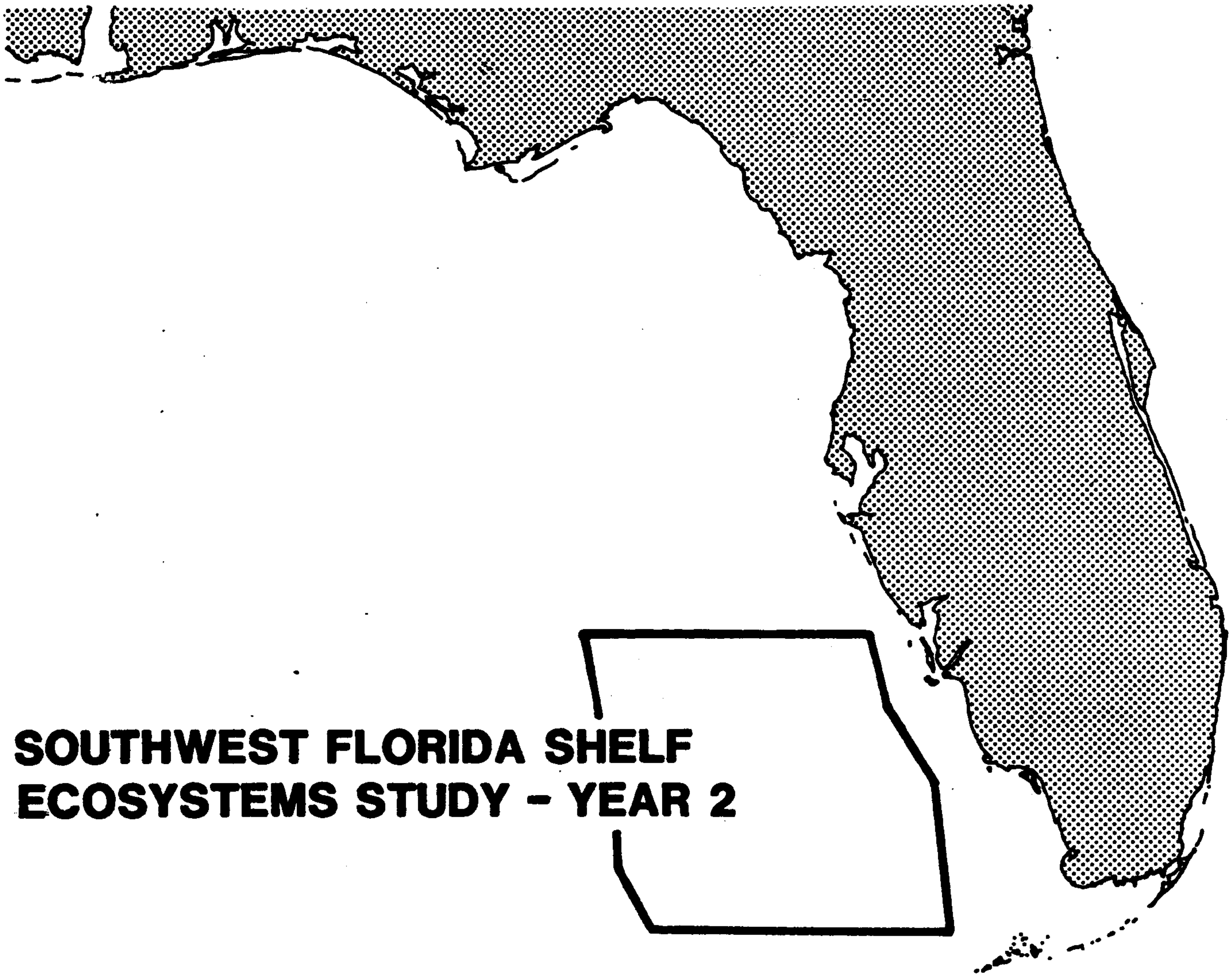
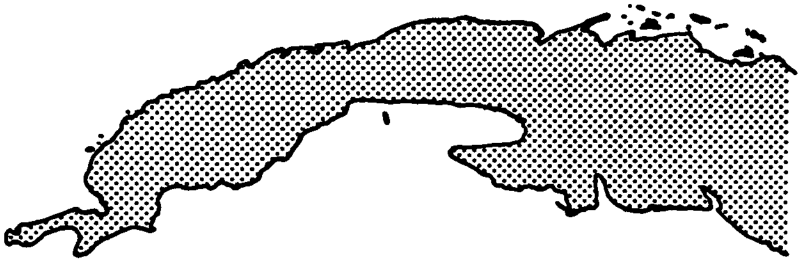
VOLUME 4 - FINAL REPORT III



