6	0.2	39.7
IV-D-4	31	2	165	135	48	4	1.62	39	335	21	11	0.6	1.0	65.0
Cruise - 4														
V-C-1	55	8	155	20	26	3	0.92	25	188	1	7	<0.2	0.4	25
V-C-2	70	14	660	55	64	15	2.96	57	520	30	21	<0.2	1.5	86
V-C-3	84	16	755	99	79	25	3.92	83	487	40	29	0.3	2.1	129
V-C-4	104	14	790	181	88	24	4.19	104	514	42	36	0.5	2.6	134
V-M-1	30	12	295	28	33	6	1.31	39	214	9	9	0.4	0.5	39
V-M-2	21	3	85	24	11	2	0.44	22	70	3	3	<0.2	<0.2	8
V-M-3	34	4	150	37	37	4	1.18	21	278	7	10	<0.2	0.7	43
V-M-4	65	9	420	78	74	21	3.52	66	433	39	23	0.3	2.0	106
V-D-1	13	2	45	8	6	1	0.13	3	18	1	2	<0.2	<0.2	<5
V-D-2	<10	3	16	19	4	1	0.17	5	44	1	2	<0.2	<0.2	7
V-D-3	21	13	55	123	16	2	1.42	22	337	8	7	<0.2	<0.2	19
V-D-4	34	5	190	165	50	14	1.69	57	331	22	15	1.0	0.9	52

the other cruises which shows the strong effect of relocating a station even slightly if it is moved into an area with more clay rich sediments.

Sediments from all 12 stations are characterized as to grain size, calcium carbonate content and organic carbon concentration elsewhere in this report, and it should be noted here that these parameters have a strong influence on trace metal concentration. A fine-grained sediment in this, and most other, areas implies a more clay mineral rich sediment and these are enriched in Al, Fe, and trace metals compared to quartz sand rich and calcium carbonate rich sediment. Organic carbon usually associates with clay rich sediment and may enhance the clay minerals ability to adsorb trace metals.

The Mississippi River is a prominent source of clay rich sediment for the Gulf of Mexico and its influence can be clearly seen at Stations C3 and C4. Clay rich sediment is also supplied by other rivers and some of this material no doubt adds to that from the Mississippi to make up the sediment found at Stations M3, M4, D3 and D4. Sediment from the shallow water stations (1 and 2) on each transect has less clay because it is winnowed away by bottom currents. These samples are, therefore, less trace metal rich. In most cases, the iron content of the sediment reflects the grain size, with the deep water, more clay rich sediment being high in iron and the shallow water stations being iron poor. The good correlation between Fe and silt+clay is shown in Figure 5-1. The five samples well above the general trend (~1.7% Fe and 95% silt+clay) are fine grained carbonate, whereas the few samples lying off the trend towards high Fe are Fe-stained sand.

The correlation between iron, grain size and trace metal concentration has been pointed out by Trefry and Presley (1976) and many other authors and is an expected relationship for unpolluted sediment. Examples of the correlation between Fe and some of the trace metals measured in the MAMES samples are shown in Figures 5-2 to 5-6. Trefry and Presley (1976) and much unpublished data from Presley's laboratory, document an approximately constant trace metal to iron ratio in most Gulf of Mexico sediments. Based on this observation, high trace metal to iron ratios can usually be taken as an indicator of metal pollution. The trace metal to iron ratio does vary somewhat with sediment type; however, so caution

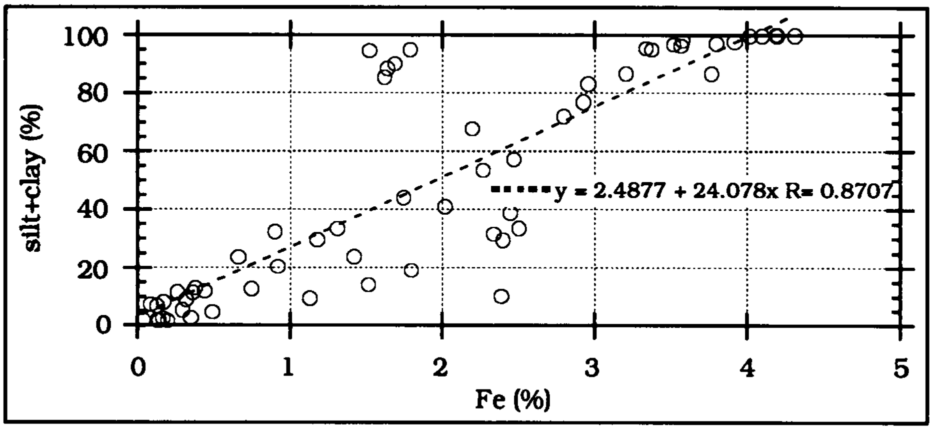


Figure 5-1. Plot of Fe vs. silt+clay in MAMES sediment samples from five cruises of the MMS Mississippi-Alabama Marine Ecosystem Study.

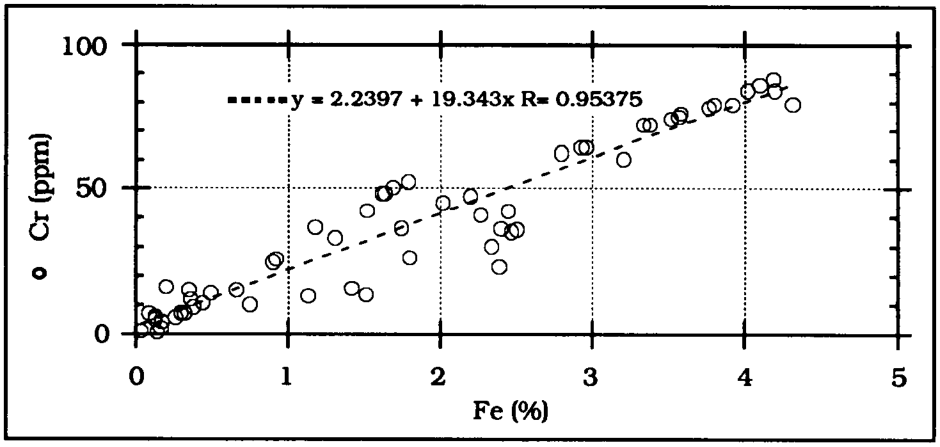


Figure 5-2. Plot of Fe vs.Cr in MAMES sediment samples from five cruises of the MMS Mississippi-Alabama Marine Ecosystem Study.

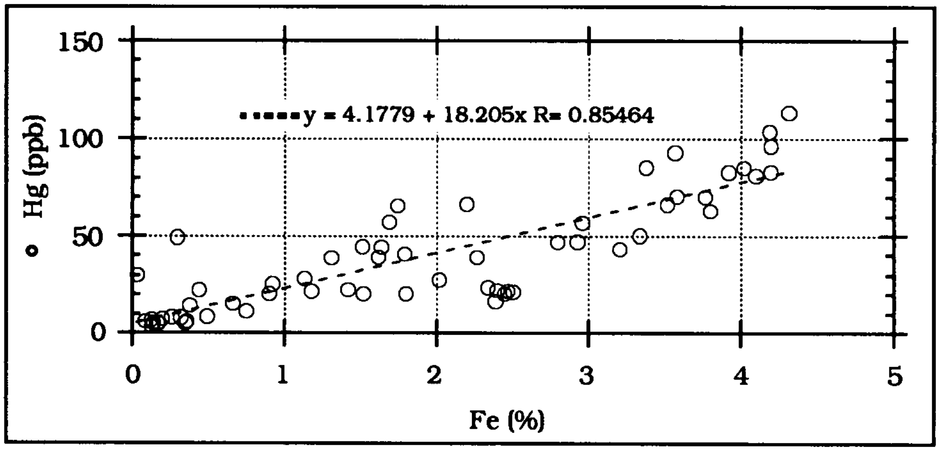


Figure 5-3. Plot of Fe vs.Hg in MAMES sediment samples from five cruises of the MMS Mississippi-Alabama Marine Ecosystem Study.

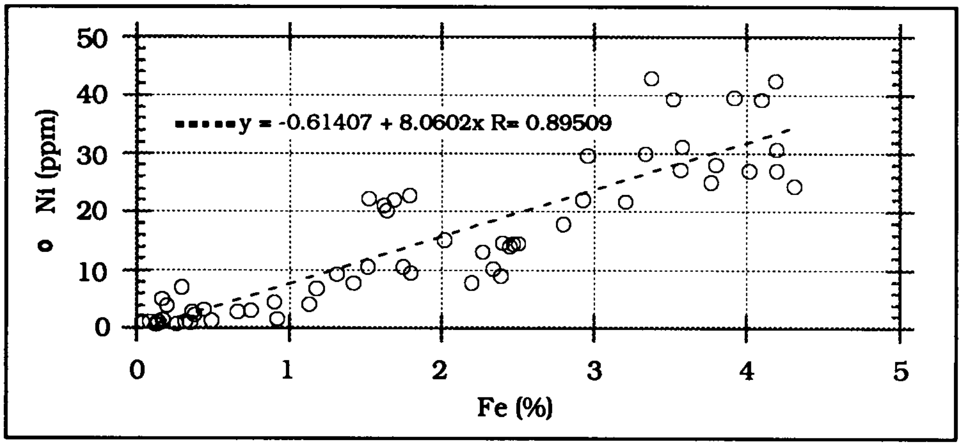


Figure 5-4. Plot of Fe vs. Ni in MAMES Sediment samples from five cruises of the MMS Mississippi-Alabama Marine Ecosystem Study.

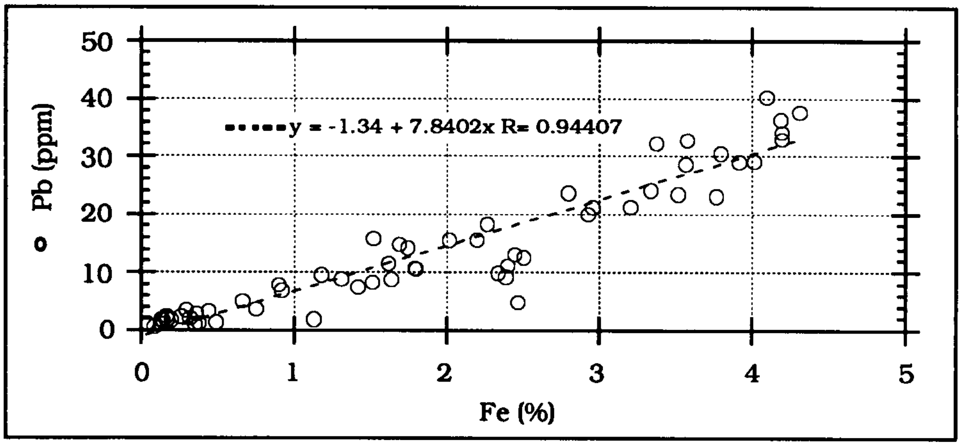


Figure 5-5. Plot of Fe. vs. Pb in MAMES sediment samples from five cruises of the MMS Mississippi-Alabama Marine Ecosystem Study.

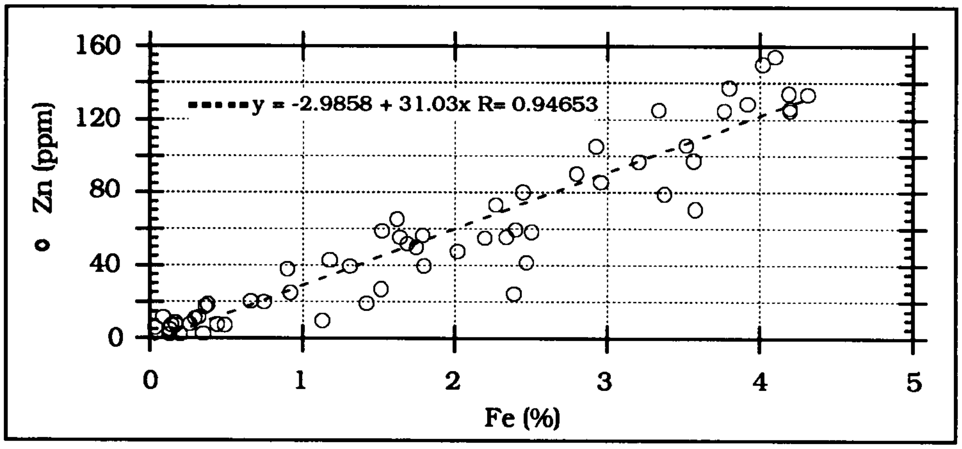


Figure 5-6. Plot of Fe. vs. Zn in MAMES sediment samples from five cruises of the MMS Mississippi-Alabama Marine Ecosystem Study.

should be exercised in concluding that pollutant metal is present. Natural processes such as reduction, diffusion and re-oxidation can also redistribute metals in the sediment column leading to metal enriched layers. This is well documented for Mn (Trefry and Presley, 1982) and may be important for Cd (Trefry et al. 1986).

The sediment in the present study area is a very heterogeneous mixture of quartz sand, biogenic carbonate and clay. A given sample can consist of from <5% to >90% of any of the end member constituents. Furthermore, the carbonate end member itself can vary from algae to mollusc shells, and in some cases is old material that has been buried and re-exposed by erosion. Quartz sand and especially shell material from some samples has been observed to be stained with iron oxides and cemented with iron oxides and iron carbonates (see section 6.0). No data are available on trace metals in those stains, coatings and cements but they obviously complicate the simple picture of a sediment consisting of iron and trace metal-rich clay diluted by pure calcium carbonate and quartz sand. Low trace metal to iron ratios are more common than are high trace metal to iron ratios in the samples analyzed here; thus, it appears that iron oxide coatings and iron carbonate cements must be generally low in trace metal content. This needs to be further investigated.

The sediment from the study area gives little indication of pollutant influence from the Mississippi River or from Mobile Bay, the most likely sources of pollutant trace metals. Subtle influences would be hard to recognize, however, especially in the samples with low trace metal levels where the precision of the data is not as good. There is a definite indication of drill mud influence in the Ba concentrations of samples from transect C, where some samples seem to be enriched by about a factor of two over what would be expected for Mississippi River derived sediment. This is illustrated in Figure 5-7 where Ba in the MAMES samples is plotted against Fe. Values of Fe and Ba in a number of Mississippi River suspended matter samples analyzed in this lab for other projects are also shown and it can be seen that some MAMES samples are richer in Ba than is this likely source material. The added Ba comes from oil well drilling in the area. These same samples seem to be enriched in As by about 25 percent but this is less definite. In any case, neither the Ba nor As concentrations are likely to

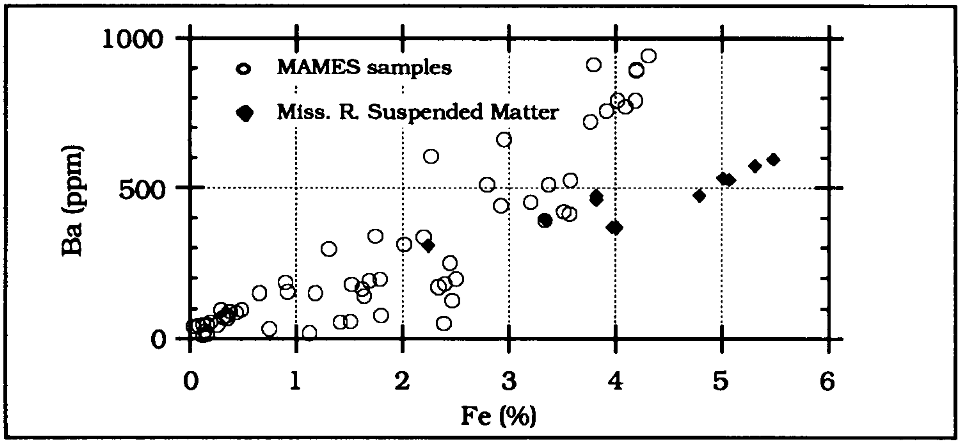


Figure 5-7. Plot of Fe vs. Ba in MAMES sediment samples from five cruises of the MMS Mississippi-Alabama Marine Ecosystem Study and Mississippi suspended matter.

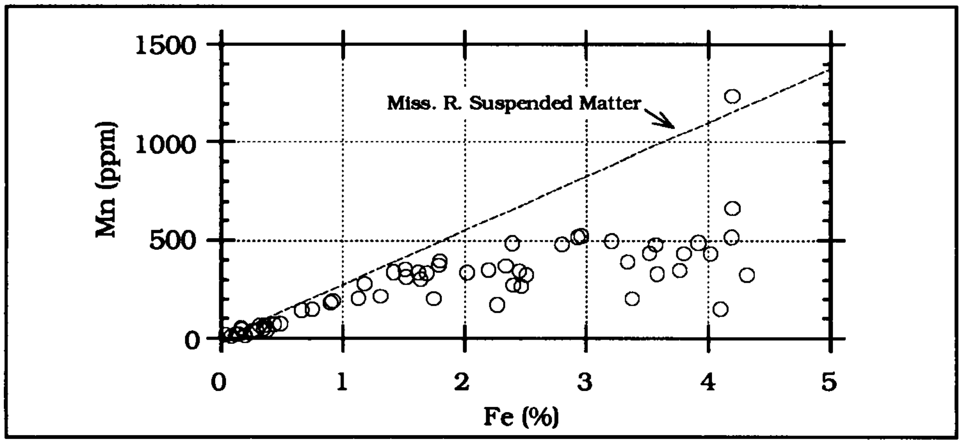


Figure 5-8. Plot of Fe vs. Mn in MAMES sediment samples from five cruises of the MMS Mississippi-Alabama Marine Ecosystem Study.

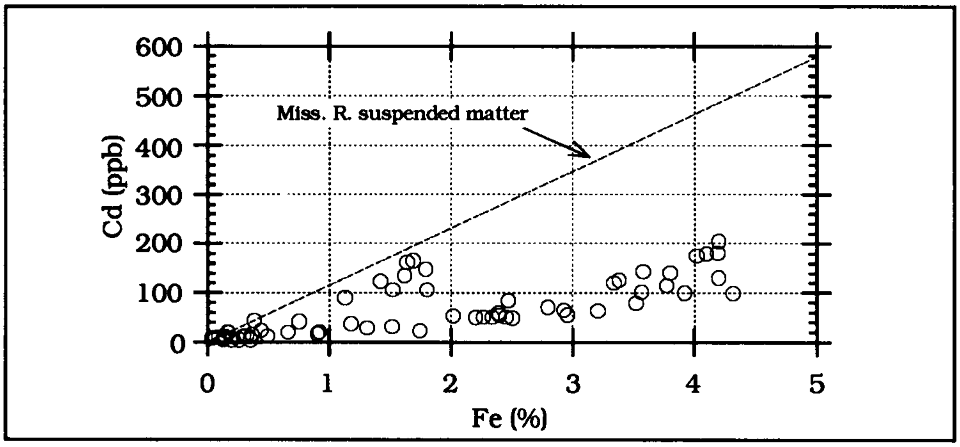


Figure 5-9. Plot of Fe vs. Cd in MAMES sediment samples from five cruises of the MMS Mississippi-Alabama Marine Ecosystem Study.

cause biological effects, as the enrichments are relatively small compared to those known to cause effects (Pavlou 1987; Neff et al. 1988).

Manganese and Cd concentrations are generally less than expected for the observed Fe concentrations, in many samples by a factor of two (Figures 5-8 and 5-9). This shows that biological activity is intense in the sediments, leading to oxygen depletion and Mn oxide reduction. Cadmium may be associated with the Mn oxide coatings on sediment grains and mobilized with Mn. This process is further indicated by a few Fe and Mn-enriched sediment samples, where the metals mobilized at one place have precipitated in another. The Mn and other trace elements show somewhat more variability from station to station and from cruise to cruise than does iron (Figures 5-10 to 5-19), but generally they show the same pattern in almost all cases. In those few cases where a trace metal (Cd for example) is higher in a low Fe sample than a high Fe sample, subtle pollution is suspected but natural variability cannot be ruled out. It will be very difficult to document subtle (<25%) enrichments in trace metals in these complex and variable sediments.

5.4 Summary and Conclusions

Sediment from the 12 stations sampled in the Mississippi-Alabama offshore area varied greatly in iron and trace metal content, but the variations seem to be largely the result of natural variability in grain size and mineralogy. Deep water sediments were enriched in Fe and trace metals compared to shallow water ones, but both had metal to iron ratios typical of unpolluted Gulf of Mexico shelf sediment. A few samples from transect C (near the Mississippi River) seem to be enriched in Ba by about a factor of two over what would be expected but there were few other indications of trace metal pollution in the area. Manganese and Cd concentrations were only about half of that expected based on iron concentration for many of the samples. This shows the sediments of the area to be biochemically active and capable of solubilizing Mn, Cd, and perhaps other metals which are either susceptible to reductive mobilization or associated with elements that are.

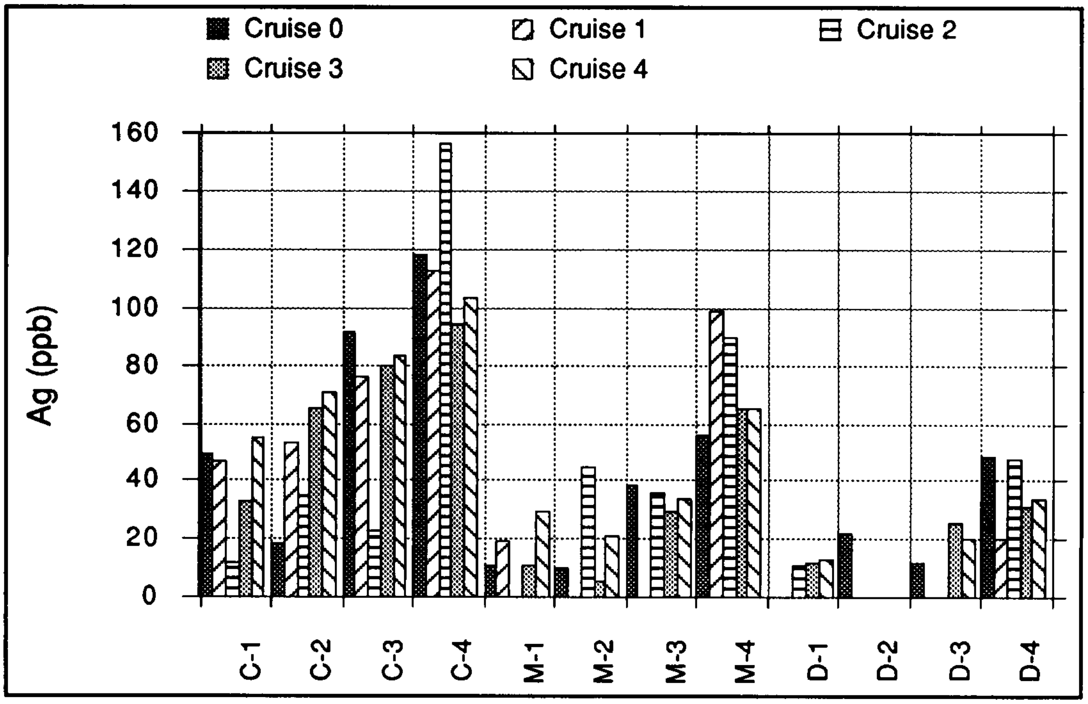


Figure 5-10. Silver concentrations in sediment samples from five cruises of the MMS Mississippi-Alabama Marine Ecosystem Study.

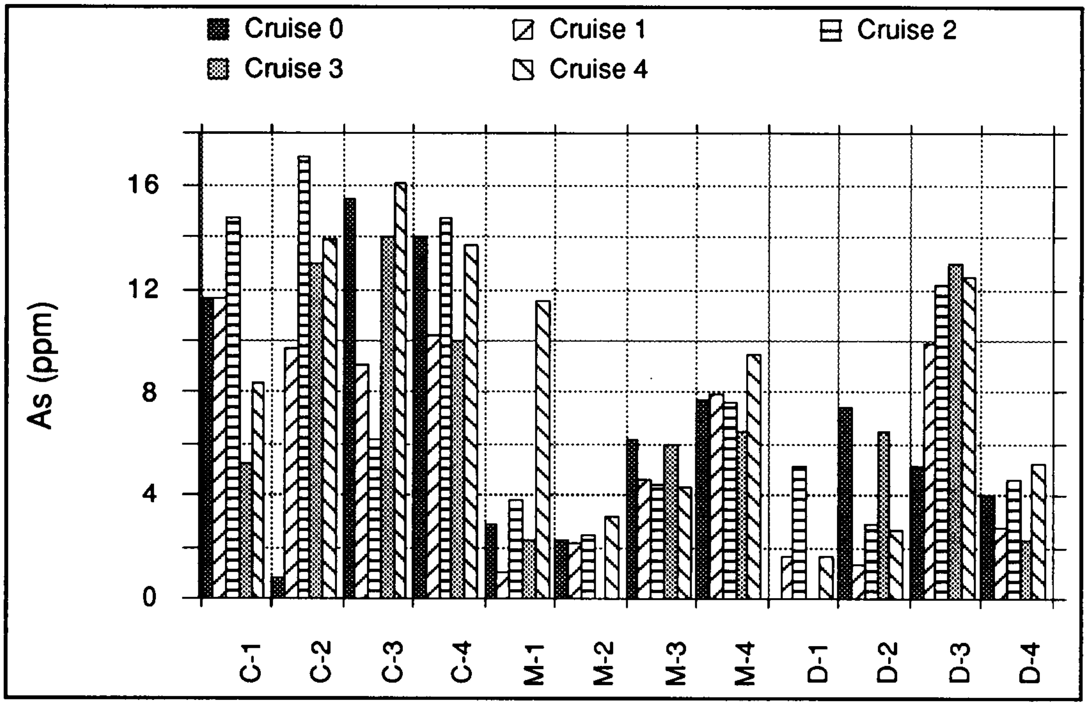


Figure 5-11. Arsenic concentrations in sediment samples from five cruises of the MMS Mississippi-Alabama Marine Ecosystem Study.

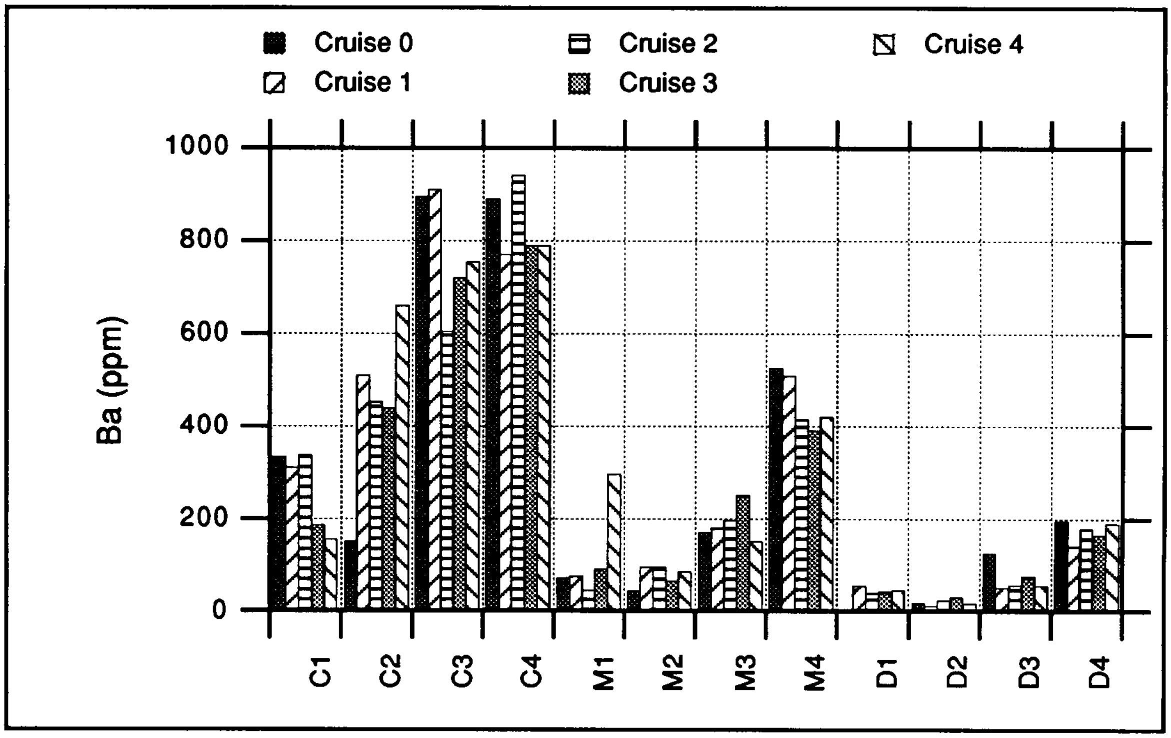


Figure 5-12. Barium concentrations in sediment samples from five cruises of the MMS Mississippi-Alabama Marine Ecosystem Study.

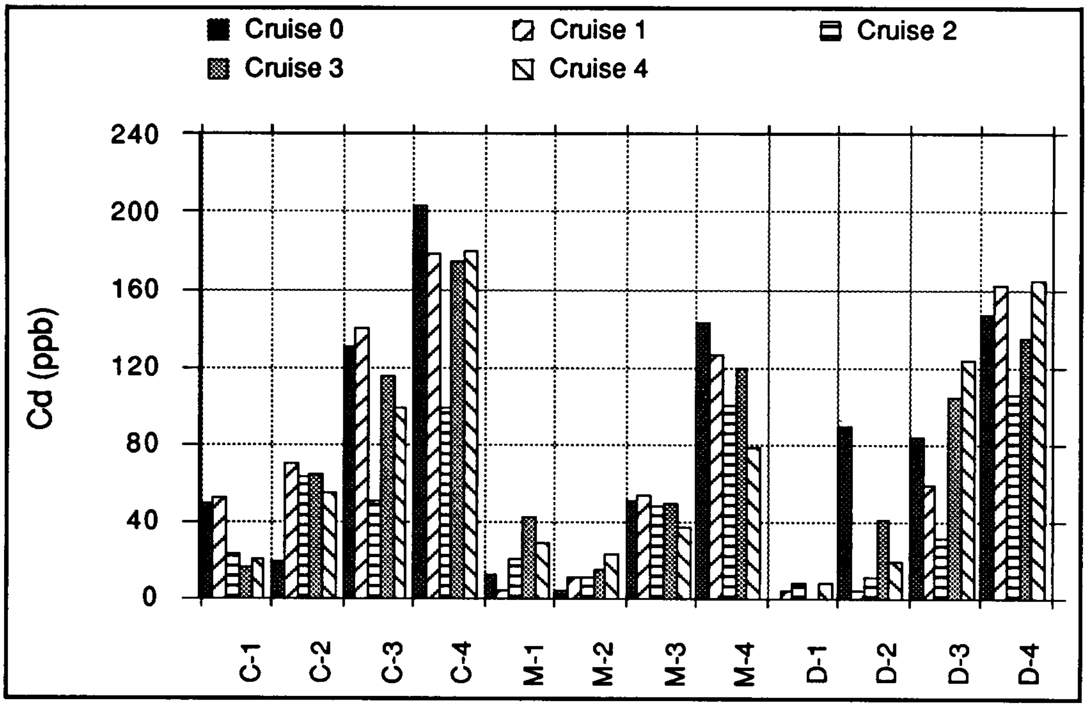


Figure 5-13. Cadmium concentrations in sediment samples from five cruises of the MMS Mississippi-Alabama Marine Ecosystem Study.

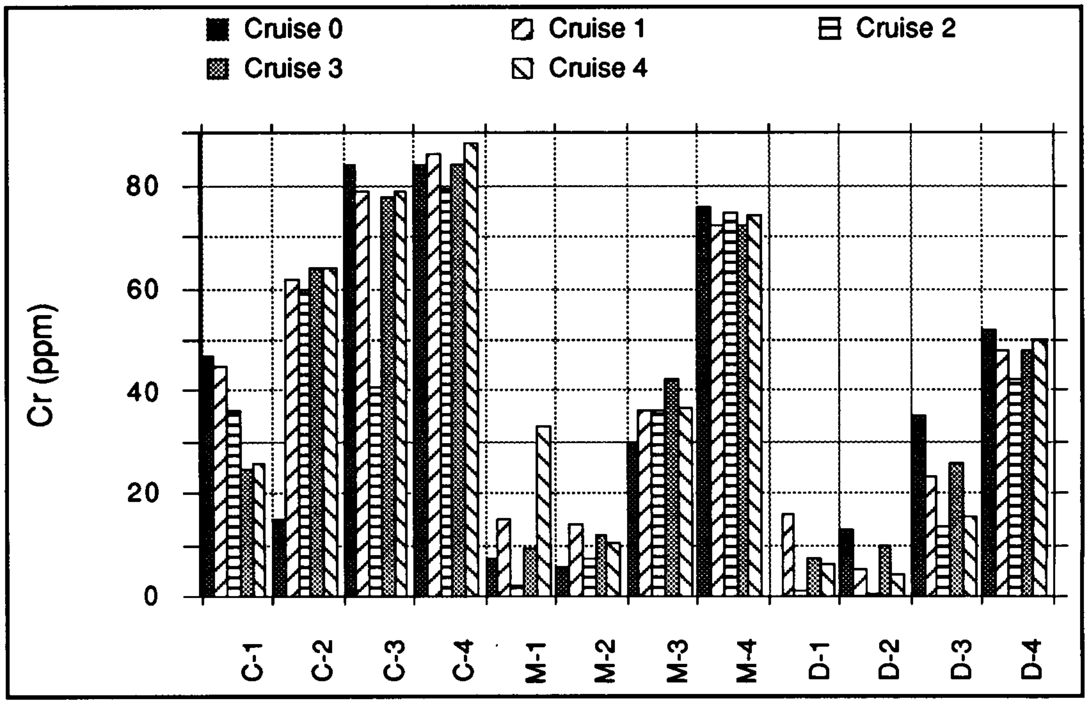


Figure 5-14. Chromium concentrations in sediment samples from five cruises of the MMS Mississippi-Alabama Marine Ecosystem Study.

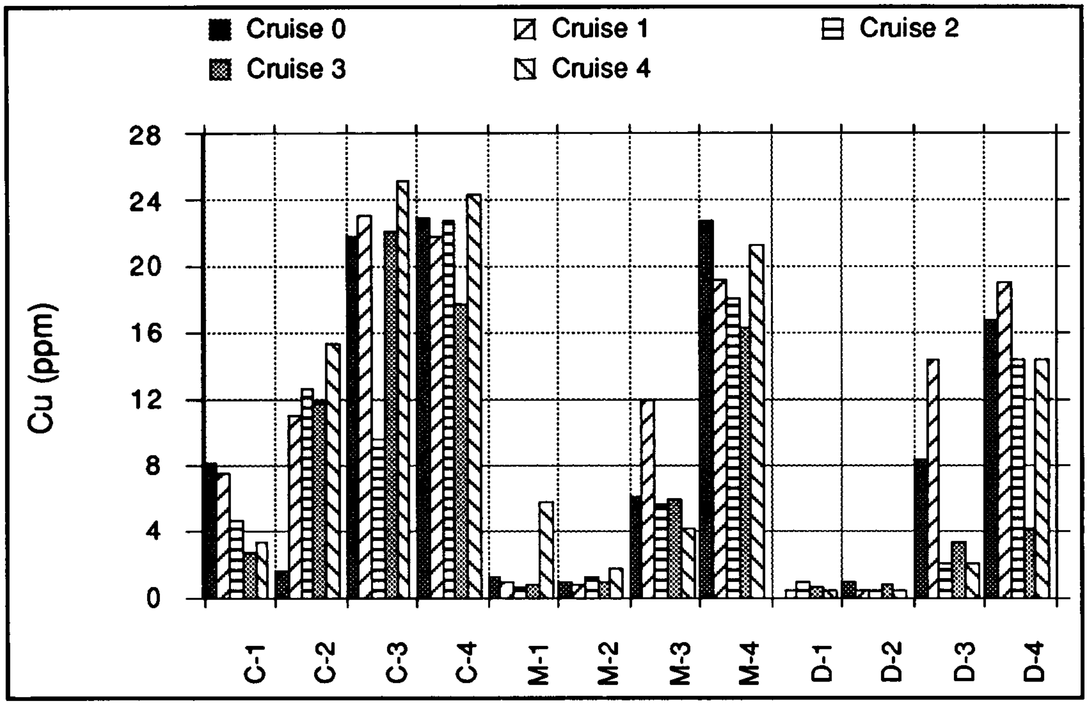


Figure 5-15. Copper concentrations in sediment samples from five cruises of the MMS Mississippi-Alabama Marine Ecosystem Study.

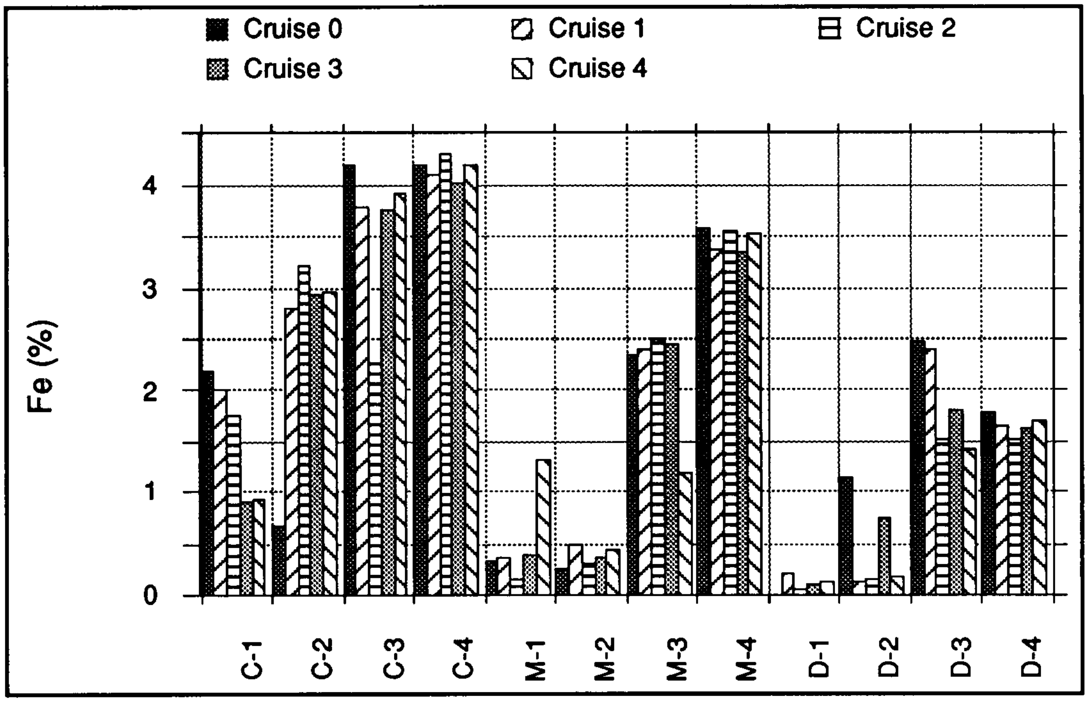


Figure 5-16. Iron concentrations in sediment samples from five cruises of the MMS Mississippi-Alabama Marine Ecosystem Study.

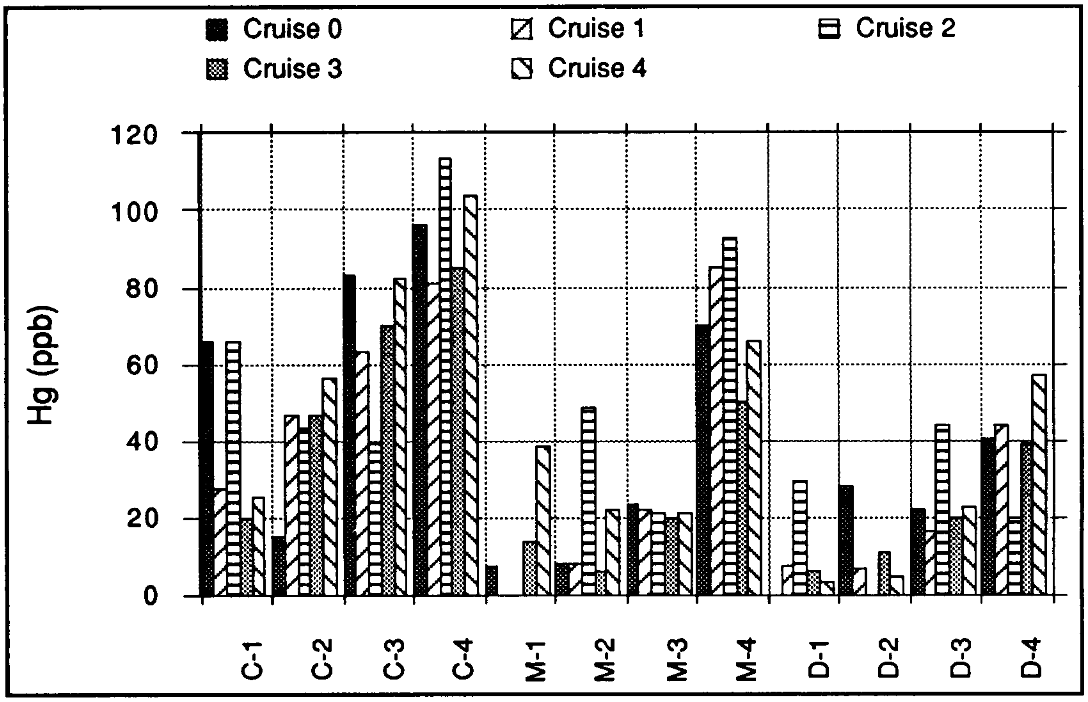


Figure 5-17. Mercury concentrations in sediment samples from five cruises of the MMS Mississippi-Alabama Marine Ecosystem Study.

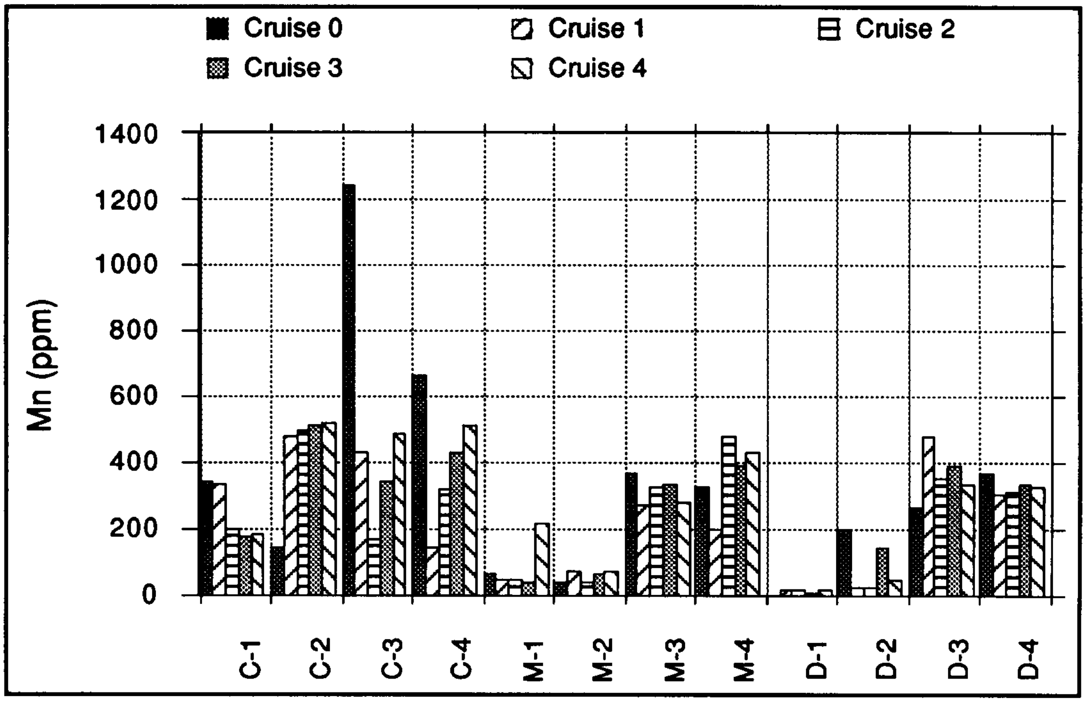


Figure 5-18. Manganese concentrations in sediment samples from five cruises of the MMS Mississippi-Alabama Marine Ecosystem Study.

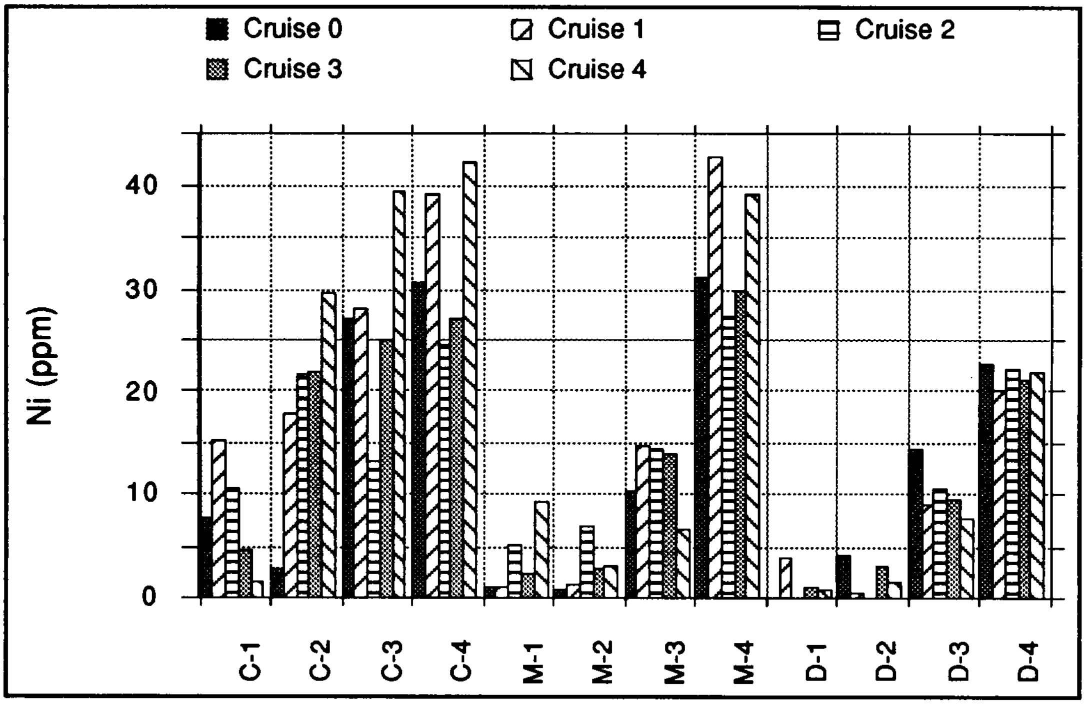


Figure 5-19. Nickel concentrations in sediment samples from five cruises of the MMS Mississippi-Alabama Marine Ecosystem Study.

5.5 Recommendations for Further Study

The variability from station to station and cruise to cruise makes it difficult to exactly characterize sediment from a given station, even when the data is normalized to Fe content. More analyses are required if subtle pollution effects are to be recognized. Analyzing 10 samples collected within a 200 m circle at one middle shelf station would help determine if the metal to Fe ratio variations from cruise to cruise at a given station are due to sediment heterogeneity or to sediment transport between cruises; but we also need other indicators of sediment transport. Large benthic organisms collected in the area should be analyzed for trace metals for background information and/or an indication of trace metal bioavailability.

6.0 SEDIMENT ANALYSES

Richard Rezak, Kenneth S. Davis, and William W. Schroeder

6.1 Introduction

The most comprehensive studies of sediment facies on the Mississippi-Alabama Outer Continental Shelf were published by Ludwick (1964) and Upshaw et al. (1966). Grady's (1970) map of sediment types in the northern Gulf of Mexico is a compilation of published studies and Grady does not cite his sources. However, it is evident when comparing the Grady (1970) map with those in Ludwick (1964) that the major source was the Ludwick paper. Other references to sediments in the published record deal with the heavy mineral suites and their provenance (Van Andel, 1960; Van Andel and Poole, 1960; Fairbank, 1979; Doyle and Sparks, 1980), the paleogeomorphology of the study area (Ballard and Uchupi, 1970), or part of a larger study (Dames and Moore,1979; Pyle et al.,1975; Swift et al, 1971; Gould and Stewart,1955; Ludwick and Walton,1957. Boone,1973, is a review paper. Recent papers by Mazzullo and Bates (1985) and Peterson and Mazzullo (1987) have dealt with the question of sources of the sands on the Mississippi-Alabama continental shelf based on grain shapes and surface textures.

Kindinger *et al.* (1982) and Kindinger (1989a) describe the depositional history of the Louisiana-Mississippi outer continental shelf, in the western part of our study area, based on single channel high resolution seismic surveys. Kindinger (1989a) suggests that the surficial sediments of the Mississippi-Alabama continental shelf are relict deltaic deposits of Late Wisconsinan and Holocene age. The source of the Late Wisconsinan delta was to the north and east and he attributed the delta to the paleo-Pearl and/or the paleo-Mobile rivers. Kindinger (1989b) named it the Lagniappe Delta (Figure 6-1). Our work further to the east indicates that the paleo-Mobile River also was building shelf-edge deltas to the east of the Lagniappe Delta. The patchy distribution of sediment facies on the Mississippi-Alabama continental shelf is due to reworking of these delta complexes by shoreline processes and longshore currents during the post Wisconsinan rise of sea level and after the abandonment of the St. Bernard Delta.

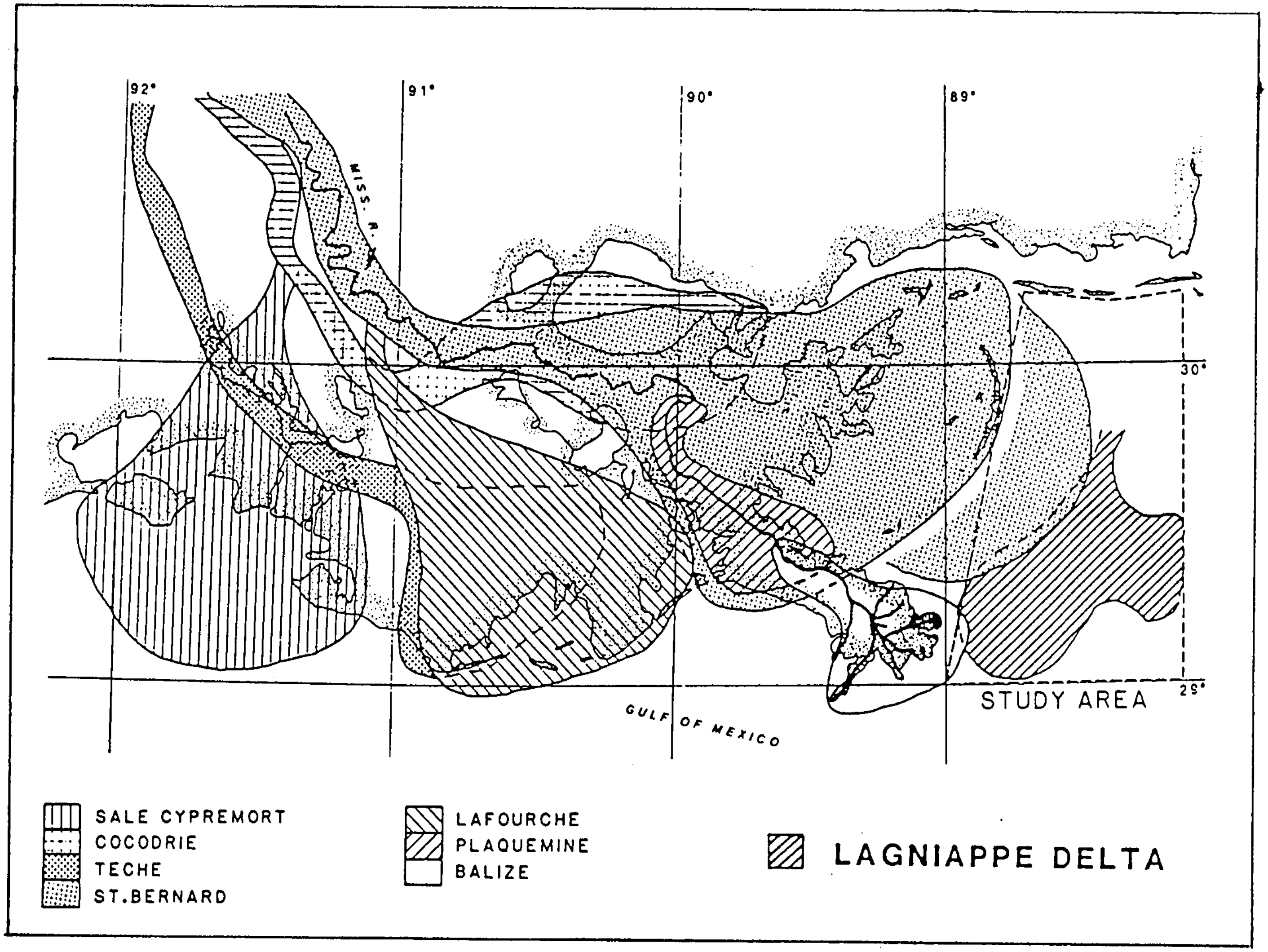


Figure 6-1. Map showing Mississippi River delta lobes including the Lagniappe Delta (from Kindinger, 1989b).

6.1.1 Sediment Facies

Ludwick (1964) described the following five sediment facies on the Mississippi- Alabama Outer Continental Shelf:

1. Chandeleur Facies
2. St. Bernard Prodelta Facies
3. Mississippi-Alabama Sand Facies
4. Mississippi-Alabama Reef and Interreef Facies
5. Mississippi Prodelta Facies

Figure 6-2 illustrates the distribution of sediment facies, after Ludwick, 1964. Figure 6-3 shows the distribution of sediment types and the locations of the soft-bottom transect stations sampled during the present study.

The Chandeleur Facies is a fine grained, well sorted, quartz sand. The Chandeleur Islands have resulted from the redistribution of St. Bernard Subdelta sands. The St. Bernard Subdelta is that part of the Mississippi River Delta complex which consists of the modern Chandeleur Facies and the Holocene.St. Bernard Prodelta Facies (Otvos, 1985). After abandonment of a delta lobe, bay fill sedimentation stops, subsidence and coastal retreat become the principal natural process. Coarse sediments become reworked by wave action and barrier islands and bars may develop near the fringes of the once active delta lobe (Penland and Boyd, 1981).

The St. Bernard Prodelta Facies lies as a broad arc on the western part of the shelf. The sediment consists of a homogeneous silty clay that is overlain to the west by the Chandeleur Facies and other remnants of the abandoned St. Bernard delta lobe. To the east, the prodelta sediments overlie the Mississippi-Alabama Sand Facies. Between the two facies, there is a transition zone varying in width from a few to about 10 miles.

The Mississippi-Alabama Sand Facies is a relict Pleistocene deposit that has been studied in detail by Mazzulo and Bates (1985) They have divided the facies into two sand provinces based on grain shape and surface texture. The Mississippi Province includes the St. Bernard and birdfoot lobes of the Mississippi delta. The Eastern Gulf Province includes the area to the east of the St. Bernard delta lobe. The Eastern Gulf Province is divided into the Eastern Sand deposit which consists predominantly of a

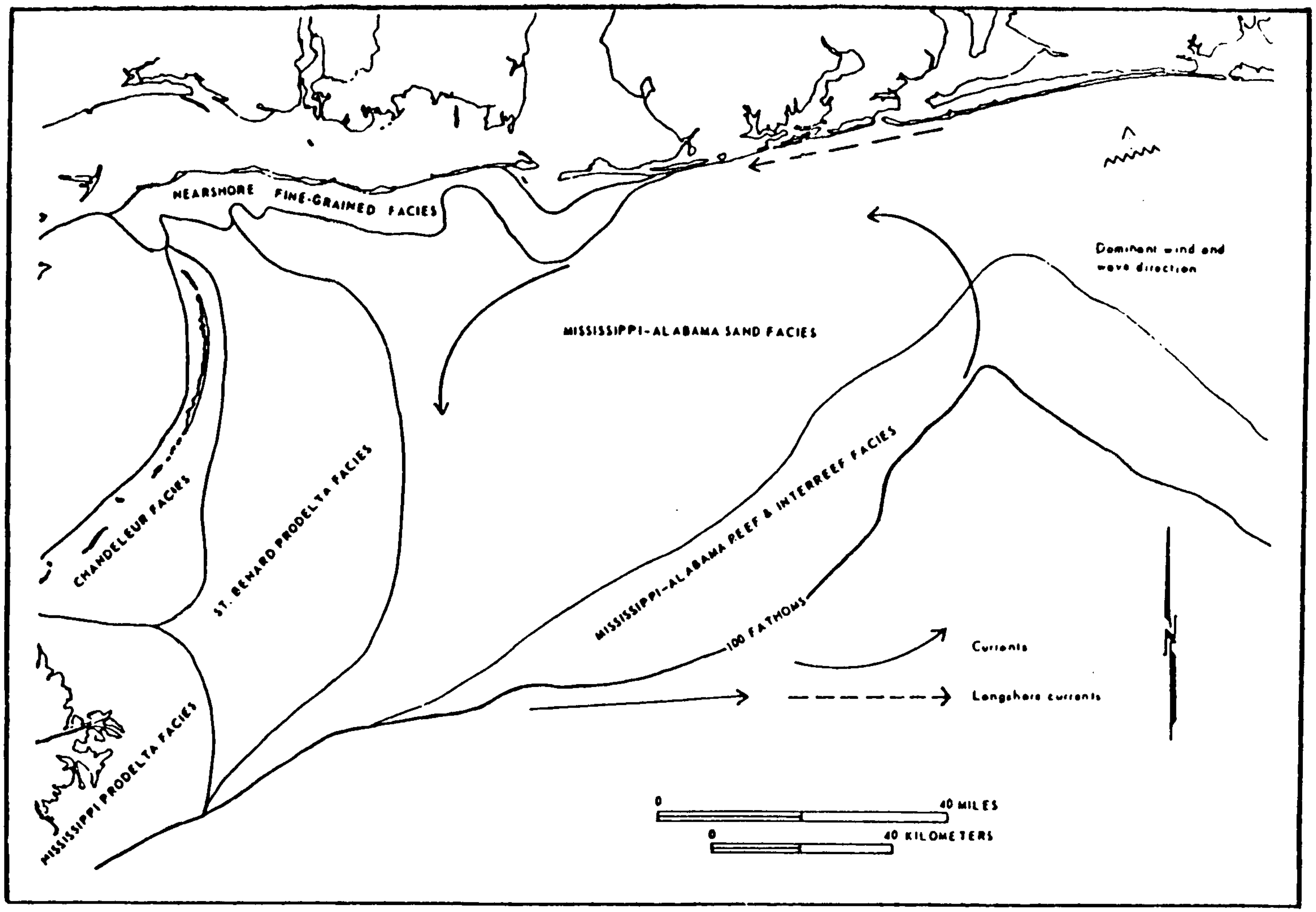


Figure 6-2. Ludwick (1964) sediment facies on Mississippi-Alabama OCS (after Boone 1973).

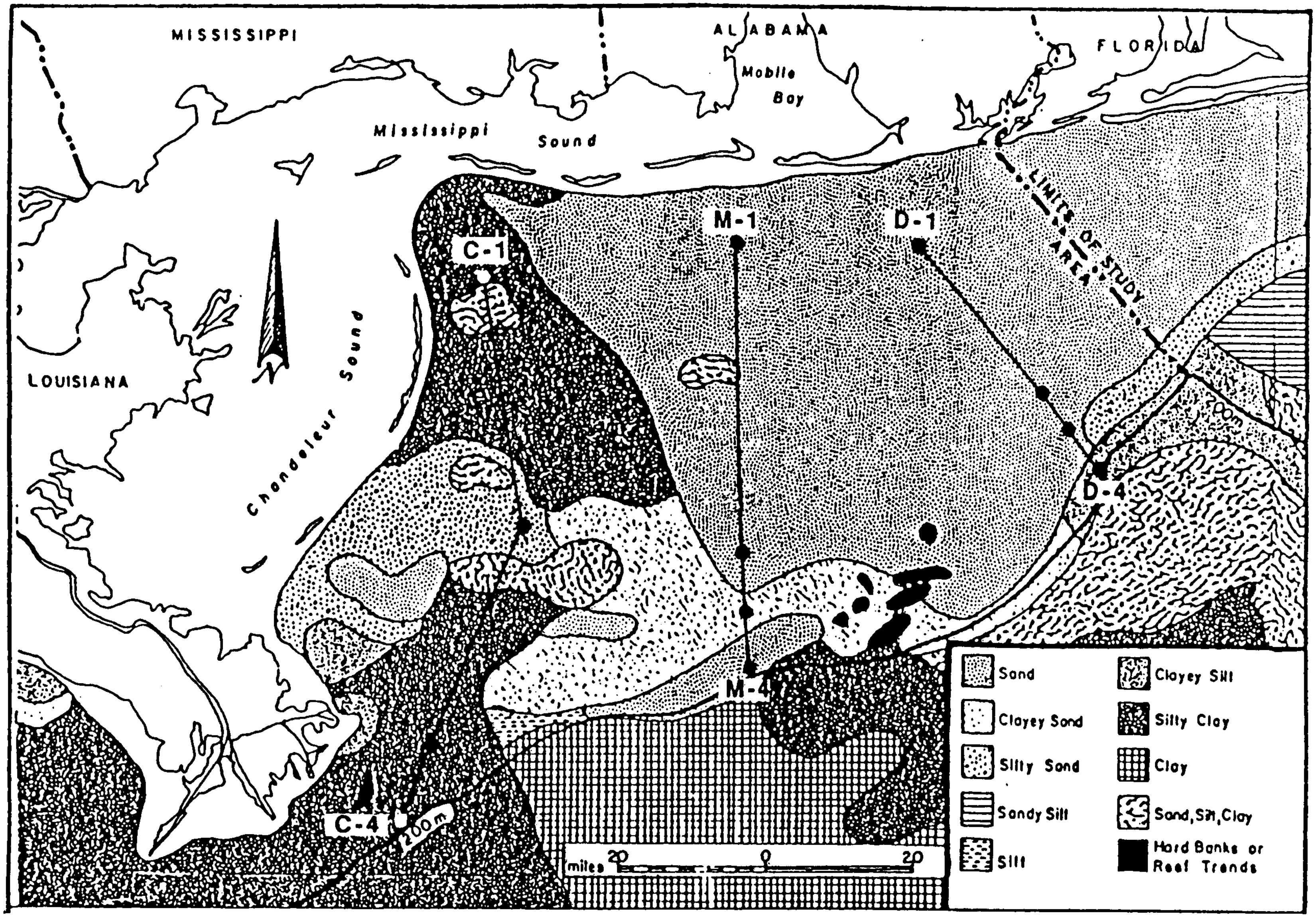


Figure 6-3. Map showing Ludwick (1964) sediment facies and location of transect stations.

well sorted, spherical to elongate grained, fine to medium, quartz sand of Late Pleistocene to Early Holocene age located on the outer shelf, and an inner shelf fine-grained facies composed of sand and mud deposits of the barrier islands and bays of the coastal zone. Shelly sands occur locally but these are usually black to brown stained mollusks that in many places include disarticulated oysters that must have grown in protected brackish water environments. Ludwick interpreted the Eastern Sand deposit to be a transgressive sand reworked from regressive fluvial and coastal deposits. Van Andel and Poole (1960) suggested that the source of the sand in the Eastern Sand deposit was the Cretaceous and Tertiary strata of the coastal plain. Mazzullo and Bates (1985) found an additional source to be the Lower Paleozoic sandstones and Precambrian and Paleozoic granite intrusives of the Southern Appalachian Mountains..

Peterson and Mazzullo (1987) identified two silt provinces On the Mississippi-Alabama shelf. The first province covers the entire shelf directly offshore and to the west of Mobile Bay. It is characterized by angular, fractured crystalline grains derived from plutonic and metamorphic rocks of Paleozoic age in the Appalachian Mountains. The material was transported by the Alabama River, a major tributary of the Mobile River and was the source of terrigenous sediment for the northern shelf during times of lowered sea level.

The Mississippi-Alabama Reef and Interreef Facies lies to the southeast of the relict quartz sand facies. Beginning adjacent to DeSoto Canyon and running to the west along the shelf break, the reefs, described by Ludwick and Walton (1957) appear to have developed due to the growth of coralline algae. Sediments in the areas of reef growth are composed of a mixture of about 70% carbonate skeletal material and the remainder terrigenous sediment primarily in the silt and clay size range. Stations D-2 and D-3 lie close to reef structures. The amount and size of carbonate particles present in the sediment decreases with increasing distance from the reef.

Sediments in the Mississippi Prodelta Facies are clay and silt size material that is either deposited very rapidly at the shelf edge or carried westward by the prevailing surface currents. The sediment that is not transported seaward or westward is deposited on the older sediments of the Chandeleur and St. Bernard Prodelta Facies as a clastic wedge.

6.2 Methods

6.2.1 Grain Size

Sample analyses followed the procedures described by Folk (1974). Samples were homogenized, treated with an aliquot of 30 percent hydrogen peroxide (H_2O_2) to oxidize organic matter, and washed with distilled water to remove soluble salts. Sodium hexametaphosphate was added to deflocculate each sample. The samples were wet-sieved using a 62.5 micron (4 phi) sieve to separate the sand and gravel from the mud fraction.

The total gravel and sand fraction was then oven dried, weighed, and sieved at 1/2 phi intervals (-1.5, -1.0, -0.5, 0.0, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, and 4.0). Each fraction was examined for aggregates, and aggregates, when found, were disaggregated. Fractions were weighed to three significant figures. The mud fraction was analyzed for particle size distribution by the pipette method at 4.5, 5.0 5.5, 6.0, 7.0, 8.0, 9.0, and 10.0 phi intervals.

The individual size fraction weights were then entered into a program developed for the Macintosh computer to merge the coarse and fine fractions of each sample and to calculate, using the method of moments, the sediment parameters shown on the sediment compilation sheets.

6.3 Results

During the five sampling cruises, 425 sediment textural analyses were conducted on samples collected from the twelve transect stations (Figure 6-3). Samples were taken from nine separate lowerings of the sampling device at each station. Six of the samples came from separate lowerings and a composite grain size sample (labeled "cgs") was created by mixing sediment from the other three lowerings. The data are presented in three tables in Appendix A. The first of these is "Sediment Texture Summary Arranged by Sample". It lists the weight percent of each size fraction plus the percents gravel, sand, silt, and clay, and the sediment parameters derived using the method of moments. The data listed under the "Sorting" category are the standard deviations of the samples which are expressed in Phi units. Each column represents a single sample and the samples are arranged by cruise and station. No composite grain size samples are included. "Sediment Texture Summary Arranged by Station" is a compilation of the percents gravel, sand, silt, and clay and sediment parameters arranged by station. Each sample station is represented on a single page and all the samples analyzed for that station from each cruise are listed on that page. "Sedment Texture Summary Arranged by Cruise" is similar in format except that all the analyses for each station are listed in sequence for each cruise giving a more or less synoptic view of the grain size distribution.

There is considerable variation in the grain size distribution at several of the stations in samples taken during different cruises. There is no apparent seasonal change in grain size distribution although there are some changes at some stations over the entire sampling period (e.g. C-1, D-2, D-3, and M-1) while there is practically no change at others (e.g. D-1). The variation in sediment texture reported by Pyle et al. (1975) is attributed to the presence of relict deposits on the shelf representing several different environments, including lagoons, barrier islands and bars and coastal dunes. The spectrum of relict deltaic deposits also present on the Mississippi-Alabama outer continental shelf, can be added to this list (Kindinger, 1989b and the present investigation). To complicate matters, the advancing shoreline, during the post-Pleistocene rise of sea level, has smeared the boundaries of each facies while reworking the facies in varying degrees. The ultimate reworking of facies is demonstrated by the Chandeleur Islands which lie on a barrier bar that consists of a lag deposit that was left by the winnowing effect of wave action and tidal and longshore currents as sealevel rose to its present level. The original deposits from which the sands were derived are the typical deltaic distributary and interdistributary muddy sands and sandy muds. The St. Bernard Prodelta Facies which was deposited in deeper water during Holocene time was not affected by the sealevel rise and has remained relatively undisturbed.

6.4 Summary and Conclusions

The sediments of the Mississippi-Alabama outer continental shelf are reworked Pleistocene and Holocene deposits. The facies delineated by Ludwick (1964) are still valid and useful. Our sampling of the 12 transect stations, although great in number, was severely limited in areal coverage. About all that can be said about shelf sediment distribution is that analyses of sediment textures at each station show that the sediments at those stations are as would be predicted from Ludwick's sediment facies map. The primary purpose of the sediment texture analyses was to supply biologists and chemists with textural data to aid in the interpretation of the chemistry and in-fauna of the sediments.

Most samples from a given station and cruise show a remarkable degree of consistency. However, drastic differences do occur from one cruise to the next at a given station and are most probably due to the following: (1) proximity to a reef or bank; (2) inability of the ship to maintain its position on station due to strong current or wind conditions; (3) location of the station in a transition zone between two relict facies; (4) aperiodic tropical storms; (5) local, small scale differences in sediment types due to irregularities of the seafloor which may influence bottom boundary layer current velocities that are close to the critical velocities for transporting silt and clay size particles; and/or (6) differences in sampling techniques.

7.0 MACROINFAUNA AND MACROEPIFAUNA

Donald E. Harper, Jr.

7.1 Introduction (including historical background)

Benthic macroinfaunal organisms are good subjects for studying not only the general ecology of an area, but also acute and chronic effects associated with discharges of organic and toxic substances into the environment. The infauna are primarily non-motile or slow moving, small organisms. The larvae tend to be induced to metamorphose by specific sediment types and the adults tend to remain associated with that type of sediment. Infaunal organisms cannot easily escape an environmental stress (i.e., a discharge) and those that cannot tolerate the stress perish. If the stress persists, larvae of these organisms may be unable to settle and metamorphose and the stressed area will remain devoid of intolerant species.

The macroepifaunal category of organisms has both slow moving (i.e., bivalves, snails, most echinoderms) and fast moving (i.e., shrimp, portunid crabs) representatives. Slow moving species can also be used to study specific ecological habitats, and the effects of a stress on the slow moving organisms may be identical to that of the infauna. Motile macroepifauna, however, tend to cover a broader range of habitat types, and generally remove themselves from a stressed area (Pavela et al. 1983). Also, motile macroepifaunal organisms may be able to repopulate an acutely affected area much more quickly than the other forms once the stress is removed.

Major (either area-wide or long-term) studies of assemblages of benthic organisms inhabiting soft bottoms have been conducted at one time or another in much of the northern Gulf of Mexico. Defenbaugh (1976) compiled information on distributions of macroepifaunal organisms in the northern Gulf of Mexico; his specimens were trawled from the continental shelf between Mexico and Tampa Bay, Florida. The present study area was included in that study area. Other research which was conducted in the present study area includes: one transect of the MAFLA study (Dames and Moore 1979); a pre-drilling benthic survey within lease tract 112 (Continental Shelf Assoc. 1981); a macroinfaunal study offshore of Mississippi Sound (Shaw et al. 1982). Vittor and Associates, Inc. (1985)

summarized existing knowledge of the macroinfauna and macroepifauna on the Mississippi-Alabama continental shelf. He commented that prior studies were designed to address specific objectives, and that the entire study area had not been characterized either spatially or seasonally.

In the western Gulf of Mexico, several research efforts may be used for comparison with the results of this study. Projects which included infauna and macroepifauna are: the Central Gulf Platform Study (Southwest Research Institute 1981; Fitzhugh 1984) and the West Hackberry Study (McKinney, Harper and Nance 1984, Landry, Pitts and Kirby 1985). Other projects on the Texas shelf involving multi-season or multi-annual macroinfaunal studies include the Buccaneer Oil/Gas Field study (Harper et al. 1975), the SEADOCK study (Harper and Case 1975), and the Bryan Mound study (Harper, McKinney and Nance 1985, Harper *et al.* 1991).

Several trends are evident from these western Gulf data that apply to the present study. Distribution of infaunal and non-motile macroepifaunal organisms appear primarily governed by sediment type and water depth, the latter probably resulting from increasing stability of other abiotic factors, i.e. the constantly low temperature and high salinity. Shallower water, in contrast, is much less stable, being subjected to seasonal variations in temperature and salinity. Researchers have attempted to classify the shelf inhabitants into assemblages based on depth distributions. These are: the inner shelf assemblage (= "white shrimp grounds" in the western Gulf) from 0-20 m depth; the pro-delta slope assemblage from 4-20 m depth (Defenbaugh 1976), the intermediate shelf assemblage (= "brown shrimp grounds" in the western Gulf) from 20-60 m depth, an outer shelf assemblage from 60-120 m depth, and an upper slope assemblage from 120-200 m depth (Chittenden and McEachran 1976, Defenbaugh 1976, Moore et al. 1970, Parker 1960). In general, as one proceeds across the shelf, abundances of organisms decrease with increasing depth and seasonal variability in species composition decreases with increasing depth. Infaunal assemblages are generally dominated by polychaetous annelids if the substrate is soft mud. Mollusks or crustaceans may dominate in sandy to shelly bottoms. Further, evaluation of infaunal data from the western Gulf of Mexico has indicated that both the northern Gulf and the southwestern Gulf have similar species, but the abundances of species appears to decrease considerably south of Matagorda Bay (Harper and Nance 1985).

7.2 Study Area

Five semi-annual collections (Table 7-1) of benthic macroinfaunal and macroepifaunal organisms were made during the course of the Mississippi/Alabama Marine Ecosystem Study (MAMES). The study area consisted of a region of the continental shelf in the eastern Gulf of Mexico bounded by the Mississippi Delta on the west, the DeSoto Canyon on the east, and the 200 m isobath offshore. Three transects were established which ran more or less normal to the coast, each having four stations (20 m, 60 m, 100 m and 200 m depths); C-transect was adjacent to the Chandeleur Islands, M-transect extended offshore from Mobile Bay, and D-transect extended offshore from just east of Mobile Bay and terminated at the DeSoto Canyon (Figure 7-1).

Table 7-1. Inclusive dates of each of the five semi-annual cruises in which the benthos were sampled during the Mississippi-Alabama Marine Ecosystem Study.

Cruise #	Inclusive dates	Season
0	31 Jan - 3 Feb 1987	Spring 1987
1	28 Sep - 5 Oct 1987	Fall 1987
2	10 Mar - 17 Mar 1988	Spring 1988
3	19 Aug - 24 Aug1988	Fall 1988
4	11 Feb - 18 Feb 1989	Spring 1989

7.3 Methods

7.3.1 Field Techniques

Field activities were recorded in a log book as events occurred. The time of arrival on station and LORAN coordinates were noted, and general comments regarding the sea state, weather, etc. were noted. The LORAN coordinates were used to determine if the vessel had drifted off station

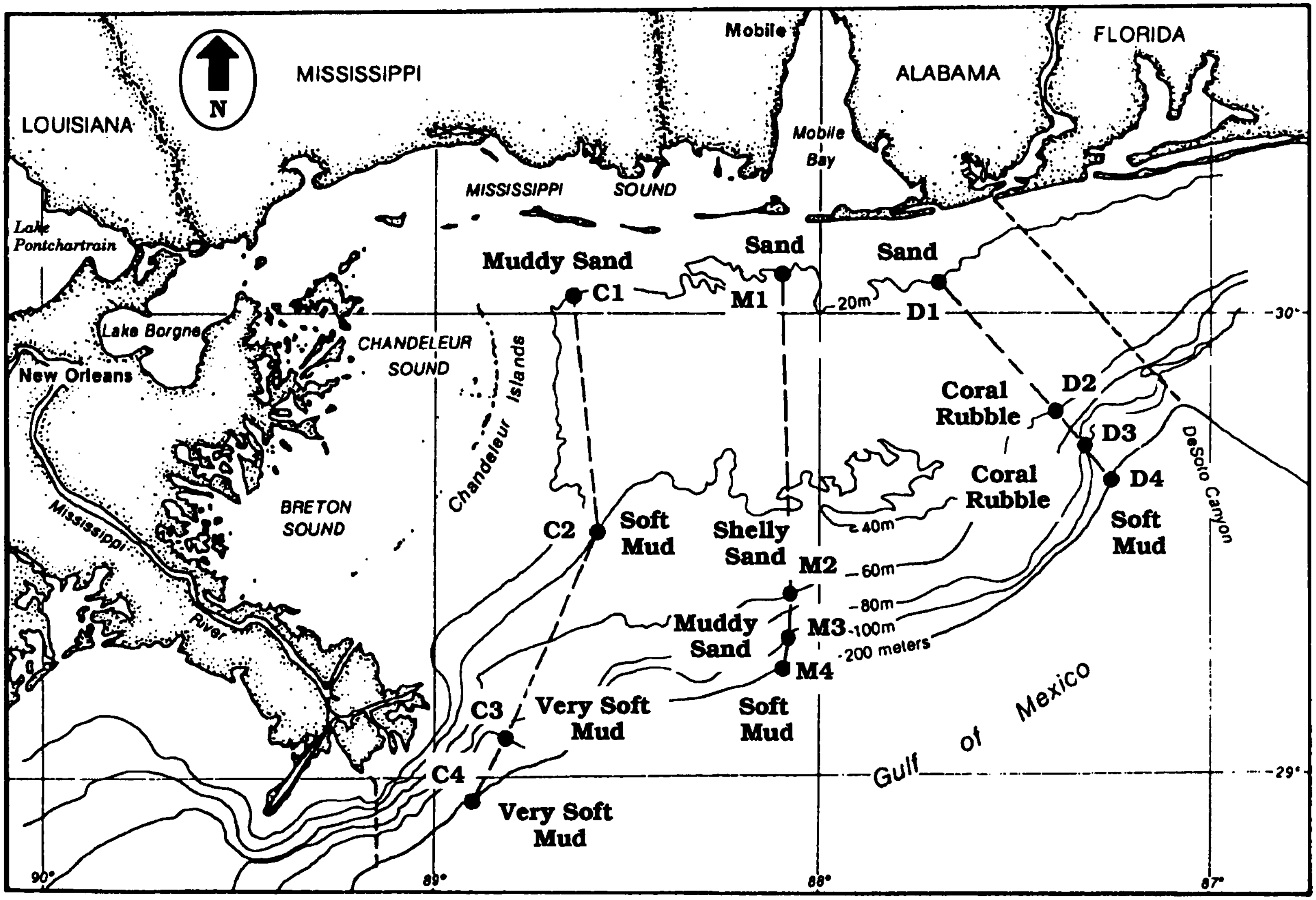


Figure 7-1. Map of the Mississippi-Alabama continental shelf study area showing the location of each of the 12 stations and the general type of sediment encountered at each station.

during the course of sample collection. If this occurred, sampling was suspended while the vessel returned to station. The time off station and LORAN position were also noted.

Macroinfauna - Macroinfaunal samples were collected using either a 0.1 m^2 box core or a 0.1 m^2 Smith-McIntyre (S-M) grab. It was determined during Cruise 0 that sediments at several stations consisted of hard sand or coral rubble; complete sets of samples were not collected at two stations (D1 and D2) because the box core (the only sampler on board) would not penetrate the bottom. Therefore, both machines were used during subsequent cruises. If we determined that a good sample could not be obtained with the box corer because the substrate composition impeded penetration of the box, the S-M grab was used.

The time of each drop was recorded when the instrument hit bottom. In some cases it was necessary to make in excess of 20 or more drops to obtain the requisite 9 samples. Of these 9 samples, 6 were used for macroinfaunal analysis and three for sediment analyses. When each grab was brought aboard, supernatant water was siphoned onto a sieve, and a meter stick was pushed into the sediment to determine depth of penetration. If the sample was to be used for macroinfauna, a syringe was used to remove a sediment subsample. This subsample was placed in a plastic bag. The characteristics of the sediments (i.e., sand, mud, shelly, etc.) were recorded in the logbook for each sample used for infaunal analysis.

Sediments were removed from the sampler using a scoop or by hand and placed in a large, numbered bucket. Water was added to the bucket to prepare the sediments for sieving. If sediments were soft, the stream of water was directed down the inside of the bucket. This created an upwelling pressure and brought small organisms to the surface. The supernatant water was then poured onto a 0.5 mm mesh sieve. This was done at least twice to remove soft bodied invertebrates and the sieve contents were emptied into a prelabeled jar. The firmer sediments were then hand stirred and poured onto the sieve in batches. These sediments were washed away using a spray attachment on a hose.

When all sediments were removed, the sieve contents were placed in the jar, and Epsom salts ($MgSO_4$) and a plastic Dymolabel with embossed station and date information were placed in the jar. About 30 minutes after the sixth bucket had been processed, the jar contents were fixed in 5% seawater-formalin.

Macroepifauna - Macroepifaunal samples were collected using a 6.6 m (20 ft) otter trawl having solid iron doors and a net having 3.18 cm (1.25 in) stretch mesh and a 0.64 cm (0.25 in) mesh liner in the cod end. When the vessel was brought on station (using LORAN coordinates), the trawl was deployed and line was payed out until a scope of about 3:1 or 4:1 was attained. Trawl durations were 15 minutes each and were timed from the time the winch was dogged until it was started again. Two replicate trawls were attempted on all cruises except the preliminary cruise during which single trawls were made. When the trawl was brought aboard, the contents were emptied on deck or on a sorting table, separated into vertebrates and invertebrates and placed in separate buckets. The contents of the invertebrate buckets were weighed, narcotized with $MgSO_4$ (30 minutes) and fixed in 10% seawater formalin. Each bucket was identified with an external grease pencil label and an internal Dymolabel, both identifying the bucket by station and date.

At two stations near the Mississippi Delta (C3 and C4) enormous numbers of heart urchins, *Brissopsis* spp. (Echinodermata: Echinoidea) were collected. Representatives of these were retained. The remainder (or a subsample) were measured and/or weighed and discarded.

7.3.2 Laboratory Methods

Macroinfauna - Upon return to the laboratory, macroinfaunal samples were washed on a 0.5 mm mesh sieve with fresh water to remove formalin and any remaining sediments. The samples were then preserved in rose bengal-stained 70% ethanol. After at least 24 hours had elapsed the samples were examined using a dissecting microscope and all organisms were removed (picked) and placed in vials of unstained 70% ethanol. The vial contents were separated to major taxa (Polychaeta, Crustacea, Mollusca, *etc.*) and these were weighed. Because the Polychaeta constituted the dominant taxon, both in terms of numbers of species and individuals, they were separated to family after being weighed *en masse*. When the entire cruise collection had been sorted in this manner, all vials containing a particular polychaete family were identified and counted as a unit before identification of the next family was begun. The other taxa were not nearly so numerous and were not split to smaller taxonomic units prior to being identified. All members of each species were placed in a separate, labeled vial. These were assembled in taxonomic units and stored.

Raw data were recorded in lab notebooks. These data were transferred to formatting sheets. When all samples from a cruise had been completed, the sheets were sent to the Data Manager for entry into a computer file. A verification printout was generated and this was checked against the raw data. When all data were correct, the Data Manager was notified that the data set was ready to be transmitted to data storage.

Macroepifauna - Upon return to the laboratory, macroepifaunal samples were washed with fresh water to remove formalin and were then preserved in 70% ethanol. The contents of each bucket were subsequently sorted to major taxa or species and placed in separate containers. The contents of these containers were identified, measured, counted and weighed. Data were recorded in laboratory data books. When a collection had been completed, the data were recorded on formatting sheets. The sheets were sent to the Data Manager for entry into a computer file. Verification followed the procedure described for macroinfauna.

7.4 Results and Discussion

7.4.1 Sediments and Bottom Topography

The bottom sediments, as determined by visual observation, were of two basic types (Figure 7-1). Soft mud to muddy sand occurred on C-transect, along the Mississippi Delta, and at all the 200 m deep stations. Coarser sediments, including sand to shelly sand to coral rubble, occurred at most of the M- and D-transect stations. The box core was used on softer sediments, but would not penetrate hard bottoms; the Smith-McIntyre grab had to be used on the latter.

Cross-sectional profiles of each transect (Figure 7-2) shows that the shelf was much broader on C- and M-transects than on D-transect. However, D- and M-transects have a much steeper slope seaward of the shelf break.

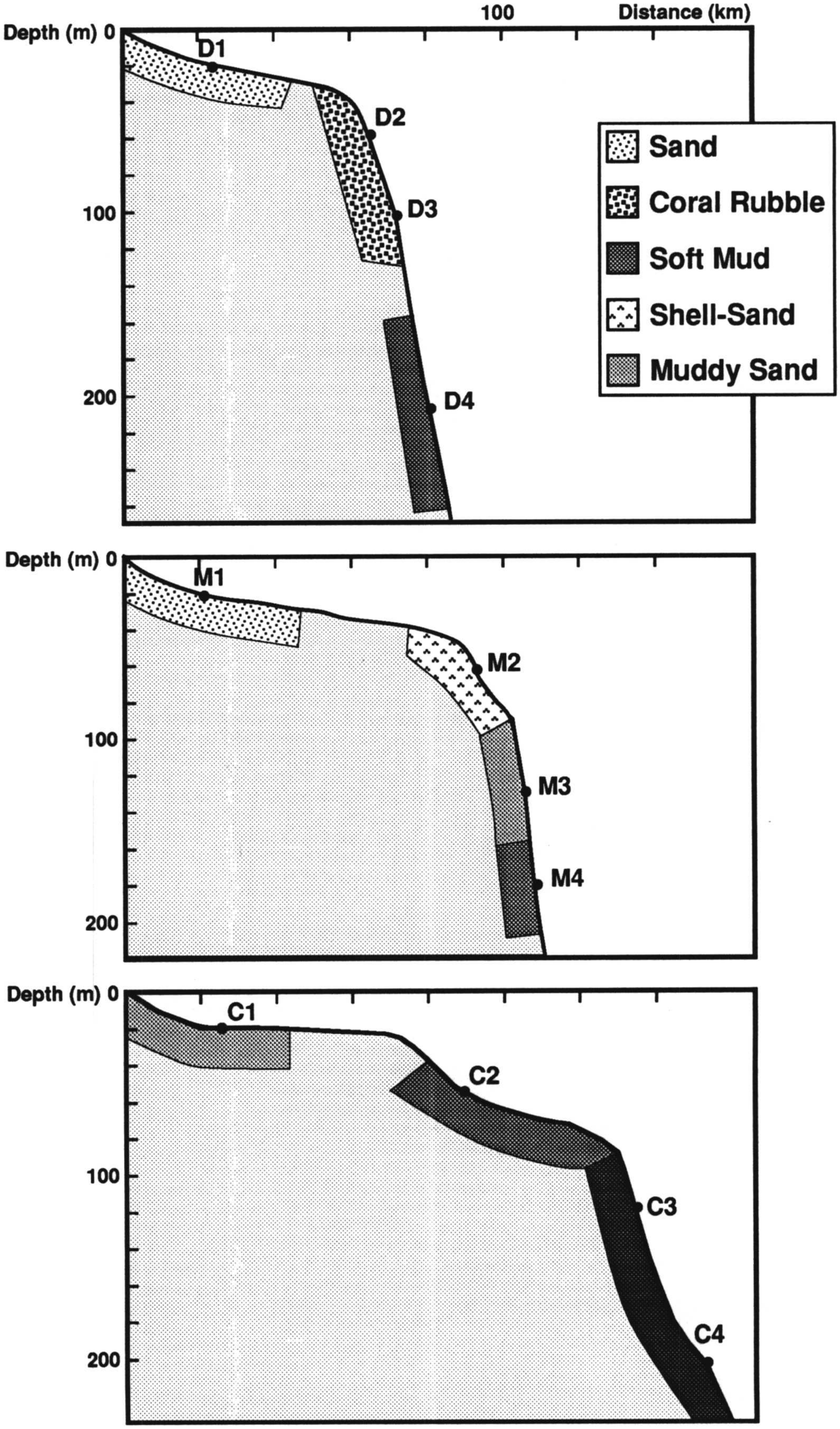


Figure 7-2. Cross-sectional profiles of each transect on the Mississippi-Alabama continental shelf showing station locations and substrate types.

7.4.2 General Characterization of the Biota

Macroinfauna - The percent composition of individuals for all cruises combined are shown in Table 7-2. The macroinfauna of the Mississippi-Alabama continental shelf was dominated by polychaetous annelids (58.3% of all individuals collected). Bivalves and amphipods were the second and third ranking dominants (12.2 and 9.4%, respectively). No other taxon comprised more than 3% of the total.

Table 7-3 lists the 20 most abundant species collected during the study. As expected from the data in Table 7-2, the majority of these are polychaetous annelids, with bivalves and amphipods comprising smaller numbers. The majority of these species are deposit feeders (direct or indirect), or filter feeders. The dominant species in this study were also dominants in studies in the northern Gulf of Mexico west of the Mississippi Delta (e.g., Southwest Research Institute 1984, Fitzhugh 1984, Harper, McKinney, Salzer and Nance in press).

Macroepifauna - Percent composition of macroepifaunal taxa is listed in Table 7-2. Decapod crustaceans were the numerical dominant (77.8%), followed by the Echinodermata (including Holothuroidea, Ophiuroidea, Asteroidea and Echinoidea) was second with 9.75% and Mollusca (Gastropoda, and Bivalvia combined) was third with 7.70%. Dominance of the decapods was mainly due to the collection of very large numbers of shrimp at certain stations.

Parapenaeus politus was the numerical dominant (Table 7-4), but, in contrast to the infaunal species *Armandia maculata*, comprised only about 13% of all organisms collected. Most of the numerical dominants were decapod crustaceans, and most of those were species of shrimp. Swimming and benthonic crabs were also well represented. Echinoderms and bivalves comprised the remainder of the dominants.

Nine of the first ten species in the list attained maximum abundance during cruises 2 and/or 3 (Spring 1988 and/or Fall 1988). Only two species, *Loligo plei* and *Callinectes similis*, appeared to display a repetitive seasonal pattern; both were most abundant during spring.

Table 7-2. Percent composition of abundances of macroinfaunal and macroepifaunal taxa, all cruises combined, on the Mississippi-Alabama continental shelf study area.

Macroinfauna		Macroepifauna	
Taxon	% of individuals	Taxon	% of individuals
Protozoa	0.39	Anthozoa	0.58
Cnidaria	0.16	Gastropoda	3.33
Nemertea	2.00	Bivalvia	4.37
Bryozoa	2.20	Stomatopoda	1.63
Brachiopoda	0.69	Decapoda	77.80
Gastropoda	2.50	Holothuroidea	0.16
Bivalvia	12.24	Ophiuroidea	2.88
Sipunculida	1.20	Asteroidea	3.38
Polychaeta	58.31	Echinoidea	3.33
Oligochaeta	0.10	Other	2.15
Ostracoda	0.47		
Amphipoda	9.40		
Isopoda	1.21		
Cumacea	0.83		
Tanaidacea	0.40		
Decapoda	3.04		
Echinodermata	4.60		
Cephalochordata	0.59		
Other	2.15		

Table 7-3. The 20 most abundant infaunal species collected during the Mississippi-Alabama marine ecosystem study. Combined abundance and abundances for each cruise are listed.

		CRUISE				
Species	All Cruises	0	1	2	3	4
Armandia maculata (P)	1630	20	44	1506	27	33
Lumbrineris verrilli (P)	1088	129	339	383	237	*
Paraprionospio pinnata (P)	1301	151	321	288	281	260
Tellina versicolor (B)	871	3	143	217	337	165
Prionospio cristata (P)	769	11	10	571	135	42
Mediomastus californiensis (P)	504	64	53	243	118	26
Lumbrineris sp. D (P)	440	2	281	98	60	*
Neanthes micromma (P)	427	27	104	149	34	113

Table 7-3. (Continued)

Spiophanes bombyx (P)	388	29	19	205	51	84
Aglaophamus verrilli (P)	372	24	44	54	84	166
Ampelisca abdita (A)	362	8	39	147	81	104
Ampharete sp. A (P)	347	--	23	132	175	16
Bryozoan, cup-shaped	307	--	16	270	7	13
Nephtys incisa (P)	283	46	45	69	71	57
Cupuladria sp. (Br)	276	1	144	64	28	41
Nuculana sp. A (B)	279	--	224	49	--	6
Amphipoda, conical snout	277	--	13	23	19	222
Parvilucina multilineata (B)	264	--	75	9	157	23
Laonice cirrata (P)	254	8	103	96	32	15
Phoxocephalidae, small eye (A)	231	--	17	83	27	104

Abbreviations: A - Amphipoda; B - Bivalvia; Br - Bryozoa; P - Polychaeta

Table 7-4. The 20 most abundant macroepifaunal species collected during the Mississippi-Alabama marine ecosystem study. Combined abundance and abundances for each cruise are listed.

		Cruise				
Species	Total	0	1	2	3	4
Parapenaeus politus (D)	4862	182	1963	2525	121	69
Portunus spinicarpus (D)	2258	228	317	196	1371	146
Plesionika tenuipes (D)	1713	13	270	1428	---	2
Sicyonia brevirostris (D)	599	18	26	251	272	32
Stylocardis affinis (E)	593	2	10	161	409	---
Trachypenaeus constrictus (D)	530	69	251	114	76	20
Solenocera vioscai (D)	494	21	104	240	101	28
Ophiolepis paucispina (O)	493	---	3	216	274	--
Sicyonia dorsalis (D)	454	6	45	233	107	63
Loligo plei (C)	330	2	174	18	112	74
Parthenope agonus (D)	340	6	41	36	245	12
Luidia clathrata (A)	289	33	93	64	87	--
Anasimus latus D)	272	76	66	93	26	11
Processa guyanae (D)	271	2	---	62	207	---
Callinectes similis (D)	255	28	132	4	87	3
Aequipecten glyptus (B)	246	11	105	74	52	--
Portunus gibbesii (D)	236	63	119	6	23	25
Solenocera atlanticus (D)	224	20	33	131	38	1
Yoldia solenoides (B)	198	--	3	--	195	--
Raninoides louisianae (D)	196	11	62	88	12	12

Legend: A - Asteroidea; B - Bivalvia; C - Cephalopoda; D - Decapoda; E - Echinoidea; O - Ophiuroidea

7.4.3 Temporal Distributional Trends

Macroinfauna - The mean abundance of infaunal individuals was lowest during Spring 1987 (Figure 7-3). Mean abundance increased through Fall 1987, reached a peak in Spring 1988, and then decreased through Spring 1989. The almost straight-line increase and decrease are, however, most likely not even a remotely accurate representation of the real fluctuations in abundances. Figure 7-4 depicts a multi-year data set from the northwestern Gulf of Mexico, showing the monthly fluctuations in abundances, compared with the perceived abundance trends if semi-annual samples had been collected. Note that some very significant maxima and minima would have been completely missed.

Comparison of the seasonal trends at each station shows that the most radical cruise-to-cruise fluctuations in abundance occurred at stations on C-transect, where three of the four stations experienced at least one population spike (Figure 7-5). Note that Spring 1987 abundances were uniformly low, and that abundances at stations D4 and M4 (200 m depth) and C3 and M3 (100 m depth) remained low throughout the study. Seasonal trends of infaunal abundances at each station on each of the transects are shown in more detail in Figure 7-6. Again, the changes in abundances from cruise to cruise appear more muted on D-transect and M-transect, whereas all the stations appeared to have low abundances except for single irruptions in the populations of one or more species. Stations D1, M1, and C1 (20 m depth), D2 and M2 40 and 60 m depth) and D3 (100 m depth) maintained fairly high abundances (except for February 1987). These are all stations having bottoms described as containing a high proportion of sand, shell hash or coral rubble (see Figure 7-1, 7-2). The stations having bottom consisting of soft to very soft mud (D4, M3, M4, C2, C3, C4) tended to have much smaller abundances of organisms. Note that this tendency is interrupted at C2 (August 1988) and C4 (March 1988). In the former case a large population of *Paraprionospio pinnata* was the principal cause of the spike, and in the latter case it was a large population of *Armandia maculata.*

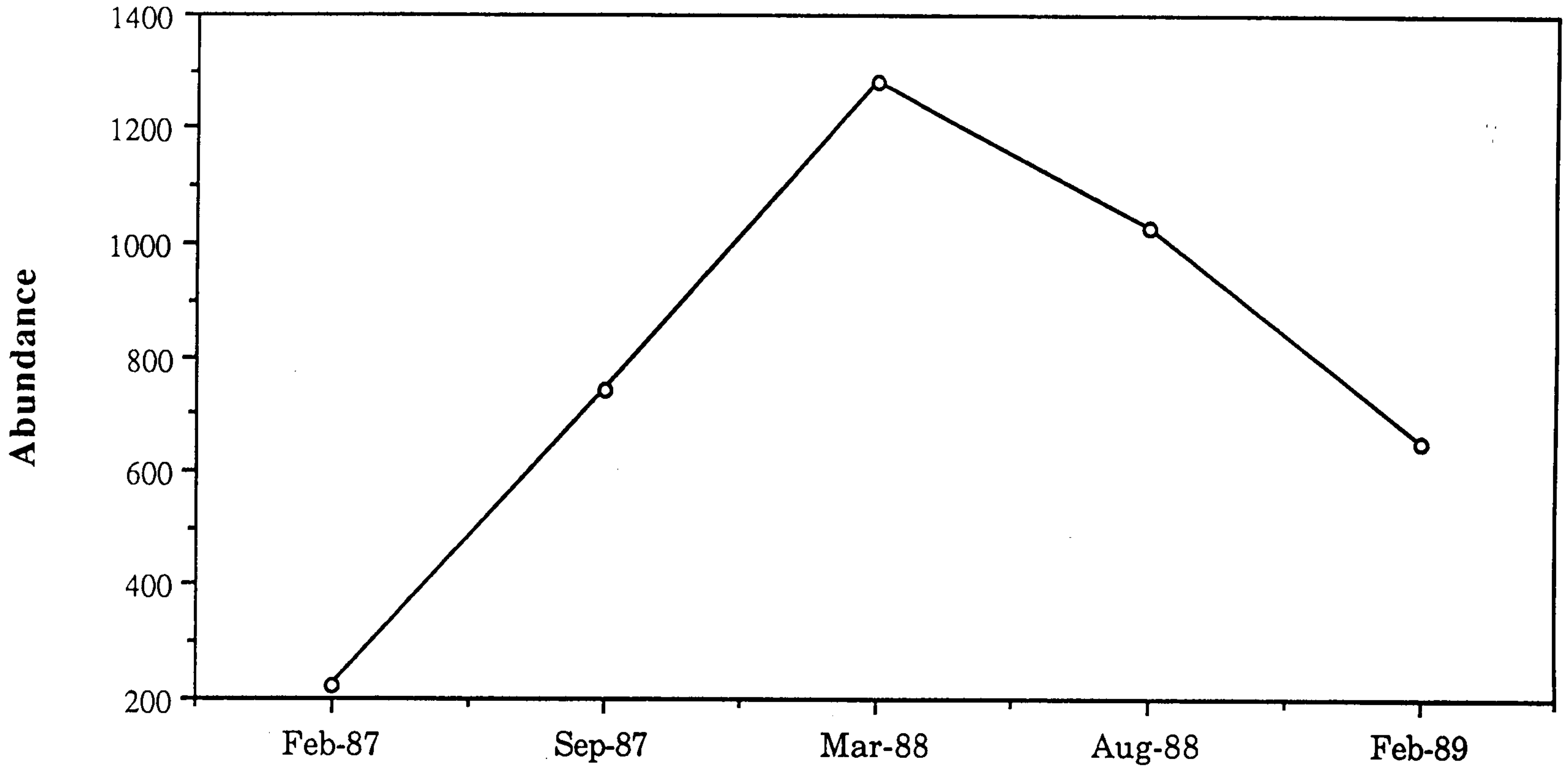


Figure 7-3. Temporal trends in mean macroinfaunal abundance (all stations) from the Mississippi-Alabama continental shelf.

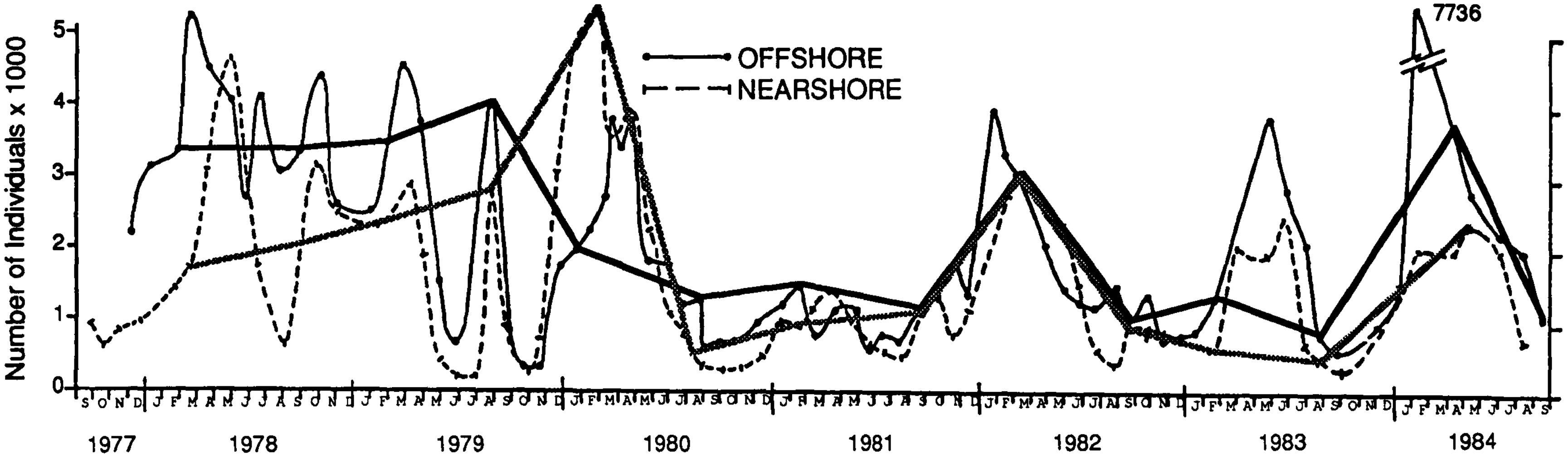


Figure 7-4. **Temporal trends of benthic infaunal diversity and abundance data from two study sites off** Freeport, Texas, with temporal trends superimposed that would have resulted from semi-annual spring-fall collections.

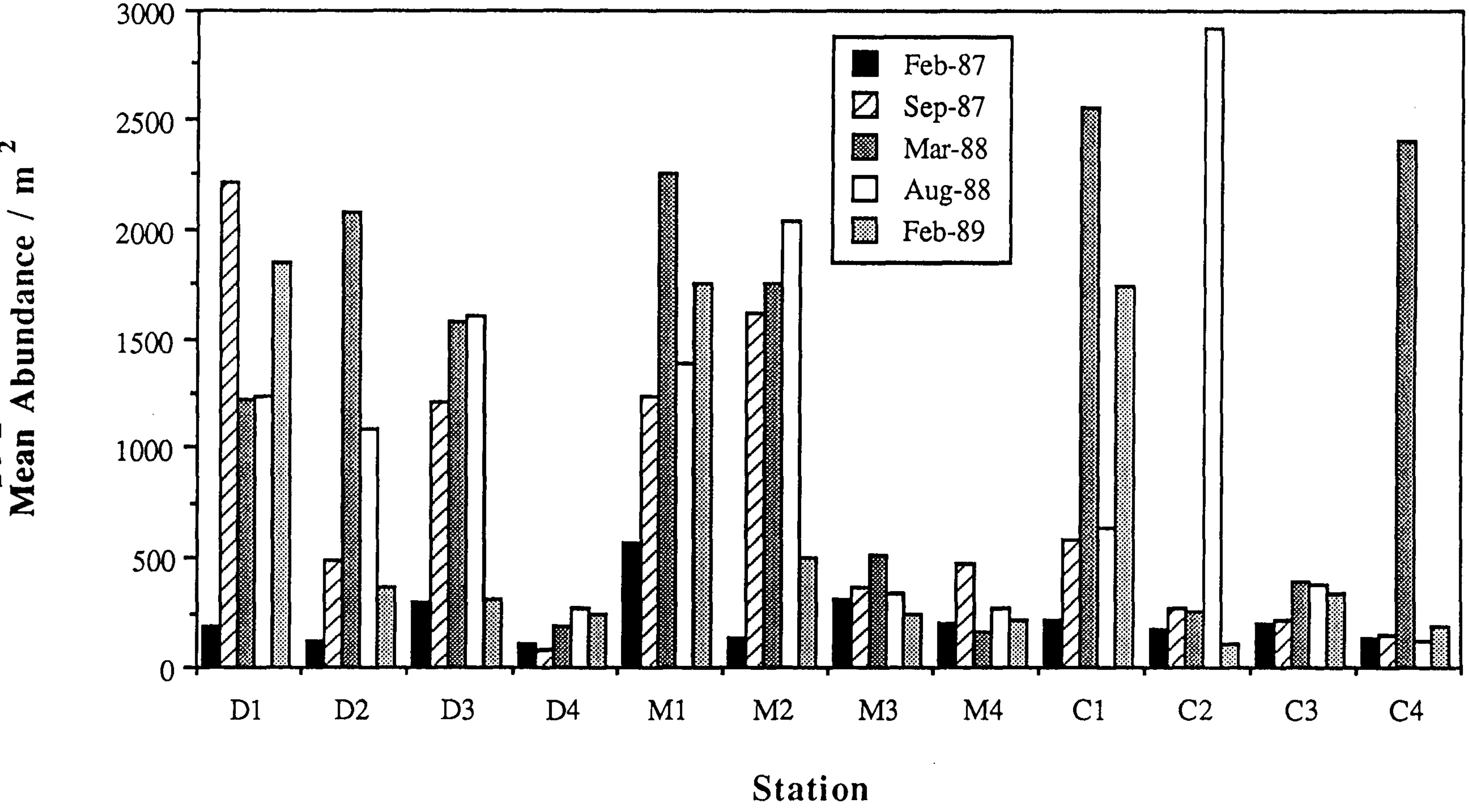


Figure 7-5. Comparison of seasonal changes in macroinfaunal abundance at each station in the Mississippi-Alabama continental shelf study area.

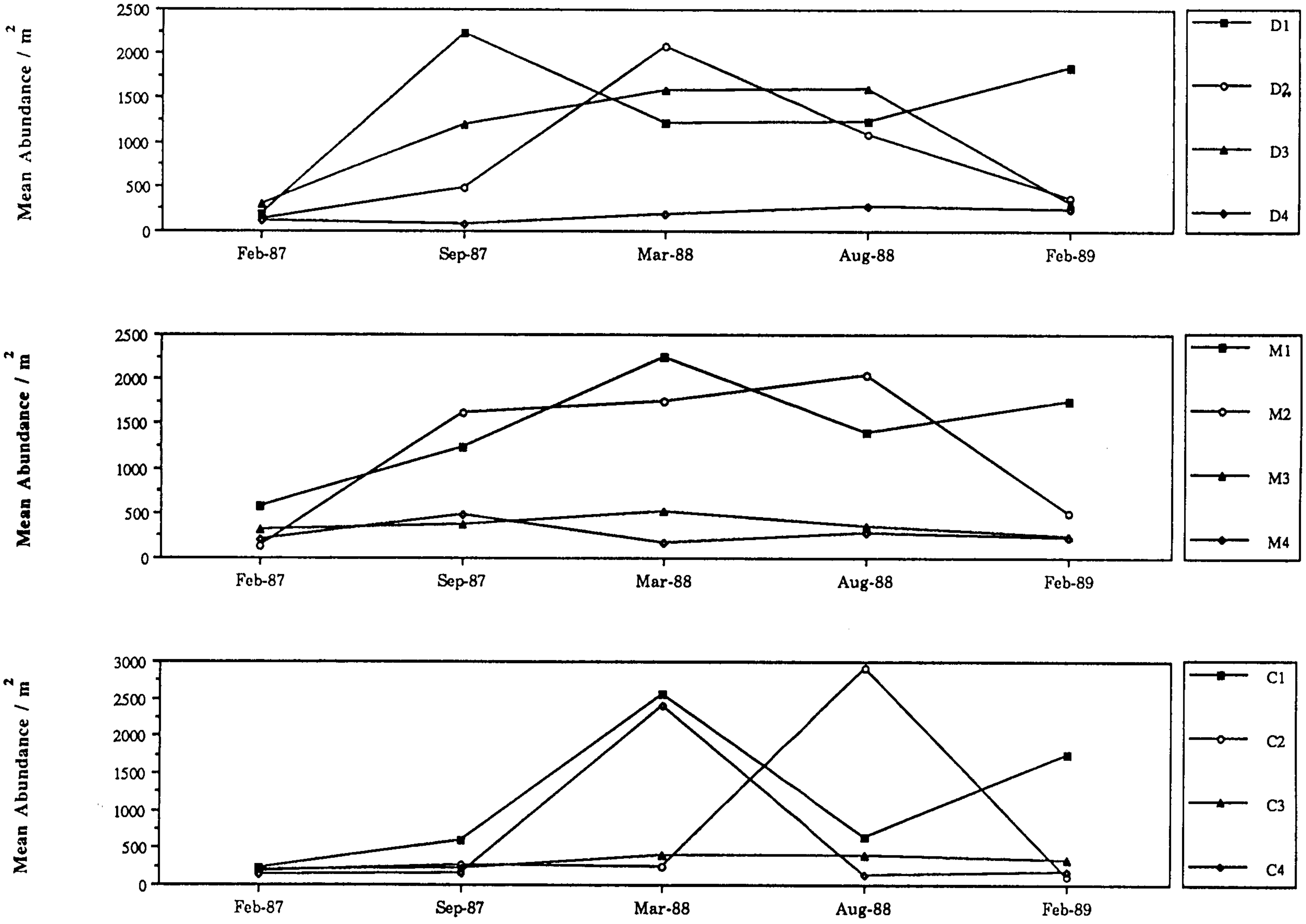


Figure 7-6. Comparison of macroinfaunal seasonal abundance trends among stations on each transect in the Mississippi-Alabama continental shelf study area.

Comparison of numbers of individuals of the top 20 dominant species reveals that much of the overall increase in abundances sampled during the middle three cruises was caused by population irruptions of several species (Table 7-2). The extreme example of this occurrence was *Armandia maculata.* This species was the overall dominant, yet 92.3% of all individuals were collected during Spring 1988 and it was otherwise a minor component of the infaunal assemblages. *Paraprionospio pinnata*, and *Lumbrineris verrilli*, the second and third dominants in terms of overall numbers, appear to have had fairly stable populations throughout the study. *P. pinnata* would probably have been the numerical dominant had it not been for the one-time, large population of *Armandia.* Population stability, however, may be an artifact of the time interval between cruises. In the western Gulf of Mexico, data from a long-term study showed that *P. pinnata* was normally the numerically dominant species, but that its population underwent considerable fluctuations with season (Harper et al. in press).

Macroepifauna - Seasonal macroepifaunal trends are shown in Figure 7-7. The pattern is similar to that displayed by the macroinfauna, except that the decline between August 1988 and February 1989 is even more striking. This was probably the most outstanding feature of the 5 cruises. Personnel who had participated in all cruises were surprised by the small quantities of fish and invertebrates that were collected during the last cruise. The trawl came up empty at a some stations and trawl tows were repeated to be sure that the bottom was actually devoid of organisms, and that sampling error was not a factor.

7.4.4 Areal Distributions

Macroinfauna - Data in Table 7-5 list the total number of taxa (species or higher taxon), and total abundances of all organisms, by station. The trends indicate a decrease in organismal diversity and abundance with increase in depth. The highest abundances on all transects were at the 20 m stations. The smallest numbers of individuals occurred at the 200 m stations on transects D and M, but a large population of *Armandia maculata* (see above) caused station C4 to have nearly twice as many total organisms as C2 and C3.

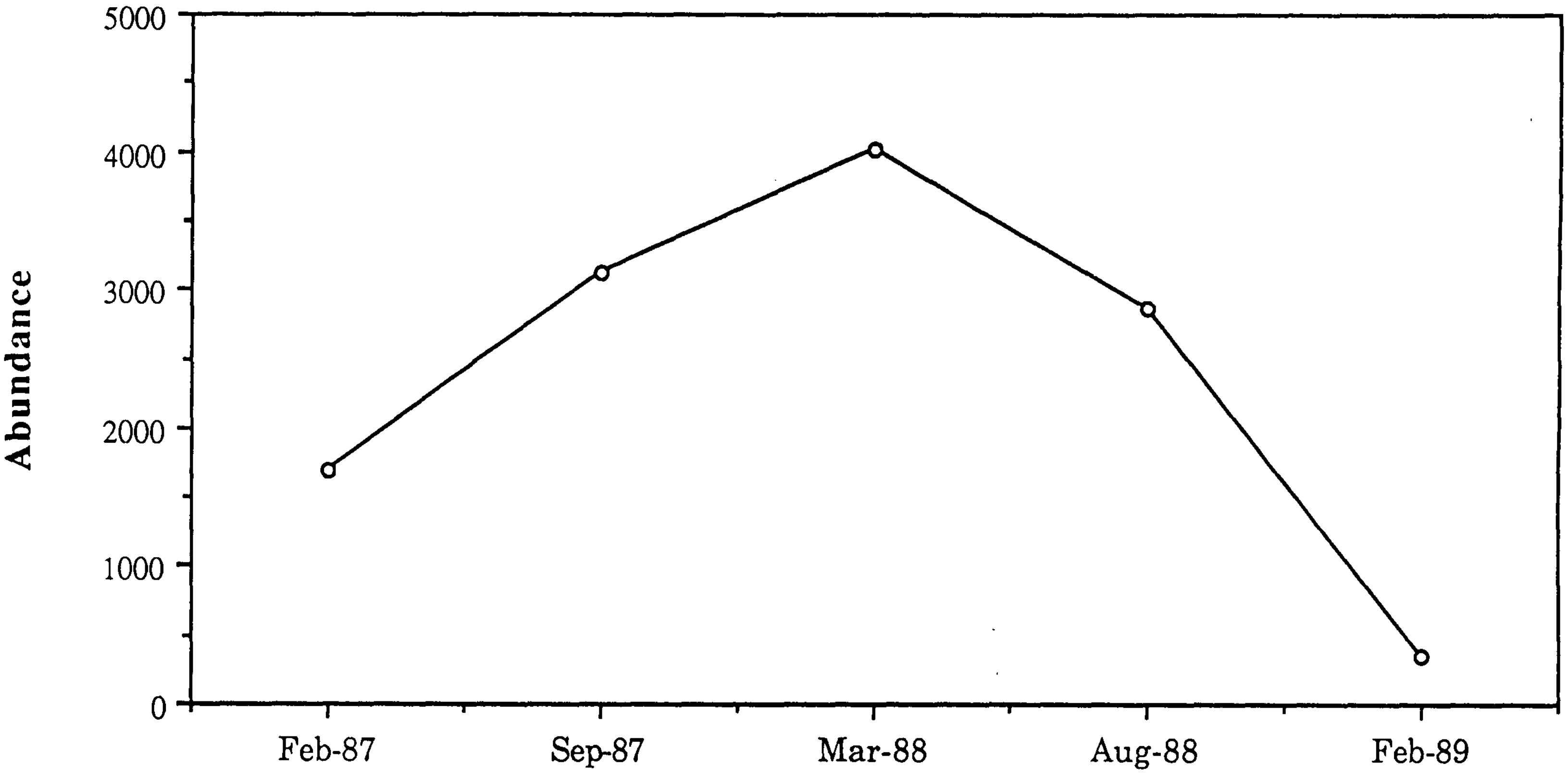


Figure 7-7. Temporal trends in mean macroepifaunal abundance (all stations) from the Mississippi-Alabama continental shelf.

Table 7-5. Comparison, by transect and depth (station), of the total number of taxa and abundances of macroinfaunal organisms collected during the Mississippi-Alabama continental shelf study.

		Transect D		Transect M		Transect C	
Sta	Depth	# Taxa	Abundance	# Taxa	Abundance	# Taxa	Abundance
1	20	314	4194	355	4908	219	3564
2	60	271	2641	302	3416	176	955
3	100	340	2737	213	1233	168	917
4	200	145	561	120	826	89	1888

Polychaetous annelids constituted the dominant group (Table 7-6). Percentages ranged from about 40% to about 90% during the course of the study. When the percentage of polychaetes was reduced, it was usually because of large numbers of bivalves and/or amphipods. There do not appear to be any obvious trends in abundance among any of the individual taxa, either alongshore or perpendicular to the coast.

Table 7-7 lists the 20 numerically dominant species and provides the numbers of individuals collected at each station during the course of the study. Two trends are very obvious. First, the highest abundances of a majority of species were at the 20 m stations, and second, there are many zeros in the columns of the 200 m stations. Low numbers of individuals might be expected at the deep stations because of the previously discussed rather uniform low abundances over time. However, the complete absence of many of these species was not expected. The table also indicates that a few of the dominants were principally shallow water forms that were distributed across the study area (i.e., *Tellina versicolor*, *Lumbrineris verrilli*, *Ampelisca abdita*) and even fewer were principally deep water forms (i.e., *Armandia maculata*, *Nephtys incisa*), none of which were widely distributed. In some cases, the majority of specimens were collected at one station only (i.e. *Nuculana* sp. A, Phoxocephalidae, *Lumbrineris* sp. D).

Cluster analyses (Bray-Curtis, flexible sorting, log transformation) were run for all cruises combined and for each individual cruise. Combined cruise data produced fairly tight clusters (Figure 7-8). The stations described as having bottoms consisting of a large component of shell, sand or coral rubble

Table 7-6. Percent composition of macroinfaunal abundances for each station in the Mississippi-Alabama continental shelf study area, all cruises combined.

	Stations											
Taxon	D1	D2	D3	D4	M1	M2	M3	M4	C1	C2	C3	C4
Foraminiferida	0.10	1.48	0.24	17.69	----	0.12	0.85	6.62	0.03	0.33	1.39	1.16
Cnidaria	0.15	0.24	0.20	0.18	0.11	0.14	0.43	----	----	----	0.93	0.06
Nemertea	1.51	1.12	1.31	4.33	2.58	0.55	2.73	7.12	1.93	3.97	5.79	0.50
Nematoda	0.59	1.08	5.83	0.36	0.82	0.14	0.68	1.62	----	0.55	0.23	----
Bryozoa	1.98	5.73	2.26	1.62	5.54	1.73	----	----	----	0.11	----	----
Brachiopoda	0.45	0.08	0.87	0.36	2.54	0.26	----	0.12	0.28	0.33	----	----
Gastropoda	3.74	1.28	0.44	1.08	2.50	6.80	1.02	0.12	1.25	3.75	1.74	0.50
Bivalvia	15.32	10.29	3.29	3.43	15.63	25.87	15.60	5.49	8.20	5.41	6.25	2.75
Sipunculida	0.32	0.20	1.59	1.81	0.69	2.07	8.10	0.37	0.37	0.11	0.12	0.06
Polychaeta	42.26	58.67	65.40	47.83	58.32	40.54	61.38	68.54	67.26	61.37	68.52	91.85
Oligochaeta	0.15	0.44	0.12	0.18	0.04	0.12	----	----	----	----	----	----
Ostracoda	0.67	1.56	0.60	0.36	0.28	0.49	0.51	----	0.09	0.22	----	----
Amphipoda	24.21	9.21	9.48	5.23	3.80	6.45	1.62	2.00	14.43	11.92	3.82	0.22
Isopoda	0.30	1.40	3.33	1.08	0.35	3.77	1.28	0.62	----	0.44	0.93	0.39
Cumacea	2.68	0.40	0.28	1.81	0.50	0.09	0.26	0.75	1.25	0.66	0.58	----
Tanaidacea	0.77	0.12	0.12	2.53	0.22	0.17	----	----	0.34	2.10	0.46	0.22
Decapoda	0.92	3.08	2.78	1.62	3.95	6.51	1.62	3.37	1.35	5.85	6.25	0.44
Echinodermata	1.24	0.94	1.27	4.67	0.58	1.56	1.79	1.50	0.89	0.99	1.27	0.81
Cephalochordata	1.59	1.64	----	----	1.04	0.06	----	----	0.06	----	----	----
Other	1.22	0.54	0.59	3.53	0.51	2.56	2.13	1.76	2.27	1.90	1.72	1.04

Table 7-7. The 20 numerically dominant macroinfaunal species and their abundances at each station, all data combined. Station with the highest abundance in each transect is in bold. Station with overall greatest abundance is underlined.

		Stations											
Species	Total	D1	D2	D3	D4	M1	M2	M3	M4	C1	C2	C3	C4
Armandia maculata (P)	1630	40	59	9	**64**	14	2	14	7	24	32	10	**1355**
Paraprionospio pinnata (P)	1288	37	49	**57**	10	127	39	160	**292**	**202**	119	153	43
Tellina versicolor (B)	865	**310**	114	5	-	**177**	113	4	-	**128**	8	6	-
Prionospio cristata (P)	755	42	**336**	15	-	**80**	26	1	-	**249**	3	3	-
Mediomastus californiensis (P)	499	16	1	9	2	103	**111**	55	3	**186**	8	5	-
Lumbrineris verrilli (P)	468	**119**	-	6	-	**173**	33	6	17	**54**	8	14	38
Neanthes micromma (P)	425	8	-	4	-	**120**	59	2	8	**197**	19	16	-
Ampelisca abdita (A)	415	**68**	9	11	4	**81**	40	1	-	**156**	41	4	-
Spiophanes bombyx (P)	385	**184**	35	-	-	**132**	27	2	-	2	3	-	-
Aglaophamus verrilli (P)	372	2	5	**50**	-	51	**117**	58	-	**85**	3	1	-
Ampharete sp. A (P)	346	48	25	**84**	3	**104**	70	1	-	9	1	2	-
Bryozoan, cup-shape	306	21	**70**	9	-	**187**	19	-	-	-	-	-	-
Nephtys incisa (P)	288	1	1	4	**74**	7	-	3	**50**	42	40	37	47
Lumbrineris sp. D (P)	283	**212**	-	6	-	57	1	1	-	-	5	1	-
Nuculana sp. A (B)	279	-	-	6	-	9	**208**	44	-	-	5	4	3
Amphipoda, conical snout	277	**273**	13	-	-	-	-	-	-	1	-	-	-
Cupuladria sp. (Br)	276	58	**61**	40	9	**68**	40	-	-	-	-	-	-
Parvilucina multilineata (B)	264	42	1	8j	2	**144**	45	4	-	14	-	4	-
Laonice cirrata (P)	246	8	28	**104**	1	11	**71**	17	2	1	-	3	-
Phoxocephalidae sm. eye (A)	113	**88**	16	-	4	-	-	-	-	-	-	-	-

Legend: A - Amphipoda; B - Bivalvia; Br - Bryozoa; P - Polychaeta

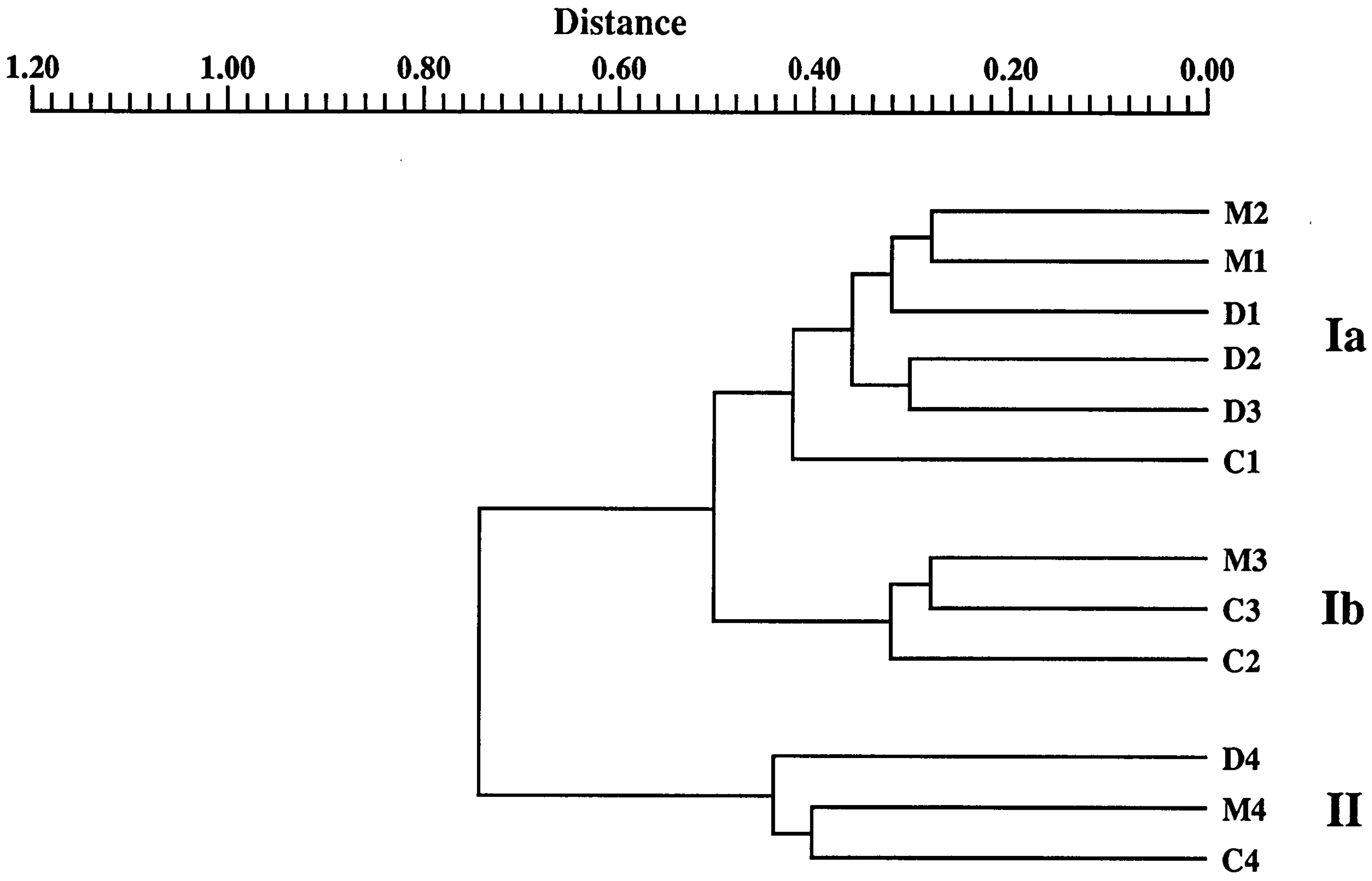


Figure 7-8. Site group dendrogram produced by cluster analysis of combined macroinfaunal data from all cruises.

formed a cluster (Site Group I); station C1 is probably part of this latter cluster rather than a distinct site group (Figure 7-9). Three stations with fairly soft bottoms (C2, C3 and M3) formed a group (Site Group II). The three deepest (200 m) stations (Site Group III) were the most distinctly separated. Analysis of the two-way table (not shown) indicates separation of Site Group III is primarily due to absence or very small numbers of two major species groups which contained a combination of polychaetes, bivalves and amphipods. Site Group II is distinguished by the virtual absence of one major species group. The cluster groupings are very similar to those of Vittor, 1985; Fig. 6.18.

Cluster analyses of individual cruise data show that the deeper stations usually comprise one or more site groups and the shallower stations form others (Figures 7-10 through 7-14). The boundaries of these site groups move about in response to the presence and altering abundances of infaunal organisms. In all instances, the two-way table shows that the deeper stations formed separate groups because of the absence or reduced abundance of one or more species groups.

Macroepifauna - The number of taxa collected during the study was relatively similar for all stations except the two middle stations (2 and 3) on transect D, where the numbers were almost twice as large as at most other stations (Table 7-8). These two stations were distinguished by having substrates with large amounts of coral rubble and coarse sand. The 200 m stations did not have reduced numbers of epifaunal taxa as occurred with the infauna. The pattern of abundance distribution was the reverse of the infaunal trend. The largest numbers of individuals were collected in deeper water.

Only 9 macroepifaunal taxa contributed substantially to the shelf assemblages, compared with 19 infaunal taxa (Table 7-9). Decapod crustaceans comprised the greatest percentage of infaunal organisms at all stations, ranging from 38 to 94%. The percentages of decapods were smaller on D-transect than on either M- or C-transects (38-57% on D vs. 66-94% on M and C). At the same time, D-transect also had the largest percentages of bivalves and echinoderms, and these tended to reduce the decapod percentage.

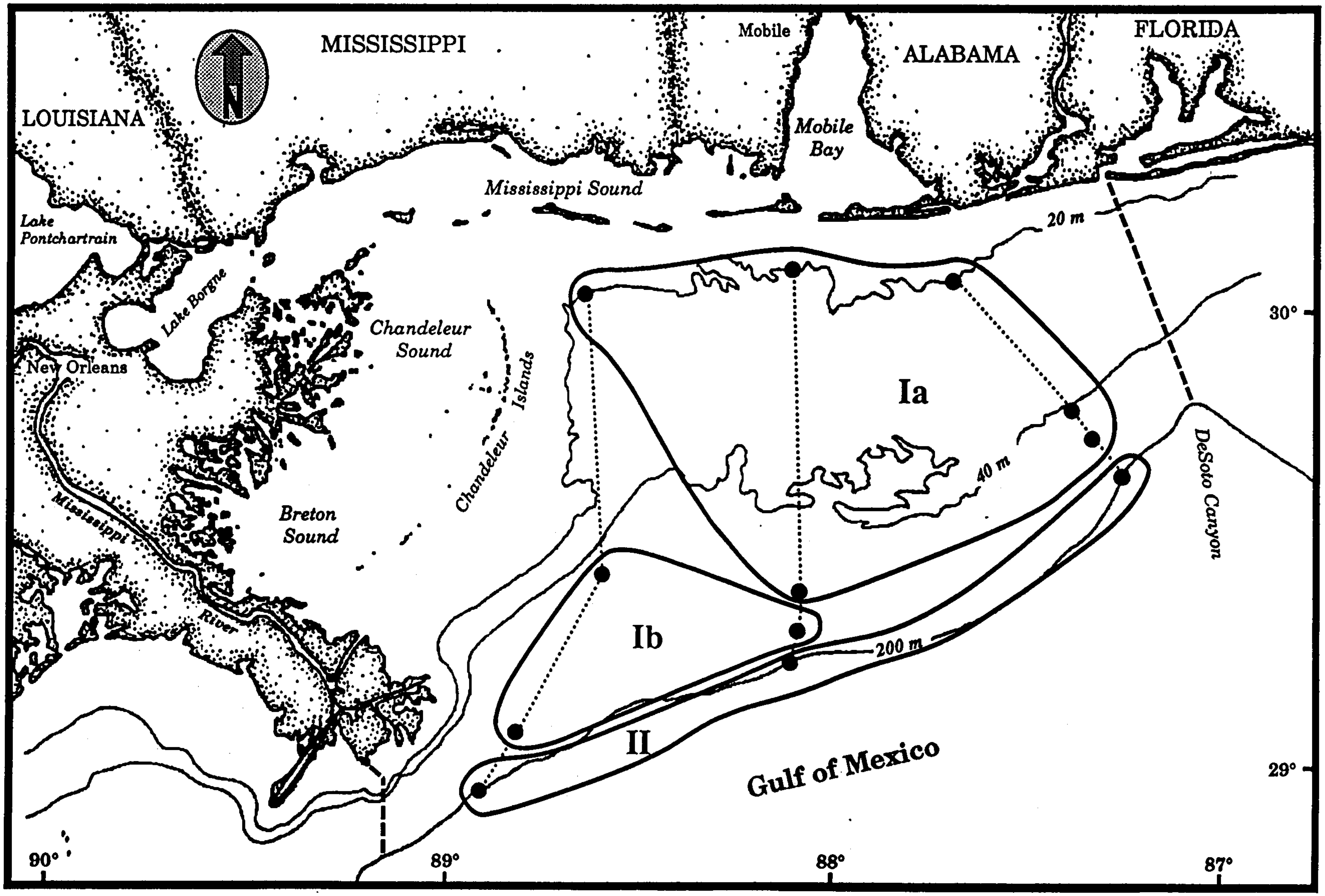


Figure 7-9. Map of the Mississippi-Alabama continental shelf study area showing the site groups derived from cluster analysis of combined macroinfaunal data from all cruises.

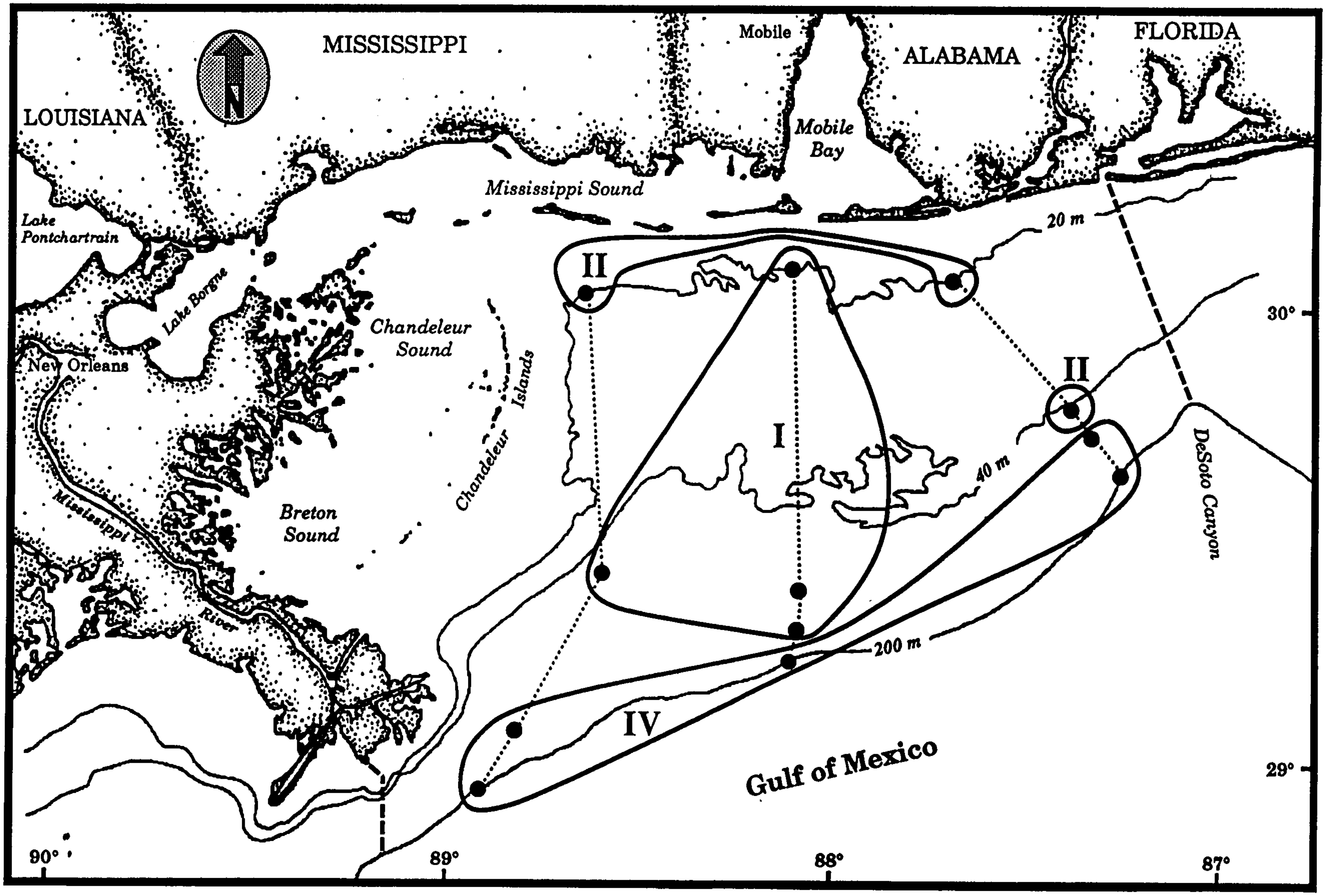


Figure 7-10. Map of the Mississippi-Alabama continental shelf study area showing the site groups derived from cluster analysis of macroinfaunal data form the Spring 1987 cruise.

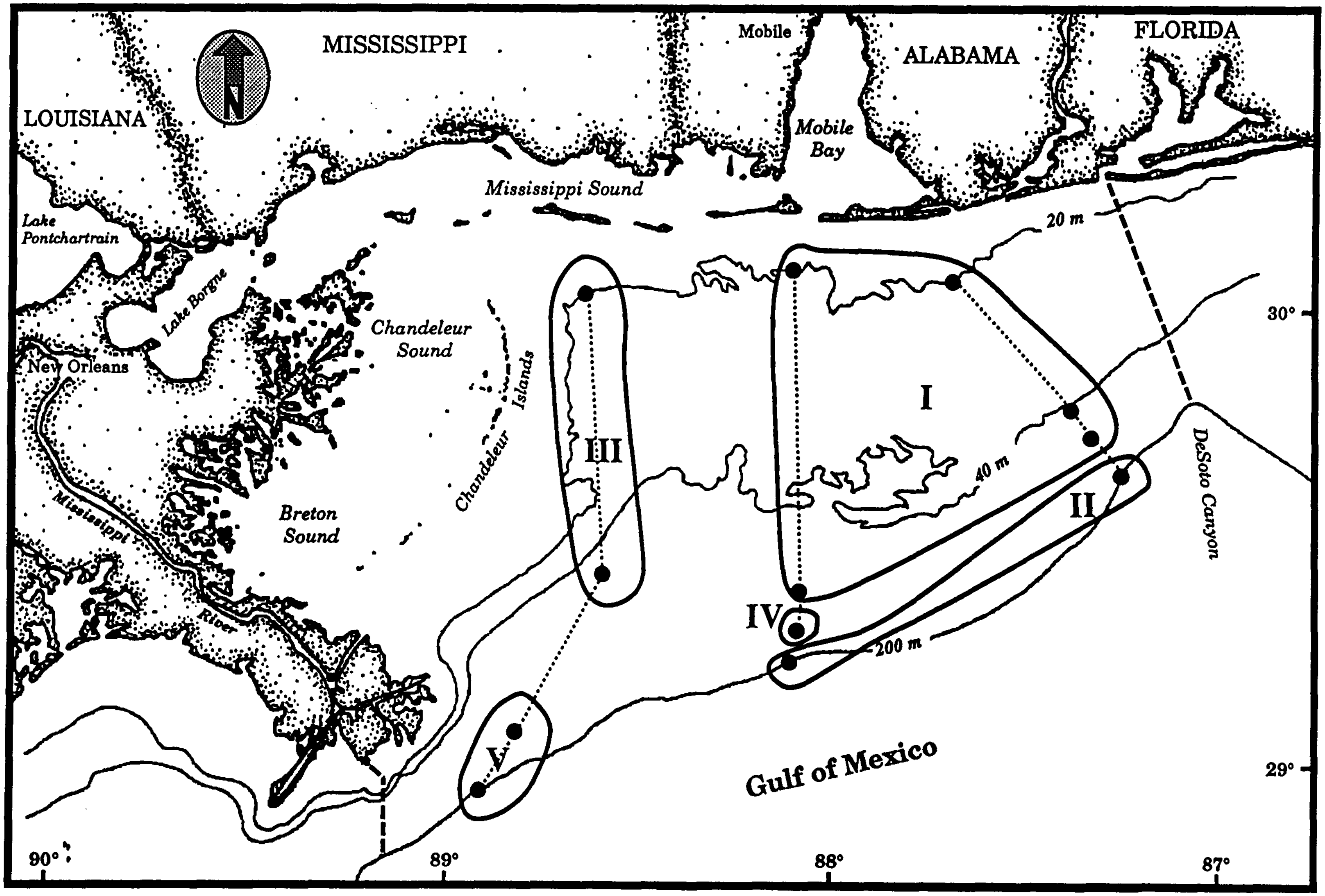


Figure 7-11. Map of the Mississippi-Alabama continental shelf study are showing the site groups derived from cluster analysis of macroinfaunal data from the Fall 1987 cruise.

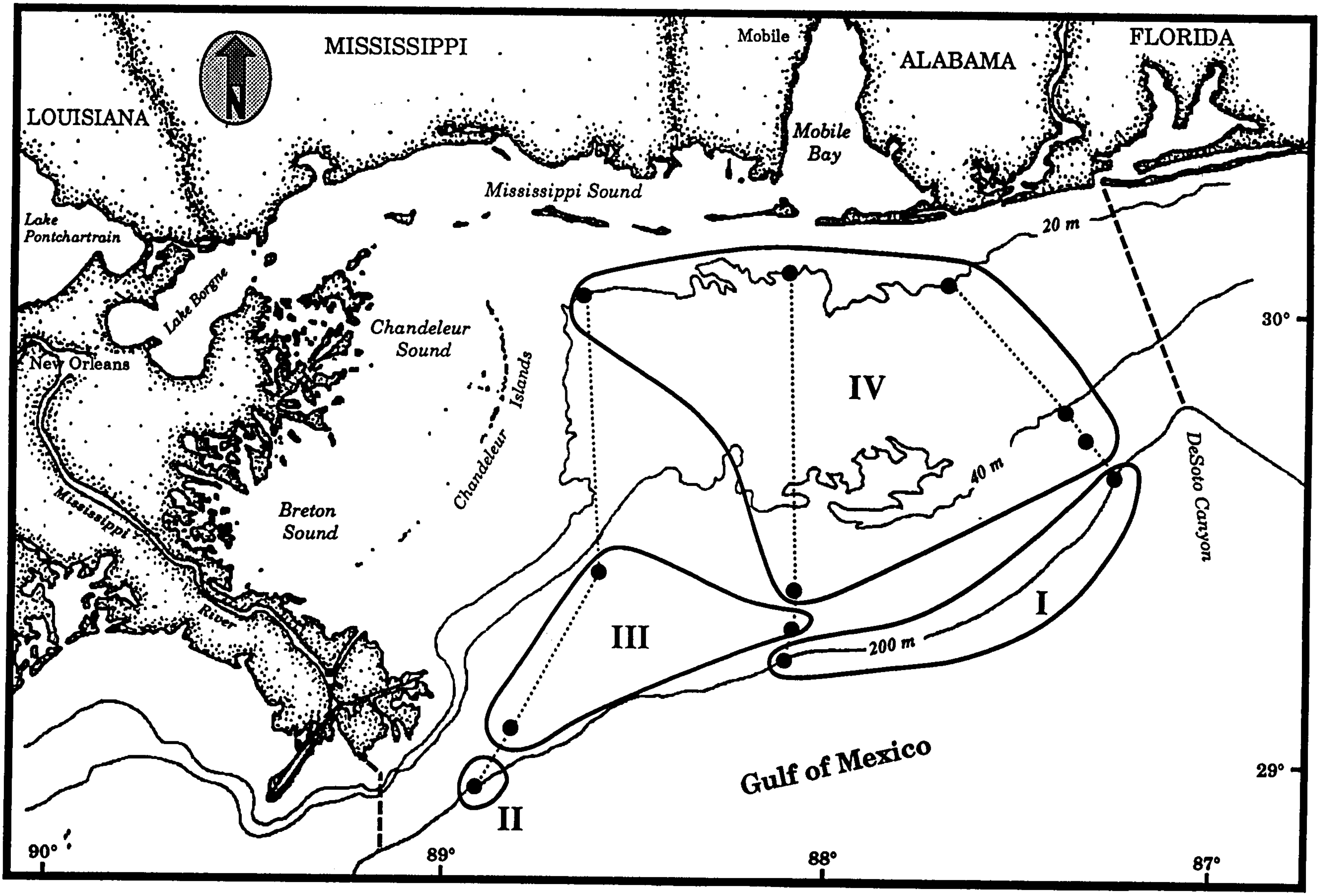


Figure 7-12. Map of the Mississippi-Alabama continental shelf study area showing the site groups derived from cluster analysis of macroinfaunal data from the Spring 1988 cruise.

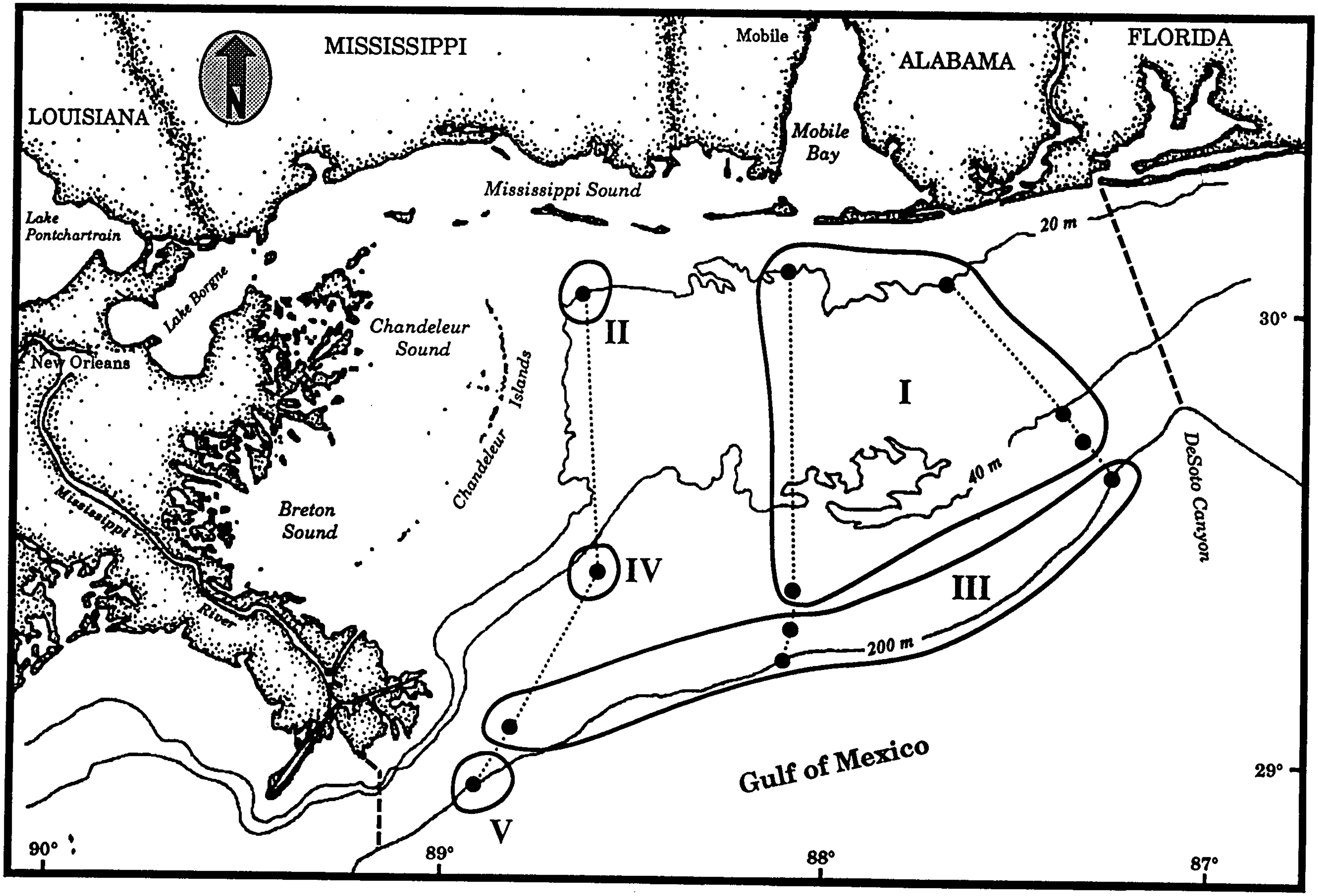


Figure 7-13. Map of the Mississippi-Alabama continental shelf study area showing the site groups derived from cluster analysis of macroinfaunal data from the Fall 9888 cruise.

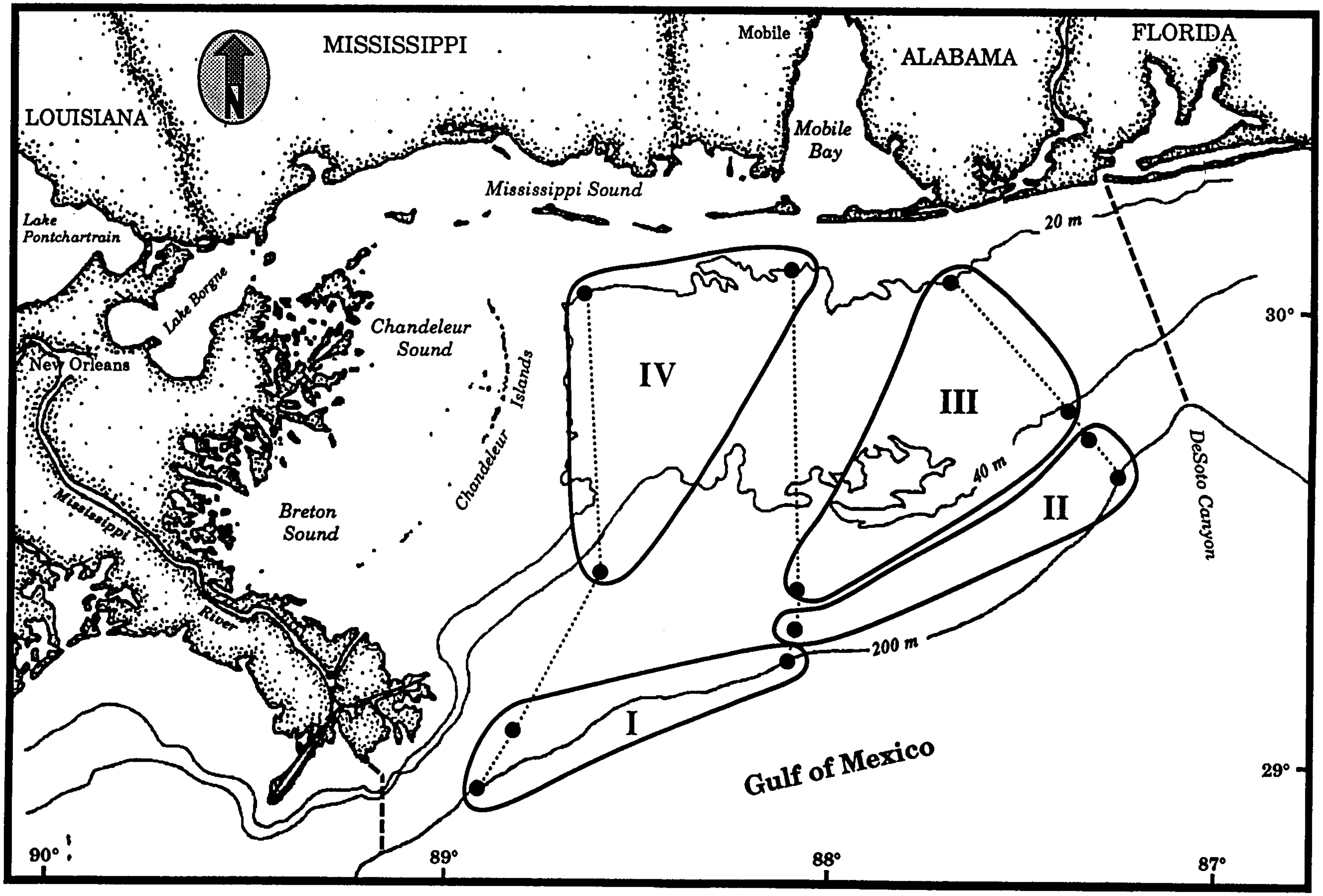


Figure 7-14. Map of the Mississippi-Alabama continental shelf study area showing the site groups derived from cluster analysis of macroinfaunal data from the Spring 1989 cruise.

Table 7-8. Comparison, by transect and depth (station), of the total number of taxa and abundances of macroepifaunal organisms collected during the Mississippi-Alabama continental shelf study.

		Transect D		Transect M		Transect C	
Sta	Depth	# Taxa	Abundance	# Taxa	Abundance	# Taxa	Abundance
1	20	61	794	68	959	51	1342
2	60	121	1473	64	1290	73	2068
3	100	110	1559	54	785	87	2941
4	200	77	1239	72	1828	65	4907

Table 7-9. Percent composition of macroepifaunal abundances for each station in the Mississippi-Alabama continental shelf study area, all cruises combined.

	Stations											
Taxon	D1	D2	D3	D4	M1	M2	M3	M4	C1	C2	C3	C4
Cnidaria	----	1.31	0.76	----	2.70	2.29	1.82	0.33	0.61	0.34	0.21	0.03
Gastropoda	11.18	3.01	2.03	6.39	2.60	1.80	20.73	5.27	8.17	0.43	2.49	0.30
Bivalvia	0.89	2.62	11.53	20.12	0.80	1.90	0.70	6.83	0.23	0.67	5.80	3.32
Stomatopoda	0.25	0.39	2.22	0.96	1.00	0.28	2.80	1.39	5.50	5.69	1.37	0.10
Decapoda	41.68	57.24	55.51	38.67	76.20	82.34	66.95	83.24	71.15	85.16	83.13	94.13
Holothuroidea	0.13	0.07	0.76	0.12	----	0.19	----	0.06	----	----	0.21	0.19
Ophiuroidea	2.80	1.77	1.20	22.41	2.20	3.42	0.56	1.11	0.84	0.34	5.33	1.82
Asteroidea	33.42	5.55	1.71	11.08	1.60	3.51	3.36	0.78	8.86	2.31	0.24	0.03
Echinoidea	1.65	23.42	23.13	----	0.10	2.28	----	----	0.76	----	----	----
Other	8.00	4.62	2.67	0.25	12.80	1.99	3.08	0.99	3.88	5.06	12.2	8.00

Seven of the 20 numerically dominant macroepifaunal species were penaeid or caridean shrimp, three were swimming (portunid) crabs and 3 were benthonic crabs (Table 7-10). Only 6 species were echinoderms or mollusks. Four species (*Stylocardis affinis*, *Parthenope agonus*, *Luidia clathrata*, and *Processa guayanae*) were collected entirely or principally on D-transect, whereas only 2 were characteristic of C-transect, and none of M-transect. The species were about equally divided between principally shallow, mid-depth and deep dwellers. Most species that were common to all three transects, such as *Portunus spinicarpus*, *Sicyonia brevirostris*, *Trachypenaeus constrictus*, *Loligo plei*, *Solenocera atlanticus*, were nektonic; *Anasimus latus* and *Aequipecten glyptus* were the members of this group that was benthonic.

Cluster analysis of the macroepifaunal data produced three site groups (Figure 7-15). Group I consisted of the three stations in 20 m depth and station C2 in 40 m depth (Figure 7-16). Group III consisted of deep stations along the continental slope. Group III was comprised of three stations with coral rubble to shell/sand bottoms. Analysis of individual cruise data shows that while there is considerable variability in the clustering arrangement of stations, there is a tendency for shallow stations to cluster together and deep stations to cluster together (Figures 7-17 to 7-21).

7.4.5 Biomass

Macroinfauna - The biomass of macroinfauna (exclusive of very large individuals which skewed the biomass totals) varied considerably at any given station from cruise to cruise (Table 7-11). The pattern that emerges when the mean values for all cruises are calculated is that the mean biomass at most stations ranged from 5 to 9 g/m^2. One station, M1, had a mean above that range, principally due to large quantities of polychaetes collected during cruises 2, 3 and 4, and one station, D4, had a mean below that range. The latter station consistently had small quantities of biomass. Also, the biomass collected during the Spring 1987 cruise was uniformly fairly small, compared with subsequent cruises. Overall numbers of individuals were also smallest in Spring 1987.

Table 7-10. The 20 numerically dominant macroinfaunal species and their abundances at each station, all data combined. Station with the highest abundance in each transect is in bold type. Station with overall greatest abundance is underlined.

Species	**Total**	**Stations**											
		D1	D2	D3	D4	M1	M2	M3	M4	C1	C2	C3	C4
Parapenaeus politus (D)	2825	-	1	-	**38**	-	3	121	**203**	-	106	**1421**	1404
Portunus spinicarpus (D)	2255	1	57	**240**	23	50	**561**	206	6	1	**943**	115	52
Plesionika tenuipes (D)	1675	-	-	-	-	-	-	-	**372**	-	-	314	**989**
Stylocardis affinis (E)	597	3	255	**334**	5	-	-	-	-	-	-	-	-
Sicyonia brevirostris (D)	594	**102**	42	39	1	**158**	71	-	2	25	**150**	6	-
Trachypenaeus constrictus (D)	521	**103**	-	-	-	**132**	-	-	**219**	67	-	-	
Solenocera vioscai (D)	499	-	19	19	11	-	-	17	**147**	-	114	26	**146**
Sicyonia dorsalis (D)	451	-	-	4	-	**132**	-	-	-	**259**	51	3	2
Ophiolepis paucispina (O)	433	-	-	-	**160**	-	-	2	18	-	3	**156**	106
Parthenope agonus (D)	342	3	**208**	122	8	-	-	-	-	-	-	-	1
Loligo plei (C)	314	**61**	23	-	-	**121**	6	-	-	39	**64**	-	-
Luidia clathrata (A)	283	**190**	37	3	-	-	**23**	-	-	**27**	3	-	-
Anasimus latus (D)	271	-	11	**31**	8	-	7	5	8	1	6	**193**	1
Processa guyanae (D)	269	-	70	**197**	-	-	2	2	-	-	-	-	-
Callinectes similis (D)	254	1	-	-	-	**47**	-	-	-	**107**	97	1	1
Portunus gibbesii (D)	237	9	3	-	-	**90**	-	-	-	**128**	6	-	1
Aequipecten glyptus (B)	233	1	-	-	**77**	1	8	1	**77**	-	-	7	**61**
Solenocera atlanticus (D)	225	1	34	**36**	-	21	**122**	-	-	7	1	3	-
Yoldia solenoides (B)	206	-	-	-	-	-	-	-	3	-	-	**157**	46
Raninoides louisianae (D)	194	-	-	8	4	-	8	17	**59**	-	6	**86**	6

Legend: A - Asteroidea; B - Bivalvia; C - Cephalopoda; D - Decapoda; E - Echinoidea; O - Ophiuroidea

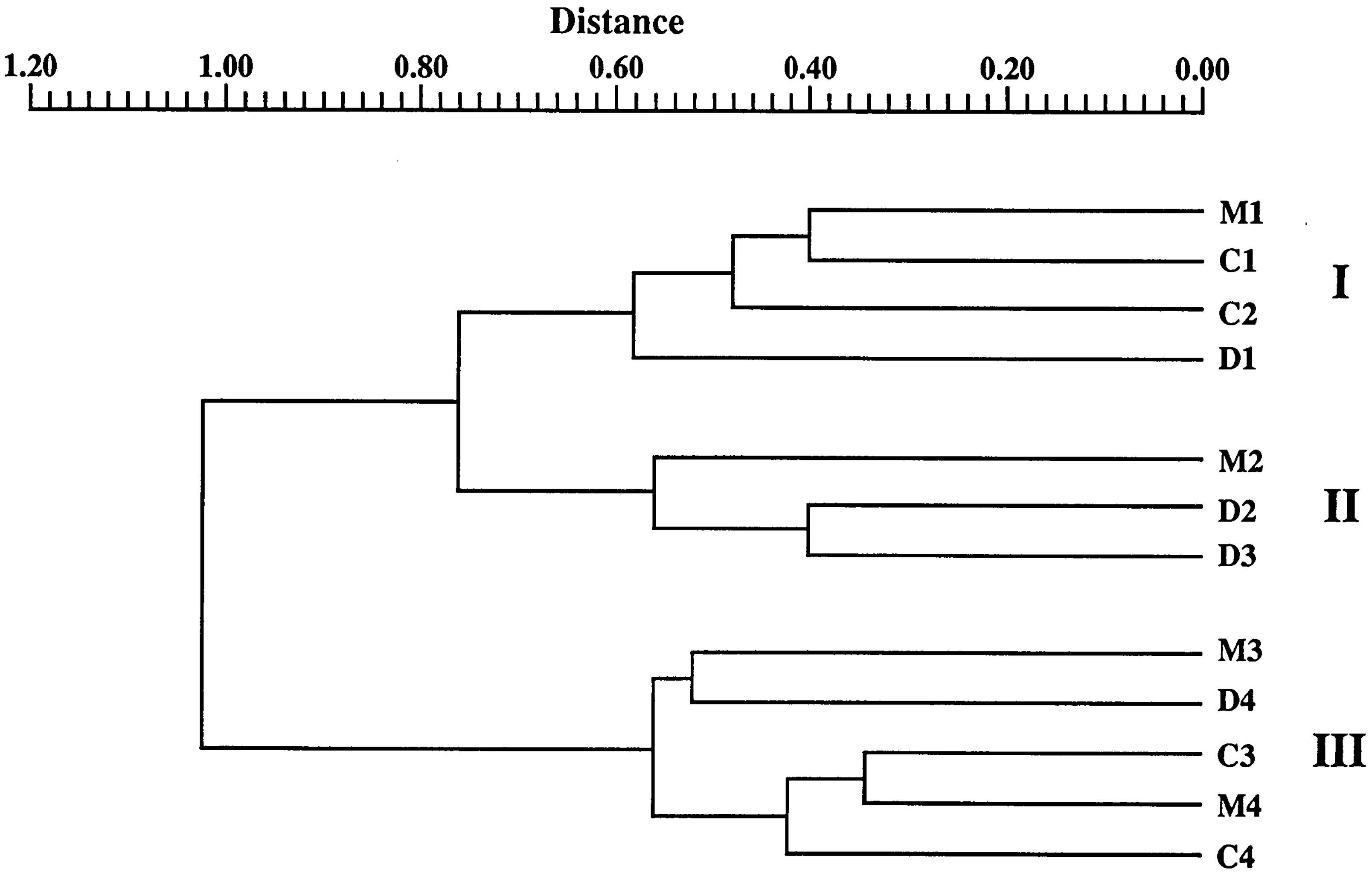


Figure 7-15. Site group dendrogram produced by cluster analysis of combined macroepifaunal data from all cruises.

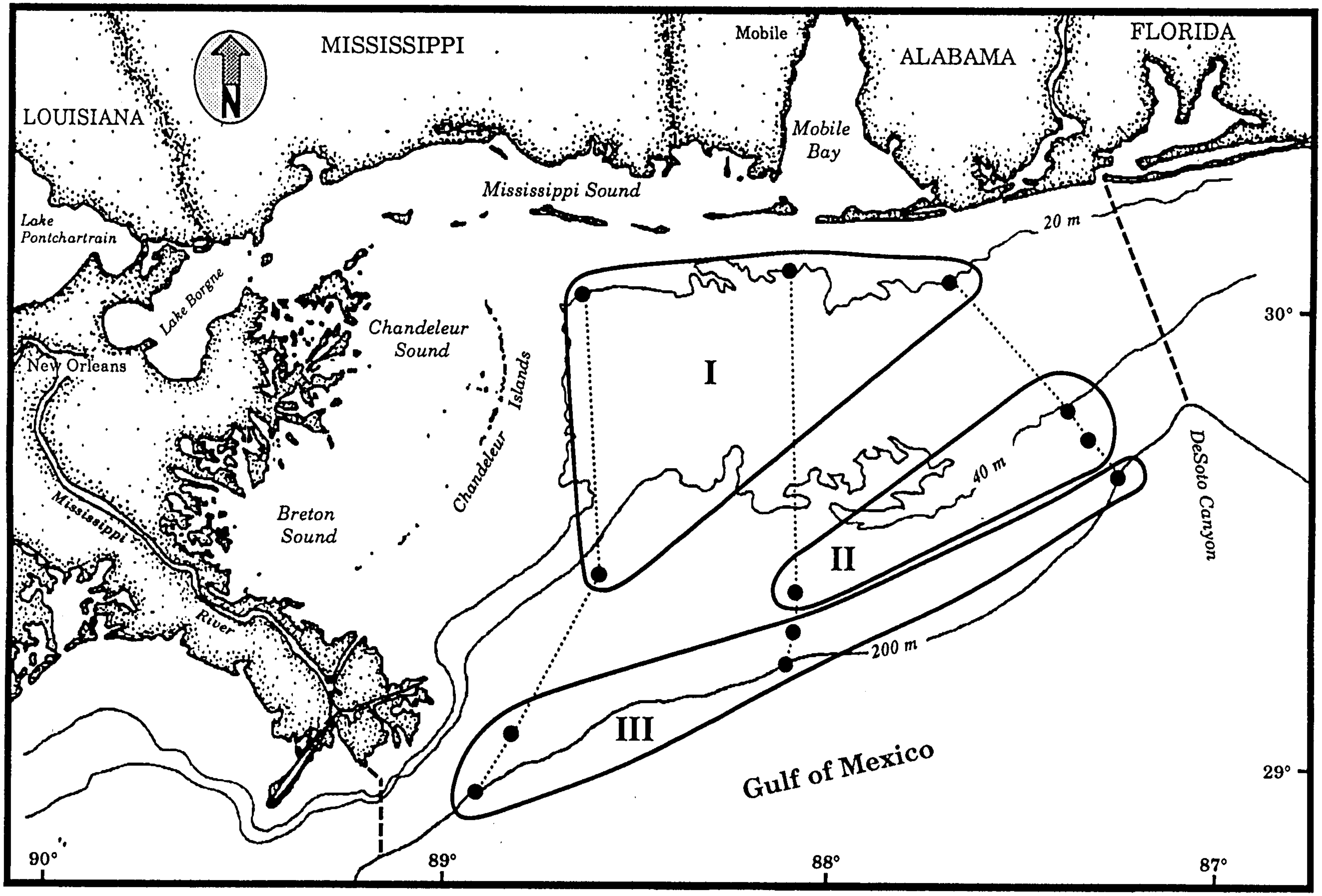


Figure 7-16. Map of the Mississippi-Alabama continental shelf study area showing the site groups derived from cluster analysis of combined macroepifaunal data from all cruises.

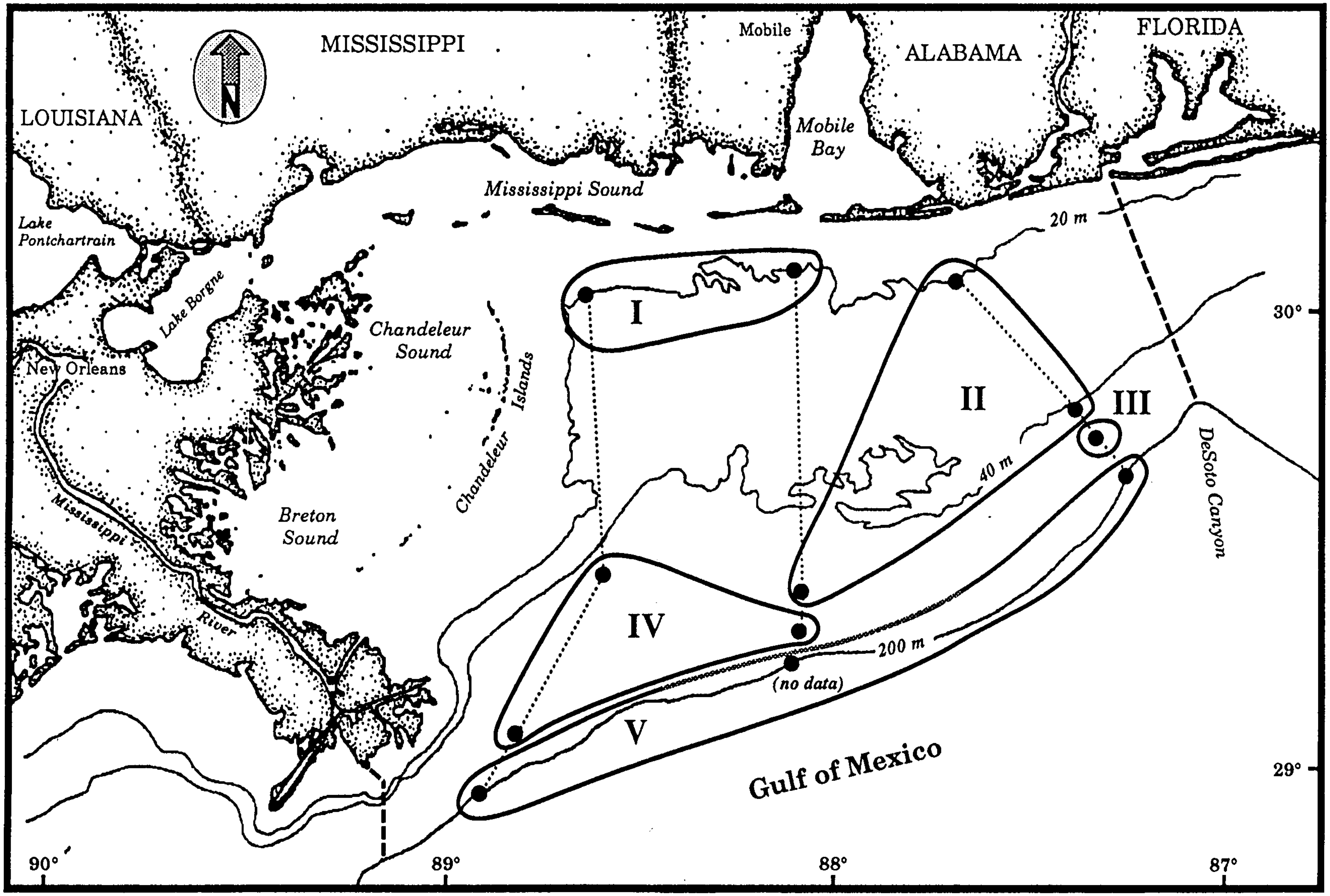


Figure 7-17. Map of Mississippi-Alabama continental shelf study area showing the site groups derived from cluster analysis of macroepifaunal data from the Spring 1987 cruise.

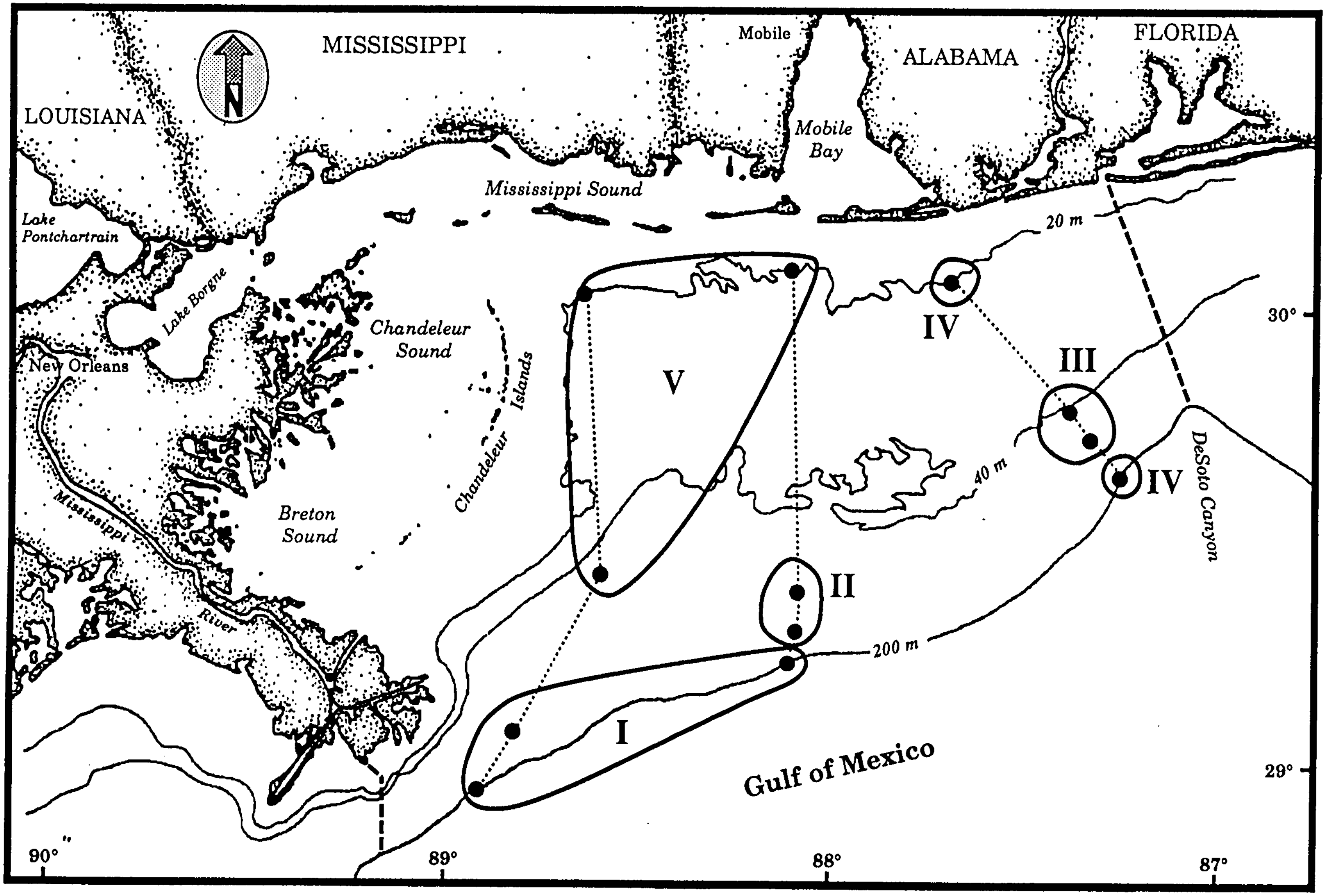


Figure 7-18. Map of the Mississippi-Alabama continental shelf study area showing the site groups derived from cluster analysis of macroepifaunal data from the Fall 1987 cruise.

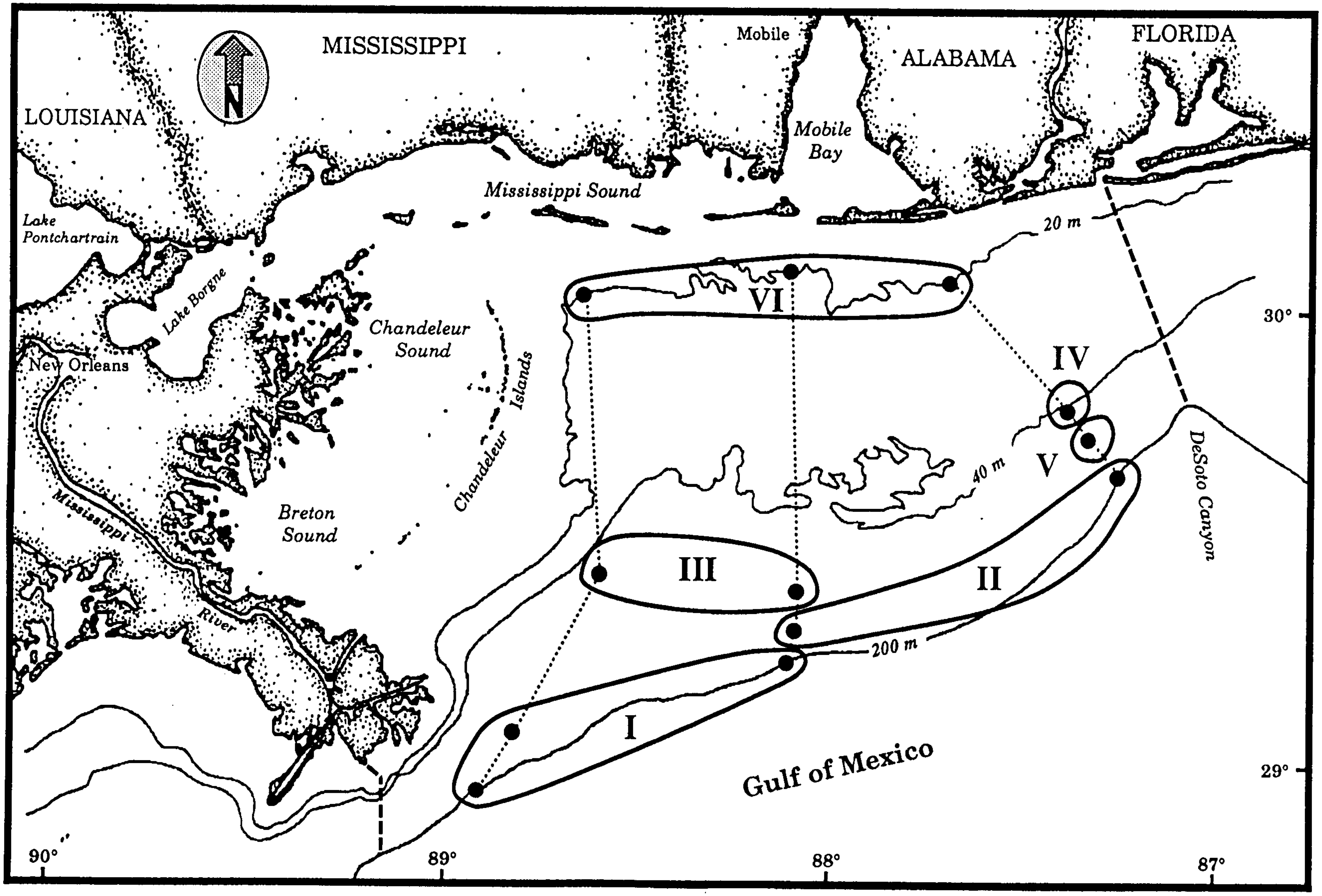


Figure 7-19. Map of the Mississippi-Alabama continental shelf study area showing the site groups derived from cluster analysis of macroepifaunal data from the Spring 1988 cruise.

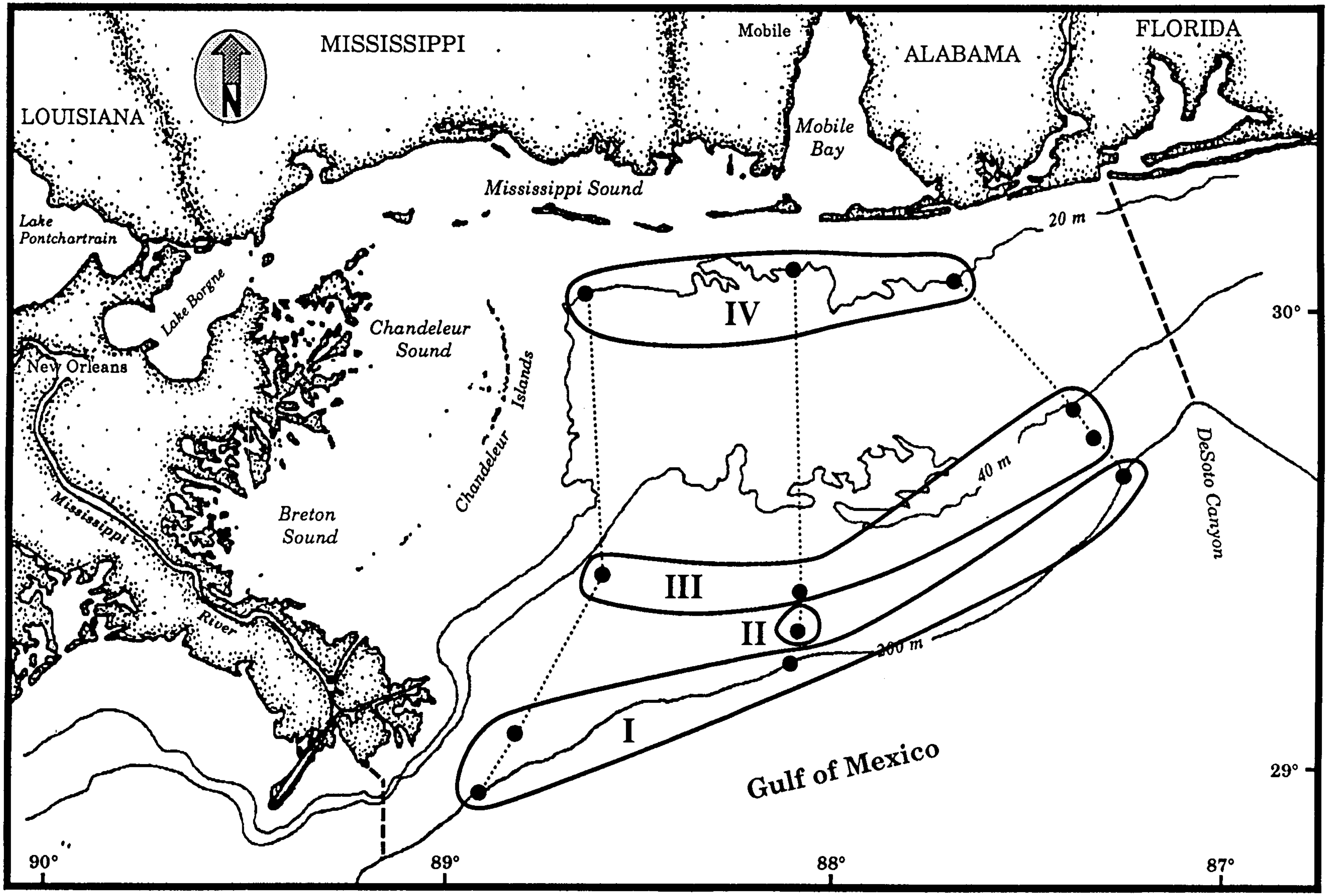


Figure 7-20. Map of the Mississippi-Alabama continental shelf study are showing the site groups derived from cluster analysis of macroepifaunal data from the Fall 1988 cruise.

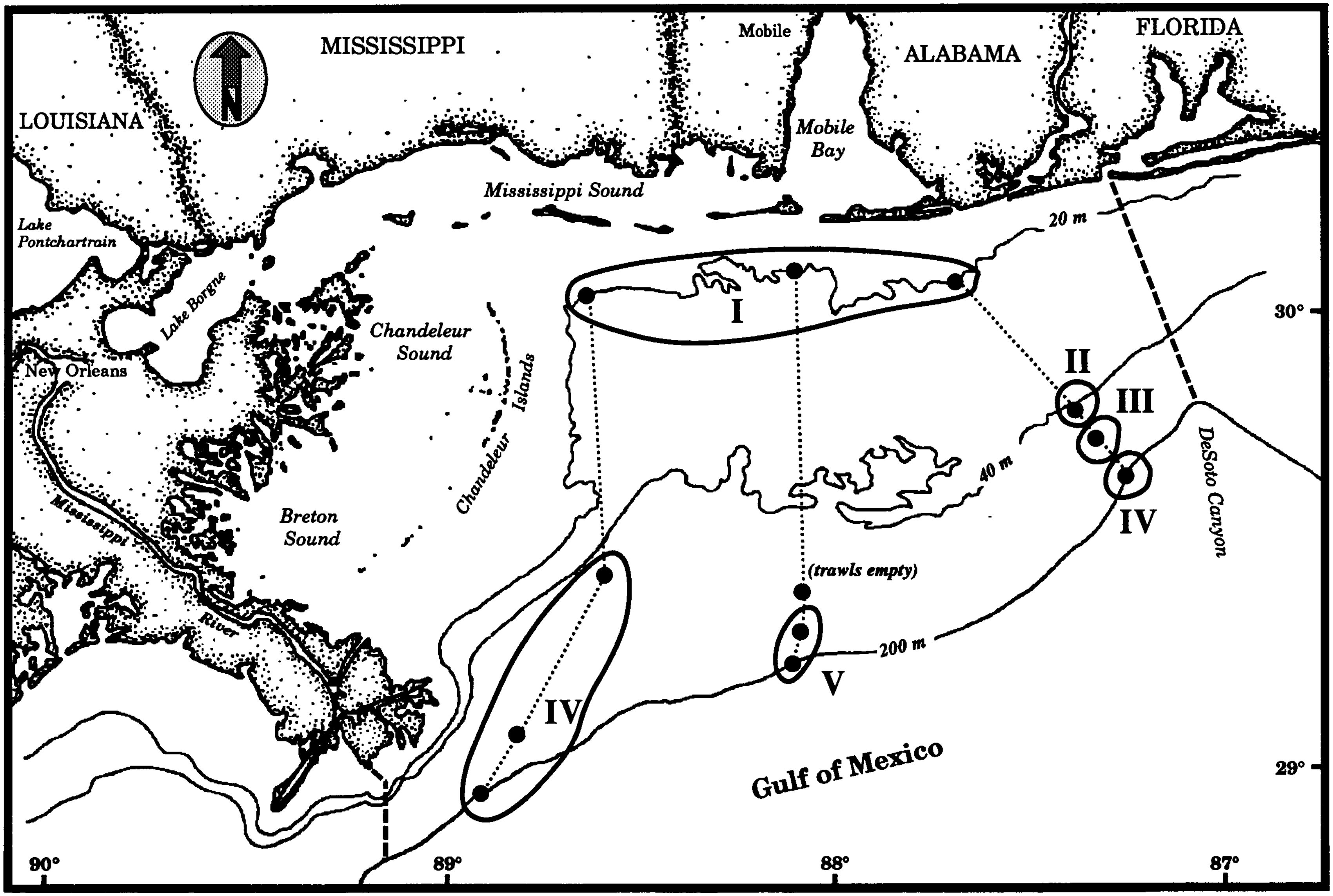


Figure 7-21. Map of the Mississippi-Alabama continental shelf study area showing the site groups derived from cluster analysis of macroepifaunal data from the Spring 1989 cruise.

Table 7-11. Comparison of mean macroinfaunal biomass (g/m^2) totals (exclusive of very large individuals) from each Mississippi-Alabama continental shelf study cruise.

	Stations											
Cruise	**C1**	**C2**	**C3**	**C4**	**M1**	**M2**	**M3**	**M4**	**D1**	**D2**	**D3**	**D4**
Spring 1987	1.77	2.31	2.07	0.30	0.86	3.92	4.06	2.80	0.15	0.60	1.88	3.05
Fall 1987	2.30	3.72	5.23	9.72	6.13	15.53	5.51	10.92	8.85	8.81	P	3.59
Spring 1988	14.10	0.16	10.50	20.83	19.66	3.66	13.00	4.16	5.16	2.33	7.16	P
Fall 1988	12.50	7.16	11.83	2.83	24.66	8.66	12.00	2.66	11.00	12.16	9.83	0.83
Spring 1989	17.60	14.50	18.00	3.66	20.50	6.16	3.50	12.66	13.33	2.16	5.83	2.66
Mean	9.65	5.55	9.52	7.64	14.36	7.59	7.61	6.64	7.70	5.21	4.94	2.03

Table 7-12. Comparison of mean macroepifaunal biomass (g) totals from each Mississippi-Alabama continental shelf study cruise.

	Stations											
Cruise	C1	C2	C3	C4	M1	M2	M3	M4	D1	D2	D3	D4
Spring 1987	*591	*466	*20	*261	*81	*912	*1595		*1139	*864	*981	*591
Fall 1987	1247	*644	634	42	1502	2580	1127	651	2018	1572	1551	2091
Spring 1988	952	136	310	507	1094	500	173	2194	398	75	817	5221
Fall 1988	815	2404	1929	243	1495	1640	198	484	1053	2297	889	498
Spring 1989	545	340	286	164	84	0	41	64	27	23	4	245
Mean	830	798	636	243	851	1126	626	848	927	966	848	775

* - data based on one trawl tow.

Macroepifauna - Macroepifaunal biomass varied greatly at a given station from cruise to cruise and there does not appear to be a pattern to the data (Table 7-12). Only C-transect appears to display a pattern of decreasing mean biomass toward the deep stations.

7.4.6 Heart Urchin Community

As noted in section 7.3.1, large quantities of heart urchins in the genus *Brissopsis* (the community appears to be comprised of *Brissopsis alta*, *Brissopsis atlantica* and intergrades between them) were collected by trawl at the deeper stations, especially at C3 and C4. These urchins, and their associated fauna, are infaunal organisms and were also collected by box core. However, because of the very soft characteristics of the sediments, were obtained with macroepifaunal species as the trawl dug in deeply. The urchins are treated separately here because they are infaunal but were collected with epifauna. Another reason for separate treatment is that it was not possible to obtain accurate abundance or count data; when the trawl was brought aboard the vessel, the net was usually dropped on the deck, especially if the vessel was pitching, and this crushed large numbers of urchins.

The crew on the first cruise were unprepared for the quantity of material that was in the trawl. At station C4, records indicate "14 garbage cans of urchins were thrown overboard." However, because the size of the garbage can was not recorded, it is not possible to estimate numbers of individuals or total weight of urchins collected during Cruise 0. On subsequent cruises, attempts were made to measure all the urchins, but this proved to be impractical because of sea conditions or numbers of urchins.

Table 7-13 lists the mean abundance and test length of *Brissopsis alta*, the dominant species of heart urchin, collected during each cruise at station C4, where the urchins were most abundant. Also listed is the mean weight as recorded in the field (converted from wet weight pounds). The decrease in total trawl catch during cruise 4 was also apparent at station C4. Not only were the abundances of urchins greatly reduced, but the size decrease sharply from the previous cruise. The on-board investigators noted that most of the urchins collected appeared to be younger and smaller than collected during previous cruises. The cause for this decrease in size and number is unknown, but it gives the appearance of a die-off or removal of the older urchins from the community.

Table 7-13. Mean test length of *Brissopsis alta*, and mean urchin weight collected at station C4 during each MAMES cruise.

	length (mm)	weight (kg)
Cruise 0	62.63	
Cruise 1	53.86	250
Cruise 2	62.72	68
Cruise 3	57.56	170
Cruise 4	47	5

7.5 Summary

The Mississippi-Alabama continental shelf has three basic sedimentary regimes which appear to influence the community composition of infauna and, to a degree, epifauna, i.e., coarse sand-coral rubble at stations D2 and D3, very soft mud at stations C3, C4, M4 and D4. The remaining stations have a sandy to sand-shell sediment.

The macroinfaunal communities were dominated by polychaetous annelids. Of these, *Armandia agilis*, the most abundant species, attained very large numbers only during cruise 3 (Spring 1988) and was an insignificant member of the community otherwise. The most "stable" infaunal dominant species were *Lumbrineris ernesti* and *Paraprionospio pinnata*. Bivalves and amphipods constituted the second and third most abundant groups. Most of the dominant species have also been reported as dominating assemblages in the western Gulf of Mexico. Abundances of macroinfauna decreased in deeper water on two of the three transects; the *Armandia agilis* population was very large at station C4 in Spring 1988 and caused the total abundance to be much higher than at M4 or C4.

Abundances of macroinfauna increased between Spring 1977 and Spring 1988 and then declined through Spring 1989. Cluster analysis of data indicates that the assemblages are influenced by sediment type; the deep stations (200 m depth) formed a cluster distinct from the sand/sand-shell/coarse sand stations.

Macroepifaunal assemblages were dominated by crustaceans, especially penaeid and caridean shrimp and portunid crabs. Abundances of macroinfauna increased between Spring 1977 and Spring 1988 also, and then declined through Spring 1989; the decrease in Spring 1989 was extreme as very few organisms were obtained by trawl at any station. There did not appear to be a trend of decreasing abundance from nearshore to offshore.

Cluster analysis indicated that the inshore stations (20 m depth) and the deep stations (150 and 200 m) each formed distinct groups, and the sand-shell/coarse sand bottomed stations in between (D2, D3 and M2) formed a separate cluster.

The heart urchin communities, which were principally located at stations C3 and C4, near the Mississippi River Delta, were comprised of a species complex of the genus *Brissopsis*, which included *B. alta*, *B. atlanticus*, and two morphs that intergraded between the two "species." The urchin populations appeared to be relatively stable from Spring 1987 through fall 1988. In Spring 1989, the numbers and sizes of urchins were greatly reduced, suggesting that some event had eliminated the adult urchins from the community, and the community was being repopulated by younger individuals.

8.0 DISTRIBUTION OF FISHES

John D. McEachran

8.1 Introduction

The Mississippi-Alabama continental shelf has long been known for its diverse and productive fishery resources. Gunter (1963), noting that 21 percent of the nation's marine fish landings occurred in ports from Pascagoula, Mississippi, to Port Arthur, Texas, referred to the region as the "fertile fisheries crescent". The composition and distribution of the demersal fish species of the Mississippi-Alabama continental shelf have been discussed by Franks et al. (1972), Darnell (1985) and Darnell and Kleypas (1987). The ichthyofaunal assemblage of the area is often considered to be transitional between that of the soft, terrigenous substrata of the northwestern Gulf of Mexico and that of the carbonate substrata off peninsular Florida. However, Darnell and Kleypas (1987), noting the high diversity and productivity of the area, the mix of eastern and western species, and the presence of some unique species, considered the Mississippi-Alabama shelf assemblage to be in many respects a unique system unto itself.

The present study was designed to build upon the foundation of historic data and to provide an up-to-date and semi-quantitative picture of the composition and distribution of the ichthyofauna of this shelf area to a depth of 200 m. Summer and winter surveys along three transects were made with stations at depths of approximately 20, 60, 100 and 200 m. The three transects extended seaward near the Chandeleur Islands (Transect "C"), off Mobile Bay (Transect "M") and near DeSoto Canyon (Transect "D"). Paired trawl hauls were made at each station, and the data were analyzed to determine species composition, species distribution patterns, faunal assemblages and associations of faunal assemblages with physical factors.

8.2 Materials and Methods

8.2.1 Collection and Processing of Fish Specimens

Field collections were made during three winter and two summer cruises. During most cruises some difficulties were encountered due to bad weather and high seas, and bottom obstructions resulted in gear loss, particularly at the two deeper stations on the DeSoto Canyon transect. Nevertheless, a total of 104 successful trawl collections was made including 59 during the three winter cruises and 45 during the two summer cruises. All of the twelve stations were sampled at least four times during each season. In all, 46 sets of paired trawl collections were made (i.e., samples taken at the same station, one right after the other). The catch of these paired samples was later analyzed to provide information on the variability of the trawl collections. In the field, all specimens were preserved in 10% buffered formalin. In the laboratory, all fishes were rinsed in water, transferred to 70% ethanol, identified, weighed to the nearest gram and measured to the nearest millimeter of total length. Representative specimens are being stored in the Texas Cooperative Wildlife Collection, and voucher specimens of each species are being shipped to the National Museum of Natural History, Smithsonian Institution.

8.2.2 Standardization of the Trawl Data

To facilitate comparison of the data from different stations and seasons, each trawl haul was standardized to a common unit of area. To accomplish this, the actual area covered by each trawl was determined by multiplying the trawl spread by the distance trawled. This value, in turn, was employed to determine what the catch would have been if the trawl had sampled an area of one hectare (10,000 m^2). This unit was selected because most of the trawls actually sampled between 5,000 and 10,000 m^2 (mean area sampled was 5,431 m^2). The trawl used in the sampling had a head rope length of 9.0 m (29.5 ft.). The actual spread of this trawl under operating conditions was determined by scuba divers who measured the distance between the tracks left in the substrate by the trawl boards at two different depths. Several measurements were made at each depth. The results showed that at a depth of 11.6 m (38 ft.) the trawl spread only 92.5%

as wide as it did at 33.5 m (110 ft.) (11.7 ft. vs 12.08 ft. spread). The difference was statistically significant ($P < 0.05$), so the width of the trawl path had to be corrected for depth according to the following regression equation:

$$y = 10.678 + 0.0141x$$

where x is the depth in meters and y is the width of the trawl path in meters. The distance trawled was determined from Loran positions measured at the time the trawl hit the bottom and the time retrieval began. Most trawls were of 15 minute duration, but in the few deviant cases the time was corrected to 15 minutes according to formulae presented in Darnell and Kleypas (1987).

Once all trawl samples had been standardized to the catch per hectare, paired trawl samples were averaged to provide a single set of data for each station and cruise. For winter/summer comparisons the standardized data for each station within a given season were averaged to provide the best station estimates for the particular season.

8.2.3 Analysis of Sample Variability

The 46 sets of paired samples were used to provide information on the variability of the trawl collections. All computations were conducted on data standardized to the catch per hectare. For each pair of samples, the deviation was calculated as a percentage of the mean number of fishes captured in the two samples. The mean, standard deviation and standard error of these deviations were then compared to the mean number of fishes captured to provide information on the variability of the catch.

8.2.4 Length Frequency Analyses

Total lengths of the 20 most abundant species captured over the five surveys were rounded to the nearest centimeter and plotted against frequency of occurrence. Plots were generated for each of the five surveys and for all winter surveys combined and for both summer surveys combined. Because of the similarities among the winter surveys and between the summer surveys in the length frequency plots and the relatively small sample sizes for most of the 20 species on each of the surveys, only the combined seasonal length frequencies are presented below.

8.2.5 Species Diversity

The Shannon-Weiner diversity indices (H') were calculated from the mean standardized number of individuals per species captured per station to facilitate comparisons among stations, transects, depths, surveys and seasons. The Shannon-Weiner diversity index formula is:

$$H' = -\sum_{i=1}^{n} Pi\ (Log^{2}Pi)$$

Where, Pi = proportion of the ith species in each sample. This index is sensitive to both species richness (number of species) and to species evenness (equitability of abundance).

8.2.6 Clustering

The Canberra metric dissimilarity coefficient was used to estimate faunal affinities. This index is the sum of a series of fractions. The Canberra metric index formula is:

$$D_{jk} = \sum_{i=1}^{n} \frac{|X_{ij} - X_{ik}|}{(X_{ij} + X_{ik})}$$

Where, Djk = the dissimilarity between entity j and k; X_{ij} and X_{ik} = values of attributes of species in entities j and k, respectively.

The coefficients are expressed as a dendrogram, which is formed using agglomerative hierarchical clustering strategies. This strategy operates by an interactive process of fusing pairs of entities, then pairs of groups of entities until the entire population is fused. The flexible sorting option, and both normal and inverse classifications were used. Entities are collections (stations) in the normal classification and the degree of overall similarity between assemblages of fishes is measured. Species are entities in the inverse classification and their presence and/or abundance in collections are the attributes.

8.3 Results

8.3.1 Variability of the Trawl Catches

Variability of the catch by trawl nets may result from biological, physical and mechanical factors. Biological factors involve susceptibility of fishes to capture (position in the water column, net avoidance, etc.) and chance encounter of schools or feeding aggregations of fishes. Physical factors include weather, sea state and water currents, as well as bottom topography, all of which can affect behavior of bottom trawls. Mechanical factors involve human activities: operation of the ship and trawl winch, accuracy of Loran readings and estimation of fishing time of trawl on bottom. Although the independent effect of each of these factors cannot be assessed, the cumulative effect can be estimated by examining the catch of paired tows.

In the present study, 46 pairs of trawl tows were made. For each pair the mean catch was determined and the deviation from this value was calculated as a percent of the catch mean. For all 46 pairs, the average deviation turned out to be 37.1% (range = 0.76 — 92.4%). The standard error of the deviation was + 24.4%, and the standard error of the mean was 3.60%. Thus, on the average, the deviation was a little over one-third of the mean catch, and the 95% confidence interval (+2 standard deviations) was about one-half the mean catch. Although this is a fairly large percentage, it is noted that all the cruises were plagued by stormy weather which likely caused the trawl to bounce along the bottom in some instances. Examining the data in greater detail, in 9 out of the 46 cases (19.6%) the deviation from the mean was less than 8%. In 8 out of the 46 cases the deviation was greater than 60%, and one-half of these occurred at depths of 200 m where highly irregular bottoms and strong currents may have interfered with trawl operation.

8.3.2 Species Composition and Abundance

During the study 16,182 fish specimens were collected weighing 312.6 Kg. These averaged 323.3 fishes per hectare weighing 6.22 Kg per hectare. This is a very low density and is about one-fourth of what might be expected. It is suggested that the narrow trawl spread (3.6 to 4.3 m) facilitated net avoidance by most of the larger, heavier and fast swimming fishes, and indeed, these were extremely rare in collections. From this group of fishes a total of 225 taxa were identified, including 207 recognizable to the species level. These taxa, together with their numbers and weights are listed in Table 8-1. All scientific and common names are in accordance with Robins, et al. (1980) except the following: The genus *Ogcocephalus* of the family Ogcocephalidae were recently revised by Bradbury (1980), and these names are used. *Prionotus longispinosus* is employed in place of P. salmonicolor following Robins et al. (1986). *Gymnothorax nigromarginatus* and *G. ocellatus* are retained as distinct species following Boehlke et al. (1989), although Robins et al. considered them a single species.

Sixty-eight families are represented in the list. The most speciose families are the Bothidae (18 species); Serranidae (17 species); Triglidae (14 species); Ophidiidae (9 species); Ogcocephalidae, Sciaenidae and Scorpaenidae (7 species); and Congridae, Synodontidae, Gadidae, Lutjanidae and Cynoglossidae (6 species each). These 12 families include over 2 of the species of fishes encountered.

In Table 8-2, the top 100 species are listed in order of numerical abundance, and the number and percentage of each is given. This group represents over 97% of the total number of individuals captured. Surprisingly there is no clear pattern of numerical dominance by any species or small group of species, and estuarine species are not a dominant or even a significant proportion of the catch.

The most abundant species constitutes only 10.3%, the top five species make up 30.5%, the top ten species account for 45.1% and the top twenty species comprise 61.0% of the total catch. Below the distributions, abundances and length frequencies of the twenty most abundant species are discussed.

Halieutichtys aculeatus - Pancake fish

Halieutichthys aculeatus is the most abundant and ubiquitous species. This species was captured in high abundance on both winter and summer surveys, and was taken on all transects and depths (Table 8-3). It was

Table 8-1. List of fish species taken by trawls during the present study. Common names are given where available. The standardized abundance values represent the numbers of individuals captured and weights (grams). The values are standardized to represent the combined data from all twelve stations, each station being represented by a single trawl collection covering one hectare (10,000 m^2).

Scientific Name	Common Name	Abundance	
		Number	Weight
Rajidae	SKATES		
Raja eglanteria	clearnose skate	6.4	740.2
Raja olseni	spreadfin skate	0.9	490.6
Raja texana	roundel skate	2.1	272.3
Moringuidae	SPAGHETTI EELS		
Neoconger mucronatus	ridged eel	0.1	0.5
Xenocongridae	FALSE MORAYS		
Kaupichthys nuchalis	collared eel	0.9	25.8
Muraenidae	MORAYS		
Gymnothorax nigromarginatus	blackedge moray	6.8	455.8
Gymnothorax ocellatus		0.4	22.7
Gymnothorax saxicola	ocellated moray	4.7	375.4
Gymnothorax miliaris	goldentail moray	0.4	39.4
Nettastomatidae	DUCKBILL EELS		
Hoplunnis macrurus	freckled pike-conger	7.3	64.4
Hoplunnis tenuis	spotted pike-conger	6.2	44.6
Nettastomatidae sp.		1.9	50.1
Congridae	CONGER EELS		
Ariosoma balearicum	bandtooth conger	2.5	31.0
Conger oceanicus	conger eel	0.2	0.5
Gnathophis bathytopos	blackgut conger	0.3	2.2
Hildebrandia flava	yellow conger	11.9	686.3
Hildebrandia gracilior	whiptail conger	1.1	113.6
Paraconger caudilimbatus	margintail conger	0.9	7.2
Paraxenomystax sp.		0.8	3.7
Congridae sp.		0.2	5.9
Ophichthidae	SNAKE EELS		
Bascanichthys bascanium	sooty eel	0.3	0.5
Echiophis intertinctus	spotted spoon-nose eel	0.9	249.1
Echiophis punctifer	stippled spoon-nose eel	0.2	12.7
Myrophis punctatus	speckled spoon-nose eel	0.9	7.9
Ophichthus ocellatus	palespotted eel	1.8	113.9

Table 8-1. Cont'd.

Scientific Name	Common Name	Abundance	
		Number	Weight
Clupeidae	HERRINGS		
Brevoortia patronus	gulf menhaden	1.2	36.4
Etrumeus teres	round herring	0.2	1.9
Harengula jaguana	scaled sardine	4.9	41.3
Engraulidae	ANCHOVIES		
Anchoa cubana	Cuban anchovy	115.7	111.5
Anchoa hepsetus	striped anchovy	132.8	499.6
Anchoa lyopepis	dusky anchovy	0.9	6.2
Anchoa mitchilli	bay anchovy	50.4	104.6
Argentinidae	ARGENTINES		
Argentina striata	striated argentine	1.7	51.4
Melanostomiidae	SCALELESS DRAGONFISHES		
Echiostoma sp.		0.2	0.2
Sternoptychidae	HATCHETFISHES		
Polyipnus asteroides		14.5	22.0
Synodontidae	LIZARDFISHES		
Saurida brasiliensis	largescale lizardfish	37.4	98.9
Saurida normani	shortjaw lizardfish	0.5	37.7
Synodus foetens	inshore lizardfish	46.6	3,177.7
Synodus intermedius	sand diver	3.9	13.9
Synodus poeyi	offshore lizardfish	25.3	79.1
Trachinocephalus myops	snakefish	6.5	274.1
Chlorophthalmidae	GREENEYES		
Chlorophthalmus agassizi	shortnose greeneye	0.6	1.7
Parasudis truculenta	longnose greeneye	2.7	40.8
Ariidae	SEA CATFISHES		
Arius felis	hardhead catfish	14.1	2,504.1
Batrachoididae	TOADFISHES		
Porichthys plectrodon	Atlantic midshipman	57.0	515.4
Lophiidae	GOOSEFISHES		
Lophiodes reticulatus	reticulate goosefish	0.2	32.9
Antennariidae	FROGFISHES		
Antennarius ocellatus	ocellated frogfish	0.1	7.0
Antennarius radiosus	singlespot frogfish	8.0	126.1
Ogcocephalidae	BATFISHES		
Halieutichthys aculeatus	pancake batfish	398.1	2,700.7
Ogcocephalus corniger		7.1	224.5
Ogcocephalus declivirostris		19.3	378.2

Table 8-1. Cont'd.

Scientific Name	Common Name	Abundance	
		Number	Weight
Ogcocephalus nasutus		10.3	209.2
Ogcocephalus pantostictus		0.6	2.8
Ogcocephalus parvus	roughback batfish	28.8	229.0
Ogcocephalus sp.		0.3	0.3
Zalieutes mcgintyi	tricorn batfish	16.2	157.4
Bregmacerotidae	CODLETS		
Bregmaceros atlanticus	antenna codlet	38.5	14.5
Gadidae	CODFISHES		
Merluccius albidus		0.2	8.6
Physiculus fulvus		7.9	41.5
Steindachneria argentea	luminous hake	9.7	63.4
Urophycis cirrata	gulf hake	17.1	1,622.2
Urophycis earlli	Carolina hake	0.4	43.8
Urophycis floridana	southern hake	22.5	2,126.0
Macrouridae	GRENADIERS		
Bathygadus macrops		28.9	417.5
Bathygadus melanobranchus		16.6	234.3
Coelorinchus caribbaeus	blackfin grenadier	63.4	715.3
Coelorinchus coelorhinchus	saddled grenadier	0.4	1.8
Ophidiidae	CUSK-EELS		
Brotula barbata	bearded brotula	5.4	1,338.0
Lepophidium graellsi	blackedge cusk-eel	38.4	541.4
Lepophidium jeannae	mottled cusk-eel	14.7	400.6
Lepophidium sp.		2.1	3.2
Neobythites gillii		14.1	97.5
Neobythites sp.		6.2	5.4
Ophidion beani	longnose cusk-eel	0.4	25.6
Ophidion grayi	blotched cusk-eel	0.8	71.3
Ophidion holbrooki	bank cusk-eel	1.4	118.6
Ophidion welshi	crested cusk-eel	3.0	112.7
Ophidion sp.		0.2	2.0
Otphidium omostigmum	polka-dot cusk-eel	7.5	23.6
Atherinidae	SILVERSIDES		
Menidia peninsulae	tidewater silverside	0.4	1.1
Polymixiidae	BEARDFISHES		
Polymixia lowei	beardfish	2.2	31.8
Holocentridae	SQUIRRELFISHES		
Ostichthys trachypoma	bigeye soldierfish	1.3	51.3
Plectrypops retrospinis	cardinal soldierfish	0.2	---
Zeidae	DORIES		
Zenopsis conchifera	buckler dory	0.3	17.4

Table 8-1. Cont'd.

Scientific Name	Common Name	Abundance	
		Number	Weight
Fistulariidae	CORNETFISHES		
Fistularia petimba	red cornetfish	0.4	183.5
Centriscidae	SNIPEFISHES		
Macrorhamphosus gracilis	slender snipefish	6.1	31.2
Macrorhamphosus scolopax	longspine snipefish	27.6	55.5
Syngnathidae	PIPEFISHES		
Hippocampus erectus	lined seahorse	0.7	9.7
Syngnathus louisianae	chain pipefish	1.8	6.5
Perchichthyidae	TEMPERATE BASSSES		
Synagrops bellus	blackmouth bass	7.9	78.0
Synagrops spinosa		10.4	48.9
Serranidae	SEA BASSES		
Centropristis ocyurus	bank sea bass	26.1	725.6
Centropristis philadelphica	rock sea bass	45.4	2,264.4
Centropristis striata	black sea bass	0.3	0.2
Diplectrum bivittatum	dwarf sand perch	109.8	1,171.2
Diplectrum formosum	sand perch	5.9	315.3
Epinephelus flavolimbatus	yellowedge grouper	0.3	599.3
Epinephelus striatus	Nassau grouper	0.2	10.1
Hemanthias aureorubens	streamer bass	0.4	3.3
Hemanthias leptus	longtail bass	1.4	---
Hemanthias vivanus	red barbier	2.7	5.6
Liopropoma eukrines	wrasse bass	0.5	0.1
Pikea mexicana	yellowtail bass	4.7	81.2
Serraniculus pumilio	pygmy sea bass	61.9	208.4
Serranus atrobranchus	blackear bass	127.6	2,329.4
Serranus notospilus	saddle bass	55.4	239.2
Serranus phoebe	tattler	7.8	74.8
Serranus subligarius	belted sandfish	0.4	0.7
Serranus sp.		1.1	0.5
Grammistidae	SOAPFISHES		
Rypticus maculatus	whitespotted soapfish	0.4	1.4
Priacanthidae	BIGEYES		
Pristigenys alta	short bigeye	0.4	121.6
Apogonidae	CARDINALFISHES		
Apogon pseudomaculatus	twospot cardinalfish	2.5	10.0
Malacanthidae	TILEFISHES		
Caulolatilus intermedius	anchor tilefish	3.6	421.0

Table 8-1. Cont'd.

Scientific Name	Common Name	Abundance	
		Number	Weight
Carangidae	JACKS		
Caranx latus	horse-eye jack	0.2	7.4
Chloroscombrus chrysurus	Atlantic bumper	49.0	463.9
Decapterus macarellus	mackerel scad	0.1	1.9
Decapterus punctatus	round scad	0.7	12.4
Selene vomer	lookdown	0.6	0.8
Trachurus lathami	rough scad	8.2	172.7
Lutjanidae	SNAPPERS		
Lutjanus analis	mutton snapper	0.2	0.6
Lutjanus campechanus	red snapper	0.4	16.1
Lutjanus mahogoni	mahogany snapper	1.0	36.7
Ocyurus chrysurus	yellowtail snapper	0.5	0.6
Pristipomoides aquilonaris	wenchman	18.7	544.8
Rhomboplites aurorubens	vermilion snapper	3.8	48.5
Gerreidae	MOJARRAS		
Eucinostomus argenteus	spotfin mojarra	0.2	1.4
Haemulidae	GRUNTS		
Haemulon aurolineatum	tomtate	8.1	232.9
Orthopristis chrysoptera	pigfish	9.3	532.4
Sparidae	PORGIES		
Archosargus probatocephalus	sheepshead	0.2	481.5
Calamus sp.		0.2	4.5
Lagodon rhomboides	pinfish	7.1	169.1
Stenotomus caprinus	longspine progy	358.1	6,048.3
Sciaenidae	DRUMS		
Cynoscion arenarius	sand seatrout	13.2	1,585.7
Equetus acuminatus	high hat	0.2	39.2
Equetus lanceolatus	jackknife-fish	0.8	13.1
Equetus umbrosus	cubbyu	4.2	366.9
Equetus sp.		3.4	431.5
Leiostomus xanthurus	spot	13.4	1,005.2
Menticirrhus americanus	southern kingfish	0.4	26.5
Micropogonias undulatus	Atlantic croaker	17.5	1,046.5
Mullidae	GOATFISHES		
Mulloidichthys martinicus	yellow goatfish	1.6	107.1
Mullus auratus	red goatfish	0.6	38.9
Kyphosidae	SEA CHUBS		
Kyphosus sectatrix	Bermuda chub	0.7	16.2
Chaetodontidae	BUTTERFLYFISHES		
Chaetodon aya	bank butterflyfish	2.5	54.1

Table 8-1. Cont'd.

Scientific Name	Common Name	Abundance	
		Number	Weight
Labridae	WRASSES		
Decodon puellaris	red hogfish	0.6	7.8
Halichoeres sp.		2.1	37.4
Sphyraenidae	BARRACUDAS		
Sphyraena borealis	northern sennet	1.0	160.8
Polynemidae	THREADFINS		
Polydactylus octonemus	Atlantic threadfin	7.9	162.3
Opistognathidae	JAWFISHES		
Lonchopisthus micrognathus	swordtail jawfish	1.4	0.6
Opistognathus lonchurus	moustache jawfish	0.2	0.6
Percophidae	FLATHEADS		
Bembrops anatirostris	duckbill flathead	30.6	811.2
Uranoscopidae	STARGAZERS		
Gnathagnus egregius	freckled stargazer	0.2	12.3
Kathetostoma albigutta	lancer stargazer	3.2	177.4
Clinidae	CLINDS		
Chaenopsis limbaughi	yellowface pikeblenny	0.2	0.1
Gobiidae	GOBIES		
Bathygobius soporator	frillfin goby	1.2	1.1
Bollmannia communis	ragged goby	27.0	75.3
Gobiosoma bosci	naked goby	1.2	0.3
Gobiosoma sp.		0.6	0.1
Gempylidae	SNAKE MACKERELS		
Epinnula orientalis	sackfish	0.2	9.9
Trichiuridae	CUTLASSFISHES		
Trichiurus lepturus	Atlantic cutlassfish	1.8	90.3
Scombridae	MACKERELS		
Scomberomorus cavalla	king mackerel	0.2	18.0
Scomberomorus maculatus	Spanish mackerel	0.4	61.5
Stromateidae	BUTTERFISHES		
Peprilus burti	gulf butterfish	64.5	1,358.7
Scorpaenidae	SCORPIONFISHES		
Neomerinthe hemingwayi	spinycheek scorpionfish	0.3	52.8
Pontinus longispinis	longspine scorpionfish	114.7	2,031.4
Scorpaena agassizi	longfin scorpionfish	4.6	152.8
Scorpaena brasiliensis	barbfish	13.4	319.5
Scorpaena calcarata	smoothhead scorpionfish	47.0	549.0

Table 8-1. Cont'd.

Scientific Name	Common Name	Abundance	
		Number	Weight
Scorpaena dispar	hunchback scorpionfish	2.4	403.3
Scorpaena plumieri	spotted scorpionfish	0.2	0.5
Triglidae	SEAROBINS		
Bellator brachychir	shortfin searobin	0.1	0.8
Bellator egretta	streamer searobin	0.8	11.9
Bellator militaris	horned searobin	47.6	260.0
Persistedion gracile	slender searobin	6.6	60.1
Prionotus alatus	spiny searobin	22.5	491.6
Prionotus longispinosus	blackwing searobin	63.2	2,357.8
Prionotus martis	barred searobin	28.6	208.0
Prionotus ophryas	bandtail searobin	2.8	73.8
Prionotus paralatus	Mexican searobin	79.9	1,679.0
Prionotus roseus	bluespotted searobin	35.2	1,373.4
Prionotus rubio	blackfin searobin	29.9	1,292.7
Prionotus scitulus	leopard searobin	24.1	374.1
Prionotus stearnsi	shortwing searobin	27.9	216.5
Prionotus tribulus	bighead searobin	1.6	77.8
Dactylopteridae	FLYING GURNARDS		
Dactylopterus volitans	flying gurnard	0.6	---
Bothidae	LEFTEYE FLOUNDERS		
Ancylopsetta dilecta	three-eye flounder	4.7	176.0
Ancylopsetta quadrocellata	ocellated flounder	1.0	111.9
Citharichthys cornutus	horned whiff	13.0	17.9
Citharichthys macrops	spotted whiff	3.6	91.2
Citharichthys spilopterus	baywhiff	2.6	18.3
Cyclopsetta chittendeni	Mexican flounder	3.6	229.2
Cyclopsetta fimbriata	spotfin flounder	3.1	290.9
Engyophrys senta	spiny flounder	8.1	15.8
Etropus crossotus	fringed flounder	26.9	192.7
Etropus microstomus	smallmouth flounder	9.6	32.1
Etropus rimosus	gray flounder	64.2	297.2
Etropus sp.		0.2	0.5
Gastropsetta frontalis	shrimp flounder	0.2	8.4
Monolene sp.		27.9	198.7
Paralichthys albigutta	gulf flounder	0.5	220.9
Paralichthys squamilentus	broad flounder	4.3	1,514.7
Syacium gunteri	shoal flounder	137.5	827.1
Syacium micrurum	channel flounder	1.2	2.8
Syacium papillosum	dusky flounder	160.6	5,739.5
Syacium sp.		0.8	0.8
Trichopsetta ventralis	sash flounder	95.7	1,272.1
Trichopsetta sp.		1.2	7.1
Pleuronectidae	RIGHTEYE FLOUNDERS		
Poecilopsetta beani		7.4	44.3

Table 8-1. Cont'd.

Scientific Name	Common Name	Abundance	
		Number	Weight
SOLEIDAE	SOLES		
Gymnachirus melas	naked sole	2.2	94.8
Gymnachirus texae	fringed sole	15.2	158.9
Cynoglossidae	TONGUEFISHES		
Symphurus civitatus	offshore tonguefish	55.3	502.1
Symphurus diomedianus	spottedfin tonguefish	21.6	268.9
Symphurus parvus	pygmy tonguefish	6.0	19.4
Symphurus pelicanus	longtail tonguefish	4.7	7.9
Symphurus piger	deepwater tonguefish	2.3	30.5
Symphurus plagiusa	blackcheek tonguefish	49.3	617.3
Triacanthodidae	SPIKEFISHES		
Parahollardia lineata	jambeau	0.6	10.3
Balistidae	LEATHERJACKETS		
Aluterus schoepfi	orange filefish	0.2	151.7
Monacanthus hispidus	planehead filefish	1.8	22.3
Ostraciidae	BOXFISHES		
Lactophrys quadricornis	scrawled cowfish	0.2	35.6
Tetraodontidae	PUFFERS		
Lagocephalus laevigatus	smooth puffer	0.2	12.1
Sphoeroides dorsalis	marbled puffer	1.3	52.0
Sphoeroides parvus	least puffer	28.3	116.5
Sphoeroides spengleri	bandtail puffer	3.0	20.0
Unclassified			
unidentified species		2.5	109.9
TOTALS		3,879.3	74,652.1
MEANS (mean abundances/hectare)		323.3	6,221.0

Table 8-2. List of the fish species taken by trawl in the present study arranged in numerical order of abundance and giving both number of individuals and percent of the total catch. The data have been standardized as in Table 8-1. For brevity, only the hundred most abundant species are listed.

Rank	Taxon	Abundance	
		Number	Percent
1.	Halieutichthys aculeatus	398.1	10.3
2.	Stenotomus caprinus	358.1	9.2
3.	Syacium papillosum	160.6	4.1
4.	Syacium gunteri	137.5	3.5
5.	Anchoa hepsetus	132.8	3.4
6.	Serranus atrobranchus	127.6	3.3
7.	Anchoa cubana	115.7	3.0
8.	Pontinus longispinis	114.7	3.0
9.	Diplectrum bivittatum	109.8	2.8
10.	Trichopsetta ventralis	95.7	2.5
11.	Prionotus paralatus	79.9	2.1
12.	Peprilus burti	64.5	1.7
13.	Etropus rimosus	64.2	1.7
14.	Coelorinchus caribbaeus	63.4	1.6
15.	Prionotus longispinosus	63.2	1.6
16.	Serraniculus pumilio	61.9	1.6
17.	Porichthys plectrodon	57.0	1.5
18.	Symphurus civitatus	55.3	1.4
19.	Serranus notospilus	54.7	1.4
20.	Anchoa mitchilli	50.4	1.3
21.	Symphurus plagiusa	49.3	1.3
22.	Chloroscombrus chrysurus	49.0	1.3
23.	Bellator militaris	47.6	1.2
24.	Scorpaena calcarata	47.0	1.2
25.	Synodus foetens	46.6	1.2
26.	Centropristis philadelphica	45.4	1.2
27.	Bregmaceros atlanticus	38.5	1.0
28.	Lepophidium graellsi	38.4	1.0
29.	Saurida brasiliensis	37.4	1.0
30.	Prionotus roseus	35.2	0.9
31.	Bembrops anatirostris	30.6	0.8
32.	Prionotus rubio	29.9	0.8
33.	Bathygadus macrops	28.9	0.7
34.	Ogcocephalus parvus	28.8	0.7
35.	Prionotus martis	28.6	0.7
36.	Sphoeroides parvus	28.3	0.7
37.	Prionotus stearnsi	27.9	0.7
38.	Monolene sp.	27.9	0.7

Table 8-2. Cont'd.

Rank	Taxon	Abundance	
		Number	Percent
39.	Macrorhamphosus scolopax	27.6	0.7
40.	Bollmannia communis	27.0	0.7
41.	Etropus crossotus	26.9	0.7
42.	Centropristis ocyurus	26.1	0.7
43.	Synodus poeyi	25.3	0.7
44.	Prionotus scitulus	24.1	0.6
45.	Prionotus alatus	22.5	0.6
46.	Urophycis floridana	22.5	0.6
47.	Symphurus diomedianus	21.6	0.6
48.	Ogcocephalus declivirostris	19.3	0.5
49.	Pristipomoides aquilonaris	18.7	0.5
50.	Micropogonias undulatus	17.5	0.5
51.	Urophycis cirrata	17.1	0.4
52.	Bathygadus melanobranchus	16.6	0.4
53.	Zalieutes mcgintyi	16.2	0.4
54.	Gymnachirus texae	15.2	0.4
55.	Lepophidium jeannae	14.7	0.4
56.	Polyipnus asteroides	14.5	0.4
57.	Neobythites gillii	14.1	0.4
58.	Arius felis	14.1	0.4
59.	Scorpaena brasiliensis	13.4	0.4
60.	Leiostomus xanthurus	13.4	0.4
61.	Cynoscion arenarius	13.2	0.4
62.	Citharichthys cornutus	13.0	0.4
63.	Hildebrandia flava	11.9	0.3
64.	Synagrops spinosa	10.4	0.3
65.	Ogcocephalus nasutus	10.3	0.3
66.	Steindachneria argentea	9.7	0.3
67.	Etropus microstomus	9.6	0.2
68.	Orthopristis chrysoptera	9.3	0.2
69.	Trachurus lathami	8.2	0.2
70.	Engyophris senta	8.1	0.2
71.	Haemulon aurolineatum	8.1	0.2
72.	Antennarius radiosus	8.0	0.2
73.	Synagrops bellus	7.9	0.2
74.	Polydactylus octonemus	7.9	0.2
75.	Physiculus fulvus	7.9	0.2
76.	Serranus phoebe	7.8	0.2
77.	Otophidium omostigmum	7.5	0.2
78.	Poecilopsetta beani	7.4	0.2
79.	Hoplunnis macrurus	7.3	0.2
80.	Lagodon rhomboides	7.1	0.2

Table 8-2. Cont'd.

Rank	Taxon	Abundance	
		Number	Percent
81.	Ogcocephalus corniger	7.1	0.2
82.	Gymnothorax nigromarginatus	6.8	0.2
83.	Peristedion gracile	6.6	0.2
84.	Trachinocephalus myops	6.5	0.2
85.	Raja eglanteria	6.4	0.2
86.	Neobythites sp.	6.2	0.2
87.	Hoplunnis tenuis	6.2	0.2
88.	Macrorhamphosus gracilis	6.1	0.2
89.	Symphurus parvus	6.0	0.2
90.	Diplectrum formosum	5.9	0.2
91.	Brotula barbata	5.4	0.1
92.	Harengula jaguana	4.9	0.1
93.	Symphurus pelicanus	4.7	0.1
94.	Ancylopsetta dilecta	4.7	0.1
95.	Pikea mexicana	4.7	0.1
96.	Gymnothorax saxicola	4.7	0.1
97.	Scorpaena agassizi	4.6	0.1
98.	Paralichthys squalmilentus	4.3	0.1
99.	Equetus umbrosus	4.2	0.1
100.	Synodus intermedius	3.9	0.1

Table 8-3. Numerical density distribution, by station and transect, of the twenty most abundant fish species in winter and summer collections. For each species the seasonal distribution of the catch, expressed as a percentage, is given above each table. Abundance values are expressed as percentage of the number collected during the season.

WINTER **SUMMER**

58.4% *Halieutichthys aculeatus* 41.6%

Sta.	C	M	D	Σ
1	5.9	0.1	---	6.0
2	7.8	11.1	2.1	21.0
3	49.7	19.0	4.2	72.9
4	---	0.2	---	0.2
Σ	63.4	30.4	6.3	

Sta.	C	M	D	Σ
1	32.6	0.9	---	33.5
2	0.3	6.1	13.4	19.8
3	38.1	4.0	4.3	46.4
4	---	0.1	---	0.1
Σ	71.0	11.1	17.7	

20.3% *Stenotomus caprinus* 79.7%

1	13.0	4.3	24.9	42.2
2	5.3	33.8	1.0	40.1
3	3.8	13.4	---	17.2
4	---	---	---	---
Σ	22.1	51.5	25.9	

1	71.4	10.9	0.3	82.6
2	10.2	0.4	2.1	12.7
3	1.1	3.4	0.1	4.6
4	---	0.3	---	0.3
Σ	82.7	15.0	2.5	

37.4% *Syacium papillosum* 62.6%

1	---	3.1	17.4	20.5
2	2.6	44.6	22.8	70.0
3	---	---	9.7	9.7
4	---	---	---	---
Σ	2.6	47.7	49.9	

1	---	5.0	5.1	10.1
2	0.4	10.6	77.0	88.0
3	---	---	1.8	1.8
4	---	---	---	---
Σ	0.4	15.6	83.9	

10.9% *Syacium gunteri* 89.1

1	38.8	2.8	22.3	63.9
2	36.0	---	---	36.0
3	---	---	---	---
4	---	---	---	---
Σ	74.8	2.8	22.3	

1	92.8	3.0	---	95.8
2	4.1	---	---	4.1
3	0.1	---	---	0.1
4	---	---	---	---
Σ	97.0	3.0	---	

Table 8-3. Cont'd.

WINTER **SUMMER**

22.4% *Anchoa hepsetus* 77.6%

Sta.	C	M	D	Σ
1	85.2	11.1	3.8	100.0
2	---	---	---	---
3	---	---	---	---
4	---	---	---	---
Σ	85.2	11.1	3.8	

Sta.	C	M	D	Σ
1	83.2	10.0	1.2	94.4
2	5.2	---	---	5.2
3	0.5	---	---	0.5
4	---	---	---	---
Σ	88.9	10.0	1.2	

50.0% *Serranus atrobranchus* 50.0%

1	2.4	8.3	---	10.7
2	11.3	0.4	---	11.7
3	72.3	5.0	---	77.3
4	---	0.3	---	0.3
Σ	86.0	14.0	---	

1	---	---	---	---
2	48.2	0.9	---	49.1
3	39.8	9.9	0.4	50.1
4	---	0.8	---	0.8
Σ	88.0	11.6	0.4	

100.0% *Anchoa cubana* 0.0%

1	---	---	100.0	100.0
2	---	---	---	---
3	---	---	---	---
4	---	---	---	---
Σ	---	---	100.0	

1	---	---	---	---
2	---	---	---	---
3	---	---	---	---
4	---	---	---	---
Σ	---	---	---	

48.1% *Pontinus longispinis* 51.9%

1	---	---	---	---
2	---	---	---	---
3	8.0	6.4	0.4	14.8
4	58.9	17.8	8.4	85.1
Σ	66.9	24.2	8.8	

1	---	---	---	---
2	---	---	---	---
3	40.8	5.5	5.0	51.3
4	35.1	9.9	3.8	48.8
Σ	75.9	15.4	8.8	

38.5% *Diplectrum bivittatum* 61.5%

1	45.7	4.9	46.9	97.5
2	0.3	1.5	0.6	2.4
3	---	---	---	---
4	---	---	---	---
Σ	46.0	6.4	47.5	

1	56.6	40.9	1.5	99.0
2	1.0	---	---	1.0
3	---	---	---	---
4	---	---	---	---
Σ	57.6	40.9	1.5	

Table 8-3. Cont'd.

WINTER **SUMMER**

58.6% *Trichopsetta ventralis* 41.4%

Sta.	C	M	D	Σ
1	---	---	---	---
2	0.2	---	---	0.2
3	82.5	7.8	---	90.3
4	5.1	4.4	---	9.5
Σ	87.8	12.2	---	

Sta.	C	M	D	Σ
1	---	---	---	---
2	6.9	---	---	6.9
3	75.6	14.5	---	90.1
4	---	3.1	---	3.1
Σ	82.5	17.6	---	

84.2% *Prionotus paralatus* 15.8%

1	---	---	---	---
2	1.0	1.0	---	2.0
3	0.9	97.1	---	98.0
4	---	---	---	---
Σ	1.9	98.1	---	

1	---	---	---	---
2	---	1.7	---	1.7
3	59.8	38.4	---	98.2
4	---	---	---	---
Σ	59.8	40.1	---	

79.8% *Peprilus burti* 20.2%

1	87.8	11.1	---	---
2	1.1	---	---	---
3	---	---	---	---
4	---	---	---	---
Σ	88.9	11.1	---	

1	21.7	---	---	21.7
2	4.0	---	---	4.0
3	1.1	73.0	---	74.1
4	---	---	---	---
Σ	26.8	73.0	---	

12.1% *Etropus rimosus* 87.9%

1	75.3	2.6	3.6	81.5
2	---	18.5	---	18.5
3	---	---	---	---
4	---	---	---	---
Σ	75.3	21.1	3.6	

1	7.6	27.6	2.4	37.6
2	---	62.4	---	62.4
3	---	---	---	---
4	---	---	---	---
Σ	7.6	90.0	2.4	

79.7% *Coelorinchus caribbaeus* 20.3%

1	---	---	---	---
2	---	---	---	---
3	---	4.4	---	4.4
4	71.5	4.7	19.4	95.6
Σ	71.5	9.1	19.4	

1	---	---	---	---
2	---	---	---	---
3	---	---	---	---
4	5.4	94.6	---	100.0
Σ	5.4	94.6	---	

Table 8-3. Cont'd.

WINTER **SUMMER**

32.7% *Prionotus longispinosus* 67.3%

Sta.	C	M	D	Σ
1	12.5	6.7	7.2	26.4
2	0.7	42.9	30.0	73.6
3	---	---	---	---
4	---	---	---	---
Σ	13.2	49.6	37.2	

Sta.	C	M	D	Σ
1	0.9	15.6	2.6	19.1
2	---	0.9	80.0	80.9
3	---	---	---	---
4	---	---	---	---
Σ	0.9	16.5	82.6	

4.8% *Serraniculus pumilio* 95.2%

1	14.9	14.2	---	29.1
2	---	---	---	---
3	---	---	70.3	70.3
4	---	---	---	---
Σ	14.9	14.2	70.3	

1	1.6	0.4	---	2.0
2	---	0.4	19.8	20.2
3	---	---	77.8	77.8
4	---	---	---	---
Σ	1.6	0.8	97.6	

40.6% *Porichthys plectrodon* 59.4%

1	---	---	---	---
2	6.8	21.7	---	28.5
3	27.5	32.8	2.8	63.1
4	2.1	6.2	---	8.3
Σ	36.4	60.7	2.8	

1	3.3	---	---	3.3
2	22.8	38.7	---	38.7
3	4.0	23.8	---	23.8
4	---	7.6	---	7.6
S	30.1	70.1	---	

32.2% *Symphurus civitatus* 67.8%

1	21.2	6.8	---	28.0
2	1.6	---	---	1.6
3	14.2	12.4	---	26.6
4	17.0	25.2	1.3	43.5
Σ	54.0	44.4	1.3	

1	54.5	2.0	---	56.5
2	37.4	---	---	37.4
3	4.6	1.0	---	5.6
4	---	0.5	---	0.5
Σ	96.5	3.5	---	

31.5% *Serranus notospilus* 68.5%

1	---	---	---	---
2	---	---	8.7	8.7
3	---	---	91.4	91.4
4	---	---	---	---
Σ	---	---	100.1	

1	---	---	---	---
2	---	---	---	---
3	0.4	---	99.6	100.0
4	---	---	---	---
Σ	0.4	---	99.6	

Table 8.3. Cont'd.

WINTER 100.0% *Anchoa mitchilli* **SUMMER** 0.0%

Sta.	C	M	D	Σ
1	100.0	---	---	100.0
2	---	---	---	---
3	---	---	---	---
4	---	---	---	---
Σ	100.0	---	---	

Sta.	C	M	D	Σ
1	---	---	---	---
2	---	---	---	---
3	---	---	---	---
4	---	---	---	---
Σ	---	---	---	

absent at only three stations (C4, D1 and D4). Greatest abundance occurred at station C3 (100 m), although is it relatively less abundant at station C3 and relatively more abundant at station C1 (20 m) on the summer surveys. Lengths of specimens ranged from 6 to 11 cm, with the highest frequency at 8 cm, on the length frequency plot for the combined winter surveys and from 4 to 10 cm, with highest frequency at 8 cm for the length frequency plot for the combined summer surveys (Figure 8-1). Spawning is apparently protracted and two age classes, young of the year and one year olds, are represented in the samples.

Stenotomus caprinus - Longspine porgy

Stenotomus caprinus is second in abundance and wide spread; however, it is more abundant at the two inshore stations (20, 60 m) than at the two offshore stations (100, 200 m) (Table 8-3). It was equally abundant at the two inshore stations on the winter surveys, but was by far most abundant at station C1 on the summer surveys. Abundance was greater on the summer surveys than on the winter surveys. Lengths of specimens ranged from 3 to 19 cm, with modes at 4 and 12 cm, for the length frequency plot for the combined winter surveys, and from 2 to 17 cm, with the highest frequency at 8 cm, for the length frequency plot for the combined summer surveys (Figure 8-2). Apparently spawning is protracted and two age classes, young of the year and one year olds are represented in the samples.

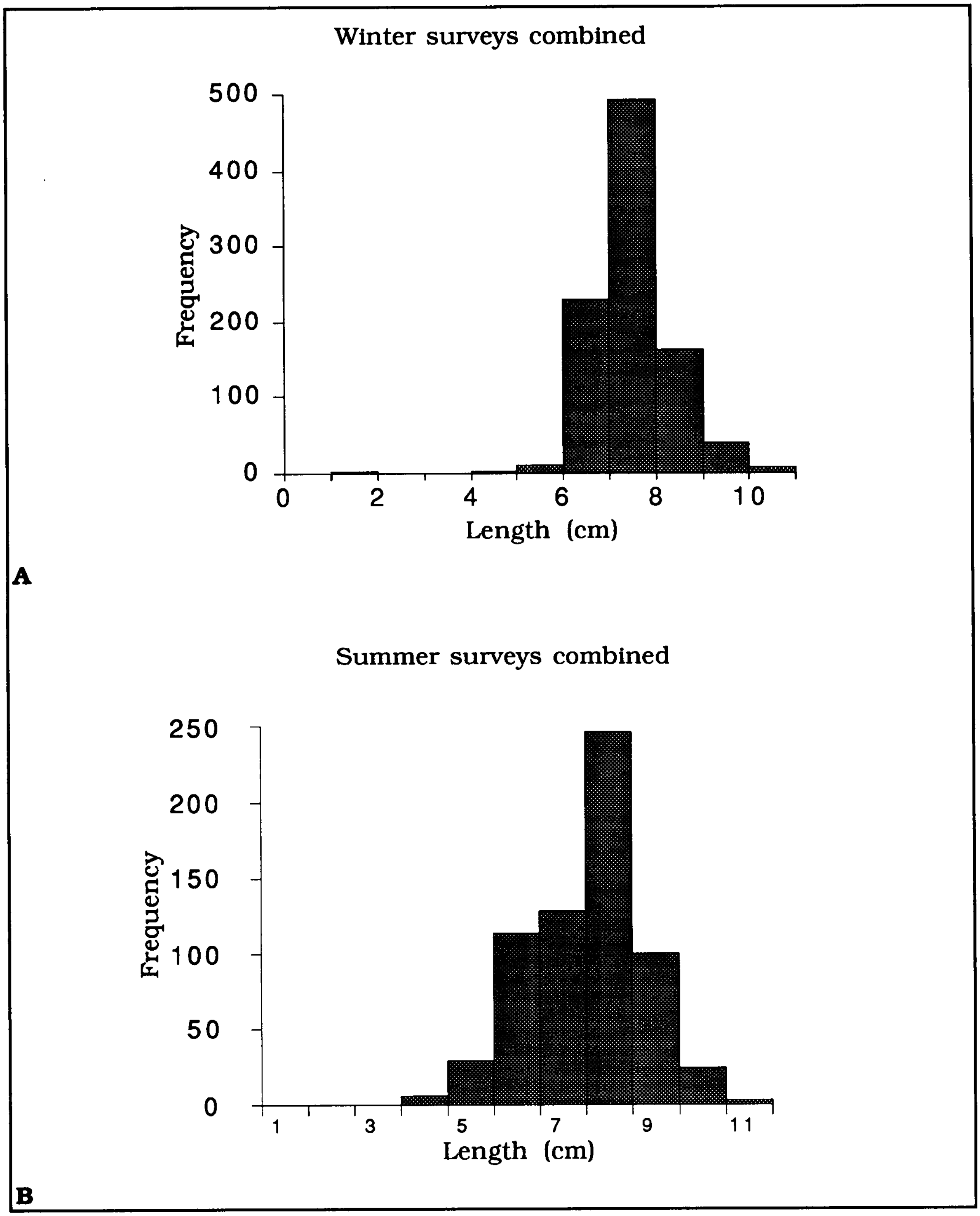


Figure 8-1. Length Frequency distributions for *Halieutichthys aculeatus*.

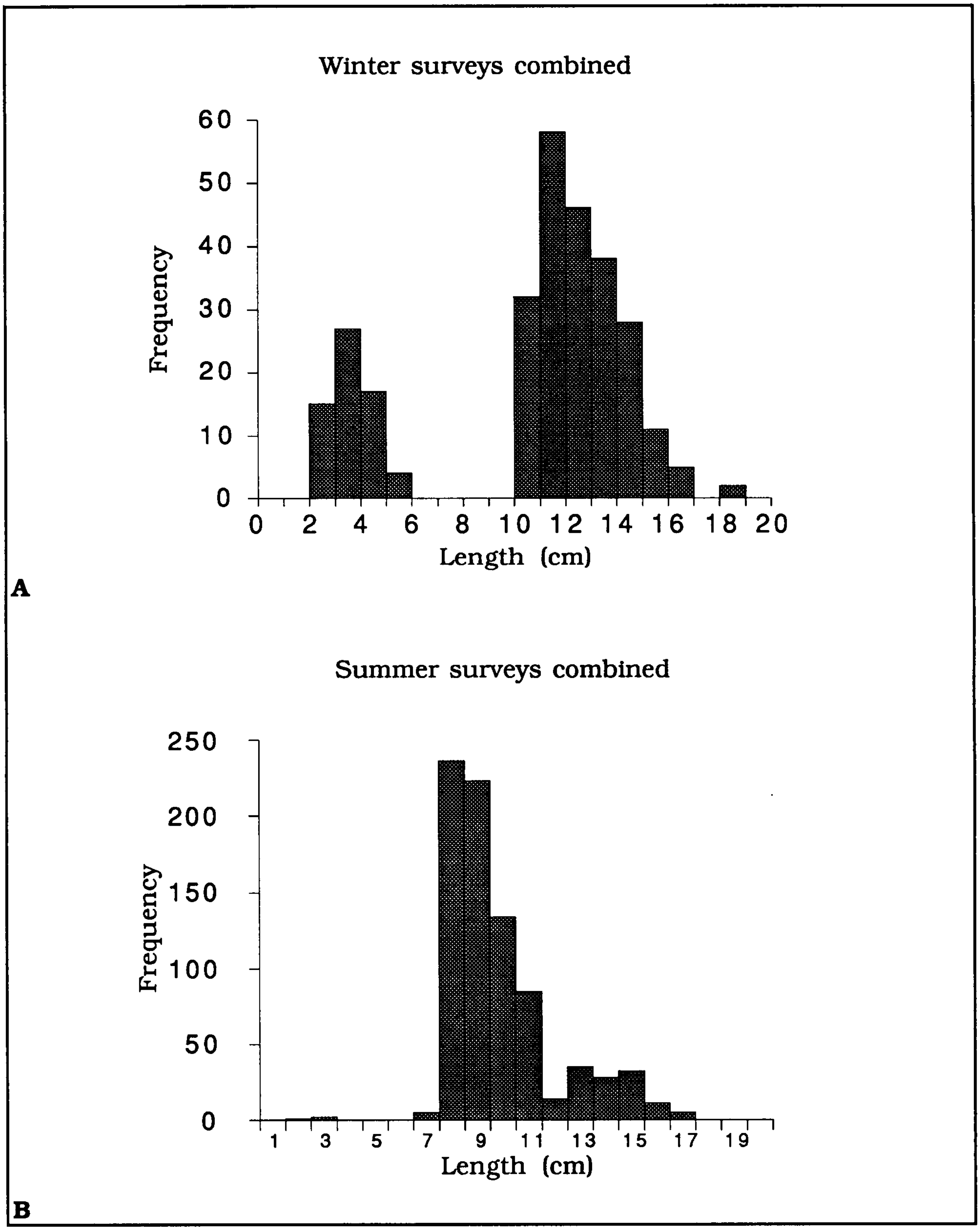


Figure 8-2. Length frequency distributions for *Stenotomus caprinus*.

Syacium papillosum - Dusky flounder

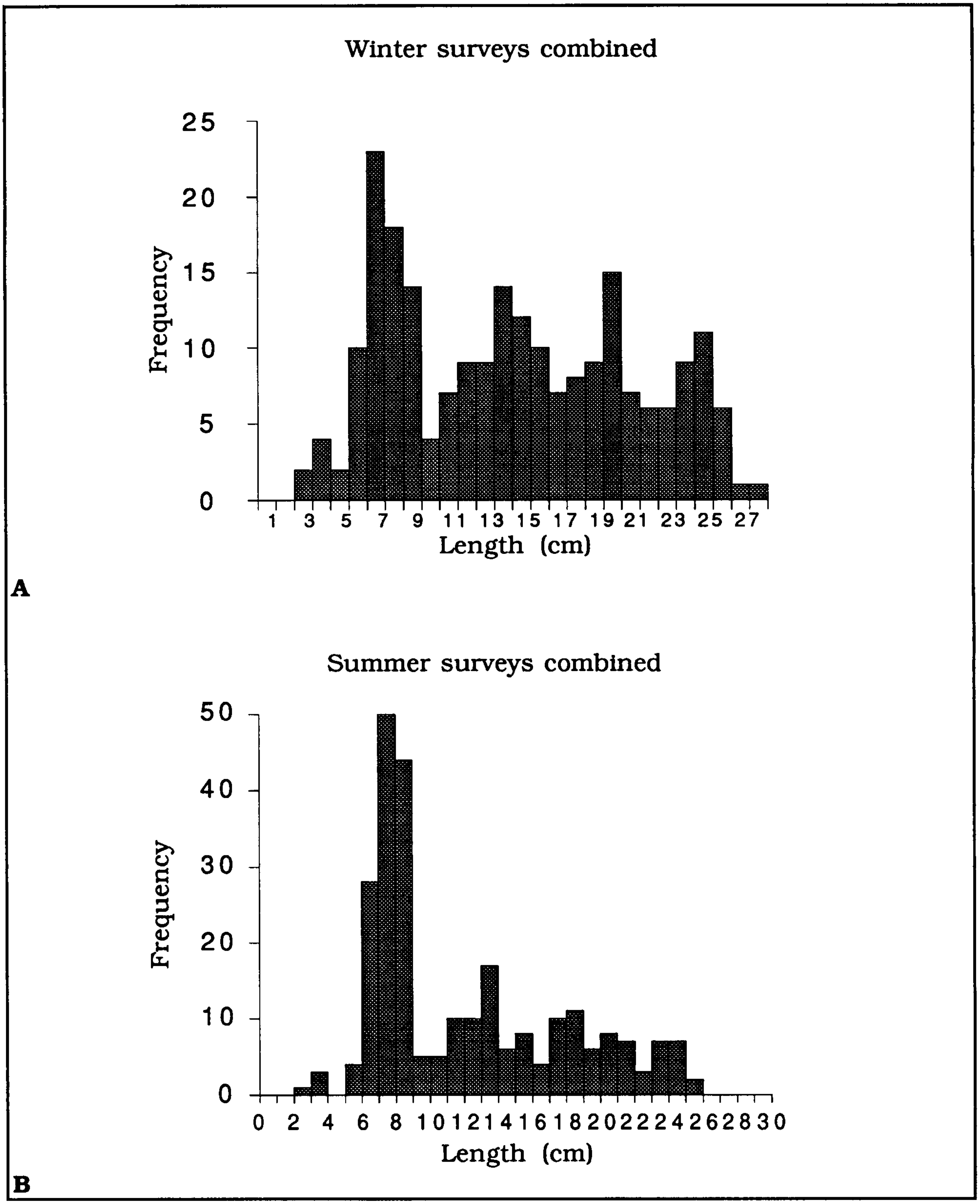
Syacium papillosum is third in abundance and most common at station M2 and D2 (60 m) (Table 8-3). It was least abundant along the Chandeleur Islands transect, about equally abundant along the two other transects on the winter surveys but most abundant along the DeSoto Canyon transect on the summer surveys. Abundance was higher on the summer surveys than on the winter surveys. Lengths ranged from 3 to 26 cm, with modes at 7, 14, 20 and 25 cm, for the length frequency plot of the combined winter surveys, and ranged from 3 to 26 cm, with modes at 8, 12, 18, 21 and 25 cm, for the length frequency plot of the combined summer surveys (Figure 8-3). Spawning is apparently protracted and several age classes may be represented in the samples.