SOUTHWEST FLORIDA SHELF ECOSYSTEMS STUDY - YEAR 2



Prepared for:
U.S. Department of the Interior, Minerals Management Service
Gulf of Mexico OCS Region, Metairie, Louisiana
Contract 14-12-0001-29144
July 1985

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Woodward-Clyde Consultants
Consulting Engineers, Geologists and Environmental Scientists

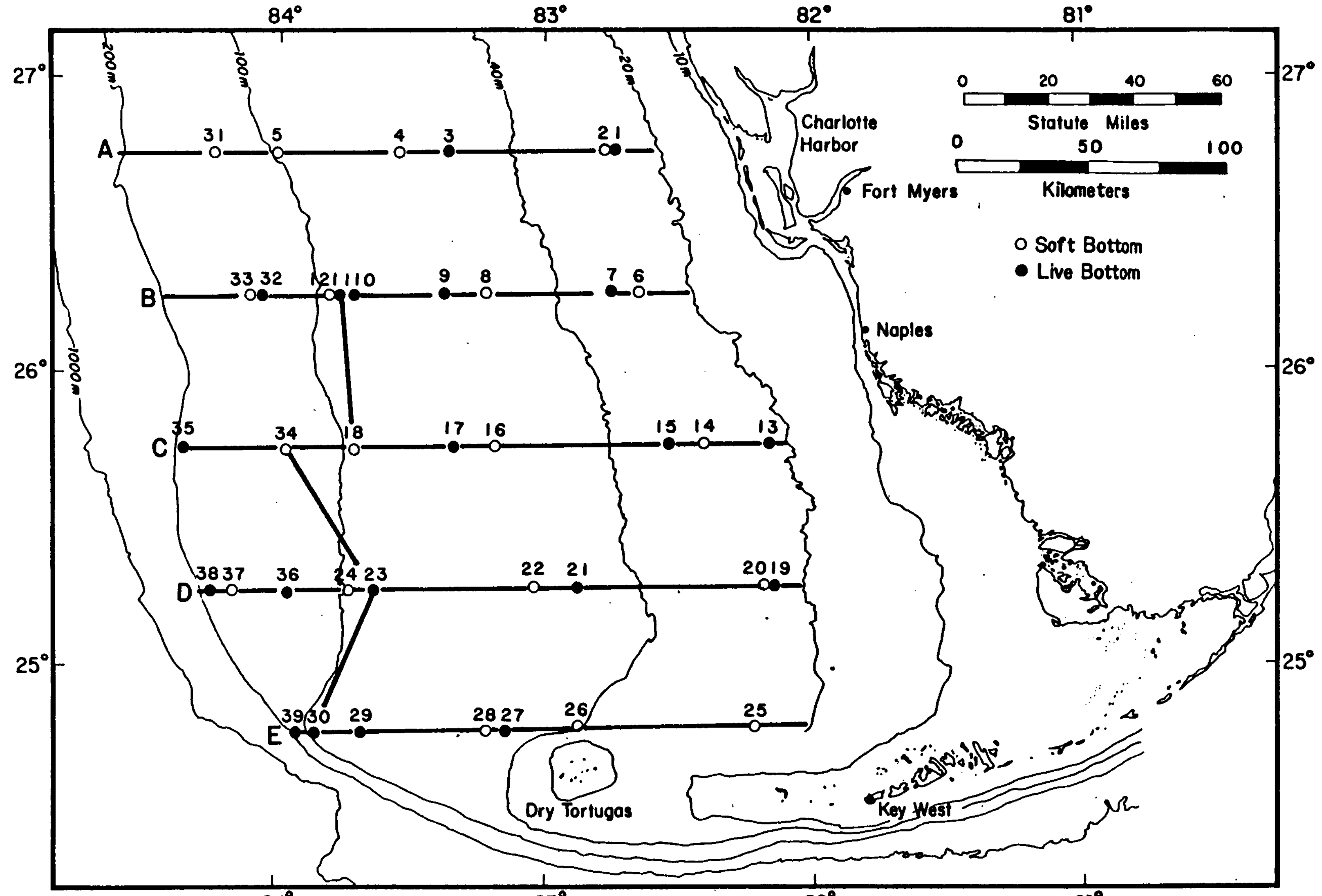
CSA
Continental Shelf Associates, Inc.
"Applied Marine Science and Technology"

PREFACE

THE SOUTHWEST FLORIDA SHELF ECOSYSTEMS STUDY

To meet present and future energy requirements of the United States, the Department of the Interior has acted to expedite development of oil and gas deposits beneath the outer continental shelf (OCS). Under the Department's accelerated 5-year leasing program, the Minerals Management Service (MMS) is proposing to offer for lease certain tracts in the eastern Gulf of Mexico. The protection of marine and coastal environments is mandated by the OCS Lands Act of 1963, the National Environmental Policy Act of 1969, and the OCS Lands Act Amendments of 1978. As manager of the OCS Leasing Program, the Department of the Interior is responsible for ensuring that proposed OCS development will not irreparably damage the marine environment and its resources. To help meet this responsibility, and to provide basic environmental information for the eastern Gulf of Mexico, the Minerals Management Service initiated (1980) the multiyear, multidisciplinary, Southwest Florida Shelf Ecosystems Study Program.