Syacium gunteri - Shoal flounder

Syacium gunteri is fourth in abundance and most common at stations C1 and C2 (20, 60 m) (Table 8-3). It was about equally abundant at these two stations on the winter surveys but was almost exclusively taken at the inshore station during the summer surveys. Overall abundance was considerably greater during the summer than during the winter surveys. Lengths ranged from 5 to 24 cm, with the highest frequency of specimens at 8 cm, for the length frequency plot of the combined winter surveys, and ranged from 6 to 15 cm, with the highest frequency of specimens at 7 and 8 cm, for the length frequency plot of the combined summer surveys (Figure 8-4). Spawning is considered to be protracted and two or more age classes may be represented in the samples.

Anchoa hepsetus - Striped anchovy

Anchoa hepsetus is fifth in abundance, almost entirely limited to the shallowest station (20 m) and most abundant along the Chandeleur Islands transect (Table 8-3). It was over three times as abundant on the summer surveys than on the winter surveys. Lengths ranged from 6 to 14 cm, with modes at 6 and 11 cm, for the length frequency plot of the combined winter surveys, and ranged from 2 to 15 cm, with the highest frequency of specimens at 7 cm, for the length frequency plot of the combined summer


Winter surveys combined

Summer surveys combined

Figure 8-3. Length frequency distributions for *Syacium papillosum*.

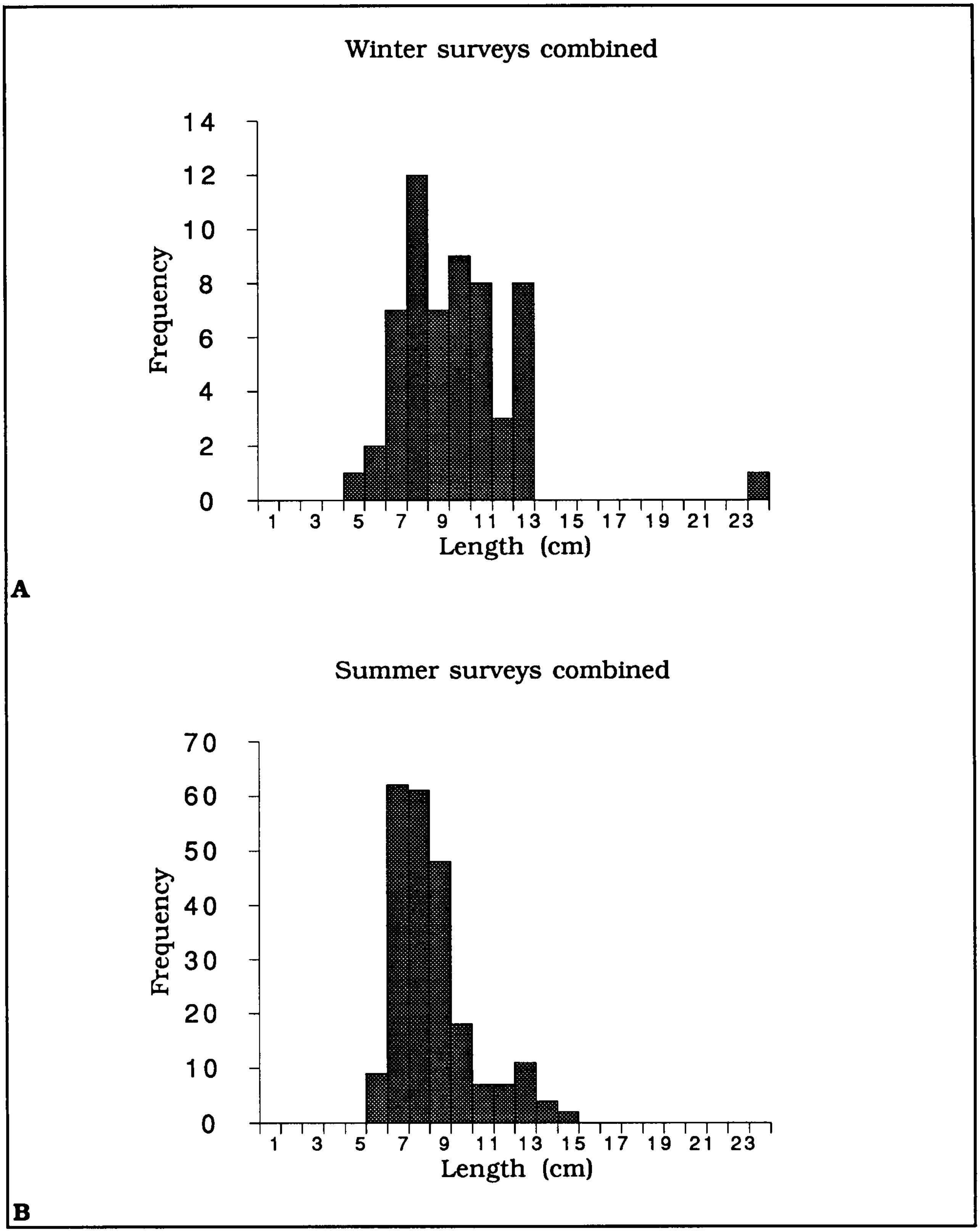


Figure 8-4. Length frequency distributions for *Syacium gunteri*.

surveys (Figure 8-5). Apparently spawning is protracted and two age classes, young of the year and one year old specimens are represented in the samples.

Serranus atrobranchus - Blackear bass

Serranus atrobranchus is sixth in abundance and was most abundant along the Chandeleur Islands transect at stations of intermediate depth (60, 100 m) (Table 8-3). It was least abundant along the DeSoto Canyon transect, and relatively more abundant at the second station than at the third station of the Chandeleur Islands transect on the summer surveys. Abundance was similar for the winter and summer surveys. Lengths ranged from 2 to 15 cm, with the highest frequency of specimens at 13 cm, for the length frequency plot of the combined winter surveys, and ranged from 4 to 14 cm, with modes at 7 and 13 cm, for the length frequency plot of the combined summer surveys (Figure 8-6). Apparently spawning is protracted and two age classes, young of the year and one year olds are present in the samples.

Anchoa cubana - Cuban anchovy

Anchoa cubana is seventh in abundance but it was caught only on the first winter survey (B-0) at station D1 (20 m) (Table 8-3). Specimens ranged from 6 to 8 cm and probably represent a single age class (Figure 8-7).

Pontinus longispinis - Longspine scorpionfish

Pontinus longispinis is eighth in abundance and was exclusively captured at the outer two stations (100, 200 m) of each transect (Table 8-3). It was most abundant along the Chandeleur Islands transect and least abundant along the DeSoto Canyon transect. Abundance was similar during the winter and summer surveys, but specimens were relatively more abundant at the third (100 m) rather than at the fourth station (200 m) of each transect during the summer than during the winter surveys. Lengths ranged from 1 to 28 cm, with modes at 3, 9 and 13 cm, for the length frequency plot of the combined winter surveys, and ranged from 6 to 28 cm, with modes at 8 and 14 cm, for the length frequency plot of the combined

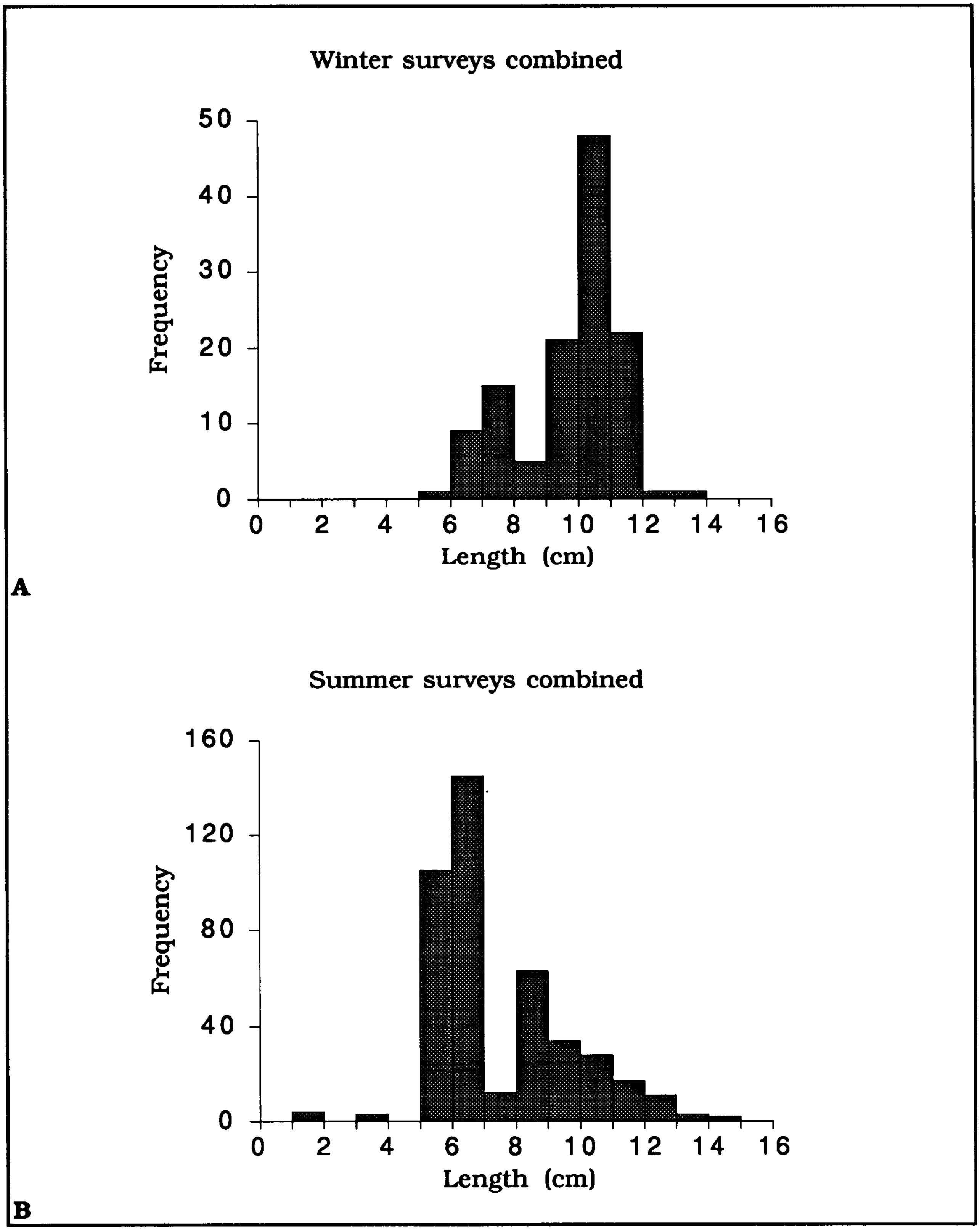


Figure 8-5. Length frequency distributions for *Anchoa hepsetus*.

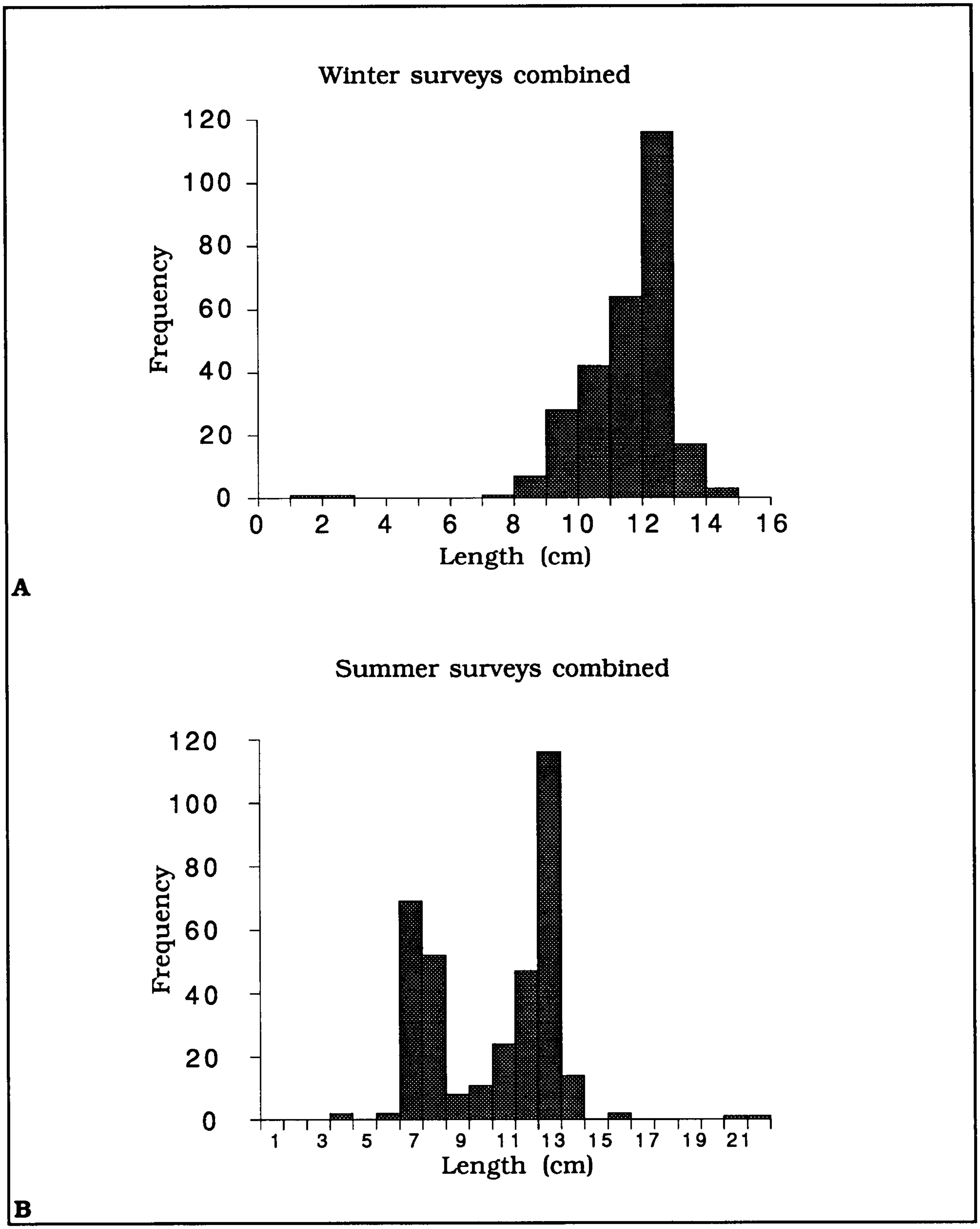


Figure 8-6. Length frequency distribution for *Serranus atrobranchus*.

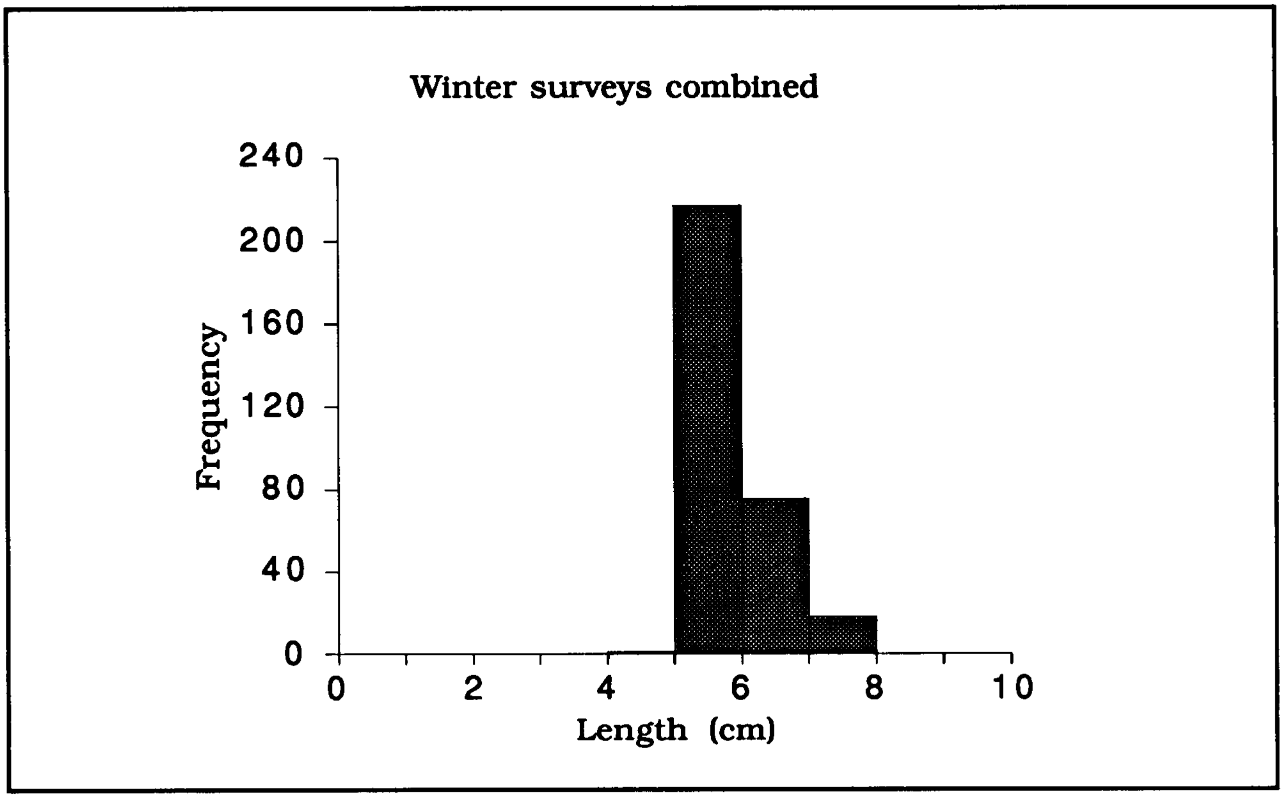


Figure 8-7. Length frequency distributions for *Anchoa cubana*.

summer surveys (Figure 8-8). Apparently spawning is protracted and several age classes are represented in the samples.

Diplectrum bivittatum - Dwarf sandperch

Diplectrum bivittatum is ninth in abundance and was almost exclusively captured on station 1 (20 m) of each transect (Table 8-3). It was most abundant on the Chandeleur Islands and DeSoto Canyon transects during the winter surveys and on the Chandeleur Islands and Mobile Bay transects during the summer surveys. Abundance was higher on the summer than on the winter surveys. Lengths ranged from 1 to 31 cm, with the highest frequency of specimens at 12 cm, for length frequency plot of the combined winter surveys, and ranged from 1 to 29 cm, with the highest frequency of specimens at 12 cm, for the length frequency plot of the combined summer surveys (Figure 8-9). Spawning is apparently protracted and several age classes may be present in the samples.

Trichopsetta ventralis - Sash flounder

Trichopsetta ventralis is tenth in abundance and was most abundant at station C3 (100 m) (Table 8-3). It was not taken along the DeSoto Canyon transect and its abundance did not appear to shift in depth or along the coast between winter and summer surveys. Abundance was slightly greater during the winter than during the summer surveys. Lengths ranged from 6 to 18 cm, with the highest frequency of specimens at 13 cm, for the length frequency plot of the combined winter surveys, and ranged from 6 to 19 cm, with modes at 11 and 14 cm, for the length frequency plot of the combined summer surveys (Figure 8-10). Spawning is apparently protracted and two or more age classes may be present in the samples.

Prionotus paralatus - Mexican searobin

Prionotus paralatus is eleventh in abundance and was most abundant at stations C3 and M3 (100 m) (Table 8-3). It was more abundant on the Mobile transect during the winter surveys and more abundant along the Chandeleur Islands transect during the summer surveys. Abundance was higher during the winter than during the summer surveys, although no specimens were captured on the third cruise (B-2, winter) or on the fifth

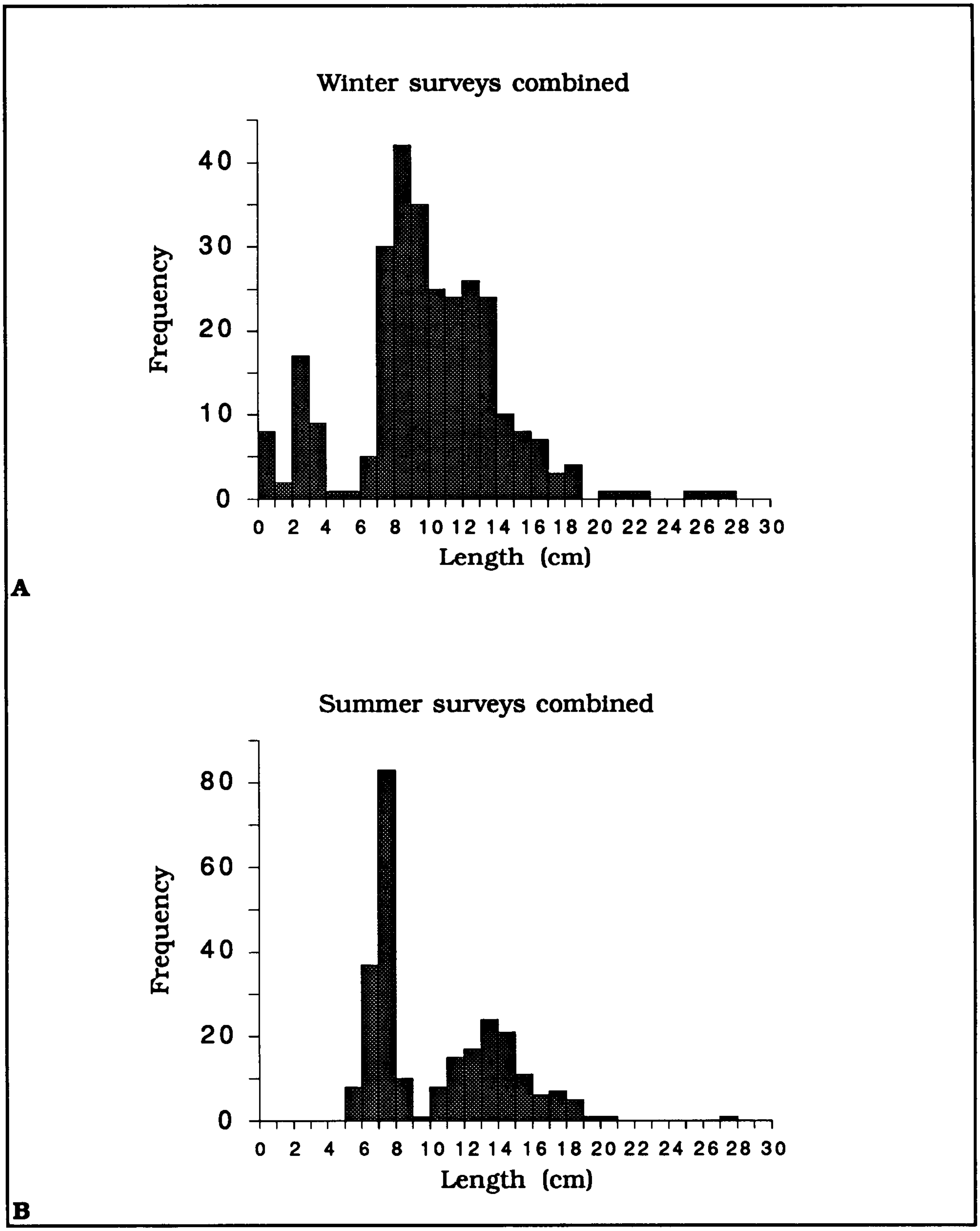


Figure 8-8. Length frequency distributions for *Pontinus longispinis*.

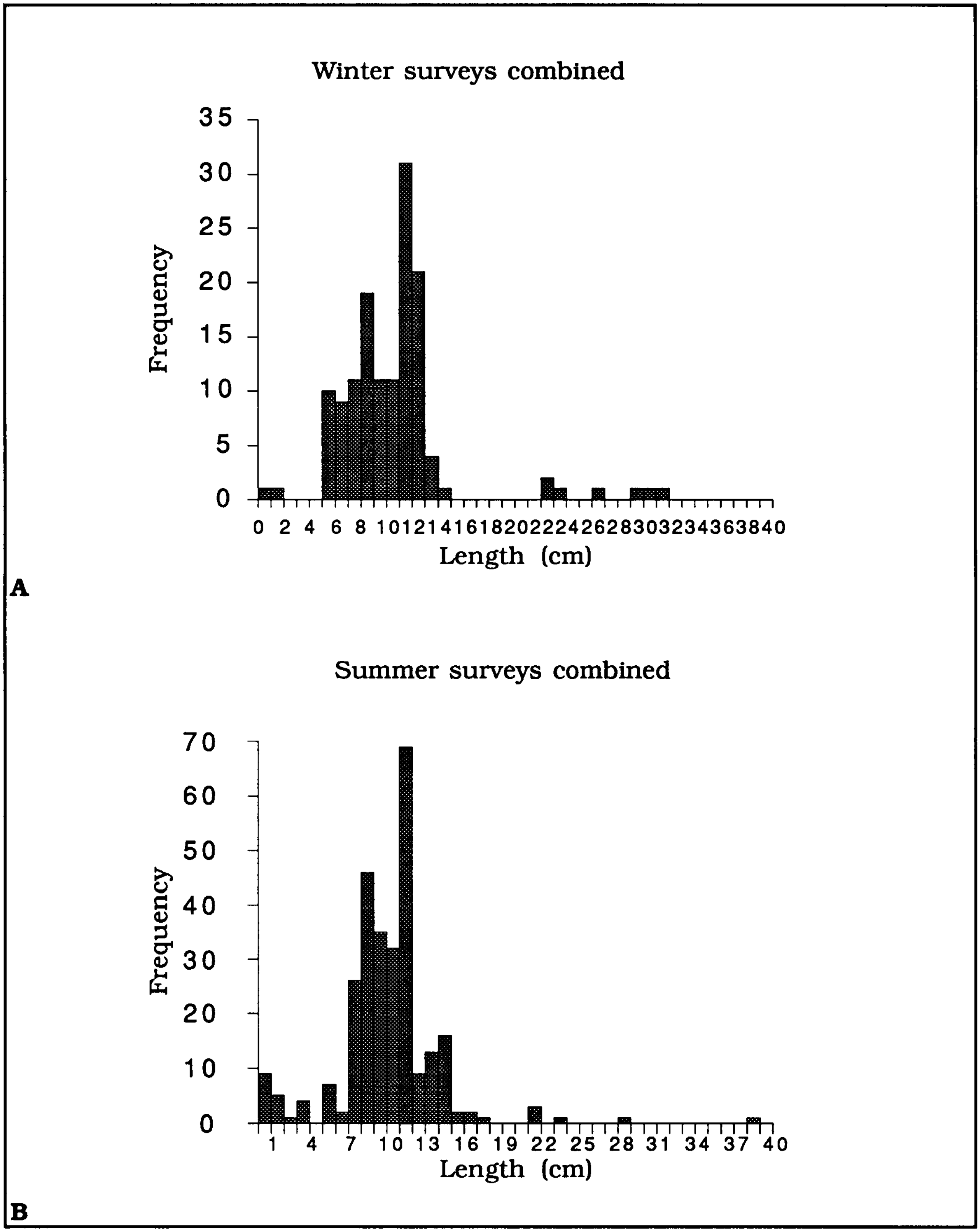


Figure 8-9. Length frequency distributions for *Diplectrum bivittatum*.

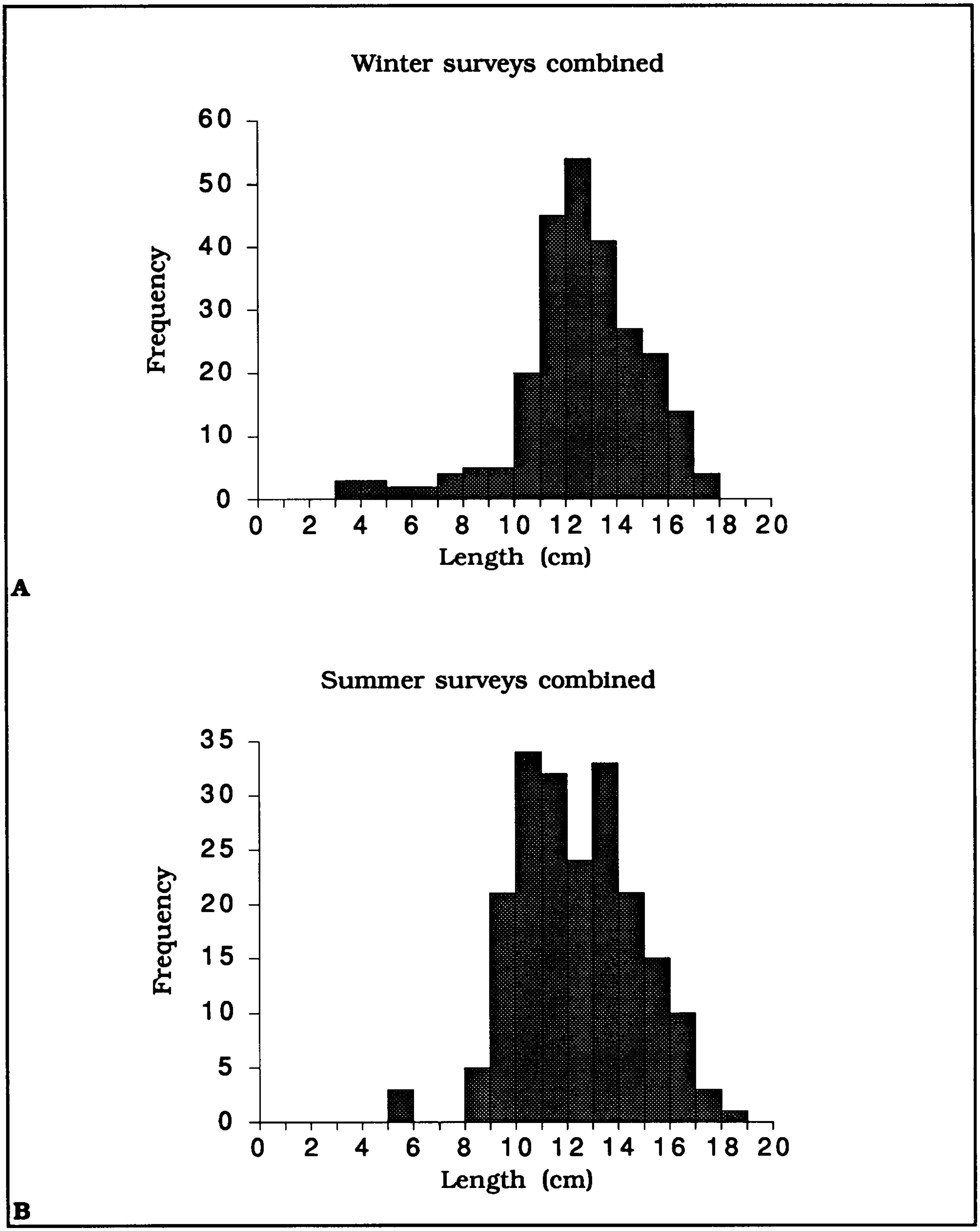


Figure 8-10. Length frequency distributions for *Trichopsetta ventralis*.

cruise (B-4, winter). Lengths ranged from 10 to 28 cm, with the highest frequency of specimens at 10 cm, for the length frequency plot of the winter surveys, and ranged from 7 to 17 cm, with the highest frequency of specimens at 15 cm, for the length frequency plot of the combined summer surveys (Figure 8-11).

Peprilus burti - Gulf Butterfish

Peprilus burti is twelfth in abundance but was captured on only the third (B-2, winter) and fourth (B-3, summer) surveys (Table 8-3). It was taken only on the Chandeleur Islands and Mobile Bay transects, and was most abundant at station C1 (20 m) on the winter survey and at station M3 (100 m) on the summer survey. Abundance was about four times higher on the winter survey than on the summer survey. Lengths ranged from 10 to 14 cm, with the highest frequency of specimens at 11 cm, for the length frequency plot of the winter survey, and ranged from 13 to 22 cm, with the highest frequency of specimens at 15 cm, for the length frequency of the summer survey (Figure 8-12).

Etropis rimosus - Gray flounder

Etropis rimosus is thirteenth in abundance and most abundant at the first station (20 m) of each transect (Table 8-3). It was most abundant along the Chandeleur Islands transect on the winter surveys and most abundant along the Mobile Bay transect on the summer surveys, and was least abundant along the DeSoto Canyon transect for both seasons. Abundance was considerably greater on the summer surveys than on the winter surveys. Lengths ranged from 4 to 11 cm, with modes at 4 and 10 cm, for the length frequency plot of the combined winter surveys, and ranged from 1 to 13 cm, with the highest frequency of specimens at 7 cm, for the length frequency plot for the combined summer surveys (Figure 8-13). Apparently spawning is protracted and two age classes, young of the year and one year olds are represented in the samples.

Coelorinchus caribbaeus - Blackfin grenadier

Coelorinchus caribbaeus is fourteenth in abundance and was most abundant at the outer station (200 m) of each transect (Table 8-3). It was

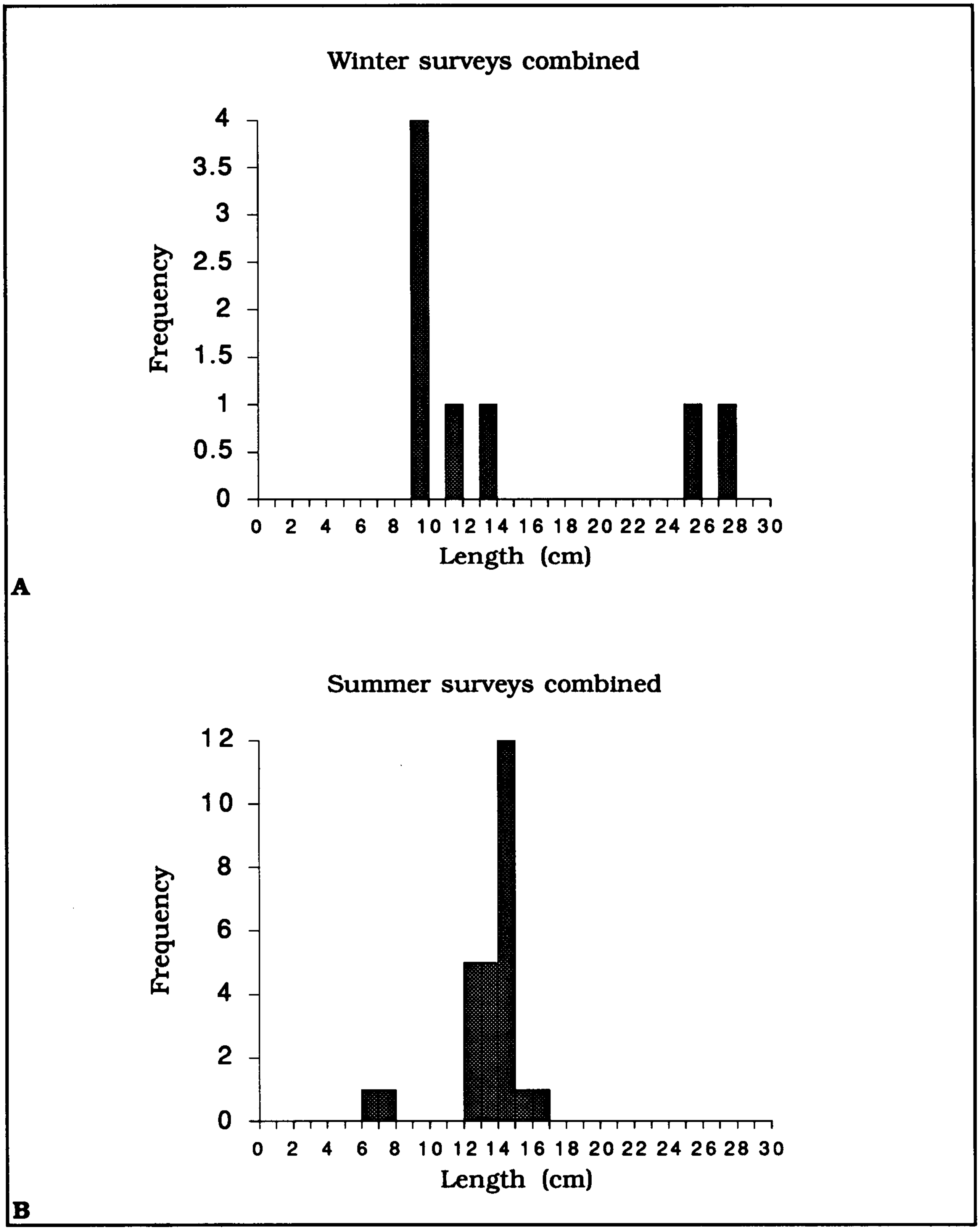


Figure 8-11 Length frequency distributions for *Prionotus paralatus*.

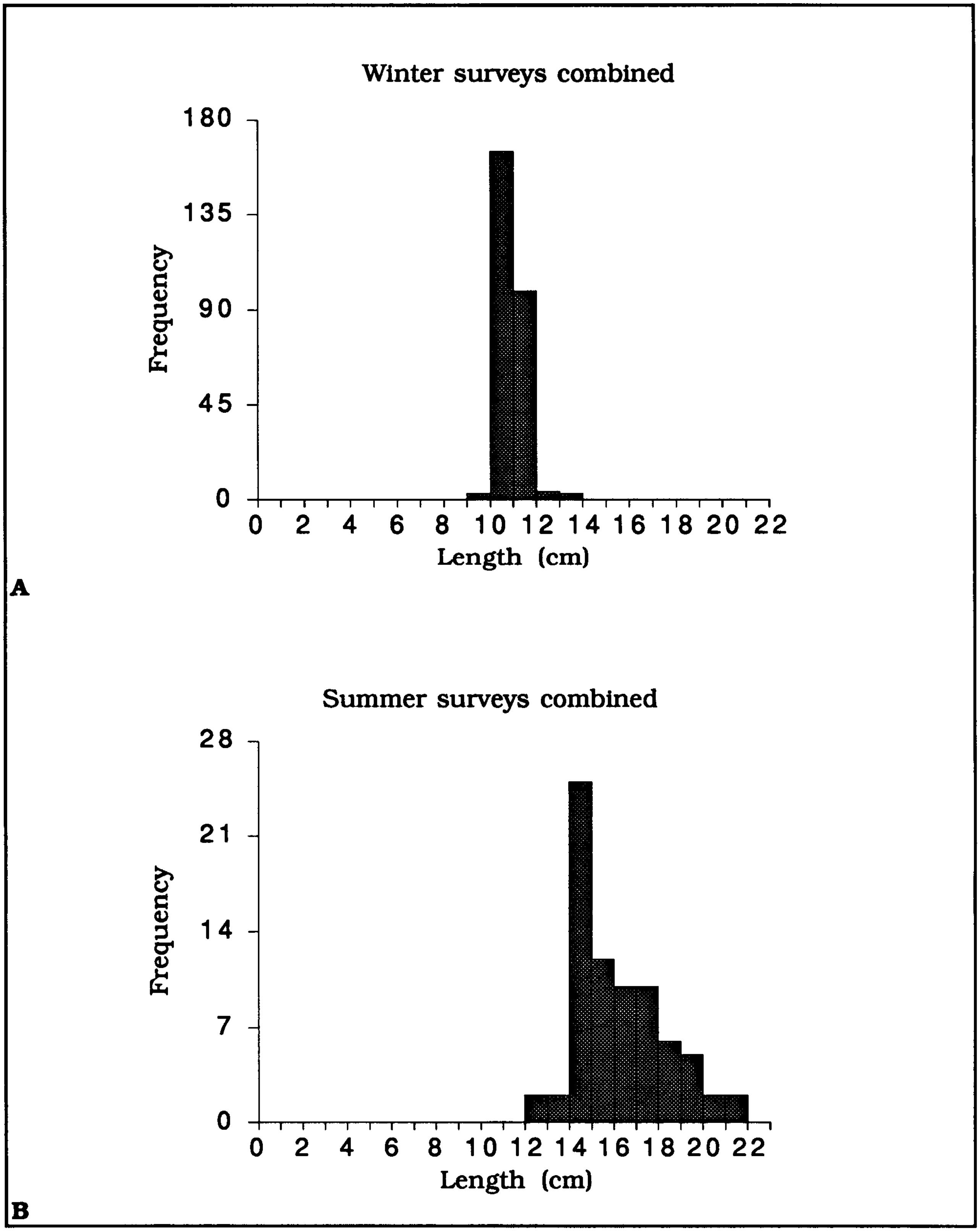


Figure 8-12. Length frequency distributions for *Peprilus burti.*

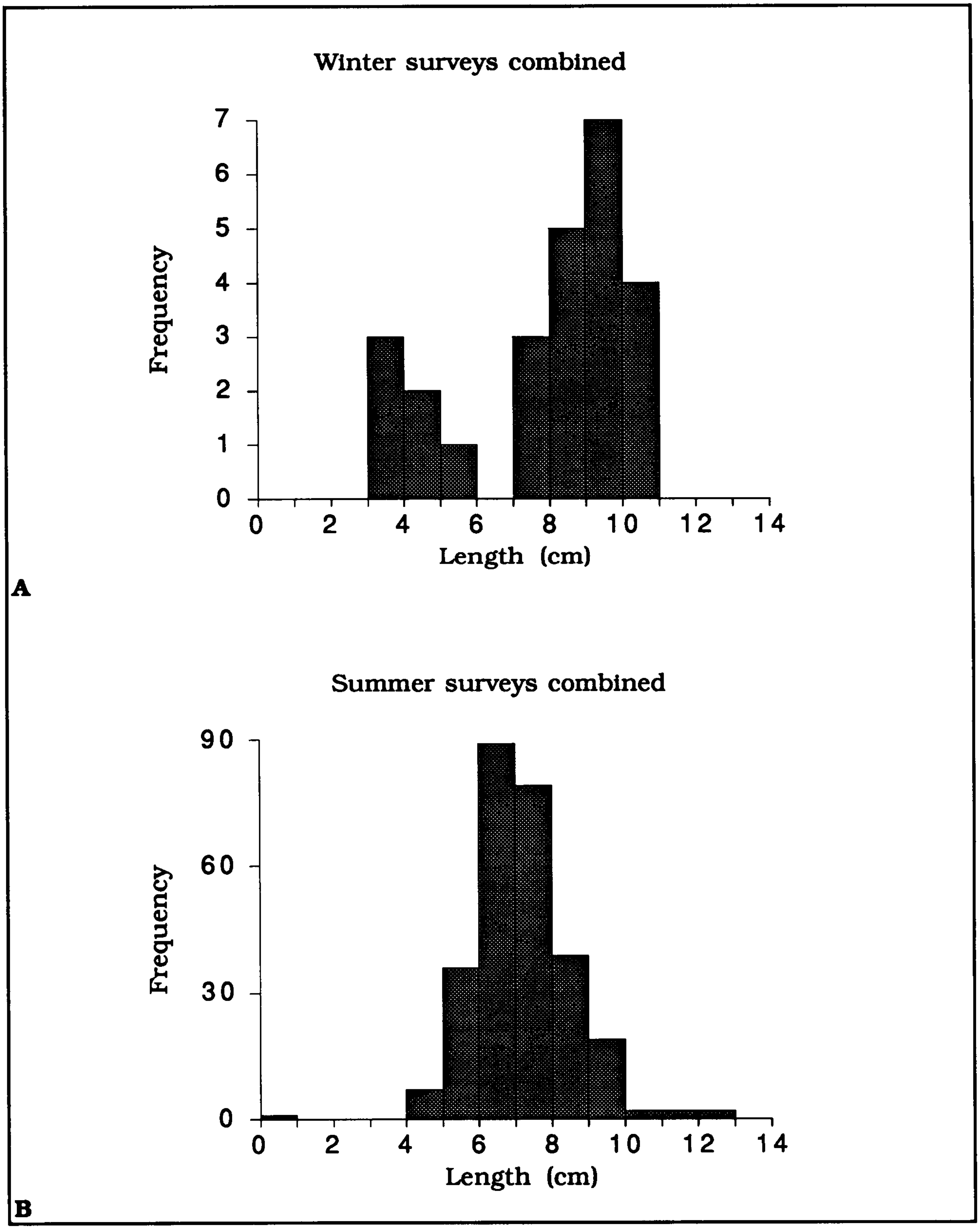


Figure 8-13. Length frequency distributions for *Etropis rimosus*.

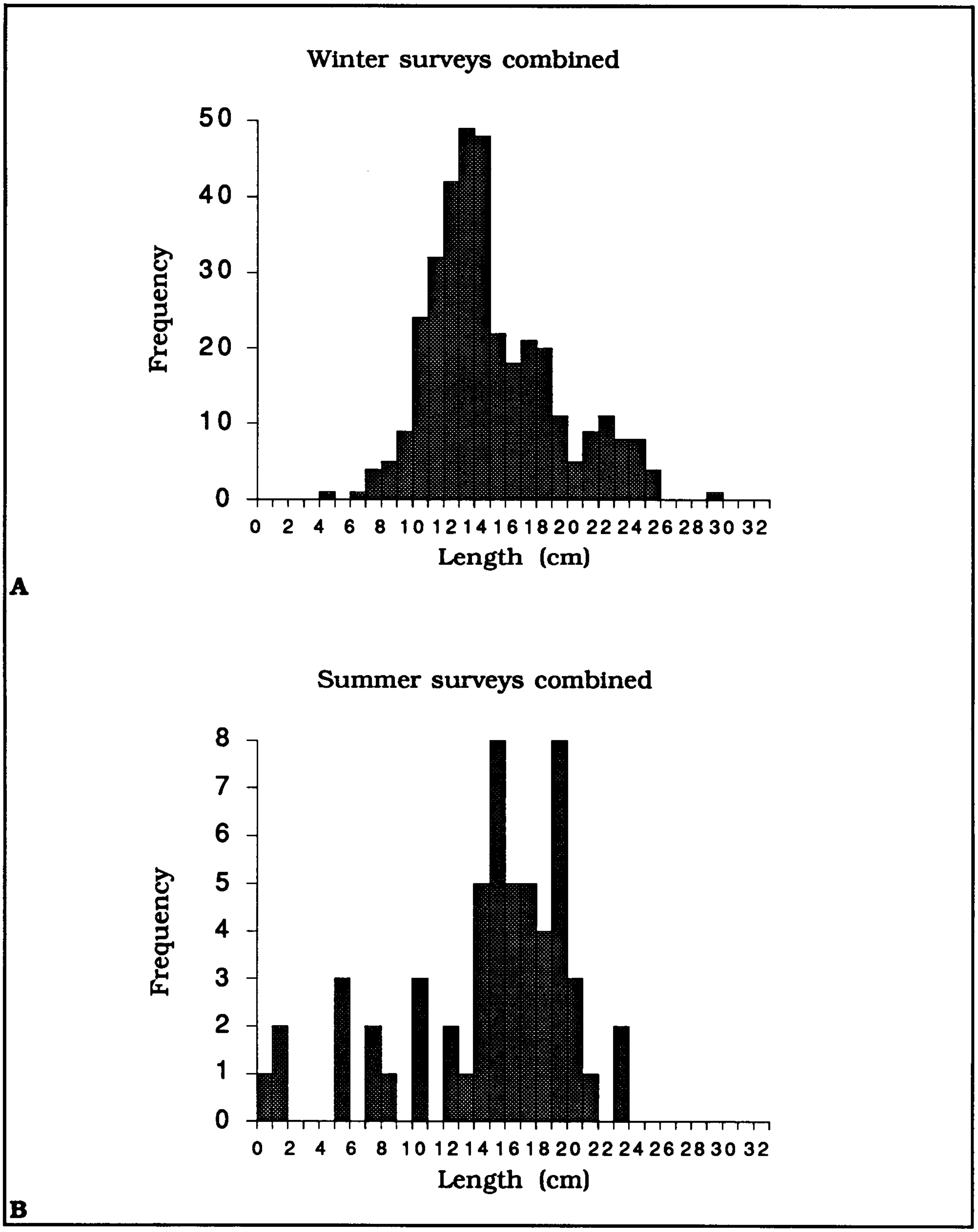
most abundant at station C4 on the winter surveys and at station M4 on the summer surveys. Abundance was higher on the winter surveys than on the summer surveys. Lengths ranged from 5 to 30 cm, with the highest frequency of specimens at 14 cm, for the length frequency plot of the combined winter surveys, and ranged from 6 to 24 cm, with highest frequency of specimens at 16 and 24 cm, for the length frequency plot of the combined summer surveys (Figure 8-14). Spawning is apparently protracted and several age classes may be represented in the samples.

Prionotus longispinus - Blackwing searobin

Prionotus longispinus is fifteenth in abundance and was most abundant at station 2 (60 m) at each transect, except that it was rare or absent at station C2 (Table 8-3). It was most abundant on the Mobile Bay transect on the winter surveys and was most abundant on the DeSoto Canyon transect on the summer surveys. Abundance for the summer surveys was over twice that of the winter surveys. Lengths ranged from 6 to 25 cm, with modes at 10 to 11 and at 20 to 21 cm, for the length frequency plot of the combined winter surveys and ranged from 3 to 22 cm, with modes at 10 to 11 and at 20 cm, for the length frequency plot of the combined summer surveys (Figure 8-15). Spawning apparently is protracted and two age classes may be represented in the samples.

Serraniculus pumilio - Pygmy seabass

Serraniculus pumilio is sixteenth in abundance and most abundant at station D3 (100 m) (Table 8-3). Along the Chandeleur Islands and Mobile Bay transects it occurred only at station 1 (20 m) and at the shallowest two stations (20, 60 m) respectively. Abundance was considerably greater on the summer surveys than on the winter surveys, although it was not taken on the second survey (B-1, summer). Lengths ranged from 5 to 8 cm, with the highest frequency of individuals at 7 cm, for the length frequency plot of the combined winter surveys, and ranged from 1 to 9 cm, with the highest frequency of individuals at 6 cm, for the combined length frequency of the summer surveys (Figure 8-16). Spawning appears to be protracted and two age classes are apparently represented in the samples.


Winter surveys combined

Summer surveys combined

Figure 8-14. Length frequency distributions for *Coelorinchus caribbaeus*.

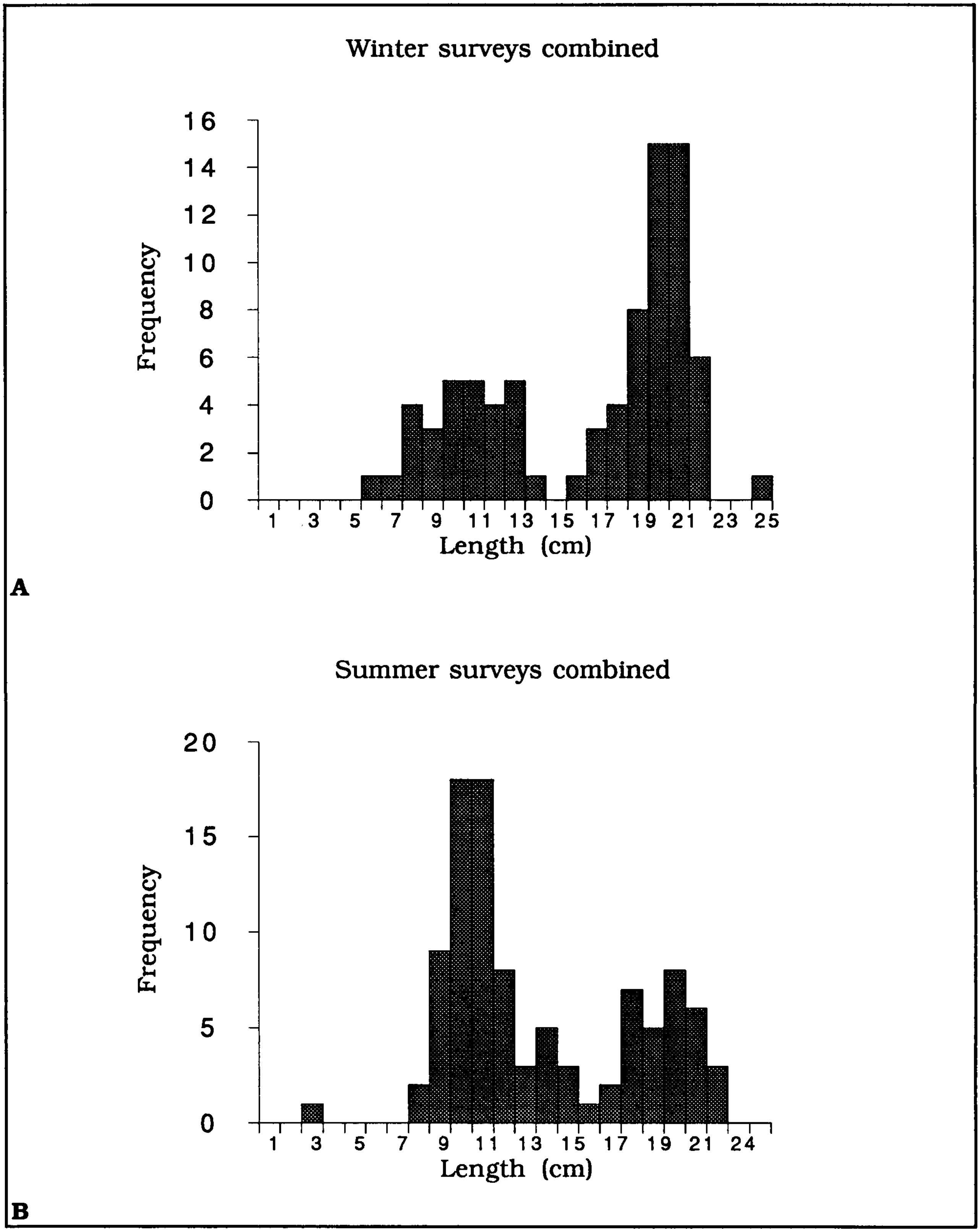


Figure 8-15. Length frequency distributions for *Prionotus longispinus*.

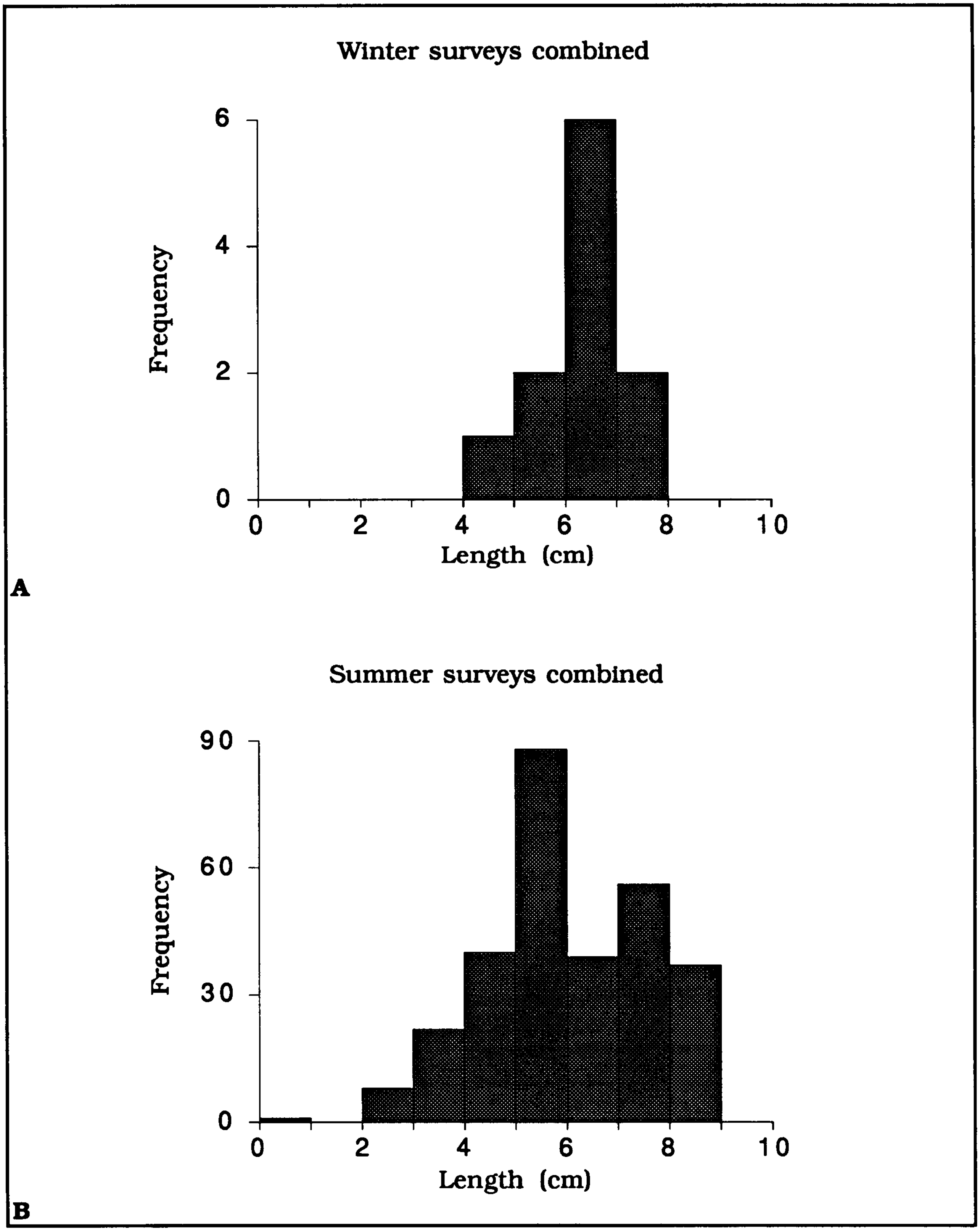


Figure 8-16. Length frequency distributions for *Serraniculus pumillio.*

Porichthys plectrodon - Atlantic midshipman

Porichthys plectrodon is seventeenth in abundance and was most abundant along the Mobile Bay transect (Table 8-3). It was most abundant on the third station (100 m) of each transect on the winter surveys and was most abundant on the second station (60 m) on the summer surveys, except that none were taken on the DeSoto Canyon transect. Abundance was slightly greater for the summer surveys than for the winter surveys. Lengths ranged from 7 to 23 cm, with the highest frequency of specimens at 11 cm, for the length frequency plot of the combined winter surveys, and ranged from 8 to 17 cm, with the highest frequency of specimens at 10 cm, for the length frequency plot of the combined summer surveys (Figure 8-17).

Symphurus civitatus - Offshore tonguefish

Symphurus civitatus is eighteenth in abundance and was most abundant along the Chandeleur Islands transect (Table 8-3). It was most abundant at the deepest station (200 m) of each transect on the winter surveys and at the shallowest station (20 m) of each transect on the summer surveys although none were captured on the DeSoto Canyon transect during the summer surveys. Abundance on the summer surveys was about twice that on the winter surveys. Lengths ranged from 6 to 14 cm, with the highest frequency of specimens at 12 cm, for length frequency plots of the combined winter surveys and ranged from 6 to 14 cm, with the highest frequency of specimens at 12 cm, for length frequency plot of the combined summer surveys (Figure 8-18). Spawning is apparently protracted and two age classes appear to be represented in the samples.

Serranus notospilus - Saddle bass

Serranus notospilus is nineteenth in abundance and was most abundant at station D3 (100 m), although no specimens were captured on the first (B-0, winter) or fifth (B-4, winter) cruises (Table 8-3). Abundance was higher on the summer surveys than on the winter surveys. Lengths ranged from 5 to 8 cm, with the highest frequency of specimens at 8 cm, for the length frequency plot of the winter survey, and ranged from 4 to 10 cm, with the highest frequency of specimens at 8 cm, for the length frequency plot of the combined summer surveys (Figure 8-19).

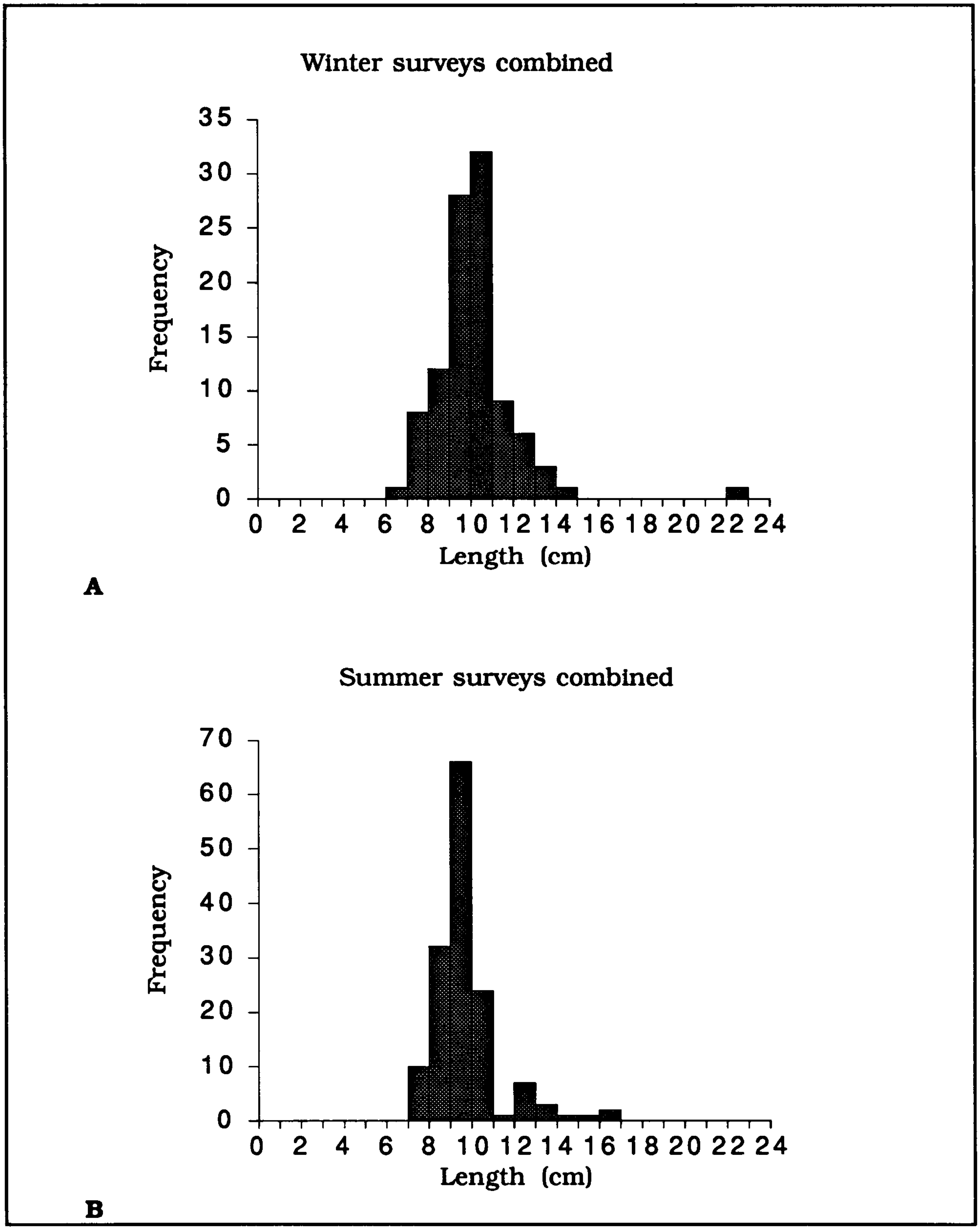


Figure 8-17. Length frequency distributions for *Porichthys plectrodon.*

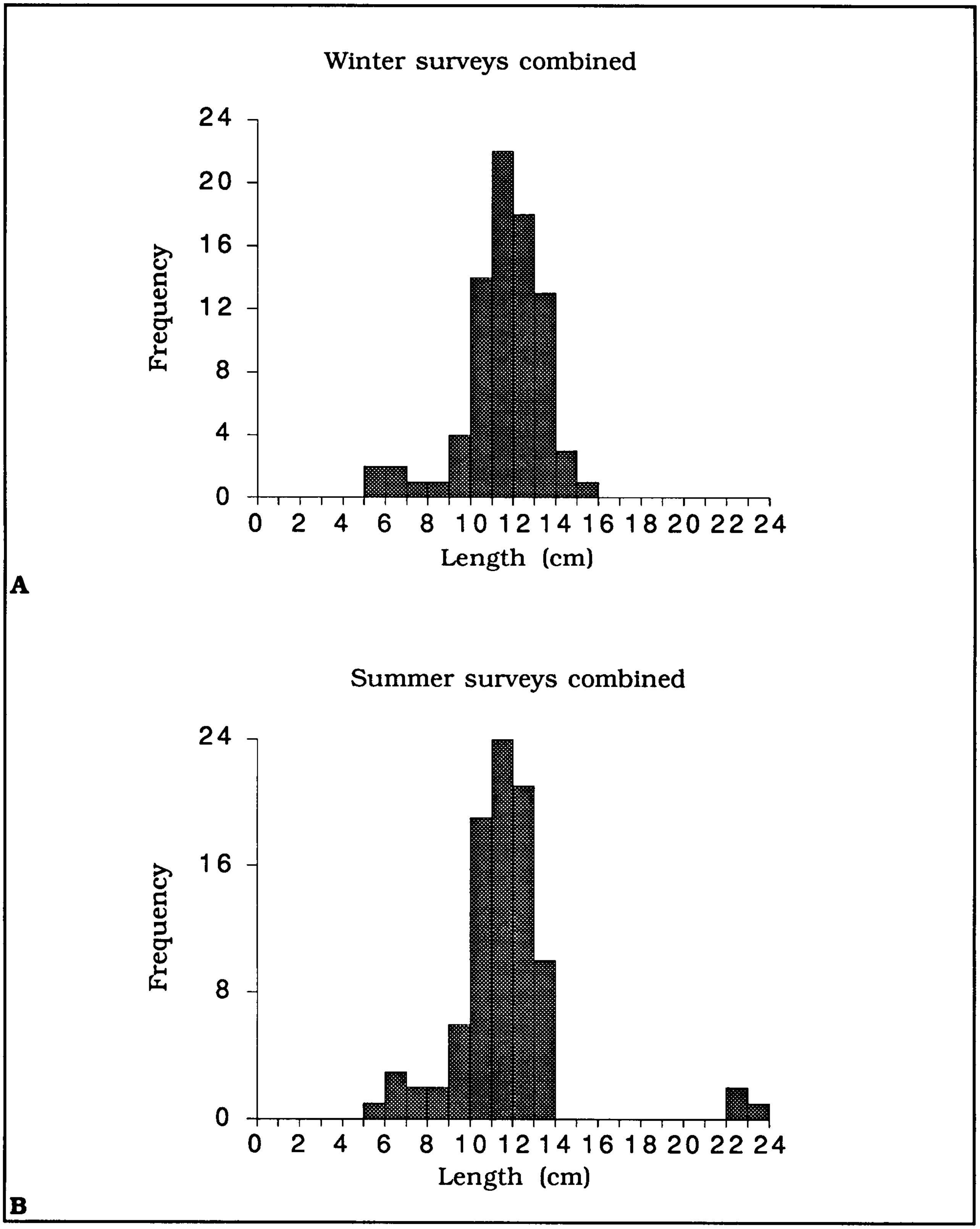


Figure 8-18. Length frequency distributions for *Symphurus civitatus*.

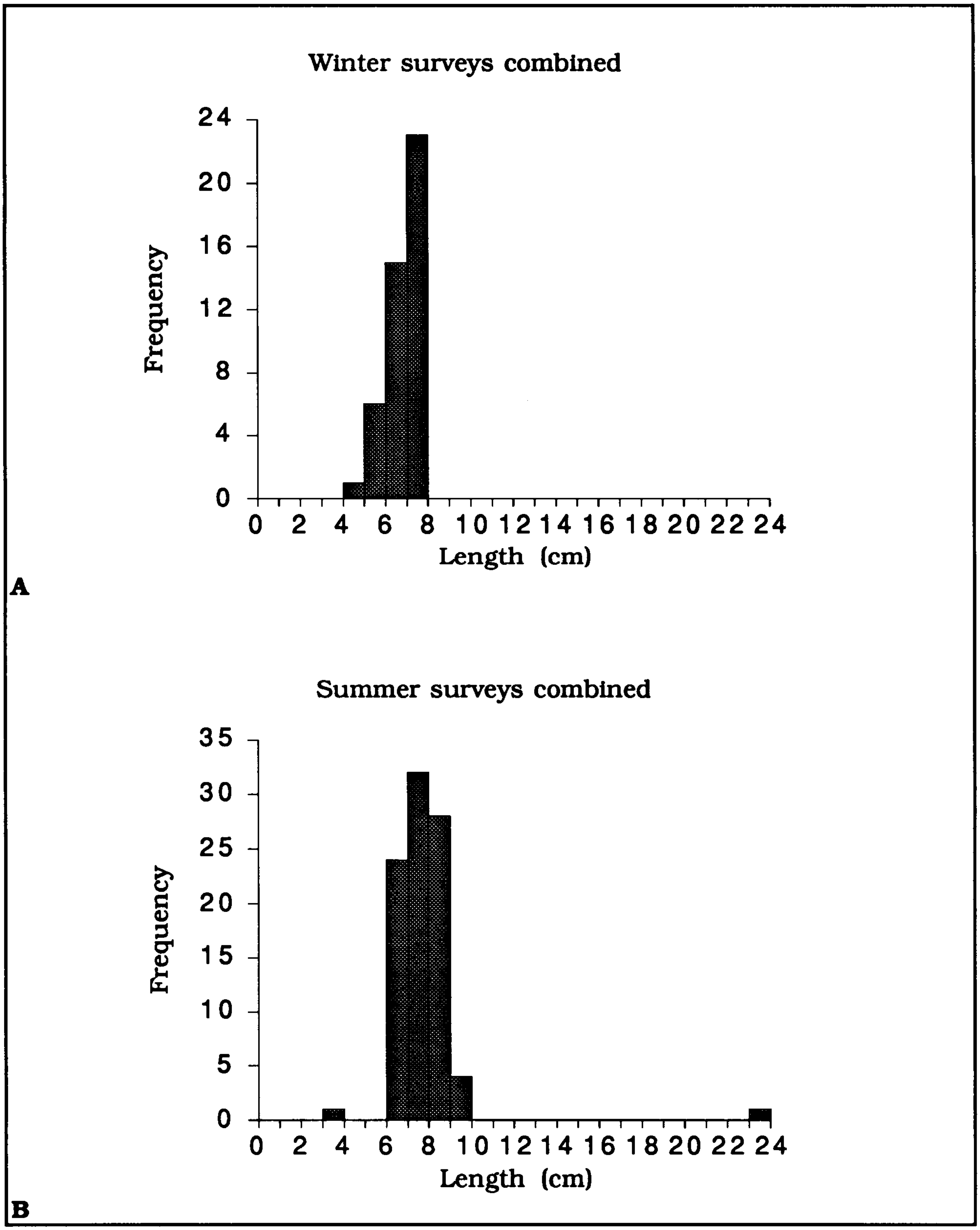


Figure 8-19. Length frequency distributions for *Serranus notospilus*.

Anchoa mitchilli - Bay anchovy

Anchoa mitchilli is twentieth in abundance despite the fact that it was captured on only the third cruise (B-2, winter). All specimens were captured at station C1 (20 m). Lengths ranged from 7 to 9 cm, with the highest frequency of specimens at 7 cm (Figure 8-20).

Each of the twenty most abundant species is distinguished by a combination of its distribution and seasonality in the study area, and by its population structure; however, several patterns are evident. Several species are most abundant at the intermediate stations (60, 100 m) along the Chandeleur Islands transect, i.e., *Halieutichthys aculeatus*, *Serranus atrobranchus*, *Trichopsetta ventralis*, *Prionotus paralatus*, and *Porichthys plectrodon*. Of these *P. paralatus* and *P. plectrodon* were abundant at both the Chandeleur Islands and Mobile Bay transects while the other species were considerably more abundant at Chandeleur Islands transect than at the Mobile Bay transect. *Halieutichthys aculeatus*, S. *atrobranchus* and *T. ventralis* had similar abundances on the winter and summer surveys, while *P. paralatus* and *P. plectrodon* were relatively more abundant on the summer than on the winter surveys.

Two species were most abundant at station C4 (200 m), i.e., *Pontinus longispinis* and *Coelorinchus caribbaeus*. *Pontinus longispinis* was about equal in abundance on the winter and summer surveys, and *C. caribbaeus* was more abundant during the winter than during the summer surveys.

Several species, i.e., *Syacium gunteri*, *Anchoa hepsetus*, *Peprilus burti*, *Etropus rimosus* and *Anchoa mitchilli*, were most abundant at station C1 (20 m). Unlike the other species *E. rimosus* was also abundant along the Mobile Bay transect. *Syacium gunteri*, *A. hepsetus* and *E. rimosus* were more abundant during the summer than during the winter surveys, and *P. burti* and *A. mitchilli* were more abundant during the winter than during the summer surveys.

Symphurus civitatus was unique in making wide scale shifts in abundance between the seasons. It was most abundant at stations C3, M3, C4 and M4 (100, 200 m) on the winter surveys and was most abundant at the stations C1 and C2 (20, 60 m) on the summer surveys.

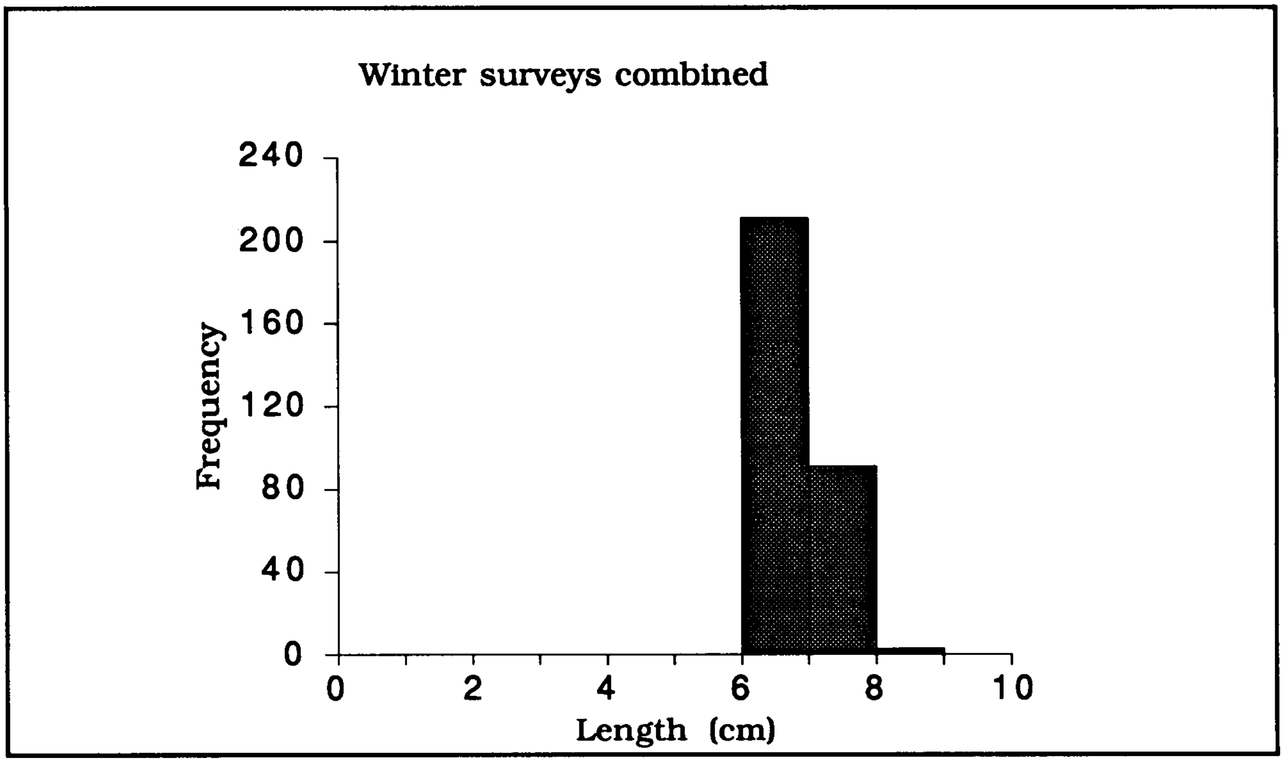


Figure 8-20. Length frequency distributions for *Anchoa mitchilli.*

Syacium papillosum and *Prionotus longispinosus* were most abundant at stations D1, D2, M1 and M2 (20, 60 m), and both were more abundant on the summer than on the winter surveys.

Serraniculus pumilio and *Serranus notospilis* were most abundant at station D3 (100 m). Both were more abundant during the summer than during the winter surveys.

Stenotomus caprinus and *Diplectrum bivittatum* were most abundant at the inner two stations (20, 60 m) or inner station of the Chandeleur Islands and Desoto Canyon transects during the winter surveys but were most abundant at the shallowest station of the Chandeleur Islands or Chandeleur Islands and Mobile Bay transects during the summer surveys.

A majority of the species appear to be short-lived, in that the samples comprise two age classes, immature young of the year and mature one year olds. However, *Syacium papillosum, S. gunteri, Pontinus longispinis, Diplectrum bivittatum, Coelorinchus caribbaeus* and *Prionotus longispinosus* appear to have several age classes represented in the samples, and may not mature until their second year of life.

8.3.3 Variation among Stations, Transects and Cruises.

8.3.3.1 Number of Species

Number of species captured at the 12 stations over the five surveys ranged from 3 on the fifth survey (B-4, winter) at station C4 (200 m) to 32.5 on the fourth survey (B—3, summer) at station C2 (60 m) (Table 8-4). Number of species averaged about 20 per station for all of the surveys except for the last survey on which the number of species averaged 11.3 per station. The next lowest average species per station was 17.6 for the second survey (B-1, summer).

The mean number of species captured at the 12 stations for the three winter surveys combined ranged from 10.0 at station C4 to 24.5 at station M3 (Table 8-5). The smallest average number species was captured at the fourth station and largest average number of species was captured at the third station of each transect. The DeSoto Canyon transect produced the lowest average number of species and the Mobile Bay transect produced the highest average number of species.

Table 8-4. Distribution of total fish catch for all cruises and stations. Data are given for the number of species, number of individuals, and weights, all expressed on a per hectare basis. The cruises are separated by season.

NUMBER OF SPECIES

WINTER

Cruise	C-1	C-2	C-3	C-4	M-1	M-2	M-3	M-4	D-1	D-2	D-3	D-4	$\overline{X}$
0	23.0	19.5	30.0	9.0	17.0	26.0	26.0	—	24.0	16.0	—	13.0	20.3
2	19.0	16.0	22.5	18.0	20.0	29.0	29.5	27.0	10.5	9.5	19.0	17.5	19.8
4	20.5	17.0	11.0	3.0	5.0	7.5	18.0	10.0	7.5	12.0	10.5	14.0	11.3

SUMMER

1	19.5	16.5	26.0	5.5	18.5	17.0	21.5	14.0	10.0	16.0	29.0	—	17.1
3	28.5	32.5	26.5	4.0	23.0	21.5	22.5	16.0	14.0	23.0	30.5	10.0	21.0

NUMBER OF INDIVIDUALS

WINTER

0	505.2	219.7	752.4	126.0	125.6	456.3	815.8	—	935.3	240.7	—	114.4	410.1
2	722.7	45.7	618.9	372.2	161.6	393.7	189.5	254.3	127.3	110.8	240.6	234.4	289.3
4	311.2	77.3	127.6	30.0	13.7	54.6	83.3	47.2	56.6	50.0	120.1	131.2	91.9

SUMMER

1	1,233.7	354.4	902.6	171.6	676.5	275.7	275.6	140.2	68.3	1,094.2	343.4	—	510.9
3	1,859.2	754.8	212.6	16.2	228.0	352.8	211.5	173.5	203.8	353.1	487.4	142.1	416.3

Table 8-4. Cont'd.

TOTAL WEIGHTS (kg)

WINTER

Cruise	C-1	C-2	C-3	C-4	M-1	M-2	M-3	M-4	D-1	D-2	D-3	D-4	$\bar{X}$
0	3.94	2.54	12.32	2.94	3.50	11.04	24.79	—	8.15	5.74	—	2.23	7.3
2	8.64	0.97	15.80	6.22	3.60	8.80	4.57	5.86	3.22	4.17	5.58	5.32	6.1
4	3.68	4.31	4.35	1.01	0.30	2.48	3.09	0.97	2.46	2.26	2.95	7.28	2.98

SUMMER

1	8.81	4.77	17.38	5.49	10.49	2.68	8.32	4.50	2.73	32.50	10.49	—	9.8
3	20.59	9.42	5.10	0.60	3.65	2.94	6.72	4.52	4.51	9.66	7.86	1.18	6.4

Table 8-5. Distribution of total fish catch, by station and transect, for the winter and summer cruises. All data are mean values and are calculated on a per hectare basis.

WINTER **SUMMER**

Mean number of species

Sta.	C	M	D	$\bar{x}$	Sta.	C	M	D	$\bar{x}$
1	20.8	14.0	14.0	16.3	1	24.0	20.8	12.0	18.9
2	17.5	20.8	12.5	16.9	2	24.9	19.5	19.5	21.3
3	21.2	24.5	14.8	20.2	3	26.2	22.0	29.8	26.0
4	10.0	18.5	14.8	14.4	4	4.8	15.0	10.0	9.9
$\bar{x}$	17.4	19.5	14.0		$\bar{x}$	20.0	19.3	17.8	

Mean number of individuals/hectare

1	513.0	300.9	393.1	395.7	1	1,546.5	452.3	136.1	711.6
2	114.0	294.9	133.8	180.9	2	554.6	314.3	723.7	530.9
3	499.6	362.9	180.4	347.6	3	557.6	243.6	415.4	405.5
4	176.1	150.9	160.0	162.3	4	93.9	156.9	142.7	131.2
$\bar{x}$	325.7	277.4	211.8		$\bar{x}$	688.2	291.8	354.5	

Mean weights (kg)/hectare

1	5.42	2.47	4.17	4.17	1	14.70	7.07	3.62	8.46
2	2.61	7.44	4.06	4.70	2	7.09	2.81	21.08	10.33
3	10.82	10.81	4.26	8.63	3	11.24	7.52	9.17	9.31
4	3.39	3.42	4.94	3.92	4	3.03	4.51	1.18	2.91
$\bar{x}$	5.56	6.04	4.47		$\bar{x}$	9.02	5.48	8.77	

The mean number of species captured at the 12 stations for the two summer surveys ranged from 4.8 at station C4 to 29.8 at station D3. The smallest average number was captured at the fourth station and the largest average number of species was captured at the third station of each transect. The DeSoto Canyon transect produced the lowest average number of species and the Chandeleur Islands transect produced the highest average number of species.

8.3.3.2 Number of Individuals

The number on individuals per hectare captured at the 12 stations over the five surveys ranged from 13.7 on the fifth survey (B-4, winter) at station M1 (20 m) to 1,859.2 on the fourth survey (B-3, summer) at station C1 (20 m) (Table 8-4). The average number of individuals per hectare per survey ranged from 91.9 for the fifth survey to 510.9 for the second survey (B-1, summer). The average for the last survey was about one-third of that for the second lowest average (third survey, B-2, winter) of the entire survey. The mean number of individuals per hectare for the three winter cruises combined ranged from 114.0 at station C2 to 513.0 at station C1 (Table 8-5). The smallest average number of individuals per hectare was captured at the fourth station (200 m) of each transect and the largest average number was captured at the first station (20 m) of each transect. The DeSoto Canyon transect produced the smallest average number of individuals per hectare and the Chandeleur Islands transect produced the highest average number.

The mean number of individuals per hectare for the two summer surveys combined ranged from 93.9 at station C4 to 1,546.5 at station C1 of the Chandeleur Islands transect. The smallest average number of individuals per hectare were captured at the fourth station (200 m) of each transect and the largest average number were captured at the first station of each transect (20 m). The Mobile Bay transect produced the smallest average number of individuals per hectare, and the Chandeleur Islands transect produced the largest average number of individuals.

8.3.3.3 Total Weight of Fishes

The total weight of fishes per hectare captured at the 12 stations over the five surveys ranged from 0.38 Kg on the fifth survey (B-4, winter) at station M1 (20 m) to 32.50 Kg on the second survey (B-1, summer) at station D2 (60 m) (Table 8-4). The average total weight per hectare per cruise ranged from 2.93 Kg for the fifth survey to 9.83 Kg per hectare for the second cruise. The average total weight for the last survey was about one-half that for the next lowest average for the third survey (B-2, winter).

The mean weight per hectare for the three winter surveys combined ranged from 2.47 kg at station M1 to 10.82 kg at station C3. The lowest mean weight per hectare was caught at the fourth station (200 m) of each transect and the highest mean weight was captured at the third station (100 m) of each transect. The DeSoto Canyon transect produced the lowest mean weight per hectare and the Mobile Bay transect produced the highest mean weight per hectare.

8.3.3.4 Indices of Diversity

Indices of diversity, H', for the 12 stations over the five surveys ranged from 1.16 on the fifth survey (B-4, winter) at station C4 (200 m) to 3.13 on the third survey (B-2, winter) at station M3 (100 m) (Table 8-6). The first survey (B-0, winter) had the lowest mean diversity and the third cruise had the highest average diversity.

Mean diversity for the three winter cruises combined ranged from 1.48 at station C4 (200 m) to 2.74 at station M3 (100 m) (Table 8-7). The fourth station had the lowest mean diversity, and the third station had the highest mean diversity. Chandeleur Islands transect had the lowest, and Mobile Bay had the highest mean diversity.

Mean diversity for the two summer surveys combined ranged from 1.35 at station D4 (200 m) to 2.77 at station M3 (100 m) (Table 8-7). The fourth station had the lowest mean diversity and the third station had the highest mean diversity. DeSoto Canyon transect had the lowest mean diversity, and Mobile Bay transect the highest mean diversity.

8.3.3.5 Summary

The mean number of species, mean number of individuals per hectare, mean total weight per hectare and diversity indices (H') did not completely co-vary, but these values did indicate some relationships and trends among stations, depths, transects, surveys and seasons. The lowest number of species, mean number of individuals per hectare and mean total weight per hectare were lowest for the fifth cruise (B-4, winter). The fourth survey (B-3, summer) had the highest average number of species, and the second survey had the highest average number of individuals and highest average total weight per hectare. The third survey (B-2, winter) had the highest

Table 8-6. Shannon Weaver indices of diversity for all cruises and stations. The cruises are separated by season.

WINTER

Cruise	C-1	C-2	C-3	C-4	M-1	M-2	M-3	M-4	D-1	D-2	D-3	D-4	x
0	2.20	2.35	2.02	1.40	2.14	2.43	2.13	---	1.59	1.61	---	2.15	2.00
2	1.86	2.69	2.31	1.89	2.75	2.71	3.13	3.00	2.05	2.00	2.44	2.29	2.43
4	2.86	2.27	1.94	1.16	1.94	1.98	2.96	2.43	2.15	2.45	2.29	2.66	2.26

SUMMER

Cruise	C-1	C-2	C-3	C-4	M-1	M-2	M-3	M-4	D-1	D-2	D-3	D-4	x
1	1.82	2.55	2.35	1.24	2.15	2.42	2.92	2.32	2.56	2.23	2.10	---	2.24
3	1.69	2.78	2.79	1.51	2.61	2.18	2.62	2.34	1.51	2.62	2.30	1.35	2.11

Table 8-7. Mean seasonal values of the Shannon Weaver index of diversity for each station, separated by season.

Winter

Sta.	C	M	D	$\bar{X}$
1	2.31	2.28	1.93	2.17
2	2.43	2.37	2.02	2.27
3	2.09	2.74	2.37	2.40
4	1.48	2.71	2.37	2.19
$\bar{X}$	2.08	2.53	2.17	

Summer

Sta.	C	M	D	$\bar{X}$
1	1.75	2.38	2.03	2.05
2	2.67	2.30	2.43	2.47
3	2.57	2.77	2.20	2.51
4	1.38	2.33	1.35	1.69
$\bar{X}$	2.09	2.45	2.00	

---

average H' diversity. The deepest stations (200 m) had the lowest average number of species, lowest average number of individuals per hectare and lowest average total weight per hectare but not necessarily the lowest H' diversity. DeSoto Canyon transect had the lowest average number of species, lowest average number of individuals per hectare and lowest average total weight per hectare on the winter surveys. Chandeleur Islands transect had the highest average number of species, highest average number of individuals per hectare and highest average total weight per hectare on the summer surveys.

8.3.4 Cluster Analysis - Station Clusters

For the first cruise (B-0, winter) the 10 stations sampled are divided into three major groupings (Figure 8-21). Stations M4 and D3 were not sampled. Group A consists of stations C1, M1 and D1 and station M2 and D2. Within Group A, stations D1 and D2 and station M2 form one subgroup and stations C1 and M1 form the other subgroup. Group B consists of stations C2 and C3 and station M3. The two stations along the Chandeleur Islands transect are more similar to each other than either is to the station along the Mobile Bay transect. Group C consists of station C4 and D4.

For the second survey (B-1, summer) 11 stations sampled are divided into two groups (Figure 8-22). Station D4 was not sampled. Group A consists of the first two stations along the three transects. Within Group A, station D1 is the most dissimilar, stations C1 and C2 are grouped together, and stations M1 and M2 and D1 are grouped together. Group B consists of stations 3 and 4 along the three transects and station C3, and stations M3 and M4 are grouped together.

For the third survey (B-2, winter), the 12 stations sampled are divided into three major groups (Figure 8-23). Group A consists of station C3 and M3 and station 4 along the three transects. Within Group A, station D4 is the most dissimilar, stations C4 and M4 are grouped, and stations C3 and M3 are grouped. Group B consists of station 1 along the three transects and station C2 . Within Group B, the two stations along the Chandeleur Island transect are grouped, and stations M1, M2, D1 and D2 are grouped. Group C consists of stations D2 and D3 and station M2, and station M2 and D2 are grouped.

For the fourth survey (B-3, summer), the 12 stations sampled are divided into three groups (Figure 8-24). Group A consists of station 4 along the three transects, with the stations along the Mobile Bay and DeSoto Canyon transets grouped together. Group B consists of station M3 and stations C1, C2 and C3, and within the group station C1 is most dissimilar. Group C consists of stations D1, D2 and D3 and stations M1 and M2. Stations M1 and D1 are grouped, and station M2, D2 and D3 are grouped.

For the fifth survey (B-4, winter) the 12 stations sampled were divided into three groups (Figure 8-25). Group A consists of stations C1, C2 and C3, and stations M2, M3, D2 and D3. Within Group A, station C1, M2, D2 and

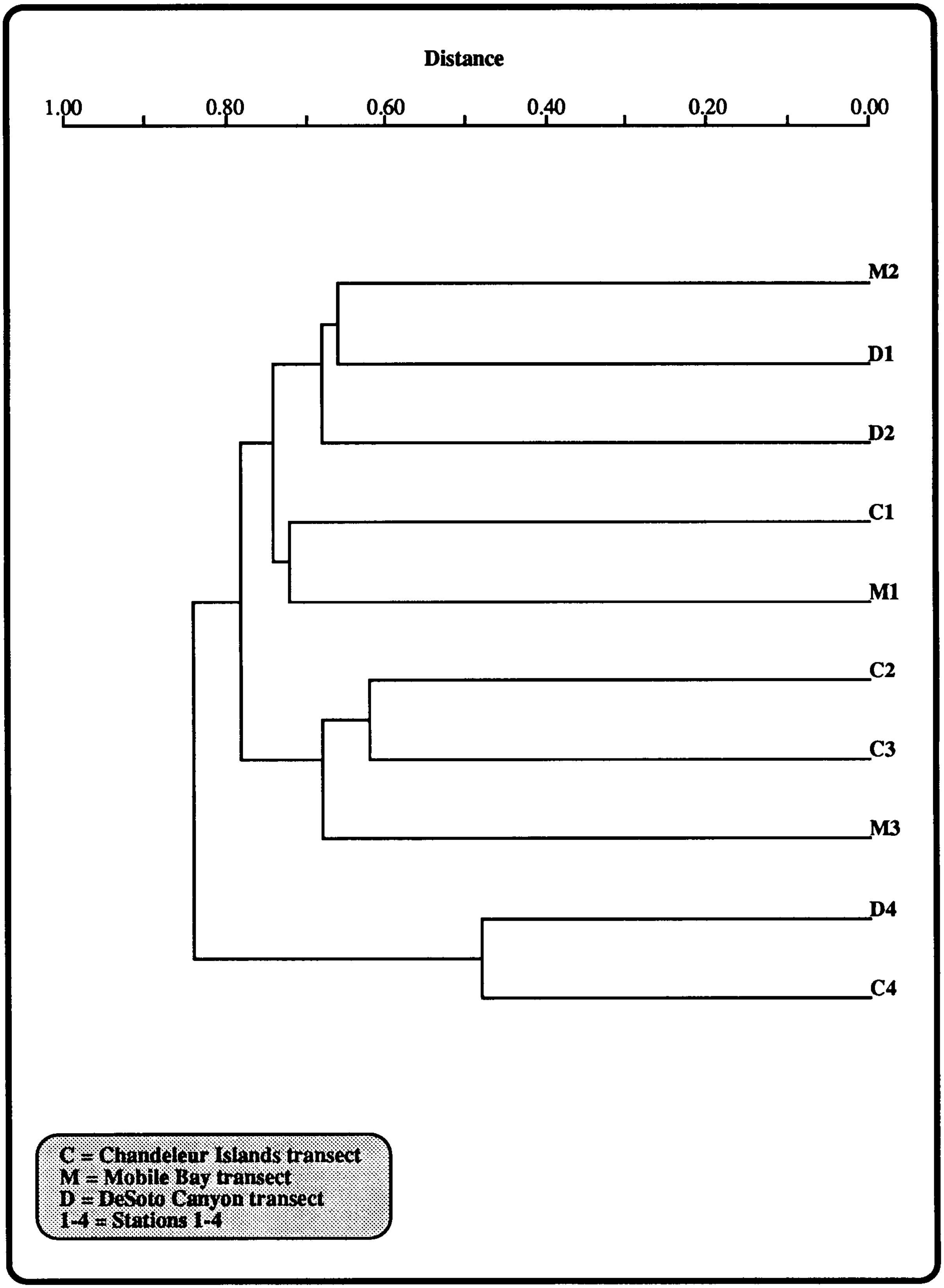


Figure 8-21. Station Clusters Cruise B-0, Winter.

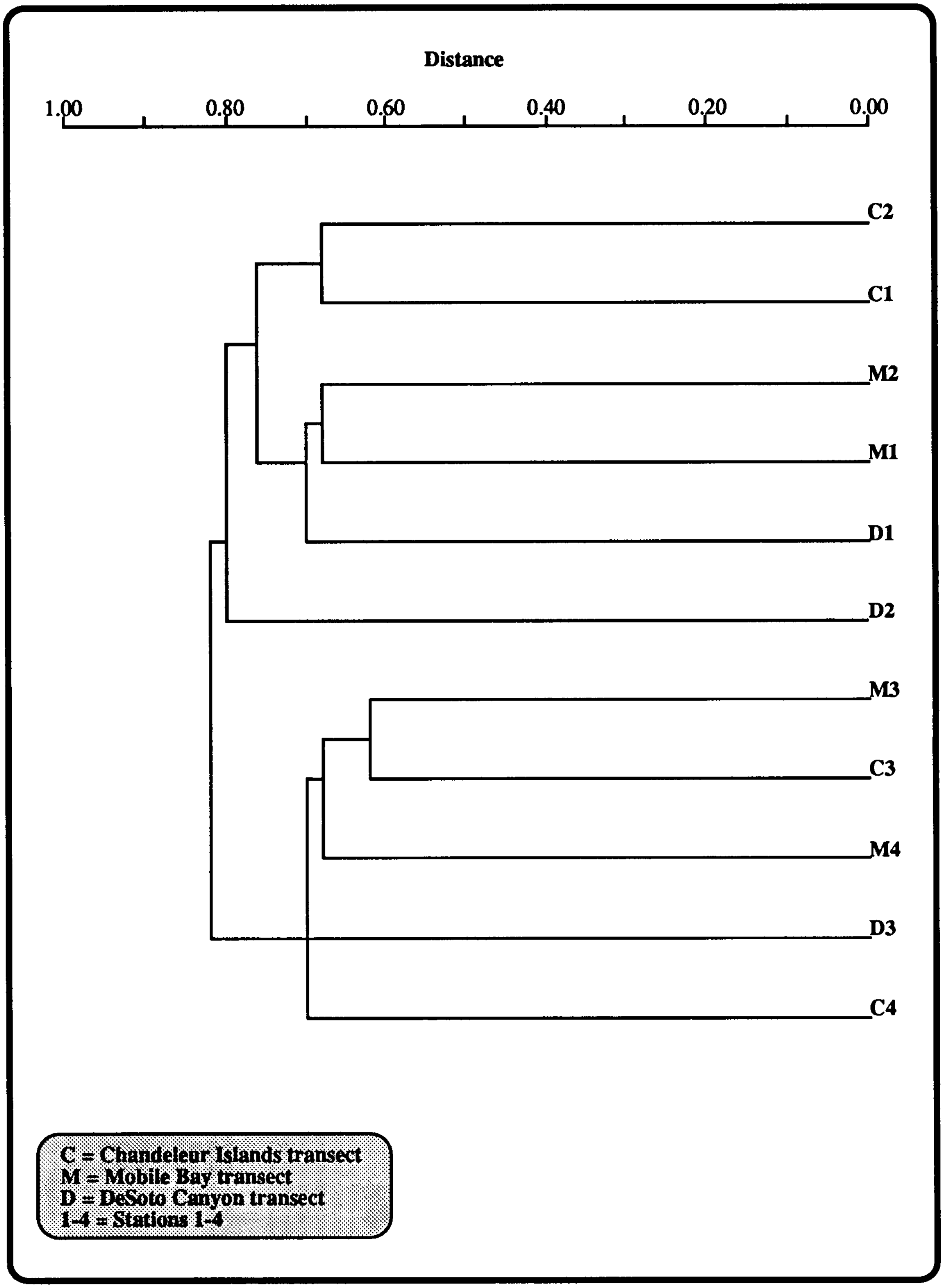


Figure 8-22. **Station Clusters** Cruise B-1, Summer.

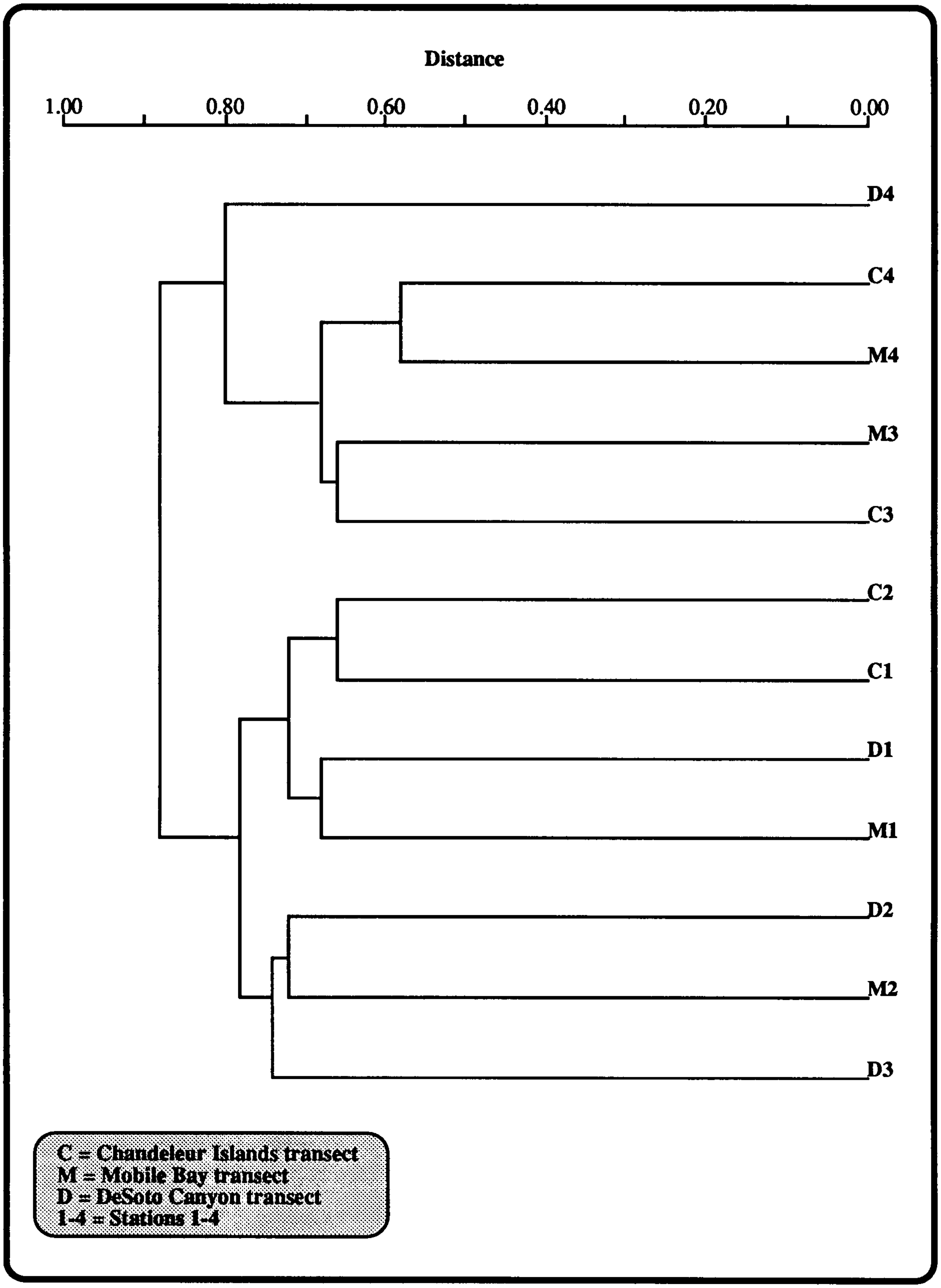


Figure 8-23. Station Clusters Cruise B-2, Winter.

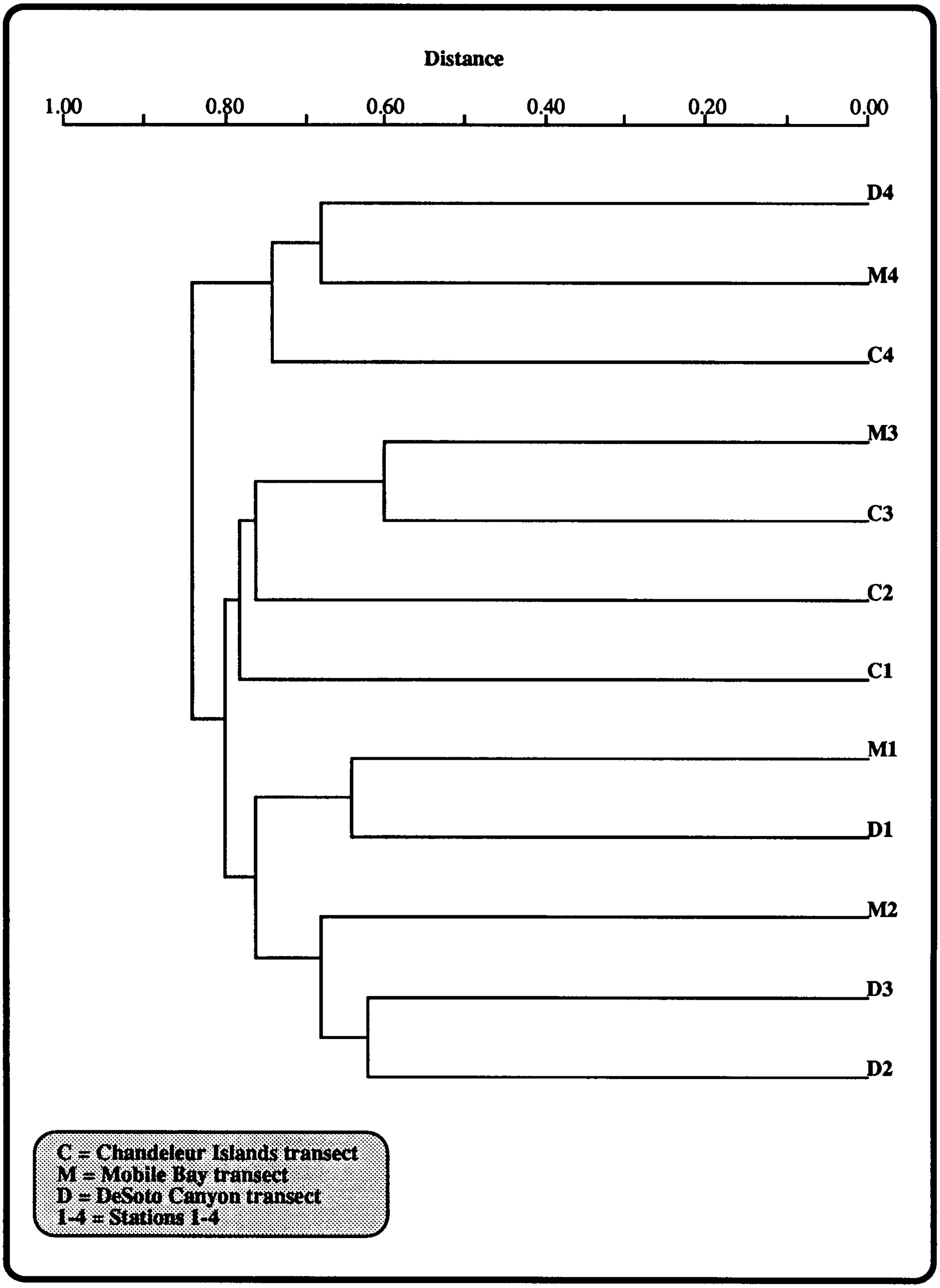


Figure 8-24. Station Clusters Cruise B-3, Summer.

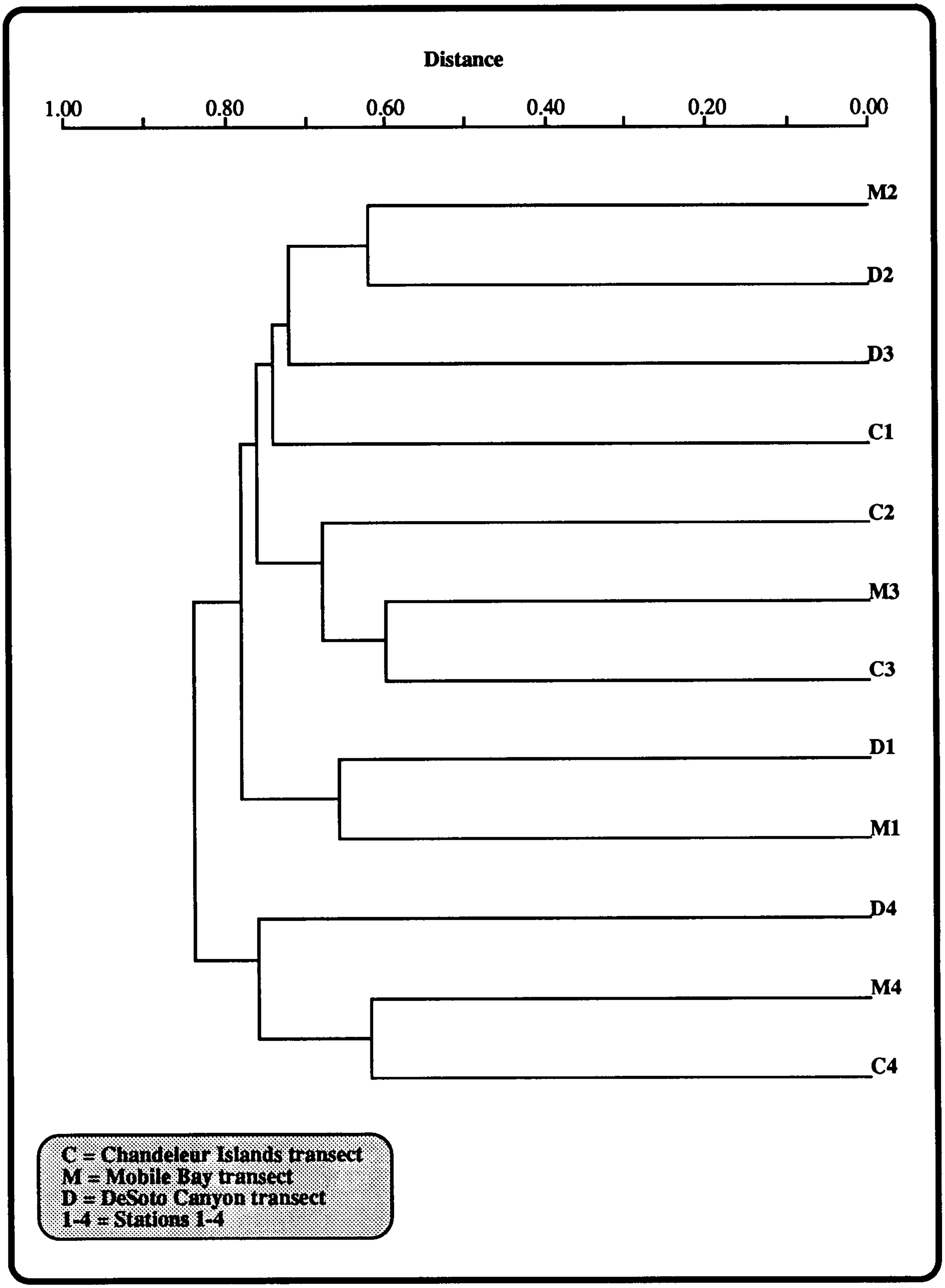
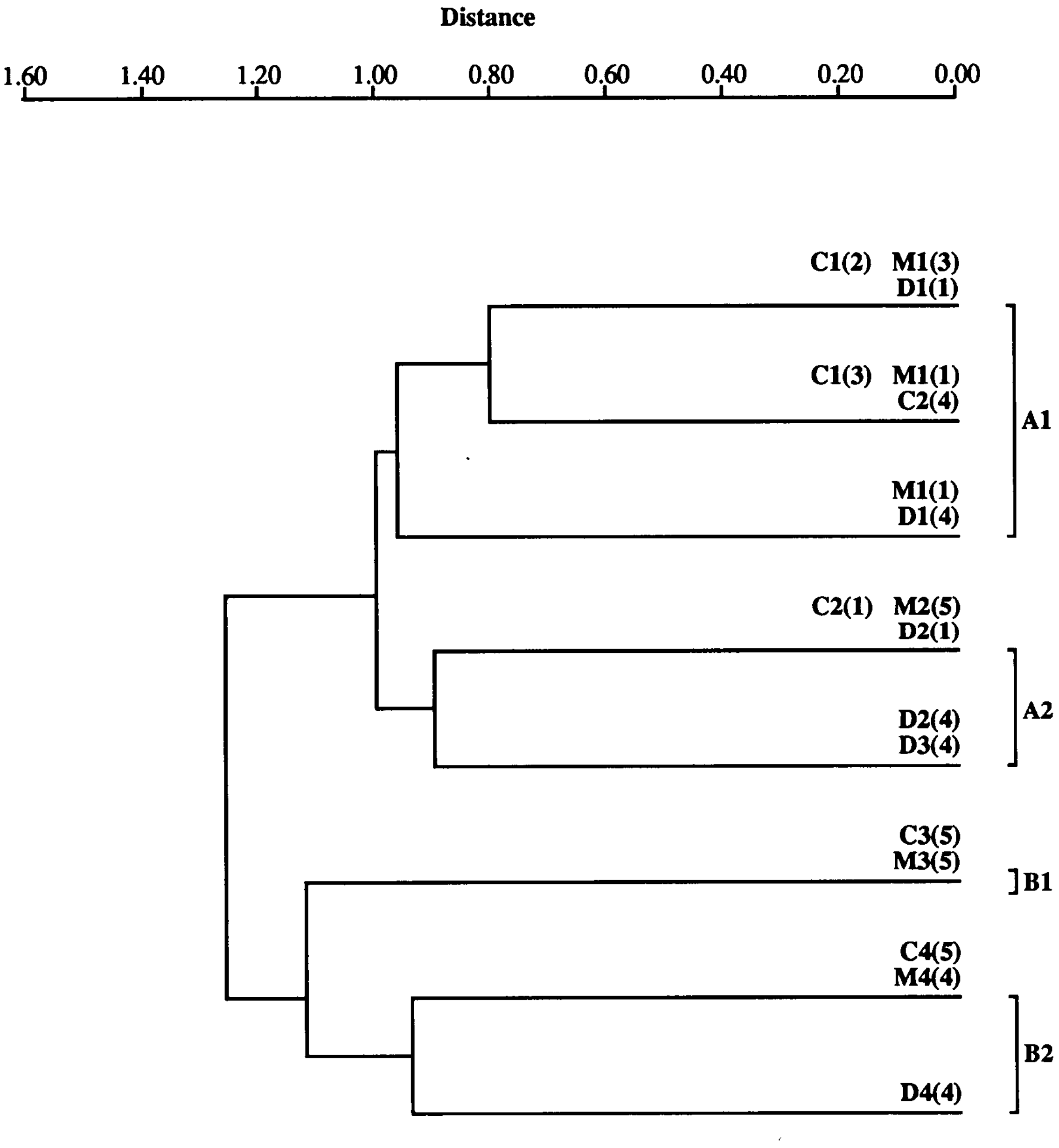


Figure 8-25. **Station Clusters** Cruise B-4, Winter.

D3 form one subgroup and station C2 and C3 and station M3 form the other subgroup. Group B consists of station M1 and D1. Group C consists of station 4 along each transect, and the Chandeleur Islands and Mobile Bay stations form a subgroup.

For all of the surveys, the 57 stations sampled (collections) are divided into two major Groups (A and B) of 34 and 23 collections, respectively (Figure 8-26). Each of the major groups is in turn subdivided into two major subgroups. Group A has one major subgroup consisting of 19 collections (Subgroup A1) and the other consisting of 15 collections (Subgroup A2). Subgroup A1 includes all of the collections at station 1 along the three transects, in addition to four of the five collections at station C2. Four of the five collections at station D1 clustered together and were the most distinct of the subgroup. Subgroup A2 consists of all of the collections at station M2 and D2 and one collection at station C2, in addition to the four collections at station D3. Within Subgroup A2, the collections along the Chandeleur Islands, the Mobile Bay transects and one along station D2 clustered together, and the remainder of the collections along the DeSoto Canyon clustered together. Group B has two major subgroupings, B1 and B2 consisting of 10 and 13 collections respectively. Subgroup B1 consists of all of the collections at the third stations along the Chandeleur Islands and Mobile Bay transects. Subgroup B2 consists of all the collections at station 4 along the three transects. The Desoto Canyon stations clustered together and the Chandeleur Isalnds and Mobile Bay stations clustered together.

Clustering by stations both for the individual cruises and for all cruises combined indicates that depth is important in the clustering of stations. Also, stations along the Chandeleur and DeSoto Canyon transects are more distinct from each other than either is from the stations along the Mobile Bay transect. Stations along the Mobile Bay transect are more closely grouped with the stations of the Chandeleur Islands transect on some occasions and with the stations along the DeSoto Canyon transect on other occasions. Collections along station 4 of each transect are most distinct, and among these stations, those along the Chandeleur Islands and Mobile Bay transects are more similar to each other than either is to the DeSoto Canyon station. Station 3 is more similar to station 4 along each transect than they are to stations 1 or 2, except that stations D2 and D3 clustered together and



C = Chandeleur Islands transect
M = Mobile Bay transect
D = DeSoto Canyon transect
1-4 = Stations 1-4
(1-5) = number of collections at station

Figure 8-26. Station Clusters for All Cruises Combined.

were distinct from station D4. Station 2 of the three transects have greater affinity for station 1 of each transect than with any other of the stations. Station C2 generally clustered more closely with station 1 of the three transects than with station 2 of the other two transects.

8.3.5 Cluster Analysis—Species Clusters

For the first cruise (B-0, winter), the 105 species captured at the 10 stations clustered into four groups (Figure 8-27). Group A consists of 12 species that were captured at station C3 (100 m), station D4 (200 m), or both stations (three species). *Hildebrandia flava*, *Physiculus fulvus* and *Neobythites* sp. were the most frequently captured species, but all species were of minor importance on the five surveys.

Group B consists of 23 species that were captured at stations C2, C3, M2, and M3 (60, 100 m), with some species also occurring at the first station along stations D1 and D4. Most of the species were captured at two or more of the stations. Representatives of the twentieth most abundant species of the overall survey were: *Serranus atrobranchus*, *Pontinus longispinis*, *Trichopsetta ventralis*, *Prionotus paralatus*, *Coelorinchus caribbaeus* and *Porichthys plectrodon*.

Group C consists of 64 species that were captured predominately at the shallowest stations of the three transects. This group was divided into two subgroups. One subgroup consisted of a small assemblage of species that were taken at station M1 or M2 (20, 60 m). Except for *Serraniculus pumilio* (sixteenth in abundance over the five surveys), the species of this subgroup were rare over the five surveys. The other subgroup consisted of a large assemblage of species primarily captured at two or more of stations 1 and 2 along each transect, although several were captured at station D4. Representatives of the twentieth most abundant species in this subgroup were: *Halieutichthys aculeatus*, *Stenotomus caprinus*, *Syacium papillosum*, *S. gunteri*, *Anchoa hepsetus*, *A. cubana*, *Diplectrum bivittatum*, *Prionotus longispinosus* and *Symphurus civitatus*.

Group D consists of six species restricted to station D1. All of the species were of minor importance over the entire survey.

For the second survey (B-1, summer), the 132 species captured at the 11 stations clustered into six groups (Figure 8-28). Group A consists of 50

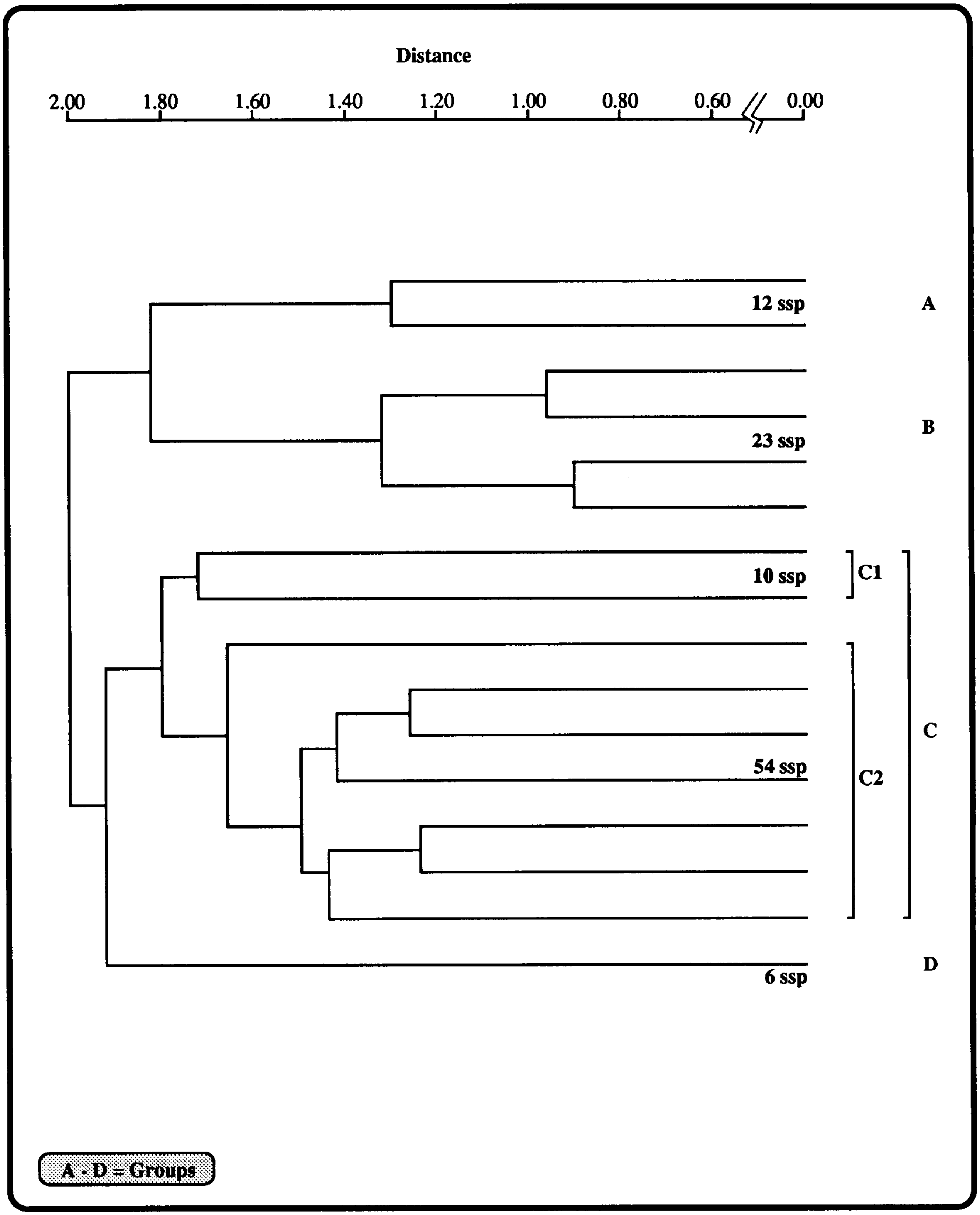


Figure 8-27. Species Clusters Cruise B-0, Winter.

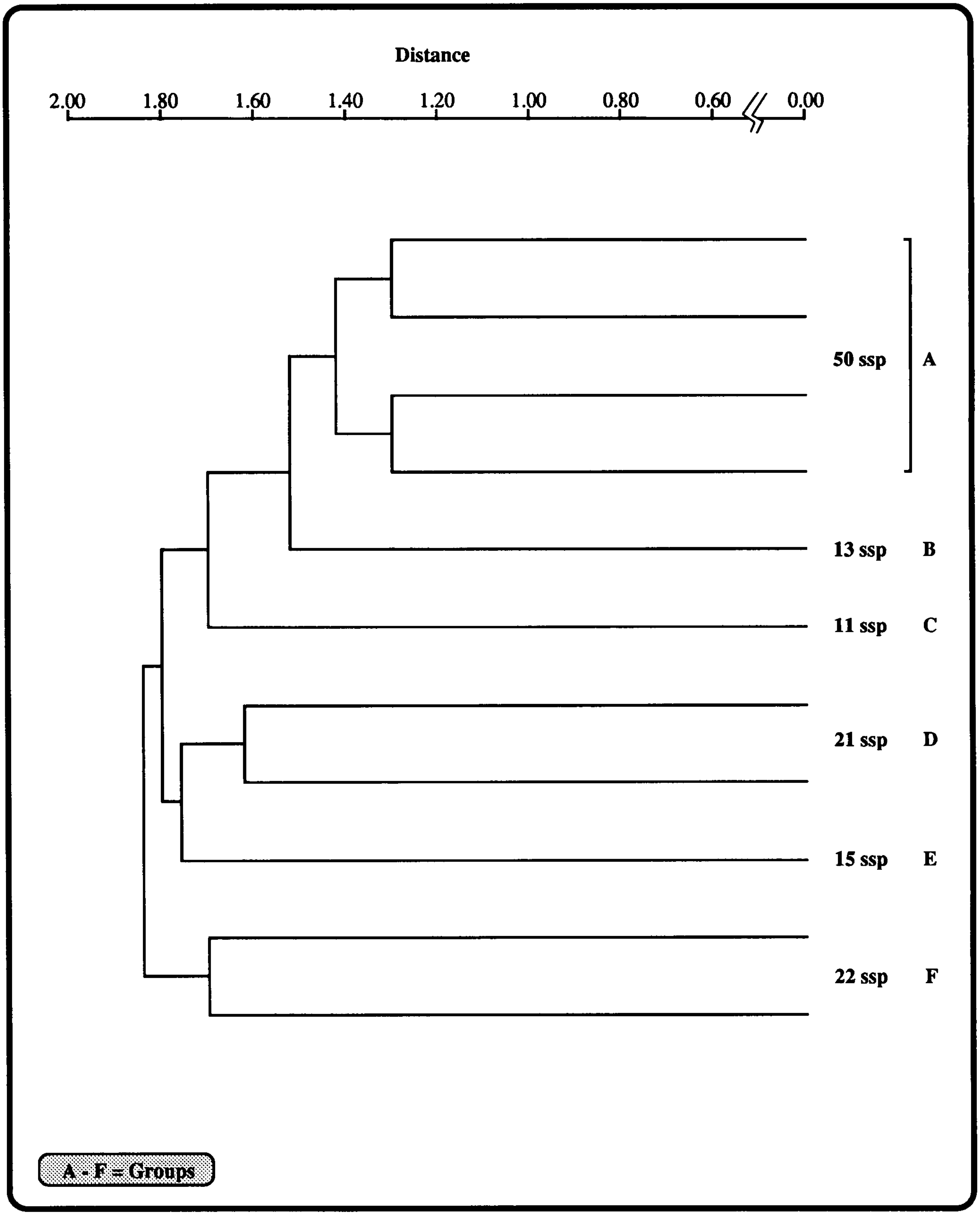


Figure 8-28. Species Clusters Cruise B-1, Summer.

widespread species most frequently captured at stations 2 and 3 (60, 100 m) of each transect, with some also caught at stations 1 and 4 of the transects. Representatives of the twenty most abundant species on the five surveys were: *Halieutichthys aculeatus, Stenotomus caprinus, Syacium gunteri, Serranus atrobranchus, Pontinus longispinis, Trichopsetta ventralis, Prionotus paralatus, Coelorinchus caribbaeus, Porichthys plectrodon, Symphurus civitatus* and *Serranus notospilus.*

Group B consists of 13 species primarily captured at station C3 and, to a slightly lesser extent, at stations M3 and M4 and C4. *Saurida brasiliensis* and *Bathygadus macrops* were the most frequently captured species but they and the other species were of minor importance over the five surveys.

Group C consists of 11 species primarily captured at station D1 and, to a lesser extent, at station M1, M2, C1 and C2. Representatives of the twenty most abundant species on the five surveys were: *Syacium papillosum, Diplectrum bivittatum, Anchoa hepsetus* and *Etropus rimosus.*

Group D consists of 21 species primarily captured at stations C2, C3. C4 and M4. All of the species were of relatively low abundance.

Group E consists of 15 species captured at station C1 and M1. All species were of low abundance.

Group F consists of 22 species primarily captured at stations D2 and D3, although some were also taken at stations C1, C2 and C3. All species were of low abundance on the five surveys.

For the third survey (B-2, winter) the 134 species captured at the 12 stations clustered into five groups (Figure 8-29). Group A consists of seven species exclusively captured at station D3. None of the species were of high abundance.

Group B consists of 8 species primarily caught at station M4. *Ogcocephalus declivirostris, O. coniger* and *Hoplunnis macrurus* were additionally caught at stations C3 and M3 but none of the species were caught in high abundance over the five surveys.

Group C consists of 49 species primarily caught at the deeper stations along the three transects. A majority of the species were caught at two or more stations. Representatives of the twenty most abundant species were: *Serranus atrobranchus, Pontinus longispinis, Trichopsetta ventralis, Serraniculus pumilio, Porichthys plectrodon* and *Symphurus civitatus.*

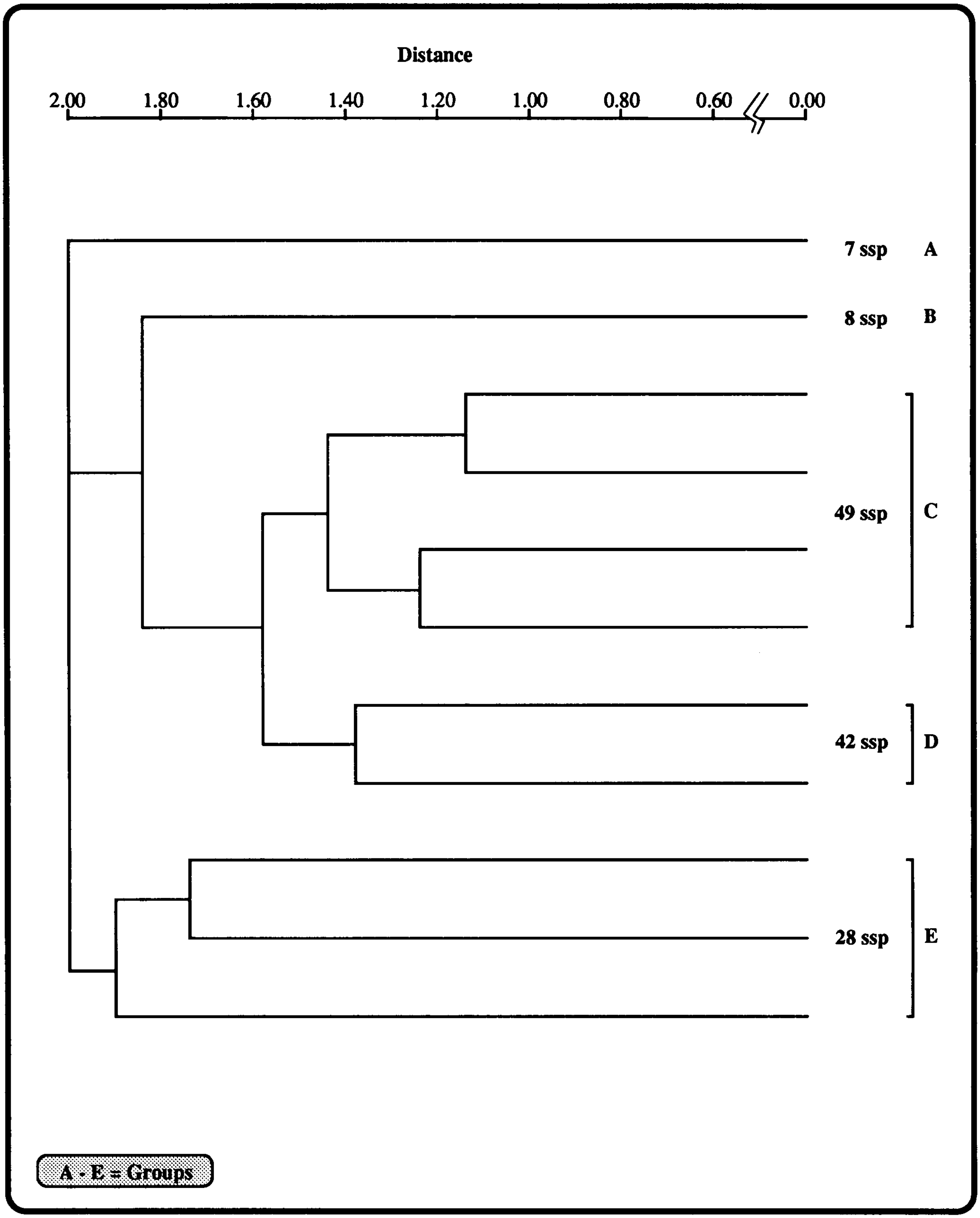


Figure 8-29. Species Clusters Cruise B-2, Winter.

Group D consists of 42 species primarily captured at the shallowest and intermediate stations along the three transects. A majority of the species were caught at two or more of the stations. Representatives of the twenty most abundant species were: *Halieutichthys aculeatus*, *Stenotomus caprinus*, *Syaciium papillosum*, *Diplectrum bivittatum*, *Peprilus burti*, *Etropus rimosus*, *Prionotus longispinosus*, *Serranus notospilus* and *Anchoa mitchilli*.

Group E consists of 28 species caught at single stations along the Mobile Bay and DeSoto Canyon transects. All species were of relatively low abundance on the five surveys.

For the fourth survey (B-3, summer), the 146 species captured at the 12 stations cluster into seven groups (Figure 8-30). Group A consists of six species caught at station C1. All of these species except *Leiostomus xanthurus* were of low abundance over the course of the five surveys.

Group B consists of eight species caught at station C3. Only *Serranus notospilus* and, to a lesser extent, *Physiculus fluvus* were relatively abundant on the five surveys.

Group C consists of 15 species captured at single stations along the Mobile Bay or DeSoto Canyon transects. All of the species except *Hoplunnis tenuis* were in low abundance over the five cruises.

Group D consists of 46 species primarily caught at the shallower stations along the three transects. A majority of the species were captured at two or more of the stations. Also most of the species were captured along the Mobile Bay and DeSoto Canyon transects, with a small subset captured exclusively along the Chandeleur Islands transect. Representatives of the twenty most abundant species were: *Syacium papillosum*, *Etropus rimosus*, *Prionotus longispinosus* and *Serraniculus pumilio*.

Group E consists of 41 species primarily captured at the shallower stations along the three transects. A majority of the species were captured at two or more stations. Also, most of the species were captured along the Chandeleur Islands and Mobile Bay transects, although several were additionally caught along the DeSoto Canyon transect. Representatives of the twenty most abundant species were: *Halieutichthys aculeatus*, *Stenotomus caprinus*, *Syacium gunteri*, *Anchoa hepsetus*, *Serranus*

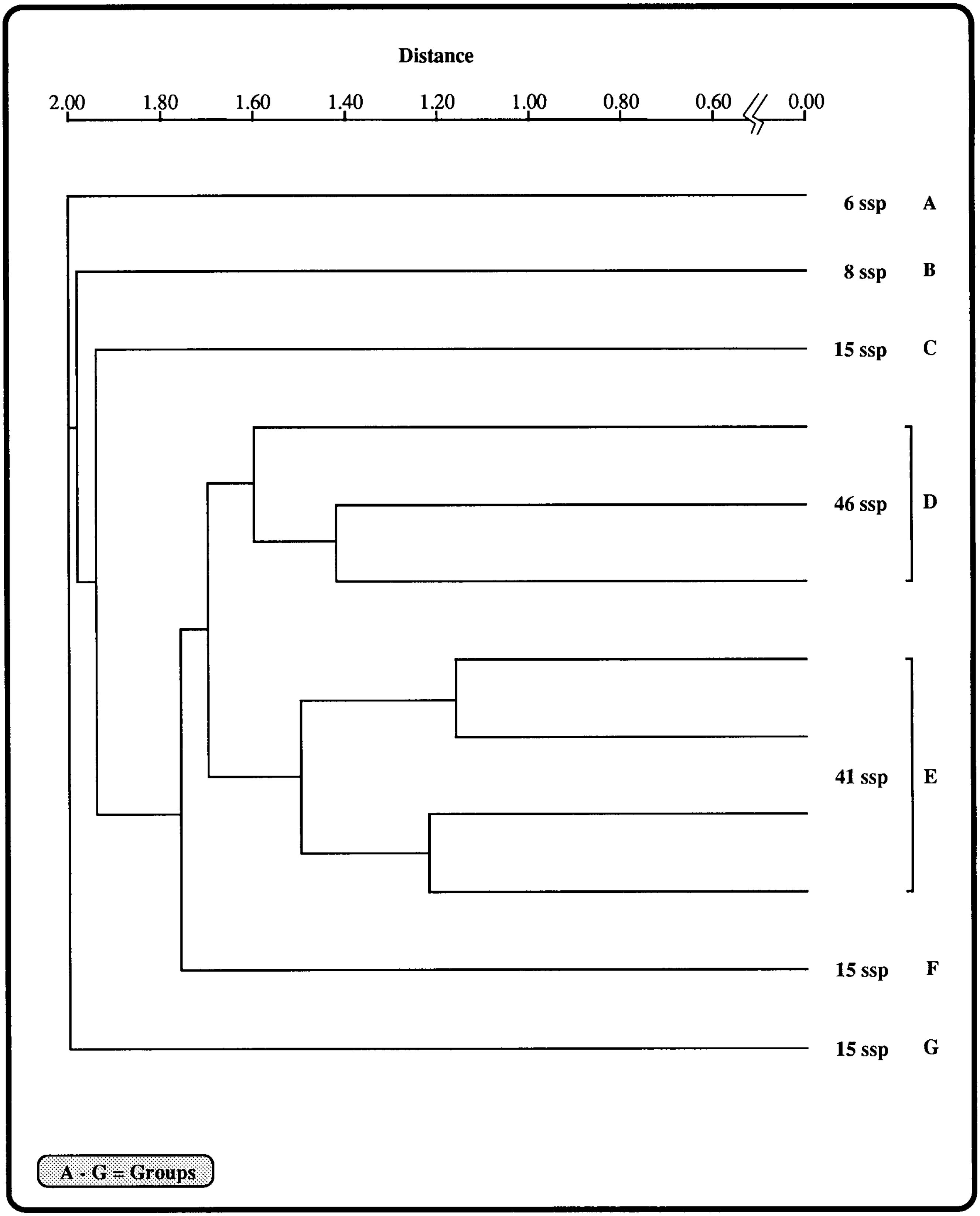


Figure 8-30. Species Clusters Cruise B-3, Summer.

atrobranchus, *Diplectrum bivittatum*, *Trichopsetta ventralis*, *Peprilus burti*, *Porichthys plectrodon* and *Symphurus civitatus.*

Group F consists of 15 species primarily caught at stations M4 and D4. A majority of the species were captured at two or more of the stations and a few were additionally captured at a station along the Chandeleur Islands transect. Representatives of the twenty most abundant species were: *Pontinus longispinis* and *Coelorinchus caribbaeus.*

Group G consists of 15 species captured at station D3. None of these species were abundant over the course of the five surveys.

For the fifth survey (B-4, winter), the 94 species captured at the twelve stations clustered into four groups (Figure 8-31). Group A consists of 12 species captured at station C2 or station D3. Only one species, *Gymnothorax nigromarginatus* was captured at both stations and it was the only species that was relatively abundant on the survey.

Group B consists of 16 species captured at the deeper stations along the three transects but especially along the DeSoto Canyon transect. A majority of the species were captured at two or more of the stations. Representatives of the 20 most abundant species were: *Pontinus longispinis* and *Coelorinchus caribbaeus.*

Group C consists of 42 species captured at the intermediate to deepest stations, especially those along the Chandeleur Islands and Mobile Bay transects. A majority of the species were captured at two or more of the stations. Representatives of the 20 most abundant species were: *Halieutichthys aculeatus*, *Stenotomus caprinus*, *Syacium papillosum*, *Serranus atrobranchus*, *Trichopsetta ventralis*, *Serraniculus pumilio* and *Porichthys plectrodon.*

Group D consists of 24 species captured at stations C1 and D1. A majority of the species were captured at two or more of the stations of intermediate depth along the Chandeleur and Mobile Bay transects. Representatives of the 20 most abundant species were: *Syacium gunteri*, *Anchoa hepsetus*, *Etropus rimosus*, *Prionotus longispinosus* and *Symphurus civitatus.*

The species captured on each of the five surveys clustered into four to seven groups. Two or three of the groups on each of the surveys contained the majority of the species, including those captured at two or more of the

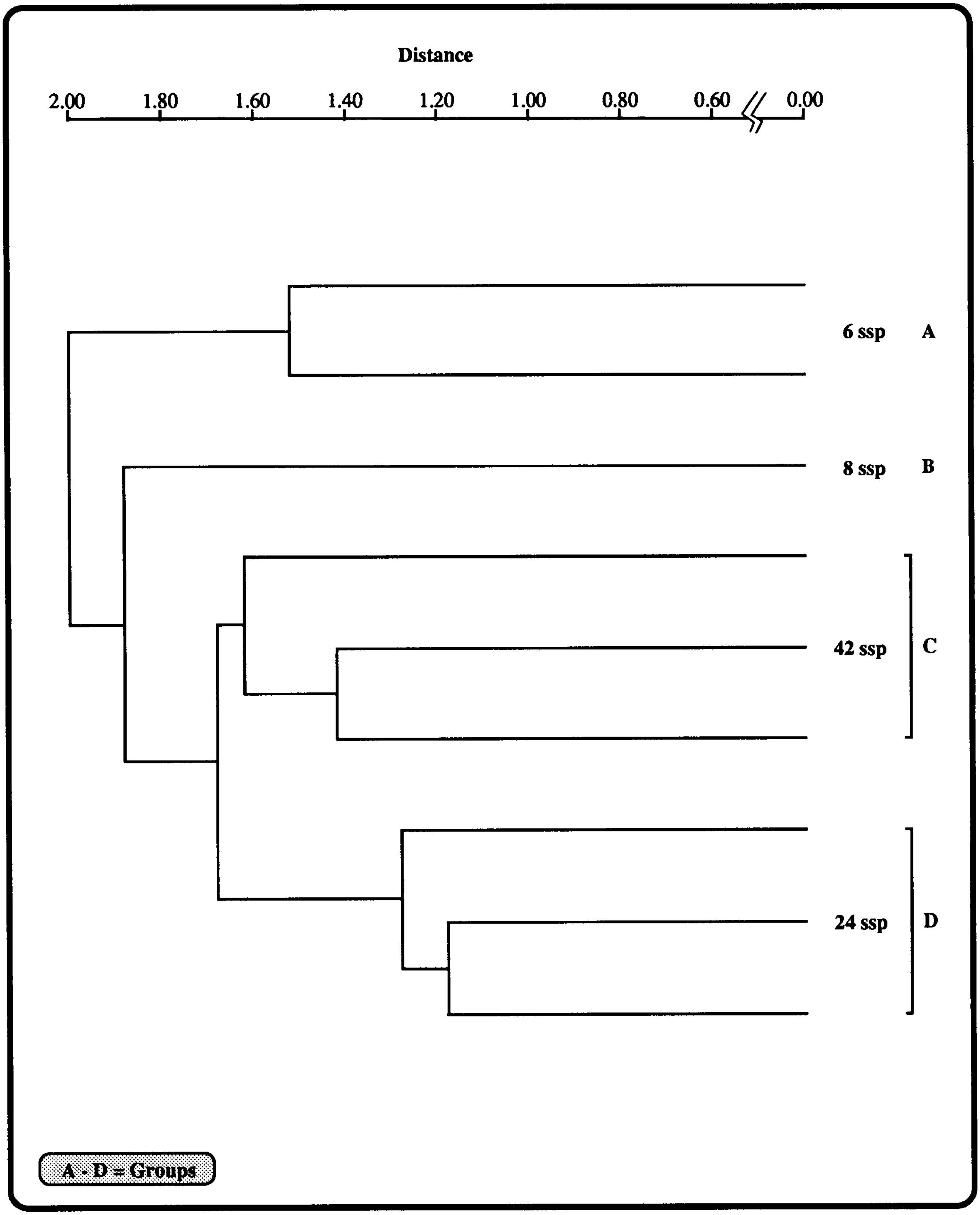


Figure 8-31. Species Clusters Cruise B-4, Winter.

stations and those representing the 20 most abundant taxa of the combined survey. These groups were made up of inshore species, those captured primarily at stations 1 and 2 of each transect, intermediate depth species, those captured primarily at stations 2 and 3 along each transect, or deep dwelling species, those captured primarily at the deepest station of each transect. Species captured at station 3 more frequently clustered with those captured at station 4 than with those captured at station 2, and those most frequently capturued at station 2 were more frequently captured with those captured at station 1 than those captured at station 3 over the course of the surveys. To a lesser degree, species were clustered within the two or three major groups according to transect. Those most frequently captured at the inshore stations along the Chandeleur Islands transect tended more frequently to cluster with those from the inshore stations of the Mobile Bay transect than with those of the inshore stations along the DeSoto Canyon transect. Also, species taken at stations of intermediate depth and greatest depth along the DeSoto Canyon transect tended to cluster with those of stations of similar depth along the Mobile Bay transect, except that those of the third station along the DeSoto Canyon transect were often distinct from those of the remainder of the stations and formed one of the minor groups. The two to four of the remaining groups (minor groups) of each survey, in part consist of species of low abundance captured at single stations, and were grouped by similarity in abundance rather than similarity in habitat preference. However, the clusters at station D3 appear to represent a unique assemblage clearly distinct from the assemblages at the other stations.

Several of the 20 most abundant species were consistently taken together at the same stations over the course of the surveys. *Serranus atrobranchus*, *Trichopsetta ventralis*, *Prionotus paralatus* and *Porichthys plectrodon* clustered together on all five of the surveys and were predominately captured at stations of intermediate depth. *Halieutichthys aculeatus* and *Stenotomus caprinus* also clustered together over the five surveys but they were primarily associated with the dominant inshore species group on the first, third and fourth surveys and with the dominant intermediate depth species group on the second and fifth surveys.

For all of the surveys combined, the 225 species captured at the total of 57 stations clustered into 10 groups (Figure 8-32). Group A consists of 38 species that were primarily captured at stations C2, C3, M2 and M3. Percent occurrence was higher at station 3 than at station 2 along the three transects. Representatives of the 20 most abundant species were: *Serranus atrobranchus, Trichopsetta ventralis, Prionotus paralatus, Peprilus burti, Porichtys plectrodon, Symphurus civittatus* and *Anchoa mitchilli.*

Group B consists of 19 species that were primarily captured at stations 3 and 4 of each transect. Percent occurrence was highest for station 4 of each transect and along the DeSoto Canyon transect among the transects. Representatives of the 20 most abundant species were: *Pontinus longispinis* and *Coelorinchus caribbaeus.*

Group C consists of four species captured at station C4 and, to a lesser extent, station C3. These four species occurred on only one survey and are considered of minor importance.

Group D consists of 14 species primarily captured on stations 1 and 2 of each transect. Percent occurrence decreased from the Chandeleur Islands transect though the DeSoto Canyon transect and was higher at station1 than at station 2 of each transect. Representatives of the 20 most abundant species were: *Halieutichthys aculeatus, Stenotomus caprinus, Syacium papillosum, S. gunteri, Anchoa hepsetus, Diplectrum bivittatum, Etropus rimosus* and *Prionotus longispinosus. Syacium papillosum* was progressively less abundant from the DeSoto Canyon through the Chandeleur Islands transect and *P. gunteri* was progressively less abundant from the Chandeleur Islands through the DeSoto Canyon transect. *Syacium papillosum* occurred only three times on the Chandeleur Islands transect and *S. gunteri* occurred only once on the DeSoto Canyon transect.

Group E consists of 24 species that were captured primarily at stations 1 and 2 of each of the transects. Percent occurrence decreased from the DeSoto Canyon though the Chandeleur Islands transect, and was relatively higher at station 1 than at station 2 along the Chandeleur Island and Mobile Bay transects, but relatively higher at station D2 than at station D1. Also percent occurrence was relatively higher at station D3 than at stations C3 or M3. Representatives of the 20 most abundant species included only *Serraniculus pumilio.*

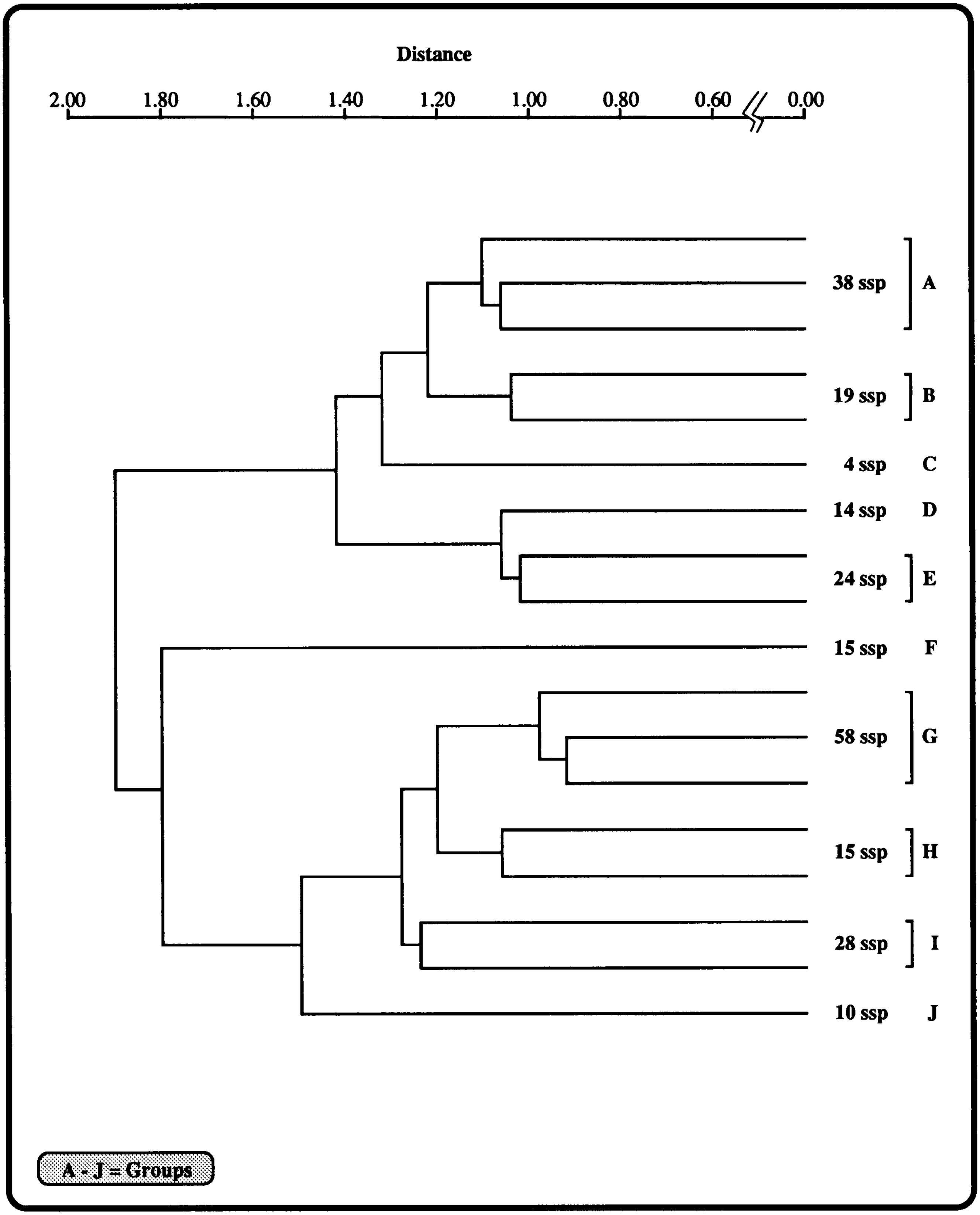


Figure 8-32. **Species Clusters for All Cruises Combined.**

Group F consists of 15 species that were captured at stations D3 and M4. Each of the species, except for *Scorpaena brasiliensis*, was captured on a single cruise and was of low overall abundance.

Group G consists of 58 species captured at a variety of stations along the three transects but all species but *Anchoa cubana* and *Serranus notospilus* were of relatively low abundance over the five surveys. *Anchoa cubana* was taken at only a single station, station D1, over the five surveys. *Serranus nitospinus* was captured at station D2 and D3 and at station C3. For the most part, the species of this group appeared to be grouped by their low abundance than by co-occurrence.

Group H consists of 15 species primarily captured at stations D2 and D3. All species were in low abundance although the majority occurred on two or more of the stations and on two or more of the cruises.

Group I consists of 28 species that, with one exception, were captured at stations 1 and 2 of each transect. Percent occurrence was highest for station C1. All species were in low abundance.

Group J consists of 10 species captured at stations D3 and D4. All were captured on the same survey and were low in abundance.

8.4 Discussion

8.4.1 Variability of the Trawl Catches

Trawl samples can, at best, be considered semi-quantitative because of the large source of variables inherent in the sampling procedures, i.e., coastal currents, sea state, wind, bottom topography and composition, operation of the ship, trawl winch and trawl, various degrees of clumped distribution among the fish species, location of fishes in relation to the bottom and relative ability of different fish species to avoid the trawl. However, despite these variables sequential tows, made at approximately the same location in rapid succession, deviated slightly over 3 from the mean value of the two tows. Also, there is general agreement among surveys and combined seasonal surveys for average number of species, average total number of individuals, average total weight and average H' diversity. The sole exception was the fifth survey in which the average number of species, average total number of individuals and average total weight were greatly reduced and the average H' diversity was moderately reduced. The deviations between sequential tows and correspondance among the first four surveys suggest that the lower values for the fifth survey are real, and the result of a major environmental perturbation.

8.4.2 Species Composition

The present study is remarkable because no species or group of species is dominant in abundance, suggesting that more than a single fish community was sampled along the coast of the study area. The most abundant species made up 10.3% of the catch, the top five species constituted 30.5%, the top 10 species comprised 45.1% and the 20 most abundant species made up 61.0% of the total catch. These relative abundances are similar to those given in Darnell and Kleypas (1987) for the entire eastern Gulf Mexico but are radically different from values given by Chittenden and McEachran (1976) and Darnell et al (1983) for the northwestern Gulf of Mexico. Darnell and Kleypas (1987) compiled data collected on groundfish surveys from the Mississippi River to the Florida Keys, and presented the following relative abundances: most abundant species 13.0%, top five species 31.2%, top 10 species 44.5% and top 20 species 60.0% of the total catch. The area covered by Darnell and Kleypas is two to three times the area covered in the present study and extends over almost the entire range of contiental shelf habitats in the Gulf of Mexico. In a study of the fishes caught incidental to shrimp fishing off the Texas coast from Galveston Bay to Matagorda Bay, Chittenden and McEachran (1976) listed the following relative abundances for the most abundant species of fishes: top species comprised 30%, top five species 75% and top 10 species 85% of the total catch for the inshore waters to 21 m; and the top species made up 39% and top five species 59% of the total catch for the middle section of the continental shelf, from 22 to 91 m. Darnell et al. (1983) compiled the data for a number of groundfish surveys from Louisiana to the Rio Grande River and reported the following relative abundances for the most abundant species of fishes: most abundant species consituted 24.9%, the top five species 61.3%, the first 10 species 76.8% and the 20 most abundant species 86.7% of the total catch.

The difference among these surveys in relative abundance may be due to variation in the substratum along the coast of the northern Gulf of Mexico.

The substratum of the northwestern Gulf of Mexico is soft and terrigenous, while that of the eastern Gulf of Mexico ranges from soft and terrigenous off the mouth of the Mississippi to calcareous off the west coast of Florida, the areas surveyed by Darnell and Kleypas (1987). The area surveyed in the present study ranges from soft and terrigenous to the transition zone between this and the calcareous substratum off the west coast of Florida. Different fish faunas dominate on the different substrata (Darnell and Kleypas 1987) and this may explain the differences in the relative abundances in fish species in the eastern and northwestern Gulf of Mexico.

The present study differs from all of the above cited surveys in the paucity of estuarine dependent sciaenids captured. Darnell and Kleypas (1987) reported that *Micropogonias undulatus* was second, *Bairdiella chrysoura* was ninth and *Leiostomus xanthurus* was eleventh in overall abundance. Chittenden and McEachran (1976) stated that *M. undulatus* was first, *Cynoscion nothus* was third, *Stellifer lanceolatus* was fourth and *C. arenarius* was fifth in abundance on the inner waters of the continental shelf (shore to 21 m). Darnell et al (1983) listed *M. pogonius* first, *C. nothus* fifth, *L. xanthurus* sixth and *C. arenarius* eighth in abundance. In the present study *M. undulatus* was fiftieth, *L. xanthurus* was sixtieth, *C. arenarius* was sixty-first in abundance and *B. chrysoura*, *C. nothus* and *S. lanceolatus* were not captured. No explanation is offered for the discrepencies among these studies.

8.4.3 Station Affinities

Stations clustered primarily by depth and secondarily by transects or diagonally across transects. Stations 1 and 2 (20, 60 m) clustered together, and, with exception of station D3, stations 3 and 4 (100, 200 m) clustered together. Within the first cluster, the first stations clustered together and grouped with most of the collections of station C2. Most of the collections of station D1 formed a subgroup of this cluster. The second stations, with exception of most of the collections at station C2, formed a cluster with the collections of station D3. Within the second cluster the third stations, with exception of the collections at station D3, clustered together and the fourth stations clustered together. Within the fourth stations, the collections along the DeSoto Canyon transect formed a separate grouping. Based on the clustering, it appears that stations C1 and C2 are very similar, that stations D2 and M2 and station D3 are very similar and that the fourth stations are very similar. Also, across transects there is a faunal break between the Chandeleur Islands and DeSoto Canyon transects.

8.4.4 Species Affinities

The species captured on the five surveys clustered into four to seven groups. Two or three of these were major groups, containing species in relatively high abundance that were taken at two or more stations on the survey, and the rest were minor groups, i.e., the species were of low abundance and generally were taken at only one station on the survey. The major groups were made up of inshore species, those captured at the first two stations along each transect (20, 60 m), intermediate depth species, those captured at the second and third stations along each transect (60, 100 m), and deep living species, those captured at the third and especially the fourth station along each transect (100, 200 m). To a lesser degree, the species clustered within the two or three major groups according to transect or diagonally across transects. Species of the inshore stations along the Chandeleur Islands transect clustered with those of the inshore stations along the Mobile Bay transect to a greater degree than either did with the inshore stations along the DeSoto Canyon transect. Species of deep stations along the DeSoto Canyon transect tended to cluster with those of the intermediate and deep stations of the Mobile Bay transect to a greater degree than with those of the Chandeleur Islands transect. Species of station D3 tended to form one of the small clusters.

Three major clusters resulted when all species captured in the study were combined in a single cluster analysis. These included an inshore assemblage, an intermediate depth assemblage and a deep dwelling assemblage of fishes. The inshore group was most abundant along stations C1 and C2 (20, 60 m) and least abundant at the inshore station along the DeSoto Canyon transect. Dominant species of this assemblage included: *Halieutichthys aculeatus*, *Stenotomus caprinus*, *Syacium papillosum*, *S. gunteri*, *Anchoa hepsetus*, *Diplectrum bivittatum*, *Etropus rimosus* and *Prionotus longispinosus*. The intermediate depth assemblage was most abundant at stations C2, C3 M2 and M3 (60, 100 m). Dominant species included: *Serranus atrobranchus*, *Trichopsetta ventralis*, *Prionotus paralatus*, *Peprilus burti*, *Porichthys plectrodon*, *Symphurus civitatus*, and *Anchoa mitchilli*. The deep dwelling assemblage was most abundant at the third and fourth stations of each transect, especially at station D4. Dominant species included: *Pontinus longispinis* and *Coelorinchus caribbaeus*. Three of the minor clusters consisted of species caught at station D3 and M4, stations D2 and D3 and stations D3 and D4.

The station clusters and species clusters suggest that species distributions are correlated primarily by depth and secondarily by some longititudinal factor such as substratum compostion. Substrata range from soft terrigenous muds along the Chandeleur Islands transect to sandy and shelly along the DeSoto Canyon transect. The rather marked change in species composition across the transects, possibly related to the gradient in substratum composition may explain the lack of numerical dominance of one or several species as is so typical of the northwestern Gulf of Mexico.

9.0 DEMERSAL FISH FOOD ANALYSIS

Rezneat M. Darnell

9.1 Introduction

Among the functional characteristics of ecological systems, none is more basic than the flow of materials and energy through the producer, consumer, and decomposer components. Whereas, this flow is governed in all systems by physical and chemical laws, each system is unique in the way this flow is programmed through the various biological components. The pattern of material and energy flow is referred to as the trophic structure of the system, and the primary means of studying this structure is through the analysis of food habits of the component species.

In the northern Gulf of Mexico area, at least 75 articles have appeared dealing with the food habits of one or a few species of fishes, but most reveal little about the overall trophic structure of the ecosystems. Only five studies appear to address these larger systems. Darnell (1958, 1961) examined the trophic structure of Lake Pontchartrain, Louisiana, and Sheridan (1978) studied the structure of Apalachicola Bay, Florida, both of these being estuarine type systems. Livingston (1982) published a major study on the trophic organization in the shallow seagrass system of Apalachee Bay in northern Florida. Based upon analysis of eight years of detailed study, he concluded that the trophic organization of this shallow system depends primarily upon specific feeding interactions between feeding aggregations and the key habitat features and productivity cycles.

Two major studies have addressed trophic relations of the open continental shelf. Divita et al. (1983) studied the food of 81 species of fishes from the continental shelf off Texas. Although their study was aimed primarily at determining predation upon penaeid shrimp, considering the scope of the study, much information has been gained concerning the trophic structure of the ecosystem. To date, only Rogers (1977) has endeavored to examine the trophic structure of the northern gulf continental shelf ecological system per se. His study involved analysis of the food of 4,500 specimens representing 26 species of abundant fishes and provided general information on how materials and energy are programmed throughout the broad continental shelf system from south Texas through northern Florida.

The present study was designed to examine the trophic structure of the continental shelf off Mississippi and Alabama. By focusing upon this more limited area and by making repeated collections from regular stations carefully spaced throughout the area, it was anticipated that the study would reveal not only the overall trophic picture of the shelf, but also trends, gradients, and local variations in the overall picture which might be associated with depth, transect, food resource availability, and other factors. In this respect, the study represents a pioneering effort to examine local aspects of the continental shelf ecosystem through the medium of fish food consumption.

9.2 Materials and Methods

Specimens for food analysis were collected during three winter and two summer cruises. In the field, all specimens were preserved in 10% formalin. Since no really large specimens were taken, it was not felt necessary to cut or inject the bodies to insure preservation of the stomach contents, and indeed it was later found that the food was generally well preserved. In the laboratory, all specimens were soaked in water, transferred to 70% ethanol, and eventually identified. Following taxonomic identification, body length measurements on all individuals permitted the sorting of specimens into size classes for stomach analysis. Species and size classes were selected on the basis of numerical abundance in the collections. For abundant species, efforts were made to include a range of size classes, depths, and transects. In only a few species was this really achieved due to the small numbers of fishes captured, the relative lack of larger individuals, and the limited distributional ranges of individual species. Furthermore, stomach analyses had to be well underway prior to the last three cruises, and it was not possible to anticipate which species and size classes would be taken at a later date. Efforts were made to analyze 10-20 stomachs with food from each size class and station represented by a given species. Although this was not always possible, it was approximated.

Within the laboratory, stomachs were removed and the contents placed in petri dishes with grids marked on the bottoms. In cases where the volume of material was large enough, its volume was determined by water displacement. The percentage composition of the various food categories was determined by visual estimation in the gridded dishes. Food items were identified to the lowest reasonable category. For many of the food items, this consisted of class or order, but in some cases the specimens were identified to the level of family or lower. In general, the methods employed followed closely those of Darnell (1958) and Rogers (1977).

For each stomach examined, an estimate was made of the percent fullness. Individual food items were then estimated in terms of percent of the material present. From these two sets of information, the data were converted to the percent contribution of each item to what would have been a full stomach. Thus, stomachs with small amounts of food did not overweigh those which were essentially full, and a truer estimate of the contribution of each item to the overall food of the size class was arrived at.

In dealing with the problem of depth distribution of food utilization by the total fish community, it was necessary to employ an objective method of determining whether or not the observed patterns deviated from the theoretical expectation. In this case, the theoretical expectation is that the utilization of a given food category was exactly equal at all depths, and the deviations of the observed from the expected values were evaluated using the Chi Square method. This procedure was also employed to determine the significance of deviations when comparing food group utilization on the three transects.

During the present study, there were 12 collecting stations and (counting all crustacean groups as well as organic detritus) 19 identifiable food groups. One of the goals of the study was to determine objectively the relationships of the various stations to each other based upon similarities and differences in food group utilization. This was accomplished through the use of principal component analysis techniques (SAS 1982). This method takes into account all the food groups and their abundances and through matrix analysis reduces the dimensionality of the data sets to smaller, more manageable numbers. In practice, the first principal component for a given station is plotted against the second principal component to provide a two-dimensional plot in which the several stations are positioned on the basis of their overall similarities and differences.

From such plots, the investigator can observe the dispersion of stations and visually aggregate neighboring stations.

This procedure was carried out with three different data sets: A) retaining all 19 food groups, B) combining all food groups with less than 5% abundance each into a single lumped category, and C) eliminating all food groups with less than 5% abundance each. It was found that retention of all food groups appears to place undue emphasis upon the rare categories. On the other hand, lumping or discarding the rare categories eliminates much of the characteristic and distinguishing quality of each station. The most informative procedure is to retain all 19 categories, and that is the approach taken here.

9.3 General Results

As seen in Table 9-1, a total of 4,675 specimens was analyzed, representing 49 species of fishes. These included all the species analyzed by Rogers (1977) except *Ogcocephalus parvus*, *Lepophidium brevibarbe*, *Cynoscion nebulosus*, *Cynoscion nothus*, *Citharichthys spilopterus*, and *Etropus crossotus*. For 15 species, an excess of 100 individuals were analyzed. These include (in order of descending abundance): *Halieuthichthys aculeatus* (461), *Stenotomus caprinus* (398), *Syacium papillosum* (324), *Pontinus longispinis* (221), *Diplectrum bivittatum* (217), *Serranus atrobranchus* (174), *Trichopsetta ventralis* (161), *Syacium gunteri* (151), *Prionotus alatus* (145), *Coelorinchus caribbaeus* (142), *Anchoa hepsetus* (137), *Prionotus longispinosus* (125), *Bembrops anatirostris* (106), *Symphurus civitatus* (104), and *Centropristis philadelphica* (103). Among the twenty six most abundant species taken in the fish collection, all were analyzed for food except *Prionotus paralatus*. Five size classes were examined in one species, four in two species, three in ten species, two in nineteen species, and the remaining nineteen fish species were represented by a single size class each.

Results of the food analyses are presented in Tables 9-2 through 9-7. These tables display the food of individual species and size classes along the horizontal lines and the multi-species utilization of each food category down the vertical columns. The six tables consist of three paired sets. The first table of a pair shows the percentage of food in each of the major categories,

Table 9.1. Species and size classes of fishes analyzed for stomach food contents.

Species	Size Classes (mm)	Number of stomachs		Total examined for species
		Examined	With food	
Engraulidae				
Anchoa cubana	26-50	20	20	40
	51-75	20	20	
Anchoa hepsetus	26-50	23	23	137
	51-75	53	53	
	76-125	61	58	
Anchoa mitchilli	51-75	20	20	20
Sternoptychidae				
Polyipnus asteroides	26-50	20	20	20
Synodontidae				
Saurida brasiliensis	26-75	53	40	82
	76-100	29	26	
Synodus foetens	51-150	27	24	99
	151-200	36	36	
	201-400	36	34	
Synodus poeyi	51-75	23	23	49
	76-125	26	26	
Batrachoididae				
Porichthys plectrodon	51-150	64	44	64
Ogcocephalidae				
Halieutichthys aculeatus	26-50	75	56	461
	51-75	323	245	
	76-100	63	53	
Ogcocephalus nasutus	51-125	25	15	25
Zalieutes mcgintyi	51-100	38	35	38
Gadidae				
Steindachneria argentea	101-150	9	7	9
Macrouridae				
Bathygadus macrops	101-150	36	33	73
	151-200	22	22	
	201-300	15	15	

Table 9-1. Cont'd.

Species	Size Classes (mm)	Number of stomachs		Total examined for species
		Examined	With food	
Bathygadus melanobranchus	51-200	35	31	35
Coelorinchus caribbaeus	51-100	22	22	142
	101-150	44	44	
	151-200	40	40	
	201-250	36	36	
Perchichthyidae				
Synagrops spinosa	51-75	25	25	25
Serranidae				
Centropristis philadelphica	51-125	54	44	103
	126-225	49	40	
Diplectrum bivittatum	26-75	97	65	217
	76-100	86	72	
	101-125	34	29	
Serraniculus pumilio	0-50	51	41	80
	51-75	29	24	
Serranus atrobranchus	51-75	21	15	174
	76-100	119	99	
	101-125	34	30	
Serranus notospilus	26-75	66	41	66
Carangidae				
Chloroscombrus chrysurus	26-75	24	24	59
	76-150	35	35	
Trachurus lathami	101-125	23	23	23
Lutjanidae				
Pristipomoides aquilonaris	26-150	18	11	18
Rhomboplites aurorubens	51-100	16	16	16
Haemulidae				
Haemulon aurolineatum	76-150	17	16	17

Table 9-1. Cont'd.

Species	Size Classes (mm)	Number of stomachs		Total examined for species
		Examined	With food	
Sparidae				
Stenotomus caprinus	0-25	20	20	398
	26-50	30	24	
	51-75	70	69	
	76-100	192	154	
	101-125	86	76	
Sciaenidae				
Cynoscion arenarius	151-300	11	7	11
Leiostomus xanthurus	101-150	15	13	52
	151-200	37	36	
Micropogonias undulatus	101-150	55	53	72
	151-200	17	17	
Polynemidae				
Polydactylus octonemus	76-125	24	23	24
Percophidae				
Bembrops anatirostris	26-125	33	30	106
	126-150	32	31	
	151-200	41	38	
Gobiidae				
Bollmannia communis	51-75	20	18	20
Stromateidae				
Peprilus burti	76-100	46	46	87
	101-150	41	40	
Scorpaenidae				
Pontinus longispinis	26-75	83	69	221
	76-100	69	63	
	101-150	69	60	
Scorpaena calcarata	26-75	53	37	68
	76-125	15	11	
Triglidae				
Bellator militaris	26-50	31	22	71
	51-100	40	32	
Prionotus alatus	26-100	58	52	145
	101-175	87	67	

Table 9-1. Cont'd.

Species	Size Classes (mm)	Number of stomachs		Total examined for species
		Examined	With food	
Prionotus longispinosus	51-75	28	25	125
	76-125	48	41	
	126-175	49	43	
Prionotus roseus	51-125	24	24	46
	126-150	22	22	
Prionotus rubio	51-100	39	33	83
	101-175	44	38	
Prionotus scitulus	26-50	24	16	65
	101-175	41	35	
Prionotus stearnsi	26-100	57	51	57
Bothidae				
Etropus rimosus	26-50	20	20	93
	51-125	73	53	
Syacium gunteri	26-75	77	61	151
	76-150	74	55	
Syacium papillosum	26-75	76	43	324
	76-100	50	48	
	101-150	110	88	
	151-200	88	74	
Trichopsetta ventralis	26-75	24	22	161
	76-100	59	42	
	101-250	78	63	
Cynoglossidae				
Symphurus civitatus	51-100	36	32	104
	101-125	68	62	
Symphurus plagiusa	76-125	87	78	99
	126-150	12	12	
TOTAL				4,675

and the second displays the percent composition of the various crustacean groups. Trace amounts are indicated only in Table 9-2, but they are discussed later in the individual species accounts.

Tables 9-2 and 9-3 give percent composition of the food of all size classes of all fish species regardless of depth and transect. Inspection of Table 9-2 reveals that sand and/or silt, although frequently present in trace amounts, made up significant percentages (less than 5%) of the stomach contents only in bottom feeding species such as the batfish (*Ogcocephalus nasutus*), duckbill flathead (*Bembrops anatirostris*), and several flatfishes (*Syacium gunteri, Trichopsetta ventralis, Symphurus civitatus*, and *Symphurus plagiusa*). Small amounts of very fine silt appeared in stomachs of the Atlantic bumper (*Chloroscombrus chrysurus*). This filter feeder is presumed to have strained the material from the supra-benthic layer of the water column. Most of the food material appeared in the categories: polychaetes, crustaceans, fishes, and unidentified animal matter. An intermediate amount occurred in the cephalopod category, and there was little utilization of the minor phyla, valved mollusks (gastropods and bivalves), or organic detritus. Inspection of Table 9-3 reveals that among the crustaceans, shrimp formed by far the most important food category. These included the young of a great many species as well as the adults of small species (including mysidaceans). Very few adult penaeids were encountered. Crabs and amphipods occurred frequently and made up moderate percentages of the total food. The following categories consisted of less than five percent of the food consumed: small benthic crustaceans (ostracods, harpacticoid copepods, and cumaceans), calanoid copepods, isopods (including tanaids), lobsters, megalopa, and small stomatopods.

In Tables 9-4 and 9-5, the data have been sorted by both size class and depth. Because of the number of vertical columns involved, only the major identifiable food categories have been listed. In Table 9-4, the minor phyla, valved mollusks, unidentifiable animal matter, and organic detritus are deleted, leaving only the cephalopods, polychaetes, crustaceans, and fishes. Since these four groups made up over 98% of the identifiable food, little information has been lost. In Table 9-5, the identifiable crustaceans have been combined into four ecologically important categories as follows: zooplankton (calanoid copepods), benthic micro-crustaceans (ostracods,

Table 9-2. Percentage composition of the major categories of food items encountered in all size classes of all fish species examined in the present study. A trace amount is indicated by the letter 't'. In the sand/silt category 0-5% is indicated by a +, 6-10% by a ++, and greater than 10% by a +++.

Species	Size Class (mm)	Stomachs examined	No. with food	Sand/Silt present	Food categories (percent)							
					Minor phyla	Mollusks (valved)	Cephalo pods	Poly-chaetes	Crus-taceans	Fishes	Animal Matter	Organic detritus
Anchoa cubana	26-50	20	20	t					62		38	
	51-75	20	20			t		t	95	5		
Anchoa hepsetus	26-50	23	23						37		63	
	51-75	53	53			t		t	54	16	30	
	76-125	61	58					2	43	7	48	
Anchoa mitchilli	51-75	20	20						100			
Polyipnus asteroides	26-50	20	20						90	10		
Saurida brasiliensis	26-75	53	40					t	8	91	1	
	76-100	29	26					t	44	56		
Synodus foetens	51-150	27	24				5	t	10	63	22	
	151-200	36	36	t			18		3	77	2	
	201-400	36	34						3	82	14	1
Synodus poeyi	51-75	23	23					t	75	24	1	
	76-125	26	26					t	62	30	8	
Porichthys plectrodon	51-150	64	44	t					37	24	39	
Halieutichthys aculeatus	26-50	75	56	t	1			41	24	12	22	
	51-75	323	245	t	1	t		50	20	1	28	
	76-100	63	53	t	5			37	23		35	
Ogcocephalus nasutus	51-125	25	15	+++	t	t		66	25	1	8	
Zalieutes mcgintyi	51-100	38	35					97	3			
Steindachneria argentea	101-150	9	7							95	5	

Table 9-2. Cont'd.

Species	Size Class (mm)	Stomachs examined	No. with food	Sand/Silt present	Food categories (percent)							
					Minor phyla	Mollusks (valved)	Cephalo pods	Poly-chaetes	Crus-taceans	Fishes	Animal Matter	Organic detritus
Bathygadus macrops	101-150	36	33	t				5	31	57	7	
	151-200	22	22						26	72	2	
	201-300	15	15	t					8	92		
Bathygadus melanobranchus	51-200	35	31	t	2				53	45		
Coelorinchus caribbaeus	51-100	22	22					64	1		35	
	101-150	44	44					56	23		21	
	151-200	40	40					45	45			10
	201-250	36	36					29	39		32	t
Synagrops spinosa	51-75	25	25				5	t	55	40		
Centropristis philadelphica	51-125	54	44	t		t		t	72	22	6	t
	126-225	49	40	t			t	6	70	6	18	t
Diplectrum bivittatum	26-75	97	65	t				3	75	2	20	
	76-100	86	72	t				5	69		26	
	101-125	34	29					t	58		42	
Serraniculus pumilio	0-50	51	41	t				3	74		23	
	51-75	29	24						97		3	
Serranus atrobranchus	51-75	21	15					t	75		25	
	76-100	119	99	t				3	71	t	26	
	101-125	34	30	t				5	52		42	1
Serranus notospilus	26-75	66	41				3	9	44	15	29	
Chloroscombrus chrysurus	26-75	24	24	+					39		61	
	76-150	35	35	+					17	10	66	7
Trachurus lathami	101-125	23	23						42	20	38	
Pristipomoides aquilonaris	26-150	18	11	+				8	35		57	

Table 9-2. Cont'd.

Species	Size Class (mm)	Stomachs examined	No. with food	Sand/Silt present	Food categories (percent)							
					Minor phyla	Mollusks (valved)	Cephalo pods	Poly-chaetes	Crus-taceans	Fishes	Animal Matter	Organic detritus
Rhomboplites aurorubens	51-100	16	16					5	88		7	
Haemulon aurolineatum	76-150	17	16	t				55	21		24	
Stenotomus caprinus	0-25	20	20					15	63		22	
	26-50	30	24		4			29	15		52	
	51-75	70	69	+				38	16	1	45	t
	76-100	192	154	t	t	t	2	47	8	1	31	11
	101-125	86	76	t	t	t		31	20	22	19	8
Cynoscion arenarius	151-300	11	7					t	65	10	24	1
Leiostomus xanthurus	101-150	15	13	+		1		37	3		59	
	151-200	37	36	t		t		80	16	t	2	2
Micropogonias undulatus	101-150	55	53	t		t		47	32	7	13	1
	151-200	17	17	t		t		40	17		6	37
Polydactylus octonemus	76-125	24	23					t	70	30		
Bembrops anatirostris	26-125	33	30	t				14	80		6	
	126-150	32	31	t		t	2	4	36	45	13	
	151-200	41	38	++		t		2	47	31	20	
Bollmannia communis	51-75	20	18					5			95	
Peprilus burti	76-100	46	46						51		49	
	101-150	41	40					1	18		81	
Pontinus longispinis	26-75	83	69	t					74		25	1
	76-100	69	63	t				3	60	12	25	
	101-150	69	60	t				1	66	5	27	1

Table 9-2. Cont'd.

Species	Size Class (mm)	Stomachs examined	No. with food	Sand/Silt present	Food categories (percent)							
					Minor phyla	Mollusks (valved)	Cephalo pods	Poly-chaetes	Crus-taceans	Fishes	Animal Matter	Organic detritus
Scorpaena calcarata	26-75	53	37	+					88		12	
	76-125	15	11	t					98		2	
Bellator militaris	26-50	31	22	t				t	64	3	33	
	51-100	40	32	t					53	39	8	
Prionotus alatus	26-100	58	52	t				3	60	20	17	
	101-175	87	67	t				11	32	26	30	1
Prionotus longispinosus	51-75	28	25					7	76	1	16	
	76-125	48	41	t				1	94	3	2	
	126-175	49	43					t	60	18	22	
Prionotus roseus	51-125	24	24	t				t	87	2	11	
	126-175	22	22			t		2	92	t	6	
Prionotus rubio	51-100	39	33	t				5	60	23	12	
	101-175	44	38	+				t	77	7	16	
Prionotus scitulus	26-50	24	16	t				31	26		43	
	101-175	41	35	t				3	77		20	
Prionotus stearnsi	26-100	57	51	t			10		75	12	3	
Etropus rimosus	26-50	20	20					31	53		16	
	51-125	73	53	t	t			34	42		14	
Syacium gunteri	26-75	77	61	+++		t		7	56	10	27	
	76-150	74	55	+++		2		21	58		19	
Syacium papillosum	26-75	76	43	t				27	49	5	19	
	76-100	50	48	t			8	12	41	24	15	
	101-150	110	88	t				12	60	7	21	
	151-200	88	74	t		t	8	3	32	44	13	

Table 9-2. Cont'd.

Species	Size Class (mm)	Stomachs examined	No. with food	Sand/Silt present	Food categories (percent)							
					Minor phyla	Mollusks (valved)	Cephalo pods	Poly-chaetes	Crus-taceans	Fishes	Animal Matter	Organic detritus
Trichopsetta ventralis	26-75	24	22	+				11	63	9	17	
	76-100	59	42	++		t		6	63	13	17	1
	101-250	78	63	+	t	t		4	77	11	8	
Symphurus civitatus	51-100	36	32	+++		1		21	11		67	
	101-125	68	62	+++				25	10		51	14
Symphurus plagiusa	76-125	87	78	+++		2		15	34		36	13
	126-150	12	12	+++		1		9	24		52	14
Percentages					0.13	0.07	0.62	13.18	47.52	14.38	22.83	1.27

Table 9-3. Percentage composition of the crustacean categories encountrered in all size classes of all fish species examined in the present study.

Species	Size Class (mm)	Small benthic crusts.	Calanoid cope-pods	Isopods	Amphi-pods	Shrimp	Lobsters	Mega-lopa	Crabs	Stoma-topods	Unid. Crusts.	Total Crusts.
Anchoa cubana	26-50	12	18		16	16						62
	51-75	15	14		9	57						95
Anchoa hepsetus	26-50	1	14		4			18				37
	51-75	1	5		1	37		8	2			54
	76-125		3		4	28		8				43
Anchoa mitchilli	51-75		3		2						95	100
Polyipnus asteroides	26-50		15	4	7	45					19	90
Saurida brasiliensis	26-75					8						8
	76-100				3	16			16	8	1	44
Synodus foetens	51-150					5			3		2	10
	151-200					3						3
	201-400										3	3
Synodus poeyi	51-75					25	43				7	75
	76-125					25	32				5	62
Porichthys plectrodon	51-150					11				26		37
Halieutichthys aculeatus	26-50		2				18		1		3	24
	51-75			1	3	10			1	2	3	20
	76-100				3	12			2	6		23
Ogcocephalus nasutus	51-125						10				15	25
Zalieutes mcgintyi	51-100					3						3
Steindachneria argentea	101-150											0

Table 9-3. Cont'd.

Species	Size Class (mm)	Small benthic crusts.	Calanoid copepods	Isopods	Amphipods	Shrimp	Lobsters	Megalopa	Crabs	Stomatopods	Unid. Crusts.	Total Crusts.
Bathygadus macrops	101-150					31						31
	151-200					25					1	26
	201-300					8						8
Bathygadus melanobranchus	51-200					53						53
Coelorinchus caribbaeus	51-100				1							1
	101-150				4	14			5			23
	151-200			1	17	20			7			45
	201-250				2	35			2			39
Synagrops spinosa	51-75					29	14	6	6			55
Centropristis philadelphica	51-125					66			6			72
	126-225					45			11	6	8	70
Diplectrum bivittatum	26-75					70		2		2	1	75
	76-100		1	4	2	46			11		5	69
	101-125					57					1	58
Serraniculus pumilio	0-50				4	47	4		14		5	74
	51-75					49		48				97
Serranus atrobranchus	51-75					74			1			75
	76-100				2	49			18		2	71
	101-125					34	18					52
Serranus notospilus	26-75					43	1					44
Chloroscombrus chrysurus	26-75		18			21						39
	76-150		1			4		1			11	17
Trachurus lathami	101-125									42		42
Pristipomoides aquilonaris	26-150		1		18	16						35

Table 9-3. Cont'd.

Species	Size Class (mm)	Small benthic crusts.	Calanoid cope-pods	Isopods	Amphi-pods	Shrimp	Lobsters	Mega-lopa	Crabs	Stoma-topods	Unid. Crusts.	Total Crusts.
Rhomboplites aurorubens	51-100				26	62						88
Haemulon aurolineatum	76-150				2	19						21
Stenotomus caprinus	0-25	1	4		31	7					20	63
	26-50		1		7	2					5	15
	51-75				5	4		1	5	1		16
	76-100		1		1	2			3		1	8
	101-125		1			12			6		1	20
Cynoscion arenarius	151-300					54					11	65
Leiostomus xanthurus	101-150					3						3
	151-200				3	13						16
Micropogonias undulatus	101-150			3	14	14					1	32
	151-200					15					2	17
Polydactylus octonemus	76-125		11		44	6		8	1			70
Bembrops anatirostris	26-125			1	1	78						80
	126-150					34			1		1	36
	151-200				1	46						47
Bollmannia communis	51-75											0
Peprilus burti	76-100		13			23					15	51
	101-150			1		2				10	5	18
Pontinus longispinis	26-75					48	6		16		4	74
	76-100				2	29			28		1	60
	101-150				3	46			14	3		66

Table 9-3. Cont'd.

Species	Size Class (mm)	Small benthic crusts.	Calanoid copepods	Isopods	Amphipods	Shrimp	Lobsters	Megalopa	Crabs	Stomatopods	Unid. Crusts.	Total Crusts.
Scorpaena calcarata	26-75					36	4		13	27	8	88
	76-125				1	67	5		5	20		98
Bellator militaris	26-50	1	8	1	22	19			13			64
	51-100		1	1	10	22		8	11			53
Prionotus alatus	26-100		1		1	18			31		9	60
	101-175					22			10			32
Prionotus longispinosus	51-75				5	62			6		3	76
	76-125					72			22			94
	126-175			3		50			5	2		60
Prionotus roseus	51-125				1	83			3			87
	126-175					88			4			92
Prionotus rubio	51-100					48		2	10			60
	101-175					47			8		22	77
Prionotus scitulus	26-50				8	18						26
	101-175				9	39			29			77
Prionotus stearnsi	26-100			1	5	27		12	3	27		75
Etropus rimosus	26-50	1	7	11	14	20						53
	51-125	3		2	11	21		1	4			42
Syacium gunteri	26-75				20	28			8			56
	76-150				8	30			18		2	58
Syacium papillosum	26-75				4	28	4	2	10	1		49
	76-100				14	17			9	3		41
	101-150				2	28	1		23	3	3	60
	151-200					17			13	2		32

Table 9-3. Cont'd.

Species	Size Class (mm)	Small benthic crusts.	Calanoid cope-pods	Isopods	Amphi-pods	Shrimp	Lobsters	Mega-lopa	Crabs	Stoma-topods	Unid. Crusts.	Total Crusts.
Trichopsetta ventralis	26-75				1	51	5		6			63
	76-100				3	34	3				23	63
	101-250					67	5		1	3	1	77
Symphurus civitatus	51-100				4	6					1	11
	101-125			2	2	2	4					10
Symphurus plagiusa	76-125			2	14	2			15		1	34
	126-150				17				7			24
Percentages		0.75	3.08	0.82	9.00	58.61	3.81	2.69	10.05	4.17	7.03	

Table 9-4. Percentage composition of the four primary food groups encountered in all size classes of all species examined, separated by depth (1 = 20 m, 2 = 60 m, 3 = 100 m, and 4 = 200 m).

Species	Size Class (mm)	Cephalopods				Polychaetes				Crustaceans				Fishes			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Anchoa cubana	26-50									62							
	51-75									95				5			
Anchoa hepsetus	26-50									37							
	51-75									58	43			14	20		
	76-125					3				69	15			14			
Anchoa mitchilli	51-75									100							
Polyipnus asteroides	26-50												90				10
Saurida brasiliensis	26-75										9				91	100	
	76-100									100	41				59		
Synodus foetens	51-150		7							19	7			19	79		
	151-200	25								4				70	93	100	
	201-400										5			78	79	99	
Synodus poeyi	51-75										75				24		
	76-125										62				30		
Porichthys plectrodon	51-150									42	44				29		
Halieutichthys aculeatus	26-50					47	50	19		13	50	48		17			
	51-75					51	65	40	95	45	6	16				1	
	76-100						44	32			13	30					
Ogcocephalus nasutus	51-125							66				25				1	
Zalieutes mcgintyi	51-100								97				3				
Steindachneria argentea	101-150															95	

Table 9-4. Cont'd.

Species	Size Class (mm)	Cephalopods				Polychaetes				Crustaceans				Fishes			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Bathygadus macrops	101-150								15			8	75			87	
	151-200												26				72
	201-300												8				92
Bathygadus melanobranchus	51-200												53				45
Coelorinchus caribbaeus	51-100								64				1				
	101-150								56				23				
	151-200								45				45				
	201-250								29				39				
Synagrops spinosa	51-75			5								55				40	
Centropristis philadelphica	51-125										69	96			24		
	126-225										67	70				7	
Diplectrum bivittatum	26-75					3				75				2			
	76-100					5				69							
	101-125									58							
Serraniculus pumilio	0-50						3				77	20					
	51-75											97					
Serranus atrobranchus	51-75										75						
	76-100					4		4		64	79	74	50				
	101-125							5				52					
Serranus notospilus	26-75			3				9				44				15	
Chloroscombrus chrysurus	26-75									36	68						
	76-150									17				10			
Trachurus lathami	101-125											42				20	
Pristipomoides aquilonaris	26-150							10			53	30					

Table 9-4. Cont'd.

Species	Size Class (mm)	Cephalopods				Polychaetes				Crustaceans				Fishes			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Rhomboplites aurorubens	51-100					5				88							
Haemulon aurolineatum	76-150					56	30			21	10						
Stenotomus capririus	0-25					15				63							
	26-50					29				15							
	51-75					36	52			12	45			1			
	76-100		5			68	24	45		3	7	21					80
	101-125						17	54			13	32			30	9	
Cynoscion arenarius	151-300											87		20		7	
Leiostomus xanthurus	101-150					17		45		6		2		1			
	151-200					95		75		2		20		2			
Micropogonias undulatus	101-150					47		50		33		20		24			
	151-200					5		57		5		23					
Polydactylus octonemus	76-125									70				29			
Bembrops anatirostris	26-125							40				53	93				
	126-150				2				5			20	39			70	42
	151-200								2			57	46			25	32
Bollmannia communis	51-75						5										
Peprilus burti	76-100									51							
	101-150							1		1		19					
Pontinus longispinis	26-75											74	74				
	76-100								3			90	60				12
	101-150								1				66				5

Table 9-4. Cont'd.

Species	Size Class (mm)	Cephalopods				Polychaetes				Crustaceans				Fishes			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Scorpaena calcarata	26-75									54	90						
	76-125										89	100					
Bellator militaris	26-50										64				3		
	51-100										53				39		
Prionotus alatus	26-100							3			40	62			30	19	
	101-175							11				32				26	
Prionotus longispinosus	51-75					14	5			32	89				1		
	76-125						1			97	91			2	4		
	126-175										60				18		
Prionotus roseus	51-125									90	87				2		
	126-175						2				92						
Prionotus rubio	51-100					4	7			82	34			12	36		
	101-175										64	79			9	6	
Prionotus scitulus	26-50					31				26							
	101-175					3				77							
Prionotus stearnsi	26-100		11								76	48			10	49	
Etropus rimosus	26-50						31				53						
	51-125					32	36			50	36						
Syacium gunteri	26-75					7	7			61	44				33		
	76-150					25				53	84						
Syacium papillosum	26-75					34	16			43	58			8			
	76-100		9			20	11			80	39				25		
	101-150					7	14			76	59	44			9		
	151-200	20	5	4		10	2			45	29	29		1	52	62	

Table 9-4. Cont'd.

Species	Size Class (mm)	Cephalopods				Polychaetes				Crustaceans				Fishes			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Trichopsetta ventralis	26-75							11				63				9	
	76-100							9			70	61				18	
	101-250							5				71	98			13	
Symphurus civitatus	51-100					23	13			12	6						
	101-125					27	26		23	7	6		24				
Symphurus plagiusa	76-125					12	60			36	8						
	126-150					9				24							

Table 9-5. Percentage composition of the four primary crustacean food groups encountered in all size classes of all species examined, separated by depth (1 = 20 m, 2 = 60 m, 3 = 100 m, and 4 = 200 m).

Species	Size Class (mm)	Zooplankton				Benthic micro-crustaceans				Benthic small crustaceans				Larger mobile species			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Anchoa cubana	26-50	19				12				16				16			
	51-75	14				15				9				57			
Anchoa hepsetus	26-50	14				18				5							
	51-75	6	2			12				1				36	41		
	76-125	11				6	1			17				35	14		
Anchoa mitchilli	51-75	3								2							
Polyipnus asteroides	26-50			15								11				45	
Saurida brasiliensis	26-75														9		
	76-100														40		
Synodus foetens	51-150														6		
	151-200													4			
	201-400																
Synodus poeyi	51-75														68		
	76-125														57		
Porichthys plectrodon	51-150													42	43		
Halieutichthys aculeatus	26-50	1								1				10	50	48	
	51-75									10	1	2		34	4	13	
	76-100										4	2			9	28	
Ogcocephalus nasutus	51-125															9	
Zalieutes mcgintyi	51-100																3
Steindachneria argentea	101-150																

Table 9-5. Cont'd.

Species	Size Class (mm)	Zooplankton				Benthic micro-crustaceans				Benthic small crustaceans				Larger mobile species			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Bathygadus macrops	101-150															8	75
	151-200																20
	201-300																8
Bathygadus melanobranchus	51-200				1												52
Coelorinchus caribbaeus	51-100												1				
	101-150												1				20
	151-200												14				30
	201-250												1				37
Synagrops spinosa	51-75							5								50	
Centropristis philadelphica	51-125														69	96	
	126-225														53	70	
Diplectrum bivittatum	26-75					1								74			
	76-100	2								7				55			
	101-125													58			
Serraniculus pumilio	0-50										1	20			69		
	51-75							48								48	
Serranus atrobranchus	51-75														75		
	76-100	1								3	1		4	61	63	74	
	101-125															52	
Serranus notospilus	26-75															44	
Chloroscombrus chrysurus	26-75	13	68											23			
	76-150					5								4			
Trachurus lathami	101-125															42	
Pristipomoides aquilonaris	26-150		5								48	3				28	

Table 9-5. Cont'd.

Species	Size Class (mm)	Zooplankton				Benthic micro-crustaceans				Benthic small crustaceans				Larger mobile species			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Rhomboplites aurorubens	51-100									26				61			
Haemulon aurolineatum	76-150		1							1				20	6		
Stenotomus caprinus	0-25	1				3				57				3			
	26-50	2								6				3			
	51-75		4			1				3	40			7			
	76-100		1											3	4	20	
	101-125														12	32	
Cynoscion arenarius	151-300															80	
Leiostomus xanthurus	101-150					1										2	
	151-200									1		1		1		19	
Micropogonias undulatus	101-150									23				9		20	
	151-200													5		23	
Polydactylus octonemus	76-125	11				4				50				5			
Bembrops anatirostris	26-125												2			53	91
	126-150												1			20	36
	151-200												2			57	44
Bollmannia communis	51-75																
Peprilus burti	76-100	25															
	101-150									1						16	
Pontinus longispinis	26-75											1				74	67
	76-100																59
	101-150												1				65

Table 9-5. Cont'd.

Species	Size Class (mm)	Zooplankton				Benthic micro-crustaceans				Benthic small crustaceans				Larger mobile species			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Scorpaena calcarata	26-75														84		
	76-125											1			85	99	
Bellator militaris	26-50		5				1				20				30		
	51-100		1				7				8				36		
Prionotus alatus	26-100			1								1			40	45	
	101-175															32	
Prionotus longispinosus	51-75									5				27	88		
	76-125													96	91		
	126-175										5				55		
Prionotus roseus	51-125										1			90	86		
	126-175														91		
Prionotus rubio	51-100					3								79	33		
	101-175														40	66	
Prionotus scitulus	26-50									8				18			
	101-175									2				74			
Prionotus stearnsi	26-100						8	24			5	24			62		
Etropus rimosus	26-50		14				1				20				19		
	51-125		1			2				29	7			19	28		
Syacium gunteri	26-75									14	24			46	20		
	76-150									8	17			45	59		
Syacium papillosum	26-75						3			3	4			40	51		
	76-100						1				4			80	34		
	101-150									3	2	3		33	57	41	
	151-200													45	29	30	

Table 9-5. Cont'd.

Species	Size Class (mm)	Zooplankton				Benthic micro-crustaceans				Benthic small crustaceans				Larger mobile species			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Trichopsetta ventralis	26-75															63	
	76-100											1				58	
	101-250															71	97
Symphurus civitatus	51-100									4	1			7	5		
	101-125									4	3		20	4	2		3
Symphurus plagiusa	76-125									22	8			12			
	126-150									17				7			

harpacticoid copepods, and crab megalopa), benthic small crustaceans (cumaceans, tanaids, isopods, amphipods, and small anomurans), and larger mobile species (shrimp, lobsters, crabs, and stomatopods). There is clearly some overlap between the several categories in terms of size class and life habits of the component crustacean groups, but these lumped categories are generally valid and they greatly facilitate interpretation of the data.

In Tables 9-6 and 9-7, the data have been sorted by size class and transect so that it can be determined whether a size class of fishes was consuming a given food category in the Chandeleur, Mobile, or De Soto Canyon area. In these tables, the food categories have been lumped as they were in Tables 8-4 and 8-5.

9.4 Food Habits of Individual Species

The following discussions of the food of individual fish species are based upon data presented in Tables 9-2 through 9-7 supplemented by additional notes taken during the course of the stomach analyses. Individual species are taken up in phylogenetic order by family as listed in Table 9-1.

Engraulidae - Anchovies

Anchoa cubana. Twenty specimens of the Cuban anchovy were examined in each of two size classes (26-50 mm and 51-75 mm), and all contained food. This species was taken at a single station (D1) during the winter. Crustaceans made up the bulk of the identifiable food in both size classes, and some fish remains appeared in the larger size class. Unidentifiable animal matter made up about two fifths of the stomach contents of the smaller size class. Trace amounts of sediment, valved mollusks, and polychaetes revealed that the species does forage on the bottom. Small benthic crustaceans, calanoid copepods, and amphipods constituted 9-18% of the food of both size classes. Shrimp made up 16% of the food of the smaller size class and 57% of the food of the larger size class. This tropical anchovy feeds both in the water column and on the bottom. Smaller individuals depend largely upon small crustaceans, but the larger anchovies take in much more shrimp and some fishes.

Anchoa hepsetus. A total of 137 specimens of the striped anchovy was examined representing three size classes (26-50 mm, 51-75 mm, and 76-

Table 9-6. Percentage composition of the four primary food groups encountered in all size classes of all species examined, separated by transect (C = Chandeleur, M = Mobile Bay, and D = De Soto Canyon transects).

Species	Size Class (mm)	Small benthic inverteBrates			Polychaetes			Cephalopods			Crustaceans			Fishes		
		C	M	D	C	M	D	C	M	D	C	M	D	C	M	D
Anchoa cubana	26-50												62			
	51-75												95			5
Anchoa hepsetus	26-50										34	47				
	51-75										54	54		9	24	
	76-125					5					16	90		11		
Anchoa mitchilli	51-75										100					
Polyipnus asteroides	26-50												90			10
Saurida brasiliensis	26-75										5	12		95	87	
	76-100										41	100		59		
Synodus foetens	51-150									7	6	27	6	93	27	68
	151-200							9	32		5			85	65	
	201-400												11	95		75
Synodus poeyi	51-75												75			24
	76-125												62			30
Porichthys plectrodon	51-150										55	7		39		
Halieutichthys aculeatus	26-50	2			43	33	50				12	43	50	19		
	51-75	1	1		48	56	42				32	12	10		1	1
	76-100			7	40		35				40		16			
Ogcocephalus nasutus	51-125				62	71					26	24		2		
Zalieutes mcgintyi	51-100					97						3				
Steindachneria argentea	101-150													95		

Table 9-6. Cont'd.

Species	Size Class (mm)	Small Benthic invertebrates			Polychaetes			Cephalopods			Crustaceans			Fishes		
		C	M	D	C	M	D	C	M	D	C	M	D	C	M	D
Bathygadus macrops	101-150				5						28	90				
	151-200										40		16	60		81
	201-300												8			92
Bathygadus melanobranchus	51-200		10								41	90		59		
Coelorinchus caribbaeus	51-100				65	57						6				
	101-150				81	47	10				4	6	90			
	151-200				58	32					22	68				
	201-250				40	35	20				28	15	50			
Synagrops spinosa	51-75							5			55			40		
Centropristis philadelphica	51-125										74	95		24		
	126-225				1		95				76	63	5		29	
Diplectrum bivittatum	26-75				4	30					58	40	99	5		
	76-100				3	11					76	39	95			
	101-125											57	100			
Serraniculus pumilio	0-50						3						74			
	51-75												97			
Serranus atrobranchus	51-75										75					
	76-100				3	5					73	68				
	101-125				5	5					54					
Serranus notospilus	26-75						9			3	44			15		
Chloroscombrus chrysurus	26-75											32	100			
	76-150										27	5	100	28		
Trachurus lathami	101-125											42			20	
Pristipomoides aquilonaris	26-150					3	13					62	10			

Table 9-6. Cont'd.

Species	Size Class (mm)	Small benthic invertebrates			Polychaetes			Cephalopods			Crustaceans			Fishes		
		C	M	D	C	M	D	C	M	D	C	M	D	C	M	D
Rhomboplites aurorubens	51-100					5						88				
Haemulon aurolineatum	76-150					56	30					21	10			
Stenotomus caprinus	0-25				15						63					
	26-50	4						33			17					
	51-75				33	51					17	16			3	
	76-100				48	53			4		6	10	14		4	
	101-125				2	42	13				25	22	11	8	31	
Cynoscion arenarius	151-300											87		20	7	
Leiostomus xanthurus	101-150		1	1	25	42	5				15	2	1	2		
	151-200					75	96					20	2			2
Micropogonias undulatus	101-150				25	74	25				25	18	43			40
	151-200					57	5					23	5			
Polydactylus octonemus	76-125										70			29		
Bembrops anatirostris	26-125				31						64	92	90			
	126-150						8			3	53	50	25		40	52
	151-200					1	3				14	58	50	73	10	32
Bollmannia communis	51-75				5											
Peprilus burti	76-100										1	100				
	101-150					1					1	19				
Pontinus longispinis	26-75										83	63	75			
	76-100				3	4					60	58	90	18		
	101-150				1						63	72		4	8	

Table 9-6. Cont'd.

Species	Size Class (mm)	Small benthic invertebrates			Polychaetes			Cephalopods			Crustaceans			Fishes		
		C	M	D	C	M	D	C	M	D	C	M	D	C	M	D
Scorpaena calcarata	26-75										54	88	100			
	76-125												98			
Bellator militaris	26-50										50	48	74			5
	51-100											51	97		41	
Prionotus alatus	26-100				2	9					60	57	62	24	22	
	101-175					18					4	28	93	71	15	
Prionotus longispinosus	51-75					11	5					29	95			2
	76-125						1					99	90			6
	126-175											41	67		59	4
Prionotus roseus	51-125											90	87			2
	126-175						2						92			
Prionotus rubio	51-100				5						60			23		
	101-175										69	78			7	
Prionotus scitulus	26-50						31						26			
	101-175						3						77			
Prionotus stearnsi	26-100								23		95	50		5	21	
Etropus rimosus	26-50					31						53				
	51-125			5		35	28					41	67			
Syacium gunteri	26-75				3	22	89				53	73		12		
	76-100	2			22	5					55	91			4	
Syacium papillosum	26-75					42	12					38	59	10		
	76-100					18				25		24	74		37	
	101-150					12	12				100	51	66		13	3
	151-200						3			8		1	33		25	45

Table 9-6. Cont'd.

Species	Size Class (mm)	Small benthic invertebrates			Polychaetes			Cephalopods			Crustaceans			Fishes		
		C	M	D	C	M	D	C	M	D	C	M	D	C	M	D
Trichopsetta ventralis	26-75				11						63			9		
	76-100				6	9					70	7		7	64	
	101-250				6						76	77		11	10	
Symphurus civitatus	51-100	1	3		18	46					11	5				
	101-125				26	20					12	5				
Symphurus plagiusa	76-125	4			11	22					23	59	5			
	126-150	2			8	35					22	53				

Table 9-7. Percentage composition of the four primary crustacean food groups encountered in all size classes of all species examined, separated by transect (C = Chandeleur, M = Mobile Bay, and D = De Soto Canyon transects).

Species	Size Class (mm)	Zooplankton			Benthic micro-crustaceans			Benthic small crustaceans			Larger mobile species		
		C	M	D	C	M	D	C	M	D	C	M	D
Anchoa cubana	26-50			19			12			16			16
	51-75			14			15			9			57
Anchoa hepsetus	26-50	12	23		22				24				
	51-75	2	9		16				2		36	43	
	76-125		15		5	1			24		11	50	
Anchoa mitchilli	51-75	3			2								
Polyipnus asteroides	26-50	15						11			45		
Saurida brasiliensis	26-75										5	12	
	76-100										40		
Synodus foetens	51-150										6		6
	151-200										5		
	201-400												
Synodus poeyi	51-75												68
	76-125												57
Porichthys plectrodon	51-150										55	7	
Halieutichthys aculeatus	26-50	1						1			11	37	50
	51-75							6	2	1			
	76-100									3	40		13
Ogcocephalus nasutus	51-125											24	
Zalieutes mcgintyi	51-100											3	
Steindachneria argentea	101-150												

Table 9-7. Cont'd.

Species	Size Class (mm)	Zooplankton			Benthic micro-crustaceans			Benthic small crustaceans			Larger mobile species		
		C	M	D	C	M	D	C	M	D	C	M	D
Bathygadus macrops	101-150										28	90	
	151-200										40		5
	201-300												8
Bathygadus melanobranchus	51-200	1	1								41	89	
Coelorinchus caribbaeus	51-100								4			2	
	101-150					1		1	1	2	3	4	80
	151-200							11	17		11	51	
	201-250							3	1	1	25	14	50
Synagrops spinosa	51-75				6			50					
Centropristis philadelphica	51-125										74	95	
	126-225										73	61	
Diplectrum bivittatum	26-75				1	24					57	13	99
	76-100	3						2		41	72	24	43
	101-125												
Serraniculus pumilio	0-50									2			66
	51-75						48						48
Serranus atrobranchus	51-75										75		
	76-100							1	3		70	63	
	101-125										54		
Serranus notospilus	26-75												44
Chloroscombrus chrysurus	26-75		17	31						2		14	67
	76-150		1				88				11	1	
Trachurus lathami	101-125											42	
Pristipomoides aquilonaris	26-150		2						18	4		42	6

Table 9-7. Cont'd.

Species	Size Class (mm)	Zooplankton			Benthic micro-crustaceans			Benthic small crustaceans			Larger mobile species		
		C	M	D	C	M	D	C	M	D	C	M	D
Rhomboplites aurorubens	51-100								26			61	
Haemulon aurolineatum	76-150			1					1			20	6
Stenotomus	0-25	1			3			57			3		
	26-50	2						7			3		
	51-75	1			1			9	6		6	10	
	76-100	1								1		10	11
	101-125										25	22	10
Cynoscion arenarius	151-300											80	
Leiostomus xanthurus	101-150									1		2	
	151-200								1	1		19	1
Micropogonias undulatus	101-150								4	36		14	8
	151-200											23	5
Polydactylus octonemus	76-125	11			4			50			4		
Bembrops anatirostris	26-125								3		64	89	86
	126-150								2		53	44	25
	151-200							5		1	9	57	48
Bollmannia communis	51-75												
Peprilus burti	76-100		50								1		
	101-150											16	
Pontinus longispinis	26-75								1		79	56	75
	76-100										60	57	
	101-150							1			62	70	

Table 9-7. Cont'd.

Species	Size Class (mm)	Zooplankton			Benthic micro-crustaceans			Benthic small crustaceans			Larger mobile species		
		C	M	D	C	M	D	C	M	D	C	M	D
Scorpaena calcarata	26-75									3		83	95
	76-125									1			96
Bellator militaris	26-50		14				2	50	2	30		12	42
	51-100					7	16		9	3		34	78
Prionotus alatus	26-100		7			2					41	48	62
	101-175		1			6	16				4	28	93
Prionotus longispinosus	51-75								4			22	95
	76-125											99	90
	126-175									7		40	60
Prionotus roseus	51-125											90	86
	126-175									1			92
Prionotus rubio	51-100				2						59		
	101-175							2			38	66	
Prionotus scitulus	26-50									8			18
	101-175									2			75
Prionotus stearnsi	26-100				2	19		6	6		87	26	
Etropus rimosus	26-50		14			1			20			19	
	51-125		1	1		1			15	29		24	34
Syacium gunteri	26-75							20	4		33	70	
	76-150							10	5		44	86	
Syacium papillosum	26-75						2		3	3		35	54
	76-100						1		5	1		19	72
	101-150								2	2	100	39	63
	151-200											1	32

Table 9-7. Cont'd.

Species	Size Class (mm)	Zooplankton			Benthic micro-crustaceans			Benthic small crustaceans			Larger mobile species		
		C	M	D	C	M	D	C	M	D	C	M	D
Trichopsetta ventralis	26-75										63		
	76-100							1			48		
	101-250										74	76	
Symphurus civitatus	51-100							4	3		7		
	101-125							9			3	5	
Symphurus plagiusa	76-125							13	38		7	21	5
	126-150							15	37		6	16	

125 mm). All but three individuals contained food. Most of the individuals for food analysis were captured at the inshore stations of the Chandeleur and Mobile transects (C1 and M1), but a few came from the second station on the Chandeleur transect (C2). Crustaceans made up 37 to 54% of the food of all size classes, and the two larger groups consumed 7-16% fishes. Unidentifiable animal matter was prominent in the food of all size classes. Among the crustaceans, calanoid copepods and crab megalopa were present in the food of all size classes but were not prominent in the smallest fishes. Shrimp appeared in the two larger groups, and specimens of the pelagic shrimp, *Lucifer faxoni*, were identified in larger anchovies taken during the winter at station C2. Small benthic crustaceans, amphipods, and crabs, as well as mollusks and polychaetes, constituted minor components of the food. This anchovy relies primarily upon zooplankton and small benthic crustaceans during the earlier stages, while older individuals feed more heavily upon larger crustaceans together with some fishes. Since it remains near shore there was no depth effect. Rogers (1977) examined the food of 166 specimens of the striped anchovy in the size range of 26-125 mm which he divided into 25 mm size classes. He found that the smaller sized individuals were feeding upon a variety of small planktonic organisms, primarily crustaceans and larval fishes, with some evidence of bottom feeding. Larger size classes were found to feed more selectively upon shrimp, particularly *Acetes americanus*. Rogers' (1977) results are quite similar to those of the present study.

Anchoa mitchilli. Twenty specimens of the bay anchovy were analyzed, and all contained food. These represented a single size class (51-75 mm). All specimens were taken during a winter cruise at a single nearshore station (C1). Unidentifiable animal material made up most of the stomach contents, but small amounts of calanoid copepods and amphipods were encountered. This is primarily an estuarine species which occasionally strays onto the inner shelf. Since all specimens come from a single station, nothing can be said about depth or transect relations. Although the subject of many food studies in the bays and estuaries, its food habits on the shelf have apparently not previously been investigated.

Sternoptychidae - Hatchetfishes

Polyipnus asteroides. Twenty specimens of this deepwater hatchetfish were examined, all containing food. All specimens were taken at station D4 during the winter, and these represented a single size class (26-50 mm). Ninety percent of the food was crustaceans, and the remaining 10% was fishes. Shrimp constituted the bulk of the crustaceans, although calanoid copepods, isopods, and amphipods also were present. This hatchetfish is a small pelagic and benthic predator inhabiting the outer shelf and specializing in shrimp, copepods, and small fishes. Since all specimens were taken at a single station nothing can be said about variations in its food habits.

Synodontidae - Lizardfishes

Saurida brasiliensis. A total of 82 specimens of the largescale lizardfish was examined of which 66 contained food. These represent two size classes (26-75 mm and 76-100 mm). Most of the specimens were taken from a depth of 60 m on the Chandeleur and Mobile transects, but a few occurred in shallower and deeper water on the Chandeleur transect. Almost all the food of both size classes fell into two groups: crustaceans and fishes, with the latter being the dominant category. Among the crustaceans, shrimp made up all the food of the smaller size class. For the larger size class, shrimp and crabs formed the bulk of the crustacean food with lesser amounts of stomatopods and amphipods. Traces of polychaetes appeared in both size classes. Crustaceans were consumed at depths of 60 m and 100 m, but fishes were taken only at the latter depth. Fishes and crustaceans were eaten on both the Chandeleur and Mobile transects. This lizardfish is a major carnivore of the shelf, but due to its small size it does not consume larger crustaceans and fishes.

Rogers (1977) examined the food of 297 specimens of this lizardfish in the size range of 51-125 mm. He found that fishes made up at least 87% of the food of all size classes. Smaller individuals took in a variety of crustaceans, and squids became more important in the food of larger size classes. Divita et al. (1983) examined the food of 28 specimens in the size range 78-125 mm. In their study, fishes occurred in 50% of the stomachs and shrimp and squids occurred in 9% each.

Synodus foetens. Ninety-nine specimens of the inshore lizardfish were examined of which 84 contained food. Three size classes are represented (51-150 mm, 151-200 mm, and 201-400 mm). Most of the specimens for food analysis were taken at the two shallower depths (20 m and 60 m), and all three transects were represented. In all three size classes, fishes made up the bulk of the food, and the percentage increased in the larger size classes. Crustaceans constituted a small percentage of the food of all size classes, and cephalopods appeared in some abundance in the two smaller size classes. A trace of polychaetes occurred in the smallest fishes, and a trace of organic detritus appeared in the largest size class. Among the crustaceans, only shrimp and crabs were taken. Both crustaceans and fishes were consumed at the two shallow depths, but only fishes appeared in stomachs of fishes collected at 100 m. Fishes were dominant in the food of lizardfish taken on the Chandeleur and Mobile transects, whereas crustaceans and cephalopods were most abundant on the Mobile transect. The inshore lizardfish is clearly one of the top predators of the shallow shelf where it specializes in fishes, larger crustaceans, and cephalopods, in that order.

Synodus poeyi A total of 49 specimens of the offshore lizardfish was examined, and all contained food. Two size classes were included (51-75 mm and 76-125 mm). All specimens were taken on the De Soto Canyon transect at a depth of 60 m. All the food of both size classes consisted of crustaceans and fishes with crustaceans being two to three times as abundant as the fishes. A trace of polychaetes appeared in both size classes. Among the crustaceans, shrimp and lobsters made up all of the identifiable food with the latter category being slightly more abundant. With increasing size class, there was an increase in the percentage of fishes and a decrease in the percentage of crustaceans. Since all specimens came from the same station, nothing can be said about variation in food in relation to depth or transect. As in the other lizardfishes, this species is a top carnivore, but its habitat is limited to the offshore environment near the De Soto Canyon.

Batrachoididae - Toadfishes

Porichthys plectrodon. Sixty-four specimens of the Atlantic midshipman were examined, but only 44 contained food. Most of the specimens for stomach analysis were taken from the two shallowest stations of the Chandeleur and Mobile transects. All belonged to a single size class (51-155 mm). All of the identifiable food fell into two categories, crustaceans and fishes, with crustaceans constituting the greater amount. Among the crustaceans, stomatopods were about twice as abundant as shrimp, the only other category. Crustaceans were about equally abundant at 20 m and 60 m, but fishes were consumed only at the 60 m depth. Crustaceans formed a much larger component of the food on the Chandeleur transect than on the Mobile transect, and fishes were taken only on the Chandeleur transect. This species is an important benthic predator on the shallow shelf out to a depth of 60 m in the Chandeleur and Mobile transect areas.

Rogers (1977) examined 152 specimens of the Atlantic midshipman of which 109 contained food. His specimens ranged in size from 25 mm to greater than 100 mm. The smaller individuals were found to depend largely upon small benthic and planktonic crustaceans. During intermediate stages, squids became important while the larger individuals fed primarily upon fishes. Divita et al. (1983) examined the stomachs of 17 specimens of this species and found 12 to contain fishes.

Ogcocephalidae - Batfishes

Halieutichthys aculeatus. A total of 461 specimens of the pancake batfish was examined, of which 354 contained food. These represent three size classes (26-50 mm, 51-75 mm, and 76-100 mm). This widespread species was taken at all four depths and on all three transects. In all three size classes, polychaetes and crustaceans made up the bulk of the identifiable food, with polychaetes being about one and a half to two and a half times as abundant as the crustaceans. Fishes appeared as a significant item in the food of the smallest size class. Small amounts of other phyla also appeared, including coelenterates, nemerteans, mollusks, holothurians, chaetognaths, and urochordates. Much of the unidentified animal matter was probably polychaete tubes and mucus. Among the crustaceans, shrimp and lobsters were dominant, but smaller amounts of calanoid copepods, isopods, amphipods (including caprellids), crabs, and stomatopods were taken. Despite the diversity of food items encountered, there were no clear differences in the food of the different size classes.

Polychaetes and crustaceans were consumed at the three shallowest depths, and the variability was so great that no clear depth-related trends were evident. However, at the greatest depth (200 m) polychaetes were heavily consumed and crustaceans were absent. Fishes made up a significant percentage of the food only at the shallowest depth. On all three transects, polychaetes averaged between 40 and 50% of the identifiable food and crustaceans averaged between 25 and 30%. Fishes were consumed on all three transects but were most prominent on the Chandeleur transect. The pancake batfish is an opportunistic bottom feeder specializing in polychaetes and crustaceans but accepting a variety of other foods on occasion. It shows little change in food patterns in relation to size, depth, or transect.

Rogers (1977) examined the stomachs of 292 specimens, of which 170 contained food. Specimens ranged in size from 26 to 75 mm. He found little change in food in relation to size class of the fish. Food material consisted of polychaetes (68%), mysids (8%), stomatopods (6%), shrimp (3%), crabs (3%), and fishes (3%), as well as traces of ostracods, copepods, and amphipods.

Ogcocephalus nasutus. Twenty-five specimens of this batfish were examined, of which only 15 contained food. All specimens were lumped into a single size class (51-125 mm). All specimens employed in the food study derived from the 100 m depth on the Chandeleur and Mobile transects. Polychaetes constituted 66% of the food, crustaceans 25%, fishes 1%, and unidentified animal material 8%. Much of the latter category was probably polychaete tubes and mucus. Traces of minor phyla, bryozoans, and valved mollusks were present, and lobsters made up the bulk of the crustaceans. Since only a single depth was involved, nothing can be said about depth relations. Polychaetes were somewhat more abundant on the Mobile than on the Chandeleur transect, but the percentage of crustaceans remained about the same.

Zalieutes mcgintyi. Thirty-eight specimens of the tricorn batfish were examined and 35 contained food. This group formed a single size class (51-100 mm). All specimens were collected at a depth of 200 m on the Mobile transect. Only two food categories were encountered. Polychaetes constituted 97% and shrimp made up 3% of the observed food. Apparently this deepwater batfish is primarily a polychaete feeder.

Gadidae - Codfishes

Steindachneria argentea. Nine specimens of the luminous hake were examined of which seven contained food. All fell into a single size class (101-150 mm). All specimens were taken at a single station at a depth of 100 m on the Chandeleur transect. Fishes constituted 95% of the food, and undetermined animal matter (probably fish flesh) made up the remainder. This species is a deepwater predator on small fishes around the mouth of the Mississippi River. This is the only species listed here in which less than 10 stomachs were analyzed and it is included because the results are so consistent.

Macrouridae - Grenadiers

Bathygadus macrops. In the present study, 73 specimens of this grenadier were examined and 70 contained food. The specimens represent three size classes (101-150 mm, 151-200 mm, and 201-300 mm). The fishes were collected at depths of 100 m and 200 m, and all three transects were represented. Fishes constituted over half the food in all size classes and increased to over 90% in the largest size class. Shrimp, which made up 31% of the food in the smallest fishes, decreased to 8% in the largest size class. A small amount of polychaetes appeared in the food of the smallest size class, and some undetermined animal matter occurred in the two smallest size classes. No real changes in food habits could be ascribed to depth except a reduction in the amount of shrimp consumed. Shrimp were clearly more prominent in stomachs from the Mobile transect, and fishes were dominant on the Chandeleur and De Soto Canyon transects. This species feeds primarily upon fishes and is a major predator of the outer continental shelf from the Mississippi River to De Soto Canyon. Bright (1968) reported calanoid copepods and unidentified crustaceans from specimens of this species.

Bathygadus melanobranchus. Thirty-five specimens of this grenadier were examined of which 31 contained food. These formed a single size class (51-200 mm). All specimens were taken at a depth of 200 m on the Chandeleur and Mobile transects. The food consisted of shrimp (53%), fishes (45%), and minor phyla, including bryozoans (2%). Shrimp were more abundant in specimens from the Chandeleur transect, while fishes were more abundant in those taken on the Mobile transect. As in the case of the previous species, this grenadier is a major deepwater predator, but it differs from the previous species in its greater dependence upon shrimp.

Coelorinchus caribbaeus. A total of 142 specimens of the blackfin grenadier was examined, all of which contained food. These made up four size classes (51-100 mm, 101-150 mm, 151-200 mm, and 201-250 mm). Specimens were taken at a depth of 200 m on all three transects. The food of all size groups consisted of polychaetes and crustaceans, although a trace of minor phyla (including foraminiferans) appeared in the 101-150 mm group, and organic detritus occurred in the two largest size classes. Shrimp and amphipods made up the bulk of the identifiable crustaceans, but crabs were taken in some abundance and a trace of isopods appeared in the 151-200 mm category. Proceeding from the smallest to the largest size class, polychaetes decreased by more than half and crustaceans showed some increase in percentage. Among the crustaceans, the amphipods, shrimp, and crabs were most abundant in the three largest size classes and a large mud shrimp (*Callianassa* sp.) appeared in food at station C4. Polychaetes were abundant on the Chandeleur and Mobile transects and were relatively rare on the De Soto Canyon transect. Crustaceans were abundant on all transects but formed a higher percentage on the De Soto Canyon transect. This interesting deepwater predator of polychaetes and shrimp exhibits food habit changes in relation to size and transect location.

Gallaway et al. (1988) examined the stomach contents of 15 specimens of this species. The food composition by volume was as follows: polychaetes 47%, shrimp and amphipods 14% each, calanoid copepods 12%, crabs 2%, and small invertebrates and fishes (as a mixed category) 10%.

Perchichthyidae - Temperate Basses

Synagrops spinosa. Twenty-five specimens of this temperate bass were examined, all of which contained food. These formed a single size class (51-75 mm). All were taken at a depth of 100 m on the Chandeleur transect. The food included crustaceans (55%), fishes (40%), cephalopods (5%), and a trace of polychaetes. Shrimp made up about half of the identifiable crustaceans followed by lobsters, crabs, and megalopa. Nothing can be said about depth or transect relations. This small outer shelf carnivore specializes in small crustaceans and fishes.

Serranidae - Sea Basses

Centropristis philadelphica. In the present study, 103 specimens of the rock sea bass were examined, but only 84 contained food. These comprised two size classes (51-125 mm and 126-225 mm). All individuals were taken at 60 and 100 m on the Chandeleur and Mobile transects and from 100 m on the De Soto Canyon transect. In both size classes, crustaceans made up about 70% of the food. Fishes constituted 22% in the smaller and 6% in the larger size class. Polychaetes were present as a trace in the smaller class and 6% in the larger size class. Trace amounts of valved mollusks appeared in the smaller group, and traces of cephalopods and organic detritus occurred in the smaller groups. Among the crustaceans, shrimp was the most important food in both size classes. Small amounts of crabs appeared in both groups and a few stomatopods occurred in the larger group. A small specimen of the stone crab, *Menippe mercenaria*, was encountered in the largest size class. The percentage of crustaceans increased somewhat with depth, and the reverse was true for the fishes consumed. In the smaller size class, the crustaceans were more abundant on the Mobile transect and in the larger size class they were more abundant on the Chandeleur transect. Just the reverse was true for the fishes. This carnivore specializes in fishes and small crustaceans of which shrimp is the major element.

Rogers (1977) examined the food of 354 specimens of the rock sea bass, of which 279 contained food. His specimens ranged in size from 26 to 225 mm. Five size classes were established. In his study, macrocrustacea (shrimp, crabs, and stomatopods) made up between 50% and 60% of the food of all size classes. Zooplankton was important only in the smallest size class, and small benthic infaunal species, which were important in the three smallest sizes, were present only in trace amounts in the size classes above 100 mm. Fishes and squids were present only in trace amounts in the smallest size class, but they were important in all the subsequent sizes, increasing to 48% and 39% of the food of the two larger size groups. Divita et al. (1983) examined the food of 437 specimens of the rock sea bass in the size range of 85-224 mm. They found shrimp in 30%, crabs in 11%, fishes in 6%, stomatopods in 3%, squids in 1%, and miscellaneous invertebrates in 2% of the stomachs containing food.

Diplectrum bivittatum. A total of 217 specimens of the dwarf sand perch were examined, of which 166 contained food. These were divided into three size classes (26-75 mm, 76-100 mm, and 101-125 mm). The fishes were collected at a depth of 20 m on all three transects. Crustaceans made up the majority of the identifiable food in all size classes. Small amounts of polychaetes appeared in all size groups and a low percentage of fishes occurred in the smallest size group. Among the crustaceans, shrimp was by far the largest food category. In the smallest size class, a few megalopa and stomatopods appeared. In the intermediate size class, crabs (including portunids) were the second most abundant group, followed by isopods, amphipods, and calanoid copepods. Food categories changed very little with increasing size of the fish. Crustaceans were a more abundant item in the stomachs of fishes taken from the Chandeleur and De Soto Canyon transects than in those from the Mobile transect. This small inshore carnivore specializes in crustaceans, of which shrimp are the most important item, but it will consume a variety of other crustaceans and fishes on occasion.

Rogers (1977) studied the food of 76 specimens of the dwarf sand perch, of which 54 contained food. His specimens ranged in size from 26 to 125 mm. He found crustaceans to make up over half the food in all three size classes. Polychaetes decreased from 17% in the smallest to 6% in the largest size class. Fishes increased from 8% to 31% in the largest size class. Among the crustaceans, shrimp always made up the most abundant group, but amphipods, mysidaceans, crabs, and stomatopods were often present in low quantities. Divita et al. (1983) examined the food of 134 specimens of this sea bass. They found that shrimp occurred in 44%, crabs in 4%, and stomatopods in 2% of the stomachs examined.

Serraniculus pumilio - Eighty specimens of the pygmy sea bass were examined, of which 65 contained food. These were divided into two size classes (0-50 mm and 51-75 mm). All specimens were derived from depths of 50 m and 100 m on the De Soto Canyon transect. Among the identifiable items, crustaceans made up over 90% of the food of both size classes. Polychaetes represented 3% of the food of the smaller size group. Among the crustaceans, shrimp constituted almost half the food of each size class. The smaller size class also contained small amounts of amphipods, lobsters (including scyllarids), and crabs. The larger size class contained almost half crab megalopa. For the smaller sized fish, crustaceans were most important at a depth of 60 m, but for the larger fish they were most important at 100 m. This small predator feeds heavily upon small crustaceans of which shrimp is the most important item. Other crustaceans and some polychaetes are also taken.

Hastings (1973) studied many aspects of the biology of the pygmy sea bass including food habits of 29 specimens in the size range 16-54 mm. Crustaceans appeared in 96%, polychaetes in 31%, gastropods in 3%, algae in 3%, and fishes in 7% of the stomachs. Among the crustaceans, amphipods made up the largest frequency of occurrence (59%). Additional crustaceans included caprellids, copepods, tanaids, cumaceans, shrimp zoea and adults, and crab megalopa and adults.

Serranus atrobranchus. In the present study, 174 specimens of the blackear sea bass were examined, of which 144 contained food. These were divided into three size classes (51-75 mm, 76-100 mm, and 101-125 mm). These fishes were taken at all depths on the Chandeleur and Mobile transects. Crustaceans made up over half the food of all size groups, although polychaetes appeared in low percentages in all size groups and a trace of fishes occurred in the middle size group. In all size classes, shrimp was the most important category, but lobsters and crabs (including pinnotherids) made up 18% in one size group and a few amphipods appeared in another. With increasing size, the percentage of shrimp declined and the relative percentage of polychaetes increased. Crustaceans were more important in the diets at the 60 m and 100 m stations than at the shallower or deeper stations and they were more important on the Chandeleur than on the Mobile transect.

Rogers (1977) examined the stomachs of 253 specimens of the blackear sea bass of which 213 contained food. Sizes ranged from 26 to 125 mm. These were divided into four size classes. In his study, crustaceans made up over 60% of the food of all size classes with lower percentages of polychaetes and fishes in the three smallest size classes. A variety of crustaceans was consumed, but shrimp was the dominant crustacean in all size groups. The percentage of shrimp decreased as the size of the fishes increased. Divita et al. (1983) examined the food of 13 specimens of this species. Shrimp and crabs each occurred in 9% of the stomachs with food.

Serranus notospilus. A total of 66 specimens of the saddle bass was examined, of which 41 contained food. These all formed a single size class (26-75 mm). All specimens came from a depth of 100 m on the De Soto Canyon transect. The identifiable food of this species consisted of crustaceans (44%), fishes (15%), polychaetes (9%), and cephalopods (3%). Among the crustaceans, shrimp was by far the most important category, although a few lobsters were also present. Nothing can be said about depth or transect relations. This active and versatile predator feeds upon larger mobile animals as well as polychaetes.

Carangidae - Jacks

Chloroscombrus chrysurus. Fifty-nine specimens of the Atlantic bumper were examined, all of which contained food. Two size classes were represented (26-75 mm and 76-150 mm). These fishes were taken at 20 m and 60 m at all three transects. Crustaceans comprised the bulk of the food, but a significant amount of fishes was also consumed. Calanoid copepods and shrimp made up most of the crustacean food with a small amount of megalopa. Some organic detritus was present. With increasing size class, the percentage of copepods decreased and the relative percentage of shrimp and crabs increased. Fishes appeared only in the food of the larger size class. Calanoid copepods were much more abundant at the deeper stations, but the percentage of all other food items was greatest at the shallower stations. Crustaceans were most abundant on the De Soto Canyon transect, and fishes were most abundance on the Chandeleur transect.

Rogers (1977) examined the stomachs of 66 specimens of this species and found 61 with food. These formed two size classes. Fishes comprised 80% of the food of the smaller and 23% of the food of the larger size class. Crustaceans made up 16% of the food of the smaller size class and 37% of the food of the larger size group. Squids and egg masses also appeared in the stomachs of the larger fishes. Divita et al. (1983) examined the food of 32 specimens of this species and the only food encountered was listed as "detritus".

Trachurus lathami. Twenty-three specimens of the rough scad were examined and all contained food. These formed a single size class (101-125 mm). All specimens were taken at a depth of 100 m on the Mobile transect. Stomatopods made up 42% and fishes 20% of the stomach contents. These were the only identifiable items encountered. Divita et al. (1983) examined the food of eight specimens of this species and classified all the food as "detritus".

Lutjanidae - Snappers

Pristipomoides aquilonaris. A total of 18 specimens of the wenchman was examined, of which 11 contained food. These formed a single size class (26-150 mm). These fishes were taken at depths of 60 and 100 m on the Mobile and De Soto Canyon transects. Polychaetes made up 8% and crustaceans 35% of the food. Among the crustaceans, amphipods and shrimp were about equal in abundance and together constituted most of the food. A small percentage of calanoid copepods was also present. Crustaceans were most abundant at 60 m and polychaetes were taken only at 100 m. Polychaetes were more abundant on the De Soto Canyon transect, and shrimp were more abundant in fishes from the Mobile transect.

Rhomboplites aurorubens. Sixteen specimens of the vermilion snapper were examined and all had food. These comprised a single size class (51-100 mm). All were collected at a depth of 20 m on the Mobile transect. The identifiable food consisted of polychaetes (5%) and crustaceans (88%). These included amphipods (26%), and shrimp (62%). This species feeds more upon polychaetes than upon crustaceans.

Haemulidae - Grunts

Haemulon aurolineatum. Seventeen specimens of the tomtate were examined, of which 16 contained food. These formed a single size class (75-150 mm). These fishes were collected at depths of 20 and 60 m and from the Mobile and De Soto Canyon transects. The identifiable food consisted of polychaetes (55%) and crustaceans (21%). Among the latter, shrimp made up 19% and amphipods 2%. There was little variability in food intake in relation to either depth or transect. This species feeds more upon polychaetes than upon crustaceans.

Sparidae - Porgies

Stenotomus caprinus. A total of 398 specimens of the longspine porgy was examined, of which 343 contained food. These were divided into five size classes (0-25 mm, 26-50 mm, 51-75 mm, 76-100 mm, and 101-125 mm). On the average (all size classes combined), polychaetes constituted 32%, crustaceans 24%, and fishes 5%. Minor phyla, valved mollusks, echinoderms, insects, and cephalopods made up one percent or less. Among the crustaceans, shrimp and amphipods were generally present with smaller amounts of calanoid copepods, megalopa, crabs, and stomatopods. In the smallest size class, polychaetes formed only 15% of the food, but in subsequent size classes they made up 29%-47% of the food. In the smallest size class, crustaceans constituted 63% of the food, but in the remaining groups they ranged only from 8% to 20%. Fishes were never more than one percent of the food of the four smaller size classes, but in the largest group they represented 22% of the food. Among the crustacean groups calanoid copepods and amphipods decreased with increasing size of the fish and the percentage of shrimp and crabs increased. Thus, with increasing size the larger mobile species assumed a more dominant role in the food of this species, increasing from 7% in the smallest size class to 40% in the largest size class. Polychaetes showed no clear trends in relation to depth. Both crustaceans and fishes tended to increase with depth, but polychaetes showed no clear depth relations. Both polychaetes and fishes were most important on the Mobile transect.

In the northern Gulf, the food of the longspine porgy has been studied by Divita et al. (1983), Henwood et al. (1978), Rogers (1977), Sheridan and Trimm (1983), and Sheridan and Baker (1984). In all the studies, polychaetes and small benthic crustaceans tend to dominate the food, but the relative importance of these two groups varies with locality. Some organic detritus is generally present.

Sciaenidae - Drums

Cynoscion arenarius. Eleven specimens of the sand seatrout were examined, of which only 7 contained food. These formed a single size class (151-300 mm). Crustaceans made up 65% of the food and fishes made up 10%, although there were traces of polychaetes and organic detritus. The only identifiable crustaceans were shrimp, and some of these were definitely identified as *Penaeus setiferus*. Considering the small number of specimens, no conclusions could be reached on food variation in relation to depth or transect.

The food of the sand seatrout in the northern Gulf has been addressed by Divita et al. (1983), Rogers (1977), Sheridan and Trimm (1983), and Sheridan and Baker (1984). In all these studies, fishes and shrimp are the two primary categories with fishes generally the dominant one. Crabs and squids were sometimes important in the diets, as well.

Leiostomus xanthurus. A total of 52 specimens of spot was examined, of which 49 contained food. These represented two size classes (101-150 mm and 151-200 mm). Specimens were derived from the 20 m and 100 m depths and all three transects were represented. Polychaetes were by far the most important food category followed by small amounts of crustaceans and essentially trace amounts of valved mollusks, fishes, an organic detritus. Among the crustaceans, most were shrimp, but a few amphipods were also present. Among the identifiable material, the percentage of shrimp increased somewhat in the larger size class. Shrimp also increased in relation to depth. Polychaetes formed a higher percentage of the food on the Mobile and De Soto Canyon transects and crustaceans were lowest on the De Soto Canyon transect.

The food of the spot in the northern Gulf has been studied by Chen (1976), Divita et al. (1983), Govoni et al. (1983), Sheridan and Trimm (1983), and Sheridan and Baker (1984). The food of larval spot was examined by Govoni et al. (1983) and it was found that they feed upon zooplankton of which pteropods, copepods, and various invertebrate larvae were prominent. The remaining investigators examined the food of postlarval individuals. Polychaetes and crustaceans were generally the dominant groups, although lancets and fishes were sometimes important and detritus also appeared as a prominent item.

Micropognias undulatus. In the present study, 72 specimens of the Atlantic croaker were examined of which 70 contained food. These formed two size classes (101-150 mm and 151-200 mm). As in the case of the spot, specimens were captured at depths of 20 m and 100 m and all three transects were represented. The food consisted of polychaetes, crustaceans, fishes (listed in order of abundance), and a trace of valved mollusks. Organic detritus was a prominent item. Among the crustaceans shrimp were the dominant group followed by amphipods and isopods. With increasing size class, there was a decrease in the amounts of polychaetes, crustaceans, and fishes and an increase in the percentage of organic detritus. In the larger size class, the percentage of polychaetes and crustaceans increased with depth. Polychaetes were more heavily utilized on the Mobile transect and fishes were most prominent on the De Soto Canyon transect.

In the northern Gulf, the food of the Atlantic croaker has been studied by Chen (1976), Divita et al. (1983), Govoni et al. (1983), Overstreet and Heard (1978), Rogers (1977), Sheridan and Trimm (1983), and Sheridan and Baker (1984). Larval specimens were found to consume entirely zooplankton (primarily copepods and invertebrate eggs and larvae). Postlarval individuals take in a wide variety of invertebrates and small fishes but tend to specialize on polychaetes and crustaceans. Larger individuals eat larger and more mobile species. Detritus is sometimes a significant item, and the food habits often vary from one locality to another.

Polynemidae - Threadfins

Polydactylus octonemus. Twenty-four specimens of the Atlantic threadfin were examined, of which 23 contained food. The specimens all fell into a single size class (76-125 mm). All individuals were taken at a depth of 20 m on the Chandeleur transect. The food consisted of crustaceans (70%) and fishes (30%), as well as a trace of polychaetes. The crustaceans included amphipods (44%), megalopa (8%), shrimp (6%), and crabs (1%). Divita et al. (1983) examined the food of 42 specimens of this species and found "detritus" in 79%, shrimp in 14%, and fishes in 7%.

Percophidae - Flatheads

Bembrops anatirostris. One hundred-six specimens of the duckbill flathead were examined with 99 containing food. These made up three size classes (26-125 mm 126-150 mm, and 151-200 mm). The main food categories, in order of abundance, were crustaceans, fishes, polychaetes, and cephalopods, although a trace of valved mollusks was also present. Most of the crustaceans were shrimp, but small amounts of isopods, amphipods, and crabs were also present. With increasing size both polychaetes and shrimp decreased in abundance, and fishes increased. The specimens were derived from depths of 100 m and 200 m, and all three transects were represented. With increasing depth polychaetes decreased. Fishes appeared to be most abundant in deeper water on the Chandeleur transect.

Gobiidae - Gobies

Bollmannia communis. Twenty specimens of the ragged goby were examined and 18 contained food. These formed a single size class (51-75 mm). All specimens were taken at a depth of 60 m on the Chandeleur transect. The food consisted of 5% polychaetes and 95% undetermined organic matter. Roger (1977) examined the food of 66 specimens of this goby and found 46 with food. This material included crustaceans (25%), fish remains (40%), and unidentified animal material (26%). Inorganic matter made up the remainder.

Stromateidae - Butterfishes

Peprilus burti. In this study, 87 specimens of the Gulf butterfish were examined, of which 86 contained food. These represented two size classes (76-100 mm and 101-150 mm). All specimens were taken at depths of 20 m and 100 m and both the Chandeleur and Mobile transects were represented. Crustaceans made up the bulk of the recognizable food in both size classes, although a few polychaetes were also encountered. Among the crustaceans calanoid copepods, shrimp, and stomatopods were present in some abundance, and a trace of isopods was also present. With increasing size, both copepods and shrimp decreased, and stomatopods increased. With increasing depth, the copepods decreased and the larger crustaceans increased. Crustaceans were much more important on the Mobile than on the Chandeleur transect.

Divita et al. (1983) examined the food of six specimens of the Gulf butterfish and encountered shrimp in 17% of the stomachs with food. Rogers (1977) examined the stomachs of 57 specimens, of which 55 contained food. Seventy-eight percent of the material was unrecognizable animal material and of the remainder amphipods made up 18%, decapods 3%, and polychaetes 1%.

Scorpaenidae - Scorpionfishes

Pontinus longispinis. A total of 221 specimens of the longspine scorpionfish was examined with 192 containing food. These represent three size classes (26-75 mm, 76-100 mm, and 101-150 mm). Specimens were taken at 100 m and 200 m and represent all three transects. Crustaceans ranged from 60 to 74%, fishes from 0 to 12%, and polychaetes from 0 to 3% of the food. Among the crustaceans, shrimp were consistently most abundant, crabs (including raninids) next, and amphipods, lobsters, and stomatopods were present in very small amounts. Shrimp were most abundant in the smallest size class and crabs and fishes peaked in the middle size class. Fishes were consumed only at the 200 m stations. Fishes appeared to be most important on the Chandeleur transect.

Scorpaena calcarata. A total of 68 specimens of the smoothhead scorpionfish was analyzed, but only 48 contained food. These formed two size classes (26-75 mm and 76-125 mm). The specimens were taken at depths of 60 m and 100 m and were collected on all three transects. All the recognizable food was crustaceans, which included (in order of importance), shrimp, stomatopods, crabs, lobsters, and a trace of amphipods and tiny pagurids. Percentages of crustaceans were greatest in deeper water and on the De Soto Canyon transect. Divita et al. (1983) examined 7 specimens of this scorpionfish and found crustaceans in 20% of those with food.

Triglidae - Searobins

Bellator militaris. In this study, 71 specimens of the horned searobin were examined, but only 54 contained food. These include two size classes (26-50 mm and 51-100 mm). The individuals were taken at a depth of 60 m on all three transects. Two food groups were recognized, crustaceans being the more abundant. There was also a trace of polychaetes. Shrimp and amphipods were the most important crustacean groups followed by crabs, calanoid copepods, megalopa, and small benthic crustaceans. Crustaceans decreased in the larger sized fishes and the percentage of fishes increased. Likewise, calanoid copepods, amphipods, and crabs decreased and shrimp and megalopa increased in the larger fishes. Crustaceans were highest on the De Soto Canyon transect and fishes were more abundant on the Mobile transect. Calanoid copepods were consumed only on the Mobile transect and the larger mobile species, which were absent from the

Chandeleur transect, reached their highest percentages on the De Soto Canyon transect.

Lewis and Yerger (1976) reported on the food of 15 juvenile and 59 adult specimens of the horned searobin. Food of the young consisted of 42% amphipods, 26% shrimp, and less than 10% each of several other crustacean groups, as well as polychaetes and bivalves. Adults consumed 31% shrimp, 30% amphipods, 19% mysidaceans, and small percentages of other crustacean groups, polychaetes, mollusks, and small fishes.

Prionotus alatus. A total of 145 specimens of the spiny searobin was analyzed of which 119 contained food. These included two size classes (26-100 mm and 101-175 mm). These individuals were captured at depths of 60 m and 100 m, and all three transects were represented. In both size classes, crustaceans and made up the largest percentage of the food followed by fishes and then polychaetes. Among the crustaceans, shrimp and crabs were the dominant items, but traces of copepods and amphipods were also present. With increasing size, the percentage of crabs decreased, but the polychaetes, shrimp, and fishes increased. The percentage of crustaceans tended to increase with depth. Fishes were more heavily consumed on the Chandeleur transect, polychaetes on the Mobile transect, and crustaceans on the De Soto Canyon transect.

Lewis and Yerger (1976) reported on the stomach contents of 24 juvenile and 30 adult specimens of the spiny searobin. In the juveniles, the food consisted of 31% shrimp, 16% amphipods, 13% mysidaceans, 10% stomatopods, and smaller amounts of other crustacean groups, polychaetes, bivalves, and fishes. In the adults, shrimp constituted 71% of the food and crabs made up 11%. Other items in small amounts included a variety of crustaceans as well as bivalves and fishes.

Prionotus longispinosus. In the present study, 125 specimens of the blackwing searobin were examined with 109 containing food. These were divided into three size classes (51-75 mm, 76-125 mm, and 126-175 mm). Specimens were collected in depths of 20 m and 60 m on the Mobile and De Soto Canyon transects. Crustaceans made up by far the largest food category in all size groups, followed by fishes and then polychaetes. Among the crustaceans, shrimp (including *Penaeus setiferus*) were the most important group followed by crabs (including portunids). Small amounts of isopods, amphipods, and stomatopods also appeared occasionally. With increasing size, the percentage of polychaetes and shrimp declined, and the percentage of fishes increased. With increasing depth the percentage of polychaetes decreased and that of the fishes increased. Crustaceans increased in the smaller size group and remained about the same in the middle size group. Polychaetes and fishes were more important on the Mobile transect, but crustaceans were generally more important on the De Soto Canyon transect. Divita et al. (1983) examined the food of 33 specimens of this searobin (listed as *P. salmonicolor*). Shrimp were encountered in 20%, and fishes, crabs, and miscellaneous invertebrates each appeared in 5% of the stomachs containing food.

Prionotus roseus. Forty-six specimens of the bluespotted searobin were examined, all of which contained food. They formed two size classes (51-125 mm and 126-150 mm). Specimens were taken at depths of 20 m and 60 m and they were represented on the Mobile and De Soto Canyon transects. Crustaceans made up at least 87% of the food in both size classes and very small amounts of calanoid copepods, polychaetes, mollusks, and fishes were also encountered. Among the crustaceans, shrimp made up over 80% of the food with smaller amounts of crabs and amphipods. Food changed little in relation to size class, depth of capture or transect.

Divita et al. (1983) examined the stomachs of seven specimen of this searobin and shrimp appeared in 43% of the stomachs with food. Lewis and Yerger (1976) examined 14 stomachs of juvenile and 54 stomachs of adult specimens. The juveniles contained shrimp 72%, mysidaceans 13%, amphiphods 10%, and lesser amounts of bivalves, polychaetes, and crabs. The adults contained 82% shrimp and very small quantities of other crustaceans, polychaetes, bivalves, ophiuroids, and fishes.