During Year One of the Southwest Florida Shelf Ecosystems Study Program, bathymetric, seismic, and side scan sonar data were collected (September-October 1980), along with underwater television and still camera color photography of the sea floor. These data were augmented by analyses of a broad range of hydrographic measurements, and water column, sediment, and benthic biological samples. Sampling stations were established in water depths ranging from 20 to 90m at 30 locations distributed along five east-west shelf transects (Figure, Transects A through E). Biological and hydrographic sampling were completed in fall (October-November) 1980 and spring (April-May) 1981.



Southwest Florida shelf survey transects (A through F) and benthic sampling stations for Year One and Two programs.

During the Year Two program, additional visual and geophysical data were collected along a north-south tie-line (Figure, Transect F). Twenty-one of the 30 first year hydrographic and biological sampling stations were resampled twice more, once during summer (July-August) 1981, and again during winter (January-February) 1982. In addition, nine new sampling stations were established on Transects A through E, in water depths ranging from 100 to 159m.

A third study phase, the Year Two Modification contract, examined the importance of Loop Current frontal eddies to primary production along the outer edge of the southwest Florida shelf. This phase encompassed two seasonal hydrographic cruises, in April and September 1982, and included direct and indirect measurements of primary productivity. These hydrographic and primary productivity data have now been synthesized with previous study results into an overview of the driving energetic forces within the southwest Florida shelf regional ecosystem.

The southwest Florida continental shelf includes sandy soft bottom sea floor substrates; hard, "live bottom" habitat; and other areas which favor the development and concentration of marine biota. The distribution of these bottom types and their significance to the regional marine benthic and water column ecosystem is not well known. The interpretation and synthesis of data from this Program are directed at general characterization of broad areas of the southwest Florida shelf, characterization of individual study sites, and inter-site comparisons; assessment of OCS development impact/enhancement potential; methodology evaluation; water mass characterization; and formulation of recommendations for future studies.

The results of the Year One program have already been reported (Woodward-Clyde Consultants and Continental Shelf Associates, Inc., 1983), as have the results of phase three (Woodward-Clyde Consultants and Skidaway Institute of Oceanography, 1983). The present Year Two Final Report describes the results of the Year Two program and provides an integration and synthesis of information collected during all three phases of the study.

The Southwest Florida Shelf Ecosystems Study Program has expanded considerably beyond the work reported herein. Year Three (Continental Shelf Associates, Inc.) continued seafloor habitat mapping to fill in areas between the Year One and Two study transects. Inshore biological sampling stations were also established in 10 to 20m water depths. Years Four and Five (Environmental Science & Engineering) were concerned with dynamic processes that affect the shelf ecosystem -- bottom currents, sediment movements, and so forth. A sixth program year presently contemplates a thorough synthesis of all preceeding study results.

The Year Two Final Report includes a total of seven (7) volumes, as follows:

Volume 1 - Executive Summary, provides a brief, abstracted summary of the principal goals, methods used, and results obtained during the study program.

Volume 2 - Final Report I, includes a more complete introduction to the Year One and Two programs, a summary of geophysical results, a complete discussion of methods used, and accounts of the physical oceanography and substrates that characterize the southwest Florida shelf.

Volume 3 - Final Report II, includes detailed accounts of the live bottom and soft bottom biota of the shelf.

Volume 4 - Final Report III, presents a synthesis of the physical variables and biological assemblages, outlines the potential impacts of OCS development, and provides lists of literature cited and program acknowledgments.

Volume 5 - Appendix A, provides copies of Year One and Year Two hydrographic and biological sampling cruise logs, sample collection times, station tract plots, and hydrographic and sediment data collected during both study years.

Volume 6 - Appendix B, includes the Master Taxon Code List for all taxa recorded during the program, and computer listings of all soft bottom sample station otter trawl and box core data collected during Years One and Two.

<u>Volume 7 - Appendix C</u>, provides computer listings of the live bottom sample station otter trawl, triangle dredge, and quantitative slide analysis data sets for Years One and Two.

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8.0 THE SHELF ECOSYSTEM
A SUMMARY SYNTHESIS

The two previous volumes of the Year Two Final Report have described broad characteristics of the geology (Volume 1, Section 2.0), hydrography (Volume 1, Section 4.0), sample-station substrates (Volume 1, Section 5.0), live bottom (Volume 2, Section 6.0) and soft bottom (Volume 2, Section 7.0) biological distributions, across the southwest Florida shelf. This section integrates the biological distributions with physical environmental data collected from the shelf, and seeks to identify some of the driving mechanisms and controlling variables operating within the southwest Florida shelf ecosystem.