Prionotus rubio. A total of 83 specimens of the blackfin searobin was examined, of which 71 contained food. These were divided into two size classes (51-100 mm and 101-175 mm). Specimens were derived from depths of 20 m, 60 m, and 100 m and the Chandeleur and Mobile transects were represented. Crustaceans constituted 60% or more in each of the size classes, fishes 7-23%, and polychaetes 5% or less. Among the crustaceans, shrimp was the dominant item followed by crabs. A few megalopa were also encountered. With increasing body size, there was an increase in the percentage of crustaceans and a decrease in polychaetes and fishes. The percentage of polychaetes and crustaceans decreased with depth, while the percentage of fishes increased. Fishes were more heavily utilied on the Mobile transect.

Divita et al. (1983) examined the stomachs of 73 specimens of the blackfin searobin and found shrimp in 42% and crabs in 4% of the stomachs with food. Rogers (1977) found food in 134 of 193 stomachs examined. In his study, shrimp made up 41%, crabs 22%, fishes 12%, polychaetes 6%, stomatopods 5%, mysidaceans 2%, and amphipods 1%, respectively.

Prionotus scitulus. Sixty-five specimens of the leopard searobin were examined, of which 51 contained food. These represented two distinct size classes (26-50 mm and 101-175 mm). All the specimens were captured at a depth of 20 m on the De Soto Canyon transect. Crustaceans and polychaetes were the only food groups identified. The crustaceans were predominantly shrimp, although crabs and amphipods were well represented. With increasing size class, there was a reduction in the percentage of polychaetes and an increase in utilization of crustaceans, particularly shrimp and crabs. Divita et al. (1983) examined the food of two specimens of this species and found shrimp as the sole food item.

Prionotus stearnsi. A total of 57 specimens of the shortwing searobin was examined, of which 51 contained food. A single size class was represented (26-100 mm). The specimens were taken from depths of 60 m and 100 m and the Chandeleur and Mobile transects were represented. Crustaceans constituted 75% of the food, fishes 12%, and cephalopods 10%. Among the crustaceans, shrimp and stomatopods each made up 27%, megalopa made up 12%, amphipods 5%, crabs 3%, and isopods 1%. In relation to depth, crustaceans decreased and fishes increased in deeper water. Crustaceans were more abundant on the Chandeleur transect and cephalopods and fishes were more abundant on the Mobile transect.

Lewis and Yerger (176) examined the stomachs of 10 specimens of juvenile and 14 specimens of adult shortwing searobins. The young contained 87% amphipods plus copepods, isopods, shrimp, megalopa, and fishes in very low amounts. In the adults, fishes made up 64% of the food; shrimp, crabs, and megalopa 9% each; and amphipods and cephalopods represented 5% each. Rogers (1977) examined the stomachs of 153 specimens, of which 114 contained food. Fishes constituted 90% of the material, crustaceans 8%, and other invertebrates were present in trace amounts.

Bothidae - Lefteye Flounders

Etropus rimosus. In the present study, 93 specimens of the gray flounder were examined and 73 contained food. These represented two size classes (26-50 mm and 51-125 mm). The individuals were collected at depths of 20 m and 60 m on the Mobile and De Soto Canyon transects. In both size classes, crustaceans made up over 40% of the food and polychaetes made up over 30%. A trace of minor phyla was present and some individuals had been consuming hydroid polyps. Among the crustaceans, shrimp were most abundant followed by amphipods, isopods, calanoid copepods, crabs, small benthic crustaceans, and megalopa, in that order. With increasing size of the fish, polychaetes increased and shrimp decreased slightly. There was no clear pattern of change of food habits with depth. However, polychaetes were consumed in greater abundance on the Mobile transect and crustaceans were emphasized on the De Soto Canyon transect.

Syacium gunteri. In the present study, 151 specimens of the shoal flounder were examined and 116 contained food. These formed two size classes (26-75 mm and 76-150). The individuals were taken from depths of 20 m and 60 m from all three transects. Crustaceans made up over half the food of both size classes. Polychaetes and fishes were present in moderate amounts and traces of bivalve mollusks were present. Among the crustaceans, shrimp was the most abundant group and amphipods and crabs were about equal in abundance. As the shoal flounder increased in size, it consumed more polychaetes and crabs and less amphipods and fishes. However, the percentage of amphipods and fishes increased at the deeper stations. Shrimp reached their highest level on the Chandeleur transect, crustaceans on the Mobile transect, and polychaetes on the De Soto Canyon transect.

Gallaway and Martin (1980) reported on the seasonal food habits of the shoal flounder. The dominant food items, listed by season, were as follows: winter - xanthid crabs 31%, tanaids 14%, and amphipods 10%; spring - shrimp 24%, xanthid crabs 20%, polychaetes 9%, valved mollusks 6%, amphipods 5%, and fishes 4%; and fall - shrimp 76%. Rogers (1977) examined the stomachs of 246 specimens, of which 190 contained food. In his study, shrimp comprised 29%, stomatopods 26%, crabs 16%, fishes 10%, amphipods 6%, polychaetes 5%, and there were smaller amounts of other crustaceans and cephalopods.

Syacium papillosum. A total of 324 specimens of the dusky flounder were analyzed and 253 contained food. Four size classes were recognized (26-75 mm, 76-100 mm, 101-150 mm, and 151-200 mm). The food of this species, listed in order of abundance, was crustaceans, fishes, polychaetes, and cephalopods. A trace of valved mollusks was also present. Among the crustaceans, the most important food category was crustaceans followed, in order, by crabs, amphipods, and stomatopods. Very small amounts of lobsters and megalopa were also present. With increasing size, this flounder consumed progressively less polychaetes and crustaceans and more fishes. Crustaceans were consumed least on the Mobile transect and polychaetes showed highest percentages on this transect. Cephalopods were taken exclusively on the De Soto Canyon transect. This species was unique in the variety of crabs consumed. These included Hippidae, Parthenopidae, Pinnotheridae, as well as Portunidae. Divita et al. (1983) examined the stomach contents of a single specimen of this flounder and encountered shrimp and fish remains.

Trichopsetta ventralis. In the present study, 161 specimens of the sash flounder were examined and 127 contained food. Three size classes were recognized (26-75 mm, 76-100 mm, and 101-250 mm). Specimens were taken at depths of 60 m, 100 m, and 200 m and were present on the Chandeleur and Mobile transects. Crustaceans constituted by far the most abundant food category followed by fishes and then polychaetes. Small minor phyla, bryozoans, and valved mollusks made up trace amounts. Shrimp were the most important crustaceans, but small percentages of amphipods, lobsters, crabs, and stomatopods were present. Larger fishes ate fewer polychaetes and more crustaceans (especially shrimp) than did the smaller fishes. Polychaetes and fishes were consumed at a depth of 100 m. Crustaceans were consumed in abundance at all depths, but they made up all the identifiable food at the 200 m depth. No clear trends were evident in relation to transect.

Rogers (1977) examined the stomach contents of 36 specimens of the sash flounder and found 30 contained food. This included fishes (70%), shrimp (18%), crabs (5%), stomatopods (4%), and trace amounts of polychaetes, mysids, and macrurans.

Cynoglossidae - Tonguefishes

Symphurus civitatus. A total of 104 specimens of the offshore tonguefish was examined, of which 94 contained food. These represented two size classes (51-100 mm and 101-125 mm). The specimens were taken from depths of 20 m, 60 m, and 200 m and occurred on the Chandeleur and Mobile transects. Among the recognizable food material, polychaetes formed the highest percentage followed by crustaceans. A trace of valved mollusks was present. The stomachs also contained much unidentified animal material and some organic detritus. It is likely that much of this unidentified material included polychaete tubes and mucus. None of the crustacean groups made up over 6% of the total food. These included shrimp, amphipods, lobsters, and isopods. Larger flounders ate a slightly larger percentage of polychaetes, and the percentage of shrimp was greatest at the deepest station. Shrimp were more important on the Chandeleur transect.

Rogers (1977) studied the stomach contents of 159 specimens of the offshore tonguefish and found 126 to contain food. This material included polychaetes (17%), amphipods (15%), fish remains (5%), and smaller amounts of stomatopods, copepods, cumaceans, shrimp, and crabs. In his study, unidentified material (flesh, various animal remains, and sediment) made up 56% of the total stomach contents.

Symphurus plagiusa. Ninety-nine specimens of the blackcheek tonguefish were examined, of which 90 contained food. These formed two size classes (76-125 mm and 126-150 mm). The fishes were captured at depths of 20 m and 60 m on all three transects. The dominant food group was crustaceans. Polychaetes were prominent and there were small percentages of valved mollusks. Amphipods were the most abundant crustaceans, and crabs were next. Isopods and shrimp were present in very low abundance. Polychaetes and all crustacean groups except amphipods decreased in abundance in the larger sized fish. With increasing depth, the percentage of crustaceans decreased and the percentage of polychaetes increased. Both polychaetes and shrimp were consumed in highest percentage on the Mobile transect.

Rogers (1977) examined the stomachs of 22 specimens of the blackcheek tonguefish and found 17 with food. Polychaetes made up 90% of the food, although there were small percentages of cumaceans, amphipods, decapods, and bivalve mollusks.

9.5 Trophic Structure of the Shelf Ecosystem

Having examined food relations of the individual fish species, it is now important to focus upon the trophic structure of the larger system and to distinguish local variations in this structure. The analysis will proceed through the following steps. First, the utilization of the major food groups and crustacean groups by all species combined will be examined, and the food groups will be lumped into more ecologically meaningful categories. Next, food utilization will be examined in relation to depth and transect. Finally, based upon all the data, the relationship of each station to all others will be examined to determine local variations in food utilization by the fish community as a whole. By this means, those stations which are most similar in respect to trophic characteristics may be clustered together to show similarities among groups of stations and their distinctions from other such groups.

9.5.1 Food Group Utilization

Utilization of the various food groups by all species combined is shown in Table 9-8. This table represents the information derived by summing the vertical columns in Table 9-2 and 9-3 and expressing the results as percentages. These results show that crustaceans formed almost half the food of the fish community. Fishes and polychaetes each constituted over 13% of the food, and together these three groups made up over 75% of the stomach contents and 97% of the identifiable food. The additional items including minor phyla, valved mollusks, cephalopods, and organic detritus made up the remainder. Unidentified animal material constituted 23% of the total stomach contents and this apparently included masses of partially digested flesh (primarily from shrimp and fishes) as well as the tubes and mucus of polychaetes.

As seen in Table 9-8b, shrimp made up almost 60% of the crustaceans consumed and amphiphods and crabs made up over 9% each. Taken together, these three food groups accounted for 78% of the total crustaceans and 84% of the identifiable crustacean food. The remaining crustacean groups including the small benthic crustaceans (ostracods, harpacticoid copepods, and cumaceans), calanoid copepods, isopods, lobsters, megalopa, and stomatopods, together constituted about 15% of the crustaceans consumed.

Table 9-8. Summary of the percent utilization of the various food groups by all species combined.

A. Percent utilization of the major food groups.
B. Percent utilization of the various crustacean groups.

A. Major food groups

Food group	Minor Phyla	Mollusks (valved)	Cephalopods	Polychaetes	Crustaceans	Fishes	Animal Matter (undetermined)	Organic detritus
Percent	0.13	0.07	0.62	13.18	47.52	14.38	22.83	1.27

B. Crustacean groups

Food group	Small benthic crustaceans	Calanoid Copepods	Isopods	Amphipods	Shrimp	Lobsters	Megalopa	Crabs	Stomat-opods	Undeter crustaceans
Percent	0.75	3.08	0.82	9.00	58.61	3.81	2.69	10.05	4.17	7.03

It is of considerable interest to examine the food of the fish community aggregated by ecological rather than taxonomic considerations. To accomplish this, it was necessary to lump the groups as follows: zooplankton (calanoid copepods), small benthic animals (minor phyla, valved mollusks, small benthic crustaceans, amphipods, isopods, and crab megalopa), benthic infauna (polychaetes), and larger mobile animals (cephalopods, shrimp, crabs, lobsters, stomatopods, and fishes), This is admittedly an imperfect grouping because: a) the exact habitats of many of the species are unknown, b) different members of a group may occupy different habitats, c) some members may alternate between planktonic and benthic habitats, and d) species which dwell in the supra-benthic environment could as well be classified as benthic or planktonic. Nevertheless, the grouping is quite informative. In the Mississippi-Alabama shelf ecosystem, the percent distribution of the food is as follows: zooplankton (1.5%), small benthic animals (6.6%), benthic infauna (13.2%), larger mobile animals (51.4%), unidentified animal material (26.2%), and organic detritus (1.3%). Viewed as percentage of the identified animal food, the following pattern emerges: zooplankton (2.1%), small benthic animals (9.1%), benthic infauna (18.2%), and larger mobile animals (70.9%). This is a surprising pattern, especially considering the fact that most of the individuals examined were fairly small fishes. The percentage of larger mobile species would have been expected to be lower and the percentage of the other food groups should be higher, particularly the zooplankton group. Part of the explanation lies in the fact that most of the shrimp and stomatopods were very small, and some of these as well as some of the megalopa were undoubtedly planktonic. However, even allowing for this consideration, larger mobile animals constituted by far the dominant category, and this was due chiefly to the large quantities of small shrimp consumed. Shrimp included larval and subadult stages of larger penaeids as well as all life history stages of smaller species. Very few adults were encountered. The three dominant food groups, shrimp (38.4%), fishes (19.8%), and polychaetes (18.2%), accounted for 76.4% of the identifiable food. Upon these three food groups the majority of the fish community depends.

9.5.2 Food Utilization in Relation to Depth

Table 9-9 presents results of the Chi Square analysis of the depth distribution of the most important food groups. For a given group, food utilization at each depth is expressed as a percentage of its usage at all depths. Since there are four depths, the Chi Square "expectation" is 25% utilization at each depth. Deviations are expressed as Chi Square values, and

Table 9-9. Summary of the percent utilization of the various food groups in relation to depth for all species combined, together with their Chi Square values. Those values which are statistically significant at the 5% level are indicated by an asterisk (*).

A. Percent utilization of the most important major food groups.
B. Percent utilization of the major crustacean groups.

A. Major food groups (Chi Square = 7.81)

Food Group	Depth				Chi Square value
	20 m	60 m	100 m	200 m	
Cephalopods	44.55	37.62	13.86	3.96	44.33*
Polychaetes	25.66	18.31	24.17	31.86	3.72
Crustaceans	25.97	27.38	24.53	22.12	0.60
Fishes	11.23	28.87	31.60	28.29	10.36*

B. Crustacean groups (Chi Square = 7.81)

Food Group	Depth				Chi Square value
	20 m	60 m	100 m	200 m	
Zooplankton	49.60	41.94	7.66	0.81	71.12*
Benthic micro-crustaceans	42.35	11.22	46.43	0.00	63.01*
Benthic small crustaceans	46.55	29.65	10.79	13.00	33.28*
Larger mobile species	20.54	28.23	26.92	24.31	1.38

in the present case deviations exceeding 7.81 are statistically significant at the 5% level of confidence.

In Table 9-9a, it is seen that there are significant differences in the utilization of both cephalopods and fishes in relation to depth. The small squid, *Lolliguncula brevis*, is an abundant species which spawns in shallow nearshore waters and most of the squids consumed are likely young of this species. In deeper water, squids would tend to be larger, less concentrated, and more pelagic, and thus, less available as food for the consumers. Fishes are available at all depths, but in shallow water there are many more prey options for the consumers. What is particularly interesting is the fact that both polychaetes and crustaceans were utilized to about the same extent at all depths. These staple food items appear to have been universally available to the consumers.

The second part of Table 9-9 shows the depth distribution of utilization of crustacean groups. Here is is seen that consumption varies significantly with depth in the cases of zooplankton, benthic micro-crustaceans, and benthic small crustaceans. Zooplankton is used most heavily at the shallow depths and hardly at all in the deepest water. Zooplankton is most concentrated where there is phytoplankton food, so this pattern is not surprising. Benthic micro-crustaceans showed utilization peaks at the 20 m and 100 m depths, low utilization at the 60 m depth, and no utilization at 200 m. Although this unexpected pattern may be valid, it appears more likely that this is an artifact due to the chance occurrence of these rarely appearing organisms. The case of the small benthic crustaceans is another matter. This group (consisting of cumaceans, tanaids, isopods, amphipods, and small anomurans) was an important food group in many of the fishes and the great decrease in utilization with depth is a real phenomenon which probably relates to lower availability at greater depths. The larger mobile crustacean group showed a very low Chi Square value. There was no significant difference in its utilization with depth and it is this group which resulted in a low Chi Square value for the crustaceans as a whole. As noted earlier, shrimp constituted the major food category within the larger mobile crustaceans.

On the basis of this analysis, it is concluded that there is a reasonably stable food resource of polychaetes and shrimp available to the consumers at all depths of the Mississippi-Alabama continental shelf. Zooplankton, small benthic crustaceans (particularly amphipods), and cephalopds are more heavily preyed upon in shallow water than they are in deeper water. On the other hand, fishes, which form a small proportion of the diets in shallow water, become a major food resource in deeper waters of the shelf.

9.5.3 Food Utilization in Relation to Transect

Chi Square analysis of major food group utilization in relation to transect is presented in Table 9-10. Since there are only three transects, the Chi Square "expectation" is that 33.3% of the food of a given category is consumed on each transect. Here, deviations exceeding 5.99 are significant

Table 9-10. Summary of the percent utilization of the various food groups in relation to transect for all species combined, together with their Chi Square values. Those values which are statistically significant at the 5% level are indicated by an asterisk (*).

A. Percent utilization of the most important major food groups.
B. Percent utilization of the various crustacean groups.

A. Major food groups (Chi Square= 5.99)

Food Group	Transect			Chi Square value
	Chandeleur	Mobile	DeSoto	
Cephalopods	30.18	35.78	34.03	0.49
Polychaetes	28.12	44.41	27.47	5.53
Crustaceans	28.82	32.44	38.75	1.52
Fishes	44.94	26.88	28.17	6.10*

B Crustacean groups (Chi Square = 5.99)

Food Group	Transect			Chi Square value
	Chandeleur	Mobile	DeSoto	
Zooplankton	19.18	53.08	27.74	18.66*
Benthic micro crustaceans	18.18	16.58	65.25	45.92*
Benthic small crustaceans	39.96	31.99	28.06	2.21
Larger mobile species	27.60	33.30	39.10	1.99

at the 5% level. This table shows the utilization of three groups to differ significantly from the expected values, zooplankton, benthic micro-crustaceans, and fishes. The use of zooplankton was heaviest on the Mobile transect, use of benthic micro-crustaceans was greatest on the De Soto Canyon transect, and utilization of fishes was greatest on the Chandeleur transect. Reasons for these differences are not clear. Nutrients coming from Mobile Bay may stimulate phytoplankton growth leading to higher zooplankton populations in this area. Benthic micro-crustaceans may exist in denser populations or be more vulnerable to predation in the shell hash bottoms near De Soto Canyon. Near the Mississippi River Delta marshes, large populations of small fishes may be available as food or there may be a higher concentration of fish predators in this area. It is noted that the Chi Square value for the fish category is barely significant. Depth and transect are both important in determining food utilization. In any event, much more information would have to be available to permit definitive resolution of the factors responsible for the observed transect-related differences.

9.5.4 Food Utilization in Relation to Station

One of the goals of the present study is to determine the relationships of the various stations to each other based upon similarities and differences in food consumed by the fish community in the different areas. The first step in this analysis is determining a "food profile" for each station. This is presented in Table 9-11. Preparation of this table involved the following procedures for each station: lumping of the food of all species and size classes, deletion of unidentified material, and expression of the remaining items as a percentage of the total identifiable material consumed at the station. Visual inspection of this table reveals differences between stations, but no clear patterns emerge from this array of data (involving 12 columns and 19 rows). However, the statistical package, called principal components analysis, is suited for examining the characteristics of each column in relation to all other columns and expressing these relationships in cumulative terms, called principal components. A plot of the first versus the second principal component for each station provides a two-dimensional display of the position of each station with respect to all others.

Figure 9-1 is a plot of station points derived from principal components analysis of the food data presented in Table 9-11. Clusters of neighboring stations have been enclosed to aid in the visualization of station relationships. Four main clusters are displayed, one with three internal sub-clusters. Immediately obvious is the fact that stations D1 and D2 are quite distinct from each other and from all other stations. Stations D3, D4, and C3 are quite similar and fall into a single cluster. However, the presence of C3 in this group is clearly an anomaly and because of its geographic isolation must eventually be removed from this group. Its proximity to D3 and D4

Table 9-11. Distribution of food groups by station, all species and size classes combined. In preparing the table all unidentified material was deleted, and the remaining food groups were expressed as percentage of the identifiable material at each station.

Food Groups	Stations											
	C1	C2	C3	C4	M1	M2	M3	M4	D1	D2	D3	D4
Misc. small invertebrates	0.54						0.12	0.48	0.08		1.44	
Polychaetes	25.41	17.70	9.98	39.21	26.80	19.89	29.50	32.39	15.42	7.51	14.06	8.77
Mollusks (valved)	1.42	0.48	0.23		0.01	0.02	0.13		0.05			0.06
Cephalopods	0.36		0.61		1.21	3.19			1.65	2.09	2.29	0.35
Ostracods	0.14	0.03			0.03	0.11			2.80	0.10		
Harpacticoids	0.01			0.06	0.01			0.09	1.47			
Calanoids	5.13	0.51	0.01	0.07	14.61	3.87	0.22	0.09	6.35			4.30
Cumaceans	0.03	0.08			0.35				0.56			
Tanaids		0.59			0.46	0.40			0.01	0.03		
Isopods	0.92	0.05	0.33		0.50	0.07	0.05	0.87	1.40	0.77		1.16
Amphipods	13.89	3.91	0.35	3.61	5.26	6.42	0.77	4.53	11.64	2.04	2.48	2.38
Shrimp	28.58	28.58	47.47	37.72	35.09	22.87	39.63	33.33	39.82	58.75	48.19	47.47
Lobsters		0.79	6.00	0.49	0.64	0.49	1.11	1.93	0.38	6.94	1.51	
Megalopa	3.69	0.44	0.98		0.51	2.72	0.04		1.14	0.34	3.63	
Crabs	6.89	6.97	11.69	2.41	9.94	7.57	4.20	17.31	5.86	8.44	6.16	2.24
Anomurans										0.04	0.02	
Stomatopods	1.68	10.42	0.89		0.08	3.63	11.56	1.45	0.04	0.63	3.45	
Fishes	8.09	27.52	20.11	13.55	3.47	28.30	9.77	3.65	7.79	12.31	16.77	33.27
Organic detritus	3.21	1.92	1.36	2.88	1.04	0.42	2.90	3.91	3.56			

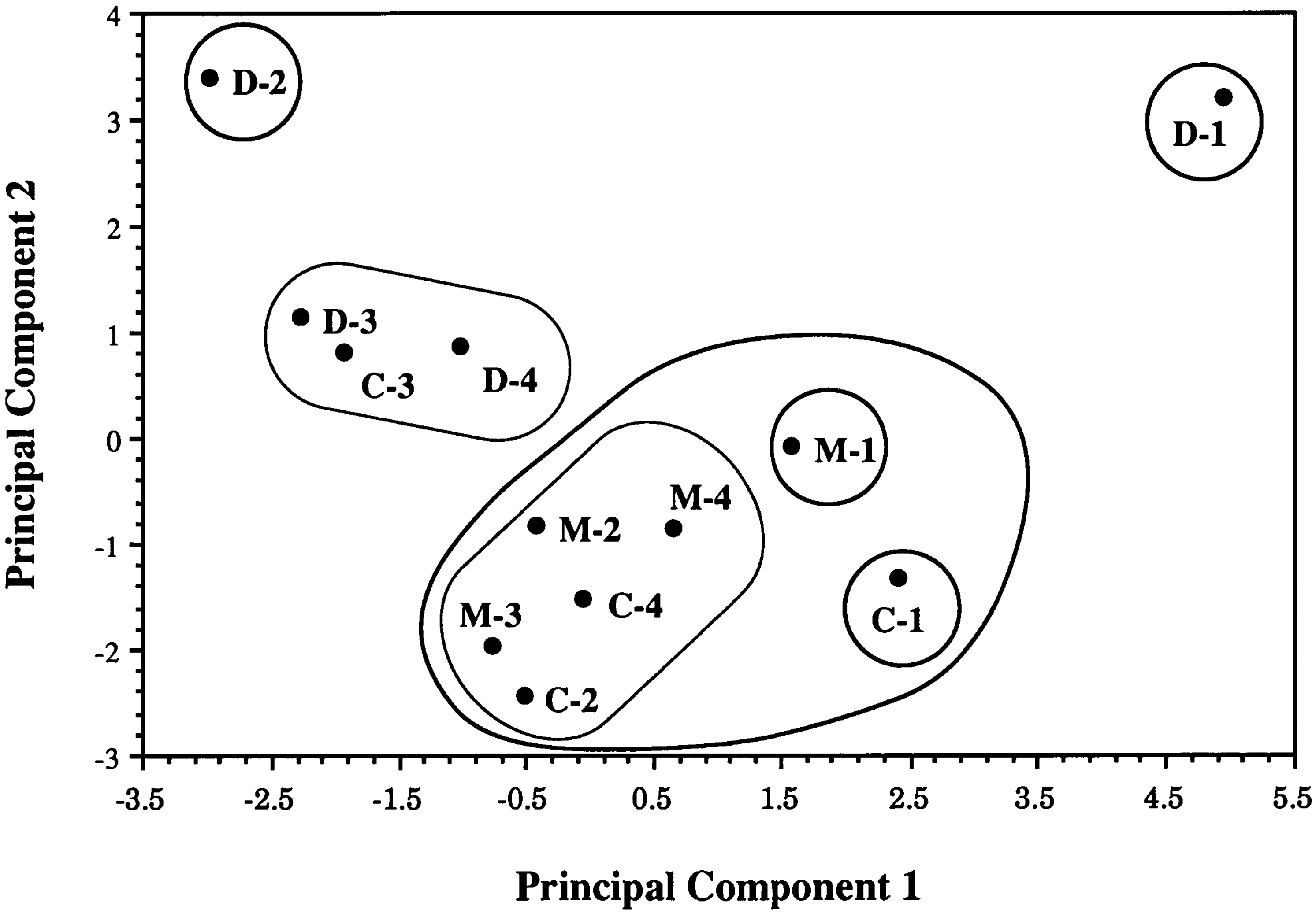


Figure 9-1. A plot of the station points and clusters derived from principal components analysis of data presented in Table 9-11.

reflects similarity in general food group utilization which, in turn, probably reflects similarities in habitat features. If the food items had been expressed in more specific terms (families, for example), almost surely this station would have been positioned some distance from D3 and D4. Within the largest cluster, stations C1 and M1 are spread some distance from the rest of the stations and from each other. Within the remaining and sub-cluster the five stations (C2, C4, M2, M3, and M4) are close and about equidistant from their nearest neighbors.

What deeper ecological meaning is reflected in the observed station positions and relationships? Examination of the distribution of station points together with information from Table 9-11 help to answer this question. A few examples will be given. First, it is apparent that all three shallow water stations (C1, M1, and D1) fall to the right of all other stations (i.e., they all have high values of principal component 1, indicating that they all share a certain combination of characteristics. Examination of Table 9-11 reveals that all three stations are characterized by relatively high values for polychaetes, calanoid copepods, cumaceans, isopods, amphipods, crabs, and organic detritus. Second, it is seen that all stations on the De Soto Canyon transect fall in the upper half of the figure (i.e., they all exhibit high values of principal component 2. Table 9-11 shows these stations are similar in having relatively high values for cephalopods, shrimp, and anomurans and low values or absence of harpacticoids, tanaids, stomatopods, and organic detritus. On the basis of such analysis, it can be determined more or less why stations are positioned as they are, but the principal components analysis provides an objective means of exact positioning.

Finally, it is instructive to examine the clustering of stations in a geographic sense, i.e., as a map. This is presented in Figure 9-2. Here the distinctness of the De Soto Canyon stations is quite apparent, as is the distinctness of station C3. The remaining stations on the Chandeleur and Mobile transects fall into a large cluster, but C1 and M1 show some identity within the larger group. This map indicates that, as far as the fish food is concerned, the De Soto Canyon area is ecologically unique and that there is something special about the C3 area. It further suggests that there is some measure of uniqueness in each of the nearshore stations. Differences between stations C2, C4, M2, M3, and M4 appear to be relatively minor.

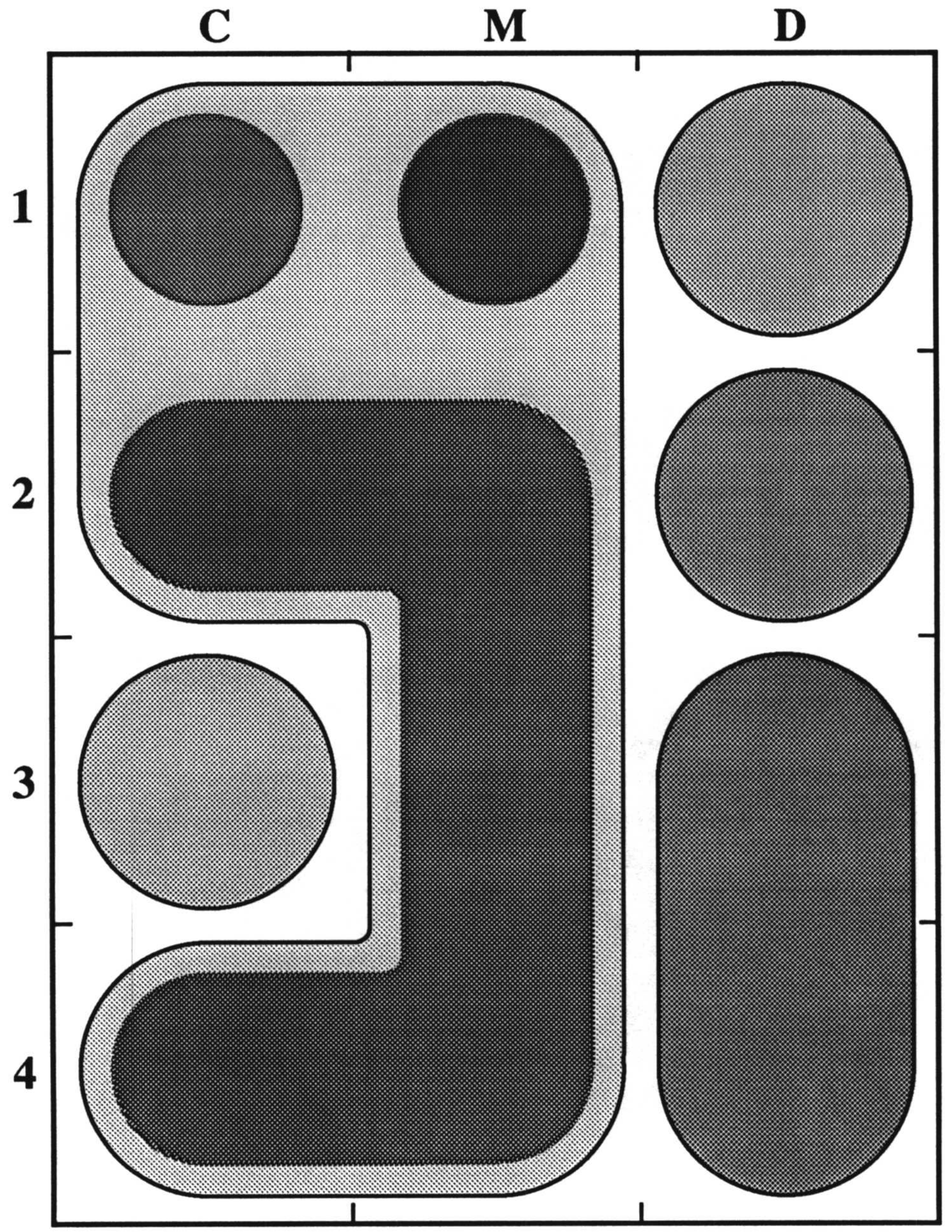


Figure 9-2. Diagrammatic map of the distribution of station clusters shown in relation to transect and depth. Station C-3 was removed from the cluster with D-3 and D-4 for geographic reasons. Details are discussed in the text.

9.6 Conclusions

In the present study, the food of 4,675 fishes representing 49 species was examined to provide information about the trophic structure of the Mississippi-Alabama continental shelf ecosystem. Differences in food consumption by individual species were noted and diet changes with increasing size class were determined. Most of the fishes ranged in size between 25 mm and 200 mm, so the food of larval fishes and the larger predators was not included.

A fairly significant amount of the food could not be specifically relegated to a particular food group and was listed as undetermined animal material. Most of this appeared to be partially digested flesh of shrimp and fishes as well as tubes and mucus of polychaetes. Of the identifiable material, crustaceans made up 60%, fishes and polychaetes about 18% each, and the remaining groups about 3%. Among the identifiable crustaceans, shrimp constituted 63%, amphipods and crabs over 10% each, and all the remaining crustacean groups about 16%. From an ecological standpoint, zooplankton made up 2%, small benthic animals 9%, benthic infauna 18%, and larger mobile animals 71% of the identifiable food. The three dominant food groups, shrimp, fishes, and polychaetes, together constituted 76% of the identifiable food.

In relation to depth, zooplankton, small benthic crustaceans, and cephalopods were consumed most heavily in shallow water and fishes were preyed upon most heavily at the greatest depths. In relation to transect, fishes were consumed most on the Chandeleur, zooplankton on the Mobile, and benthic microcrustaceans on the De Soto Canyon transect. Polychaetes and shrimp were important prey categories at all depths and on all transects. Comparison of the food profiles of all the stations revealed that all De Soto Canyon stations were different from their neighbors on the Mobile transect. Station C3 on the Chandeleur transect was also special. The remaining stations on the Chandeleur and Mobile transects clustered together, although some degree of identity was shown by the two nearshore stations (C1 and M1).

Having examined what the fish food reveals about the ecological system, it is important to question how biased this picture may be. It has already been noted that there is a bias due to the size classes of the fishes examined. Zooplankton, microbenthic fauna, and larger mobile organisms undoubtedly do not appear in the food in proportion to their abundance in the environment. However, within the size ranges which can be consumed, fishes are undoubtedly the most efficient sampling devices available. If a food resource is present, it is utilized by some species. There is a potential bias on the part of the investigator in his choice of species and size classes of fishes to examine. Such bias is considered to be minimal in the present study because all species and size classes available were examined. In general, the investigation of a large number of species (in the present case, 49 species) should provide a better overview of community food utilization than intense investigation of a few key species. For these reasons, it is concluded that the present view of the Mississippi-Alabama shelf ecosystem is reasonably accurate and more thorough than for any other area of the open continental shelf of the northern Gulf.

10.0 PHYSICAL OCEANOGRAPHY/WATER MASS CHARACTERIZATION

F.J. Kelly

10.1 Introduction

10.1.1 Objectives

The primary objective of the physical oceanography component of the Mississippi-Alabama Marine Ecosystem Study (MAMES) is to characterize the circulation on the outer shelf, with emphasis on the influence of the exchange processes between the outer shelf and the open ocean. This objective was established based on the results of the Tuscaloosa Trend Regional Data Search and Synthesis Study (Vittor & Associates 1985), which identified the outer shelf and slope as the region most in need of further field work. Of particular interest is the extent to which Loop Current intrusion influences shelf processes. A second objective is to develop a coherent description of the circulation and hydrography of the study region during the periods of interdisciplinary field sampling. A third objective, which arose from the results of interdisciplinary sampling by the other tasks, is to identify physical factors that might be related to the dramatic drop in various measures of biomass that occurred between the August 1988 and February 1989 cruises.

10.1.2 Elements of the Physical Oceanography Component

The physical oceanography component of the project maintained a cross-shelf array of three current meter moorings in the eastern part of the study area throughout 1988 and added a second array of two moorings on the outer shelf and slope in the central part of the area for 1989. All current meters recorded current velocity, temperature and conductivity. Five semi-annual, inter-disciplinary cruises collected vertical profiles of CTD/transmissivity, dissolved oxygen, and nutrients at twelve primary stations and five to ten supplemental ones. A collateral data set, consisting of meteorological, wave, river discharge, water level and satellite infrared observations, obtained from governmental agencies, supplements the time series and hydrographic data.

The Year 1 Annual Report of this project (Brooks and Giammona 1988) contains the results of the first three hydrographic surveys, the quality control procedures for the CTD and hydrographic data, and a description of the mooring configurations and instruments that were deployed during 1988. The Year 2 Annual Report (Brooks and Giammona 1990) presents the results of two additional hydrographic surveys and describes the five moorings deployed during 1989. It also details the quality control and data analysis procedures for the time series data collected by the current meters.

10.1.3 Background

The study region is approximately trapezoidal in shape, with a right angled corner to the northwest. Barrier island systems that have numerous openings to protected shallow sounds form the northern and western sides. The eastern side lies approximately along 87° W. The shelf-break and slope, which have a northeast-southwest trend, form the offshore side. In this study we have used 55° clockwise from north as the angle of the trend. The eastern side, offshore side and southernmost 28 km of the western side are open boundaries. The offshore side of the study region extends to the 500-m depth contour for all the project components, except satellite-imagery (Chapter 11), which covers most of the eastern Gulf of Mexico. The shelf break occurs at about the 100-m contour in the study area.

The term "inner shelf" is generally used to refer to the shallow shelf region where wind-driven friction dynamics dominate when the water column is barotropic or weakly stratified, and the along-shelf current leads or is in phase with coastal sea level (Schwing *et al.* 1985). In the outer shelf region, current begins to lag coastal sea level and to be less coherent with it, and inertial and other terms become important. The boundary between the inner and outer shelf in the MAMES region lies seaward of the 30-m depth contour, based on the results of Chuang *et al.* (1982) and Dinnel (1988), and shoreward of 60 m, based on the results of the present study.

The waters of the inner shelf are strongly influenced by wind stress, tides, fresh water from rivers, air-sea exchange of heat, and exchanges with waters in the sounds. The response of inner-shelf waters to wind stress, the primary forcing mechanism, is a function of the frequency, direction, and duration of wind stress, and also density stratification and coastal geometry (e.g., Csanady 1982; Chuang *et al.* 1982; Cochrane and Kelly 1986). The circulation that obtains over the MAMES inner shelf has been described by Murray (1972), Schroeder (1976), Chuang *et al.* (1982), Kjerfve and Sneed (1984), and Schroeder *et al.* (1985; 1987). Most recently, Dinnel (1988) conducted an in-depth study of current meter data collected by Raytheon for the U. S. Army Corps of Engineers (Kjerfve and Sneed 1984). He found that the observed mean flow over the inner shelf is generally westward and is consistent with wind-driven flow. Aperiodic reversals associated with northwesterly winds interrupt this flow. He hypothesized that the mean westward flow forms the inshore side of a cyclonic circulation cell, and that an anticyclonic cell lies over the outer shelf except during winter.

Inner shelf circulation is dominated by processes, such as wind-driven alongshore currents, upwelling (downwelling) transverse circulation, thermohaline flows, Kelvin waves and coastal-trapped waves, that require a lateral boundary, stratification, a seaward deepening bottom, or a combination of these. Such processes are dynamically confined to a distance from the coast of an internal Rossby radius, which is typically in the range of 10-25 km on continental shelves. The shallowness of the inner shelf water column enhances the influences of friction and dissipation and shortens frictional adjustment time. The coastal boundary is the fundamental constraint for wind-driven flow over the inner shelf because it directly forces Ekman flux divergence, even if the wind field is spatially uniform and the bottom relatively flat.

The forcing factors which affect the outer shelf and slope region include those of the inner shelf, but the response is altered by the increased depth and distance from the coastal boundary. As the influence of the coastal boundary is diminished, transfer of wind momentum to the interior geostraphic flow by Ekman flux divergence requires a spatial variation in either the wind field (wind-stress curl) or the bottom topography. The shift in the mechanism for Ekman flux divergence and the increase in frictional adjustment time result in generally lower wind-current coherences in broader frequency bands. The wind-current coherence signal also becomes mixed with signals from outer shelf, slope and open ocean processes. These are not well documented in the MAMES region, but the historical database for the northern Gulf of Mexico has examples to be further examined by this study.

Unusually intense storms can have a dramatic influence on the hydrography and currents over the shelf and slope region. The most obvious instance is the response to a hurricane. Storm-driven currents can approach 1 cm s^{-1} in the main thermocline over the shelf slope (Brooks 1983; Shay and Elsberry 1987). A strong cold front passing over the Gulf ("blue norther"), while of lesser impact than a hurricane, can also produce significant forcing of shelf waters by direct driving of the currents and by breaking down density stratification through vertical convection and mechanical stirring. The consequent reduction of vertical stability in the water column can lead to enhanced current responses at greater depths.

Even though a major storm may quickly pass over a particular location, the oceanic response to that storm can last for many days. Usually, the response to abrupt wind forcing at the surface will include waves of near-inertial frequency, which in the northeastern Gulf have periods of about one day. Inertial wave energy thus introduced will propagate downward and away from the forcing region, spreading the internal current response over a much wider area than might be expected from the size of the storm. The inertial wake of a major hurricane can produce current oscillations up to 50 cm s^{-1} in and below the mixed layer (Brooks 1983; Shay and Elsberry 1987; De Young and Tang 1990).

An additional and very significant factor of the outer shelf regime is the exchange of momentum, mass, nutrients, and biological elements across the conceptual boundary of the shelf with the open ocean. Csanady (1990) reviews the processes that have been observed to contribute to shelf-open ocean exchange in the mid-Atlantic Bight, which include rings, wind events and boluses (thickened lenses of water between two isopycnal surfaces). He concludes that "frontal mass exchange is due primarily to the instability of the baroclinic flow". Churchill and Cornillon (1990) observed intrusions of Gulf Stream water on the Virginia shelf and slope, and they found that such intrusions occur frequently and have a profound impact on the biological productivity of the region. Other possible factors in the cross-shelf exchange process include breaking internal waves (Rezak *et al.* 1985) and upwelling, particularly during vertically stratified conditions at the shelf break. Upwelling-downwelling can be driven by strong flow parallel to the isobaths, wind events, atmospheric pressure differences, etc.

The Loop Current can influence the northern slope of the Gulf of Mexico both directly during a major intrusion into the northeastern Gulf and indirectly through the eddies and filaments which it sheds. The maximum northward penetration of the Loop Current has been found in some studies to statistically occur in the summer months, and the minimum to occur in the winter months (Leipper 1970; Behringer *et al.* 1977; Vukovich *et al.* 1979), although there is substantial deviation from the average sequence of events. Molinari *et al.* (1977) for example describe a significant winter intrusion by the Loop Current north of 26°N. During maximum penetration and prior to shedding an eddy, the Loop Current can affect the northern shelf of the Gulf from the Mississippi delta to Florida by direct entrainment of shelf waters into the outer edges of the Loop Current (Schroeder *et al.* 1987). Ebbesmeyer *et al.* (1982), Molinari and Mayer (1982) and Wiseman and Dinnel (1988) describe strong current events on the upper slope of 30 to 50 cm s^{-1} that lasted for periods of 20 to 30 days. In each case the Loop Current or a feature connected to it was found close to the MAMES slope. Even when the northern edge of the main body of the Loop Current lies well south of the shelf edge, Loop Current filaments can snake northward and push onto the shelf or up De Soto Canyon. Huh *et al.* (1981) describe an intrusion of Loop Current water up De Soto Canyon and onto the West Florida shelf to within 8 km of the shore in February 1977.

Direct observations of the effect of an anticyclonic eddy on shelf slope currents were made by Brooks (1984) during a 1980-1981 field program in the northwestern Gulf. Three moorings were deployed in the 200 m - 700 m depth range. Strong topographic steering was evident and longshore current speeds at 200-m depth occasionally exceeded 70 cm s^{-1} and were persistently greater than 50 cm s^{-1} during a 2-month period in the fall. The currents were characterized by energetic fluctuations with time scales of a week to several months. Based on group speed calculations for an eddy with a radius of 100 km, the expected time scale for current fluctuations over the slope in the dispersive field is about 10 days (Brooks, personal communication). Thus the longer time scales of the current fluctuations are consistent with the dispersive decay of eddies, which were known to be influencing the mooring area at the time of the measurements.

Shelf waves, i.e., free topographic Rossby waves which propagate westward, may also be a factor at the shelf-ocean boundary. Low-frequency wave motions can exist as a consequence of vorticity dynamics and can propagate along steep topographic gradients, such as the edge of the continental shelf. They do not depend on gravity for their existence, so their most visible manifestations are horizontal current patterns, not sea-surface disturbances. Their characteristic time and length scales are a few days to weeks and hundreds to thousands of kilometers. Shelf waves in various forms are common over most continental margins, with typical current fluctuations of 10-50 cm s^{-1}. Rezak, *et al.* (1985) found that wavelike patterns in sea surface thermal data over the Texas-Louisiana shelf slope were consistent with shelf wave theory and suggested that such westward propagating waves could be generated by the topographic disturbance of the Mississippi Canyon. The distance along the continental slope between the head of De Soto Canyon and the Mississippi Delta is roughly 250 km, a relatively short distance, but sufficient to support several spatial cycles of a shelf waves with wave lengths of 50 to100 km.

10.1.4 Chapter Organization

This report focuses on the interpretation and synthesis of the time-series, hydrographic and collateral data collected during 1988 and 1989. The results are compared with previous studies and the hypotheses they generated about the circulation and processes in the region. Section 2 summarizes the data acquisition methods, data return and data analysis procedures. The reader is referred to the Year 1 and Year 2 Annual Reports for detailed descriptions of mooring configurations and data quality control procedures. Section 3 describes the major, non-periodic events that influenced the study region during 1988 and 1988. These include meteorological events, Loop Current filaments, and variations in river discharge. In Section 4 monthly means and quarterly roses illustrate seasonal variability and circulation patterns. Wind stress forcing is then analyzed in Sections 5. Also spatial coherence is examined in the vertical, along-shelf and cross-shelf directions. The circulation and hydrography of the study area during each of the survey cruises is described in Section 6. Section 7 summarizes the circulation patterns and processes and relates them to the marine ecosystem.

10.2 Data Acquisition and Methods

10.2.1 Hydrography

This study conducted five approximately semi-annual, multi-disciplinary cruises to survey the MAMES area. They were undertaken in March 1987, October 1987, March 1988, August 1988 and February 1989 and are designated Cruises 0 through 4, respectively. Chapters 3 in each of the annual reports and in this one provide details of the cruises. CTD/transmissivity vertical profiles and discrete samples by bottle were obtained at each of the twelve primary stations indicated by solid circles in Figure 10-1. Dissolved oxygen and nutrient values were determined from the bottle samples. Some CTD profiles without bottle samples were also obtained at supplemental stations as time and course permitted. The CTD was a Sea Bird Model SBE19 SEACAT Profiler with an attached 25-cm Sea Tech transmissometer. Operational and calibration procedures are described in the two annual reports.

The duration of the cruises was from five to eight days; the longer ones included a day or two in port because of weather. Cruise tracks were designed around the requirements of biological sampling and current meter servicing, so the tracks did not usually follow cross-shelf transects. Maps were constructed of the horizontal distribution of temperature, salinity and dissolved oxygen near the surface and near the bottom. Appendix C includes all the maps and a plot of the vertical profiles of temperature, salinity, density and transmissivity for each station. Selected maps and vertical profiles are used to illustrate the discussions that follow. Cross-shelf vertical sections are not used as an interpretive tool, because of the limited number of stations, their very uneven spacing and their lack of synopticity.

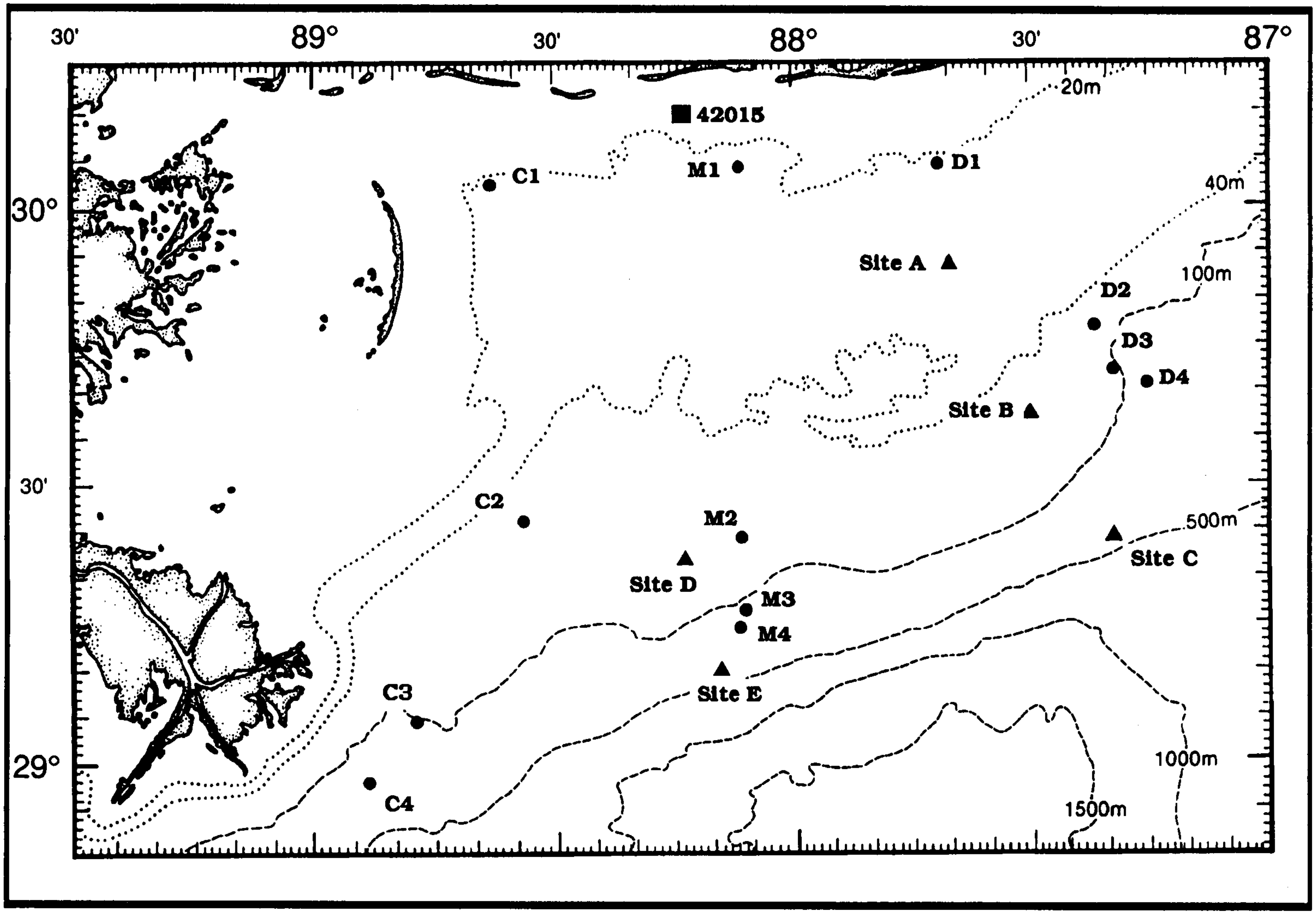


Figure 10-1. Map showing the locations of standard CTD stations (circles), current meter moorings (triangles) and meteorological Buoy 42015 (square).

10.2.2 Moored Instruments

10.2.2.1 Locations and Instruments

The moored-instrument portion of this study consists of two deployment periods, each of about one year in duration. The first began in late December 1987 with the deployment of a cross-shelf array of three moorings, designated A, B and C, and ran through mid-January 1989. The Year 2 deployment period began in mid-February 1989 and ended mid-February 1990. For this second period, a cross-shelf array of two additional moorings, designated D and E, was deployed about 85 km southwest of the first array. Figure 10-1 shows the locations of the five sites (triangles) and Table 10-1 lists their coordinates. At the beginning of the second year, the location of Mooring A was moved eastward about one-half mile because unknown parties had attempted to establish an artificial fishing reef at the original site by dumping a car body and tires close to the witness buoy.

Water depths are 30 m at Mooring A, 60 m at Moorings B and D, and 430 m at Moorings C and E. The three-mooring array lies between the middle and eastern lines of inter-disciplinary sampling stations (circles in Figure 10-1). Figure 10-2 depicts the scaled locations of the current meter moorings along a cross-shelf transect running offshore from Mobile Point. The second array lies between the middle and western inter-disciplinary sampling lines. Its cross-shelf transect is similar to that in Figure 10-2 except it has no mooring corresponding to Mooring A. Exchange processes between the western portion of the shelf and the deep Gulf as well as along-isobath propagation can be examined with the addition of the second array.

All current meters recorded four parameters: speed, direction, temperature and conductivity. The three shelf moorings had ENDECO Model 174SSM (Solid State) current meters located 10 m below the surface and ENDECO Model 174DMT (Magnetic Tape) current meters located 3 m above the bottom. The two moorings on the slope had Aanderaa RCM8 (Solid State) current meters at 20, 150 and 426 m. (During the first year, Mooring C had an ENDECO 174SSM at 20 m instead of an Aanderaa.) The Year 1 and Year 2 reports (Brooks and Giammona 1988; 1990) describe in detail the configuration of the moorings.

Table 10-1. Coordinates of Moorings A, B, C, D, and E.

Site	Latitude	Longitude
	Year I	
A	29°54.0'N	87°40.2'W
B	29°37.2'N	87°31.6'W
C	29°23.9'N	87°20.7'W
	Year 2	
A	29°54.2'N	87°36.6'W
B	29°37.2'N	87°31.6'W
C	29°23.9'N	87°20.7'W
D	29°21.07'N	88°15.95'W
E	29°09.58'N	88°10.52'W

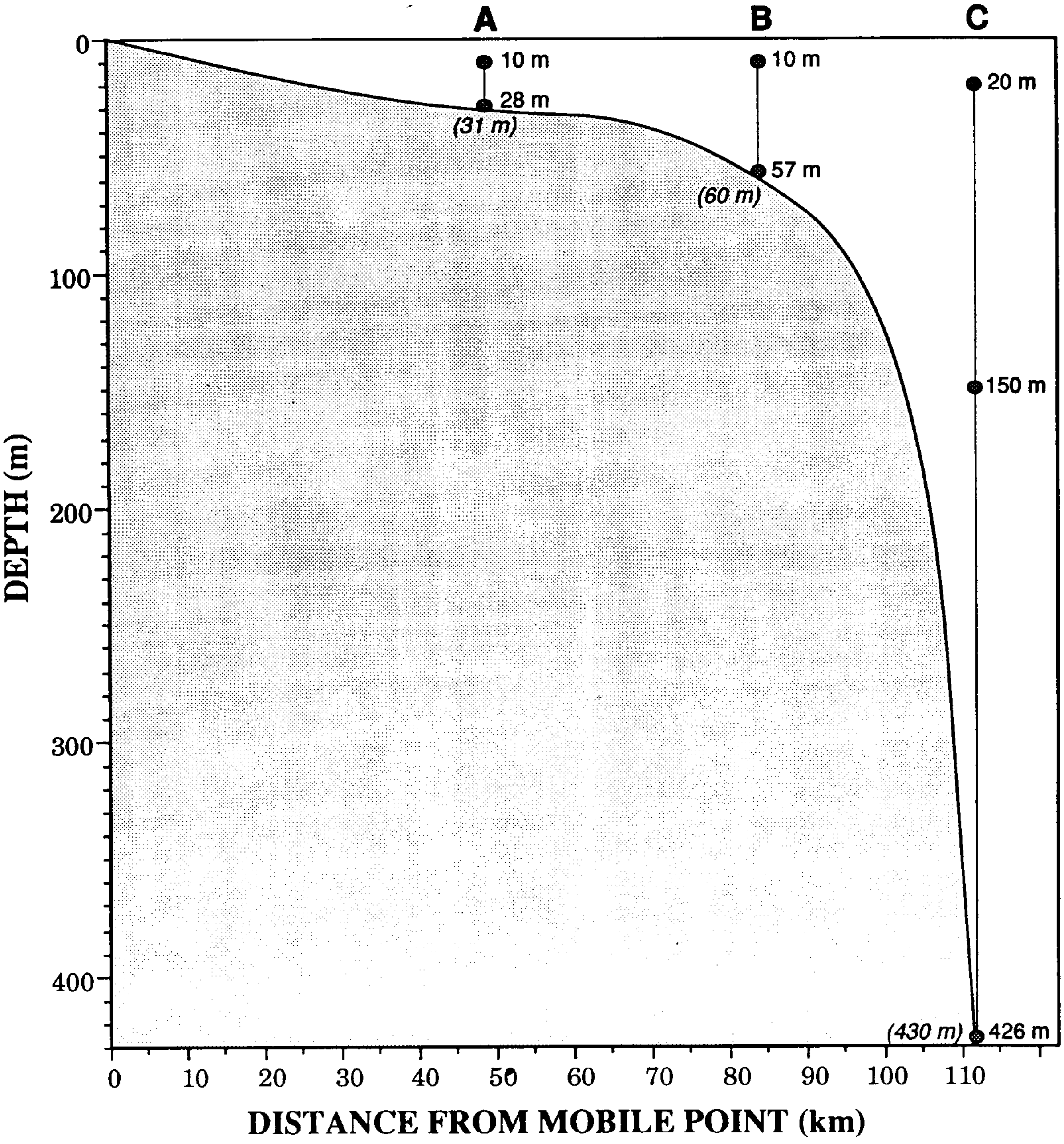


Figure 10-2. **Scaled vertical section showing locations of current meter moorings A, B and C along a cross-shelf transect running offshore from Mobile Point.**

Hereafter, the current meter locations will be referred to as AT for the top current meter on Mooring A, AB for the bottom one, etc. At times the depth of the instrument/water depth will be listed, e.g., 10/30 m.

10.2.2.2 Data Return

Figures 10-3 and 10-4 summarize the periods for which good data was obtained for each parameter: solid lines for current velocity, dotted for temperature and dashed for conducivity. Note that three periods had high percentages of concurrent data return: September-December, 1988; February-June, 1989; and June-October 1989.

10.2.2.3 Data Processing and Quality Control

The data processing procedures for the ENDECO Model 174SSM and the Aanderaa RCM8 are similar because both types sample speed and direction several times each minute and then internally vector average the current velocity data over a 30-minute recording interval. The instruments store the north-south and east-west components of the vector-averaged current velocity plus single samples of temperature and conductivity in solid-state memory every 30 minutes. After retrieval, a PC-compatible computer extracts the data from the instrument through an RS-232 communication cable using communication software provided by the manufacturer. Another program then converts the raw data to engineering units and applies the initial calibration values that are specific to each individual instrument. Salinity is computed from temperature and conductivity using the standard equations of the Practical Salinity Scale 1978 (UNESCO 1981). Then, a "preview plot" is generated which displays speed, direction, along-isobath and cross-isobath components, temperature and salinity with a time resolution of two days per inch, which permits problems with individual samples to be detected. The preview plot reveals problems in the data such as spikes, sticking or drifting sensors, indications of fouled or damaged sensors, etc. When possible, the data file is manually edited. Linear interpolation is applied across short spans of problem data. Long sequences of bad data, however, are flagged as unusable. Finally, the

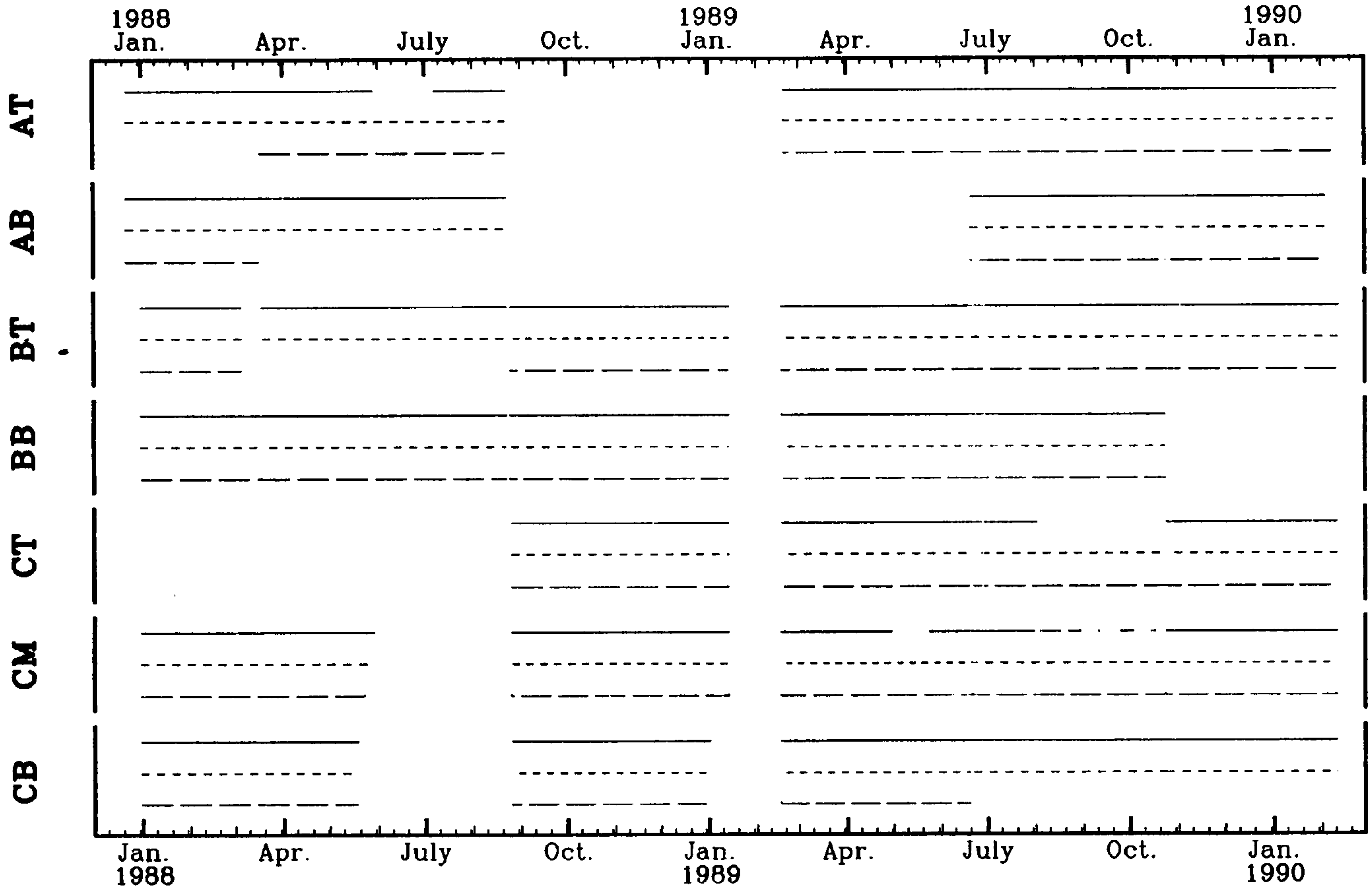


Figure 10-3. Time lines showing periods of good data return from current meters on Moorings A, B and C. Parameters recorded are velocity (solid line), temperature (dotted line) and conductivity (dashed line).

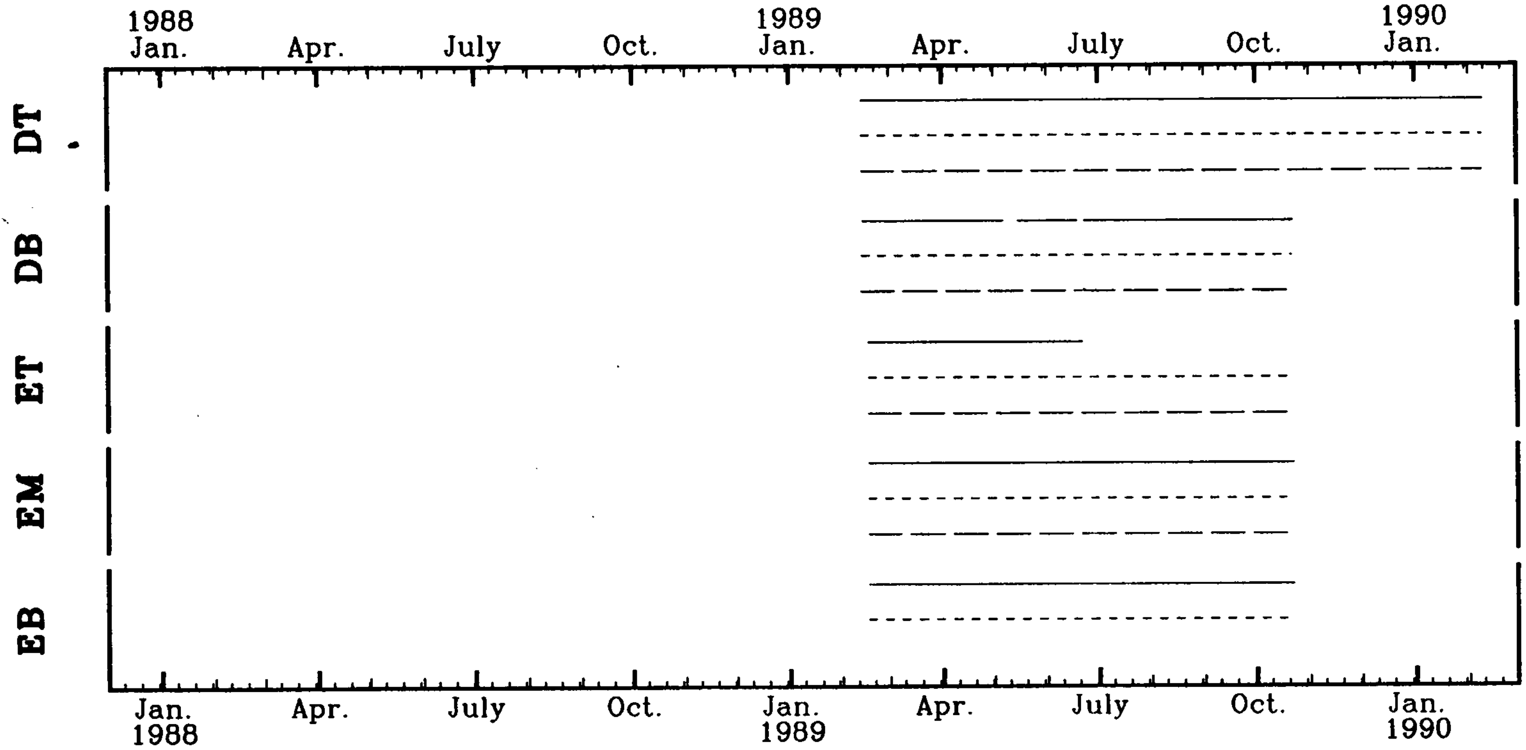


Figure 10-4. Time lines showing periods of good data return from current meters on Moorings D and E. Parameters recorded are velocity (solid line), temperature (dotted line) and conductivity (dashed line).

additional corrections for temperature and salinity are applied, if required based on the quality control procedures. At this point, the time-series data are ready for submission to NODC and for higher level processing.

Processing the data from the ENDECO Model 174DMT is more involved because it records at a 10-minute rate onto a magnetic tape cartridge and does not vector average the current velocity data. An ENDECO Model 2501 Tape Reader reads the tapes, converts the data to 80-byte ASCII records of raw data and transmits them to a personal computer. The data file is then transferred to TAMU's mainframe computer system where the data are converted to engineering units and treated as described above. Salinity however, is computed using the equation of Daniel and Collias (1971), which is a simple polynomial that is computationally efficient and adequate for the coarse salinity accuracy of this instrument. The 10-minute, calibrated and qualified data are then filtered with a 2-hour, low-pass filter (a symmetric Lanczos filter) and subsampled to a 30-minute interval, at which point the data are ready for submission to NODC and higher level processing. Figure 10-5a shows the response function for the 2-hour low pass filter.

This study uses three different models of current meters, each of which measures current speed, current direction, temperature and conductivity. Salinity is not measured directly, but is computed from the values of temperature and conductivity. Quality control procedures depend on the instrument type and whether it is serviced in the laboratory or at sea.

The ENDECO 174DMT and 174SSM models measure speed by means of a neutrally buoyant, balanced, 15-inch diameter impeller (rotor) that rides on glass ball bearings in a Delrin race, while the Aanderaa RCM8 uses a 4-inch diameter, balanced, shielded paddle rotor with a carbide bearing that rides on a stainless steel needle point. The rotation is magnetically passed through the pressure case and digitally encoded. Overall operation of the speed sensing system is checked in the laboratory by turning the rotor at an exact rate using a precision stepping motor. The rate of rotation of a rotor is directly proportional to the velocity of the water, and the linearity is high (Kelly *et al.* 1983) if the rotor is in proper condition and the bearings are in proper adjustment. Rotor imbalance, which can result from physical damage and improper painting, raises the starting threshold. Dirty,

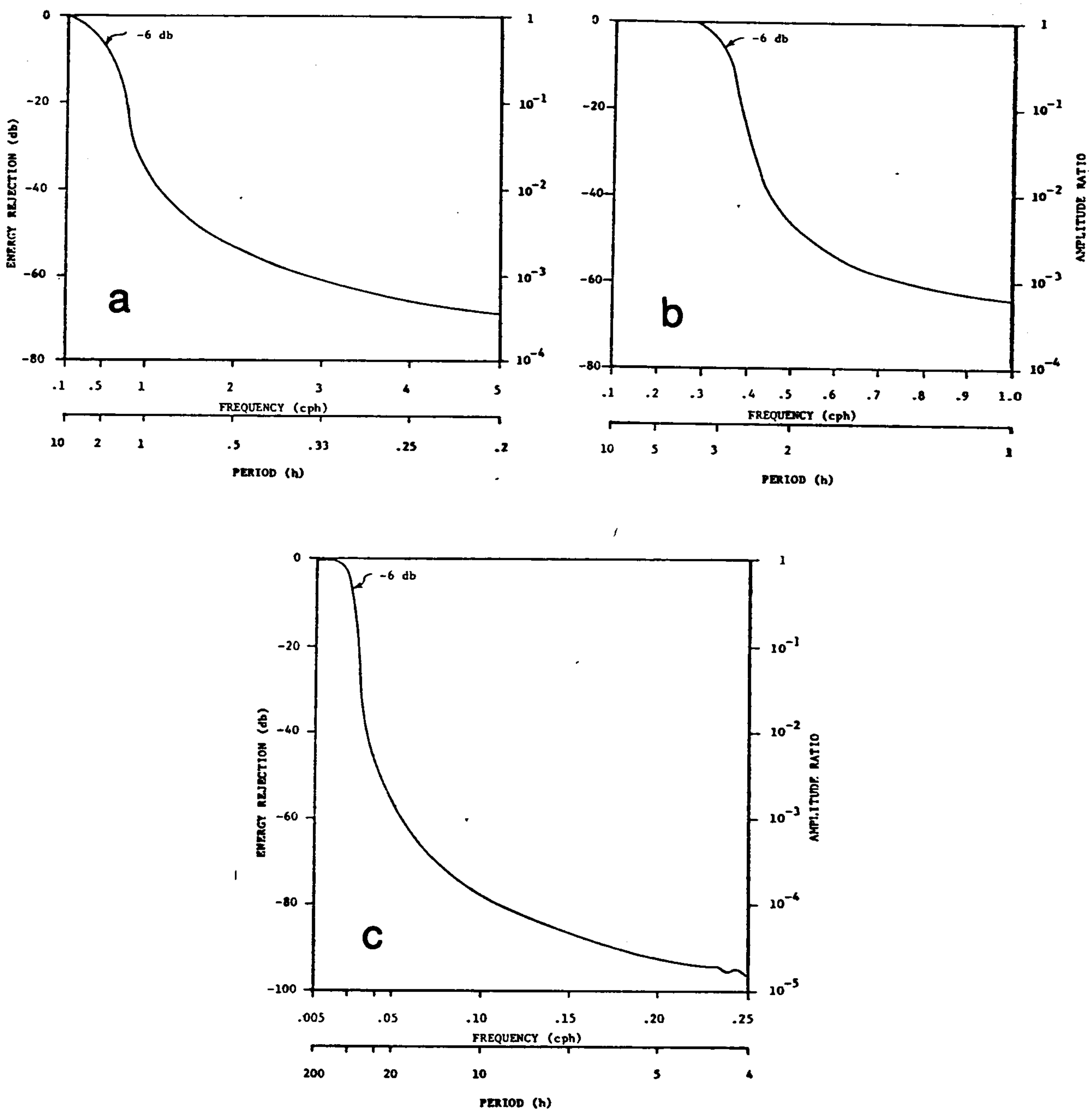


Figure 10-5. Response functions of the low pass Lanczos filters: a) 2-hour, b) 3-hour and c) 40-hour.

damaged or maladjusted bearings affect both the starting threshold and the sensitivity of the rotor. Prior to each deployment, rotors and bearings are carefully checked and adjusted according to the manufacture's recommended procedures, whether in the laboratory or at sea. When a rotor is repainted with anti-fouling paint, a very light even coat is used and care is taken to avoid drips and blobs from collecting at low points.

Current direction is measured by a gimballed, 2-axis, flux gate compass in the ENDECO models and by a magnetic compass with needle clamped to a potentiometric ring in the Aanderaa model. Each meter's direction sensor is checked, and a new calibration curve developed, if needed, whenever the meter is returned to the laboratory. A direction "swing" table designed and automatically rotates a current meter in 15° ±0.5° increments. The duration at each position is programmable. A Brunton pocket transit, Model F-2061, is used as the calibration standard.

All three models of current meters use thermolinear thermisters in stainless steel cases to measure temperature. In the laboratory, a Hewlett Packard Model 2804A quartz thermometer serves as the temperature standard and an insulated bath (3' x 3' x 3', I.D.) is used to perform temperature calibrations. The bath is not temperature controlled, but it is sufficiently insulated so that temperature changes are slow, typically much less than 0.1°C per hour. The temperature of the bath is accurately monitored as a function of time and related to the temperature time series recorded by the current meter being calibrated. A temperature controlling process is not needed because the the current meters can be set to record at a rapid rate, yielding many values before the temperature of the bath changes significantly. The accuracy (±0.2°C for the ENDECO, ±0.05°C for the Aanderaa) and resolution (0.1°C for the ENDECO, 0.03°C for the Aanderaa) of the temperature sensors on the current meters are much coarser than the accuracy (±0.01°C) and resolution (0.0001°C) of the temperature standard. At sea, the data from the CTD casts made at each mooring also provide a calibration check on temperature. The accuracy and resolution of the CTD's temperature sensor is comparable to that of the Hewlett Packard quartz thermometer. In addition, a further check on consistency is made whenever consecutive periods of deployment are available for an instrument location. The last few data values of the instrument retrieved should approximately equal the first few data values (after about one-half hour for equilibration) of the instrument which replaces it, except when a thermocline occurs at the depth of the instrument. This is called an inter-record comparison. The temperature values recorded by an instrument being calibrated are first corrected by the manufacturer's calibration values (developed from a multi-point set of calibrations). The results of calibrations in the laboratory, comparisons with the CTD data and the inter-record comparisons are subjectively combined to develop additional corrections. In most cases, the temperature data recorded by current meters lies within the rated accuracy limits and additional correction is unnecessary.

Both the Aanderaa and ENDECO current meters use inductive type conductivity sensors, but that of the Aanderaa is more accurate (±0.1 mmho/cm versus ±0.5 mmho/cm). Calibration checks are not made for conductivity directly, but rather for salinity, which is computed from conductivity and temperature. As for temperature, the calibration checks are performed in the insulated bath in the laboratory, with the CTD at sea and from inter-record comparisons. In the laboratory bath, various values of salinity are obtained using "instant ocean" type salt. A Grundy Model 6230N Laboratory Salinometer measures the salinity of bath samples, with A.P.S.I.O. Standard Sea-Water as the reference standard. The manufacturer estimates the accuracy of the salinometer to be ±0.003 ppt. The cells of inductive type conductivity sensors are sensitive to any change in inside dimensions. Both painting with antifouling paint and the growth of any organism inside the probe will alter a cell's effective dimensions. Painting produces a systematic error (constant offset), while biofouling causes a slow change or drift. The net magnitude of the error is determined by the various types of calibration checks at the times of deployment and retrieval and then linearly interpolated over the period of the record. Thus far during this study, only the ENDECO conductivity sensors were painted with anti-fouling paint and required correction. Biofouling has not seriously affected the unpainted Aanderaa conductivity sensors.

10.2.3 Meteorological Buoy Data

Hourly buoy data was obtained from the National Oceanographic Data Center (NODC) in the F191 File Format for the period from January 1988 through February 1990 for buoys 42007, 42015, 42016, DPIA1 and MPCL1. The parameters of interest are:

wind speed (8.5 min. avg.)
wind direction (8.5 min. avg.)
barometric pressure
air temperature
sea surface temperature
significant wave height
dominant wave period

The data sets were analyzed to determine when data gaps longer than a few hours occurred. Buoy 42105, located about 17 km southwest from Dauphin Island Sea Lab (Figure 10-1), had the most complete data sets, with only one major gap in all parameters, from 8 September to 14 December 1988. This was easily filled with data from Buoy 42016 located just 5 km from Buoy 42015. Gaps of a few hours were filled by linear interpolation to yield continuous time series of hourly data for the seven parameters for a 26-month period. Dinnel (1988) examined the spectral coherence squared between wind stress measured at Dauphin Island and that at Buoy 42009, which was located about 125 km southeast of Dauphin Island, or near the location of Mooring C of this study. (Buoy 42009 was deactivated prior the the beginning of this study.) Dinnel found that wind stress is coherent over the spatial scales of the shelf. Because of the numerous gaps in the data from the other buoys, and the generally large spatial scale of weather patterns compared to that of the study area, it was decided not to pursue the subtleties of the relatively small differences in magnitude and phase among the data from the five buoys.

Since the anemometers on the buoys were not at 10 m, wind speed was adjusted to the 10-m level using the standard seventh-power law (CERC 1984):

$$W_{10} = W_Z(10/Z)^{1/7}$$

where W is wind speed in meters per second and Z is the actual anemometer height in meters. The drag coefficient used to compute wind stress assumes neutral stratification (difference between air and water temperature of 0°). Non-neutral conditions were taken into account by using the air-sea temperature difference measured at the buoy and the amplification factor derived empirically by Resio and Vincent (1977). Their factor C(t) is given graphically as a function of the air-sea temperature difference, t, so a polynomial approximation was fitted to their curve as follows:

$$t = T_{AIR} - T_{WATER}$$

$$C(t) = 1.24 \qquad t < -30^\circ$$

$$C(t) = A_0 + A_1\,t + A_2\,t^2 + A_3\,t^3 + A_4\,t^4 + A_5\,t^5 \qquad -30^\circ \le t \le 0^\circ$$

$$C(t) = B_0 + B_1\,t + B_2\,t^2 + B_3\,t^3 + B_4\,t^4 + B_5\,t^5 \qquad 0^\circ < t \le 30^\circ$$

$$C(t) = 0.78 \qquad t > 30^\circ$$

where

$A_0 = 1.0035$, $A_1 = -4.4860 \times 10^{-2}$, $A_2 = -5.5022 \times 10^{-3}$
$A_3 = -3.6381 \times 10^{-4}$, $A_4 = -1.1387 \times 10^{-5}$, $A_5 = -1.3371 \times 10^{-7}$
$B_0 = 0.99391$, $B_1 = -5.2878 \times 10^{-2}$, $B_2 = 6.8900 \times 10^{-3}$
$B_3 = -4.5557 \times 10^{-4}$, $B_4 = 1.4156 \times 10^{-5}$, $B_5 = -1.6454 \times 10^{-7}$

(Since C(t) is dimensionless, the units of the coefficients A_n and B_n, where n ranges from 0 to 5, are (degrees)$^{-n}$). The wind speed corrected for non-neutral stability, W_{CORR}, is then obtained by multiplying the wind at 10 m, W_{10}, by the amplification ratio C(T):

$$W_{CORR} = C(t)W_{10}\,.$$

No fetch correction was applied for northerly winds. Wind stress was computed from the quadratic drag law using the variable drag coefficient of Wu (1982):

$$C_D = (0.8+0.065W_{CORR})\ 10^{-3}$$

Wind and wind stress were converted to the oceanographic convention for direction, i.e., the direction toward which the wind is blowing. A common direction format facilitates the comparison of wind and currents. **All tabular and graphical presentations of wind in this chapter have the oceanographic direction convention.** However, in discussions of the data, common meteorological vocabulary is used, i.e., a north (or northerly) wind refers to a wind blowing from north to south.

10.2.4 Sea Level Data

Hourly sea level data were obtained from the Sea and Lake Levels Branch of the National Ocean Survey (NOS) for the gages at Dauphin Island (8735180), Pensacola (8729840) and South Pass (876055) for the 26-month period from January 1988 through February 1990. The South Pass data set had several gaps. A preliminary comparison of sea level at Dauphin Island and Pensacola showed very high coherence, so only the Dauphin Island data were used in subsequent analyses. The mean of the 26-month Dauphin Island record is 1.00 m (3.28 ft), and the reference levels for mean sea level and mean tide level, provided by NOS, are 0.988 m (3.24 ft) and 1.00 m (3.28 ft), respectively. In order to use the sea level data in cross spectral analyses with currents the isostatic effect of barometric pressure on sea level (inverted barometer effect) was removed by adding the barometric pressure in millibars to the sea level in centimeters. The resulting series was then reduced to fluctuations by removing the mean.

10.2.5 River Discharge

Daily discharge data for the Mississippi River at Tarbert Landing for the period of January 1987 through February 1990, as well as long-term (1930-1988) monthly mean values, were obtained from the U.S. Army Corps of Engineers. Daily discharge data for the Alabama, Tombigbee and Perdido Rivers were obtained from Alabama Geological Survey (Schroeder, personal communication) for water years 1988 and 1989, i.e., October 1987 through September 1988. (River discharge data is reported in cubic feet per second; 1 cfs = 2.832×10^{-2} m^3 s^{-1})

10.2.6 Analyses of Time-Series Data

All of the physical data obtained during this study are in the form of time series, except the hydrographic vertical profiles collected during the survey cruises and the satellite imagery data (Chapter 11). The series are examined in the time domain using standard time series plots, first order statistics and, for vector quantities, joint distributions of speed and direction. In the frequency domain, relations between series are quantified with graphs of energy spectra, coherence squared (frequency-dependent correlation) and phase.

Basic statistics, i.e., minimum, maximum, mean and standard deviation, were computed for monthly periods for the half-hourly data from the current meters and for the hourly buoy data. The computations were made in double precision. The number of observations varies according to month, sample interval and the number of bad or missing points; for half-hourly data the maximum is 1440 observations in a 30-day month, etc. Tables 10-2 through Table 10-13 list the basic statistics. They are discussed in Section 10.4. Reducing a time series to monthly means is roughly equivalent to filtering the series so as to remove fluctuations with periods shorter than a month. Averaging, as opposed to true filtering, has the advantage that gaps and missing data are easily handled. (The disadvantage is esoteric and is related to the response function of a block average.) The averaging of currents and other parameters over periods of a month or longer extracts a more orderly pattern from the chaotic appearing instantaneous flow. The mean circulation is very important to understanding long-term dispersal of larvae, nutrients, sediments and contaminants.

For vector series like current and wind velocity, monthly means mask useful information about the joint variability between speed and direction. As an extreme example, consider a current that flows northeastward at 20 cm s^{-1} for half a month and southwestward at 20 cm s^{-1} for the other half; its monthly mean velocity is zero. Therefore, rose diagrams were constructed for three-month periods using the half-hourly current and hourly wind data. (The rose is a graphical representation of a table of joint distribution of speed and direction.) Three-month periods, beginning with

Table 10-2. **A TOP** monthly basic statistics for current velocity components, temperature and salinity, based on half-hourly data. **The positive along isobath and cross isobath directions are 55° and 325°, respectively.**

A TOP		U (Along Isobath) (cm s^{-1})				V (Cross Isobath) (cm s^{-1})			
MONTH	N	MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD
Dec '87	490	-9.7	15.0	-0.5	5.9	-10.8	11.2	0.4	4.9
Jan '88	1488	-25.7	15.3	-2.7	8.1	-13.6	19.1	2.8	5.2
Feb '88	1392	-32.1	24.6	1.7	9.1	-21.5	20.9	-1.2	6.9
Mar '88	1487	-20.3	31.6	3.6	9.4	-26.1	24.2	-0.9	7.5
Apr '88	1440	-28.0	47.3	7.4	11.0	-53.6	36.3	-1.8	11.0
May '88	1345	-19.7	29.3	6.4	10.2	-31.1	26.7	-1.3	10.5
Jun '88	0								
Jul '88	1212	-44.9	16.3	-1.5	8.1	-35.1	21.6	2.0	8.1
Aug '88	1035	-24.3	29.0	-1.1	8.0	-37.2	16.6	-0.3	7.5
Sep '88	0								
Oct '88	0								
Nov '88	0								
Dec '88	0								
Jan '89	0								
Feb '89	519	-17.2	16.4	1.3	8.2	-13.8	10.5	-0.5	4.9
Mar '89	1488	-30.2	32.5	-2.3	9.0	-25.6	30.6	0.9	8.4
Apr '89	1440	-29.3	31.7	2.0	10.9	-30.0	29.9	-2.9	9.7
May '89	1488	-24.6	35.5	4.1	9.7	-29.4	28.6	1.2	8.0
Jun '89	1440	-29.1	31.2	-2.7	7.6	-41.3	19.1	0.8	7.5
Jul '89	1488	-21.2	30.7	3.6	8.4	-20.0	18.3	1.3	5.6
Aug '89	1488	-15.2	19.6	1.4	5.9	-13.9	16.6	1.3	5.7
Sep '89	1440	-27.5	9.0	-4.9	6.1	-16.4	15.4	1.4	5.2
Oct '89	1487	-23.3	29.9	-1.1	8.8	-24.3	17.8	-0.4	5.7
Nov '89	1440	-33.8	20.7	-3.6	8.5	-21.3	22.3	0.4	6.2
Dec '89	1488	-23.5	16.8	-0.4	7.6	-22.5	13.4	-1.0	5.1
Jan '90	1488	-16.8	19.1	1.4	5.0	-13.9	9.5	-1.2	4.0
Feb '90	515	-3.4	12.0	2.6	3.0	-12.8	6.9	-1.1	3.4

A TOP		Temperature (°C)				Salinity (PSU)				
MONTH	N	MIN	MAX	MEAN	SD	N	MIN	MAX	MEAN	SD
Dec '87	490	18.3	20.2	19.2	0.5					
Jan '88	1488	15.0	19.3	17.6	1.1					
Feb '88	1392	13.9	17.2	15.6	0.9					
Mar '88	1487	15.3	18.8	17.3	0.7	724	34.2	35.9	35.4	0.3
Apr '88	1440	18.2	22.4	19.7	1.1	1440	32.2	36.5	35.2	0.6
May '88	1488	18.8	24.0	21.7	1.0	1488	34.5	37.3	35.6	0.8
Jun '88	1440	21.3	27.6	25.2	0.9	1440	33.9	36.9	36.3	0.5
Jul '88	1488	23.6	28.7	27.0	1.1	1488	30.9	37.0	35.8	1.1
Aug '88	1035	23.2	29.5	27.0	1.6	1035	30.8	36.9	35.3	0.6
Sep '88	0					0				
Oct '88	0					0				
Nov '88	0					0				
Dec '88	0					0				
Jan '89	0					0				
Feb '89	519	15.7	20.0	18.3	1.2	519	34.3	36.0	35.5	0.5
Mar '89	1488	16.1	20.3	17.9	1.0	1488	32.8	36.0	34.9	0.7
Apr '89	1440	19.4	23.2	20.4	0.8	1440	29.1	35.3	33.3	1.6
May '89	1488	21.2	27.4	24.1	1.4	1488	29.9	34.7	32.3	0.9
Jun '89	1440	23.5	28.3	26.9	0.8	1440	25.3	34.8	31.6	1.5
Jul '89	1488	25.3	29.7	28.1	0.5	1488	25.9	36.2	33.0	2.1
Aug '89	1488	27.5	29.9	28.9	0.5	1488	25.8	35.4	32.3	1.4
Sep '89	1440	26.8	30.4	28.9	1.1	1440	31.3	35.9	33.1	1.2
Oct '89	1487	23.1	27.1	25.2	1.2	1487	29.6	34.8	33.5	0.6
Nov '89	1440	20.5	24.1	22.4	1.0	1440	27.2	35.6	34.3	1.1
Dec '89	1488	12.4	21.2	17.1	2.0	1488	32.7	36.0	34.5	0.7
Jan '90	1488	13.6	16.7	15.2	0.7	1488	33.0	34.9	34.4	0.3
Feb '90	515	15.7	17.0	16.3	0.3	515	31.8	34.9	33.9	0.5

Table 10-3. **A BOTTOM** monthly basic statistics for current velocity components, temperature and salinity, based on half-hourly data. The positive along isobath and cross isobath directions are 55° and 325°, respectively.

A BOTTOM		U (Along Isobath) (cm s^{-1})				V (Cross Isobath) (cm s^{-1})			
MONTH	N	MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD
Dec '87	501	-11.5	14.0	-1.7	6.2	-10.6	12.4	0.2	3.6
Jan '88	1488	-20.7	11.8	-4.9	7.7	-9.1	16.8	0.7	4.3
Feb. '88	1392	-18.0	19.1	1.1	7.3	-15.2	21.9	0.5	5.0
Mar '88	1470	-22.1	21.4	1.7	8.2	-13.3	18.4	1.1	4.8
Apr '88	1440	-22.4	30.4	3.5	8.9	-29.6	25.8	2.1	6.5
May '88	1488	-19.0	14.9	2.5	5.5	-11.7	14.4	0.2	3.8
Jun '88	1440	-26.6	15.6	0.8	7.2	-14.1	13.2	0.3	4.6
Jul '88	1488	-22.3	15.8	2.1	5.9	-12.6	13.7	-0.6	4.6
Aug '88	1032	-28.3	20.9	1.0	5.5	-15.7	15.9	0.5	4.3
Sep '88	0								
Oct. '88	0								
Nov '88	0								
Dec '88	0								
Jan. '89	0								
Feb. '89	0								
Mar '89	0								
Apr '89	0								
May '89	0								
Jun '89	534	-16.7	17.2	4.4	6.3	-5.8	14.1	3.8	4.4
Jul '89	1488	-24.9	20.6	1.8	8.5	-14.5	19.2	1.7	5.0
Aug. '89	1488	-39.4	18.3	-0.6	7.8	-17.6	19.0	2.6	6.5
Sep '89	1440	-39.4	25.2	-2.9	11.4	-31.5	22.6	1.7	7.8
Oct '89	1477	-33.9	30.2	4.4	11.3	-19.9	37.5	1.9	7.5
Nov '89	1440	-20.2	24.8	-1.0	8.0	-13.1	20.6	2.0	5.6
Dec '89	1488	-16.4	21.3	3.2	7.3	-12.7	13.9	2.3	4.2
Jan '90	1488	-10.6	19.2	1.5	5.2	-16.8	14.6	1.6	4.3
Feb '90	126	-0.1	4.5	1.6	1.4	-2.0	4.6	0.6	1.5

A BOTTOM		Temperature (°C)				Salinity (PSU)				
MONTH	N	MIN	MAX	MEAN	SD	N	MIN	MAX	MEAN	SD
Dec '87	501	17.7	19.5	18.6	0.5	501	35.9	36.3	36.1	0.1
Jan '88	1488	15.5	19.0	17.2	0.9	1488	35.7	36.4	36.1	0.1
Feb. '88	1392	14.6	16.9	15.8	0.5	1392	35.3	36.2	35.8	0.3
Mar '88	1470	15.3	18.7	17.3	1.4	747	35.1	36.4	35.5	0.3
Apr '88	1440	17.6	19.8	18.9	0.6	0				
May '88	1488	18.5	19.9	19.1	0.5	0				
Jun '88	1440	18.7	21.3	20.3	0.6	0				
Jul '88	1488	20.1	21.8	20.9	0.4	0				
Aug '88	1032	20.8	25.0	21.8	0.6	0				
Sep '88	0					0				
Oct. '88	0					0				
Nov '88	0					0				
Dec '88	0					0				
Jan. '89	0					0				
Feb. '89	0					0				
Mar '89	0					0				
Apr '89	0					0				
May '89	0					0				
Jun '89	534	22.7	24.5	23.1	0.3	534	35.1	36.4	36.1	0.2
Jul '89	1488	21.8	25.5	23.5	0.7	1488	35.7	36.7	36.2	0.2
Aug. '89	1488	23.8	27.2	25.3	1.2	1488	34.7	36.2	36.0	0.1
Sep '89	1440	25.8	29.4	27.1	0.7	1440	33.8	36.3	35.5	0.7
Oct '89	1477	23.4	27.5	26.0	1.0	1477	33.1	36.1	35.1	0.6
Nov '89	1440	20.7	24.7	22.7	1.1	1440	34.3	36.1	35.4	0.4
Dec '89	1488	13.1	21.1	18.1	2.0	1488	32.5	35.9	35.0	0.4
Jan '90	1488	14.7	17.6	16.2	0.8	1488	34.1	35.5	35.0	0.2
Feb '90	126	17.6	17.7	17.6	0.0	126	35.4	35.6	35.5	0.1

Table 10-4. **B TOP** monthly basic statistics for current velocity components, temperature and salinity, based on half-hourly data. **The positive along isobath and cross isobath directions are 55° and 325°, respectively.**

B TOP		U (Along Isobath) (cm s^{-1})				V (Cross Isobath) (cm s^{-1})			
MONTH	N	MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD
Dec '87	60	-9.6	7.9	-0.8	5.6	-2.1	19.6	5.7	5.6
Jan '88	1488	-38.3	31.5	2.1	12.2	-23.7	21.0	0.9	8.7
Feb '88	1392	-19.8	39.0	6.8	10.7	-24.8	25.7	1.0	8.6
Mar '88	903	-29.8	34.9	-0.6	10.7	-22.0	29.9	-0.2	8.6
Apr '88	1440	-37.4	36.4	-1.5	11.2	-36.1	50.5	-0.4	12.2
May '88	1488	-28.5	48.6	10.9	12.2	-69.6	21.2	-7.4	12.1
Jun '88	1440	-6.1	47.8	11.1	9.0	-38.3	17.7	-3.6	8.8
Jul '88	1488	-4.5	31.3	8.5	6.6	-27.8	9.8	-4.9	7.3
Aug '88	1423	-13.2	41.1	14.1	10.9	-34.9	16.2	-8.7	9.0
Sep '88	1440	-73.5	15.5	-20.6	19.4	-36.2	45.8	0.8	12.4
Oct '88	1488	-39.7	5.4	-11.2	7.7	-18.7	33.9	-0.3	8.0
Nov '88	1440	-28.5	16.2	-2.5	8.6	-27.3	9.7	-3.8	6.0
Dec '88	1488	-14.1	16.2	0.3	4.9	-17.2	12.6	0.5	4.5
Jan '89	619	-15.6	27.9	2.4	8.6	-22.1	9.4	-1.2	6.8
Feb '89	584	-20.2	19.6	5.1	7.8	-32.9	12.7	-4.6	7.5
Mar '89	1488	-29.1	45.9	0.3	13.9	-37.7	44.2	1.1	11.8
Apr '89	1440	-33.3	28.3	3.4	9.5	-21.6	35.6	0.7	8.0
May '89	1488	-20.6	27.8	1.3	6.5	-30.0	19.9	-0.4	6.1
Jun '89	1432	-29.1	45.0	0.1	9.6	-39.5	34.0	0.9	9.0
Jul '89	1488	-26.9	37.3	3.5	11.5	-36.8	30.5	-2.4	8.9
Aug '89	1488	-22.6	49.9	1.9	12.2	-18.9	29.7	1.4	7.7
Sep '89	1440	-36.3	39.2	3.8	12.1	-21.7	23.7	0.7	8.5
Oct '89	1479	-29.2	30.8	4.9	8.0	-22.6	18.1	0.3	4.7
Nov '89	1440	-11.6	7.2	0.5	1.7	-10.8	7.2	-0.1	1.6
Dec '89	1488	-25.9	21.3	0.9	7.4	-21.3	15.2	-1.0	5.5
Jan '90	1488	-23.1	9.5	-1.3	3.1	-18.3	8.9	-3.0	4.2
Feb '90	526	-17.7	13.1	-0.7	3.6	-14.8	10.7	-1.7	2.6

B TOP		Temperature (°C)					Salinity (PSU)			
MONTH	N	MIN	MAX	MEAN	SD	N	MIN	MAX	MEAN	SD
Dec '87	60	19.2	19.7	19.6	0.1	60	35.9	36.1	36.1	0.1
Jan '88	1488	16.9	20.2	18.9	0.7	1488	35.3	36.2	36.0	0.1
Feb '88	1392	14.9	19.3	17.2	1.1	1392	34.4	36.2	35.5	0.4
Mar '88	903	16.2	20.5	17.7	1.0	187	34.8	35.7	35.3	0.2
Apr '88	1440	18.4	22.3	20.0	1.0	0				
May '88	1488	20.7	24.2	22.5	0.7	0				
Jun '88	1440	23.1	27.3	25.4	0.8	0				
Jul '88	1488	25.2	29.3	27.5	0.7	0				
Aug '88	1423	25.6	29.5	28.1	0.6	372	30.2	36.7	35.4	0.8
Sep '88	1440	27.2	29.9	28.2	0.4	1440	29.7	37.2	35.1	0.8
Oct '88	1488	24.4	28.2	25.7	1.1	1488	29.0	36.7	35.8	0.9
Nov '88	1440	22.4	24.8	23.5	0.5	1440	30.1	36.5	36.2	0.4
Dec '88	1488	18.2	22.8	21.4	0.7	1488	33.0	36.7	36.2	0.3
Jan '89	619	20.1	21.6	20.9	0.4	619	34.9	36.1	35.7	0.2
Feb '89	584	17.8	21.8	19.9	1.2	584	35.3	35.9	35.6	0.1
Mar '89	1488	16.5	21.1	19.5	1.0	1488	32.6	35.9	35.1	0.5
Apr '89	1440	19.8	22.8	21.0	0.5	1440	33.9	35.7	34.8	0.4
May '89	1488	21.0	25.6	23.4	1.0	1488	26.7	36.3	35.3	1.0
Jun '89	1432	23.8	27.9	26.6	0.9	1432	31.1	36.0	33.8	1.5
Jul '89	1488	26.7	29.3	28.2	0.4	1488	23.7	34.9	32.2	1.7
Aug '89	1488	27.9	29.7	28.9	0.3	1488	29.4	35.5	33.3	1.4
Sep '89	1440	26.9	30.2	28.8	0.8	1440	31.2	36.0	34.2	1.0
Oct '89	1479	23.8	27.3	26.0	1.0	1479	26.5	35.6	33.9	0.8
Nov '89	1440	21.3	25.2	23.7	0.9	1440	32.9	35.5	35.0	0.4
Dec '89	1488	17.8	22.3	19.6	1.3	1488	33.5	35.9	35.1	0.5
Jan '90	1488	15.8	19.1	17.9	0.5	1488	33.3	35.8	35.3	0.2
Feb '90	526	16.8	19.8	17.6	0.6	526	33.9	35.4	34.7	0.2

Table 10-5. **B BOTTOM** monthly basic statistics for current velocity components, temperature and salinity, based on half-hourly data. The positive along isobath and cross isobath directions are 55° and 325°, respectively.

B BOTTOM		U (Along Isobath) (cm s^{-1})				V (Cross Isobath) (cm s^{-1})			
MONTH	N	MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD
Dec '87	58	-15.1	12.4	-1.1	5.8	-6.8	7.7	-0.6	4.5
Jan '88	1488	-22.6	10.6	-6.7	7.3	-18.2	16.9	-2.4	5.8
Feb. '88	1392	-21.2	13.8	-2.1	6.7	-13.2	11.1	-0.8	4.0
Mar '88	1478	-16.0	14.6	-2.3	6.0	-15.0	9.1	-0.7	3.3
Apr '88	1440	-20.3	19.0	-2.5	6.2	-24.8	29.5	-0.9	4.8
May '88	1488	-14.3	17.9	-1.8	4.6	-12.2	13.1	-0.9	3.5
Jun '88	1440	-9.7	7.4	-0.6	2.6	-12.4	6.6	-0.6	2.7
Jul '88	1488	-10.1	17.0	-0.7	3.8	-23.5	12.9	-0.5	3.0
Aug '88	1423	-11.1	6.2	-1.9	3.2	-11.0	7.3	-0.4	2.6
Sept '88	1440	-32.6	15.7	-4.1	7.1	-21.5	17.5	0.4	5.1
Oct '88	1488	-15.3	11.8	-3.6	4.4	-13.7	11.0		3.3
Nov '88	1440	-21.1	13.0	-3.1	6.7	-15.6	14.9	-0.3	4.0
Dec '88	1488	-20.2	19.0	-6.1	6.9	-14.1	9.9	-0.4	4.4
Jan '89	616	-15.6	14.4	-5.7	6.2	-16.7	6.1	-2.5	4.5
Feb '89	582	-17.7	20.1	-0.4	9.1	-13.3	5.4	-3.4	3.8
Mar '89	1488	-23.6	12.3	-5.3	6.9	-27.1	13.5	-1.2	4.9
Apr '89	1440	-11.9	15.7	-0.7	4.1	-10.6	11.3	-0.1	3.1
May '89	1488	-14.7	10.3	-1.1	4.3	-9.0	7.7	-0.4	2.9
Jun '89	1427	-20.4	11.6	-1.8	4.3	-19.1	13.1	-1.0	3.5
Jul '89	1488	-19.3	7.5	-3.6	4.6	-18.4	10.6	-1.5	3.8
Aug. '89	1488	-15.0	19.3	-2.0	4.5	-15.5	10.4	-0.9	3.3
Sep '89	1440	-28.0	15.7	-1.9	5.3	-21.6	14.4	-0.5	4.7
Oct '89	1100	-15.0	12.8	-1.8	4.5	-8.8	8.7	-0.1	2.9

B BOTTOM		Temperature (°C)				Salinity (PSU)				
MONTH	N	MIN	MAX	MEAN	SD	N	MIN	MAX	MEAN	SD
Dec '87	58	19.3	19.8	19.6	0.2	58	36.0	36.2	36.1	0.1
Jan '88	1488	17.1	19.9	18.3	0.7	1488	36.1	36.4	36.2	0.1
Feb. '88	1392	15.0	17.6	16.7	0.5	1392	35.5	36.3	36.1	0.2
Mar '88	1478	15.0	18.8	17.0	0.6	1478	35.6	36.5	36.1	0.2
Apr '88	1440	15.7	19.0	17.5	0.7	1440	35.7	36.5	36.3	0.2
May '88	1488	17.3	19.9	18.5	0.6	1488	36.1	36.6	36.4	0.1
Jun '88	1440	18.5	20.1	19.0	0.3	1440	35.6	36.5	36.4	0.1
Jul '88	1488	18.4	22.5	19.6	0.9	1488	36.3	36.9	36.5	0.1
Aug '88	1423	18.7	22.6	19.8	0.7	1423	36.3	36.7	36.4	0.1
Sept '88	1440	19.3	24.1	20.9	1.1	1440	36.0	36.6	36.4	0.1
Oct '88	1488	18.6	21.3	20.2	0.8	1488	35.6	36.5	36.4	0.1
Nov '88	1440	20.2	23.4	21.6	1.0	1440	35.5	36.5	36.2	0.3
Dec '88	1488	18.3	22.3	20.2	1.0	1488	35.5	36.3	36.0	0.2
Jan '89	616	19.4	20.6	19.8	0.3	616	35.8	36.3	36.1	0.1
Feb '89	582	16.4	19.8	18.6	0.8	582	35.6	36.3	36.0	0.2
Mar '89	1488	16.9	18.6	18.0	0.4	1488	35.6	36.3	36.1	0.2
Apr '89	1440	17.9	18.6	18.3	0.1	1440	35.7	36.2	36.1	0.1
May '89	1488	18.4	19.9	18.8	0.4	1488	35.8	36.4	36.1	0.1
Jun '89	1427	19.4	22.2	21.0	0.7	1427	35.9	36.5	36.3	0.1
Jul '89	1488	20.1	23.5	21.4	0.7	1488	35.7	36.5	36.3	0.1
Aug. '89	1488	20.5	23.2	21.8	0.6	1488	36.1	36.5	36.3	0.0
Sep '89	1440	18.1	24.2	20.9	1.4	1440	36.1	36.5	36.3	0.1
Oct '89	1100	15.4	21.5	19.4	1.4	1100	35.9	36.4	36.3	0.1

Table 10-6. **C TOP** monthly basic statistics for current velocity components, temperature and salinity, based on half-hourly data. The positive along isobath and cross isobath directions are 55° and 325°, respectively.

C TOP		U (Along Isobath) (cm s^{-1})				V (Cross Isobath) (cm s^{-1})			
MONTH	N	MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD
Aug '88	324	-11.1	28.5	11.7	8.7	-28.0	24.8	5.2	10.7
Sep '88	1440	-62.0	26.0	-16.2	15.5	-41.1	26.0	-5.1	12.7
Oct '88	1488	-39.6	38.9	4.6	13.1	-40.5	29.1	-12.0	12.5
Nov '88	1440	-15.3	43.5	17.2	11.3	-47.0	7.1	-18.1	10.3
Dec '88	1488	-14.5	25.2	-0.5	6.8	-7.5	20.0	4.1	4.4
Jan '89	607	-16.8	3.8	-3.4	4.1	-8.5	9.3	0.7	2.6
Feb '89	592	-21.6	62.7	16.2	18.2	-38.3	21.2	1.5	8.0
Mar '89	1488	-51.8	62.8	13.1	20.4	-40.1	46.8	1.3	11.8
Apr '89	1440	-23.2	22.5	2.2	7.2	-18.8	24.9	4.2	6.8
May '89	1488	-24.6	45.9	18.0	15.9	-33.2	15.8	-8.4	9.1
Jun '89	1426	-22.8	45.0	12.9	10.7	-33.0	22.7	-6.8	8.3
Jul '89	1488	-4.9	58.3	21.7	12.9	-46.9	8.7	-10.2	9.5
Jul '89	51	1.2	19.8	5.6	4.8	-11.4	-0.1	-3.4	2.8
Sep '89	0								
Oct '89	391	-8.1	42.1	15.2	10.1	-30.1	21.8	-4.9	9.9
Nov '89	1440	-33.9	38.4	4.1	13.6	-29.8	38.5	0.2	11.7
Dec '89	1488	-6.9	43.0	16.9	9.5	-35.8	23.1	-1.4	7.7
Jan '90	1488	-4.3	59.8	15.8	13.1	-30.1	31.5	-3.7	7.8
Feb '90	480	-0.8	27.3	5.6	7.3	-5.5	16.4	1.4	2.8

C TOP		Temperature (°C)				Salinity (PSU)				
MONTH	N	MIN	MAX	MEAN	SD	N	MIN	MAX	MEAN	SD
Aug '88	324	22.4	29.8	26.8	2.4	324	34.6	36.8	35.8	0.5
Sep '88	1440	19.9	28.8	26.7	1.5	1440	30.2	37.2	36.4	0.4
Oct '88	1488	24.5	28.3	25.6	1.0	1488	22.8	36.9	36.3	0.8
Nov '88	1440	22.8	25.8	24.3	0.7	1440	36.1	37.3	36.7	0.3
Dec '88	1488	20.8	23.9	22.2	0.9	1488	35.2	36.7	36.0	0.4
Jan '89	607	21.1	22.0	21.7	0.2	607	34.8	35.7	35.5	0.1
Feb '89	592	19.9	23.0	21.6	0.7	592	35.7	36.3	36.1	0.1
Mar '89	1488	18.1	23.5	21.3	1.1	1488	34.0	36.4	35.4	0.6
Apr '89	1440	21.2	23.2	22.0	0.4	1440	34.5	35.9	35.5	0.2
May '89	1488	22.0	26.7	24.5	1.2	1488	32.1	35.9	35.1	0.6
Jun '89	1426	21.6	28.1	26.9	0.7	1426	31.1	36.7	34.8	1.0
Jul '89	1488	20.5	29.4	28.0	1.1	1488	30.1	36.7	35.2	0.9
Jul '89	1488	27.0	29.6	28.8	0.4	1488	33.5	36.2	35.2	0.5
Sep '89	0144	27.1	29.9	28.9	0.6	1440	33.4	35.8	35.1	0.6
Oct '89	1473	24.5	28.5	26.7	1.1	1473	33.9	36.1	35.3	0.4
Nov '89	1440	21.9	25.1	23.7	0.8	1440	34.6	35.9	35.4	0.4
Dec '89	1488	16.8	22.9	20.7	1.3	1488	33.2	35.6	35.0	0.5
Jan '90	1488	17.4	22.5	19.4	1.2	1488	33.6	35.2	34.5	0.4
Feb '90	480	17.6	21.8	20.4	1.2	480	32.9	35.2	34.5	0.5

Table 10-7. **C MIDDLE** monthly basic statistics for current velocity components, temperature and salinity, based on half-hourly data. The positive along isobath and cross isobath directions are 55° and 325°, respectively.

C MIDDLE		**U (Along Isobath) (cm s^{-1})**				**V (Cross Isobath) (cm s^{-1})**			
MONTH	N	MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD
Dec '87	52	27.6	37.0	31.9	2.2	-4.7	5.4	-0.3	2.6
Jan '88	1488	-48.6	42.0	5.5	21.3	-35.0	25.5	-4.7	8.0
Feb '88	1392	-21.4	23.0	3.0	8.3	-15.0	21.1	2.0	5.8
Mar '88	1488	-34.1	33.1	-6.5	14.3	-15.8	17.9	2.3	5.3
Apr '88	1440	-45.3	17.1	-12.6	10.8	-19.3	18.8	2.1	5.6
May '88	1353	-18.6	38.1	9.0	11.9	-19.8	21.9	1.5	9.3
Jun '88	0								
Jul '88	0								
Aug '88	324	-9.5	17.6	0.0	5.2	-10.6	8.9	2.1	3.1
Sep '88	1440	-53.3	16.2	-10.9	13.0	-23.6	16.5	-1.6	6.5
Oct '88	1488	-31.6	25.5	-11.5	8.8	-27.0	11.9	-5.3	8.5
Nov '88	1440	-17.0	36.5	3.8	10.4	-25.1	14.9	-1.7	5.2
Dec '88	1488	-22.5	22.5	1.3	8.9	-8.6	15.8	2.9	3.2
Jan '89	607	-20.6	13.0	-5.6	6.9	-12.5	11.3	1.2	4.0
Feb '89	592	-9.9	49.0	12.5	14.6	-10.1	14.6	3.1	4.5
Mar '89	1488	-36.3	22.2	-4.6	14.2	-10.4	18.7	3.9	5.1
Apr '89	1383	-21.5	18.7	2.4	6.4	-13.9	13.6	1.4	4.4
May '89	390	22.6	37.4	30.4	3.2	-8.2	5.8	-1.3	2.8
Jun '89	1426	-27.7	49.7	18.7	14.2	-25.8	12.3	-4.1	7.2
Jul '89	1441	-20.1	44.5	8.0	17.0	-19.9	22.4	-3.0	8.0
Aug '89	998	-21.5	42.7	8.9	17.6	-22.8	12.2	-5.6	5.0
Sep '89	403	-58.1	15.3	-24.6	16.7	-24.2	17.7	-2.1	7.7
Oct '89	577	-27.3	0.1	-14.5	7.0	-10.4	18.5	1.6	4.3
Nov '89	1440	-27.0	33.2	-1.0	13.1	-18.2	12.7	-1.8	4.9
Dec '89	1488	-16.3	49.2	21.0	13.7	-38.5	17.3	-2.4	7.9
Jan '90	1488	-15.9	37.3	11.9	10.9	-15.0	9.3	-2.4	4.3
Feb '90	480	-19.2	8.1	-7.3	6.0	-5.9	17.4	3.2	4.6

C MIDDLE		Temperature (°C)					Salinity (PSU)			
MONTH	N	MIN	MAX	MEAN	SD	N	MIN	MAX	MEAN	SD
Dec '87	52	15.4	16.1	15.8	0.2	52	36.1	36.2	36.2	0.0
Jan '88	1488	13.3	18.2	16.1	1.0	1488	35.8	36.4	36.2	0.1
Feb '88	1392	14.2	16.9	15.7	0.6	1392	35.9	36.3	36.1	0.1
Mar '88	1488	13.4	16.9	15.3	0.8	1488	35.7	36.2	36.0	0.1
Apr '88	1440	14.0	16.7	15.4	0.5	1440	35.8	36.2	36.0	0.1
May '88	1353	15.4	18.5	16.8	0.5	1048	36.0	36.4	36.2	0.1
Jun '88	0					0				
Jul '88	0					0				
Aug '88	324	14.2	15.2	14.6	0.2	324	35.8	36.0	35.9	0.0
Sep '88	1440	13.1	17.0	15.6	0.7	1440	35.6	36.3	36.0	0.1
Oct '88	1488	15.0	17.4	16.1	0.6	1488	35.8	36.3	36.0	0.1
Nov '88	1440	15.2	17.4	16.6	0.4	1440	35.9	36.3	36.1	0.1
Dec '88	1488	15.1	17.1	16.2	0.4	1488	35.9	36.3	36.1	0.1
Jan '89	607	16.1	17.4	16.7	0.2	607	36.0	36.3	36.1	0.0
Feb '89	592	14.8	17.6	16.4	1.0	592	35.9	36.4	36.2	0.2
Mar '89	1488	13.8	16.9	15.4	0.7	1488	35.8	36.3	36.0	0.1
Apr '89	1440	15.1	17.3	16.1	0.4	1440	36.0	36.4	36.1	0.1
May '89	1448	14.0	17.0	15.7	0.6	1488	35.8	36.3	36.1	0.1
Jun '89	1426	12.7	17.1	15.7	0.6	1426	35.6	36.3	36.1	0.1
Jul '89	1488	13.1	17.3	15.1	0.9	1488	35.6	36.3	36.0	0.1
Aug '89	1488	13.0	16.2	14.3	0.7	1488	35.6	36.2	35.9	0.1
Sep '89	1440	12.3	16.3	14.3	0.9	1440	34.8	36.1	35.8	0.1
Oct '89	1473	14.1	16.9	16.3	0.4	1473	35.8	36.3	36.1	0.1
Nov '89	1440	15.7	17.8	16.7	0.3	1440	36.1	36.4	36.2	0.0
Dec '89	1488	13.9	17.2	15.5	0.6	1488	35.8	36.3	36.0	0.1
Jan '90	1488	14.1	16.6	15.4	0.5	1488	35.8	36.2	36.0	0.1
Feb '90	480	15.1	16.4	15.9	0.3	480	36.0	36.2	36.1	0.0

Table 10-8. **C BOTTOM** monthly basic statistics for current velocity components, temperature and salinity, based on half-hourly data. The positive along isobath and cross **isobath directions are 55° and 325°, respectively.**

C BOTTOM		U (Along Isobath) (cm s^{-1})				V (Cross Isobath) (cm s^{-1})			
MONTH	N	MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD
Dec '87	52	-18.7	-5.9	-12.2	3.8	-4.0	4.6	2.3	2.1
Jan '88	1488	-30.1	18.2	-6.1	9.6	-12.8	11.3	-0.3	3.8
Feb '88	1392	-21.6	13.6	-6.6	8.3	-14.8	8.5	-0.9	4.2
Mar '88	1488	-27.7	13.0	-7.9	7.8	-20.1	17.6	0.0	4.5
Apr '88	1440	-31.2	3.1	-7.5	6.8	-18.3	11.4	0.0	3.5
May '88	849	-18.4	13.9	-3.6	6.0	-15.2	10.8	-0.2	3.2
Jun '88	0								
Jul '88	0								
Aug '88	324	-18.5	2.7	-8.9	6.2	-2.7	4.0	0.2	1.2
Sep '88	1440	-30.4	16.5	-3.6	7.7	-16.1	11.3	-0.9	4.5
Oct '88	1488	-22.1	10.1	-5.5	6.0	-11.7	12.3	-0.2	3.2
Nov '88	1440	-32.5	27.3	-4.9	9.5	-19.6	19.0	-0.7	4.5
Dec '88	1488	-29.6	17.1	-4.5	9.1	-23.5	11.3	-0.8	4.6
Jan '89	53	-7.3	1.4	-2.2	2.7	-7.1	9.4	-0.6	3.8
Feb '89	592	-33.6	16.9	-2.2	13.6	-16.3	16.1	0.0	7.5
Mar '89	1488	-28.9	16.5	-10.6	9.0	-14.5	24.8	0.9	4.9
Apr '89	1440	-43.8	16.3	-4.6	8.2	-15.4	14.4	-0.5	5.6
May '89	1488	-35.7	15.9	-8.9	7.7	-13.9	13.2	1.1	3.9
Jun ' '89	1426	-15.3	10.6	-4.3	5.9	-10.3	10.7	0.5	3.3
Jul '89	1488	-17.7	12.8	-3.9	5.5	-7.4	11.0	0.4	2.3
Aug '89	1488	-14.8	7.2	-4.1	4.1	-14.9	6.9	-0.4	2.7
Sep '89	1440	-34.7	10.9	-8.4	8.0	-12.7	14.3	-0.2	3.5
Oct '89	1473	-31.0	10.7	-10.2	6.7	-13.5	12.1	0.1	3.6
Nov '89	1440	-18.8	14.2	-3.8	6.5	-18.8	10.5	0.2	3.6
Dec '89	1488	-36.1	13.9	-10.0	9.4	-15.6	11.2	-1.1	4.8
Jan '90	1488	-31.3	19.6	-6.3	9.9	-13.0	8.8	-0.5	3.7
Feb '90	480	-28.3	0.0	-13.2	5.6	-9.2	13.0	0.4	4.0

C BOTTOM		Temperature (°C)				Salinity (PSU)				
MONTH	N	MIN	MAX	MEAN	SD	N	MIN	MAX	MEAN	SD
Dec '87	52	8.5	9.0	8.7	0.1	52	34.9	35.1	35.0	0.0
Jan '88	1488	6.8	10.6	8.5	0.6	1488	34.8	35.3	35.0	0.1
Feb '88	1392	7.0	10.4	8.8	0.6	1392	34.7	35.3	35.0	0.1
Mar '88	1488	7.0	11.0	9.2	0.8	1488	34.8	35.4	35.1	0.1
Apr '88	1440	8.2	10.4	9.1	0.5	1440	34.9	35.3	35.0	0.1
May '88	849	8.6	10.7	9.7	0.5	849	34.9	35.3	35.1	0.1
Jun '88	0									
Jul '88	0									
Aug '88	324	8.5	9.4	9.0	0.2	324	34.7	35.0	34.9	0.0
Sep '88	1440	7.7	10.6	9.1	0.6	1440	34.7	35.2	34.9	0.1
Oct '88	1488	8.4	10.5	9.4	0.4	1488	34.7	35.1	34.9	0.1
Nov '88	1440	7.3	10.8	9.5	0.7	1440	34.7	35.2	35.0	0.1
Dec '88	1488	7.6	10.2	9.2	0.6	1488	34.7	35.1	34.9	0.1
Jan '89	53	9.5	9.8	9.7	0.1	53	34.9	35.1	35.0	0.0
Feb '89	592	6.9	9.9	8.7	0.7	592	34.9	35.3	35.1	0.1
Mar '89	1488	7.9	10.4	9.1	0.6	1488	34.9	35.3	35.1	0.1
Apr '89	1440	7.9	10.5	9.4	0.4	1440	34.4	35.3	35.1	0.1
May '89	1488	7.6	9.7	8.5	0.4	1488	34.9	35.2	35.0	0.1
Jun ' '89	1426	7.7	9.8	8.7	0.5	949	34.8	35.2	35.1	0.1
Jul '89	1488	7.7	9.6	8.8	0.4					
Aug '89	1488	8.3	9.7	8.9	0.3					
Sep '89	1440	7.4	10.4	9.4	0.7					
Oct '89	1473	9.5	12.8	11.0	0.6					
Nov '89	1440	7.7	10.9	8.8	0.6					
Dec '89	1488	7.2	10.6	8.5	0.7					
Jan '90	1488	7.4	10.8	8.9	0.7					
Feb '90	480	10.0	11.0	10.6	0.3					

Table 10-9. **D TOP** and **D BOTTOM** monthly basic statistics for current velocity components, temperature and salinity, based on half-hourly data. The positive along isobath and cross isobath directions are 55° and 325°, respectively.

D TOP		U (Along Isobath) (cm s^{-1})				V (Cross Isobath) (cm s^{-1})			
MONTH	N	MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD
Feb '89	806	-30.2	38.6	10.4	13.8	-53.1	21.2	-16.2	12.7
Mar '89	1488	-28.4	38.9	2.1	13.0	-54.9	26.3	-6.0	13.1
Apr '89	1440	-37.2	45.3	5.0	10.3	-32.2	28.2	-3.6	9.7
May '89	1488	-11.1	26.3	6.5	5.4	-37.3	20.9	-6.1	5.7
Jun '89	1440	-29.7	45.9	6.9	9.4	-28.2	40.7	2.6	11.5
Jul '89	1488	-26.1	50.6	11.9	15.6	-65.6	29.2	-1.1	11.4
Aug '89	1488	-44.2	43.4	1.7	13.9	-50.6	35.2	0.0	13.0
Sep '89	1440	-33.1	30.8	5.9	12.4	-43.4	25.2	2.0	10.8
Oct '89	1488	-34.5	14.7	-5.3	8.8	-9.9	16.6	1.4	3.6
Nov '89	1440	-5.8	5.7	0.7	1.5	-6.9	2.3	-0.5	1.2
Dec '89	1488	-14.9	13.2	0.0	3.8	-23.1	8.2	-2.0	3.9
Jan '90	1488	-21.9	31.7	0.2	3.2	-17.3	19.6	-0.8	3.6
Feb '90	428	-12.4	12.3	-0.6	2.6	-6.7	33.8	-0.1	2.5

D TOP		Temperature (°C)				Salinity (PSU)				
MONTH	N	MIN	MAX	MEAN	SD	N	MIN	MAX	MEAN	SD
Feb '89	806	18.8	23.4	21.6	0.9	806	34.5	36.6	35.9	0.4
Mar '89	1488	18.2	22.5	21.2	0.8	1488	32.6	36.7	35.5	0.7
Apr '89	1440	20.4	24.4	22.0	0.9	1440	31.9	36.6	35.0	1.0
May '89	1488	21.3	26.6	24.7	0.9	1488	32.6	36.5	35.6	1.0
Jun '89	1440	23.7	28.4	26.5	1.0	1440	28.1	36.4	34.8	1.4
Jul '89	1488	25.5	29.3	28.2	0.8	1488	31.8	36.7	35.1	0.8
Aug '89	1488	27.8	29.8	28.9	0.3	1488	30.8	37.0	34.7	1.0
Sep '89	1440	26.7	30.1	29.0	0.8	1440	24.0	36.7	35.2	1.2
Oct '89	1488	23.3	28.1	26.1	1.1	1488	28.2	35.8	34.8	0.5
Nov '89	1440	22.2	25.5	23.9	0.9	1440	33.6	36.1	35.4	0.4
Dec '89	1488	16.1	22.6	20.2	1.1	1488	33.4	36.2	35.4	0.5
Jan '90	1488	17.1	19.6	18.3	0.5	1488	33.4	36.1	35.4	0.5
Feb '90	428	17.8	21.9	19.7	1.2	428	32.8	36.4	34.6	1.0

D BOTTOM		U (Along Isobath) (cm s^{-1})				V (Cross Isobath) (cm s^{-1})			
MONTH	N	MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD
Feb '89	804	-18.1	25.1	2.4	7.9	-22.8	16.3	-5.8	6.9
Mar '89	1488	-15.0	30.2	1.0	6.9	-34.5	19.5	-3.0	7.5
Apr '89	1440	-20.3	19.3	0.1	5.7	-23.1	11.5	-5.3	5.7
May '89	1095	-16.6	15.6	0.3	5.3	-24.0	6.8	-6.7	6.1
Jun '89	1250	-17.6	8.9	-3.0	4.0	-20.5	16.7	0.2	6.6
Jul '89	1488	-23.3	23.5	2.9	6.2	-17.2	16.0	-0.6	4.9
Aug '89	1488	-14.1	34.4	1.9	5.9	-18.6	27.7	2.5	7.1
Sep '89	1440	-13.8	20.2	4.0	6.0	-23.3	15.2	-2.0	5.2
Oct '89	1039	-19.1	14.0	-4.2	5.8	-21.3	15.0	-1.9	6.0

D BOTTOM		Temperature (°C)				Salinity (PSU)				
MONTH	N	MIN	MAX	MEAN	SD	N	MIN	MAX	MEAN	SD
Feb '89	804	17.6	21.0	19.6	0.8	804	35.6	36.7	36.2	0.2
Mar '89	1488	17.8	21.3	19.7	0.9	1488	35.7	36.8	36.3	0.2
Apr '89	1440	18.5	20.9	19.9	0.5	1440	35.3	36.8	36.4	0.1
May '89	1488	18.8	21.8	20.6	0.7	1488	36.2	36.7	36.5	0.1
Jun '89	1429	19.4	21.7	20.4	0.6	1429	36.1	36.7	36.5	0.1
Jul '89	1488	19.9	22.7	21.5	0.5	1488	36.0	36.6	36.4	0.1
Aug '89	1488	19.9	23.2	22.2	0.6	1488	36.0	36.4	36.2	0.1
Sep '89	1440	18.6	23.4	21.4	1.0	1440	35.9	36.4	36.1	0.1
Oct '89	1039	19.0	21.6	20.2	0.5	1039	35.9	36.6	36.1	0.1

Table 10-10. **E TOP, E MIDDLE** and **E BOTTOM** monthly basic statistics for current velocity components, temperature and salinity, based on half-hourly data. The positive along isobath and cross isobath directions are 55° and 325°, respectively.

E TOP		U (Along Isobath) (cm s^{-1})				V (Cross Isobath) (cm s^{-1})			
MONTH	N	MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD
Feb '89	632	-43.6	40.8	11.8	13.8	-53.3	22.5	-9.3	12.3
Mar '89	1488	-22.2	56.9	17.3	13.0	-52.1	19.1	-9.4	13.1
Apr '89	1440	-38.1	51.0	19.4	14.0	-45.5	24.5	-8.4	12.4
May '89	1488	-4.1	52.2	19.5	10.5	-49.0	11.9	-9.8	10.4
Jun '89	1005	-25.6	53.6	12.5	14.7	-50.7	41.1	-1.8	13.1

E TOP		Temperature (°C)				Salinity (PSU)				
MONTH	N	MIN	MAX	MEAN	SD	N	MIN	MAX	MEAN	SD
Feb '89	632	19.9	23.9	22.3	0.8	632	34.3	36.4	36.0	0.4
Mar '89	1488	20.2	24.5	22.3	0.8	1488	34.0	36.5	35.9	0.5
Apr '89	1440	21.2	24.9	23.1	1.0	1440	33.6	36.2	35.5	0.5
May '89	1488	23.1	26.6	25.4	0.8	1488	33.3	35.9	35.5	0.2
Jun '89	1440	25.9	28.4	27.3	0.6	1005	32.4	36.1	34.9	0.6
Jul '89	1488	21.3	29.2	28.2	0.9	1488	30.1	36.6	35.2	0.6
Aug '89	1488	27.3	29.9	29.0	0.4	1488	31.6	36.3	35.1	0.9
Sep '89	1440	27.0	30.0	29.1	0.6	1440	33.4	47.6	35.5	0.8
Oct '89	1052	21.9	28.5	26.7	1.3	1052	33.3	35.8	34.7	0.5

E MIDDLE		U (Along Isobath) (cm s^{-1})				V (Cross Isobath) (cm s^{-1})			
MONTH	N	MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD
Feb '89	632	-9.6	40.5	15.9	12.2	-18.2	6.8	-5.0	5.9
Mar '89	1488	-48.4	43.1	6.6	20.1	-21.4	16.9	-1.7	6.9
Apr '89	1440	-26.6	46.4	16.8	17.3	-35.3	14.7	-7.8	9.0
May '89	1488	-24.2	38.3	19.5	10.8	-28.4	8.2	-6.1	5.2
Jun '89	1440	-2.7	25.5	15.3	5.5	-31.6	10.9	-8.3	7.5
Jul '89	1488	-23.2	27.7	5.4	15.3	-20.1	20.6	0.8	7.7
Aug '89	1488	-28.9	37.8	14.5	18.4	-30.7	13.9	-6.6	5.5
Sep '89	1440	-27.5	28.7	8.5	9.8	-12.0	16.5	-0.9	4.3
Oc t '89	1052	-62.8	12.2	-24.6	16.7	-8.7	38.3	9.4	9.8

E MIDDLE		Temperature (°C)				Salinity (PSU)				
MONTH	N	MIN	MAX	MEAN	SD	N	MIN	MAX	MEAN	SD
Feb '89	632	15.4	18.2	16.9	0.6	632	36.0	36.5	36.2	0.1
Mar '89	1488	15.0	18.0	16.5	0.6	1488	35.9	36.4	36.2	0.1
Apr '89	1440	15.3	18.4	16.6	0.6	1440	36.0	36.5	36.2	0.1
May '89	1488	15.6	18.0	16.6	0.5	1488	36.0	36.4	36.2	0.1
Jun '89	1440	15.6	16.9	16.3	0.2	1440	36.1	36.3	36.2	0.0
Jul '89	1488	14.3	17.9	16.2	0.9	1488	35.9	36.5	36.2	0.1
Aug '89	1488	14.1	17.2	15.8	0.7	1488	35.9	36.4	36.2	0.1
Sep '89	1440	13.8	17.2	16.0	0.7	1440	35.1	36.4	36.2	0.1
Oc t '89	1052	13.8	16.3	15.3	0.6	1052	35.8	36.3	36.1	0.1

E BOTTOM		U (Along Isobath) (cm s^{-1})				V (Cross Isobath) (cm s^{-1})			
MONTH	N	MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD
Feb '89	632	-28.2	18.1	-2.6	9.9	-11.7	10.8	0.7	4.2
Mar '89	1488	-29.0	11.9	-4.6	7.5	-14.7	16.3	1.4	4.5
Apr '89	1440	-15.5	13.9	-0.4	6.0	-14.5	10.9	-0.4	4.2
May '89	1488	-15.5	14.7	-2.3	5.3	-13.2	14.7	0.7	3.2
Jun '89	1440	-19.7	14.9	-1.8	7.1	-11.0	12.4	0.4	3.7
Jul '89	1488	-16.8	7.1	-3.6	4.1	-14.6	11.3	0.7	3.4
Aug '89	1488	-14.3	10.9	-1.1	4.7	-12.4	13.5	-0.4	3.7
Sep '89	1440	-27.8	7.4	-4.1	6.3	-11.3	13.5	0.9	3.6
Oct '89	1052	-34.6	9.7	-8.9	8.6	-14.3	16.4	2.6	5.0

E BOTTOM		Temperature (°C)			
MONTH	N	MIN	MAX	MEAN	SD
Feb '89	632	7.5	10.2	8.8	0.7
Mar '89	1488	8.0	11.1	9.5	0.6
Apr '89	1440	8.5	11.2	9.4	0.5
May '89	1488	8.0	10.7	8.8	0.5
Jun '89	1440	8.3	10.0	9.1	0.4
Jul '89	1488	8.0	9.7	8.8	0.4
Aug '89	1488	8.4	10.0	9.0	0.4
Sep '89	1440	8.3	11.1	9.6	0.6
Oct '89	1052	9.8	12.2	11.1	0.4

Table 10-11. **Monthly basic statistics for components of wind velocity and wind stress, based on hourly data from Buoy 42015.**

		U (Along Isobath) WIND (m s^{-1})				V (Cross Isobath) WIND (m s^{-1})			
Date	**N**	**MIN**	**MAX**	**MEAN**	**SD**	**MIN**	**MAX**	**MEAN**	**SD**
Jan '88	744	-12.3	15.2	-1.52	4.54	-17.7	10.9	-4.33	6.42
Feb '88	696	-14.8	14.4	-0.03	4.84	-18.6	10.0	-2.43	6.21
Mar '88	744	-13.5	14.2	-1.05	5.52	-15.0	10.3	-0.49	5.39
Apr '88	720	-17.9	19.3	1.19	6.03	-13.1	11.9	0.78	5.07
May '88	744	-11.2	14.8	0.40	4.12	-11.9	11.9	1.18	4.49
Jun '88	720	-17.0	10.5	-0.44	5.31	-11.3	8.7	1.03	3.90
Jul '88	744	-12.1	13.0	0.58	4.44	-11.4	9.6	2.02	3.49
Aug '88	744	-22.9	9.6	-1.98	4.91	-9.4	17.6	2.19	4.35
Sep '88	720	-15.6	12.6	-3.20	5.09	-14.2	17.7	-0.39	5.43
Oct '88	744	-12.4	9.6	-2.25	3.78	-16.1	8.3	-3.77	5.50
Nov '88	720	-13.9	15.8	-1.23	5.33	-17.4	11.9	-0.87	6.78
Dec '88	744	-12.4	10.7	-2.07	4.08	-17.8	8.2	-3.27	5.57
Jan '89	744	-12.6	8.0	-2.83	3.76	-16.1	7.9	-1.93	4.99
Feb '89	672	-12.5	10.5	-1.01	3.92	-19.1	7.4	-3.38	6.45
Mar '89	744	-16.9	14.3	-0.95	4.91	-15.8	10.8	-0.78	5.70
Apr '89	720	-14.0	15.5	-0.63	4.71	-16.4	9.6	-0.08	5.88
May '89	744	-13.2	12.8	-0.19	4.97	-15.0	11.7	1.74	5.02
Jun '89	720	-11.7	18.2	1.41	3.97	-9.3	14.2	4.00	4.03
Jul '89	744	-12.4	16.7	1.54	4.69	-10.4	11.5	2.33	3.59
Aug '89	744	-12.9	9.6	-0.02	4.07	-11.4	9.2	0.44	4.03
Sep '89	720	-13.4	11.9	-2.98	4.22	-17.2	9.3	-2.79	5.17
Oct '89	744	-13.1	9.0	-1.74	4.58	-14.1	11.0	-3.40	4.07
Nov '89	720	-10.6	12.5	-1.56	4.14	-17.3	11.2	-2.15	6.16
Dec '89	744	-13.1	13.7	0.70	4.81	-19.3	8.4	-3.96	6.77
Jan '90	744	-10.8	12.5	-1.36	4.64	-13.8	9.6	-1.20	4.68
Feb '90	672	-15.4	15.1	-2.13	5.20	-14.7	10.5	-1.49	5.43

		U (Along Isobath) STRESS (dyne cm^{-2})				V (Cross Isobath) STRESS (dyne cm^{-2})			
Date	N	MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD
Jan '88	744	-3.5	5.3	-0.23	0.99	-7.8	2.3	-1.12	1.70
Feb '88	696	-5.0	5.2	0.00	1.06	-10.1	1.9	-0.84	1.93
Mar '88	744	-3.9	4.8	-0.05	1.05	-6.6	2.9	-0.24	1.17
Apr '88	720	-7.9	9.5	0.22	1.83	-3.9	5.3	-0.04	1.00
May '88	744	-2.6	5.9	0.06	0.63	-3.0	3.2	0.14	0.71
Jun '88	720	-7.3	2.0	-0.18	1.10	-3.0	1.5	0.04	0.58
Jul '88	744	-3.8	3.5	-0.01	0.67	-4.0	1.9	0.19	0.44
Aug '88	744	-15.2	2.0	-0.52	1.94	-2.2	8.6	0.45	1.16
Sep '88	720	-8.7	6.9	-0.63	1.16	-7.5	8.8	-0.17	1.27
Oct '88	744	-3.6	2.3	-0.40	0.74	-6.4	1.9	-0.85	1.37
Nov '88	720	-4.1	6.0	-0.14	1.26	-7.3	3.2	-0.46	1.56
Dec '88	744	-5.9	2.5	-0.32	0.85	-8.0	1.5	-0.79	1.36
Jan '89	744	-4.4	1.1	-0.45	0.74	-6.8	1.1	-0.48	1.13
Feb '89	672	-3.2	4.5	-0.08	0.79	-10.1	1.3	-0.94	1.66
Mar '89	744	-6.9	4.4	-0.15	0.99	-5.8	2.5	-0.32	1.13
Apr '89	720	-4.2	5.5	-0.12	0.99	-6.3	2.6	-0.25	1.31
May '89	744	-3.7	3.5	0.00	0.78	-5.1	3.2	0.20	0.82
Jun '89	720	-4.8	8.6	0.30	0.96	-3.6	5.4	0.58	0.93
Jul '89	744	-4.1	6.5	0.22	0.76	-2.3	3.3	0.28	0.55
Aug '89	744	-3.4	1.6	-0.04	0.51	-2.9	1.9	0.01	0.50
Sep '89	720	-5.0	2.8	-0.54	0.90	-7.1	1.7	-0.63	1.18
Oct '89	744	-4.4	3.4	-0.22	0.86	-5.5	2.3	-0.61	0.96
Nov '89	720	-2.7	5.5	-0.15	0.85	-9.2	2.5	-0.67	1.63
Dec '89	744	-3.6	4.0	0.19	1.00	-10.2	1.5	-1.15	1.95
Jan '90	744	-2.3	4.4	-0.07	0.79	-4.4	1.9	-0.30	0.87
Feb '90	672	-5.3	5.1	-0.25	1.10	-4.9	2.3	-0.41	1.12

Table 10-12. **Monthly basic statistics for air temperature, sea surface temperature, significant wave height and dominant wave period, based on hourly data from Buoy 42015.**

		Sea Surface Temperature (°C)				Air Temperature (°C)			
MONTH	N	MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD
Jan '88	744	10.3	16.1	13.4	1.2	2.7	19.1	10.3	4.2
Feb '88	696	9.4	17.2	13.4	1.4	-1.6	17.6	11.5	4.2
Mar '88	744	14.3	19.9	16.7	1.0	5.9	19.7	15.4	3.1
Apr '88	720	17.7	25.4	20.5	1.7	10.4	25.4	19.8	2.5
May '88	744	19.0	27.4	23.5	1.5	16.6	27.3	23.0	1.9
Jun '88	720	23.9	30.6	26.3	1.3	20.7	30.1	25.6	1.7
Jul '88	744	26.6	31.1	28.5	0.8	23.6	29.9	27.5	1.0
Aug '88	744	26.2	32.1	29.1	0.9	24.0	31.4	27.4	1.2
Sep '88	720	22.2	31.5	27.7	1.1	19.6	31.2	26.3	2.0
Oct '88	744	20.3	26.8	22.9	1.5	14.5	27.6	20.8	2.3
Nov '88	720	16.0	22.7	20.7	1.6	9.9	24.1	19.3	3.5
Dec '88	744	12.4	19.1	15.7	1.1	5.5	19.9	13.6	3.6
Jan '89	744	11.0	17.6	15.9	1.1	6.4	19.8	15.0	2.8
Feb '89	672	10.4	20.7	15.8	1.5	-1.6	21.4	12.8	5.2
Mar '89	744	12.5	22.2	17.3	2.4	2.3	21.9	15.9	4.5
Apr '89	720	16.0	26.6	20.9	2.3	8.9	25.0	19.4	3.5
May '89	744	21.2	28.9	24.7	1.9	17.4	29.7	24.1	2.3
Jun '89	720	23.0	32.8	28.0	1.2	22.2	28.5	26.8	1.3
Jul '89	744	25.8	32.9	28.4	1.5	22.7	30.8	27.6	1.3
Aug '89	744	25.0	32.0	29.2	1.1	22.7	30.7	27.9	1.6
Sep '89	720	22.8	31.3	28.3	1.9	17.3	32.9	25.8	3.3
Oct '89	744	17.2	26.9	23.1	1.6	8.0	26.5	20.7	3.8
Nov '89	720	15.8	22.9	19.8	1.4	5.8	23.7	17.3	4.3
Dec '89	744	6.7	17.3	14.0	2.1	-9.9	18.7	9.0	6.4
Jan '90	744	10.5	17.3	13.7	1.2	5.7	18.0	13.3	2.5
Feb '90	672	12.8	19.1	15.7	1.1	7.4	19.8	15.3	2.5

		Significant Wave Height (m)				Dominant Wave Period (s)			
MONTH	N	MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD
Jan '88	744	0.1	2.0	0.78	0.46	2.5	9.1	5.27	2.00
Feb '88	696	0.1	2.3	0.57	0.40	2.5	10.0	5.32	2.11
Mar '88	744	0.1	2.4	0.72	0.41	2.5	11.1	5.68	2.09
Apr '88	720	0.1	2.7	0.72	0.52	2.5	12.5	5.69	2.01
May '88	744	0.1	2.0	0.53	0.38	2.5	11.1	5.73	1.95
Jun '88	720	0.1	2.1	0.57	0.31	2.5	9.1	5.33	1.61
Jul '88	744	0.1	1.5	0.46	0.26	2.5	9.1	4.94	1.70
Aug '88	744	0.1	3.3	0.55	0.56	2.5	9.1	5.14	1.31
Sep '88	720	0.1	2.4	0.71	0.46	2.5	14.3	6.38	2.45
Oct '88	744	0.0	1.0	0.43	0.20	0.0	10.0	4.28	1.83
Nov '88	720	0.0	1.9	0.73	0.38	0.0	12.5	5.27	2.28
Dec '88	744	0.0	1.6	0.61	0.33	0.0	9.1	5.11	1.94
Jan '89	744	0.2	1.4	0.64	0.28	2.5	9.1	5.71	1.53
Feb '89	672	0.0	1.6	0.66	0.33	0.0	10.0	5.39	2.15
Mar '89	744	0.2	2.2	0.70	0.39	2.5	9.1	5.84	1.74
Apr '89	720	0.2	1.5	0.53	0.28	2.5	9.1	4.82	1.53
May '89	744	0.0	1.6	0.63	0.33	0.0	8.3	4.81	1.54
Jun '89	720	0.3	3.2	0.79	0.45	2.8	10.0	5.76	1.28
Jul '89	744	0.0	2.1	0.61	0.29	0.0	10.0	5.29	1.45
Aug '89	744	0.0	2.3	0.40	0.37	0.0	10.0	3.96	2.12
Sep '89	720	0.0	2.3	0.56	0.37	0.0	12.5	4.71	1.76
Oct '89	744	0.0	1.3	0.55	0.30	0.0	9.1	4.73	1.88
Nov '89	720	0.0	1.6	0.59	0.33	0.0	8.3	4.43	1.81
Dec '89	744	0.0	1.6	0.63	0.35	0.0	12.5	4.46	1.94
Jan '90	744	0.0	1.3	0.58	0.26	0.0	9.1	5.23	1.69
Feb '90	672	0.0	2.5	0.84	0.46	0.0	9.1	5.63	1.89

Table 10-13. Monthly basic statistics for barometric air pressure, based on hourly data from Buoy 42015.

Air Pressure (mb)

START	N	MIN	MAX	MEAN	SD
Jan '88	744	1006.3	1039.7	1024.0	6.7
Feb '88	696	1005.8	1036.2	1021.7	5.8
Mar '88	744	1007.3	1028.8	1019.4	4.4
Apr '88	720	1003.2	1022.0	1013.3	3.8
May '88	744	1008.8	1021.9	1015.6	2.9
Jun '88	720	1007.2	1024.9	1015.3	4.1
Jul '88	744	1008.8	1024.2	1017.7	2.6
Aug '88	744	1007.4	1020.7	1014.5	2.5
Sep '88	720	1006.3	1022.3	1015.9	3.6
Oct '88	744	1011.6	1030.1	1019.9	4.0
Nov '88	720	1000.5	1027.4	1018.0	4.9
Dec '88	744	1015.6	1034.7	1023.9	3.7
Jan '89	744	1015.6	1028.8	1022.4	2.7
Feb '89	672	1007.9	1039.4	1023.8	6.6
Mar '89	744	1007.5	1028.9	1018.2	4.7
Apr '89	720	1009.6	1027.4	1017.6	3.6
May '89	744	1008.9	1023.6	1016.8	2.6
Jun '89	720	1006.1	1023.6	1016.0	3.2
Jul '89	744	1009.6	1023.4	1017.2	3.1
Aug '89	744	1009.4	1021.1	1015.8	2.0
Sep '89	720	1008.7	1020.4	1014.6	2.1
Oct '89	744	1009.5	1028.8	1019.3	4.1
Nov '89	720	1005.5	1028.9	1019.1	4.9
Dec '89	744	1008.7	1037.2	1021.0	5.9
Jan '90	744	1008.8	1032.0	1021.1	4.7
Feb '90	672	1006.7	1037.5	1021.0	6.4

January, were chosen to approximate the seasons. This choice is somewhat arbitrary. Ten years of monthly wind roses and composite monthly wind roses for Dauphin Island Sea Lab (Schroeder and Wiseman 1985) demonstrate that meteorological seasons in the region are unequal in length and that the boundaries between them vary interannually. In the inner shelf, the oceanic seasons probably follow the meteorological seasons closely. For the outer shelf, where the effect of wind forcing is reduced, there is no obvious rationale for precisely defining the oceanic seasons in the absence of any long term data base, and the present choice is simply examined *a posteriori*. The rose data are summarized and discussed in section 10.4.3. Appendix C presents each of the seasonal roses along with its table of joint distribution.

All half-hourly time series were filtered with a 3-hour, low pass, symmetric, Lanczos squared filter and decimated to hourly values. These hourly series and the hourly buoy and sea level series were filtered with a 40-hour, low pass, symmetric, Lanczos squared filter and decimated to six-hourly values. Figures 10-5b and c show the response functions for the 3- and 40-hour low pass filters, respectively. The 40-hour low passed data were used in most of the subsequent analyses. Appendix C includes monthly plots of all the time-series data.

Spectral analyses were performed on time series of about three to four months length so that annual variability would appear as a trend in the seasonal segments and could be removed along with the mean. Since statistical stability requires record lengths at least 4-5 times the longest period to be analyzed, a four-month record will usefully resolve fluctuations with periods of about 24-30 days. Individual time series were transformed to the frequency domain by Fast Fourier Transform (FFT). Smoothing in the frequency domain to gain statistical stability was accomplished by repeated passes of a Hanning filter. After some experimentation, it was found that fifteen passes yielded suitably smooth spectral estimators with 20 degrees of freedom, yet with a computational bandwidth that still provided considerable detail.

Cross-spectral analysis was performed in the standard manner (Bendat and Piersol 1972) on pairs of scalar series such as, for example, coastal sea level and the along-isobath component of current to yield the individual autospectra, the cross spectrum, phase, coherence squared and, if desired, the gain. For convenience, the term coherence squared will hereafter be shortened to coherence.

For cross-spectral analysis between pairs of vector series, such as wind stress versus current velocity or current velocity at one location versus current velocity at another location, the method of cross rotary spectral analysis was used (Gonella 1972; Mooers 1973). The rotary analysis technique decomposes the spectrum of a vector time series into components which rotate counterclockwise (CCW, heavy line in the autospectra graph) and those which rotate clockwise (CW, light line). The relative intensity of the two spectrum components indicates, as a function of frequency, the polarization of the current fluctuations. Circularly-polarized currents would exhibit all their energy in either the CCW or the CW component. For example, inertial oscillations would appear as a peak in the CW spectrum (northern hemisphere) centered around the local inertial frequency. Linearly-polarized currents, which might occur near a lateral boundary or a steep topographic feature, would have equal energy in the CCW and CW components. Intermediate cases indicate elliptic polarization.

In both the Cartesian and the rotary systems, a single vector series has two component series. For a pair of vector series, there are four possible combinations of coherence (coherence squared) and phase spectra that can be computed. The rotary method groups these into "inner" and "outer" sets of two. The inner coherence and phase show the correlation between fluctuations with the same polarization, i.e., CCW with CCW (heavy line in graphs of inner phase and coherence) and CW with CW (light lines). The outer phase and coherence relate the counter-rotating pairs, i.e., CW of the first series with the CCW of the second (heavy line in graphs of outer phase and coherence) and vice-versa (light lines). Positive phase means the first series leads the second series.

In orthogonal Cartesian systems, the axes should be aligned with the axes of the principal component ellipse of the vector series. Otherwise, the two components of velocity are not independent, e.g., the cross-isobath component has along-isobath energy and vice versa. However, the coherence and phase between the components of two vector series resolved into Cartesian systems with different orientations depends on the relative orientations. The advantage of the rotary method is that coherence and phase are invariant under coordinate rotation. Our experience indicates that the rotary method will improve the signal to noise ratio when comparing velocity series from different topographic regimes. Note that both methods provide four pieces of information about spectral coherence. For the more traditional approach, two of the four are usually ignored; the along-isobath components are compared, and the cross-isobath components are compared, but usually not the along- versus cross-isobath components. With both methods, interpretation is simplified if some of the information can legitimately be ignored. Discussions of the results of spectral analyses begin in Section 10.5.

10.3 Major Events During 1988 and 1989

Large interannual fluctuations, tropical cyclones, outbreaks of intensely cold arctic air, and mesoscale intrusions of warm, salty Gulf waters are categories of events i.e., non-periodic processes, that significantly influence this continental shelf region at various times. The year of 1988 may have been unusual in that all of them did so. The signature of each one in the physical record is detectable, especially the rise in bottom temperature associated with intrusive Gulf waters. The impact on the ecosystem of numerous such physical events acting in concert is unknown. Table 10-14 summarizes the non-periodic forcing events that significantly influenced the currents and hydrography of the study area during 1988 and 1989. Tropical Storm Keith and Hurricanes Debby, Chantal and Jerry are included in the list because the effect of each one, although minimal for currents and hydrography in the study area, can be discerned in some of the data records such as wind direction and sea level. Since cooling events are a normal winter process, Table 10-14 includes only cold air outbreaks having temperatures that fell below freezing at Buoy 42015.

10.3.1 River Input

The principal large-scale weather event of 1988 was the severe drought. By summer time the Mississippi River reached near-record low levels, restricting barge and towboat traffic. The streamflows in the Alabama

Table 10-14 Summary of non-periodic events that influenced the oceanography of the MAMES region during 1988 and 1989.

Event	Time Period	Comments
Drought (Below average input to study area)	March through December 1988	May through August discharge less than 50% of long-term mean.
Loop Current Filament Intrusions onto shelf, i.e. north of 29.5°N	December 1987 January 1988 March 1988 May 1988 February 1989 March 1989 May 1989	Based on analyses of satellite images presented in Chapter 11. Surveillance suspended June through September 1988 and terminated June 1989
Loop Current-related waters north of 29°N	mid-November 1987 to mid-January 1988 (mid-November 1988)* January to mid-March 1989 mid October-mid December, 1988** early July 1989** late September 1989** early February 1990**	*Falls slightly below two degree criterion given in Chapter 11. **Based on analyses of temperature data recorded by current meters CM, CB, EM and EB
Tropical Storm Beryl	August 8 - August 10, 1988	Formed from low pressure area off Louisiana. Maximum, sustained, one-minute wind was 50 mph on August 9. Heavy rains along Gulf Coast.
Hurricane Debby	August 31 - September 5, 1988	Formed in Bay of Campeche, moved westward, 75 mph winds.
Hurricane Florence	September 7-11, 1988	Formed in south-central Gulf, made landfall over southeastern Louisiana. Maximum sustained wind was 80 mph.

Table 10-14. (cont'd)

Event	**Time Period**	**Comments**
Hurricane Gilbert	September 8-19, 1988	Formed off African Coast, made landfall near Cozumel mid-day on 14th as category 5. Moved over southwest Gulf and made final landfall late on 16th as category 3 hurricane. Large hurricane with sustained wind of 67 mph at South Padre Island. Effect clearly evident in study area in sea level and current meter records.
Tropical Storm Keith	November 17-24, 1988	Formed in Caribbean, path curved clockwise from Yucatan to Florida
Hurricane Chantal	July 30-August 3, 1989	Formed off northwestern Yucatan peninsula, moved northward to make landfall near High Island, Texas, on August 1. Maximum sustained wind of 80 mph.
Hurricane Hugo	September 10-22, 1989	Crossed Puerto Rico on 18th. Made landfall near Charleston, South Carolina on 21st.
Hurricane Jerry	October 12-16, 1989	Formed over Bay of Campeche and made landfall on Galveston Island. Maximum sustained winds of 85 mph.
Cold air outbreaks with freezing air temperature	February 7, 1988 February 12, 1988 February 24-25, 1989 December 16, 1989 December 22-25, 1989	Average air temperature in study area above normal for February 1989 The coldest outbreak of any December during this century.

and Tombigbee Rivers were also unusually low. Figure 10-6 shows the daily streamflow for the Mississippi (Tarbert Landing), Alabama, and Tombigbee Rivers for 1988 and 1989. Note that the scale for the Mississippi River flow is an order of magnitude greater than that for the other two. There is some visual correlation between the short period fluctuations that modulate the main Mississippi signal and the peaks in the streamflows of the other two. This is to be expected, because large scale weather systems frequently pass over portions of all three drainage basins. The Alabama and Tombigbee Rivers are the main components of the Mobile River. The majority of its discharge reaches the shelf via the Mobile Ship Channel, but up to one-fifth enters the MAMES area through tidal passes farther west (Vittor and Associate 1985) The percentage of the Mississippi discharge that reaches the shelf, carrying nutrients and sediment to the shelf ecosystem, is unknown. Scruton (1956) estimated that about 65% of the discharge from the Mississippi Delta consistently flows onto the Texas-Louisiana shelf. Satellite images (Chapter 11) suggest that much of the remaining 35% is entrained in the flows of mesoscale Gulf circulation systems and carried southward, away from the shelf, or eastward along the shelf slope. However, the magnitude of the Mississippi flow is large enough that even a small fraction of the 35% would be a major source of fresh water for the shelf portion of the study area.

Figure 10-7 demonstrates the impact of the drought. The heavy line shows the monthly mean Mississippi streamflow for the period 1930 through 1988. The other three lines show monthly means for the individual years of 1987, 1988 and 1989. Flow was below normal for most of 1987 and from February through November 1988; in June and July it drops to 32% of the long term mean. It is assumed that the mean discharges for the rivers of the Mobile River System during 1987 and 1988 were similarly below their long term means, given the degree of visual correlation between the Mississippi, Alabama and Tombigbee flows in Figure 10-6. The effect of the drought on the hydrography and possibly the ecosystem is noted in the discussions in the sections that follow.

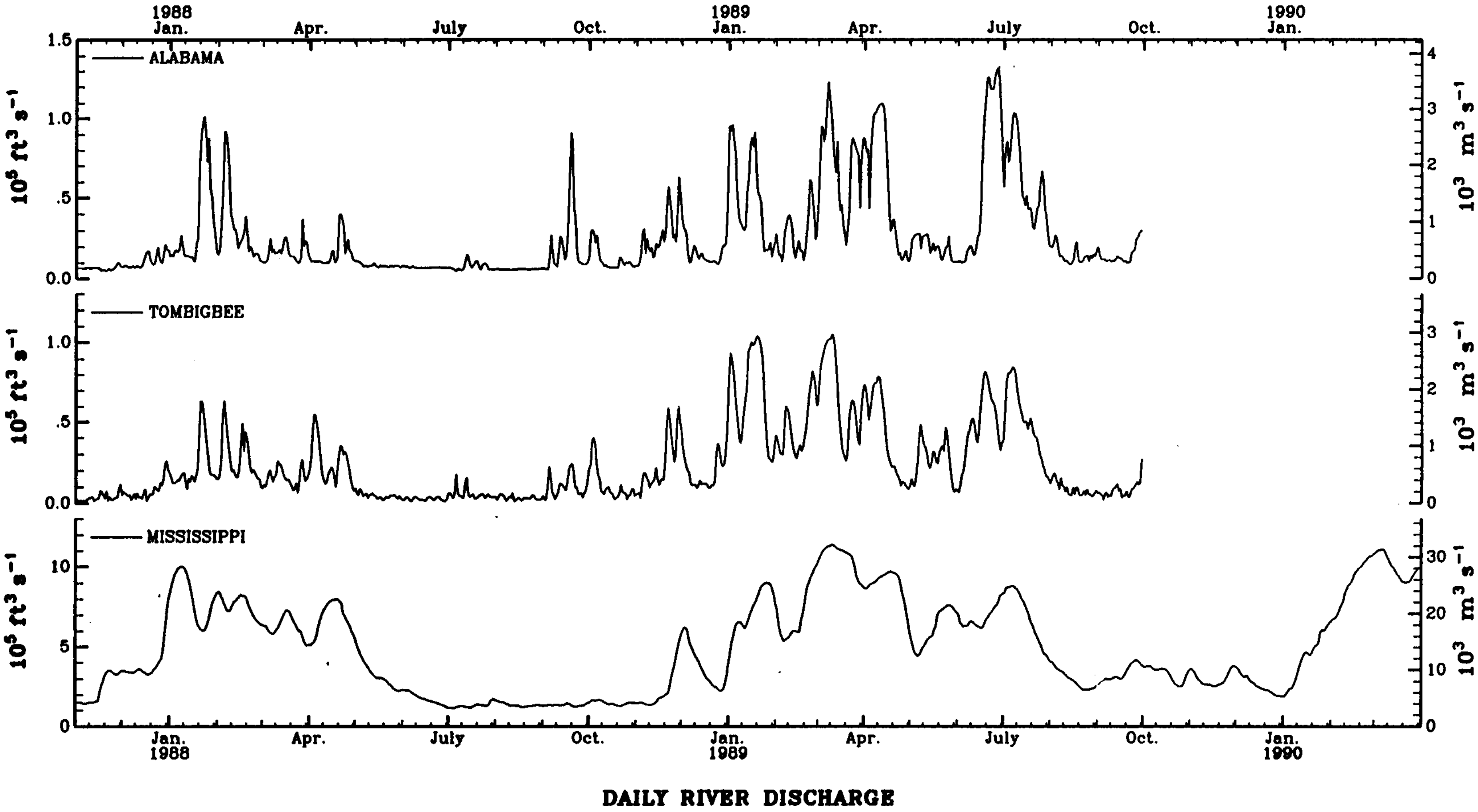


Figure 10-6. Daily river discharge for the Mississippi (Tarbert Landing), Alabama and Tombigbee Rivers for 1988 and 1989. Note that the scale for the Mississippi River flow is an order of magnitude greater than that for the other two.

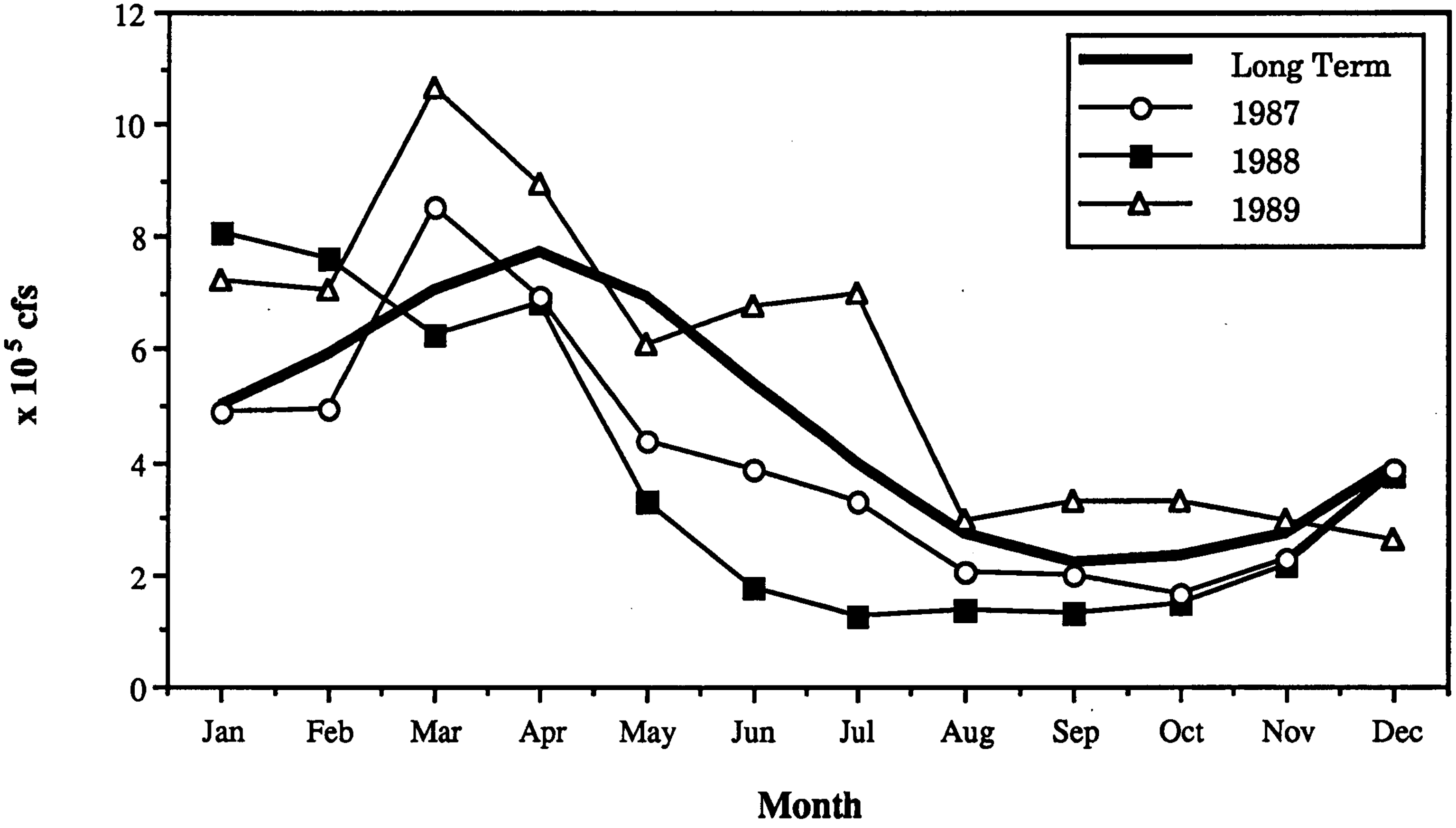


Figure 10-7. **Monthly long term mean Mississippi River flow for the period 1930 through 1988 (heavy line)** together with monthly means for the years 1987-1989.

10.3.2 Intrusions by Loop Current Filaments

It appears that we can classify into three different patterns the way northward intrusions of the Loop Current, or filaments and eddies derived from it, interact with the waters over the continental slope and shelves of the northeastern Gulf. In the first one, filaments push up the axis or the east side of DeSoto Canyon. The canonical example is that described by Huh *et al.* (1981), in which a filament moved up DeSoto Canyon to within a few miles of the coast. They suggest that topographic steering influences might cause the canyon to be a preferred path for intrusive filaments. In Chapter 11.0, Vastano *et al.* show other examples of this pattern (e.g. Figures 11-2 and 11-32) and the MAMES AVHRR image archive in Appendix E. An intrusion up DeSoto Canyon can influence the shelf waters of the MAMES area if it or submesoscale eddies developed from it expand westward, as in the case described by Huh *et al.* (1981). On the other hand, such intrusions can leave the MAMES area relatively unaffected. For example the only evidence in the moored data of the intrusion up the canyon that occured in late December, 1988 (see Section 11.3.6 and Figure 11-32.) is an increase in temperature at CM.

The second pattern of interaction is direct entrainment of outer shelf water into the northern periphery of the Loop Current or an eddy or filament derived from it. In this case the Loop Current related circulation features are located off the shelf in deep water. Such a pattern was suggested by drift bottle studies (Tolbert and Salsman 1964; Murphy *et al.* 1975; Williams *et al.* 1977; Parker *et al.* 1979). Schroeder et al. (1987) describe examples of this pattern through a careful deductive analysis of five different cases of the movement of buoys that broke free of moorings on the Alabama inner shelf and available information about wind velocity, surface salinity, river discharge and Loop Currrent position. In Chapter 11.0 Vastano *et al.* elaborate on the details of the entrainment processes, which include the seaward movement of cooler shelf waters along the eastern side of anticyclonic features, the trapping of shelf waters and Mississippi River outflow into the centers of eddies that lie off the shelf, and the eastward advection of water masses over the slope.

The third pattern involves the penetration onto the shallow shelf of diluted Loop Current related waters. Both Cruise B2 (March 10-18, 1988) and Cruise B4 (February 11-18, 1989) were conducted during periods of intrusions of Gulf water onto the shelf, providing hydrographic data that complement the data from satellite thermal imagery and moored instruments. Figure 10-8a shows the subjectively contoured, surface temperature field based on the data collected during Cruise B2. Figure 10-8b shows the satellite IR image for 2110 hours (GMT) March 13, 1988, while Figure 10-8c shows the temperature and salinity time-series records collected during March by the bottom current meter at Mooring A, located 3 m above the bottom in 31 m of water. A plume of Gulf water, characterized by higher temperature, salinity and dissolved oxygen values throughout the water column, pushed onto the western portion of the shelf and wrapped clockwise to the northeast. A southwestward return flow, with opposite water mass characteristics, was located east of the plume. The plume reached current meter Site A briefly on March 11 and then for an extended period beginning March 15. Bottom temperature rose abruptly by more than 2 C and salinity by about 1 PSU. Maps of the fields of bottom temperature and salinity collected during Cruise B2 (Section 10-9) also demonstrate that the intrusion's water mass reached the bottom. Clearly, an intrusion of Gulf water onto the shelf can displace a major portion of the shelf water and can dominate the shelf circulation for periods of days to a week or more. The intrusion also appears to have promoted the flushing of the inner shelf, which would exacerbate the effects of below normal river discharge by reducing the residence time of nutrient bearing river waters on the shelf.

The February 1989 case is an example of a more limited intrusion in terms of horizontal and vertical extent. Figure 10-9a shows the surface temperature field observed during Cruise B4, and Figure 10-10a is a satellite image for February 16, 1989 that confirms the subjectively contoured temperature field observed during the cruise. A filament moved onto the shelf near Stations M3 and M4 and pushed almost as far as Stations C1 and M1. Cool shelf water moved southward on the east side of the filament. Higher salinity values were associated with the warmer water, while the cooler southward moving water was much fresher. The bottom temperature

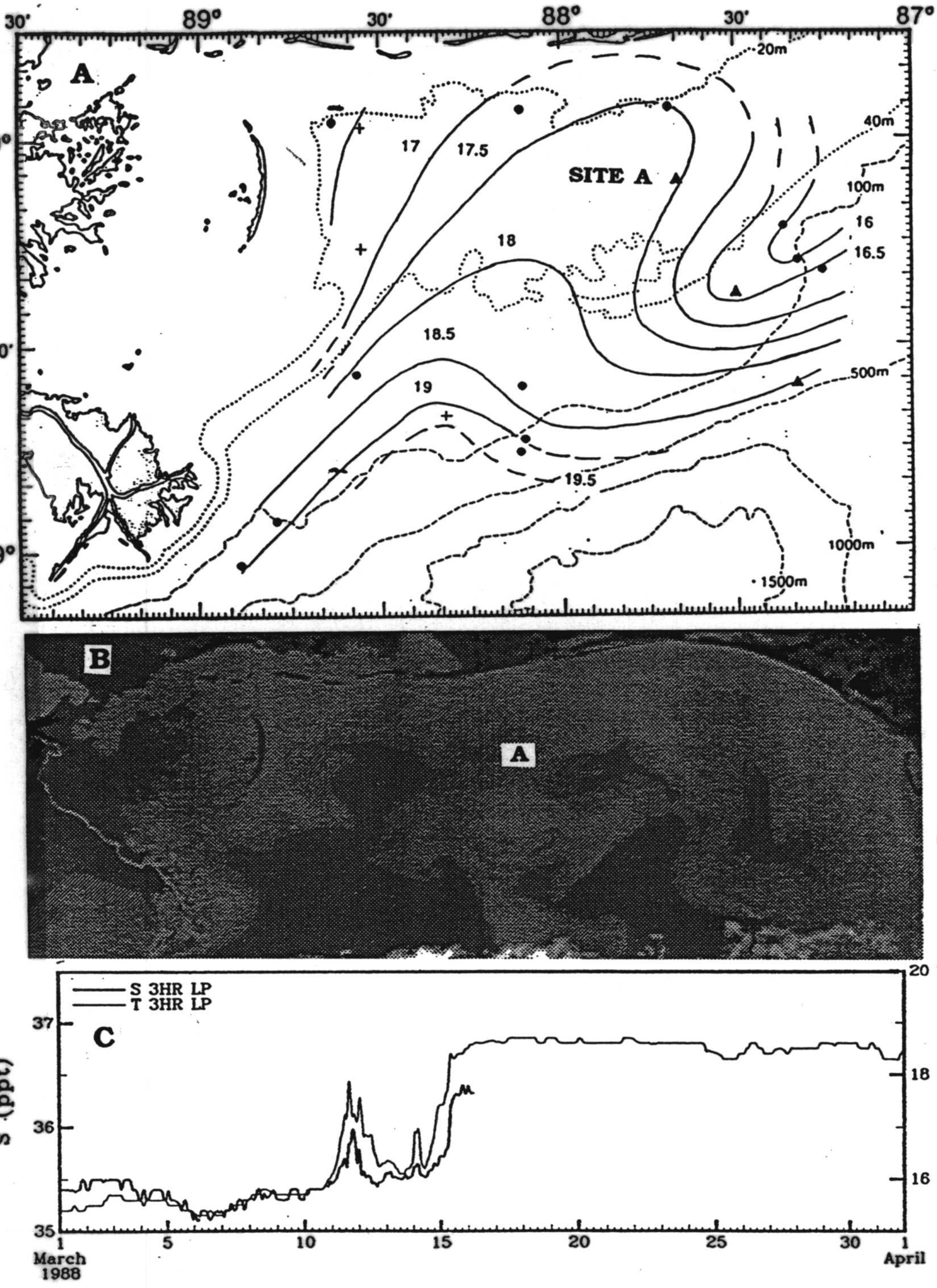


Figure 10-8. a) Surface temperature field based on Cruise B2 (10-18 March 1988); b) satellite IR image for 2110 hours GMT, 13 March 1988, darker regions correspond to warmer water; c) temperature (light line) and salinity recorded by bottom current meter at Mooring A.

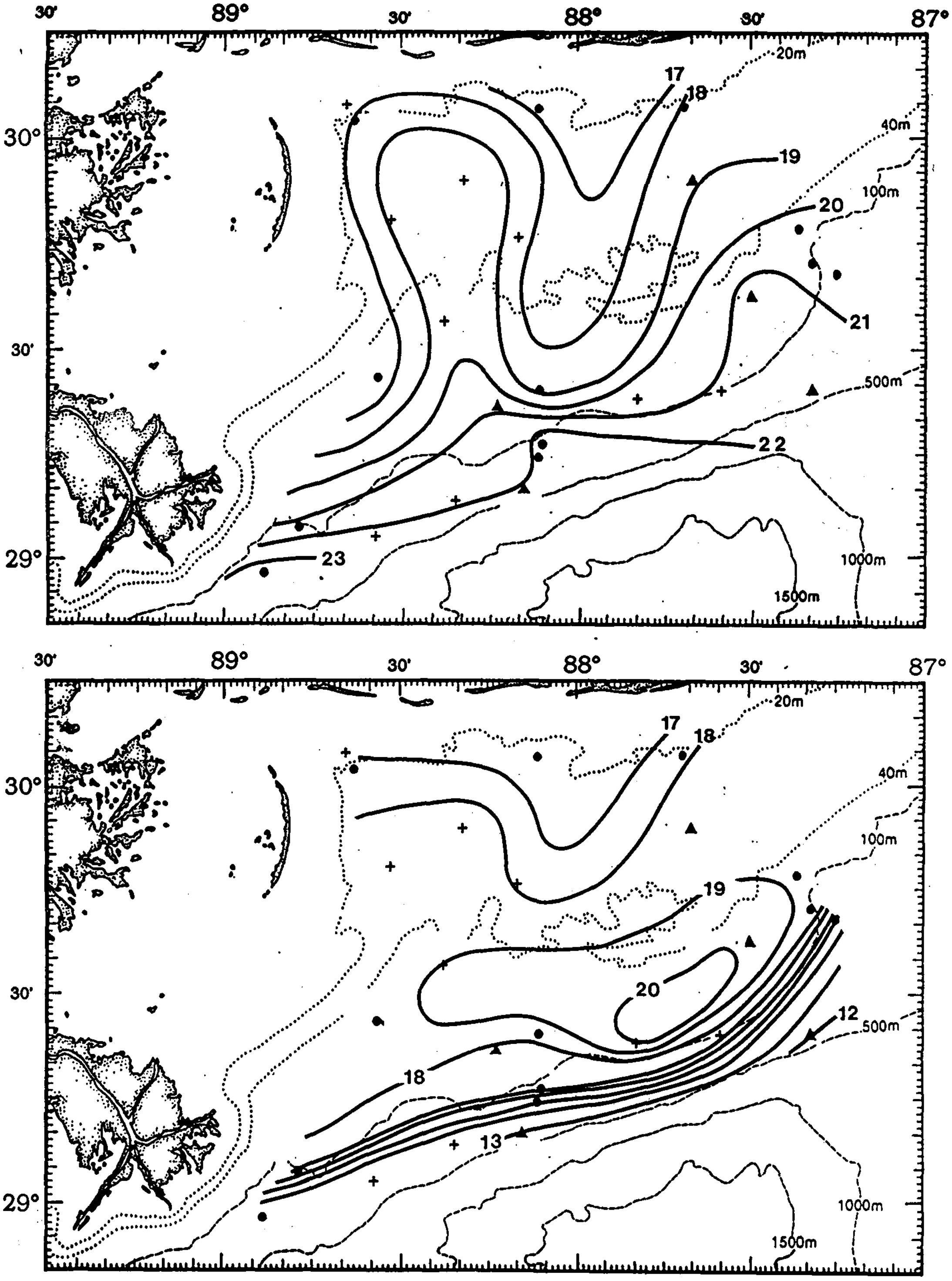
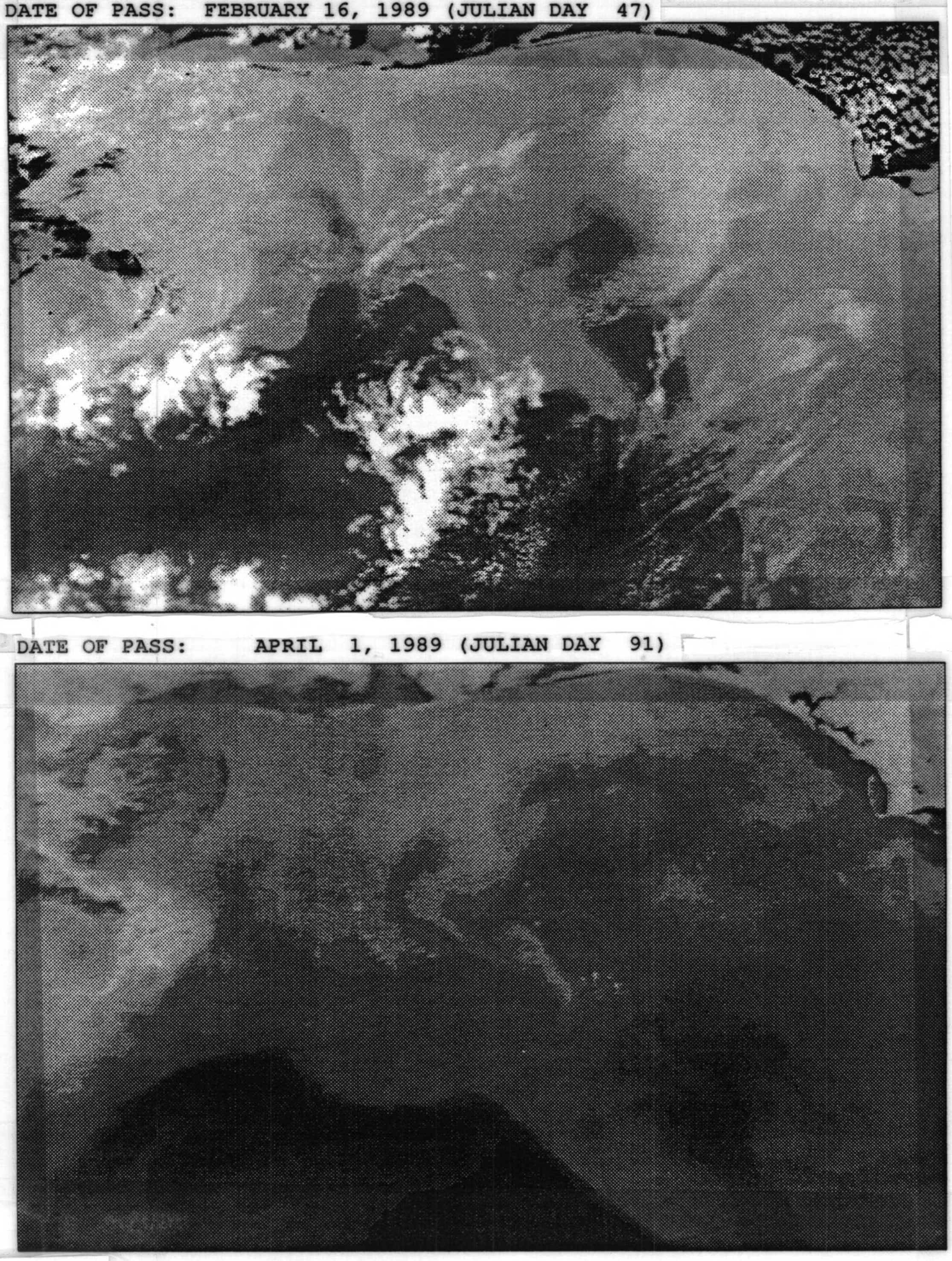


Figure 10-9. **a) Surface and b) bottom temperature fields observed during Cruise B4 (11-18 February 1989).**

Figure 10-9



DATE OF PASS: FEBRUARY 16, 1989 (JULIAN DAY 47)

DATE OF PASS: APRIL 1, 1989 (JULIAN DAY 91)

Figure 10-10. Satellite IR images taken on a) 16 February 1989; b) 1 April 1989. Warmer temperatures are darker.

field derived from the cruise data (Figure 10-9b) does not show the the intrusion of warmer water found in the surface field (Figure 10-9a), however, the temperature and salinity recorded by the DB current meter are markedly elevated during the period February 15-18 (see February 1989 plot for DB in Appendix C).

In both of the above cases, currents recorded at Moorings A, B and D were normal in magnitude (see the appropriate monthly plots in Appendix C). It appears that intrusions onto the shelf force the exchange of large amounts of mass and water properties between the shelf and open Gulf, but they do not necessarily transfer much momentum to the shelf waters.

The two cases of intrusions have similar spatial scales over the shelf. Their widths (east-west) are on the order of 30-45 km, as are the widths of the cooler southward return flows. In both cases warm water also pushes up DeSoto Canyon east of the cooler southward flow, again with a width scale of 30-45 km. Their spatial scales are small enough that they could have gone undetected by the single current meter array deployed during the first year or, during the second year, slipped between the two arrays, which were about 85 km apart.

All three types of intrusive interactions can occur simultaneously. Figure 10-10b portrays the AVHRR image for April 1, 1989, in which one can see the northern boundary of the Loop Current proper, two small filaments pushing onto the shelf, and a warm filament moving up De Soto Canyon. Cooler shelf water moves seaward and is entrained and mixed with the warmer water. It should be noted that during this period the Loop Current was in the process of forming Nelson Eddy, an unusually large anticyclone that subsequently migrated westward and played havoc in July and August, 1989, on drilling operations throughout the Green Canyon, Ewing Banks, Mississippi Canyon and Ship Shoal offshore lease areas, which were struck by two to three knot surface currents (Huh and Schaudt 1990).

Figure 10-11 shows a set of simple cartoons to summarize the three categories of Loop Current and/or eddy interaction with the MAMES shelf. The first (Figure 10-11a) is a filament that extends up De Soto Canyon. The main portion of the MAMES shelf is unaffected except for possible entrainment at the eastern end of the shelf and strong currents over the slope. In the second category (Figure 10-11b), either a filament or the Loop

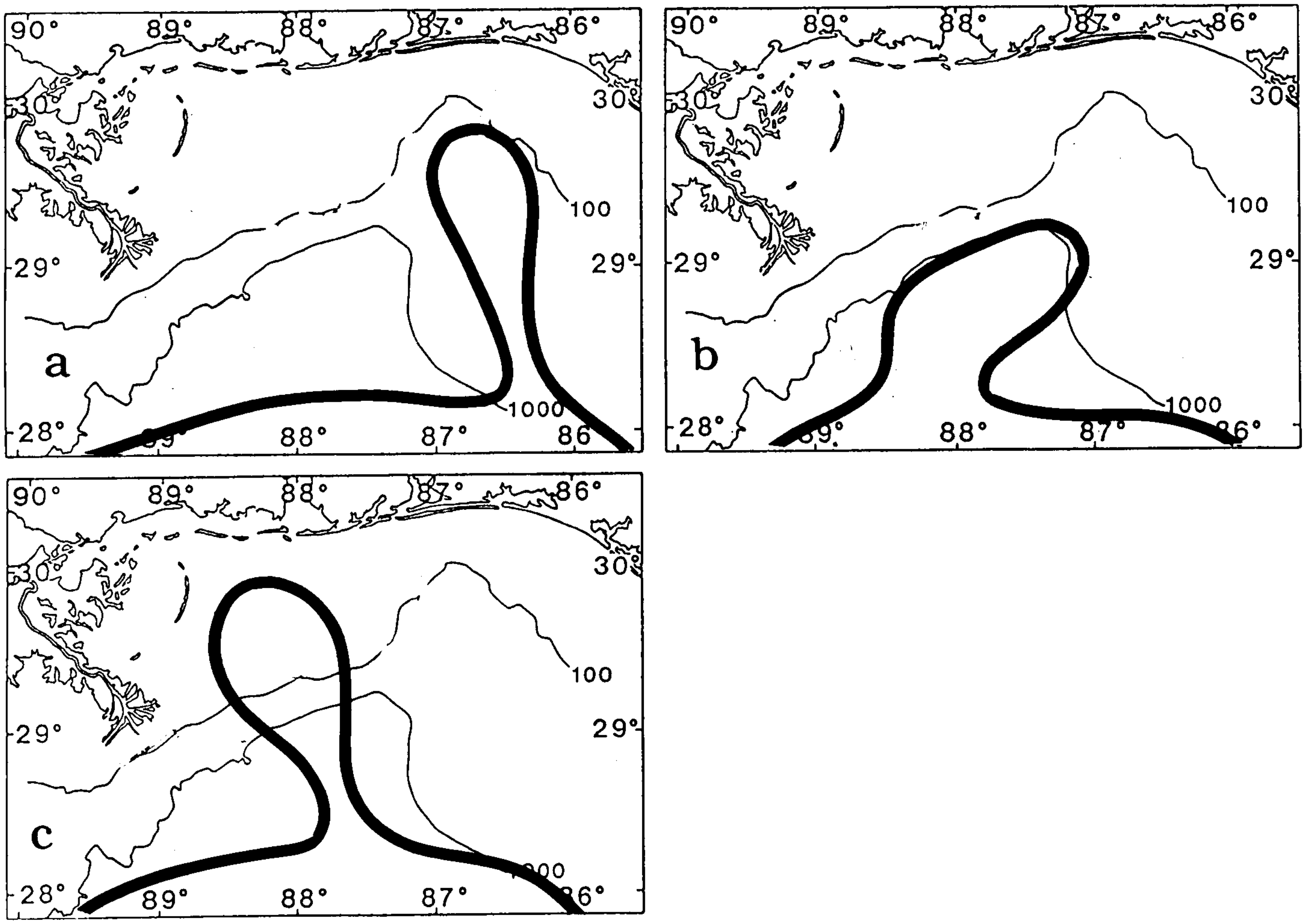


Figure 10-11. Simple illustrations of the categories described in the text of Loop Current/filament interactions with the MAMES study region: a) interaction at eastern end of study region with intrusion up De Soto Canyon; b) entrainment of shelf waters by Loop Current filament over continental slope; c) intrusion of filament into shallow shelf region. (Base map adapted from Dinnel (1988).

Current proper pushes northward but not far enough to extend up De Soto Canyon or onto the shelf. The principal effect in this case, therefore, is to entrain water from the outer shelf or slope into the eastward flow that occurs on the northern side of the Loop Current feature and drive strong slope currents. The third category (Figure 10-11c) involves a filament that actually extends northward past the 200 m contour and onto the shelf. The effect is the displacement of a major portion of the shelf water and a domination of the shelf circulation for periods of days to a week or more. Although the third category of entrusion forces the exchange of large amounts of mass and water properties between the shelf and open Gulf, it does not appear that much momentum is transferred to the shelf waters, i.e., although filaments that extend onto the shelf alter the circulation, they do not necessarily drive high velocities.

The satellite image sequence gathered during 1987-1989 indicates that filaments or plumes that extend northward from the Loop Current are a frequent and persistent influence on the Mississippi/Alabama continental shelf, and that pathways are not restricted to the axis of DeSoto canyon. Vastano et al. (Chapter 11) define the northern extreme of Loop Current intrusions based on continuity with the Loop Current and/or an intrusion-Loop Current temperature difference of less than two degrees. They find that intrusive warm waters pushed north of 29.5° N, which would be on the shelf, in December 1987, January, March and May, 1988, and February, March and May 1989. (Note: the Latitude of Mooring B is 29° 37.45' N.) Furthermore, Loop Current-related waters were persistently north of 29° N, i.e., near the continental slope, from mid-November, 1987, to mid-January, 1988, and from January to mid-March 1989. They also note that Loop Current filaments can meander hundreds of kilometers northward from the northern side of the main body of the Loop Current and that the location of the Loop Current proper is not a reliable indicator of the potential for intrusions onto the shelf because filaments can travel such considerable distances.

At present satellite imagery is the most direct and reliable means to describe and quantify Loop Current related interactions with the shelf waters of the MAMES area. Although the analysis presented in Chapter 11 found warm intrusions to be frequent, an exact count for the whole study period cannot be made by thermal imagery because intermittent cloud cover and relatively isothermal sea surface conditions during July through September interrupt the continuity. We attempted to supplement the search for intrusive events by studying the 40-hour low passed time series of adjusted sea surface elevation at Dauphin Island and water temperature recorded at 150 m and 426 m at Moorings C and E during the periods 1 January 1988 through 31 January 1989 (Figure 10-12) and 1 February 1989 through 28 February 1990 (Figure 10-13).

Sea surface elevation at the coast was examined because Dinnel (1988) estimated terms in the barotropic cross-shelf momentum balance and found the cross shelf pressure gradient to be large and unbalanced at times, and also because of the cases in which intrusions approached relatively close to the coast. As expected, however, sea surface elevation at the coast proves not to be a useful indicator of intrusions because they are primarily baroclinic phenomena, having short length scales corresponding to the baroclinic, i.e. internal, Rossby radii of deformation. Intrusions over the slope are too far from the coast to influence sea surface elevation there, while the ones that penetrate onto the shelf do not carry much momentum.

Schroeder and Wiseman (1985) found that the normal annual cycle of low-frequency (periods of one to three months) sea surface elevation at Dauphin Island follows a pattern of low-high-low-high-low. During January and February northerly winds and low water temperatures depress sea level; during March through May onshore winds, river discharge and thermal expansion raise sea level; during June through August upwelling favorable winds transport surface water offshore and depress sea level despite thermal expansion; during September and October winds switch to downwelling favorable and thermal expansion continues through September; and during November and December there is a return to winter conditions to complete the cycle. They stress that interannual variability of the processes that affect sea level can result in sea level records that differ substantially from the "uneventful" or normal cycle. Neither 1988 or 1989 were normal, particularly 1988. Winter water temperatures were lower than normal in 1988 and 1990 and higher than normal in 1989; river runoff was significantly below average in 1988 and somewhat above average in 1989; mean winds were not upwelling favorable during the summer of 1988;

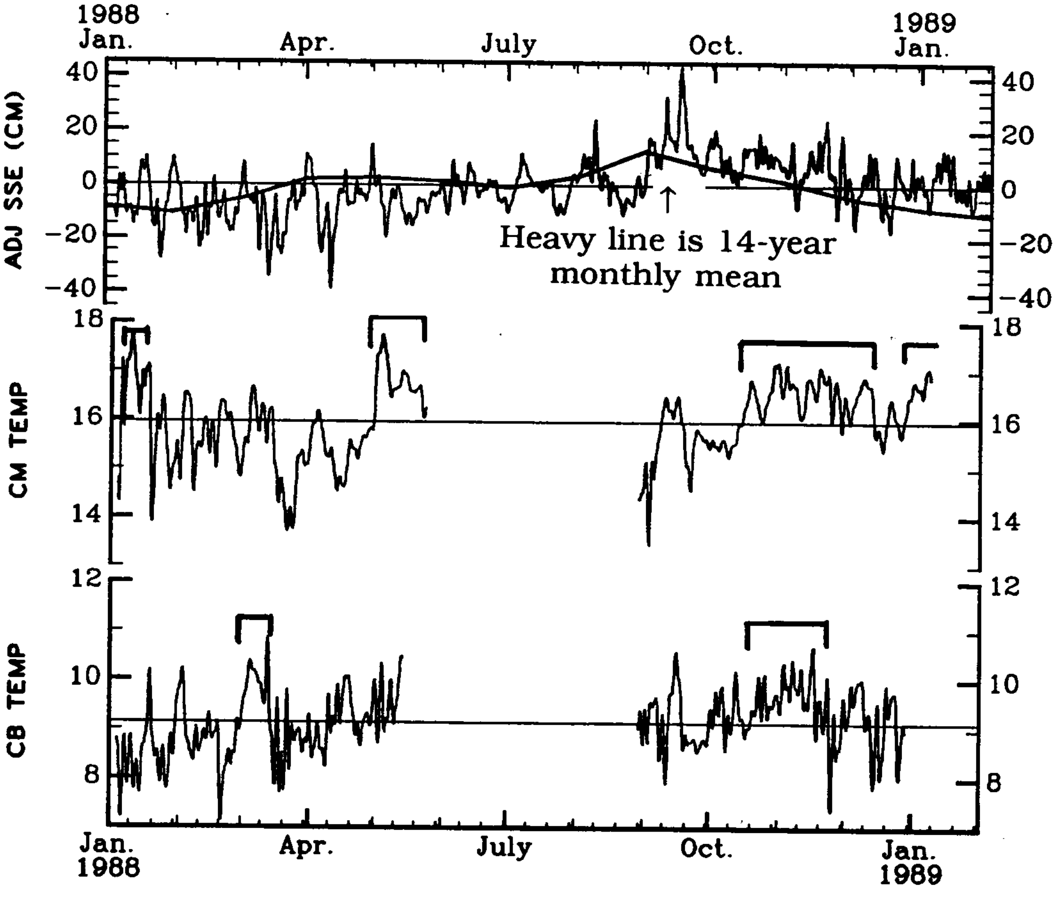


Figure 10-12. **January 1988 to January 1989. 40-hour low passed** times series of (a) adjusted sea level at Dauphin Island and temperature at (b) CM, (c) CB. The horizontal brackets indicate periods during which temperature changes are attributed to Loop Current related intrusions.

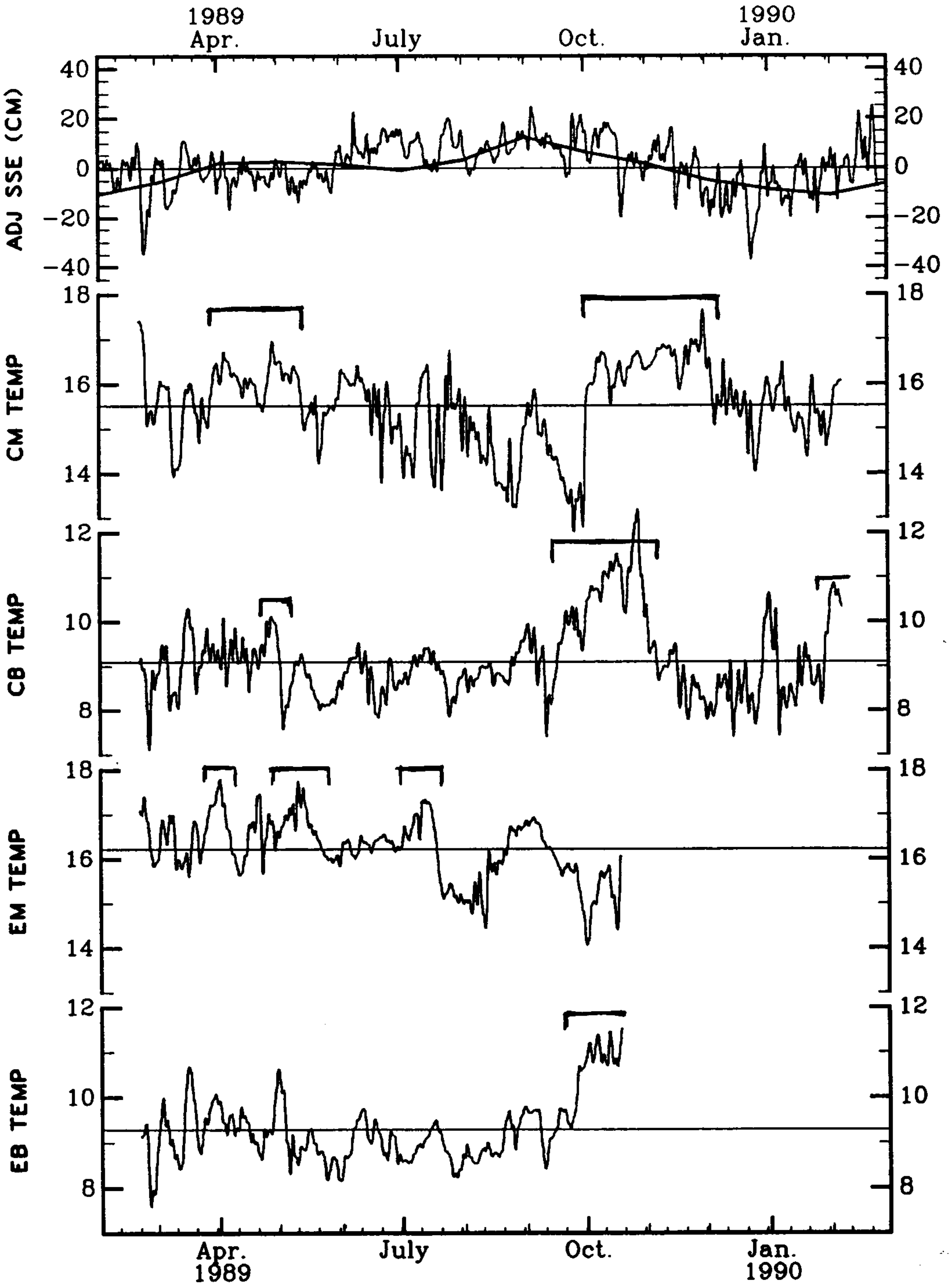


Figure 10-13. **February 1989 to February 1990. 40-hour low passed** time series of (a) adjusted sea **level at** Dauphin Island and temperature at (b) CM, (c) CB (d) EM, (e) EB. The horizontal brackets indicate periods during which temperature changes are attributed to Loop Current related intrusions.

and there were several tropical storms and a hurricane in the Gulf in September of 1988. The effect of each of these is evident in the deviation of the sea level curves in Figures 10-12a and 10-13a from a normal annual cycle based on long term monthly means (heavier curves in Figures 10-12a and 10-13a). Fourteen-year monthly means were computed by averaging monthly mean data for the years 1967, 1968, 1971-1974, 1976-1980, 1982 and 1988, which were obtained from NOS.

From the satellite analysis, intrusive warm waters were found on the shelf in January, March, and May, 1988, and February, March, and May, 1989. The specific dates of satellite images that indicated intrusive warm waters were compared with the time-series plots of water temperature recorded at 150 m and 426 m at Moorings C and E. To evaluate the magnitude of temperature changes at depth associated with the intrusions, the mean temperature at each instrument location for each of the two periods was computed using the available data for the period. These means are ploted as solid horizontal lines in figures 10-12b,c and 10-13b,c,d,e. There is clearly a rise in temperature above the mean at either 150 m or 426 m depths during the intrusions. In some cases, such as January, 1988, the increase occurs at 150 m, while in others it is more apparent at 426 m, e.g., March 1988. The satellite analysis also found the sustained presence of Loop Current related waters over the slope from Mid-November 1987 to Mid-January, 1988, and from January to mid-March, 1989. The individual images (Appendix E) suggest that Loop Current related waters also approached the slope during November and late December, 1988, but these intrusions are not included in the list given in Chapter 11 because they do not quite meet the objective criteria chosen by Vastano et al. Again, there is a clear rise in the temperature in one or more of the temperature records in Figures 10-12 and 10-13 during the times the intrusions approached the slope.

Loop Current related intrusions appear to have periods of influence that last from about ten days to months. A visual inspection of Figures 10-12 and 10-13 shows that when the temperature of the deep slope water rises at these time scales, there is no consistent correlated change in the sea level at Dauphin Island. There does appear, however, to be correlation at shorter periods in the synoptic band of about two to ten days. The correlation between deep temperature over the slope and sea level is further explored by spectral analysis in Section 10-5.

It appears that every intrusion counted in the census by satellite corresponds to a significant temperature increase lasting ten or more days at the middle or bottom current meters on the slope. Therefore, we attempt to augment the census of intrusive events by defining the following objective criterion as an indication of the presence of an intrusion: a temperature rise above the mean indicated in Figures 10-12 and 10-13 that persists for at least ten days and reaches a peak value that exceeds the mean by at least one degree. The horizontal brackets in the Figures indicate their periods that meet the criterion. Table 10-15 summarizes the periods during which intrusions were present and the data sets that indicate the presence. When the indications in the various records overlap, the total period covered by the overlapping times is counted as a single intrusive period, e.g., March 22 to May 20, 1989. Either multiple filaments or the movement of a single filament could cause this effect. The combination of satellite imagery and temperature data at Moorings C and E covers two periods: from October 5, 1987 through June 30, 1988 and from August 30, 1988 through February 8, 1990, a total of about 798 days. Intrusions are found during 11 periods of time, totaling about 355 days, or about 44 percent of the time. The longest and most dramatic period is the 75-day span from September 18 through December 1, 1989, during which the temperature at CB rose 3.4° C above the mean.

Cold excursions are also evident in the temperature records from the slope. By the definition of "mean", the total area between positive excursions of a temperature curve and the mean value must equal the total area associated with negative ones. However, fewer of the negative excursions meet the the mirror image of the event criterion given above, failing either the minimum duration or amplitude limits. Clear exceptions are the cold events preceding the warm ones associated with the September 18 through December 1, 1989 intrusion period. These very strong cold perturbations are probably caused by a cold-core cyclonic feature on the periphery of the warm intrusion, but we have no direct evidence of such a feature. Smaller cyclonic features are usually found around the periphery of Loop Current filaments and eddies and are thought to be dispersion

Table 10-15. Periods during which warm intrusions were present and the data sets that indicate their presence.

	No. Days	S	H	CM	CB	EM	EB
Nov. 15, 1899 - Jan. 7, 1988	54	X					
Jan. 8-19, 1988	12	X		X			
Mar. 1-15, 1988	15	X	X		X		
May 1-22, 1988	22	X		X			
Oct. 18 - Dec. 13, 1988	57			X	X		
Dec. 28, 1988 - Jan. 10, 1989	14	X		X			
Feb. 9-25, 1989	17	X	X			X	
Mar. 22 - May 20, 1989	60	X		X	X	X	
Jul. 1 - Jul. 18, 1989	18					X	
Sep. 18 - Dec. 1, 1989	75			X	X		X
Jan. 29 - Feb. 8+, 1990	11				X		

S = satellite AVHRR image
H = hydrographic cruise
CM = temperature recorded at 150 m at Mooring C
CB = temperature recorded at 426 m at Mooring C
EM = temperature recorded at 150 m at Mooring E
EB = temperature recorded at 426 m at Mooring E.

products related to the decay of the eddy or the interaction of the eddy with topography (SAIC 1988, 1989). Cyclonic dispersion products are another way in which energy from the Loop Current source can reach the conceptual boundary between the open ocean and the shelf-slope systems and need further study to determine if they too should be included as Loop Current related features that affect the MAMES area.

10.3.3 Meteorological Events

Tropical Storm Beryl and Hurricanes Debby, Florence and Gilbert influenced the currents and hydrography of the region to varying degrees during 1988. Beryl began as a low level circulation on August 4, 1988, organized into a depression on the 7th over southeastern Louisiana, and was upgraded to a tropical storm on the 8th after drifting back to the Gulf coast (Lawrence 1989). Beryl reversed direction on the 9th and then dissipated over southern Louisiana. The monthly plots for August in the Appendix Volume show that currents at AT were low until the 9th when they became northeastward at about 25 cm s^{-1} for a day. At BT currents were directed southeastward, i.e., offshore, at about 20 cm s^{-1} from August 4-8, and then became eastward at 30 cm s^{-1} during the 9th. Bottom currents at Mooring B remained less than 10 cm s^{-1} throughout the life of Beryl, but at AB they jumped to about 25 cm s-1 for 12 hours on the 9th. Although Beryl dumped heavy rains along the coast, its duration was too short to affect either river runoff (Figure 10-6) or salinity at the 10 m depths of AT and BT (Appendix C). Beryl also forced a 25-cm peak in the 40-hour low passed sea level record for Dauphin Island

September 1988 was an interesting month for the Gulf of Mexico because of Hurricanes Debby, Florence and Gilbert. Their effects on the shelf waters in the MAMES region are illustrated by data collected at Mooring B (Figure 10-14). The time of landfall for each hurricane is indicated in the figure by a downward arrow. Hurricane Debby, the first hurricane of the season, with 33.5 m s^{-1} winds (75 mph), became a tropical depression over the Bay of Campeche on August 31, and made landfall near Tuxpan, Mexico early on September 3rd (Lawrence 1989). Currents at BT during the first three days of September were normal, about 10-20 cm s^{-1}.

A strong 15 m s^{-1} impulse of southward wind late on September 4th (Figure 10-15) set off strong inertial oscillations in the currents at BT that can be seen in the 3-hour low pass filtered currents (light lines in the middle two frames of Figure 10-14). It also produced a rise in sea level (Figure 10-12). The wind impulse was probably a local storm event; its relation to Hurricane Debby in the Bay of Campeche, if any, is not clear.

Florence, a small hurricane with 35.8 m s^{-1} winds (80 mph), formed in the south central Gulf on September 7, headed due north and made landfall just west of the Mississippi Delta early on September 10 (Lawrence 1989). Beginning late on the 9th currents at BT jumped to southwestward at 75 cm s^{-1} and then shifted to northeastward at 15 cm s^{-1} as the northern and then south sides of the counterclockwise rotating cyclone passed over the study area (Figure 10-15). The background 40-hour low passed current was about 30 cm s^{-1} at the time, so the currents at BT underwent a fluctuation that had an amplitude of 45 cm s^{-1} about the background current. During the peak southwestward flow, sea level (Figure 10-12) rose to its second highest value in the 26-month record.

Of all the storms, Gilbert had the greatest impact on the MAMES region despite its southern Gulf track. Gilbert formed in the Atlantic, became a hurricane in the Caribbean Sea, and made landfall near Cozumel midday on September 14 as a category five hurricane (Lawrence 1989). It then moved northwestward across the Yucatan Peninsula and the southwest Gulf, making landfall near La Pesca, Mexico late on the 16th (Lawrence 1989). Figure 10-16 shows 40-hour, low pass filtered stick vectors for all the current velocity data collected during September through December 1988. During the period that Gilbert was in the Gulf, the currents at Moorings B and C flowed southwestward at all depths. Late on the 15th sea level rose to the highest level recorded during the 26-month record (Figure 10-12) and all current meter records except BT reached peak speeds. At Mooring B unfiltered current speeds reached 35 cm s^{-1} at BB on the 15th, but at BT the peak speed of 80 cm s^{-1} was not reached until the 18th. Since the winds observed at Buoy 42015 were not unusually strong during Hurricane Gilbert (Figure 10-15), the response in the MAMES region was partly a result of basin scale horizontal pressure gradients set up by Gilbert.

Water temperature at BB (Figure 10-14e) rose during September

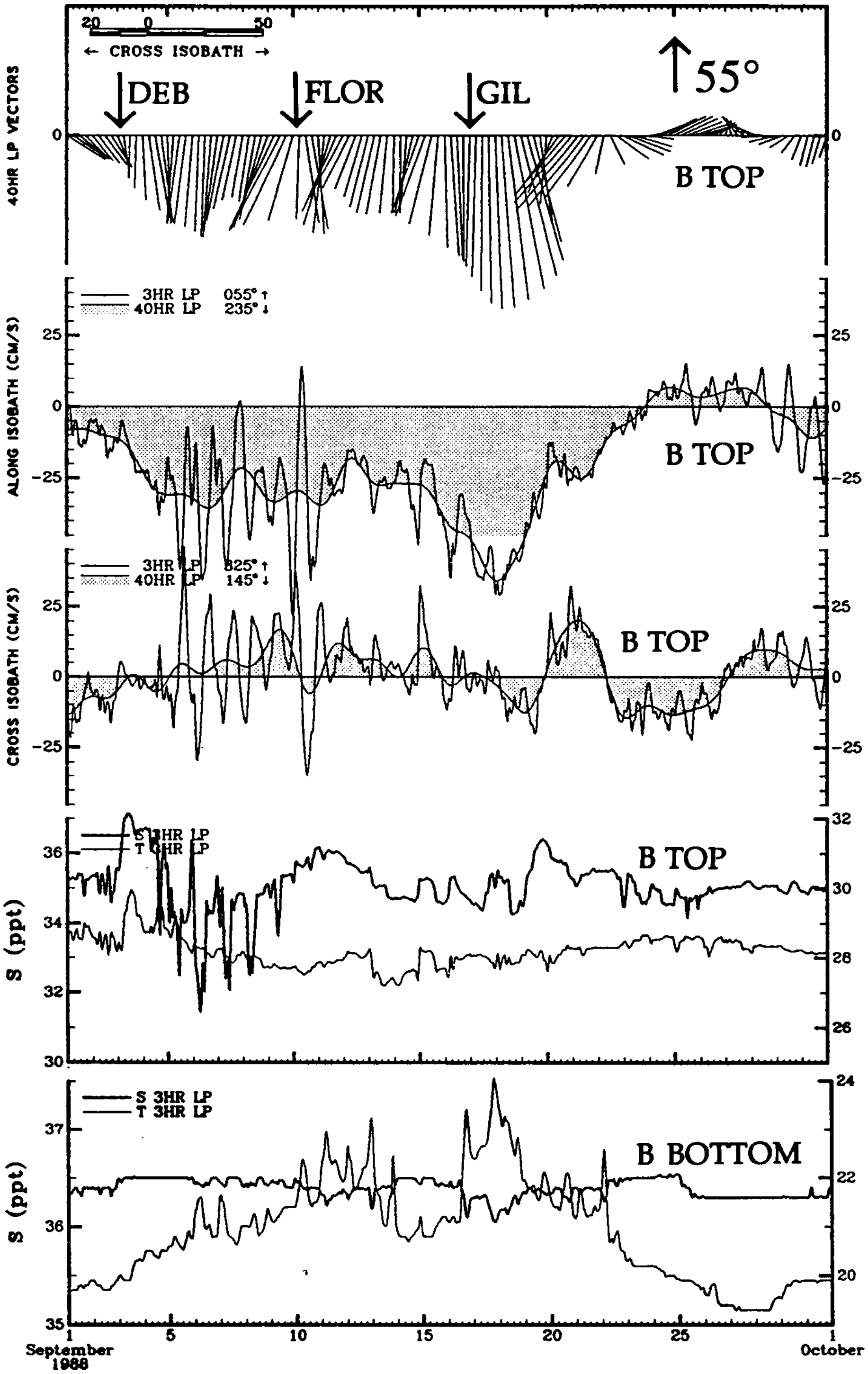


Figure 10-14. September 1988 time series recorded by the current meters at BT and BB. From the top of page: 40-hour low passed vectors at BT, 8- and 40-hour low passed components at BT, 3-hour low passed temperature and salinity at BT and BB.

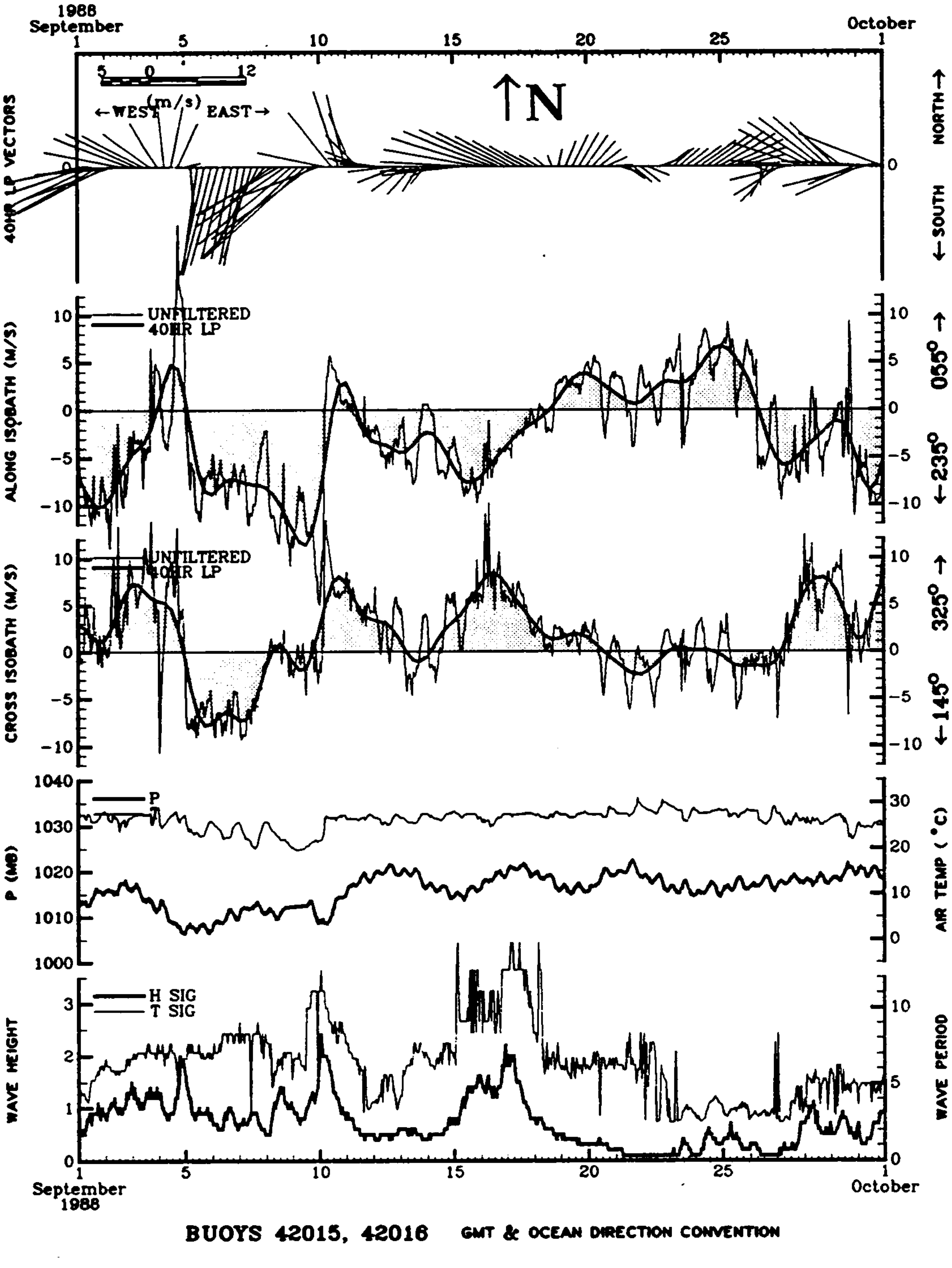


Figure 10-15. September 1988 time series recorded by meteorological Buoy 42015: 40-hour low passed vectors, 3- and 40-hour low passed components, 3-hour low passed air temperature and air pressure and original hourly wave height and period.

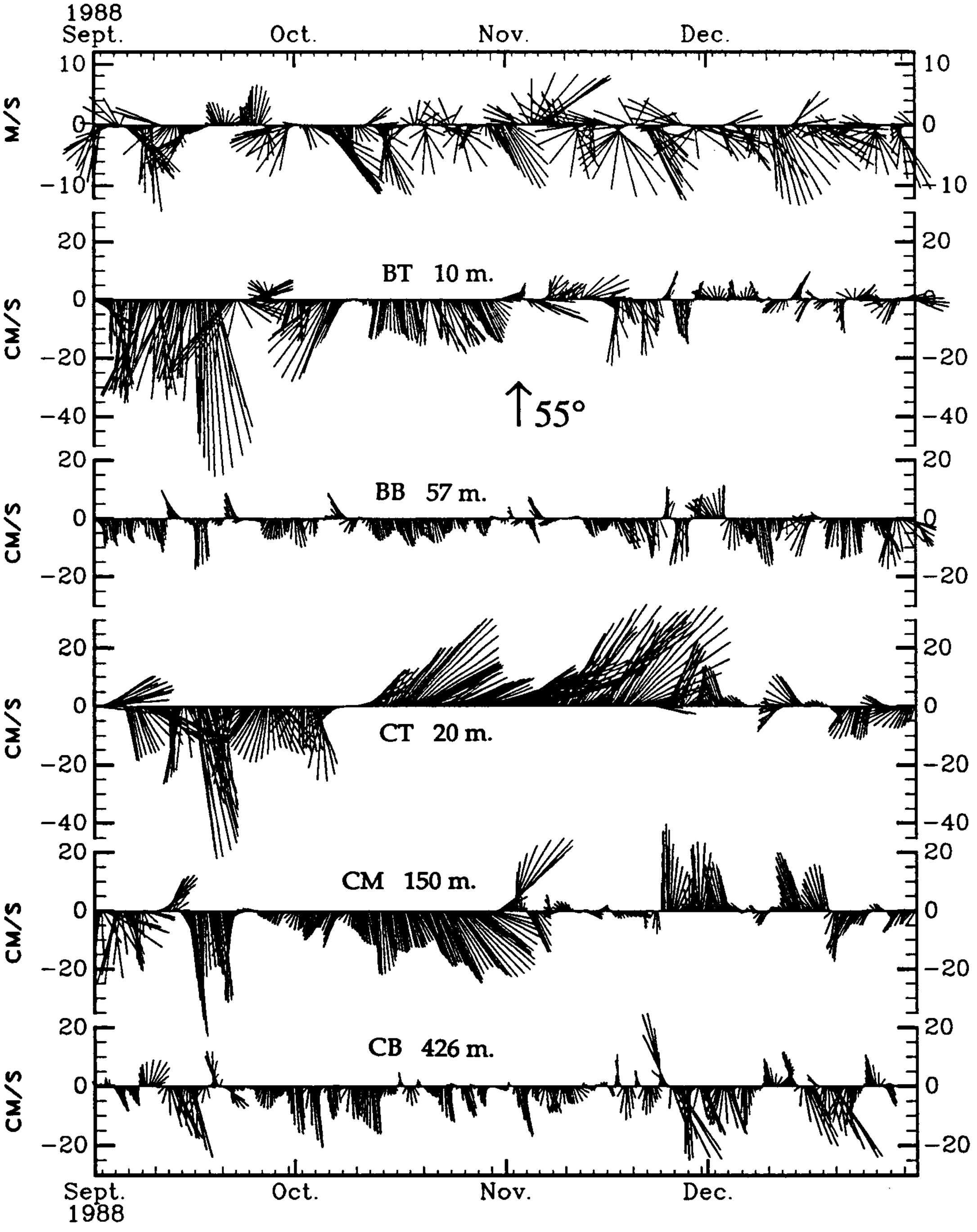


Figure 10-16. Stick plots of 40-hour, low-passed wind velocity (top frame) and currents at Moorings B and C for the period September through December 1988. Up the page is toward 55°.

whenever the bottom flow was southwestward. On September 18 the temperature at BB reached a maximum of 24.1 C, the highest bottom temperature recorded at this site during the two years of observation. The increase suggests a source of warm water in the De Soto canyon region. We have no satellite imagery to confirm the presence of an intrusion there. The temperature at CM and CB (Figure 10-12) also rose briefly around the time of the 18th. At CB the increase exceeded the mean by one degree, but the duration was less than 10 days, and so the event was not counted as an intrusion.

Tropical Storm Keith formed in the Caribbean, became a tropical storm on November 20, 1988 and crossed the tip of the Yucatan Peninsula on the 21st. Its track then turned northeasterly, and it made landfall near Sarasota, Florida early on the 23rd (Lawrence 1989). The only effect of Keith that can be found in the data records is a small rise in sea surface elevation (Figure 10-12).

During 1989 tropical cyclone activities in the Gulf consisted of Tropical Storm Allison and Hurricanes Chantal and Jerry. Allison formed in the northwest corner of the Gulf on June 24, 1989 and caused heavy flooding in southeastern Texas and western Louisiana during the following six days (Case 1990). The two hurricanes formed in the Southern Gulf and moved rapidly northward to impact the Texas coast. Chantal made landfall near High Island on August 1 with 35.8 $m\ s^{-1}$ winds (80 mph); Jerry made landfall on October 15 near Jamaica Beach on Galveston Island with winds of 38 $m\ s^{-1}$ (85 mph) (Case 1990). None of the three storms had any effect on the study area.

Cold air outbreaks with freezing air temperature at Buoy 42015 occurred on February 7 and 12, 1988. The first of the two brought about 1.5 cm of snow to Mobile (Ludlum 1988). In general, air temperature in MAMES coastal region was several degrees below normal for January and February 1988. Average air temperature in the study area was above normal for February 1989 despite a cold air outbreak during February 24 and 25 (Ludlum 1989). In December 1989, air temperature fell below freezing on the 16th, and then again during the 22nd through the 25th. The latter cold spell was the outstanding weather event of any December during this century (Ludlum 1990).

10.4 Low Frequency (Seasonal) Variability

10.4.1 Salinity

Figure 10-17, shows the monthly mean salinity observed at all near surface current meters. One should keep in mind that the salinities were recorded at a depth of 10 m at AT, BT and DT, and at 20 m at CT and ET. Although the time series data are limited, they suggest that the drought elevated the average salinity of the shelf waters, at least in the eastern portion of the study area. For example, the average salinity at 10 m at Site A for the three months of April through June 1988 was 35.7 PSU (mean of the monthly means in Table 10-2); for the same period in 1989 it was 32.2 PSU. In 1989, a year of above average discharge, the mean at AT dropped from 35.5 PSU in January to 31.6 PSU in June. Between August and December it rose to 34.5 PSU. At BT the minimum occurred one month later (July), and a return to higher values occurred sooner than at AT. The available data do not indicate mean decreases of comparable magnitude during 1988.

During 1989 mean salinities at ET and CT were similar in magnitude and trend to those at DT. In June 1989 all three locations had a mean salinity of about 34.8 PSU, while mean bottom salinity at DB (Table 10-9) was 36.5 PSU. Since CT and ET were at a depth of 20 m, the upper layer of fresher water was thick and extensive at this time. The similarity of mean salinity at DT, ET and CT suggests that Mississippi River discharge moving northeastward along the shelf break and slope is the primary source of fresher water at these locations, an hypothesis that is consistent with the mean flow described below. The increase in mean salinity between AT and BT, i.e., in an offshore direction, and the proximity of AT to the fresh water discharged from the Mobile River, suggest that it, rather than the Mississippi River, is the primary source of the low salinity observed at AT and BT. We further examine this hypothesis in following sections

Except at AB, mean salinities at depths well below the surface were relatively constant. Monthly means at BB and DB (Tables 10-5 and 10-9) ranged from 36.0 to 36.5 PSU. At CM and EM (Tables 10-7 and 10-10), they ranged from 35.9 to 36.2 PSU, and at CB (Table 10-8), they ranged from 34.9 to 35.1 PSU. Seasonal patterns in these monthly means are not

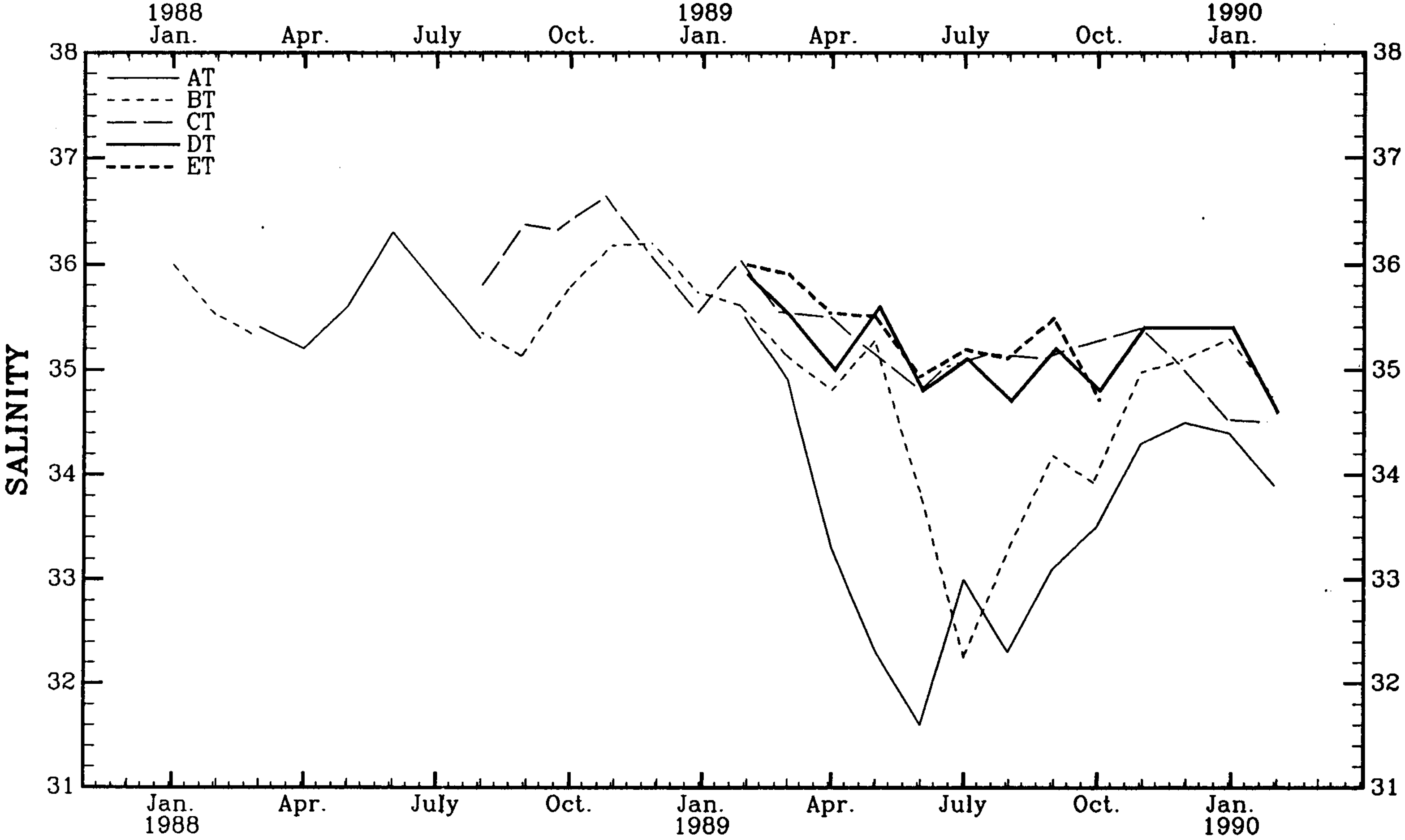


Figure 10-17. Monthly mean near-surface salinity for each of the five moorings.

apparent. The monthly mean salinity at AB (Table 10-3) ranged from 35.0 to 36.2 PSU. Low values of 35.0 PSU occurred in December 1989 and January 1990, i.e., winter months when vertical mixing is strongest. High mean bottom salinities at AB were found in June, July and August 1989, when the upper layer was much fresher, but mean bottom currents were shoreward (Table 10-3).

10.4.2 Temperature

Figure 10-18 shows that monthly mean air temperature was always colder than sea surface temperature at Buoy 42015. Mean sea surface temperature follows the air temperature, but the oceanic response is moderated by the greater heat capacity of water and heat advection by currents. During the first week of January, 1988, a severe cold wave moved down from Canada, bringing record low temperatures to the Midwest. February and March also featured a couple of memorable cold spells. Later in the year the northeast and southeast portions of the country had their third coldest October of the century (LeComte 1989). Mean air temperatures in the study area during the months of December 1988 through March 1989 were warmer than normal. The cold air outbreak of 22-25 December 1989 was a record breaker.

Figure 10-19 shows the monthly mean temperatures recorded by the top current meters on each of the five moorings. The winter patterns are as expected, with colder means in shallower water. Along the slope, ET is consistently warmer than CT. At Buoy 42015, August is usually the warmest month for air temperature and sea surface temperature (Figure 10-18), but for waters farther offshore and below the surface, September appears to be the warmest month. This is based on temperature at BT, for which there there are two full years of data. During both years, a dramatic drop in temperature occurs during October. The AT meter recorded the lowest near surface temperature value, 12.4° C, in December 1989 (Table 10-2).

Figure 10-20 shows the mean monthly bottom temperatures observed at the shelf moorings. The annual cycle of air temperature strongly influences the bottom temperature at Mooring A (30 m depth). It is felt to a

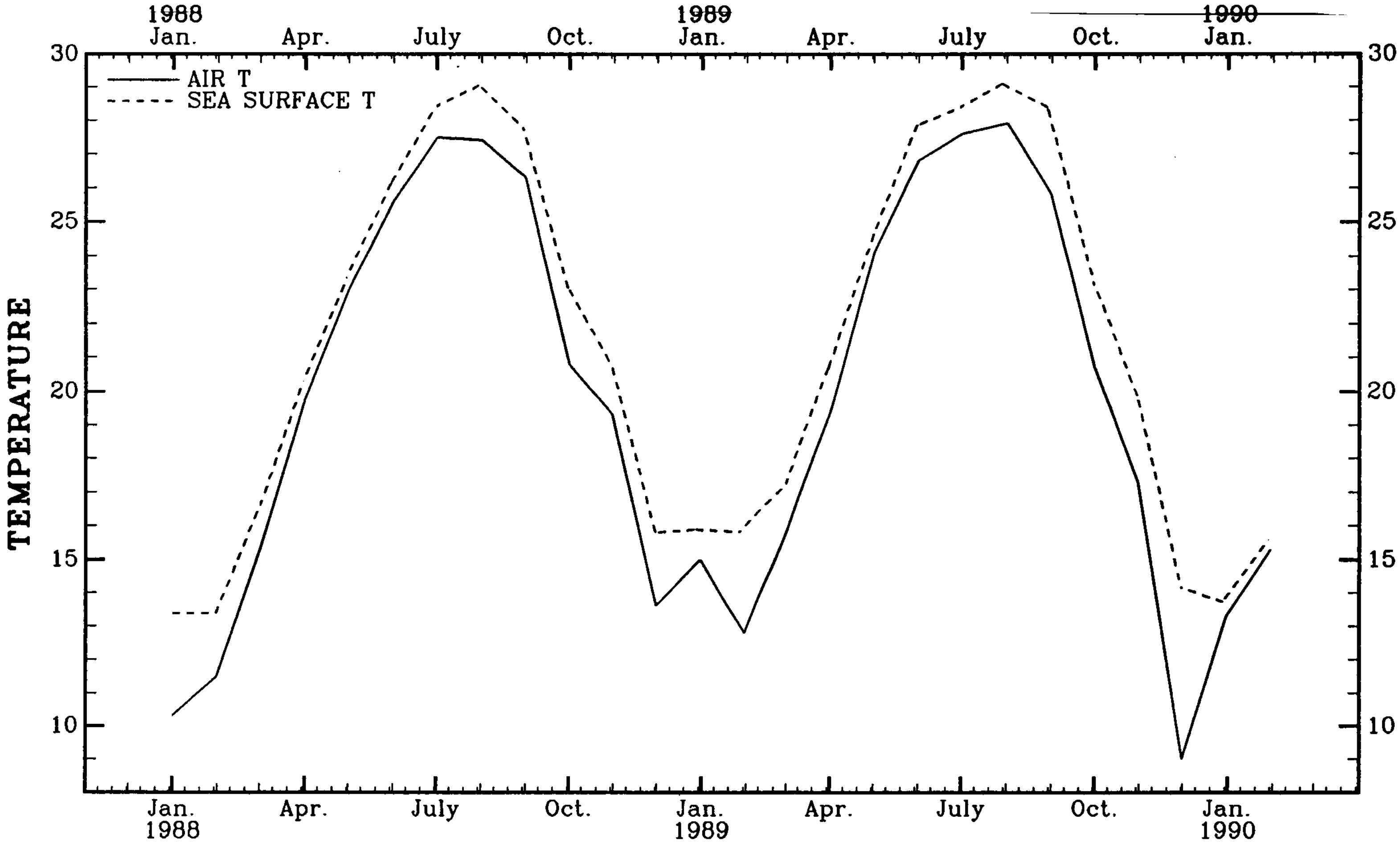


Figure 10-18. **Monthly mean air temperature and sea surface temperature at Buoy 42015.**

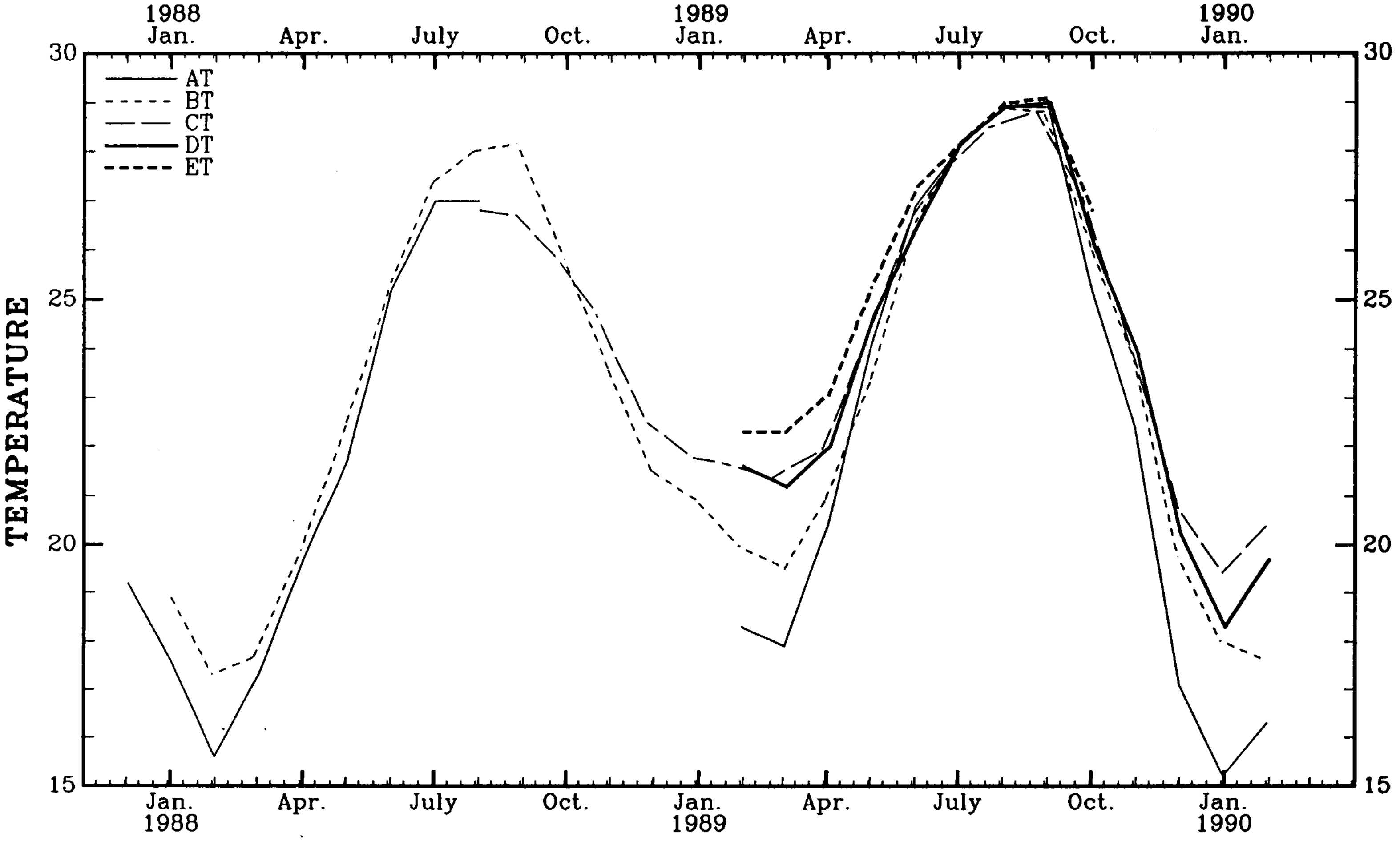


Figure 10-19. **Monthly mean near surface temperature for each of the five moorings.**

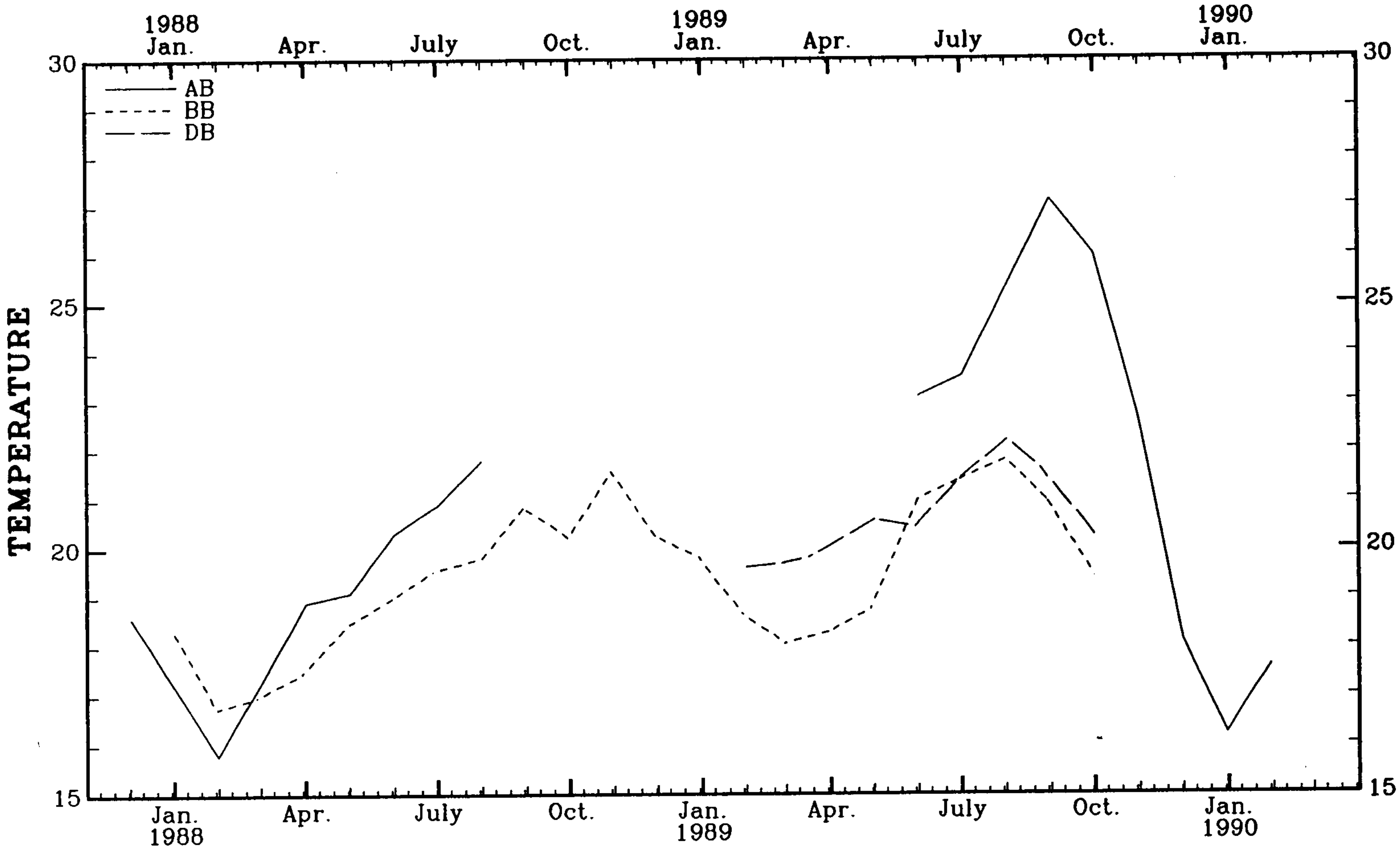


Figure 10-20. **Monthly mean bottom temperature at Moorings A, B, and D.**

lesser degree at BB and DB (60 m depth). The fall and winter portions of the bottom temperature curves follow air temperature more closely than the spring and summer portions because cooling at the surface is more readily transmitted to the bottom than warming. Cross isobath flow at the bottom, to compensate for oppositely directed upper layer flow, and intrusive events from the open Gulf complicate the cycle of mean bottom temperature on the shelf. For example, in September 1988 bottom temperature at BB increased (Figures 10-14e and 10-20) because southwestward bottom currents brought warm water from the De Soto Canyon region, where we speculate there may have been a warm intrusion. In October 1988 a cold spell reduced the bottom temperature, but in November another intrusion increased the mean bottom temperature to 21.6° C, the highest value of the two year period. From February through May, 1989, the mean temperature at DB was warmer than that at BB by one to two degrees. During this period the satellite imagery indicates that warm intrusions were pushing onto the western portion of the shelf (Figure 10-9). The mean data demonstrate that intrusions can have sufficient strength and duration to alter the mean bottom temperature by up to two degrees at least as far onto the shelf as the 60-m depth contour. Earlier we described an intrusion during March 1988 that reached the meter at AB (Figure 10-8c), but its effect on the mean for that month is not discernable from the normal warming at AB for that time of year.

Figure 10-21 depicts the variations in monthly mean temperature observed at 150 m at CM and EM and at 426 m at CB and EB (Tables 10-7, 10-8 and 10-10). Figure 10-21 can be compared with Figures 10-12 and 10-13, which show the 40-hour low-passed temperature data for these locations and were used to take a census of intrusions. The months for which mean temperature is a relative maxima in the curves in Figure 10-21 correspond to the months with intrusions (Table 10-15).

There appears to be a significant difference between the monthly mean temperatures at EM and CM, but not between those at EB and CB. For the common nine-month period, the mean of the monthly means at EM and CM are 16.24° C and 15.48° C, respectively, a difference of 0.76° C. The monthly means also emphasize the magnitude of the effect on temperature

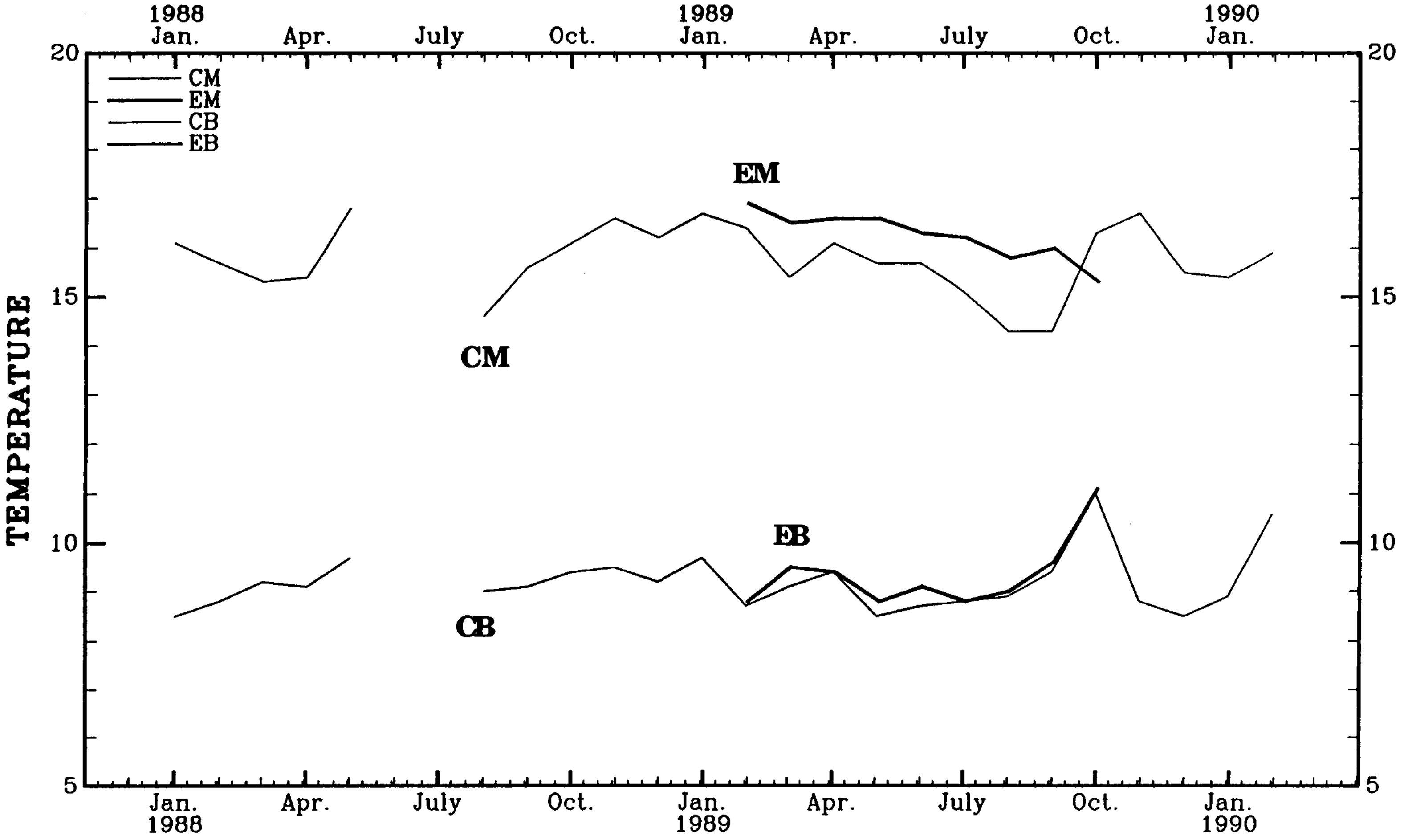


Figure 10-21. Monthly mean temperatures at 150 m and 426 m at Moorings C and E.

and the temporal and spatial extent of the warm intrusion that entered the study area during September to November 1989.

10.4.3 Wind and Currents

The low-frequency variability of the wind and currents observed during this study is examined by means of monthly mean vectors and seasonal rose diagrams. Tables 10-2 through 10-10 list the along- and cross-isobath components of monthly mean current and wind velocity. Figures 10-22 and 10-23 present the mean velocities as stick vectors in the standard compass coordinate system with north upward on the page. Figures 10-24 through 10-35 show the seasonal rose diagrams (See Section 10.2.6). The tables of joint distribution between speed and direction, which the roses graphically present, are included in Appendix C. The seasonal roses in each figure are organized sequentially from left to right and top to bottom, and they are offset so that the seasons fall into columns for ease in making inter-annual comparisons. When making comparisons among roses, one should check observations, which is the top number in the center of each rose. (The bottom number is the percent of observations that were calm, i.e., less than the speed threshold of the instrument.) Obviously, if a season is missing a significant number of observations the information in its rose diagram should be used cautiously. (Note: the component means in Tables 10-2 through 10-11 are vector means that take into account the sign, i.e., the direction of flow, whereas the tables of joint distribution (Appendix C) list average speed in a given direction sector; average speeds are usually larger than vector means because speed is a positive-definite scalar quantity.)

Schroeder and Wiseman (1985) described the annual cycle of the wind regime at the Dauphin Island Sea Lab by means of composite monthly wind roses for ten years of data collected by the meteorological station there. They found that northeasterly and northerly winds (meteorological terminology) dominate in the months from September through February. March is a transitional month, with northerly, easterly, southeasterly and southerly winds occurring approximately an equal percentage of the time.

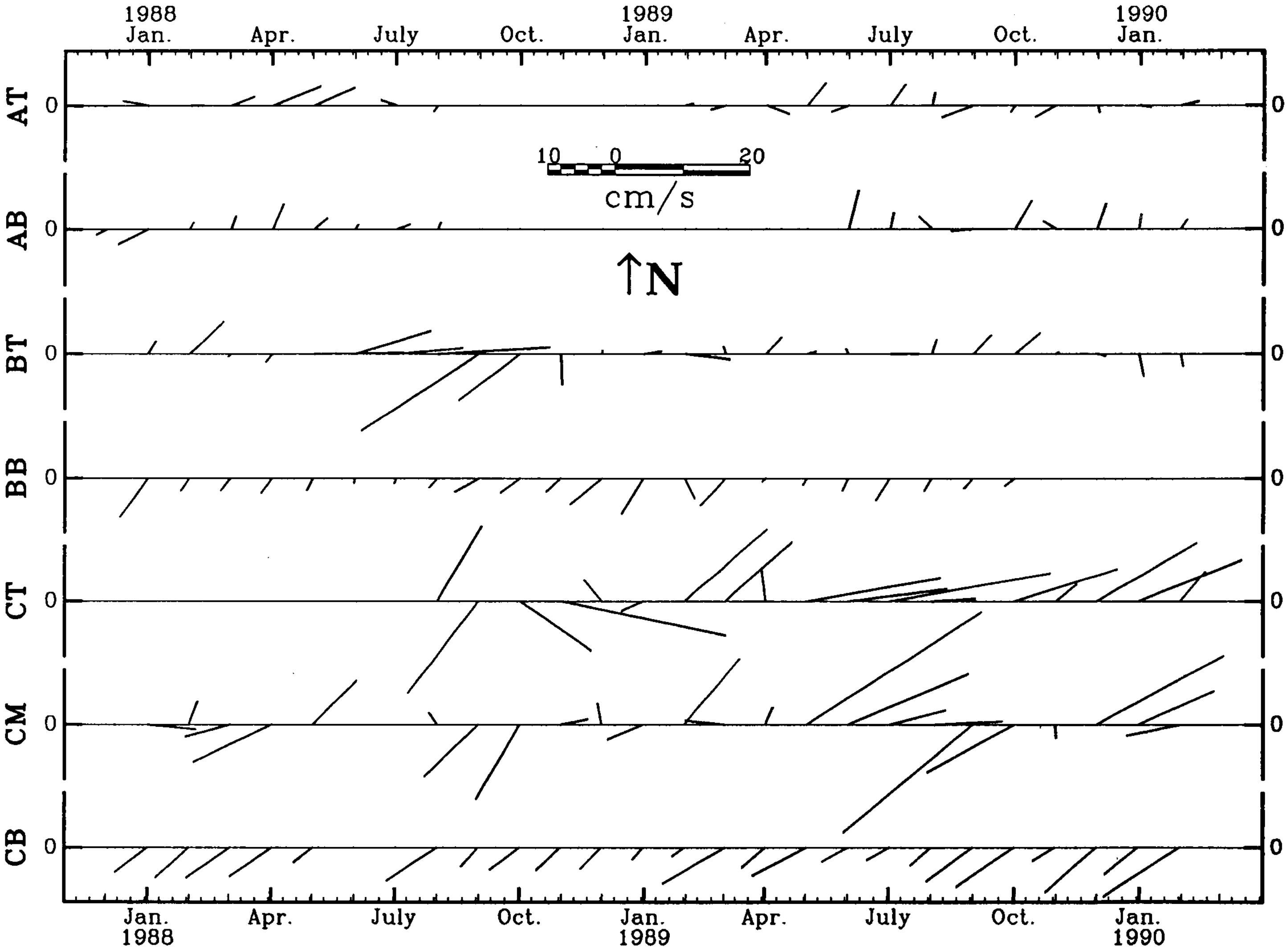


Figure 10-22. **Stick vector plots of monthly mean currents recorded by meters at Moorings A, B, and C. Up the page is North.**

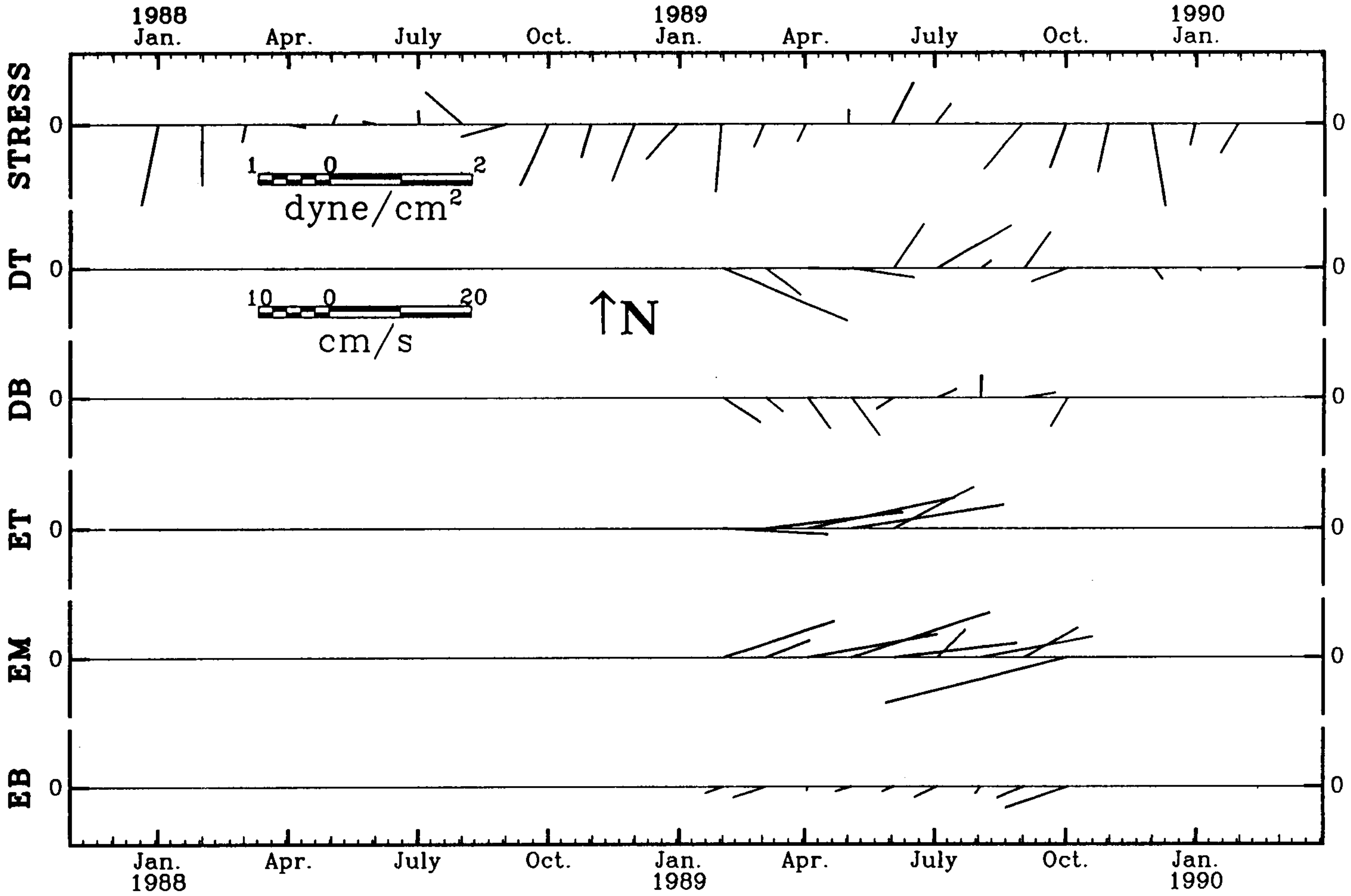


Figure 10-23. **Stick vector plots of monthly mean wind stress recorded at Buoy 42015 and monthly mean currents recorded at Moorings D and E. Up the page is North.**

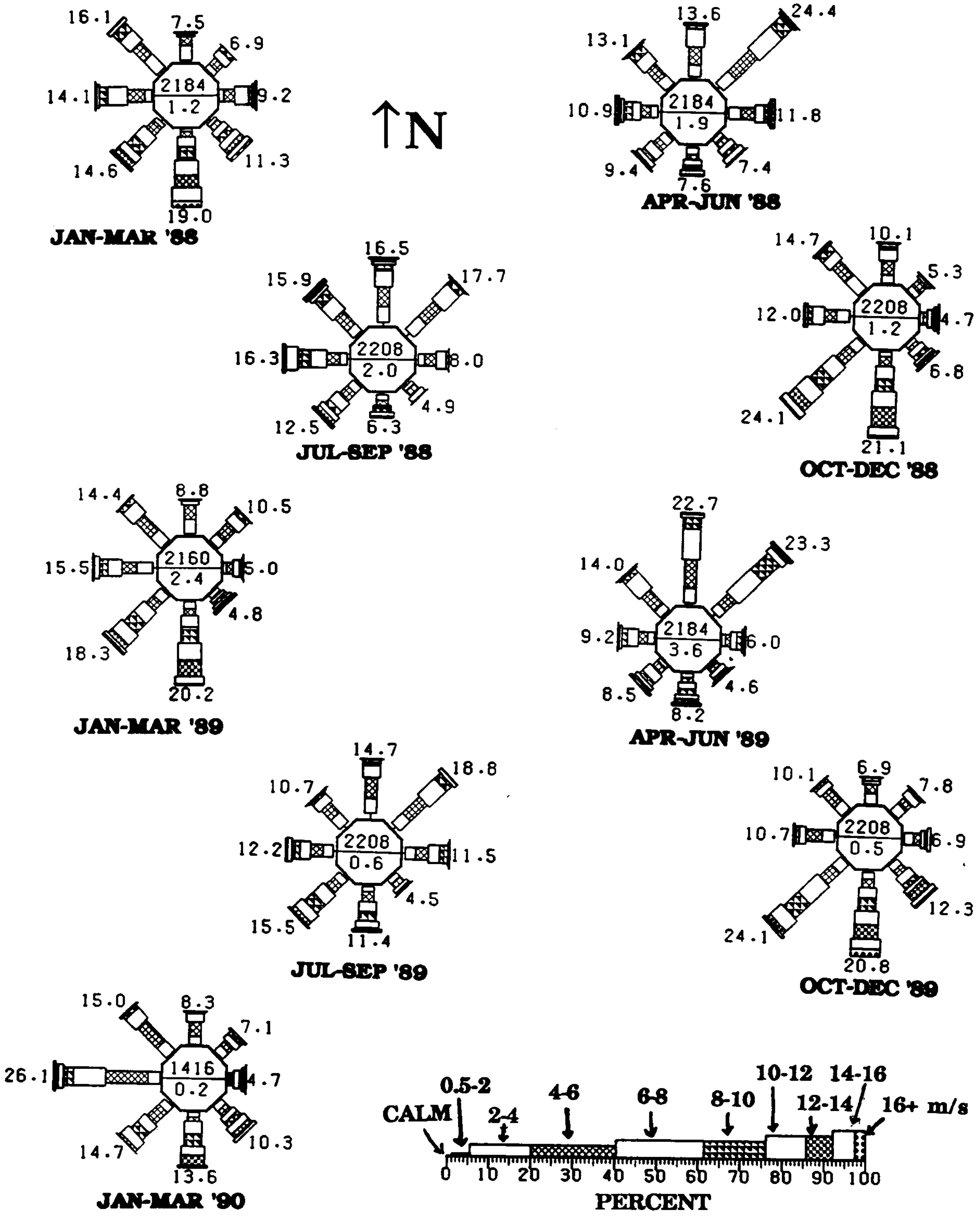


Figure 10-24. **Seasonal wind roses (oceanographic convention for direction) for Buoy 42015 data. Number of hourly observations and percent calms (speed less than 0.5 m/s) are given in the center of each rose.**

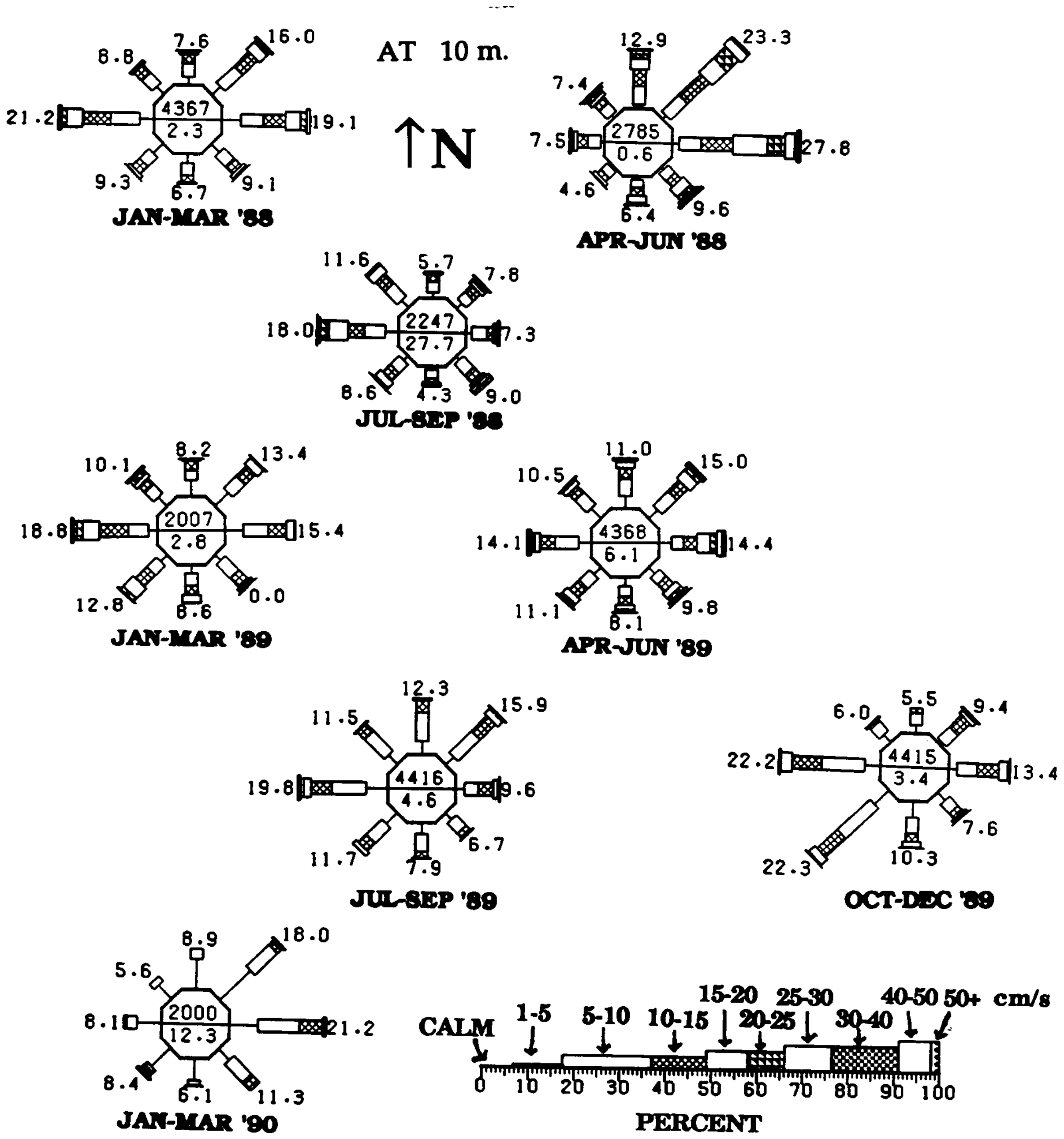


Figure 10-25. Seasonal current roses for the AT meter location (Mooring A, 10 m). Number of good half-hourly observations and percent clams (speed less than 1.0 cm/s) are given in the center of each rose.

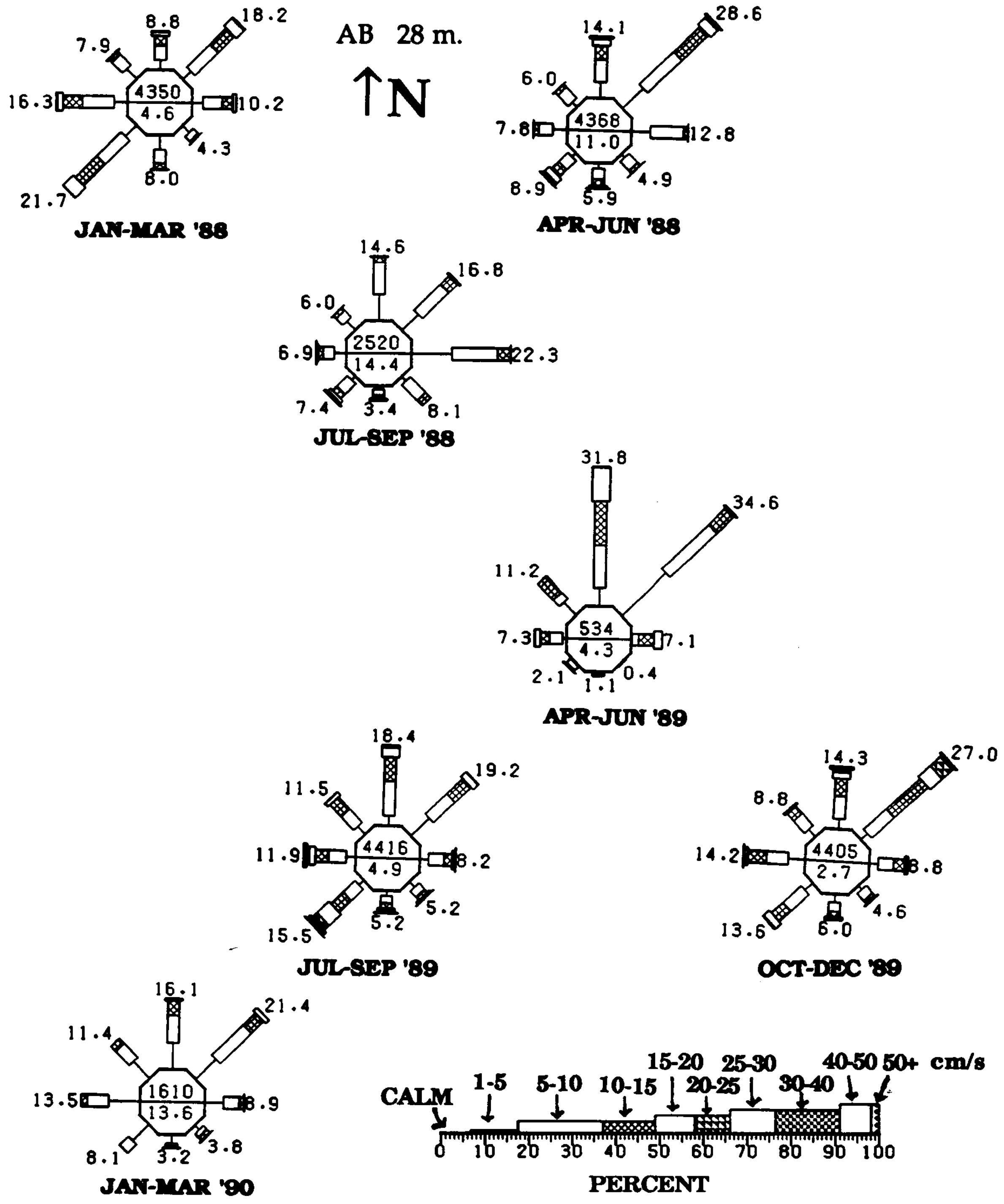


Figure 10-26. Seasonal current roses for the AB meter location (Mooring A, 28 m). Number of good half-hourly observations and percent calms (speed less than 1.0 cm/s) are given in the center of each rose.

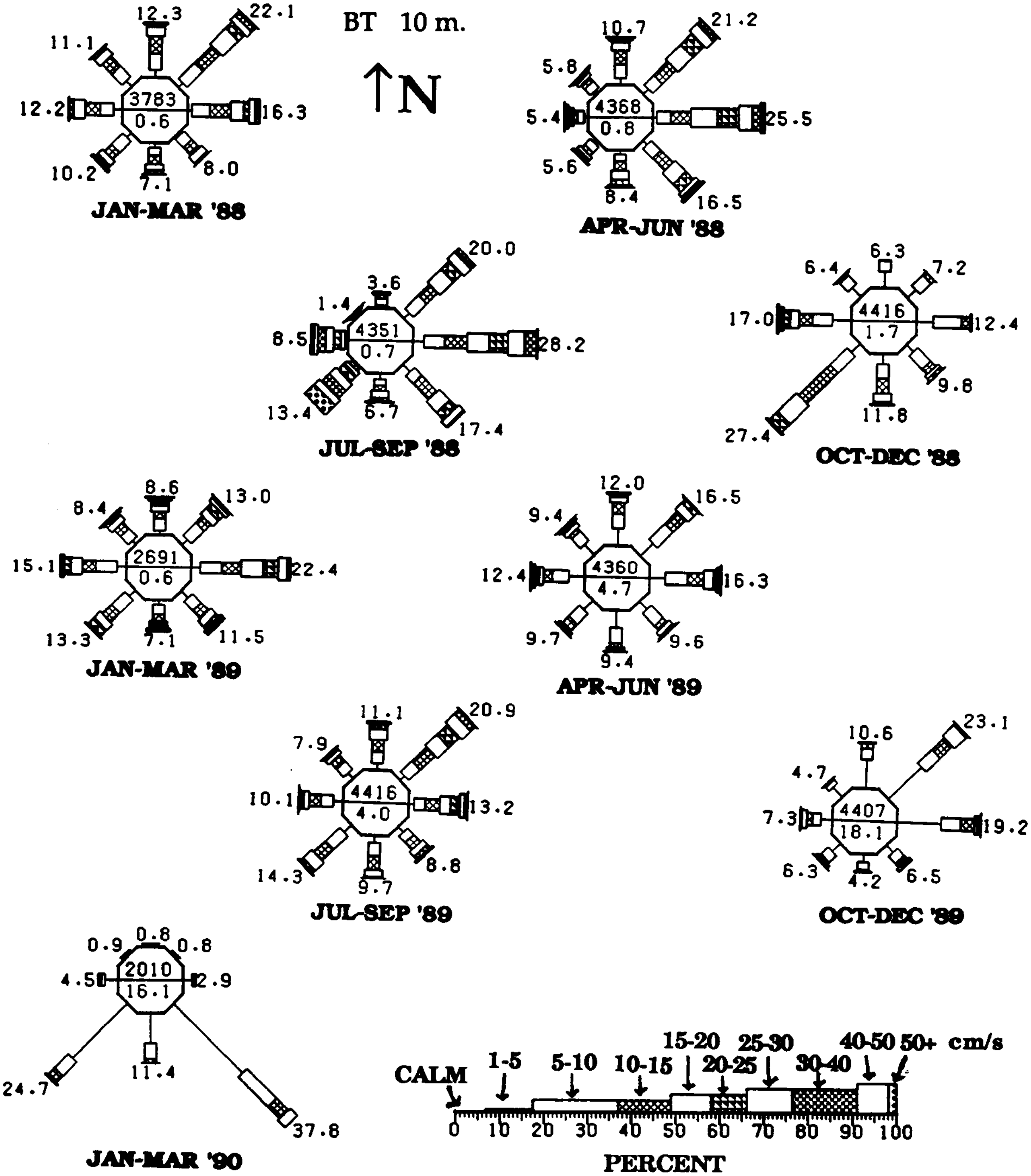


Figure 10-27. Seasonal current roses for the BT meter location (Mooring B, 10 m). Number of good half-hourly observations and percent calms (speed less than 1.0 cm/s) are given in the center of each rose.

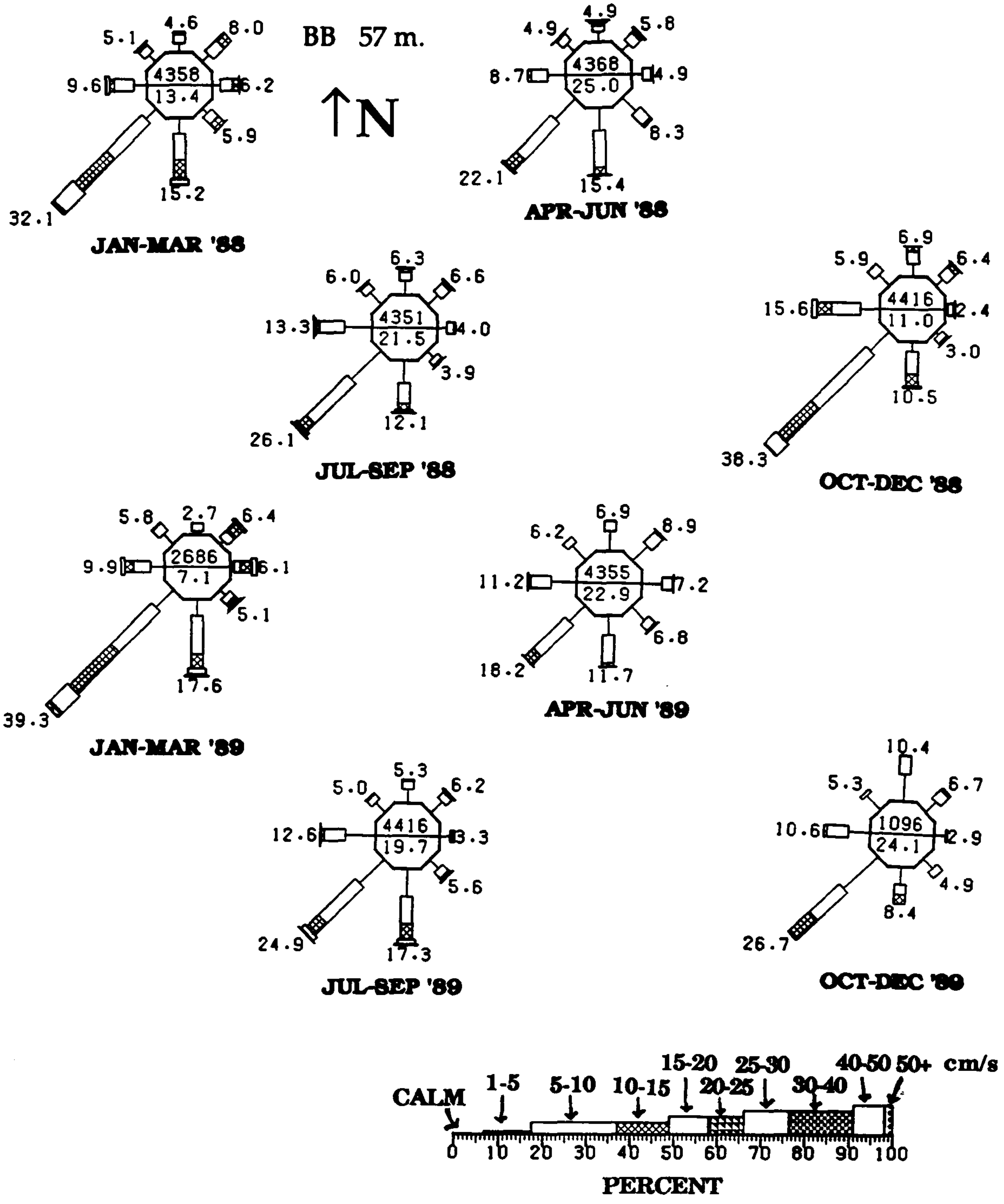


Figure 10-28. Seasonal current roses for the BB meter location (Mooring B, 57 m). Number of good half-hourly observations and percent calms (speed less than 1.0 cm/s) are given in the center of each rose.

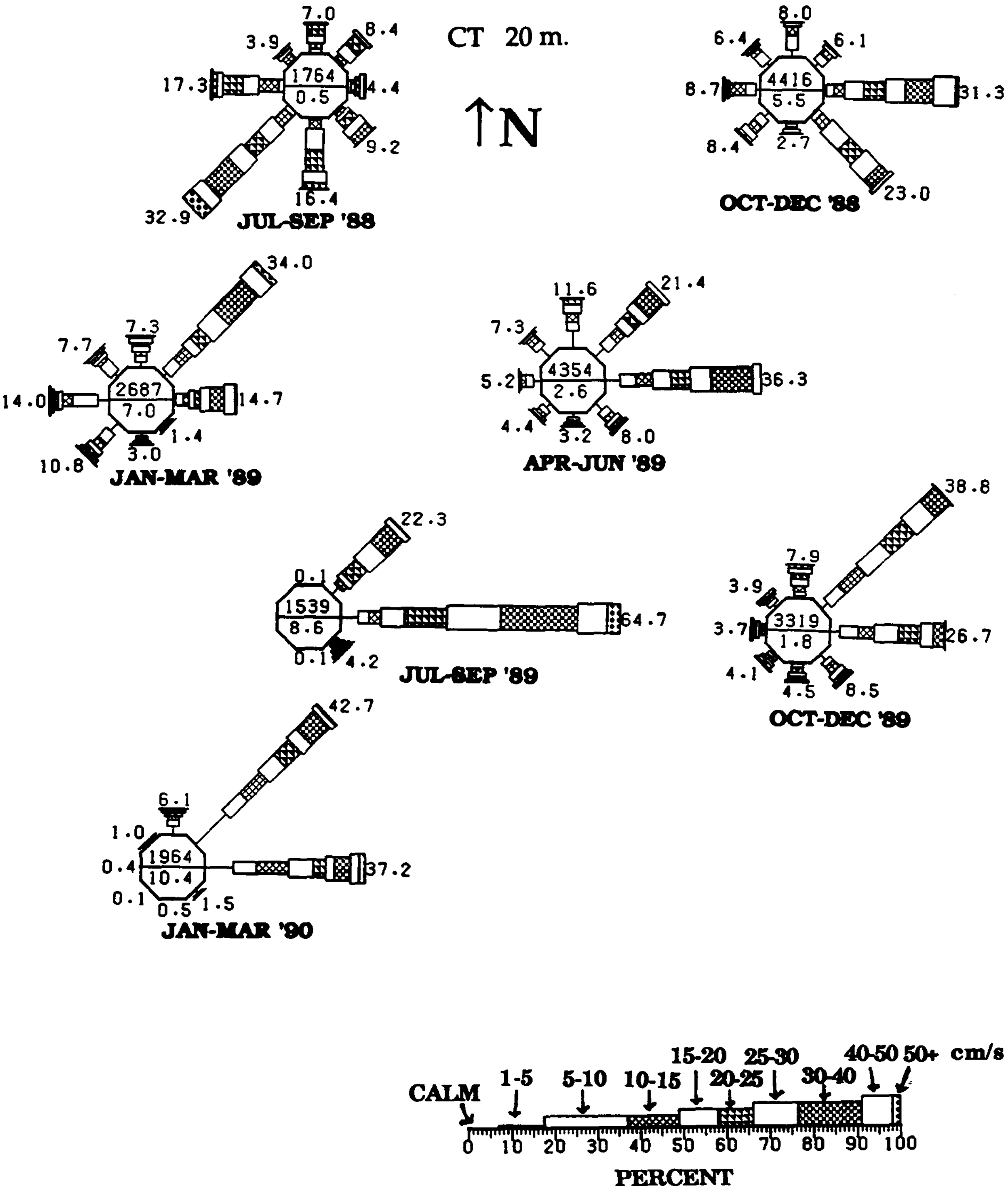


Figure 10-29. Seasonal current roses for the CT meter location (Mooring C, 20 m). Number of good half-hourly observations and percent calms (speed less than 1.0 cm/s) are given in the center of each rose.

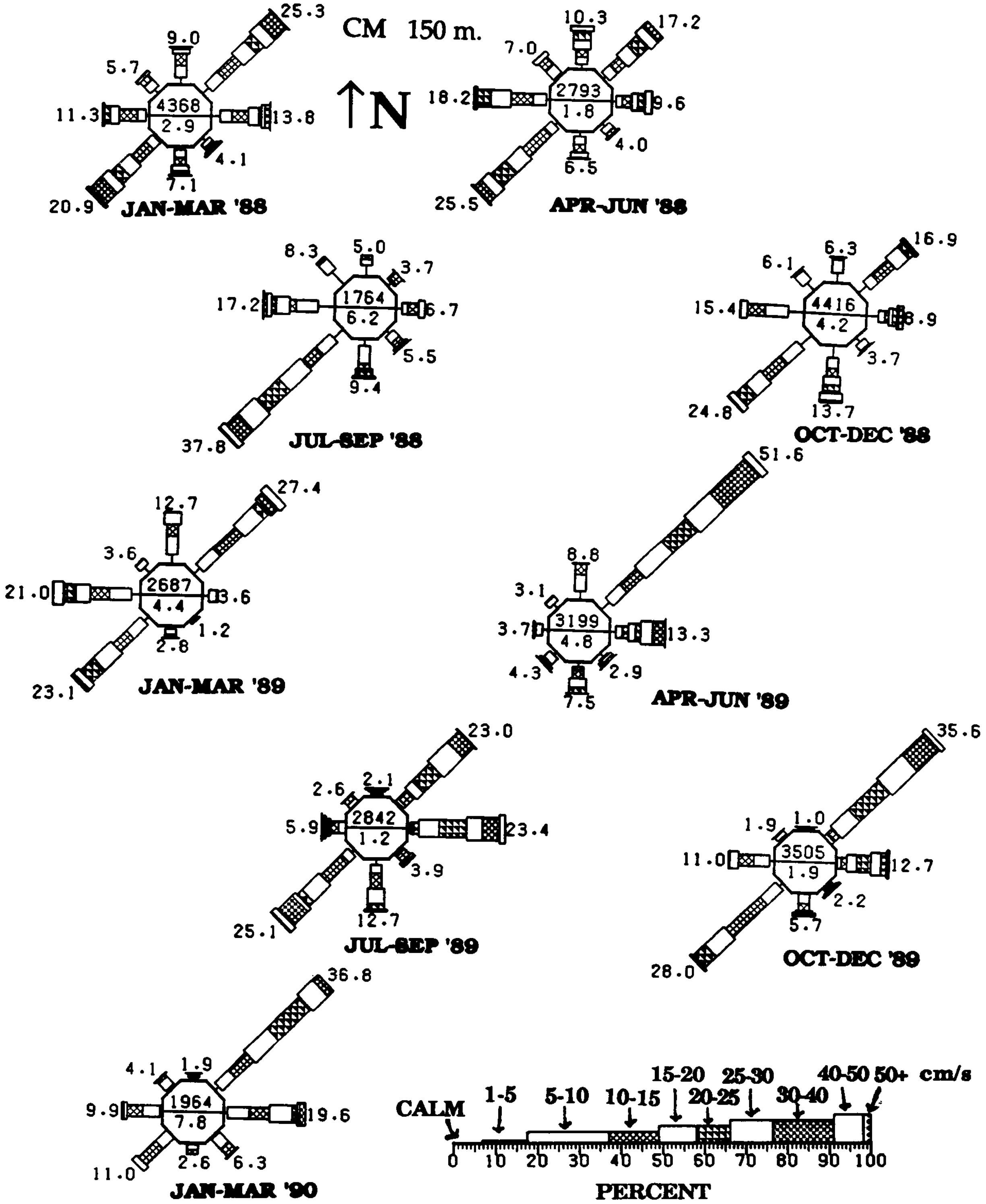


Figure 10-30. **Seasonal current roses for the CM meter location (Mooring C, 150 m). Number of good half-hourly observations and percent calms (speed less than 1.0 cm/s) are given in the center of each rose.**

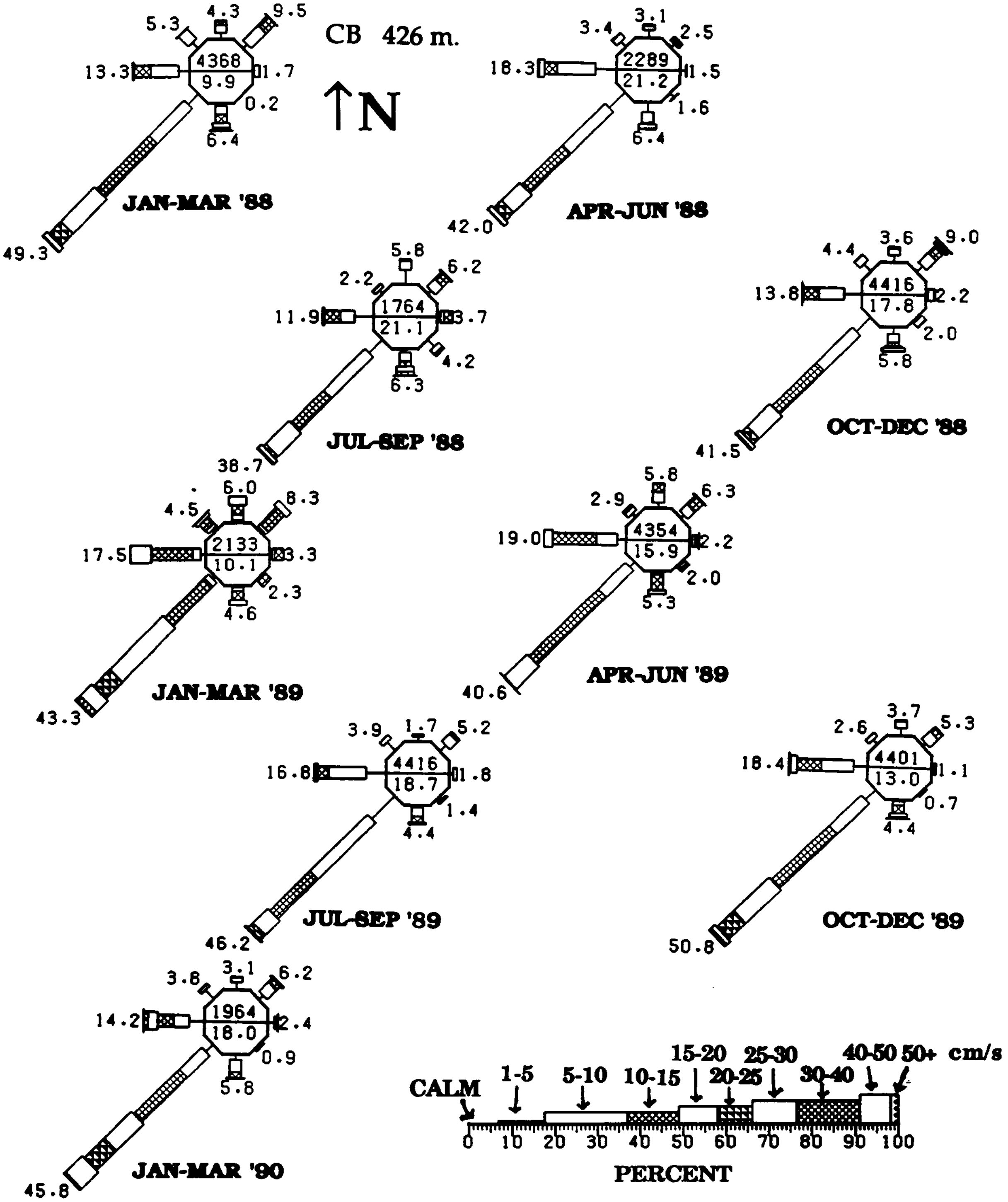


Figure 10-31. Seasonal current roses for the CB meter location (Mooring C, 426 m). Number of good half-hourly observations and percent calms (speed less than 1.0 cm/s) are given in the center of each rose.

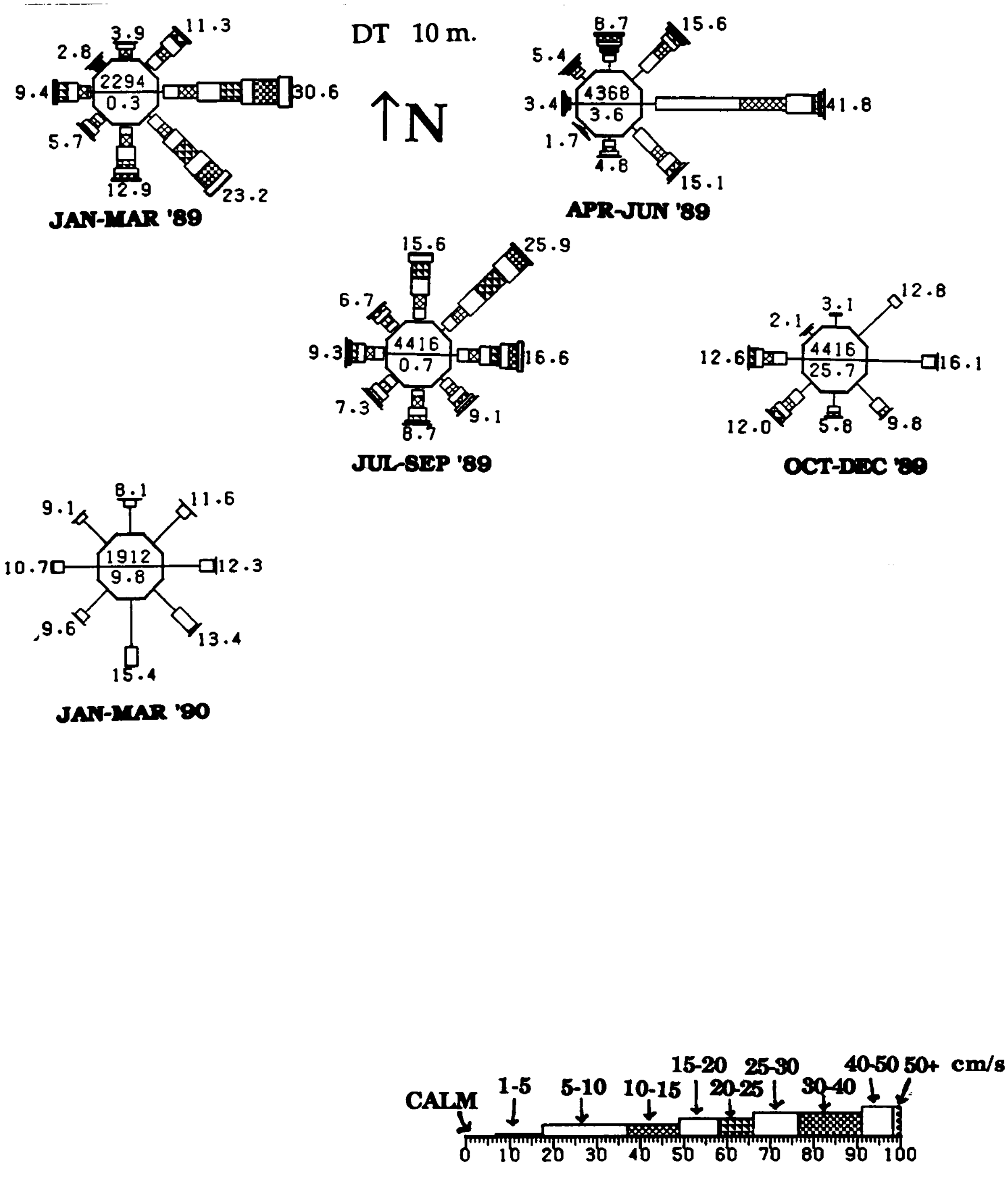


Figure 10-32. Seasonal current roses for the DT meter location (Mooring D, 10 m). Number of good half-hourly observations and percent calms (speed less than 1.0 cm/s) are given in the center of each rose.

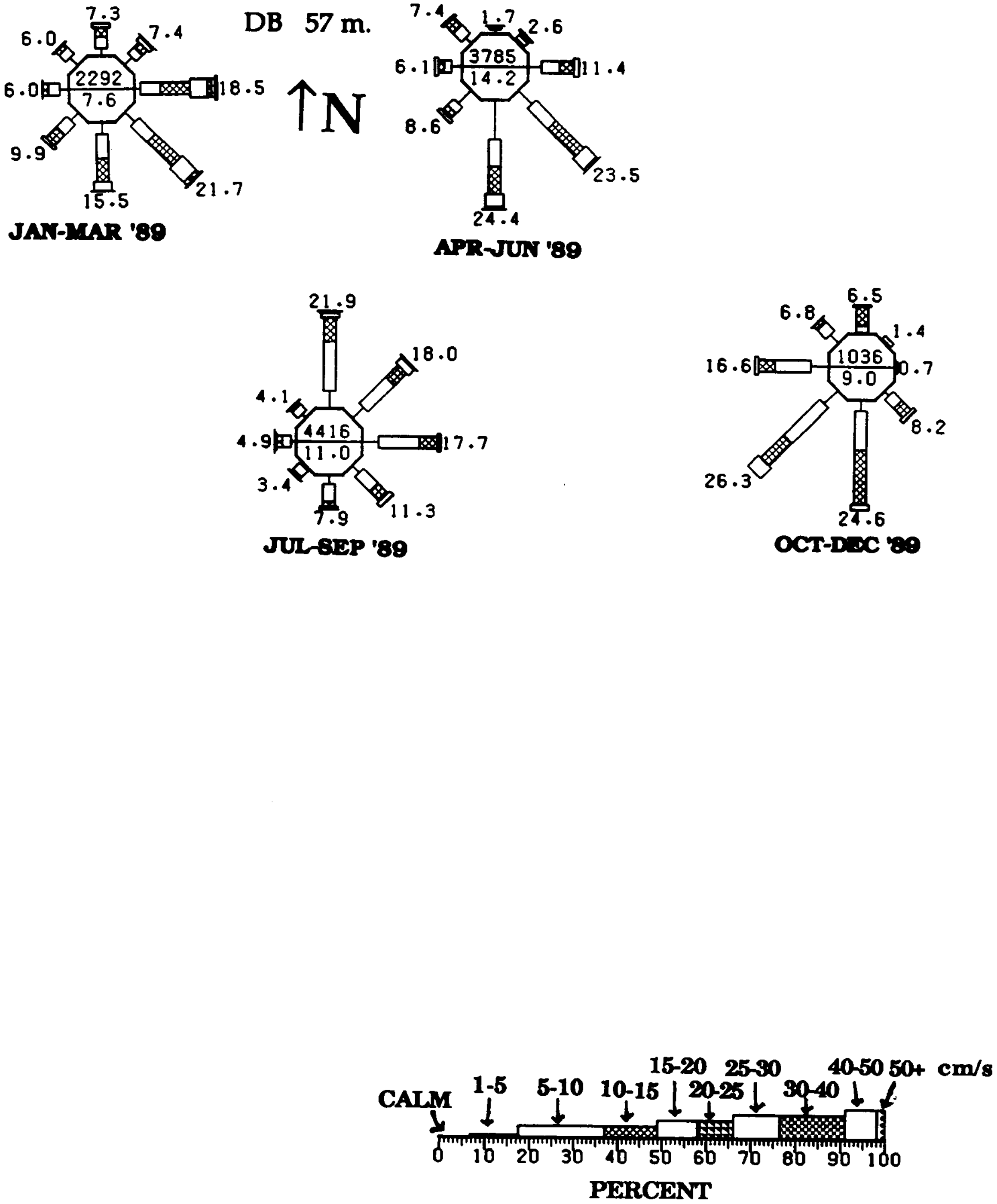


Figure 10-33. Seasonal current roses for the DB meter (Mooring D, 57 m) location. Number of good half-hourly observations and percent calms (speed less than 1.0 cm/s) are given in the center of each rose.

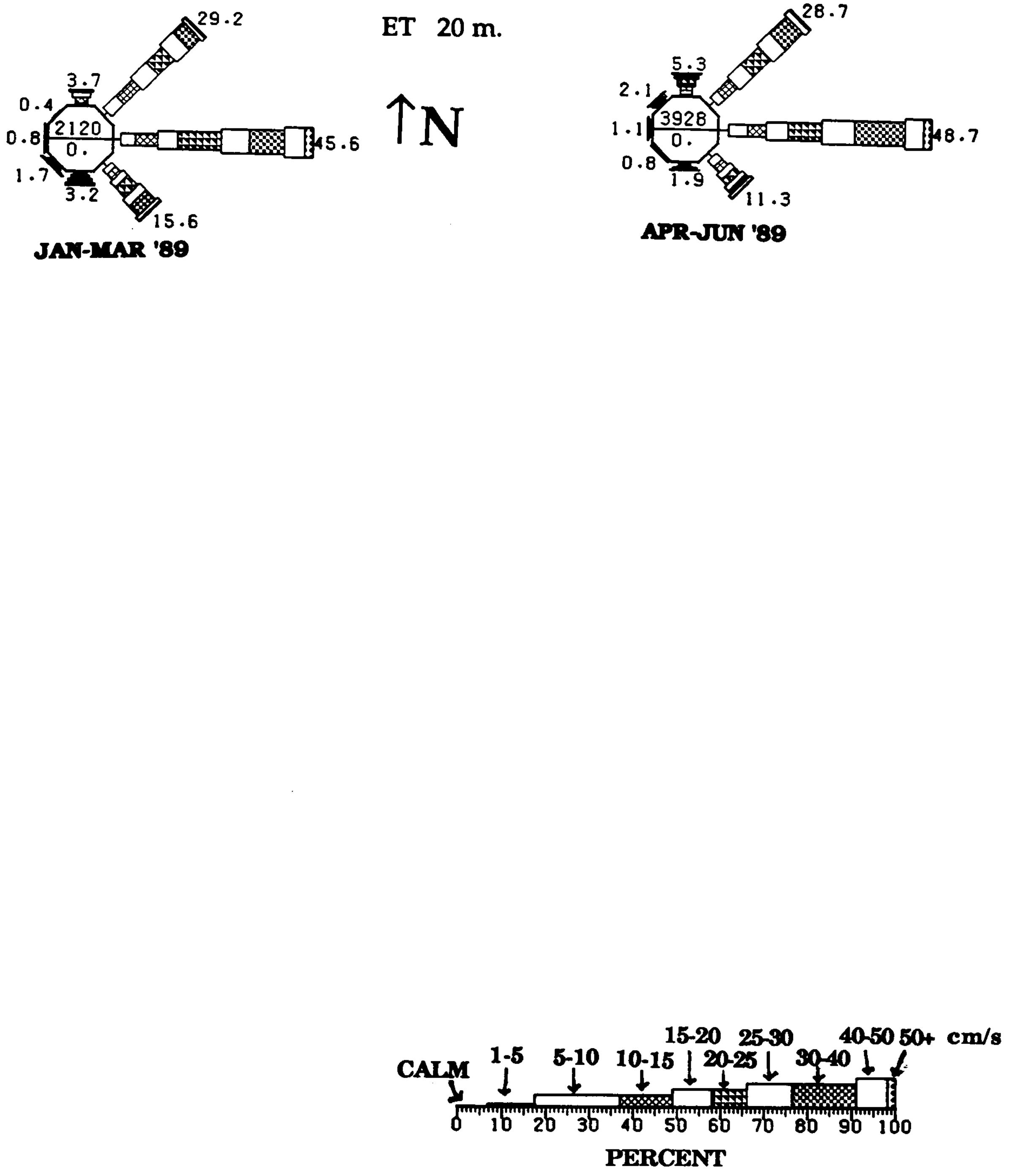


Figure 10-34. Seasonal current roses for the ET meter location (Mooring E, 20 m). Number of good half-hourly observations and percent calms (speed less than 1.0 cm/s) are given in the center of each rose.

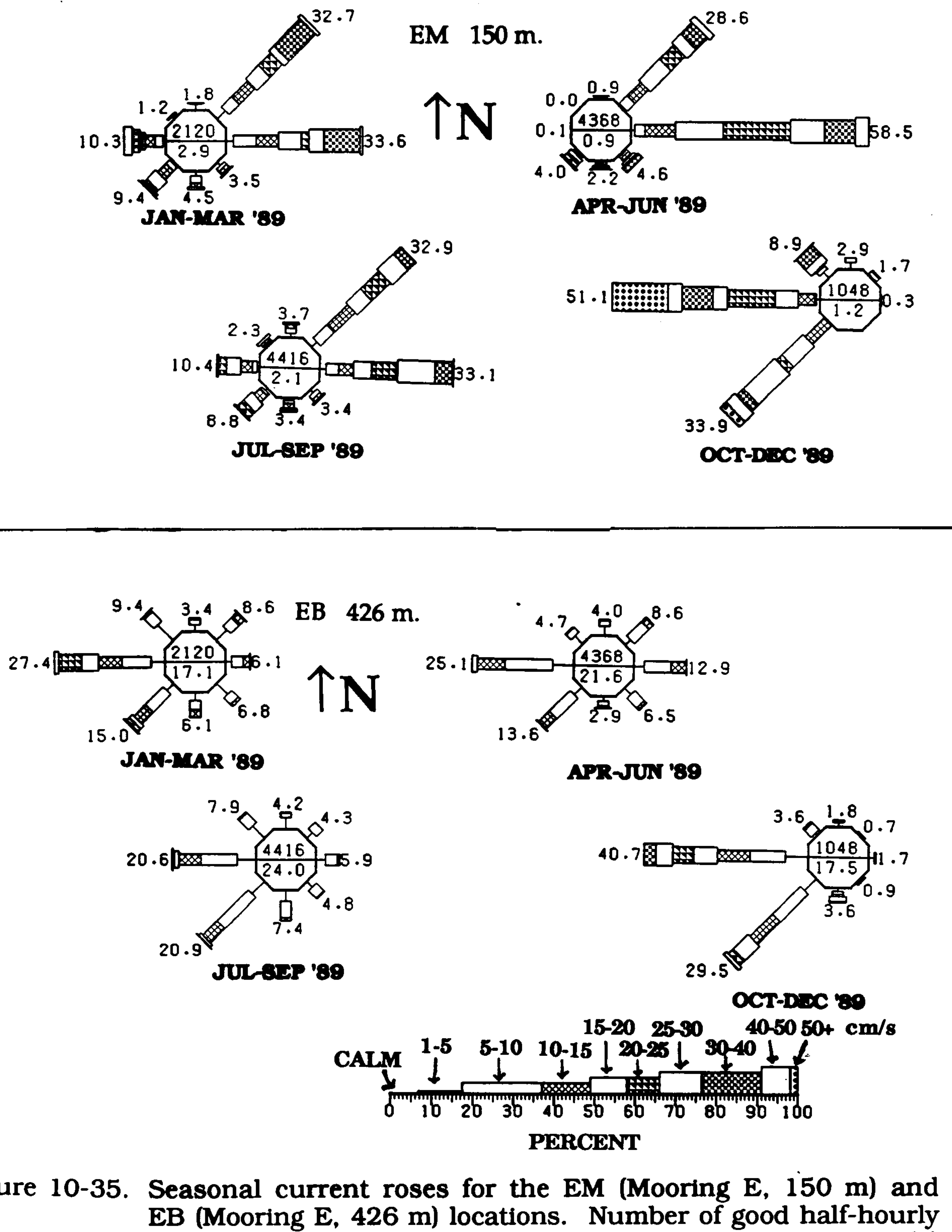


Figure 10-35. Seasonal current roses for the EM (Mooring E, 150 m) and EB (Mooring E, 426 m) locations. Number of good half-hourly observations and percent calms (speed less than 1.0 cm/s) are given in the center of each rose.

The winds rotate clockwise from southeasterly in April to a broader distribution of southerly, southwesterly and westerly winds in July. In August the winds return to southerly and southeasterly.

The seasonal wind roses during this study, derived from Buoy 42015 data, are consistent with the pattern described by Schroeder and Wiseman, taking into account inter-annual variability and the months we have chosen to group together for each season. According to Figure 10-24, northeasterly winds dominate the October-December period followed closely in frequency of occurrence by northerly winds. The reverse usually holds from January through March, except in 1990, when easterly winds occurred most frequently. During April through June, southwesterly winds occur most frequently, and southerly winds are the next most frequent. For the summer season of July through September, southwesterly winds occur most frequently, and there is a fairly equal distribution in percent occurrence among the other octants for southerly counter-clockwise to northeasterly winds.

As the wind roses in Figure 10-24 indicate graphically and the tables of joint distribution in Appendix C list explicitly, the two speed ranges of 4-6 m s^{-1} and 6-8 m s^{-1} together account for 40 to 50 percent of the observed speeds. Overall average speeds for the seasons range from 6.0 to 7.4 m s^{-1}. During the fall and winter seasons northerly winds typically have an average speed of about 10 m s^{-1}. (These are effective wind speeds derived from the buoy speeds as described in Section 10.2.3.)

Figure 10-23 displays the monthly mean wind stress vectors. For the months from October through March, moderate to strong northerly to northeasterly mean stress prevailed during the study. The mean stress became weak and variable during the months of April through July of 1988, but during May through July of 1989 mean stress was persistently south-southwesterly. The mean stress for August 1988 was southeasterly and of moderate strength, whereas that for August 1989 was essentially zero. For September of both years the mean stress was moderate and northeasterly. Note that the majority of the stress vectors have an easterly component.

Dinnel (1988) proposed a very schematic seasonal circulation pattern for the MAMES region based on an analysis of historical current meter data over the inner shelf and mean historical hydrographic data over the outer shelf and upper slope. In order to compare the present results with his work, Figure 10-36 shows the locations (stars) of the five current meter moorings superposed on his Figure 51. Dinnel (1988) found evidence for cyclonic mean circulation over the inner half of the shelf during winter, spring and summer. He lacked fall data, but proposed cyclonic circulation in that season as well because the inshore and western sides of the cyclonic flow are strongly wind forced, and the mean fall winds are similar to those of winter.

Mooring A was located in the center of the eastern portion of the cyclonic circulation cell hypothesized for each season (Figure 10-36). In such a location mean currents should be weak and variable. The monthly mean current vectors for AT in Figure 10-22 do, in general, have low magnitudes and vary widely in direction.

One test to determine if the mean of a velocity component is significantly different than zero requires that the mean exceed zero by two standard errors. The standard error, SE, (also called the standard deviation of the mean) is estimated by

$$SE = s \ / \ n^{1/2}. \qquad (10\text{-}1)$$

where s is the standard deviation of the sample and n is the sample size (not necessarily the total number of observations). Two SE's corresponds to a one-tail significance level (degree of uncertainty) of 5 percent or less when the number of degrees of freedom is five or more (e.g., Blank 1980). For time series, which usually are autocorrelated to some extent, the standard error can be estimated by

$$SE = s \ / \ (T/t_o)^{1/2}. \qquad (10\text{-}2)$$

where T is the record length, taken to be 30 days for monthly means; and t_o is a correlation time scale. The term T/t_o approximates the number of independent samples in the time series, and thus the number of degrees of freedom (Beardsley and Boicourt 1981). We estimated t_o as the time lag to the first zero crossing in the autocorrelation function, using the longer, deployment-length, half-hourly records rather than monthly sub-series. A conservative value for t_o is about three days. Wiseman and Dinnel (1988) and Dinnel (1988) found similar results in other portions of the MAMES region. Then, for monthly intervals, the denominator in the above equation is about three, and the value for two SE's approximately equals two thirds of

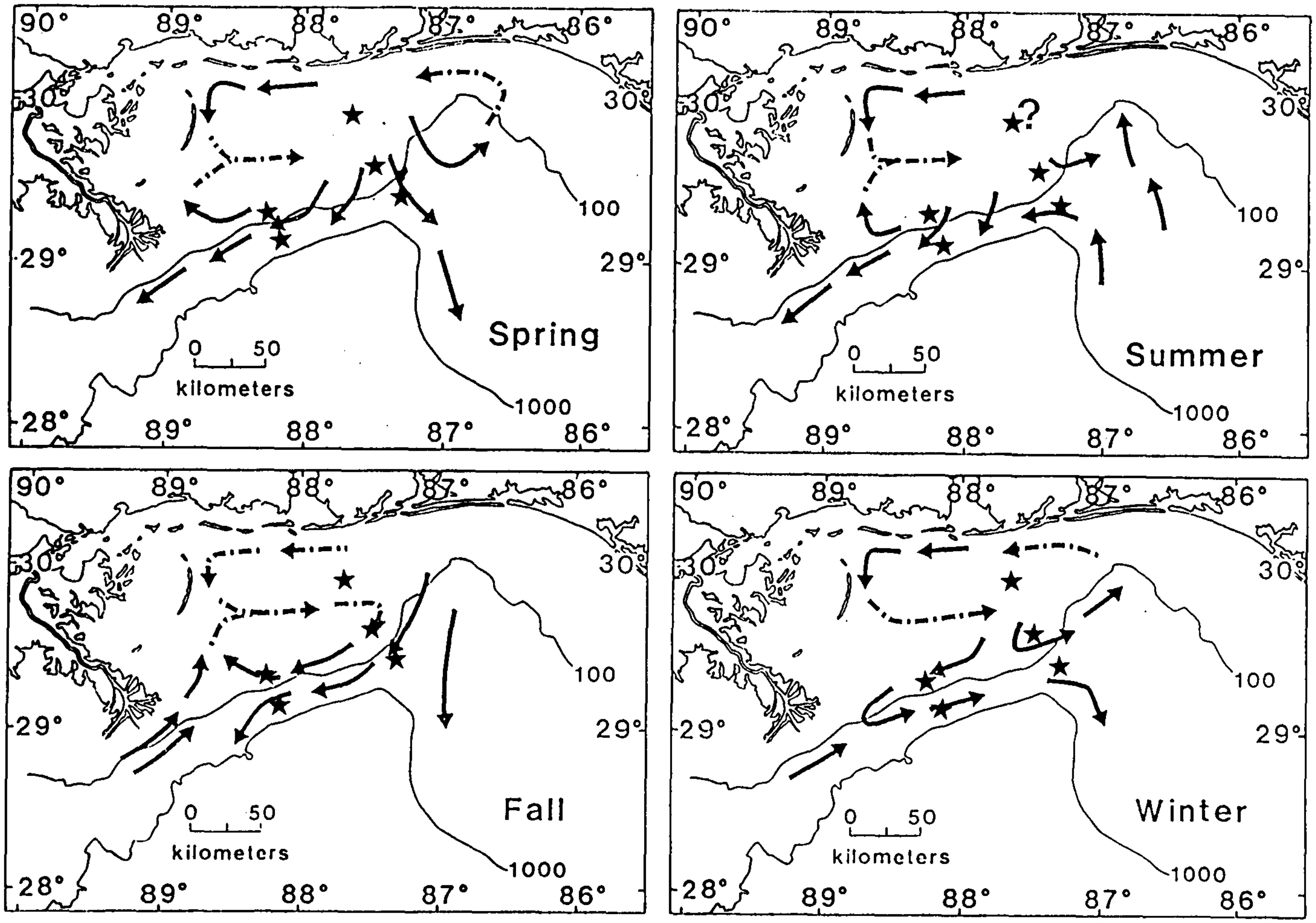


Figure 10-36. Locations (stars) of the five current meter moorings of this study superimposed on Dinnel's (1988) generalized seasonal circulation in the MAMES region. Broken lines are subjective, solid lines are objective, based on current meter observations over the inner shelf and, over the out shelf and slope, dynamic heights relative to 500 db computed from mean historical hydrographic data.

the standard deviations listed in Tables 10-2 through 10-13. This test for significant mean flow should be regarded only as a rough indicator. There is a question about whether the variance of the 3- or 40-hour low passed series should be used for determining significance. The latter should have smaller variance because the deterministic, i.e., non-stochastic, sinusoidal tidal components are removed. However, we chose the former because the amplitudes of the tidal constituents are quite small in the study region, and non-deterministic processes such as inertial oscillations and forcing by the sea breeze contribute significantly at times to the current variance at near-diurnal frequencies.

At AT (Table 10-2), only the northeastward mean flows in April and May 1988 and the southwestward mean flow in September 1989 were significant by the above criterion. Note that the strongest mean flow occurred when the mean wind stress was almost zero (Figure 10-23). The seasonal roses for AT (Figure 10-25) exhibit a rather broad distribution of occurrence among the direction octants. There is a tendency for the east-west and northeast-southwest directions to be dominant. Flow in one direction is often balanced by a similarly frequent occurrence of flow in the opposite direction, yielding the low seasonal means. The monthly means for AB (Table 10-3) are more organized in direction than those for AT, having a definite northeastward and onshore tendency (Figure 10-22), but only the mean flow for June 1989 is significant. The dominant directions for AB are frequently rotated clockwise by one octant from those at AT (cf. Figures 10-25 and 10-26). The high percentage of calms at AT for July-September 1988 was partly due to fouling by a fishing line, but note that calms were also frequent at AB, which had no fouling.

Mean currents at BT (Table 10-4) were significant in February of both 1988 and 1989 and from May through October 1988, even though mean wind stress was weak and variable from May through July 1988. The strong mean eastward current in May was definitely related to an intrusion that moved into the eastern part of the study area. We have neither satellite imagery nor temperature data at CM and CB to indicate whether during June through August 1988 intrusions were present that could have forced the strong eastward flow in those months as well. In September 1988 the combined effects of hurricanes and a possible intrusion (Figure 10-16) drove a southwestward mean current of 20.6 cm s^{-1}. Significant southwestward mean flow continued in October when there was both northeasterly wind stress and clear evidence of an intrusion.

The seasonal current roses for BT (Figure 10-27) have either east or northeast as the dominant direction sector for all seasons except October-December 1988 and January-March 1990. Mooring B was located in a complex region of convergence and divergence in the circulation schema proposed by Dinnel (1988), making difficult a comparison between it and the observations at BT. The off-shelf flow he suggests for spring (Figure 10-36) is not confirmed by either of the spring roses in Figure 10-25. However, the eastward and northeastward dominance of flow during summer is consistent with the hypothesized pattern for that season. The dominant southwestward direction in the rose for the fall of 1988 agrees with Dinnel's fall picture, but the rose for the fall of 1989 does not. The percent of calms for the latter is unusually large, suggesting a possible problem with the data; however, no fouling or instrument malfunction was found upon retrieval of the instrument, and the current rose for DT for the same period (Figure 10-32) also indicates a high percent calm. The winter roses for 1988 and 1989, which have eastward and northeastward as the dominant directions, are consistent with the generalized circulation proposed for winter.

The monthly mean vectors (Figure 10-22) indicate that the mean bottom current at BB flows persistently toward the southwest. The along isobath component means that are significant have a range from -3.6 to -6.7 cm s^{-1} (Table 10-5). The seasonal roses for BB (Figure 10-28) further illustrate the dominant nature of the southwest flow. Flow in the opposite direction, i.e., northeast, occurs only about six to eight percent of the time. According to the tables of joint distribution of speed and direction (Appendix C), seasonal mean speeds in the southwest direction range from 6.5 to 10.8 cm s^{-1}. The roses, as well as time series of stick vectors (e.g., Figure 10-14) show that flow with a cross-shelf component occurs frequently. Since the off-shelf and on-shelf components of flow are fairly balanced in frequency of occurrence, monthly means of the cross-isobath component are small.

The mean velocities recorded in the upper half of the water column at Mooring C on the upper continental slope (Table 10-6) are generally much larger than those on the shelf. The largest component means are 21.7 and 18.1 cm s^{-1} for the along and cross isobath directions, respectively. Some of the values that are relatively large are not significant because the corresponding standard deviations are also large, e.g., March 1989. For both CT and CM the mean velocities are not significantly different from zero for the months of December 1988 and March, April and November 1989; for CM a number of other months have means that are not significant as well. The seasonal rose tables for CT (Appendix C) show that average speeds in the dominant directions range from 16.6 to 28.8 cm s^{-1}. The mean along-isobath flow at CT was positive, toward 55°, for all months except September 1988, when hurricane effects dominated the forcing. The mean cross-isobath components (Table 10-6) were generally offshore, the period of December 1988 through April 1989 being the exception. Seasonal rose diagrams (Figure 10-29) emphasize the preponderance of flow with an eastward or northeastward component. We conclude that the observations do not support Dinnel's (1988) hypothesized flow pattern in the region of Mooring C for any season .

The mean flow at CM (Table 10-7) was similar to that at CT but seemingly more variable; part of the greater variability is an artifact caused by missing data in a number of months, which gives undo weight to events of more than a few days duration, e.g., May and September 1989. The flow at CB, as at BB, was persistently directed to the southwest throughout the 27-month observation period (Figure 10-22). Almost two thirds of the monthly means have significant magnitudes, the largest of which exceed 10 cm s^{-1}.

At DT (Table 10-9) the monthly mean flow had a positive (toward 55°) component from February through September 1989. Significant mean flow occurred in February, June, July and August. (The means for November, 1989 through February 1990 are unusually low; we suspect a problem with the instrument and disregard the data.) At DB significant cross-isobath mean currents caused persistent southeastward mean flow from February through May 1989. From June through October mean flow was weaker and variable in direction, but nevertheless significant at times.

Strong, persistent, northeastward mean flow was recorded at ET (Table 10-10) from February through June 1989 and at EM from February through September 1989. For October the mean flow at EM was southwestward.. Monthly means frequently exceeded 15 cm s^{-1} at both ET and EM. As at BB and CB, mean currents at EB were persistently southwestward (Figure 10-23), but only significantly so for the months of July, September and October 1989.

In order to estimate the long term mean flow at each current meter location, we computed the mean of the monthly means and the standard deviation of the mean. for the along- and cross-isobath components of current. We excluded months missing more than one-third of their data. Here the standard error (standard deviation of the mean) is computed directly rather than being estimated from a single sample (Equation 10-1). We are interested in long term means that at least exceed their corresponding standard error, even if not by a factor of two, because such means are significant at some reasonable level. Table 10-16 shows that all near surface current meter locations have positive along-isobath means, while the cross-isobath means are all near zero or negative, i.e., off shelf. However, only those for ET exceed their standard errors (but the record for ET is only four months long). More importantly, the along isobath means for BB, CB and EB are all negative and larger than their standard errors, that for CB by a factor of almost three. For AB the cross-isobath component is significantly onshore. Neither component mean is significant for DB.

The existence of a mean current at 426-m depth at CB and, to a lesser degree, EB may account for the lack of agreement between the observations of this study and the seasonal circulation patterns that Dinnel (1988) proposed for the outer shelf and slope, where he based his conclusions on seasonal maps of dynamic heights computed relative to a level of no motion at 500 m. We do find agreement with Dinnel's (1988) schema in the regions of Moorings A and B. The idea of a mean cyclonic circulation cell is supported, but the observations from Moorings C, D and E suggest that its southern side extends to the outer shelf and upper slope. We find no evidence for the anti-cyclonic mean circulation over the outer shelf and slope that Dinnel proposed.

Table 10-16. Mean of the monthly means and standard deviation of the mean for the U (along-isobath) and V (cross-isobath) components of the current velocity at each current meter location.

		U ($cm\ s^{-1}$)		V ($cm\ s^{-1}$)	
Location	N	Mean of Monthly Means	Standard Deviation of the Mean	Mean of Monthly Means	Standard Deviation of the Mean
AT	18	0.63	3.46	0.06	1.50
AB	15	0.95	2.45	1.24	0.93
BT	22	1.70	7.30	-1.26	2.85
BB	19	-2.73	1.78	-0.67	0.59
CT	12	9.15	10.72	-4.66	6.81
CM	17	2.73	9.89	-0.97	3.09
CB	19	-6.40	2.35	-0.17	0.61
DT	8	4.34	5.02	-1.35	3.50
DB	8	0.38	2.79	-2.10	2.95
ET	4	17.18	3.28	-7.35	3.75
EM	8	7.75	14.02	-2.65	5.94
EB	8	-3.35	2.68	0.74	0.97

The persistent southwestward flow at BB, CB and EB suggests the existence of a large scale east-to-west pressure gradient. Large scale pressure gradients are believed responsible for the mean southwestward flow observed on the shelf of the Mid-Atlantic Bight (Csanady 1978) and the northward undercurrent observed on the outer shelf and slope off California and Oregon (Hickey 1979, 1981; Hickey and Pola 1983). For the MAMES region the effect of such a pressure gradient is most pronounced in the eastern part over the outer shelf and slope because in the western part, mean cyclonic circulation over the shelf, the existence of which is supported by the results of this study noted above, raises mean sea level elevation along the north-south boundary of the Delta and Chandeleur Islands. The west-to-east pressure gradient at this boundary locally counters the large scale pressure gradient, and thus diminishes or eliminates the mean southwestward flow at EB and DB.

10.5 Spectral Analyses

For most of the cross-spectral analyses discussed below we have used the method of cross-rotary analysis for pairs of vector series (Section 10.2.6), which has the advantage of invariance under a coordinate rotation. The alternative is to compare Cartesian components, with all locations having a common rotation or with each location having a rotation that is chosen by some objective means. The former, although simple, must deal with cross-component coherence when the principal component of flow is not aligned along a coordinate axis, and the latter introduces shifts in coherence and phase that are a function of rotation and requires a substantial amount of additional work. Table 10-17 lists the direction, in degrees clockwise from north, of the principal axis of the 40-hour low passed current velocity for each deployment period at each current meter location. There is clearly substantial variability in the direction of the principal axes between deployment periods at a given location and among the locations, both horizontally and vertically. The right two columns in Table 10-17 show the mean direction for each meter location and the angular difference, respectively. The means exhibit more order. An interesting result is the mean counter-clockwise rotation, on the order of 25° between the principal axes of the near surface currents and the deeper

Table 10-17. Direction, in degrees clockwise from north, of the principal axis of 40-hour low passed current velocity for each deployment period of each current meter location. Dates of deployments at Mooring B are used for reference. Corresponding deployments at other moorings have slightly different dates.

Meter Location	Deployment Period						Mean	Vert. Diff.
	12-30-87 to 3-16-88	3-17-88 to 8-22-88	8-24-88 to 1-13-89	2-8-89 to 6-21-89	6-21-89 to 10-23-89	10-24-89 to 2-11-90		
AT	83	94		77	63	69	77	28
AB	56	41			43	56	49	
BT	68	84	64	76	54	70	69	28
BB	47	37	44	46	30		41	
DT				96	55		76	16
DB				77	43		60	
CT			87	72	88	66	78	25
CM	55		49	52		57	53	7
CB	43		43	46	55	45	46	
ET				91			(91)	(24)
EM				67	72		70	-7
EB				76	77		77	

ones. Our choice of a working coordinate system that has its along-isobath axis rotated clockwise 55° from north seems satisfactory, *a posteriori*.

Cross-spectral analysis, which includes the computation of auto spectra and rotary spectra, was performed on a large number of combinations of time series. Selected results that illustrate general patterns and some special features are presented below. The time periods of February 23 to June 14, 1988 and 1989 are contrasted because their data returns are fairly complete and mean stratification was significantly different between the two years. The summer periods from June 1 to August 29, 1988 and 1989 are also discussed. For reference in the time domain, Figures 10-37 and 10-38 show stick plots of wind and currents for February 18 through June 23, 1989, and Figures 10-39 and 10-40 show them for the period from June 22 through October 23, 1989; the data return is the most complete for these two periods.

10.5.1 Wind Stress and Sea Level

To relate wind stress and sea level we have used the traditional approach and performed cross-spectral analysis between the scalar time series of sea level and Cartesian components of the vector series of wind stress. The coherence between wind stress at Buoy 42015 and sea level at Dauphin Island illustrates the effect of the right angled coastal boundary. For a straight coast of infinite extent the along-shore component of wind stress is primarily responsible for synoptic period fluctuations (2-10 day periods) of coastal sea level. Direct setup by the cross-shore component is usually insignificant except in coastal regions that have shallow depths extending a considerable distance offshore (Chuang and Wiseman 1983) or when strong vertical stratification creates a distinct upper layer. Where the boundary is right angled, wind stress has an along-shore component along both sides (excepting cases where the wind is parallel to either part of the right angle, and coastal flow at any point could be both locally and remotely forced. A coordinate rotation of the wind stress components can be found that will maximize the coherence between sea level and one of the components of wind stress.

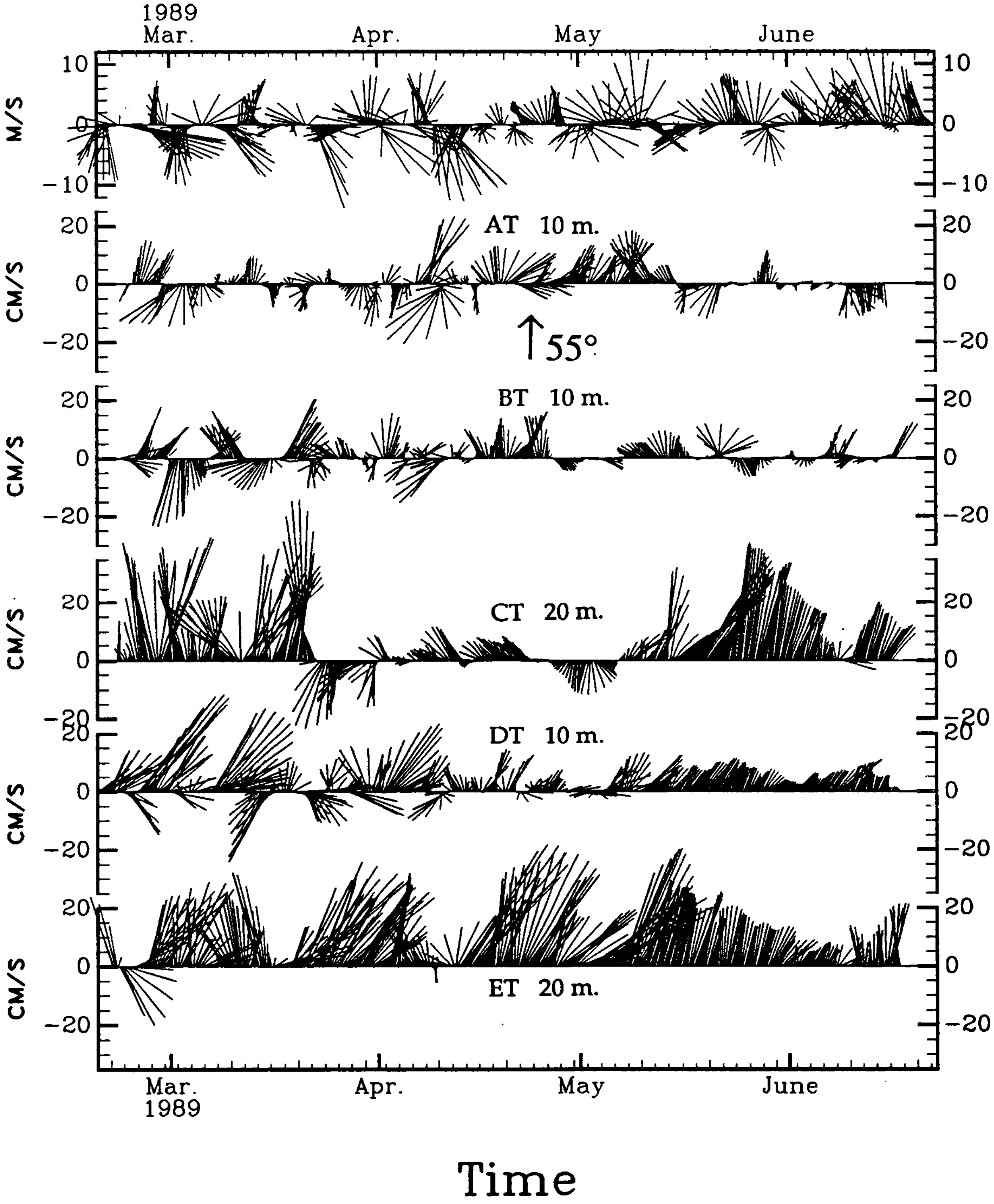
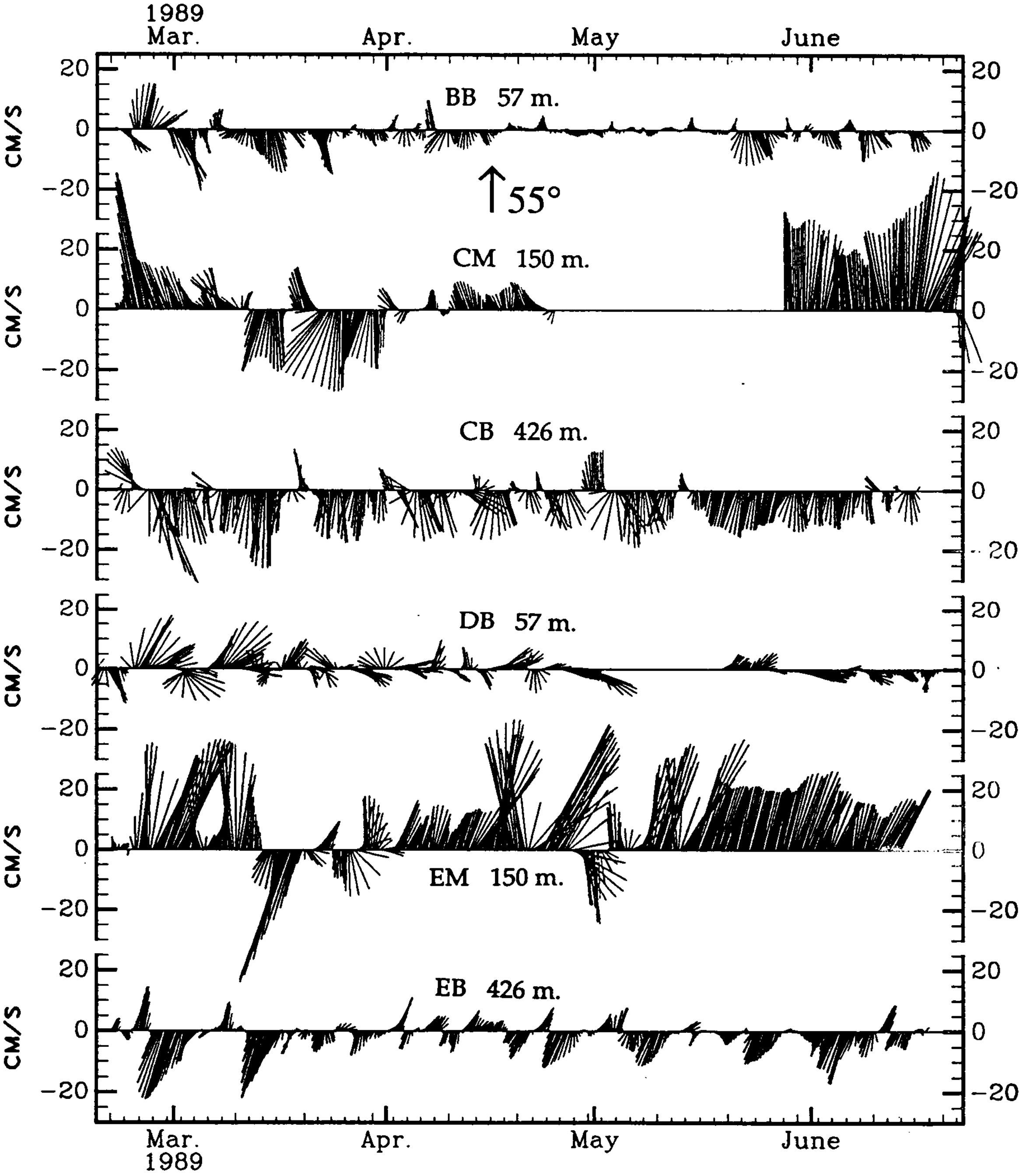


Figure 10-37. Stick plots of 40-hour, low-passed wind velocity (top frame) and currents at AT, BT, CT, DT and ET for the period February 18 through June 23, 1989. Up the page is toward 55°.



Time

Figure 10-38. Stick plots of 40-hour, low-passed currents at BB, CM, CB, DB, EM and EB for the period February 18 through June 23, 1989. Up the page is toward 55°.

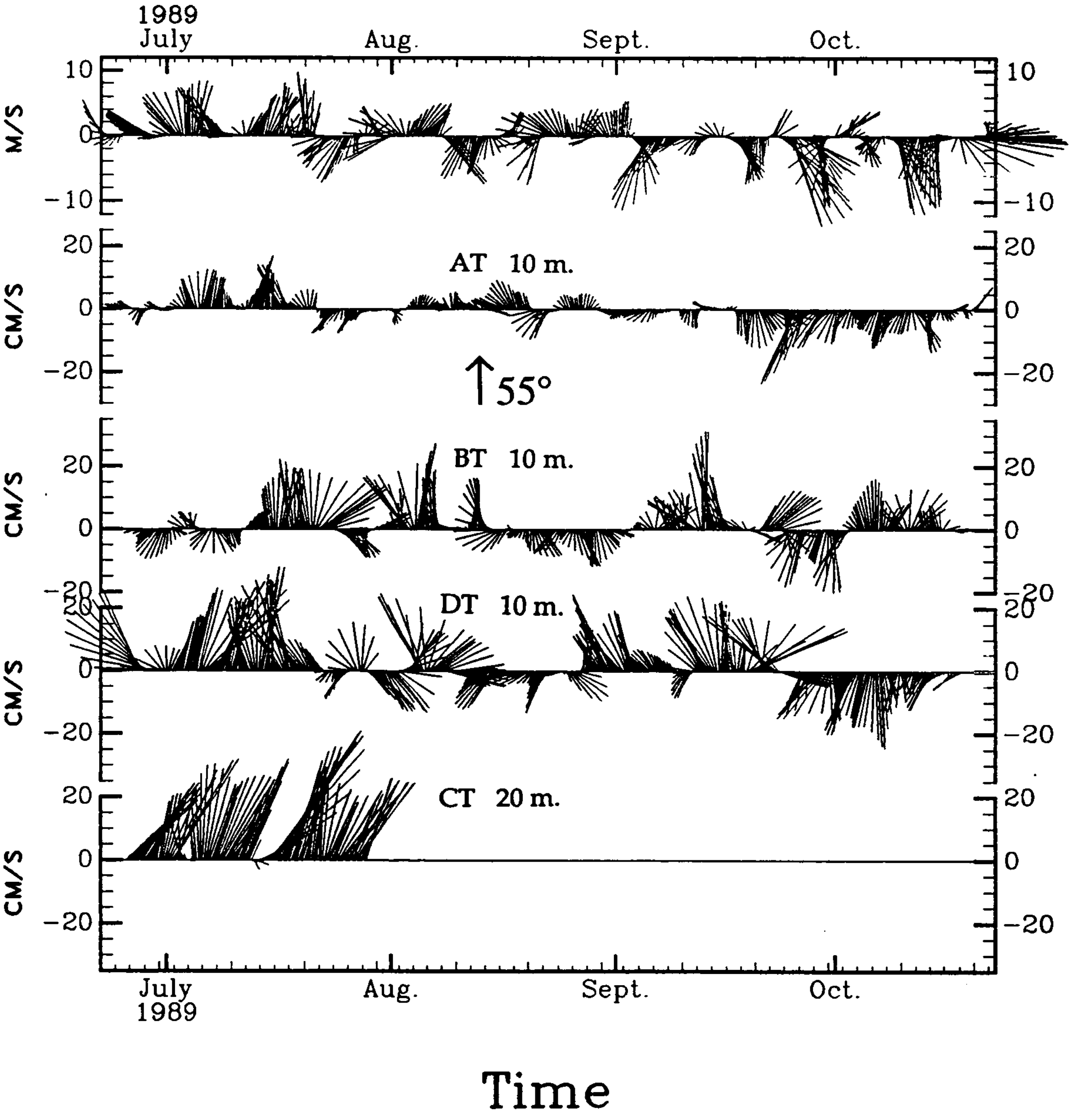


Figure 10-39. Stick plots of 40-hour, low-passed wind velocity (top frame) and currents at AT, BT, DT and CT for the period June 22 through October 23, 1989. Up the page is toward 55°.

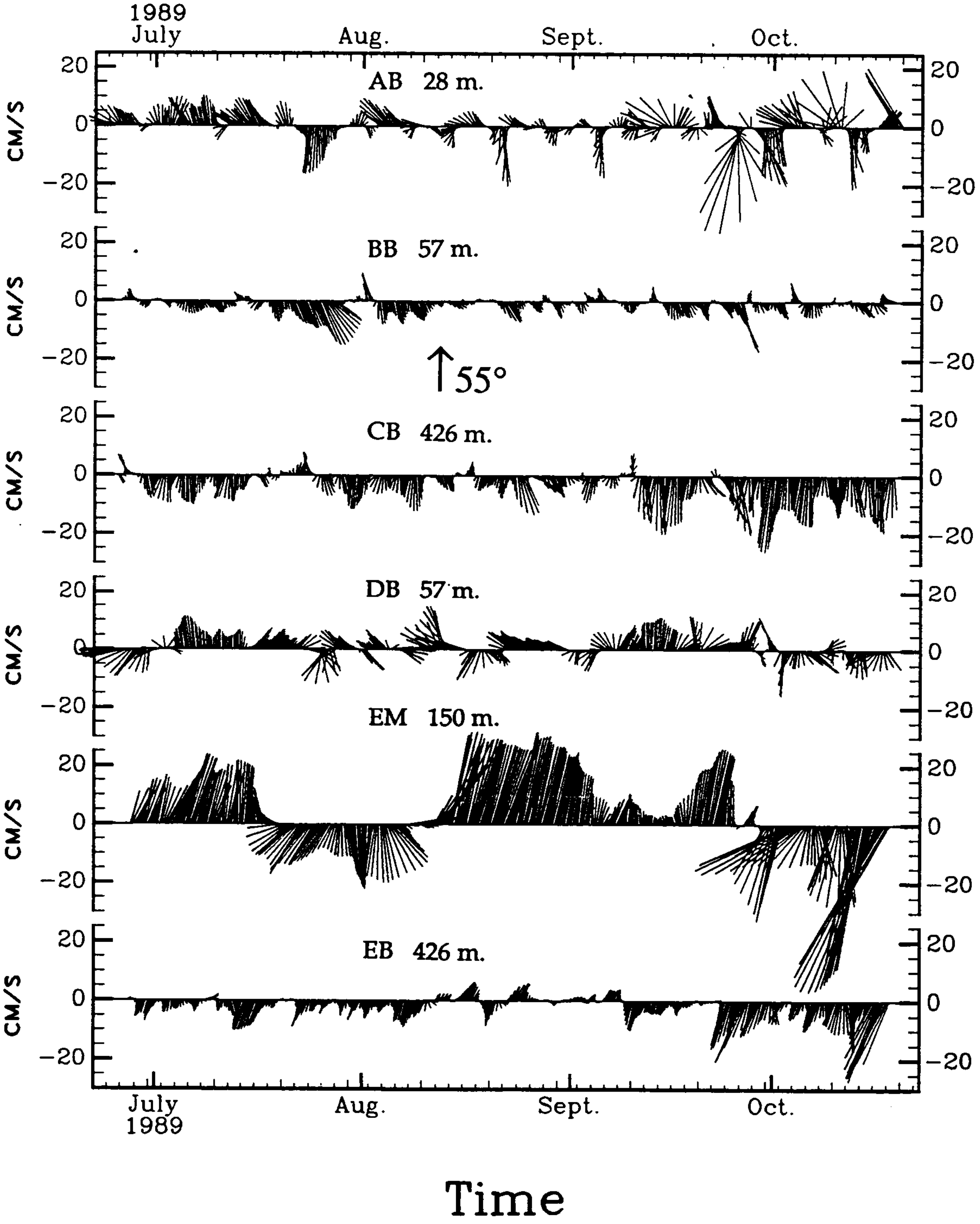


Figure 10-40. Stick plots of 40-hour, low-passed currents at AB, BB, CB, DB, EM and EB for the period June 22 through October 23, 1989. Up the page is toward 55°.

The sign of the phase spectrum can be interpreted either as lead/lag information or as direct/inverse relationship information. Since we assume *a priori* that a cause-and-effect relation exists between wind stress observed at Buoy 42015 and sea level observed 10 km away at Dauphin Island, wind stress must lead sea level. Therefore, the positive values of phase across the spectrum for all four cases studied indicate that the relation between wind stress and sea level is direct—a positive change in stress, i.e. a northwestward increase, causes a positive change in sea level, i.e. a rise. (If one were investigating wave propagation between two locations, in which case the direction of propagation is unknown, the sign of the phase would be interpreted in terms of lead/lag information.

For the period from February 23 to June 14, 1988, the wind stress component along 300° (V) maximizes the coherence (Figure 10-41a,b); the component along 30° (U) is incoherent with sea level at all frequencies (Figure 10-41c). In this coordinate system the V-wind stress and sea level are coherent at all frequencies except 0.3 cpd. The coherence is greatest from 0.06 to 0.25 cpd and at 0.4 cpd. Stress leads sea level by about 20° at low frequencies and 50° at high frequencies. For comparison, Figure 10-42 shows two other rotations, one with the U-component along 55° (Figure 10-42a, b) and the other with it along 90°, i.e., east-west. The coherence spectrum for the 55°/325° system is very similar to that for the 30°/300° system. Coherence between the U-component and sea level first appears at the higher end of the synoptic band of frequencies as one moves away from the most linearly independent rotation. Figure 10-42c,d shows that in an east/north system both components are significantly coherent with sea level, and interpretation is more difficult. Regardless of the coordinate system, it is not clear how much of the coherence is caused by remote forcing. Chuang et al. (1982) analyzed summer currents off the Alabama coast, and they too noted that the 90° change in coastline orientation complicates the relations among wind, sea level and currents.

Figure 10-43 shows the coherence between sea level and the wind stress component along 325° (V), which is the direction that maximizes coherence.for the period from February 23 to June 14, 1989. Maximum coherence occurs at 0.2 cpd, the same frequency as in 1988, but below 0.15 cpd and above 0.4 cpd coherence is much lower than in 1988. Phases corresponding to maxima in coherence are similar in both years.

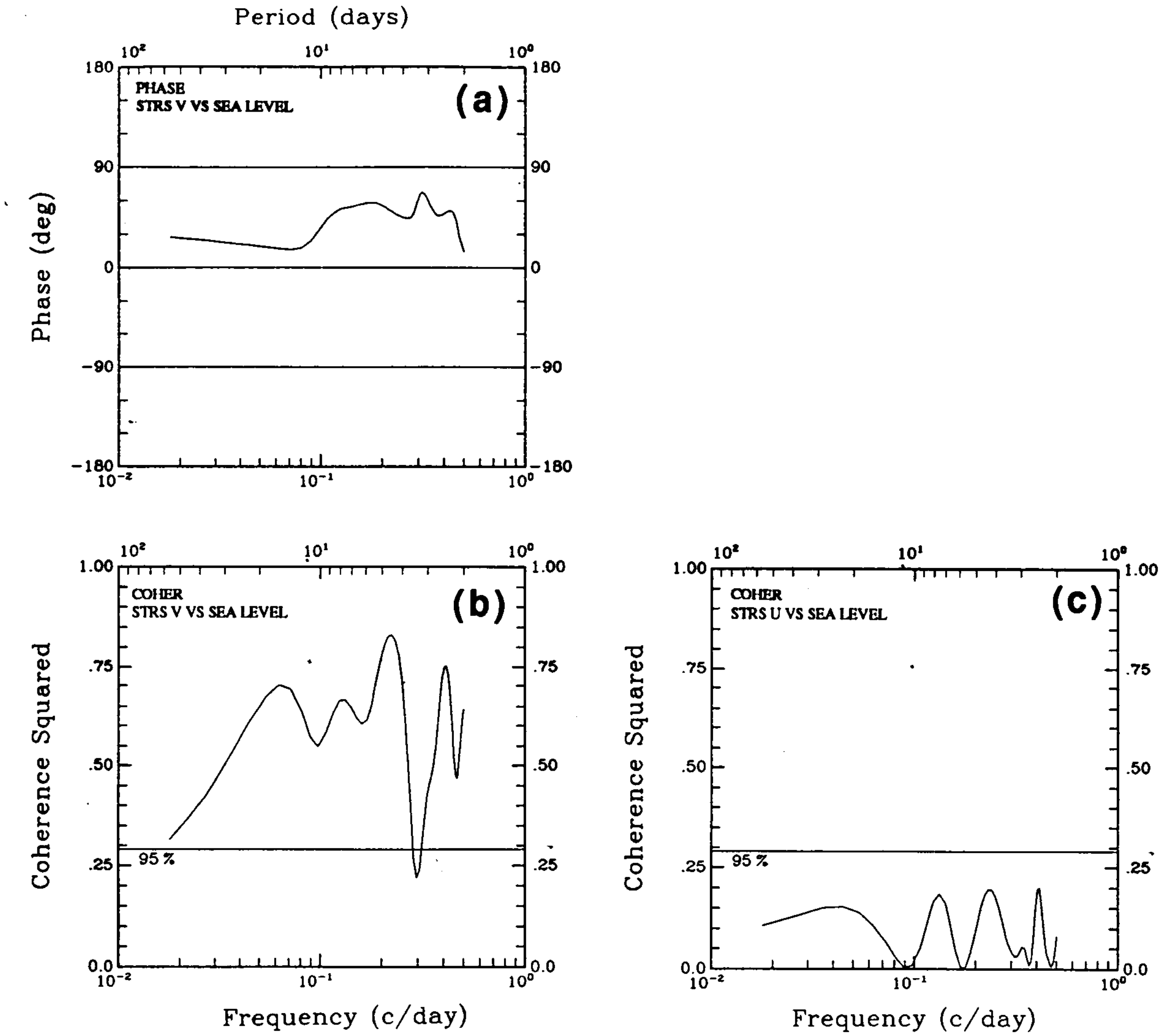


Figure 10-41. For the period from February 23 to June 14, 1988, the phase (a) and coherence (b) between the wind stress component along 300° and sea level; (c) coherence between the wind stress component along 30° and sea level.

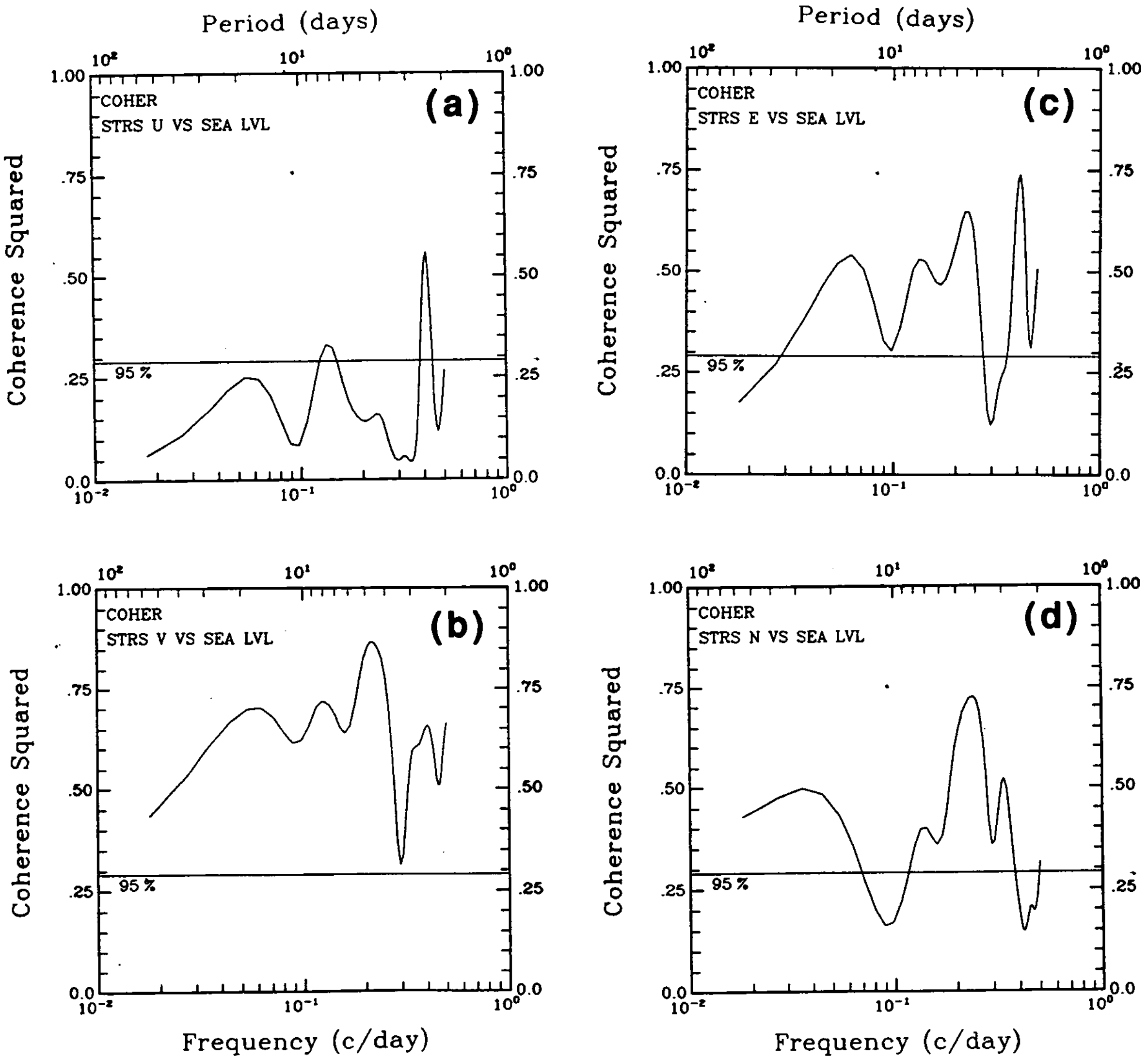


Figure 10-42. For the period from February 23 to June 14, 1988, the coherence between sea level and (a) the wind stress component along 55°, (b) the wind stress component along 325°, (c) the eastward wind stress component and (d) the northward wind stress component.

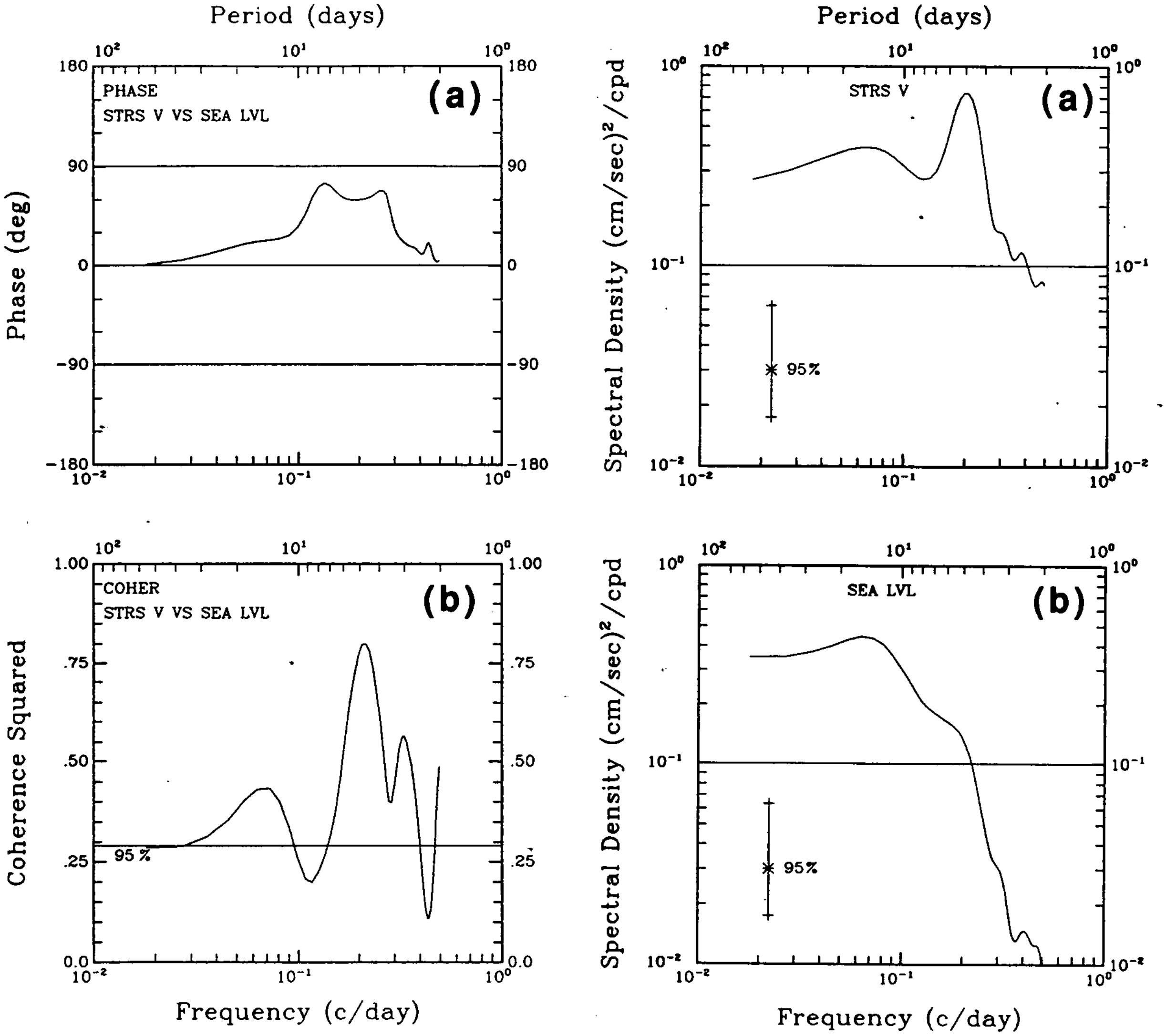


Figure 10-43. For the period from February 23 to June 14, 1989, (a) the phase and (b) coherence between the wind stress component along 325° and sea level; the autospectra for (a) wind stress component along 325° and (b) sea level.

The magnitude of the phase is about 20° at low frequencies and 50° at high ones. This translates to wind-stress change leading sea level response by about 19 hours at low frequencies and 8 hours at high ones (e.g., for a phase of 20° at 0.07 cpd, the lead is [(50°/360°) x (24 hours per day/0.07 cycles per day)] or 19 hours. The coherence (formally coherence squared) plays the role of a multiple correlation coefficient at a given frequency. The coherence between wind stress and sea level is large—it exceeds the 95% level of significance over broad frequency bands and it exceeds 0.6 somewhere between 0.2 and 0.4 cpd (2-5 day periods) for the winter/spring cases. However, the coherence spectrum also indicates that wind stress accounts for only a portion of the variability observed in the time series of sea level. From a time-domain point-of-view, we do not attempt a quantitative estimate of the actual rise or fall in sea level for a specific change in wind stress because of the frequency dependence and partial coherence of the response. (A simple linear regression of the set of data pairs formed by the two time series is not appropriate because the successive observations that form any time-series except white noise are not linearly independent.

For the period from June 1 to August 29 in both years, a V-component along 285° maximizes the coherence spectrum (Figures 10-44 and 10-45c,d). Both periods exhibit the strongest coherence at the low and high ends of the spectrum. A very interesting difference between the two summer periods is that for the 1989 data, when stratification was greater, significant coherence is also found between the U-component and sea level at frequencies greater than 0.2 cpd for all choices of rotation (Figure 10-45a,b).

The directions that maximize the component response for the 1988 and 1989 winter/spring cases are 300° and 325°, respectively. These directions are close to the angle of 315° that bisects the right angle of the coast. Thus the maximum response on the northern coast during winter/spring is due to both the shore parallel and the shore perpendicular wind-stress components. For the summer period of both 1988 and 1989 a direction of 285° maximized the coherence, which is close to the 270° direction that parallels the northern boundary. We hypothesize that the influence of the shore-perpendicular component is partly related to the

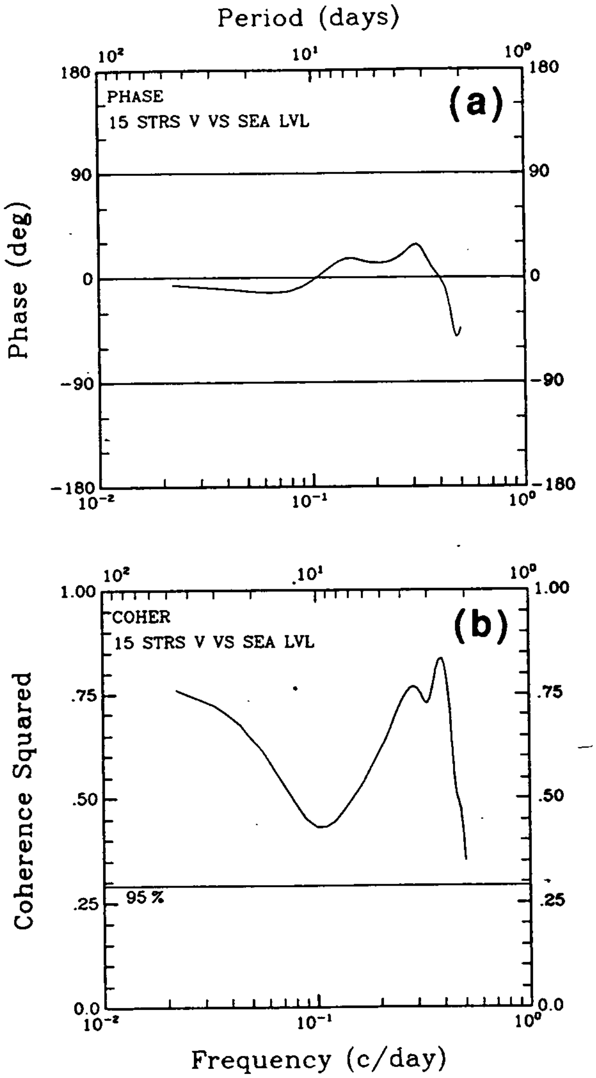


Figure 10-44. For the period from June 1 to August 29, 1988, (a) the phase and (b) the coherence between the component of wind stress along 285° and sea level.

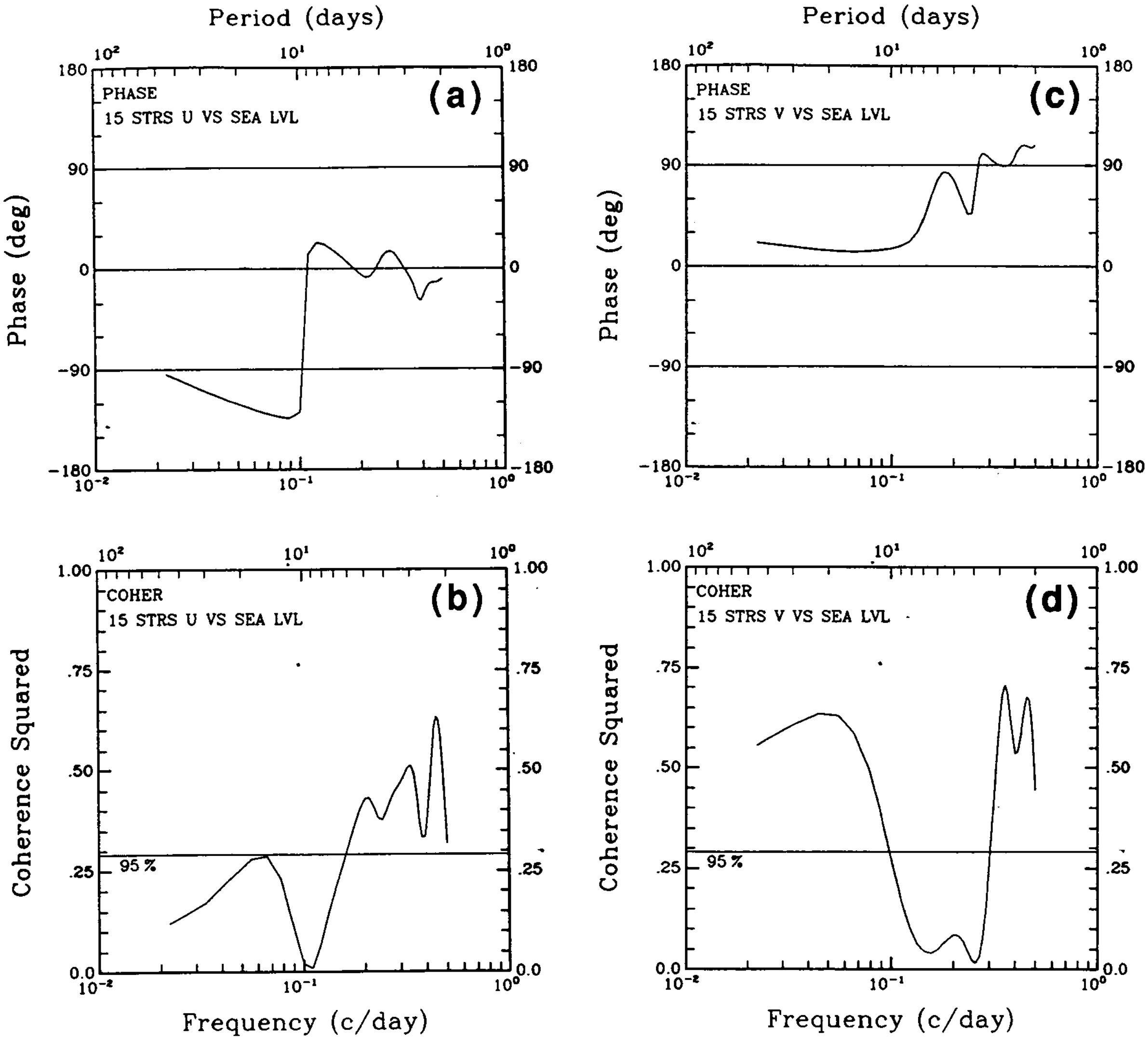


Figure 10-45. For the period from June 1 to August 29, 1989, (a) the phase and (b) coherence between the component of wind stress along 15° and sea level, and (c) the phase and (d) coherence between the component of wind stress along 285° and sea level.

degree of stratification, and thus river runoff, which was greater in spring than summer, particularly the spring of 1989.

10.5.2 Wind Stress and Currents

As expected, wind stress is highly coherent with both AT and AB currents over broad frequency bands for most of the time periods examined. The results for the period from January 5 to May 23, 1988 are fairly typical. Rotary spectra of wind stress and AT current (Figure 10-46d,e) have similar structure, with a broad maximum between 0.04 and 0.05 cpd and several relative maxima in the synoptic band of 0.1 to 0.5 cpd. The CW (light line) and CCW (heavy line) components of stress are of the same order of magnitude but unequal over most of the spectrum, which indicates elliptical polarization. The rotary components of AT current exhibit a similar relationship.

The coherence and phase between wind stress and AT current (Figure 10-47) are consistent with a simple wind driven shelf model. The inner coherence (Figure 10-47b) is strong for the co-rotating CCW components (heavy line) throughout most of the synoptic frequency band and around a broad-banded peak at 0.04 cpd. The corresponding phase angle (heavy line in Figure 10-47a) varies from 10° at 0.04 cpd, or 16 hours ((24 hr/0.04 cpd) X (10°/360°)), to -90° (12 hours) near 0.5 cpd. Positive phase means that the first named series leads the second, but a process that causes a negative relation between two series will cause the phase to be negative even though the first series physically leads the second. In our choice of a Cartesian system, on which the rotary transformation operates, the components are positive to the northeast (U) and onshore (V). Wind driven Ekman surface flow in conjunction with a coastal boundary then generates an negative correlation between alongshore stress and cross-shelf current, which gets incorporated into the rotary phase relationship. We believe that this process accounts for the negative phase values between stress and AT current in the synoptic frequency band. Co-rotating CW components (light line) are incoherent in Figure 10-47b.

The spectra of outer coherence between stress and AT current (Figure 10-47c,d) exhibits strong coherence between the counter-rotating CCW and CW pair at frequencies below 0.1 cpd, with a peak at 0.07 cpd. To get a

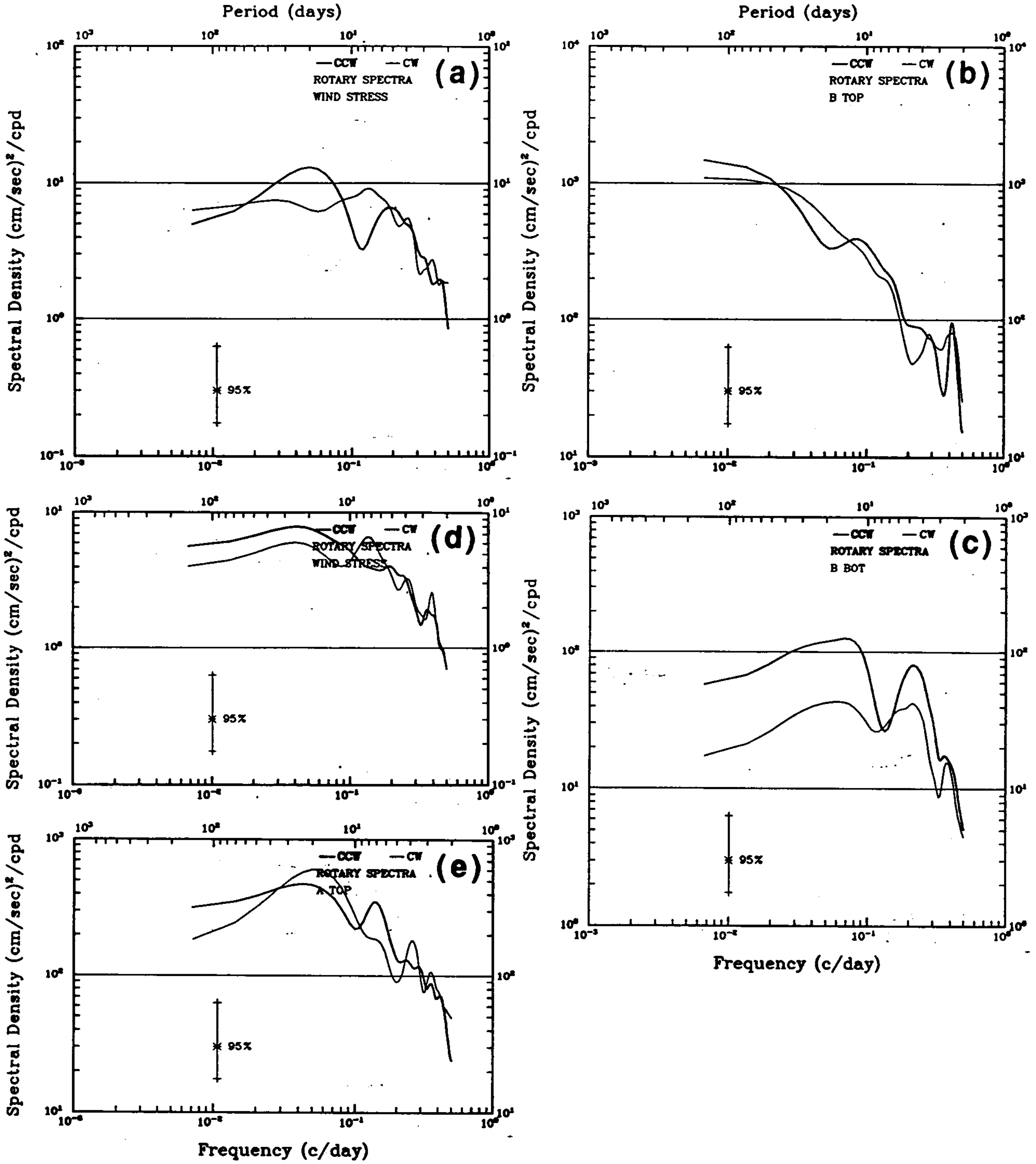


Figure 10-46. For the period from March 22 to August 18, 1988, rotary spectra for (a) wind stress, (b) BT current and (c) BB current; for the period from January 5 to May 23, 1988, rotary spectra for (d) wind stress and (e) AT current.

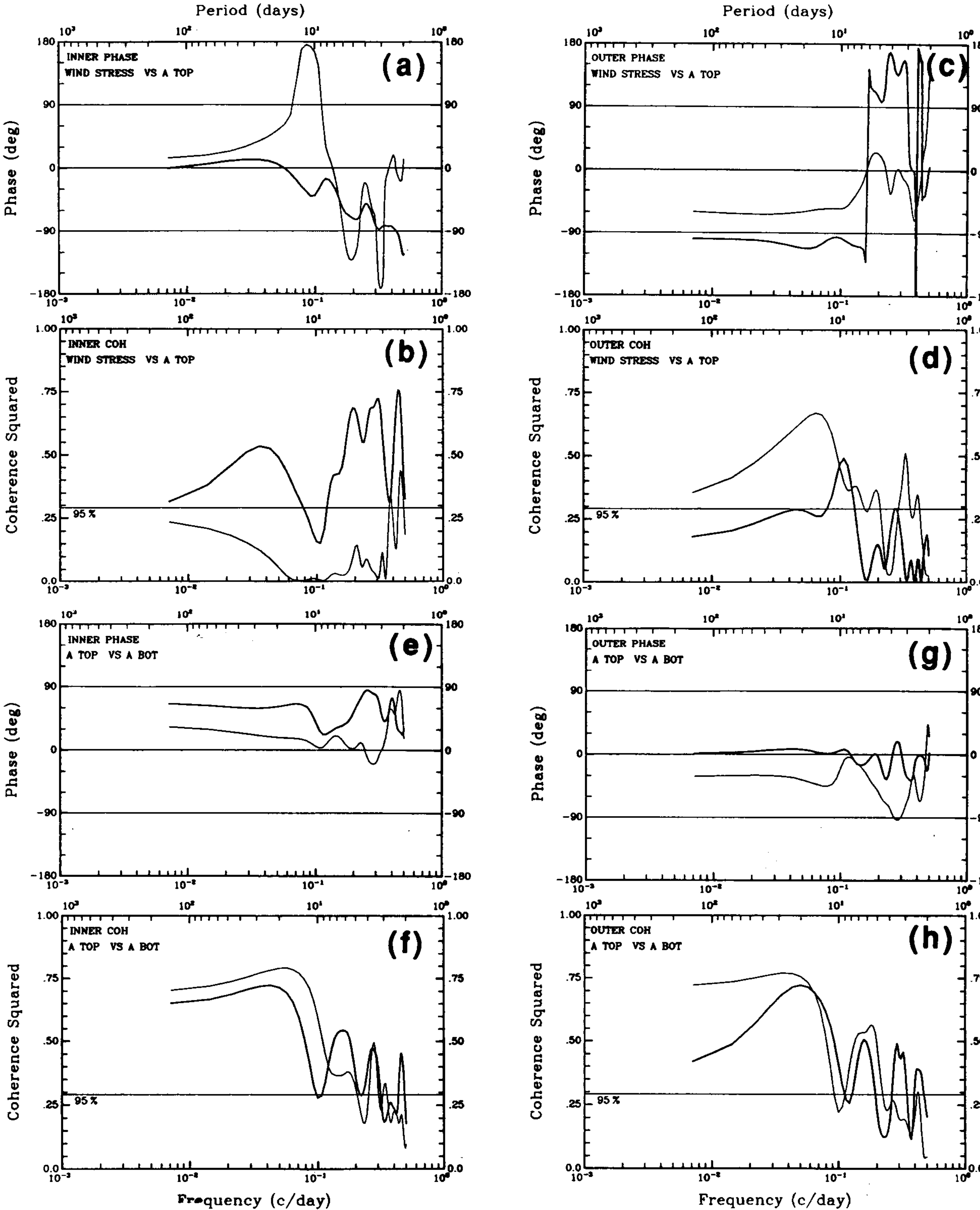


Figure 10-47. For the period from January 5 to May 23, 1988, (a) inner phase and (b) coherence and (c) outer phase and (d) coherence between wind stress and AT current; (e) inner phase and (f) coherence and (g) outer phase and (h) coherence between AT current and AB current.

corresponding time lag, the phase angle of -60° must be corrected for the orthogonal nature of the CCW and CW components by adding 90°. The resulting phase of 30° corresponds to the CCW component of stress leading the CW component of current by 28 hours. The only significant coherence between CW stress and CCW current lies in a narrow frequency band centered at 0.1 cpd. We conclude that the CCW component of wind stress was the primary forcing mechanism for AT currents during the first part of 1988. The CCW component of AT current responded rapidly, and, at synoptic frequencies, in a manner consistent with a simple Ekman coastal model. The CW response was more delayed and restricted to frequencies lower than 0.1 cpd, which may indicate remote forcing.

Coherence between stress and AB current for the above time period (not shown) was similar to that for AT. Thus wind stress is effective in driving the entire water column at this inner shelf location.

The interpretation of phase angles associated with significant values of coherence is usually difficult except when a single process is suspected to dominate, as above. Competing processes, variations in bottom topography, and density stratification can all act to randomize the phase angle. Hereafter, we usually present the plots of phase along with the plots of coherence for general reference but do not attempt an interpretation. We focus primarily on frequency bands for which coherence is strong between the quantities being analyzed.

For BT and BB, currents during the period from March 22 to August 18, 1988 are analyzed. This period partly overlaps that used above for AT currents. The rotary spectra for these time series are shown in Figures 10-46. The CCW component of wind stress during this period (Figure 10-46a) is the most energetic, with broad, well defined peaks near 0.05 and 0.2 cpd. The CW spectrum has a slight peak at 0.14 cpd, a flat spectrum at lower frequencies and sharp fall off in energy above this value. The BT rotary components (Figure 10-46b) are both red and close in magnitude, indicating almost rectilinear motion. In contrast, the CCW component dominates the BB spectrum (Figure 10-46c), i.e., circular polarization, and presents strong peaks at 0.07 and 0.2 cpd. The CCW component of the BB spectrum is very similar to that of the AT spectrum (Figure 10-46e) but with lower energy.

Figure 10-48 shows the coherence between wind stress and currents at BT and BB for the period from March 22 to August 18, 1988. Inner coherence between stress and BT current (Figure 10-48a) was limited to frequencies near 0.12 cpd for the CCW components and 0.4 cpd for the CW ones. Outer coherence (not shown) was not significant at any frequency. Thus wind forcing was responsible for very little of the variability at BT during the stated period. On the other hand, the coherence between stress and BB current was strong over broad frequency ranges in the inner coherence spectrum and much of the synoptic band in the outer coherence spectrum (Figures 10-48d,f).

For 1989 there is data from the top current meters at all five moorings for the period from February 23 to June 14, 1989. Figures 10-49 and 10-50 illustrate the rotary spectra for wind stress and currents at AT, BT and DT during this period. Wind stress energy (Figure 10-49a) is almost an order of magnitude lower in 1989 than for the similar time period in 1988. The polarization is again elliptical, but the CW component dominates. As noted for the 1988 period, the rotary components of stress for this 1989 period have a broad peak near 0.07 cpd and a more well defined one in the range 0.15 to 0.2 cpd. The CCW spectrum of AT current (Figure 10-49b) is red with no well defined peaks, while the CW spectrum has peaks at 0.7 and 0.14 cpd. The BT rotary spectra (Figure 10-49c) are not as red as those for 1988. The CCW spectrum of BT has a pronounced maximum near 0.08 cpd, while the CW spectrum has little structure except for a peak near 0.33 cpd. In the synoptic band the BT rotary spectra indicate nearly linear polarization. The BB rotary spectra (Figure 10-49d) have peaks near 0.8 cpd and in the range of 0.3 to 0.35 cpd. The CCW component has the greater energy, as it did for the 1988 period, but for this period the polarization is more elliptical than circular. The DT spectra (Figure 10-50a) are relatively flat below 0.1 cpd; the CCW component has peaks at 0.2 cpd and 0.3-0.4 cpd. Polarization for DT is variable. The CW component dominates the DB rotary spectra (Figure 10-50b), with a well defined peak near 0.12 cpd and almost circular polarization between 0.05 and 0.2 cpd. Rotary spectra of CT and ET currents during this 1989 period (not shown) are similar to each other. Below 0.1 cpd the spectra are red, with an order of magnitude more energy than the AT, BT or DT currents, while above this frequency the CCW spectrum of each has a well defined peak at 0.2 cpd.

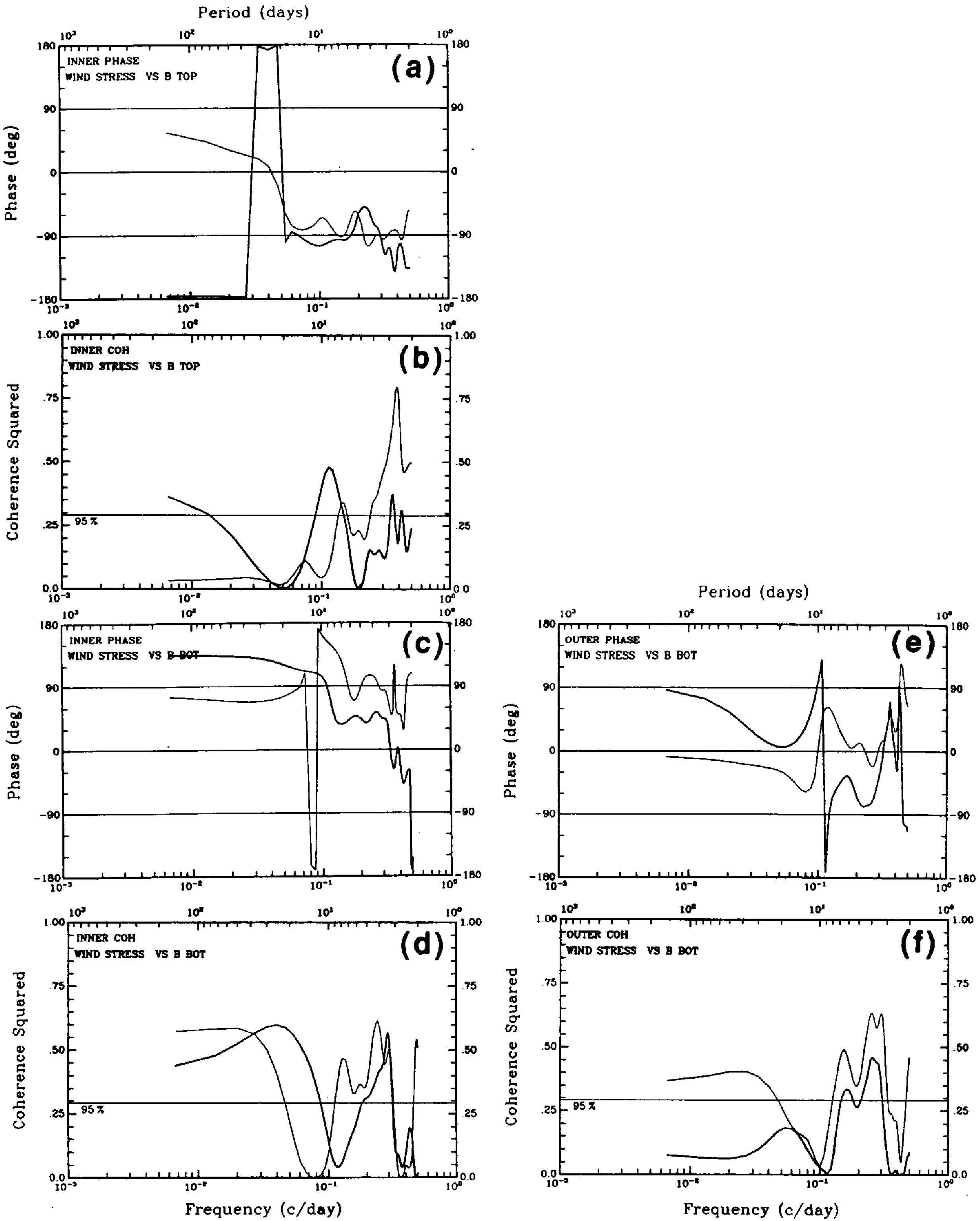


Figure 10-48. For the period from March 22 to August 18, 1988, (a) inner phase and (b) coherence between wind stress and BT current; (c) inner phase and (d) coherence and (e) outer phase and (f) coherence between wind stress and BB current.

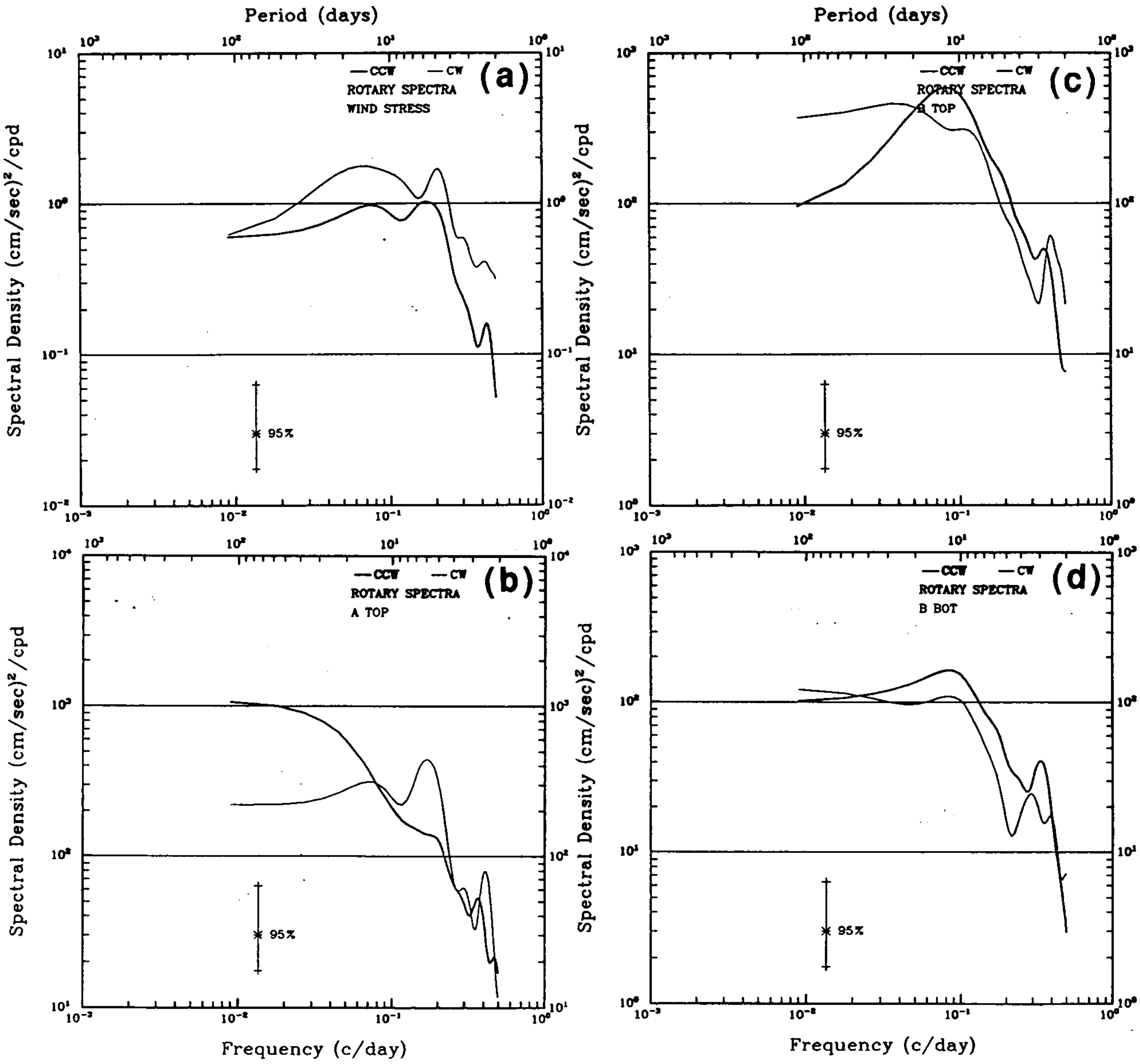


Figure 10-49. For the period from February 23 to June 14, 1989, rotary spectra for (a) wind stress, (b) AT current, (c) BT current and (d) BB current.

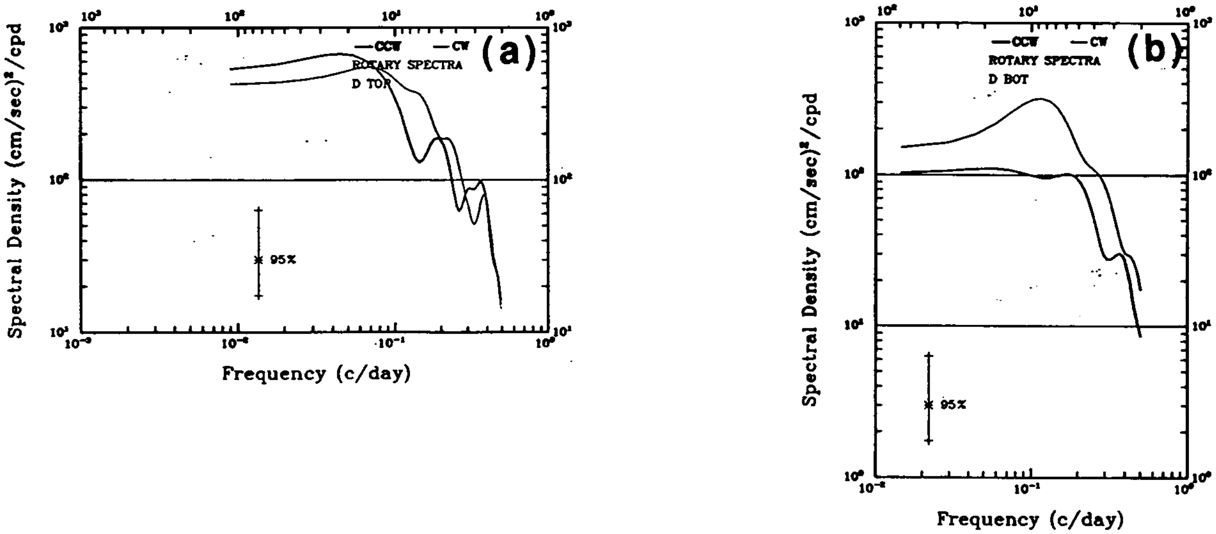


Figure 10-50. For the period from February 23 to June 14, 1989, rotary spectra for (a) DT current and (b) DB current.

Figure 10-51a-d demonstrates that the correlation between wind stress and AT currents is much lower for the 1989 period under discussion (February 23 to June 14) than for the similar period in 1988 (Figure 10-47a-d). Inner coherence is strong only at 0.16 cpd, and outer coherence, while significant over a broad band, is less than 0.4 everywhere. There are no data for AB during this period. Wind stress is coherent with BT currents (not shown), only in the outer spectrum at 0.2 cpd, and wind stress is completely incoherent with BB currents for this period (not shown). Coherence is also very restricted between stress and currents at Mooring D. For DT (not shown) there is coherence at 0.06 cpd in the inner spectrum and 0.14 cpd in the outer spectrum, while for DB (not shown) there is coherence below 0.06 cpd in both coherence spectra and at 0.04 cpd in the inner spectrum.

The coherence between wind stress and the shelf currents was also computed for other time periods for which data were available at each location. In general, the results were more similar to those described above for the first part of 1988 than for the first part of 1989. It appears that wind stress was a much weaker forcing mechanism over the shelf during the latter period. Possible reasons are that during the first part of 1989 wind energy was lower, stratification was stronger and Loop Current intrusions were more frequent. Normally, currents at both AT and AB are strongly coherent with wind stress. Near bottom currents at BB and DB are also coherent with wind stress, but less strongly than at AB and over more restricted frequency ranges. Near surface currents at BT and DT are usually only weakly correlated with stress, and at just a few frequencies. For all locations, coherence with wind stress is most commonly observed at frequencies near 0.08 and 0.2 cpd.

Wind stress is also incoherent with currents recorded at CT and ET during February 23 to June 14, 1989. The are no data from CT for the corresponding period in 1988. In order to determine whether wind stress forcing is ever significant at CT, cross rotary analysis was also performed for other periods. For the period from August 30, 1988 to January 8, 1989 coherence between stress and CT is weak but significant near 0.3 and 0.4 cpd (not shown). For the period from October 30, 1989 to January 30, 1990, however, they are strongly coherent at several frequencies, including 0.3, 0.2, 0.15 cpd and below 0.05 cpd.

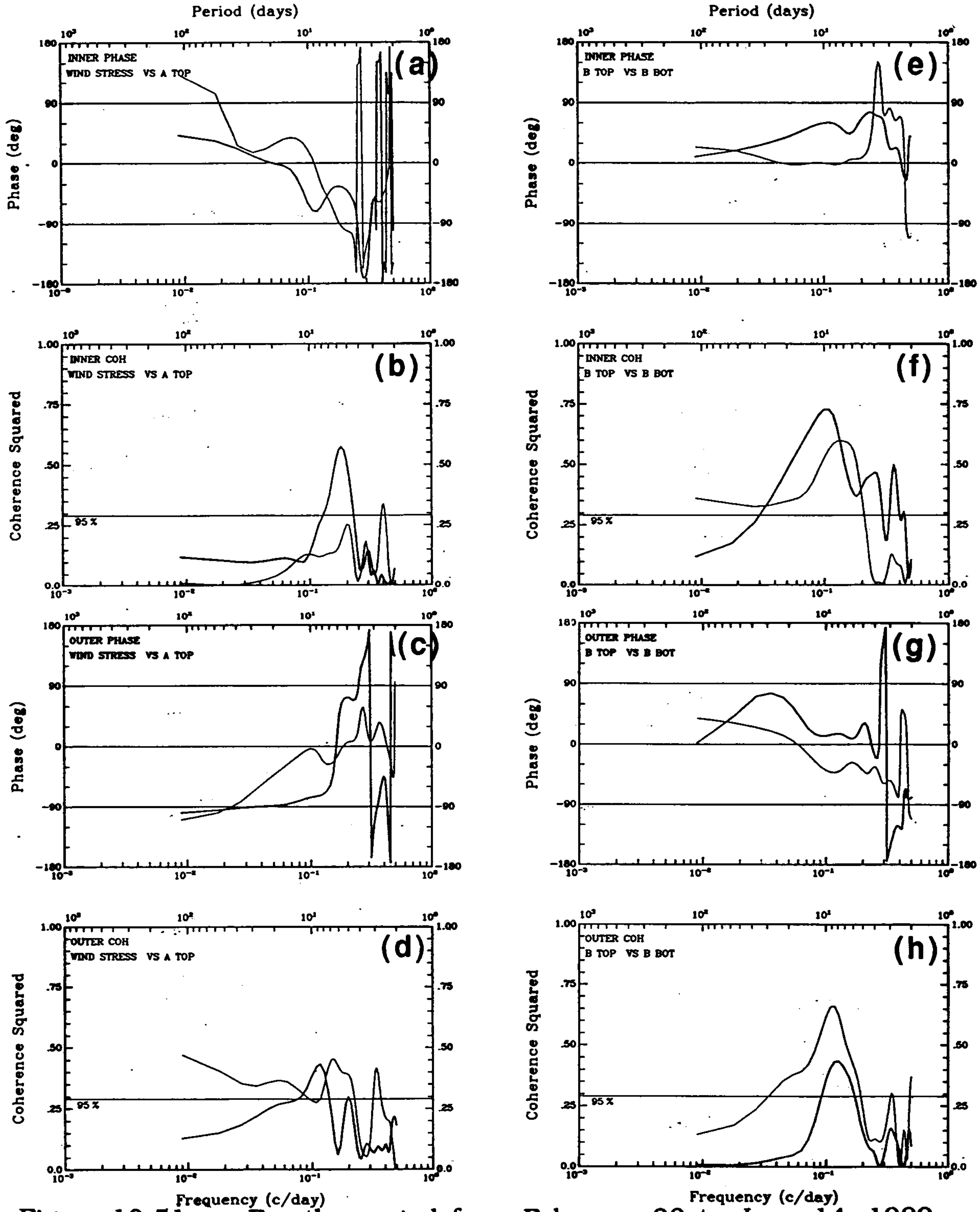


Figure 10-51. For the period from February 23 to June 14, 1989, (a) inner phase and (b) coherence and (c) outer phase and (d) coherence between wind stress and AT current; (e) inner phase and (f) coherence and (g) outer phase and (h) coherence between BT current and BB current.

10.5.3 Along-Isobath Coherence

The elements of each of the two along-isobath arrays, B-D and C-E, are separated by about 85 km. Along-isobath coherence between currents is illustrated for the period from February 23 to May 1, 1989. Although this period was anomalous with regard to wind forcing, it appears that it was not so with regard to spatial coherence, because similar results are found for the limited number of other periods of 1989 for which data availability permits along-isobath comparisons (Figure 10-3). Figure 10-52e-h shows the coherence between BT and DT currents. Coherence is very strong between the co-rotating CCW components at 0.09 cpd and the CW components at 0.14 and 0.3 cpd. The outer coherence is also strong at 0.09 cpd between the CCW component of BT and the CW component of DT. The negative phase angles indicate that DT leads BT. Since wind stress exhibits a broad energy peak around 0.09 cpd, the results suggest a forced wave mode. Figure 10-53 shows the corresponding coherence between currents at BB and DB. The components of coherence have insignificant values at high frequencies; they rise to a maximum near 0.7 and 0.09 cpd and remain high at lower frequencies.

Over the slope, coherence was not significant between CT and ET currents for this time period, which is the only one available for this pair. Data gaps in the CM and EM time series limit the evaluation between this pair to short intervals, which were not considered. Figure 10-54g,h shows the inner coherence between currents at EB and CB. Both components are strongly coherent at 0.07 cpd. The outer coherence (not shown) is almost identical. A similar but weaker pattern of coherence was also found for the period from June 28 to October 17, 1989 (not shown). Phase angles in both cases suggest both free and forced wave modes

10.5.4 Vertical Coherence

Vertical coherence is generally strong between top and bottom currents on the shelf, particular at lower frequencies. Figure 10-47e-h shows the inner and outer coherence between AT and AB currents for the period from January 5 to May 23, 1988. Coherence is significant at almost

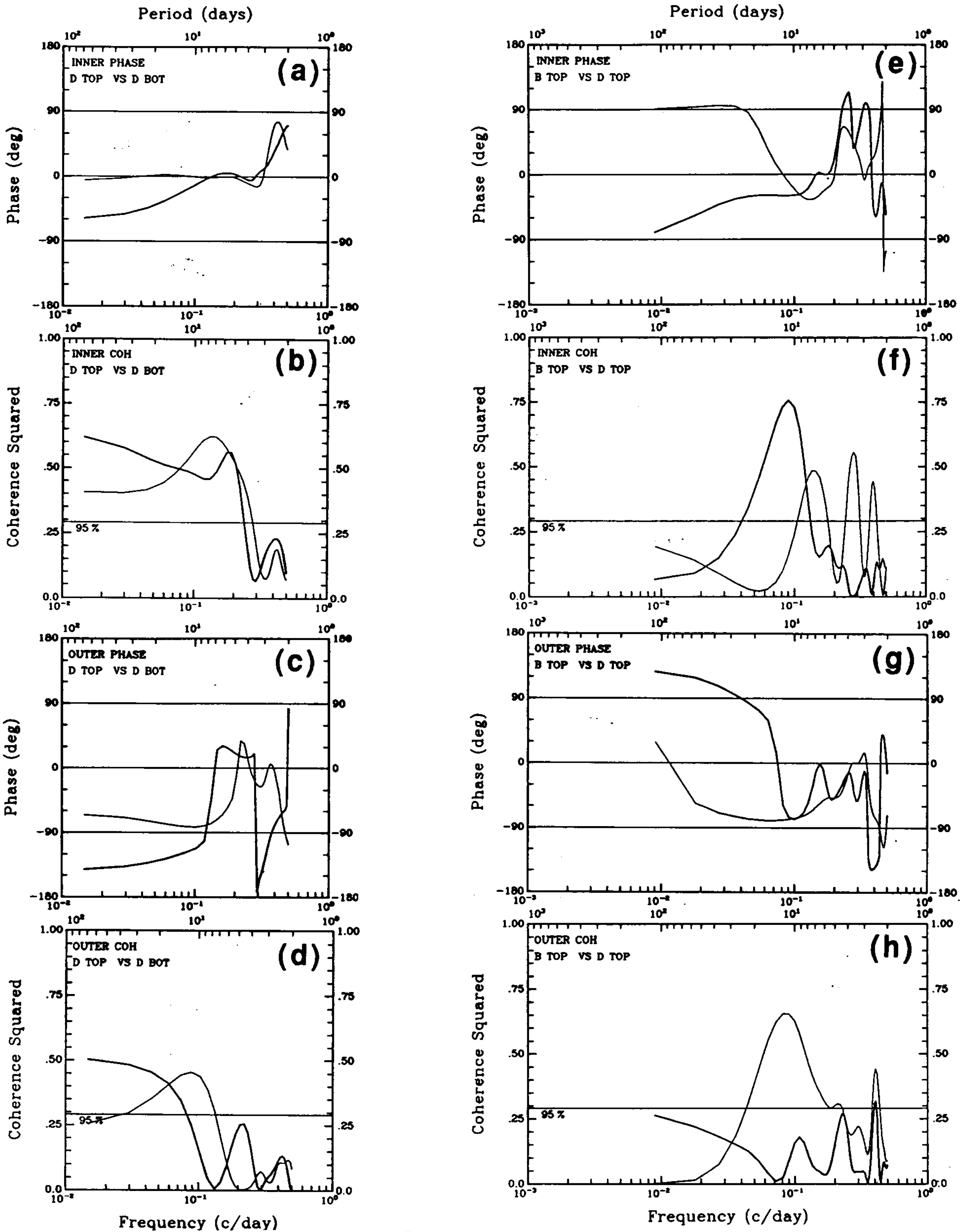


Figure 10-52. For the period from February 23 to May 1, 1989, (a) inner phase and (b) coherence and (c) outer phase and (d) coherence between DT current and DB current. For the period from February 23 to June 13, 1989 (e) inner phase and (f) coherence and (g) outer phase and (h) coherence between BT current and DT current.

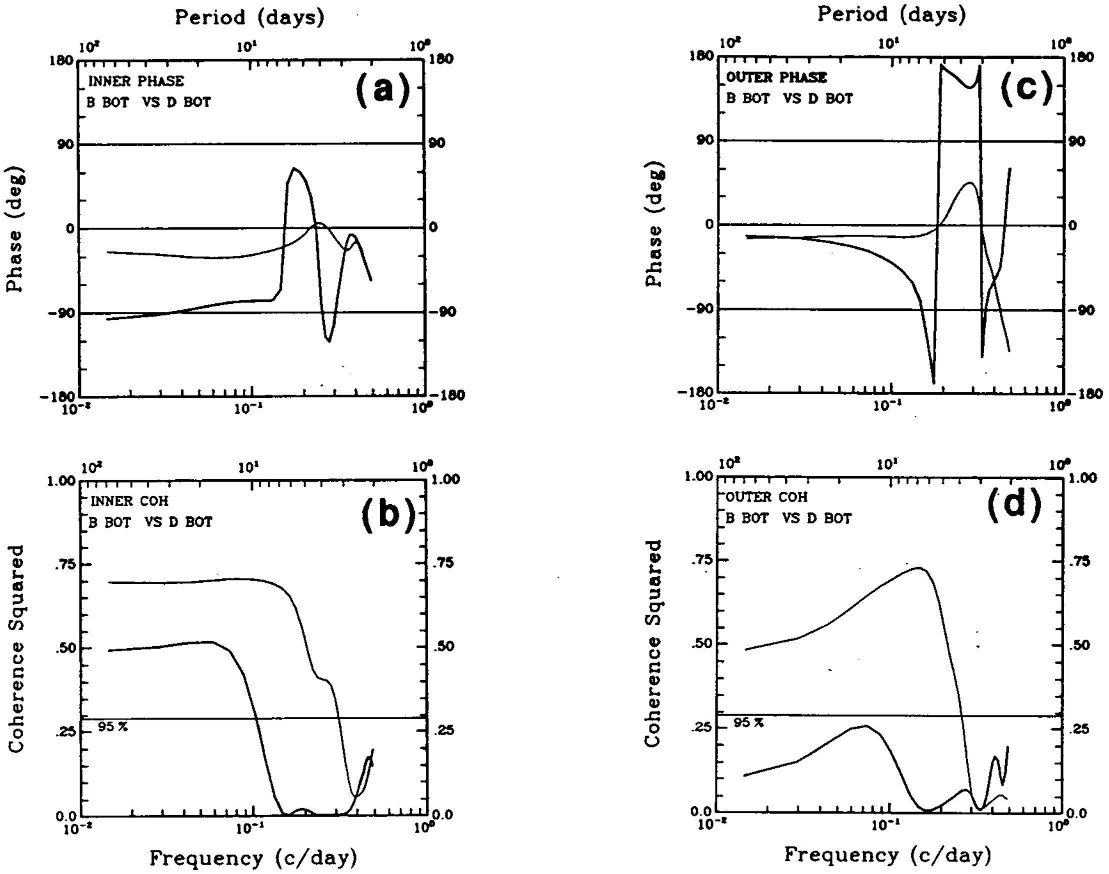


Figure 10-53. For the period from February 23 to May 1, 1989, (a) inner phase and (b) coherence and (c) outer phase and (d) coherence between BB current and DB current.

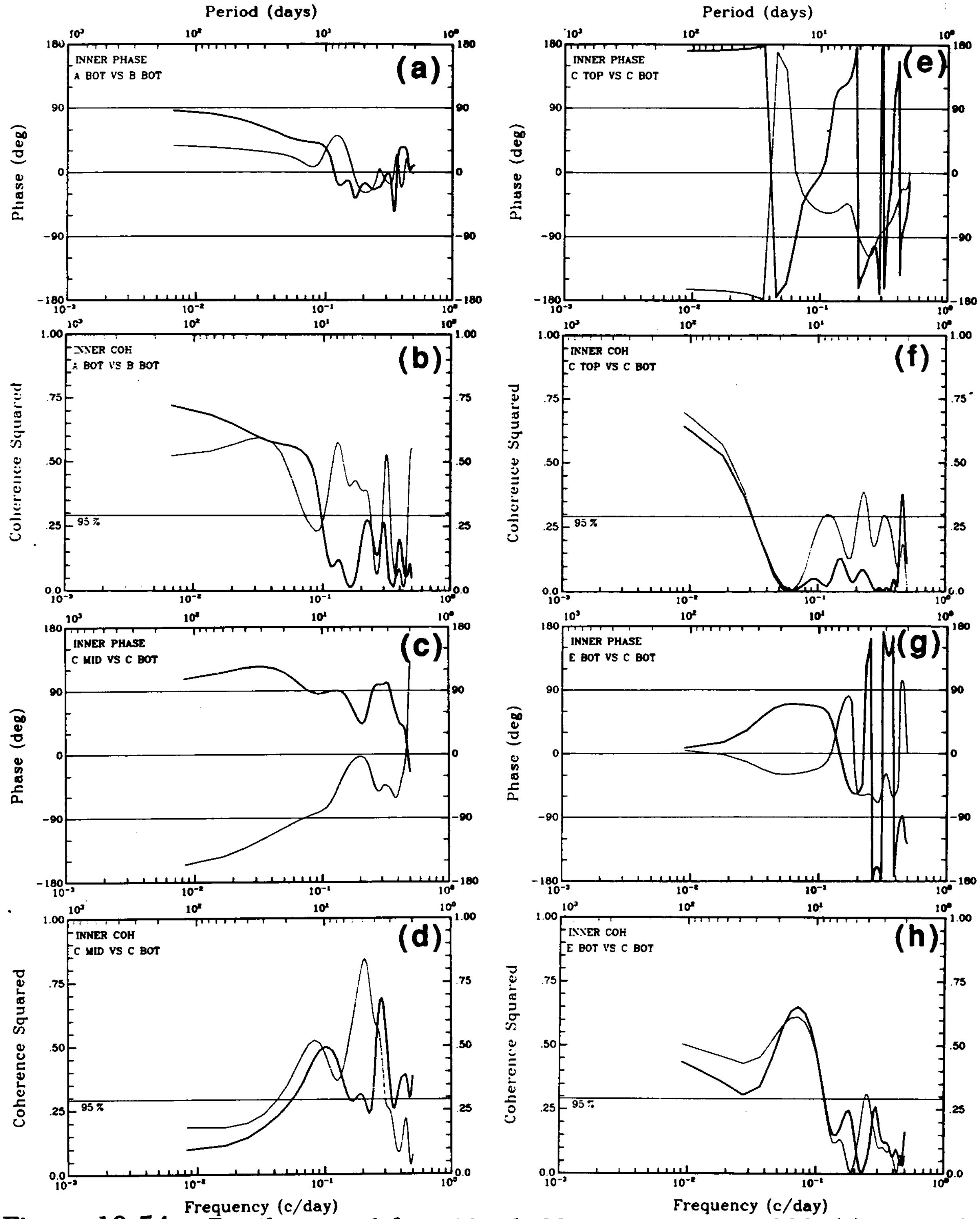


Figure 10-54. For the period from March 22 to August 17, 1988, (a) inner phase and (b) coherence between AB and BB. For the period from August 30 to December 27, 1988, (c) inner phase and (d) coherence between CM and CB. For the period from February 23 to June 13, 1989, (e) inner phase and (f) coherence between CT and CB; (g) inner phase and (h) coherence between EB and CB.

all frequencies. This result is expected given the strong response of both AT and AB to wind stress. Figure 10-51e-h presents the coherence between BT and BB for the period from February 23 to June 14, 1989. Again, there is strong coherence, but it is limited to the frequency range from 0.02 to 0.12 cpd. An example of the coherence between DT and DB is given for the period from February 23 to May 1, 1989 (Figure 10-52a-d). Coherence is strong in the synoptic band from 0.1 to 0.2 cpd and at frequencies below 0.05 cpd.

Over the continental slope coherence between top and bottom currents at Moorings C and E is typically low or insignificant except at the lowest resolvable frequencies (e.g., Figure 10-54e,f). The phase angle of 180° at these low frequencies indicates a coherence for the first baroclinic mode rather than the barotropic mode. Coherence between currents at 20 m and those at 150 m (not shown) is usually significant in a number of frequency bands, as might be expected given the strong visual correlation between them (e.g., Figure 10-16). For Mooring C, coherence between the currents at 150 m and the bottom is typically strong between 0.06 and 0.3 cpd (e.g. Figure 10-54c,d). For Mooring E, however, the coherence between currents at these two depths (not shown) is strong at low frequencies, i.e., below 0.05 cpd, and in a few narrow frequency bands centered near 0.9 and 0.3-0.4 cpd.

10.5.5 Cross-Isobath Coherence

As Figure 10-2 indicates, the cross-isobath separation between the moorings is about 30-35 km. Despite this relatively large separation, a significant degree of coherence between currents occurs in the across-isobath direction. For the three time periods examined, the coherence between currents at AB and BB is high at most frequencies. Figure 10-54a,b is an example. The coherence of near surface currents for the pairs AT-BT, BT-CT and DT-ET is demonstrated by Figures 10-55e,f, 10-55g,h and 10-55c,d, respectively. The time period is February 23 to June 14, 1989, the only period for which all five moorings returned near surface currents. Significant peaks in coherence occur in the synoptic band for the three pairs, and, for the DT-ET pair, the coherence is also strong at all frequencies below 0.05 cpd. The results are similar for the other periods

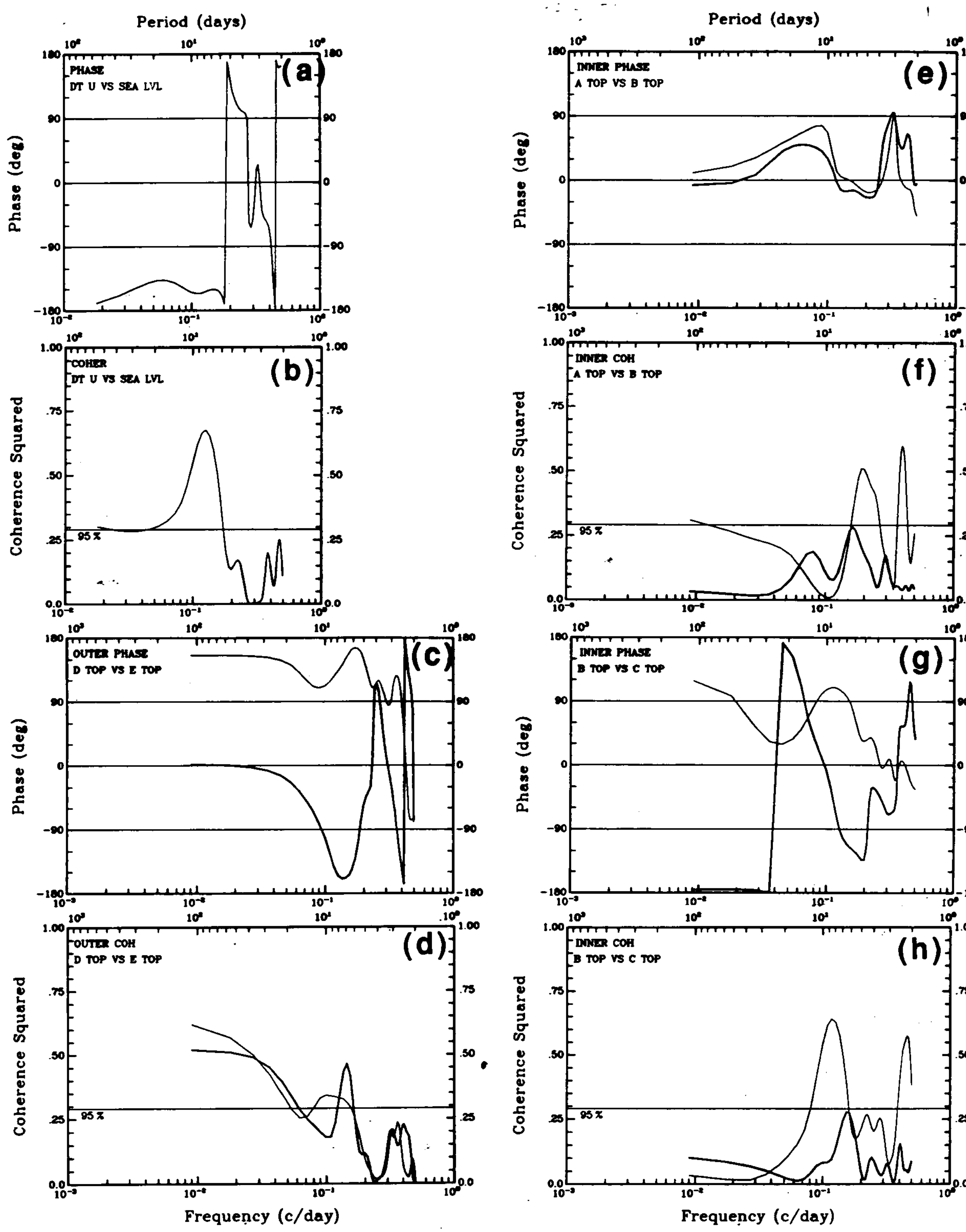


Figure 10-55. For the period from February 23 to June 14, 1989, (a) phase and (b) coherence between the along-isobath current at DT and sea level; (c) outer phase and (d) coherence between DT and ET; (e) inner phase and (f) coherence between AT and BT; (g) inner phase and (h) coherence between BT and CT.

for which cross-isobath pairs can be formed (not shown); in some cases the coherence is stronger or more broadly distributed. The distance between AT and CT is about 70 km, and, as might be expected, the currents between these two location are incoherent. With the available data, we can conclude the cross-shelf length scale is at least about 30 km but less than 70 km.

We also examined the temperature and salinity time series for cross-shelf correlation. Since the instruments near the bottom were at different depths relative to the local pycnocline depth at any instant of time, the results of the spectral analyses were inconclusive. However, a time-domain study of the salinity series was fruitful. Although salinity is a dynamical variable, it is useful at times to treat it as a tracer. Figures 10-56 and 10-57 show the time series of near surface salinity recorded at the five moorings for February 15 to June 21, 1989 and June 20 to October 21, 1989, respectively. The meter depths were 20 m except for AT which was at a depth of 10 m. In Figures 10-56 and 10-57 there are fluctuations in salinity that appear to be correlated between two or more of the series. Events selected for discussion are labeled with a lower case letter. Figures 10-37 and 10-39 show the corresponding currents for these two periods. (For these stick vector plots, up the page is toward 55°, the along-isobath direction. Vectors with an offshore component will point to the right of vertical.)

For event (a), a pulse of low salinity water was advected offshore beginning at Mooring A on March 14, passing Mooring B starting March 18 and arriving at Mooring C beginning March 22. Along the line of the moorings, the distance between them is 36 km for A-B and 30 km for B-C (Figure 10-2). If advection occurred along a straight line the average rate would be about 9 cm/s, but we do not know the actual flow patterns over the shelf during this period. We do know that currents at AT (Figure 10-37) shifted to seaward beginning March 14; those at BT shifted to eastward, i.e. a significant cross shelf component, beginning March 18; and those at CT shifted to southwestward beginning March 22. The observed currents suggest a somewhat curved anti-cyclonic path from A to C. The source for the fresher water is presumed to be river discharge at the northern coast. The other potential source is Mississippi River discharge at the delta, but currents at DT had a strong offshore component during the week prior to March 14, eliminating this possibility.

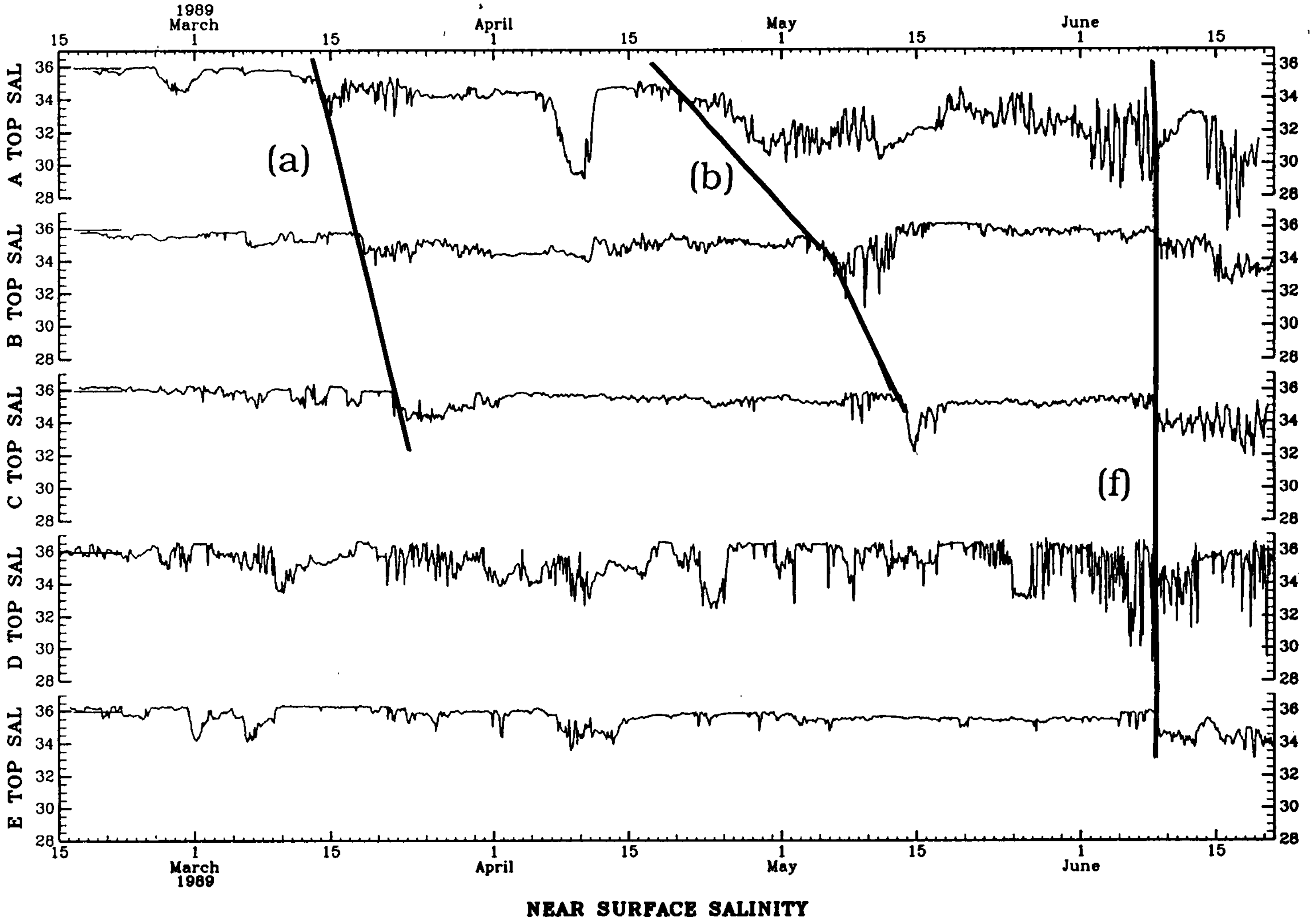


Figure 10-56. Hourly (3-hour low passed) time series of near surface salinity recorded at the five mooring locations during the period February 15 to June 21, 1989. The instrument depth was 10 m at AT and 20 m at the other locations.

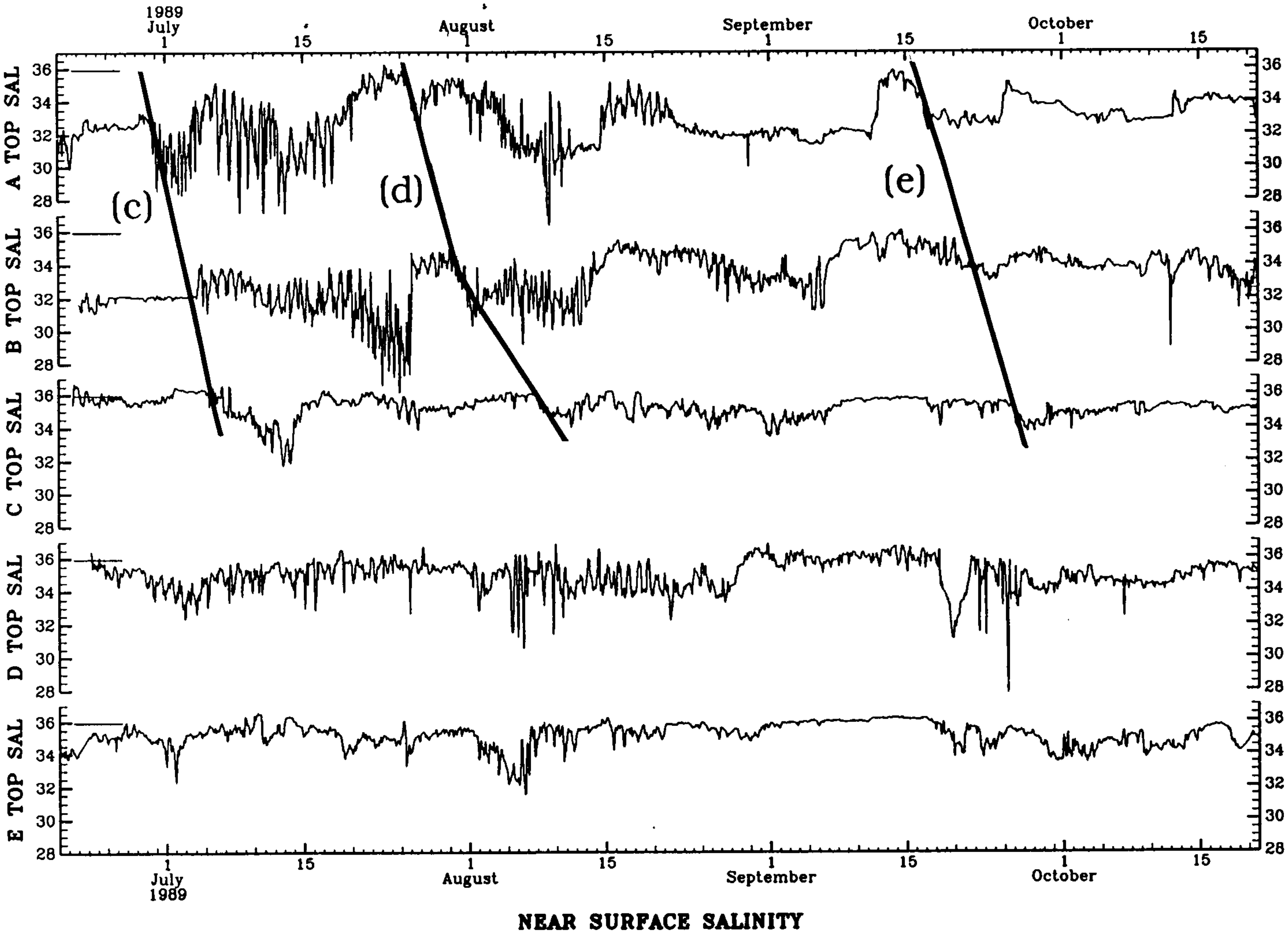


Figure 10-57. Hourly (3-hour low passed) time series of near surface salinity recorded at the five mooring locations during the period June 20 to October 21, 1989. The instrument depth was 10 m at AT and 20 m at the other locations.

Event (b) is a stronger example of cross-shelf flushing of fresher inshore water. The drop in salinity begins about April 20 at AT, May 4 at BT and May 13 at CT. Straight line advection times are 3 cm s^{-1} for AT to BT and 4 cm s^{-1} for BT to CT. Currents at these times are consistent with fairly direct offshore advection and Table 10-15 identifies this period of cross-shelf flushing as coinciding with an intrusion. An order of magnitude estimate can be made of the rate of fresh water flushing from the shelf during this event. Assume that the water being flushed is 2 PSU below an ambient of about 36 PSU, so that the fresh water fraction is 2/36. Assume also that the region of seaward moving water is about 30 km wide (see discussion in section 10.3.2), that the depth of the fresher water mass is about 20 m, and that it advects at about 4 cm s^{-1}. Then, fresh water is flushed from the shelf at a rate of about 1.3 x 10^3 m^3s^{-1} [(2/36) x 20 m x 3 x 10^4 m x 0.04 m s^{-1})]. For reference, the Tombigbee and Alabama Rivers had mean daily discharge rates during water year 1989 of 0.99 x 10^3 m^3 s^{-1} and 1.03 x 10^3 m^3 s^{-1}, respectively.

In the case of event (c) (Figure 10-57), there was a decrease in salinity at Mooring A beginning June 29 that appears to be correlated with one that occurred at Mooring C a week later, but salinity at Mooring B increased during this period. Currents at Moorings A and B were westward and at Mooring C they were northeastward (Figure 10-39). If these salinity events were indeed related, as we hypothesize, the advective path consistent with the currents was cyclonic. Events (d) and (e) (Figure 10-57) are two more examples of lower salinity pulses that appear to be correlated among the three moorings. According to Table 10-15, the periods of salinity events (c) and (e) coincide with Loop Current related intrusions events.

A curious event, labeled (f) in Figure 10-56, occurred on June 8, 1989. Near surface salinity at all five moorings dropped, almost simultaneously, by 1.5 PSU or more. We note it but do not have enough data to offer a hypothesis to explain it.

The salinity series for DT and ET show that variability was clearly greater at DT, although they were only 23 km apart, were about the same distance from the Delta, and had the near surface instruments at the same depth. The series for BT and CT exhibit a similar difference in variability, which supports a hypothesis that the moorings over the slope were located in a different current regime than those over the outer shelf. The DT and

ET salinity series do not exhibit fluctuations that are as readily suggestive of correlated events the way the eastern ones do, except for event (f) noted above. However, periods of increased variability in the ET record do in general correspond to increased variability in the DT record.

10.5.6 Coherence Between Currents and Sea Level

The coherence between sea level at Dauphin Island and the Cartesian along-isobath component of current was examined because of the significant degree of cross shelf coherence discussed above. Coherence is strong between sea level and the currents at AT and AB over a broad frequency range (not shown). The results for currents at BT and DT are similar (e.g., Figure 10-55a,b). The coherence is limited to a single frequency band, with a peak at 0.07 cpd. The results for the same time period for sea level versus CT and ET also exhibit a peak near this frequency (Figure 10-58a,d). Sea level versus the U component of CB is incoherent, but versus that of EB there is coherence at 0.2 cpd and below 0.6 cpd.

10.6 Hydrography

The low frequency variability of temperature and salinity recorded by the moored instruments in the eastern and outer shelf/slope portions of the study area are described in Section 10-4. Detailed realizations of sea surface temperature distributions for the entire study area are provided by the satellite thermal imagery presented in Chapter 11. Here we focus on the five shelf-wide hydrographic surveys conducted during the study. Given the strong temporal and spatial variability imposed by the various forcing mechanisms, the distributions observed during a given cruise cannot be considered as representative of a given season. They do, however, yield a quasi-synoptic realization of the effects of the processes in progress just prior to and during the cruise. The surveys also provide information about vertical distributions and parameters such as dissolved oxygen and

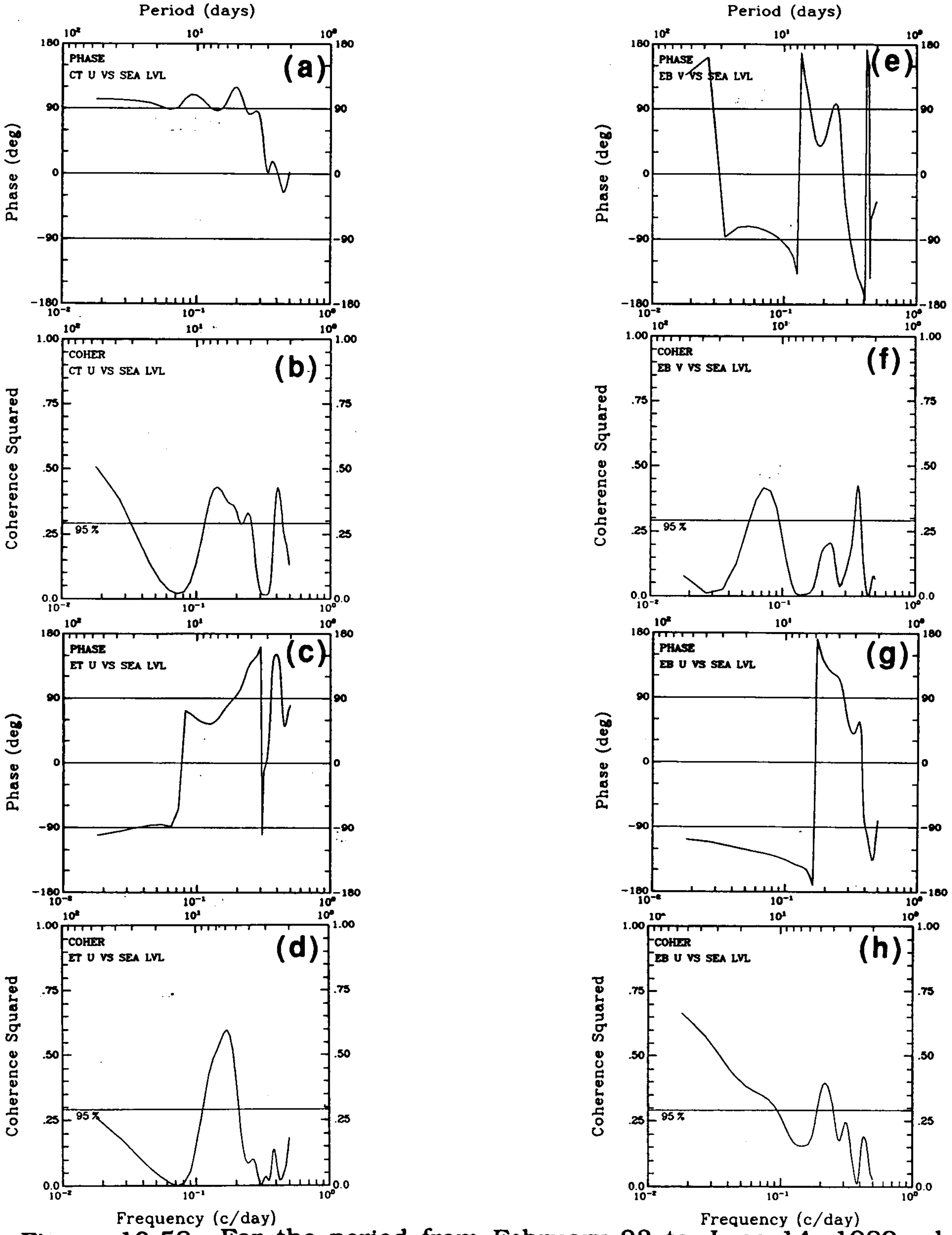


Figure 10-58. For the period from February 23 to June 14, 1989, phase and coherence between sea level and: (a), (b) the along-isobath current at CT; (c), (d) the along-isobath current at ET; (e), (f) the cross-isobath current at EB; (g), (h) the along isobath current at EB.

transmissivity, which cannot be obtained from the moored and satellite sensors.

The results are presented for each survey in the form of near surface and near bottom distributions of temperature, salinity and dissolved oxygen and selected CTD profiles (Figures 10-59 to 10-72).

Cruise 0 (February 25 - March 5, 1987)

During the March 1987 cruise, surface temperature (Figure 10-59) increased monotonically seaward from 15° C in shallow water to 18° C over the shelf slope. Isotherms followed the trend of the isobaths. A tongue of water with lower salinity and higher dissolved oxygen values extended southward from Mobile Bay across the shelf. In the southeastern portion of the study area, i.e., on the west side of De Soto Canyon, surface waters had the highest salinity and lowest oxygen values. The surface distributions, particularly that of salinity, suggest southwestward surface flow. Near the bottom (Figure 10-60), values of dissolved oxygen decreased monotonically from about 7.5 mg l^{-1} in shallow water to 4.5 mg l^{-1} at the 100 m isobath. The distributions of temperature and salinity near the bottom had a maximum between the 40 and 100 m isobaths

Cruise 1 (September 28- October 5, 1987)

During the October 1987 cruise, a surface water mass with higher temperature and salinity and lower dissolved oxygen (Figure 10-61) entered the study region from the southeast and spread northwestward over the shelf. Bottom temperatures (Figure 10-62) decreased seaward from the shallow inshore waters. The distribution of bottom salinity suggests a high tongue extending westward across the shelf. The highest value was 36.8 PSU at Station D-2. The distribution of dissolved oxygen generally decreased seaward, except for the value at M-1. This value is anomalous, and a more parabathic contouring of the bottom dissolved oxygen is also reasonable.

The satellite AVHRR images for October 5 and 6, 1987, which are the first ones available for this study (Appendix E) confirm that a Loop Current related intrusion of warm water extended northwestward onto the shelf, at least near the end of the cruise. We did not count this event in the objective census of intrusions (Table 10-15) because we do not know when it began. The general circulation that is suggested by the data is northeastward flow

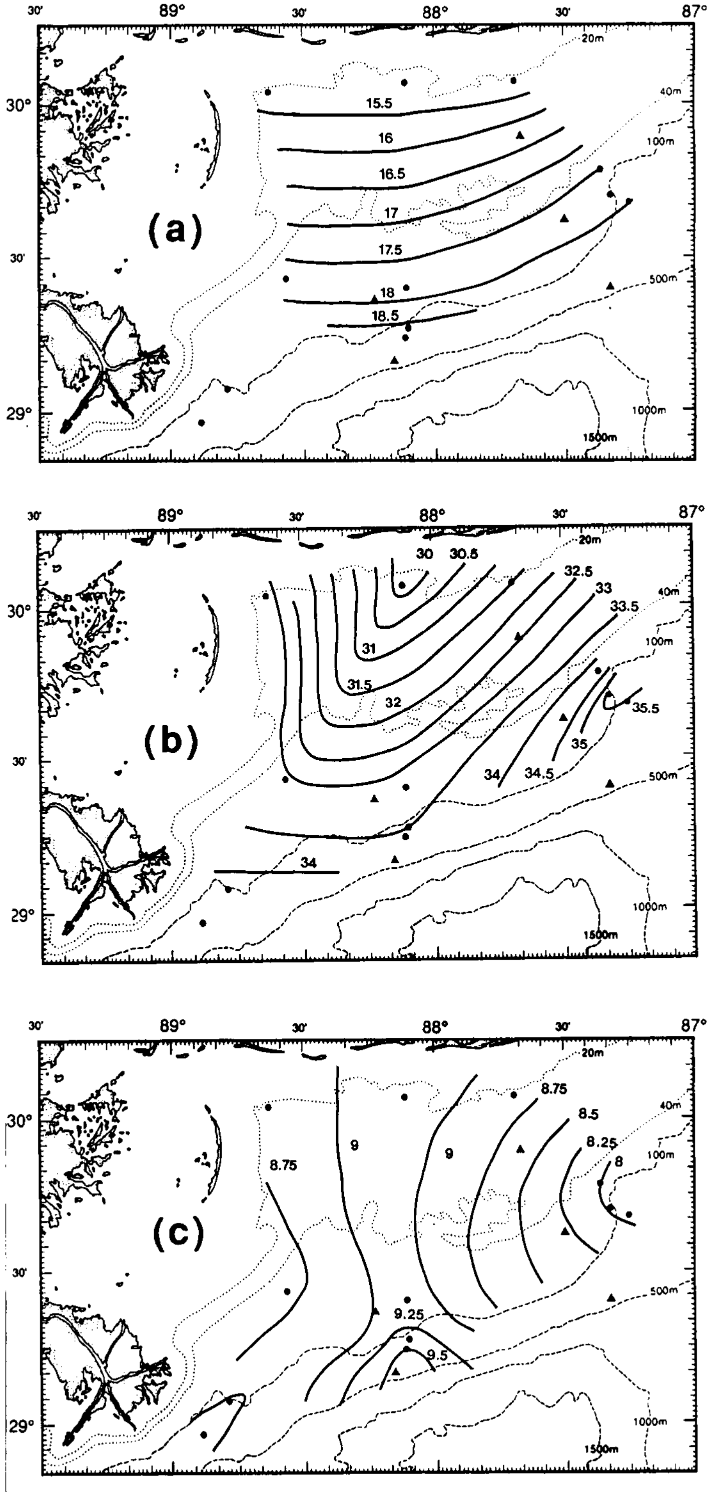


Figure 10-59. **Cruise 0 (February 25-March 5, 1987) near surface distributions of (a) temperature (°C), (b) salinity (PSU) and (c) dissolved oxygen (mg l^{-1}).**

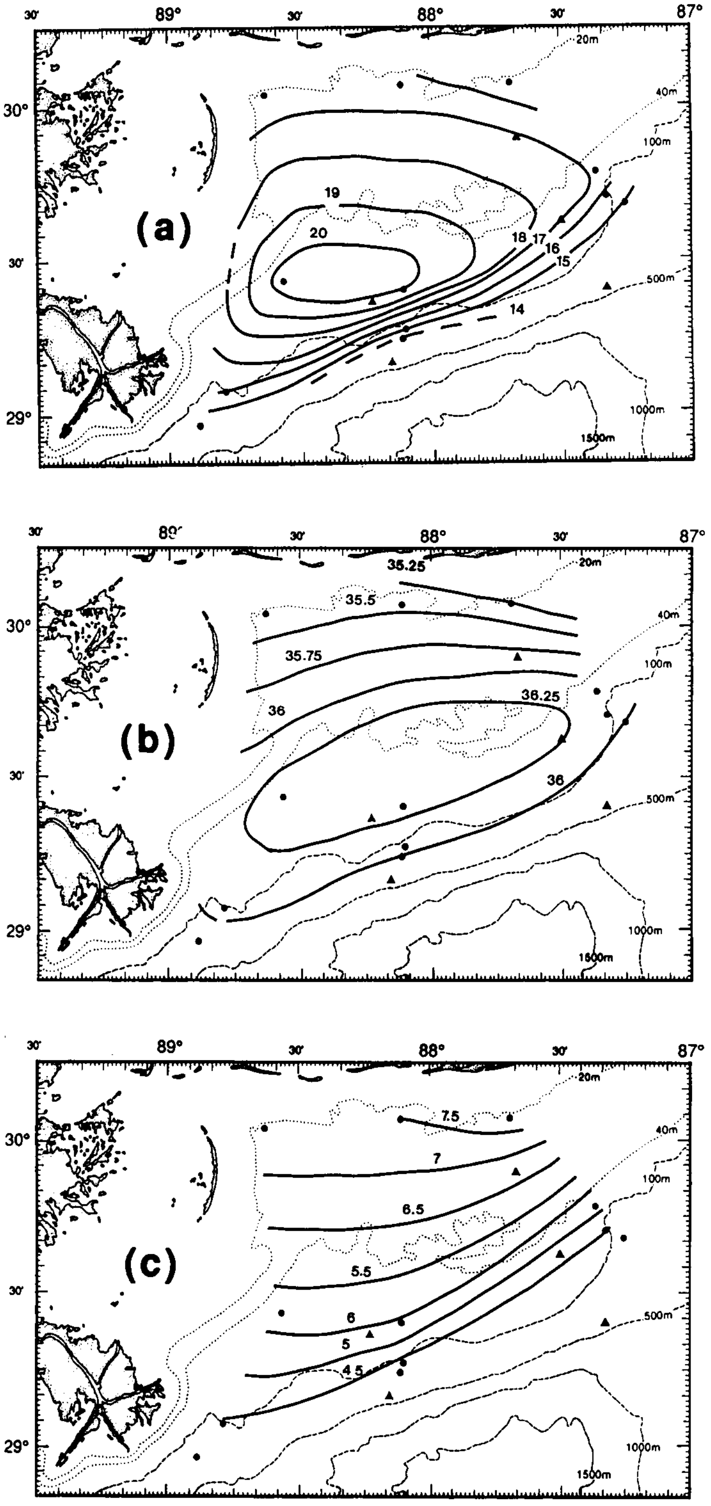


Figure 10-60. **Cruise 0 (February 25-March 5, 1987) near bottom distributions of (a) temperature (°C), (b) salinity (PSU) and (c) dissolved oxygen (mg l^{-1}).**

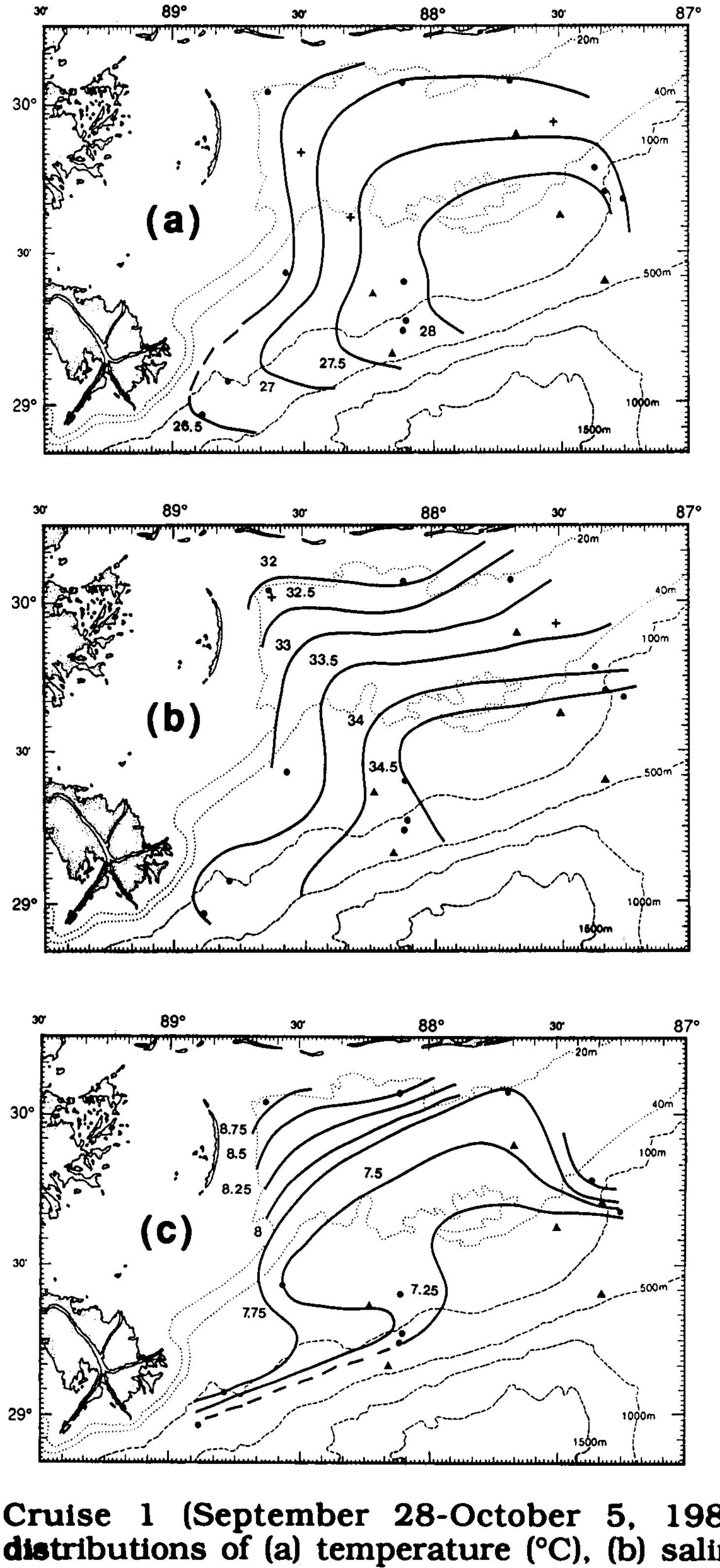


Figure 10-61. **Cruise 1 (September 28-October 5, 1987) near surface distributions of (a) temperature (°C), (b) salinity (PSU) and (c) dissolved oxygen (mg l^{-1}).**

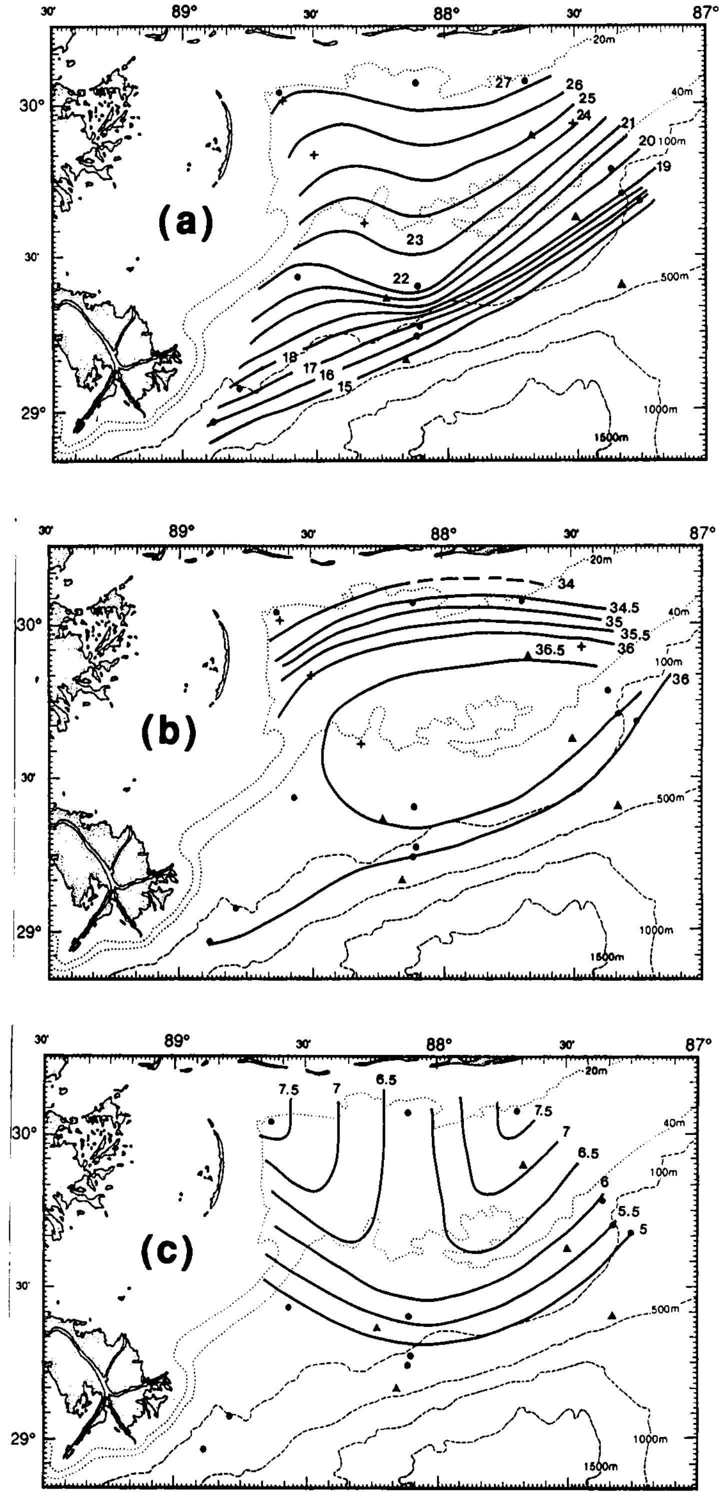


Figure 10-62. Cruise 1 (September 28-October 5, 1987) near bottom distributions of (a) temperature (°C), (b) salinity (PSU) and (c) dissolved oxygen (mg l^{-1}).

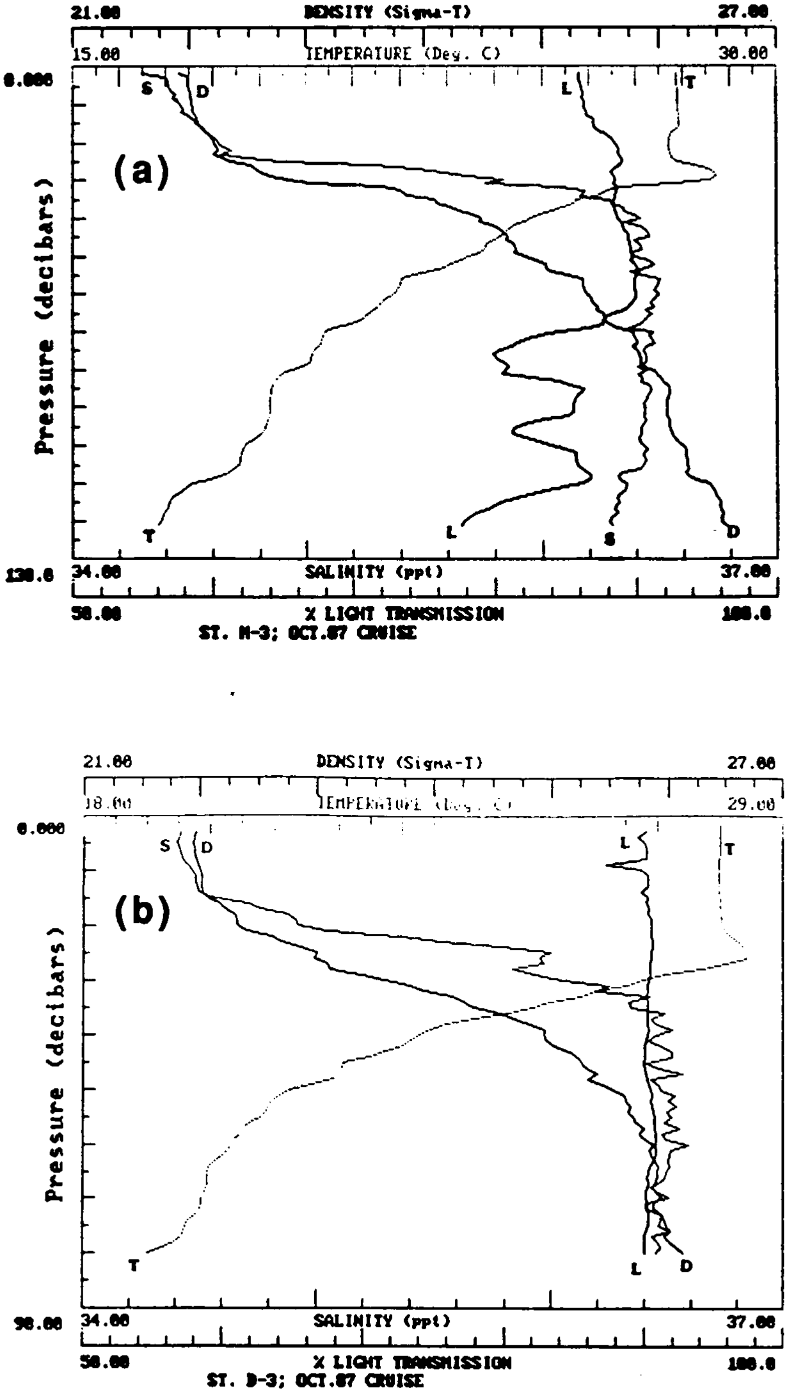


Figure 10-63. Cruise 1, stations (a) M-3 and (b) D-3, vertical profiles of temperature (T), salinity (S), density (D) and transmissivity (L).

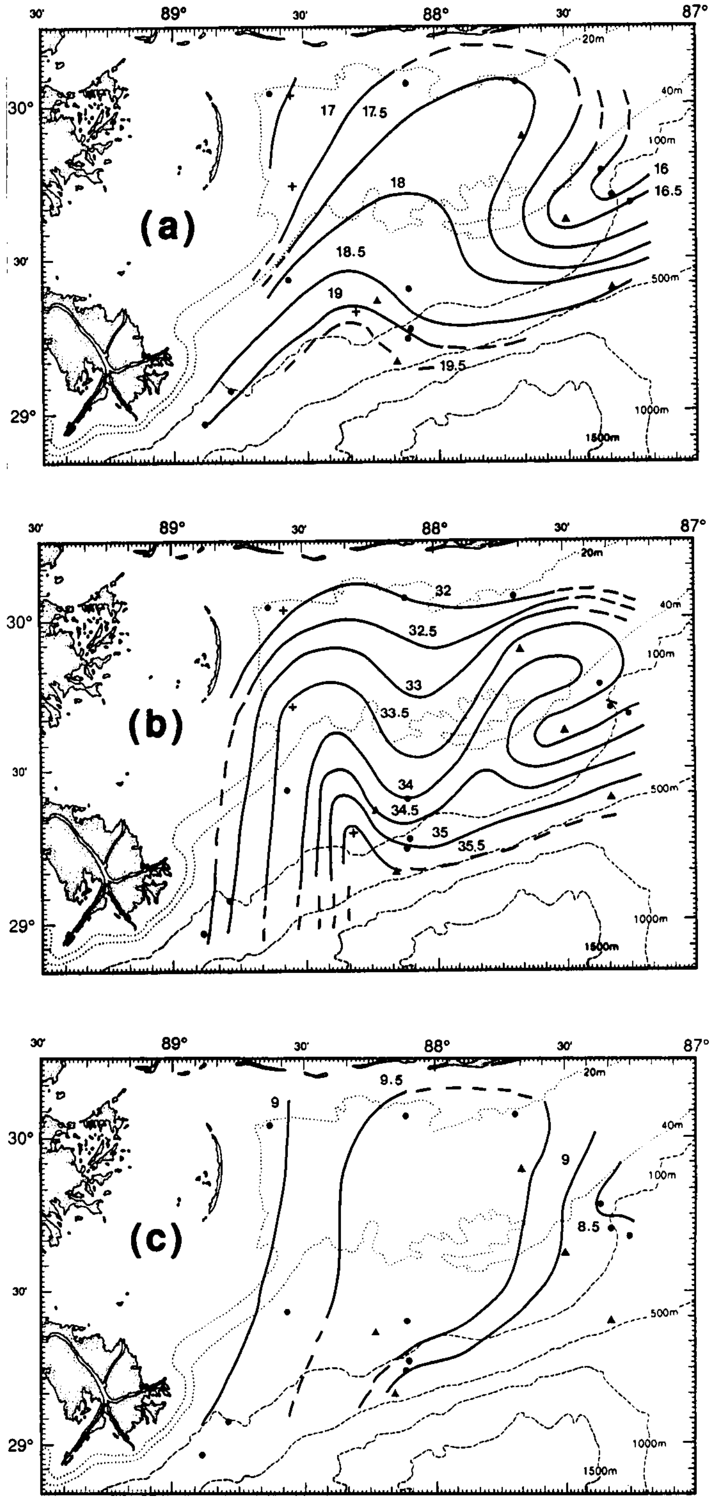


Figure 10-64. **Cruise 2 (March 10-March 18, 1988) near surface distributions of (a) temperature (°C), (b) salinity (PSU) and (c) dissolved oxygen (mg l^{-1}).**

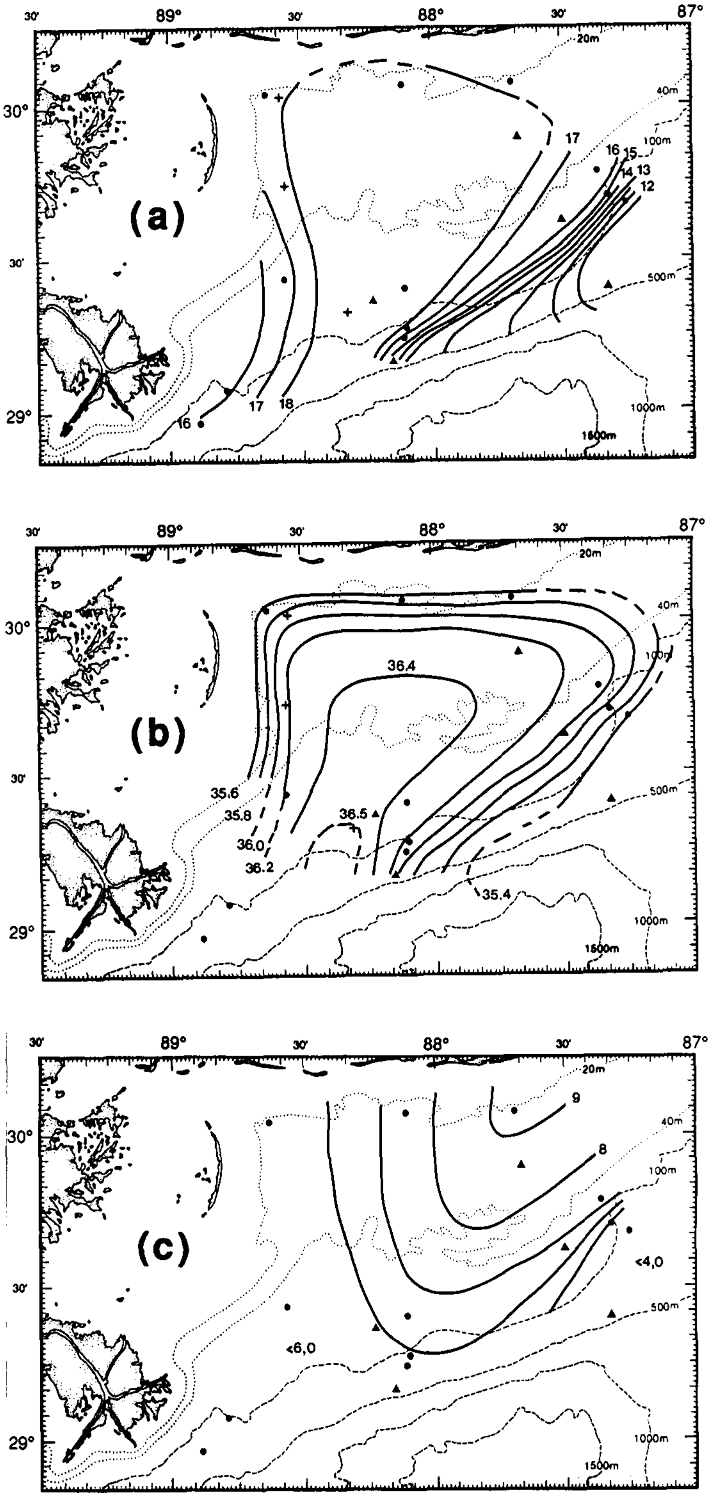


Figure 10-65. **Cruise 2 (March 10-March 18, 1988) near bottom distributions of (a) temperature (°C), (b) salinity (PSU) and (c) dissolved oxygen (mg l^{-1}).**

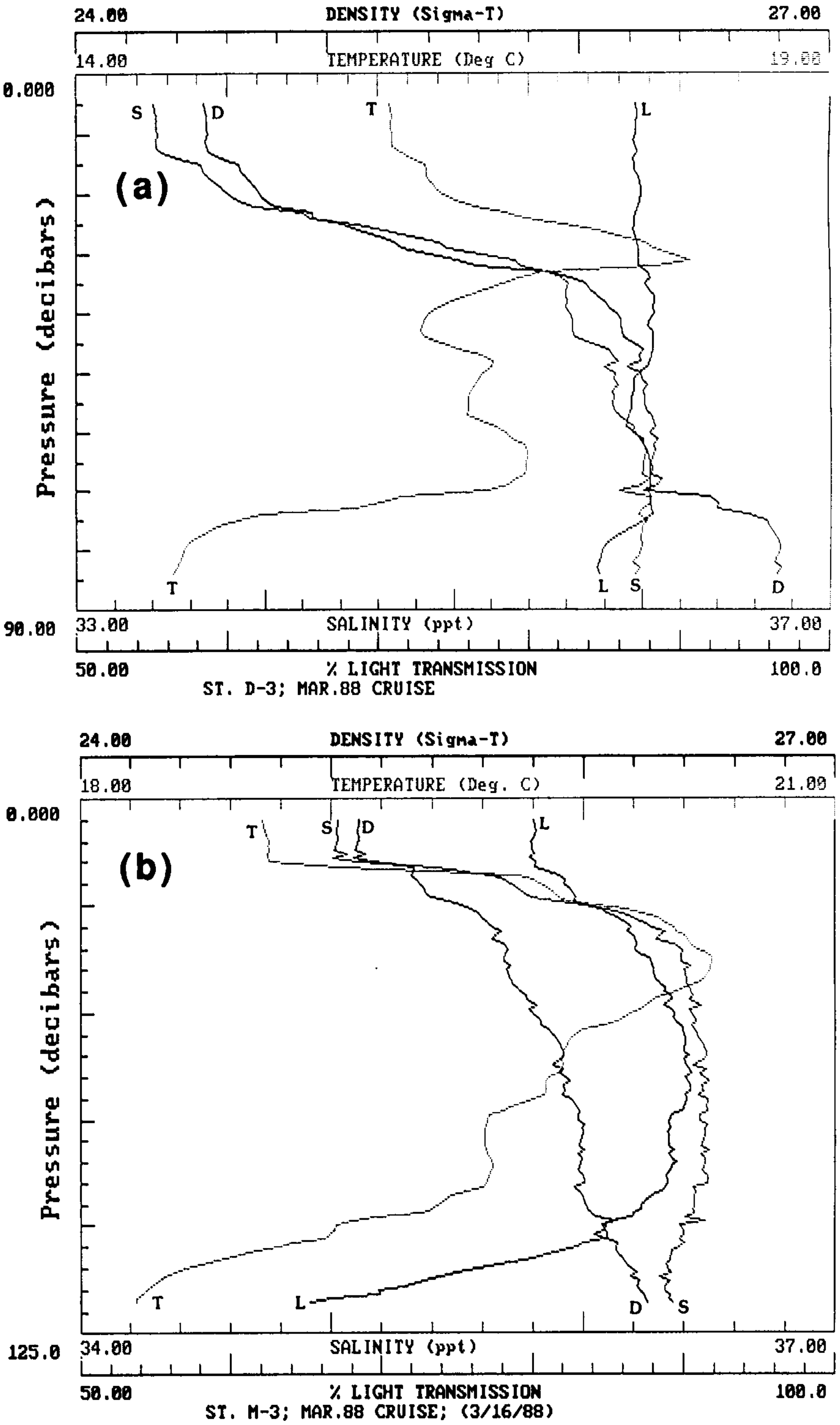


Figure 10-66. **Cruise 2, stations (a) M-3 and (b) D-3, vertical profiles of temperature (T), salinity (S), density (D) and transmissivity (L).**

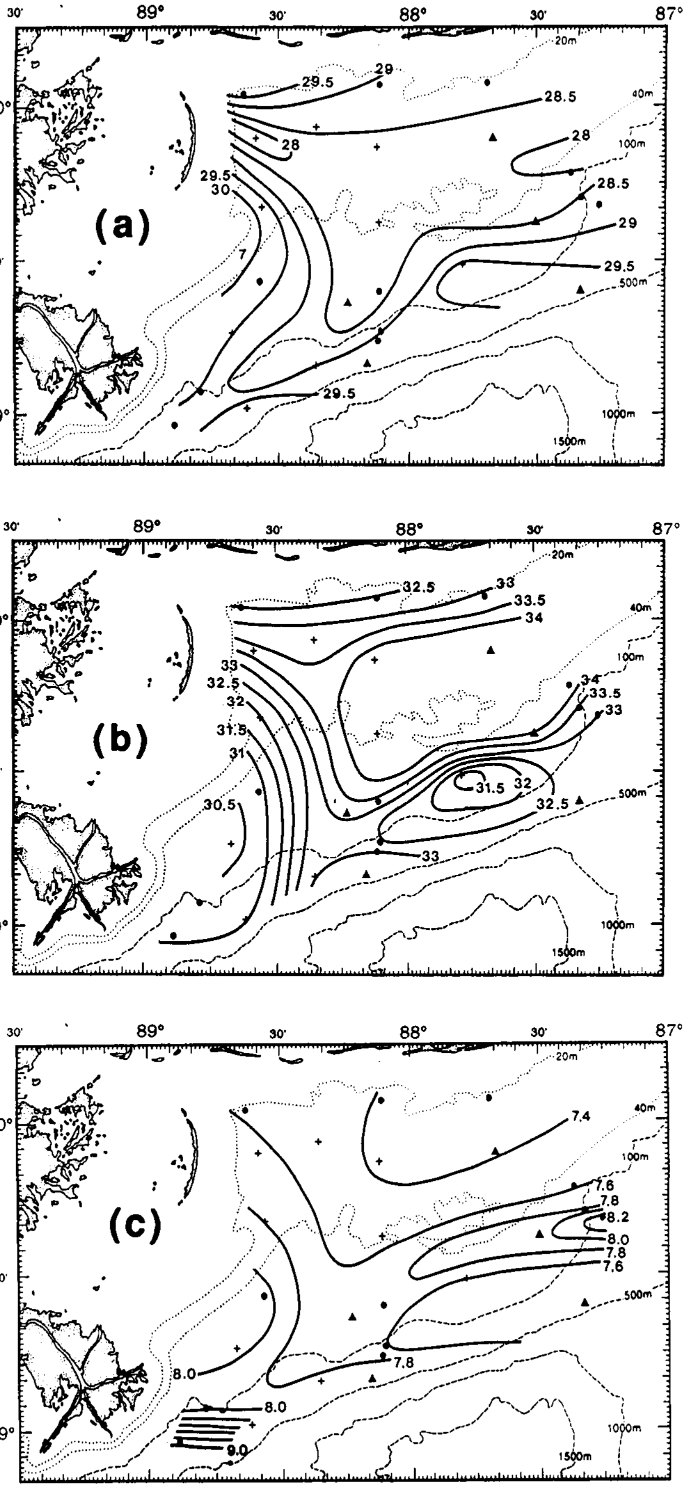


Figure 10-67. Cruise 3 (August 19-25, 1988) near surface distributions of (a) temperature (°C), (b) salinity (PSU) and (c) dissolved oxygen (mg l^{-1}).

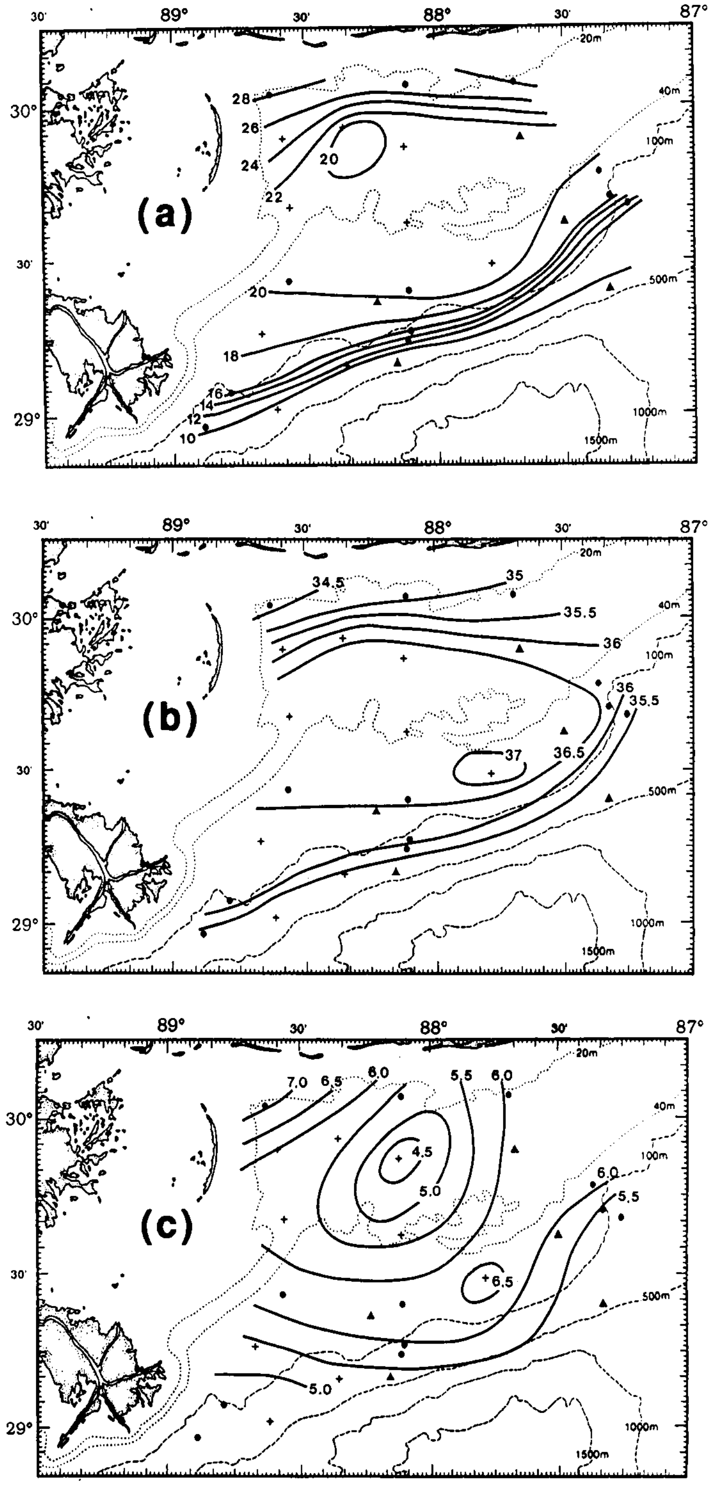


Figure 10-68. **Cruise 3 (August 19-25, 1988) near bottom distributions of (a) temperature (°C), (b) salinity (PSU) and (c) dissolved oxygen (mg l^{-1}).**

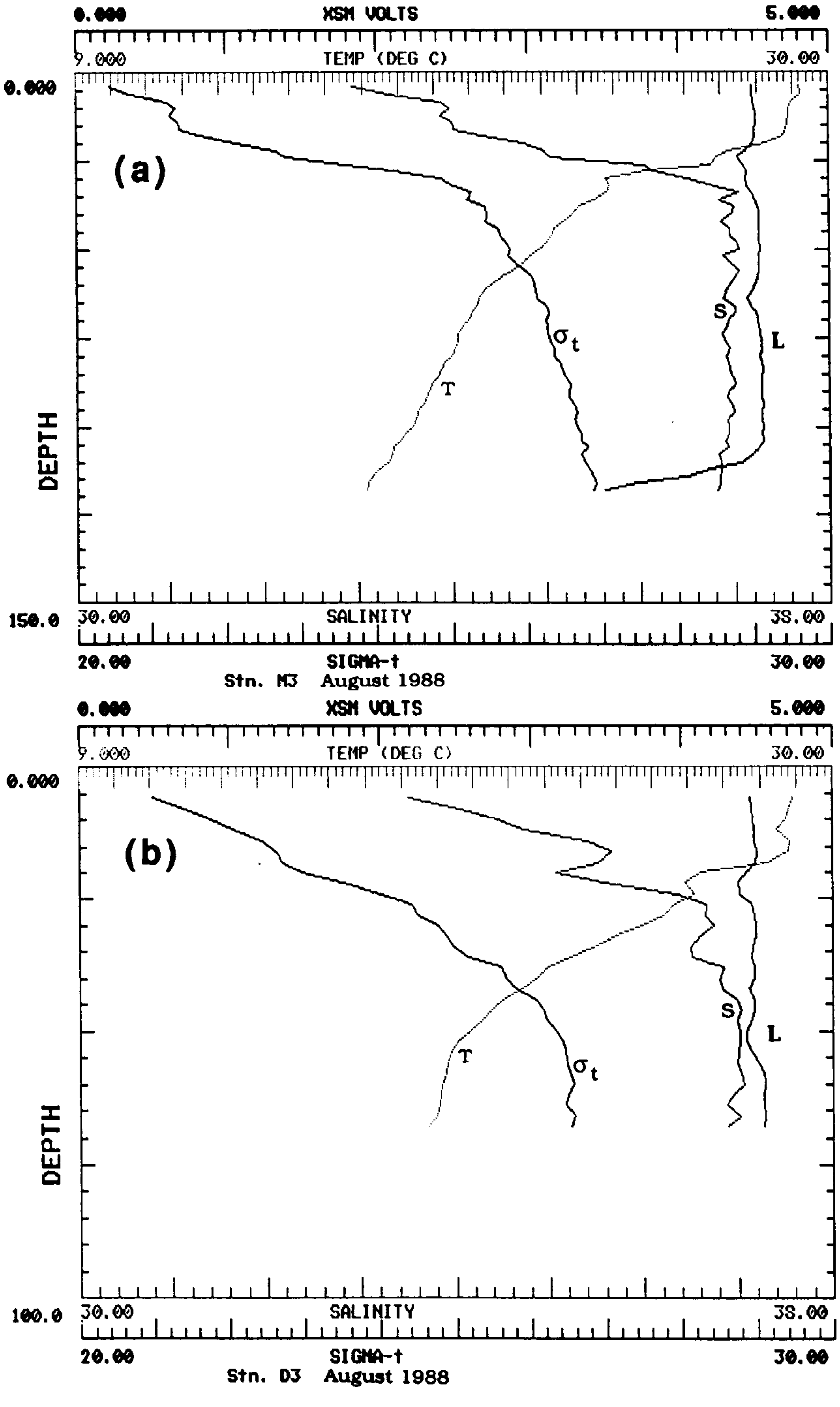


Figure 10-69. **Cruise 3, Stations (a) M-3 and (b) D-3, vertical profiles of temperature (T), salinity (S), density (D) and transmissivity (L).**

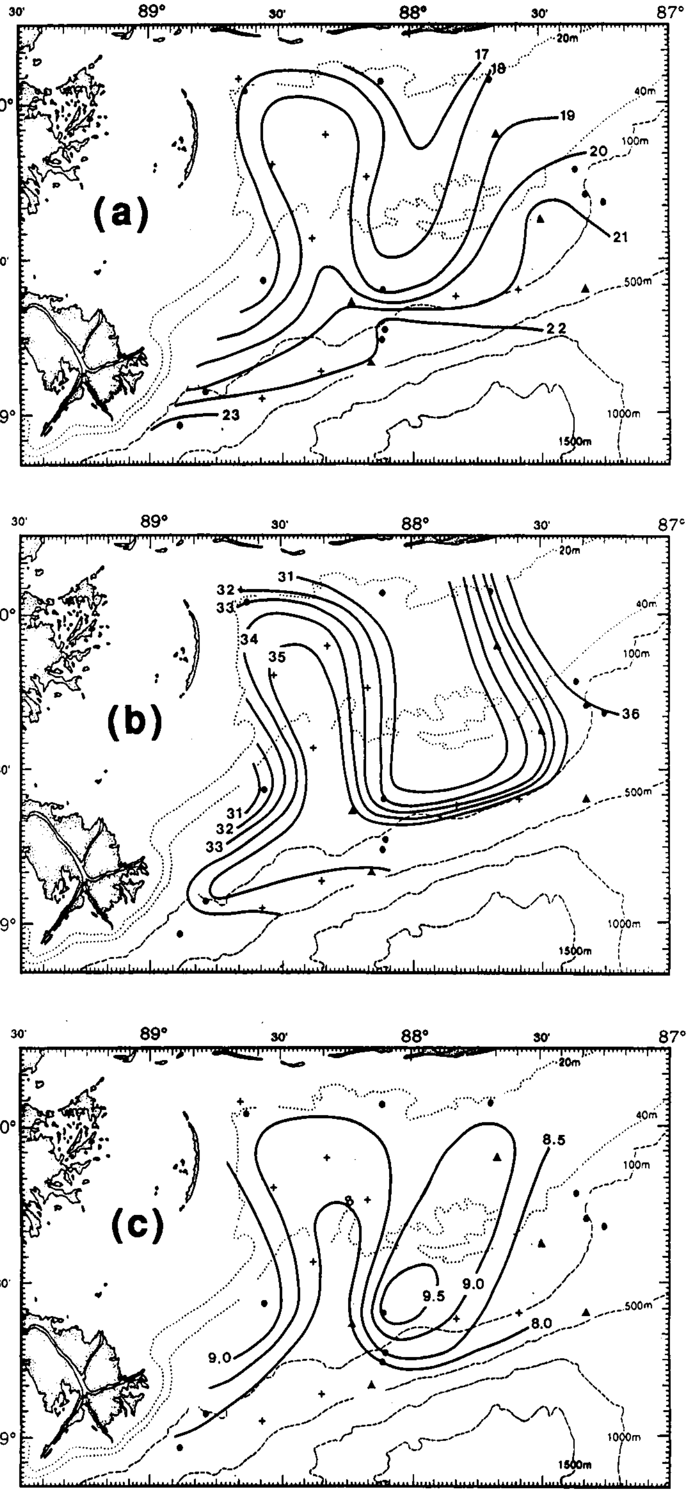


Figure 10-70. Cruise 4 (February 11-18, 1989) near surface distributions of (a) temperature (°C), (b) salinity (PSU) and (c) dissolved oxygen (mg l^{-1}).

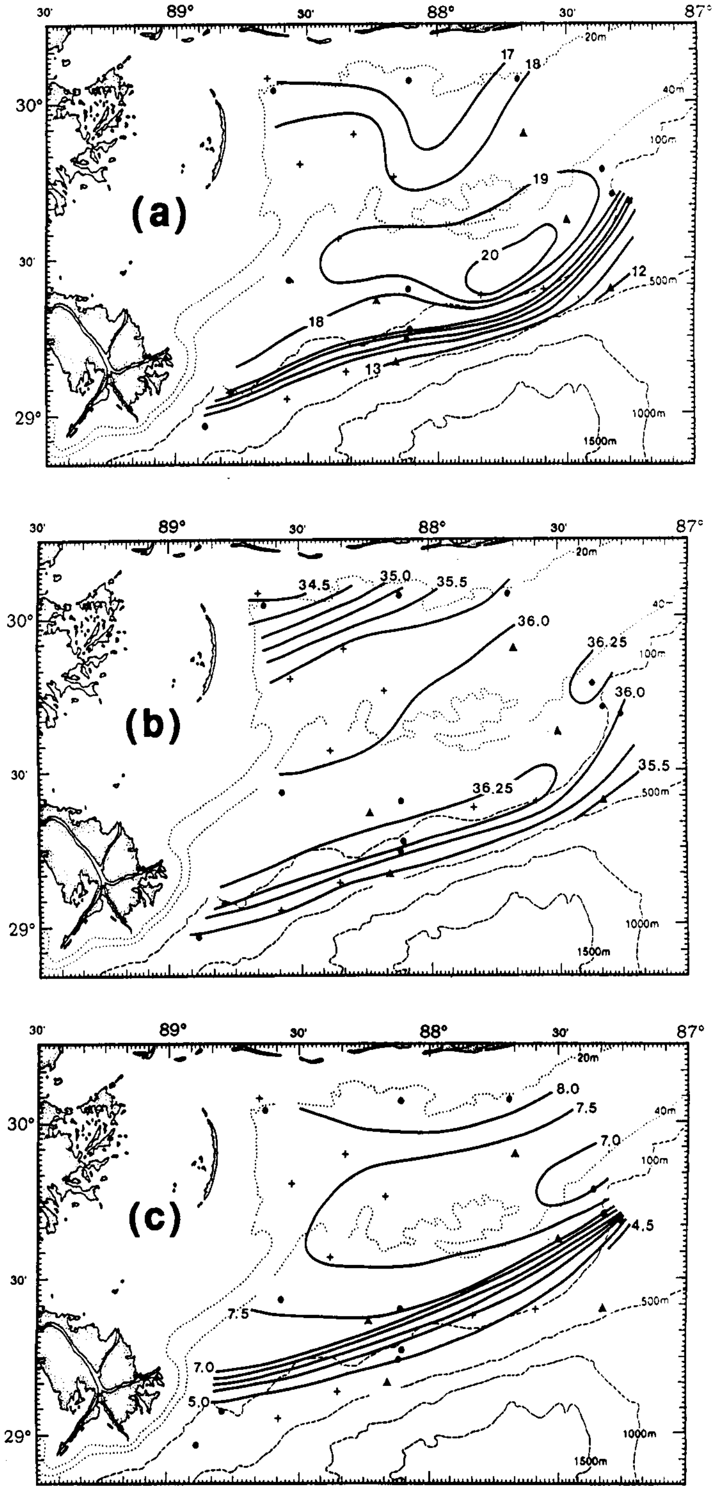
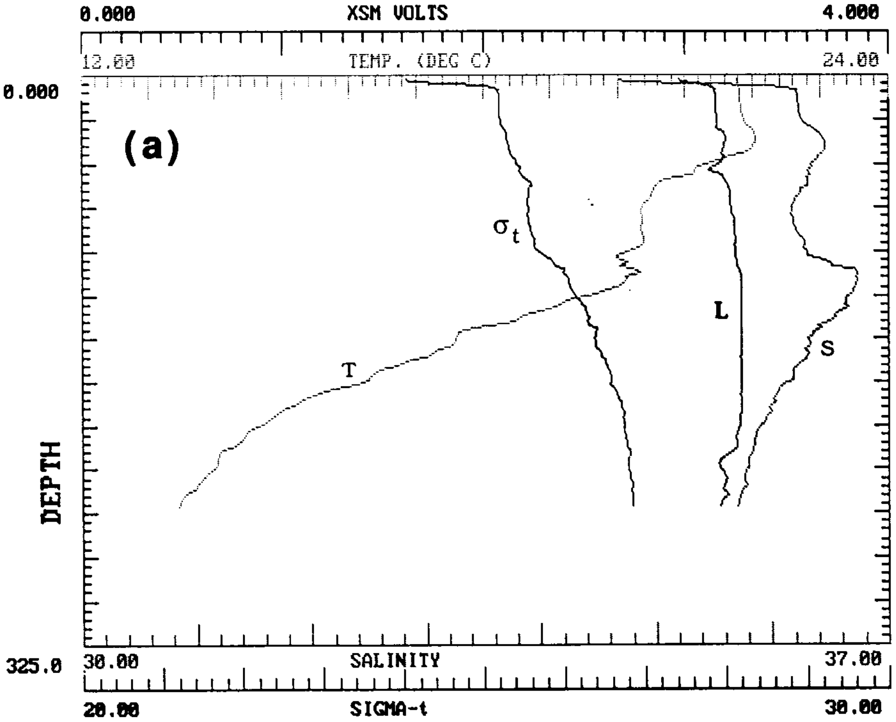
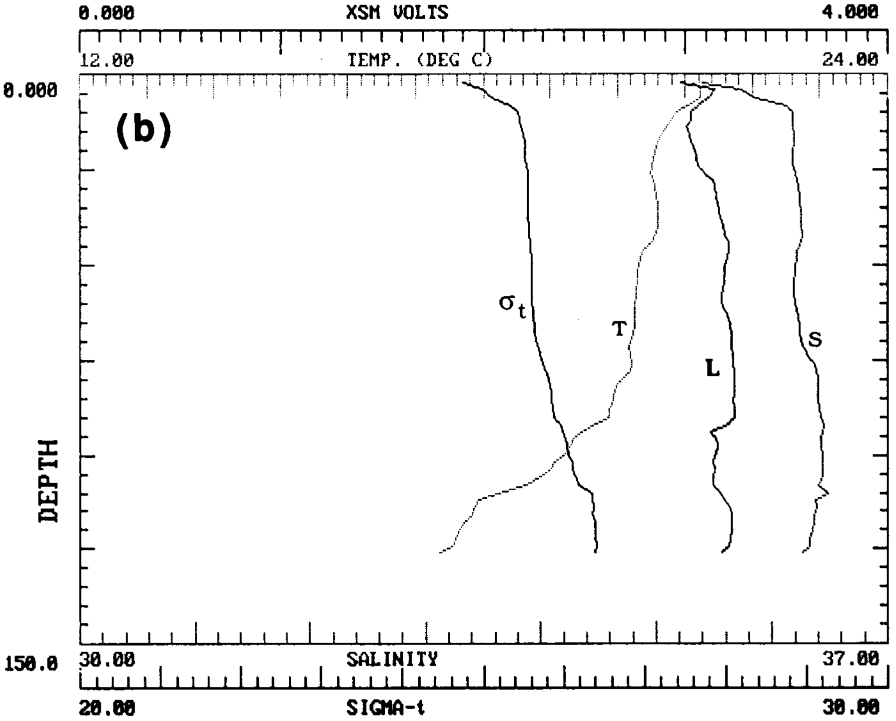


Figure 10-71. **Cruise 4 (February 11-18, 1989) near bottom distributions of (a) temperature (°C), (b) salinity (PSU) and (c) dissolved oxygen (mg l-1).**



Stn. S5 February 1989



Stn. S7 February 1989

Figure 10-72. **Cruise 4, Stations (a) S5 and (b) S7, vertical profiles of temperature (T), salinity (S), density (D) and transmissivity (L).**

just east of the Delta and eastward flow in the shallow northern part of the region.

Figure 10-63a shows the CTD vertical profile at Station M-3, located in the intrusive water mass. The mixed layer extends down to about 20 m. Below it salinity increases to a maximum of about 36.5 PSU at 55 m, and then decreases gradually. Temperature has a subsurface maximum in the pycnocline at 30 m, and then decreases. Below 55 m temperature exhibits numerous stair-step features. Transmissivity increases slightly to a maximum that coincides with the salinity maximum. Below this transmissivity becomes highly variable, with pronounced minima at depths corresponding to the bases of the stair steps. Station D-3 was located on the eastern periphery of the intrusion. Its salinity and temperature profiles (Figure 10-63b) are similar to those at M-3, but the subsurface temperature maximum and the stair steps are less pronounced. Transmissivity is high and decreases only slightly with depth.

Cruise 2 (March 10-18, 1988)

As noted in Section 10.3.2, this cruise documented a major Loop Current related intrusion. The filament entered the study area between Stations C-4 and M-4 and wrapped clockwise to the north east. The filament contained water with higher temperature, salinity and dissolved oxygen values both near the surface and near the bottom (Figures 10-64 and 10-65). A southwestward return flow, with opposite water mass characteristics occurred in the southeast part of the study area.

Station M-3 (Figure 10-66b) was located in the intrusion. The mixed layer, with temperature and salinity values of about 18.7°C and 35 PSU, extends to about 15 m Below this salinity increases to 36.5 PSU at 60 m. At 100 m it begins to decrease gradually. Temperature rises to a maximum of 20.5°C at 40 m and then decreases, with some pronounced stair steps. Transmissivity is low in the mixed layer and increases to high values where salinity is high. Beginning about 25 m above the bottom, transmissivity drops markedly. Station D-3, located outside the intrusion, also has a 15-m deep mixed layer with a temperature and salinity of about 15.1°C and 33.4 PSU, respectively. Temperature has an absolute maximum at 30 m and two pronounced relative maxima below this depth. Salinity reaches only 36.0 PSU at 60 m. Transmissivity is high from the surface to about 15 m above the bottom, where it begins to decrease.

Cruise 3 (August 19-25, 1988)

During Cruise 3, the near-surface temperature and salinity distributions (Figure 10-67) were dominated by two water masses. Water cooler than 29°C and saltier than 33 ppt pushed westward over the middle shelf, while warmer, fresher water lay to the northwest, west and southeast. The latter two regions were separated by a tongue of the cooler, saltier water that pushed southwestward between Stations C2 and M2. Higher values of dissolved oxygen were generally associated with the cooler, saltier water mass. Near the bottom (Figure 10-68), a relatively homogeneous water mass, with salinities above 36.5 ppt and temperatures between 20 and 22°C, dominated the middle shelf. North and south of this water mass meridional gradients were strong. A region of relatively low oxygen was centered on Station S-7, while a band with values above 6.0 mg l^{-1} girded the low region on the south and east. Highest oxygen values near the bottom were found in the northwest corner of the study region, while lowest values lay offshore on the deeper slope.

The CTD profiles at stations D-3 and M-3 (Figure 10-69) suggest that they were located in similar water masses.. At both stations there was no mixed layer, since salinity started increasing immediately below the surface from values near 33 PSU to values of about 36.8 PSU at 30 m depth. These high salinity values continued to the bottom. Although Loop Current core water has values as high as 36.8 PSU, the temperatures associated with the high salinity water mass on the shelf are completely inconsistent with Loop Current core water properties. Rather, the mass of high salinity water, which also has high transmissivity, is probably related to the 1988 drought, coupled with high rates of evaporation at the sea surface.

Cruise 4 (February 11-18,1989)

During the period of Cruise 4, the infrared satellite images (e.g., Figure 10-10a) clearly show that two warm filaments from the northeast corner of the Loop Current extended onto the shelf. The satellite data confirm the interpretation given the near surface temperature distribution (Figure 10-70) based on the less synoptic data collected during Cruise 4. One filament moved onto the shelf near Stations M3 and M4 and pushed almost as far as stations C1 and M1. The other influenced the eastern portion of the study region. Cool shelf-water moved southward between them. Higher salinity and lower oxygen values were associated with the warmer water, while the cooler southward moving water was higher in oxygen and much fresher. Near the bottom (Figure 10-71), the property distributions were oriented along the isobaths. A band of warmer more saline water lay along the line of stations D2, M2, C2. North of this line, oxygen values were relatively uniform, although the distribution suggests that slightly higher values entered from the east. South of the line, oxygen values decreased sharply as bottom depth increased.

The CTD stations at S5 and S7 (Figure 10-72) were clearly located in different water masses. A very thin layer of cooler fresher water was at the surface of each station. Although the stations have similar transmissivity and density profiles, they have quite different temperature and salinity profiles. Station S5 has a sharp, subsurface salinity maximum of 36.7 PSU at 115 m depth and an associated temperature of about 20.4°C, which is consistent with Loop Current core water properties. Also, the Loop Current was in the process of shedding Nelson Eddy during this time, and its northern boundary was close to the MAMES slope region.

10.7 Summary and Conclusions

The continental shelf and slope water of the MAMES region is a very dynamic system. There are four primary forcing mechanisms that drive the system: synoptic scale wind stress, Loop Current related intrusions, river discharge and tropical cyclones. The first is a stochastic process, and the other three are non-stochastic event processes that strongly modulate the first. The year 1988 was somewhat unusual because of the number and variety of events that occurred. The principal weather event of 1988 was a severe drought. The Mississippi discharge fell to as low as 32% of its long term mean during the summer months. The resulting decrease in vertical stratification of the shelf water increased the its response to stochastic wind forcing. Coherence between wind stress and currents during 1988 was stronger than in 1989 when Mississippi River discharge increased to above average rates.

Through a combination of satellite imagery, moored instruments and surveys by ship, the nature and frequency of Loop Current related intrusions into the study area were quantitatively assessed. Three categories or patterns of intrusions were defined. In the first one filaments push up the axis or east side of De Soto Canyon. The second pattern is frictional entrainment of outer shelf water into the northern periphery of the Loop Current or an eddy filament derived from it. The third pattern involves the penetration onto the shallow shelf of diluted Loop Current related waters.

An objective census of intrusions was accomplished by correlating temperatures recorded by the current meters at 150 and 426 m over the outer slope with observations by satellite of filament intrusions, which defined an intrusion signature in the temperature records. The temperature records were then used to count intrusions when satellite imagery was not available. During a 798-day period, intrusions were found during eleven periods of time, with a total duration of about 355 days, or 44 percent of the time. Given this frequency, it is not surprising that intrusions were observed during three of the five hydrographic survey cruises. The intrusion of March 1988 was particularly strong. It displaced or flushed much of the shelf water, further exacerbating the problem of diminished river discharge.

A number of tropical storms and hurricanes occurred in the Gulf during 1988 and 1989. The three most influential to the study area all occurred during September 1988. They generated strong southwestward currents that also promoted flushing of the shelf.

Low frequency or seasonal patterns of wind and current were analyzed by monthly means and seasonal wind and current roses. The annual cycle of the wind regime observed during the 26 months of field work for this study is consistent with the pattern described by Schroeder and Wiseman based on the ten year's of data collected at Dauphin Island Sea Lab, taking into account inter-annual variability. Northeasterly and northerly winds dominate in the months from September through February. March is a transitional month, with northerly, easterly, southeasterly and southerly winds occurring an approximately equal percentage of the time. The winds rotate clockwise from southeasterly in April to a broader distribution of southerly, southwesterly and westerly winds in July. In August the winds return to southerly and southeasterly. The principal exception to this regime was January through March in 1990 when easterly winds were dominant.

The majority of the monthly mean wind-stress vectors had an easterly component, which would tend to force a mean westward flow in the northern inner shelf region. Mooring A was located about 38 km offshore, which would place it outside the coastal boundary layer and in the central portion of the mean cyclonic circulation cell suggested by Dinnel (1988). Consistent with such a location, the monthly mean currents at AT in general had low magnitudes and varied widely in direction. Mooring B was located in a complex region of convergence and divergence in Dinnel's circulation schema, making difficult comparison with our observations. Seasonal current roses show that flow at BT was dominantly east or northeast except October-December 1988 and January-March 1990. The observations support Dinnel's summer and winter patterns. The off-shelf flow he suggests for spring was not observed in either 1988 or 1989. The dominant southwestward direction in the rose for the fall of 1988 agrees with Dinnel's fall picture but the rose for the fall of 1989 does not. At Mooring C the mean along-isobath flow at CT was positive (toward 55°) for all months except September 1988, when hurricane effects dominated the forcing. The observations at DT and ET are relatively short, but the available data shows that at DT the monthly mean flow had a positive component from February through September 1989, and at ET it was strong, persistent and northeastward from February through June 1989. The observations do not support Dinnel's hypothesized flow patterns in the region of Moorings C, D or E.

The monthly means for currents at AB were more organized in direction than those for AT, having a definite northeastward and onshore tendency. However, mean bottom currents at BB, CB and EB were persistently toward the southwest. At DB significant cross-isobath mean currents caused persistent southeastward mean flow from February through May 1989, while from June through October mean DB flow was weaker and variable in direction. The persistent southwestward flow at BB, CB and EB suggests the existence of a large scale east-to-west pressure gradient.

In general, we find agreement with Dinnel's (1988) circulation schema in the regions of Mooring's A and B. Over the inner and middle shelf he suggested a cyclonic circulation pattern based primarily on direct current meter observations. Over the outer shelf and slope he was forced to rely on seasonal maps of dynamic heights computed relative to a level of no motion at 500 m, and these results suggested an anticyclonic circulation cell with southwestward flow over the slope. The MAMES direct observations of current, however, do not support the existence of the anticyclonic cell. Part of the discrepancy may lie in the existence of the large scale pressure gradient which the persistent southwestward bottom flow at BB, CB and DB suggests. A southwestward bottom flow would affect dynamic geostrophic calculations. We suggest an hypothesis, as tentatively as Dinnel did for his, that the mean circulation on the shelf consists only of the cyclonic circulation cell and that its southern side extends to the outer shelf and slope.

Using spectral analysis methods, both wind stress and sea level at Dauphin Island were found to be highly coherent with current at both AT and AB. The vertical coherence (formally coherence squared) between near surface and near bottom currents was similarly high at this mooring. The coherence between wind stress and sea level was examined to determine the coordinate rotation of wind stress components that maximized the coherence between sea level and one of the wind stress components. Data from four periods were used: winter/spring and summer of 1988 and 1989. The directions that maximized the component response for the 1988 and 1989 winter/spring cases were 300° and 325°, respectively. These directions are close to the angle of 315° that bisects the right angle of the coast. Thus the maximum response on the northern coast during winter/spring was due to both the shore-parallel and the shore-perpendicular wind stress components. For the summer period of both 1988 and 1989 a direction of 285° maximized the coherence, which is close to the 270° direction that parallels the northern boundary. We hypothesize that the influence of the shore perpendicular component is partly related to the degree of stratification, and thus river runoff, which was greater in spring than summer, particularly the spring of 1989. The coherence between wind stress and sea level, as well as between currents at AT and sea level, was large--it exceeded the 95% level of significance over broad frequency bands, indicating a primarily wind driven response. However, a quantitative estimate of the actual rise or fall in sea level was not made because of the frequency dependent nature of the response and the fact that the coherence, although high, was only partial.

Near surface currents at BT and DT were usually only weakly correlated with stress, and at just a few frequencies. Near bottom currents at BB and DB were more strongly coherent with stress than surface currents at these moorings, but less strongly than the coherence between stress and currents at AB. For all shelf locations, coherence between wind stress and currents was most commonly observed at frequencies near 0.08 and 0.2 cpd. In the along-shelf direction, the coherence between currents at Moorings B and D, both surface and bottom, also exhibit the strongest coherence near these frequencies. Since wind stress exhibits a broad energy peak around 0.09 cpd, the results suggest a wind-forced wave mode dominates the middle and outer shelf response. Wind stress was generally incoherent with with currents recorded at CT and ET, except for the period from October 30, 1989 to January 30, 1990, when stress and CT currents were strongly coherent at several frequencies, including 0.3, 0.2, 0.15 cpd and below 0.05 cpd. Coherence between EB and CB currents was strong at 0.07 cpd. Phase angles suggest both forced and free wave modes.

The cross-isobath separation between moorings was about 25-35 km. A significant degree of spectral coherence was found between adjacent moorings, but not between AT and CT, which were about 70 km apart. We examined the salinity time series in the time domain for qualitative correlation, and found a number of low salinity pulses that appear to indicate cross-shelf flushing events. They frequently occurred during periods for which there was also evidence for Loop Current related intrusions. With only three moorings in the cross shelf direction in one array and two in the other, we can conclude that the cross shelf length scale of motion are at least about 30 km but less than about 70 km.

The principal conclusion of this portion of the study is that Loop Current related intrusions strongly modulate the stochastically wind-forced shelf circulation. The response to the wind forcing is relatively mild, except during tropical storms and hurricanes, and results in a shelf wide circulation that is cyclonic on a seasonal mean basis. This latter conclusion is speculative because of the few number of moorings. The intrusions are chaotic in occurrence. However, because of their frequency of occurrence, about 45% of the time, their strong effect, and the range of shelf region that can be influenced, estimates of consequences such as residence time for water in the area and actual transport paths, as opposed to mean flow, for pollutants and larvae cannot be made.

MARCH 3, 1849

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.