Building on the seasonal hydrographic overview presented in Section 4.4.4 and the work of Woodward-Clyde Consultants and Skidaway Institute of Oceanography (1983), Section 8.0 begins with an examination of driving mechanisms controlling shelf hydrography. The role of Loop Current-related upwelling in providing nutrients to support both subsurface water column production and mid to outer shelf benthic production is stressed. The onshore-offshore "zonation" of several water column variables across the shelf is also emphasized. This section closes with a brief overview of geologic structure and substrate characteristics across the shelf.

The second major portion of Section 8.0 uses weighted discriminant analysis to explore quantitative, predictive relationships between benthic biological communities and near-bottom physical environmental variables measured across the southwest Florida shelf.

8.1 THE PHYSICAL ENVIRONMENT

The hydrographic regimes of the southwest Florida shelf are significantly affected by Loop Current influences offshore and shelf/near-shore influences onshore. The nature of these influences are described in the following section, along with some of their more important implications for water column and benthic biological communities. A summary of regional substrate trends concludes this overview of the southwest Florida shelf physical environment.

8.1.1. Hydrography

This section focuses on synthesizing important physical and chemical features observed during the water column studies and reviewing their potential biological significance. Prior to this study little water column work had been pursued on the southwest Florida shelf, particularly in relation to the overall ecosystem. This study collected baseline data which provide a general overview of potential driving mechanisms influencing biological production on the shelf. While this is a significant addition to knowledge of the southwest Florida shelf, it is only a "snapshot view" providing direction for more detailed studies such as that of Woodward-Clyde Consultants and Skidaway Institute of Oceanography (1983). Specific examples of hydrographic features noted during the four water-column sampling cruises will be cited in order to describe and discuss their importance to overall shelf dynamics. For detailed discussions of individual cruise results, consult the Year One Final Report (Woodward-Clyde Consultants and Continental Shelf Associates, Inc., 1984) and Volume 2, Section 4.0 of this Year Two Final Report.

During the early stages of data reduction it became apparent that near-bottom topographic upwelling was a major influence on the southwest Florida shelf. This process did not exhibit seasonal patterns but several mechanisms can be proposed that could bring colder, less oxygenated, nutrient-rich waters into the study area. The implications of this process to the biology of the Shelf are discussed below in Section 8.1.1.3.

8.1.1.1. Loop Current Influences

The potential influence of the Loop Current must be a prime consideration when assessing physical driving mechanisms affecting hydrographic regimes within the study area. The Loop Current is an extension of the Yucatan Current which enters the Gulf of Mexico Basin through the Yucatan Straits, turns anticyclonically within the Basin, and exits through the Florida Straits as the Florida Current. The Loop Current then becomes part of the Gulf Stream system flowing along the eastern seaboard. It has been suggested that the Loop Current has a seasonal flow into the northern latitudes with a spring intrusion, summer maximum, and fall retreat (Leipper, 1970). This classical development pattern, however, is not necessarily accurate. Maul (1977) confirmed a seasonal growth and decay but also found significant year to year variability. Molinari et al. (1977), using satellite data, found the current extended well into the Gulf (above 26°N latitude) during the winters of 1974-1977, further documenting variability.

Molinari et al. (1975) defined "Loop Current Waters" as those having a salinity maximum of 36.5 o/oo. These higher salinities are generally associated with Subtropical Underwater (SUW) which is normally found below the 100m depth within the Loop Current structure. Leipper (1970) used the depth of the 22°C isotherm (150 to 220m) to define the Loop Current, while Austin (1971) used selected indicator organisms to identify Loop Current Waters.

The southwest Florida outer continental shelf has the potential for continual influence by the Loop Current either by direct impingement or indirect processes. The primary method for determining Loop Current boundaries is by thermal contrast using satellite imagery. Imagery was obtained during the Fall 1980, Spring 1981, and Winter 1982 Cruises. These images not only depicted the continual proximity of the Loop Current to the southwest Florida shelf study area but also showed the short-term variability in the features associated with the outer edge of the current. (Specific imagery will be discussed later in this section.) Summer thermal data are rarely available because of the isothermal surface signature in the Gulf of Mexico from June through October.

The Loop Current is known to reach speeds of 200cm/sec (about 4 knots). For currents along the west Florida shelf, Moders and Price (1975) and Niiler (1976) have found extreme velocities of 100cm/sec associated with storms, but flow was generally less than 20cm/sec. They found southerly, northerly, cross-shelf, and counter-currents, but the studies were not comprehensive enough to explain the forcing functions. Flow generally paralleled the isobaths and tidal oscillations produced negligible net flow. Rehrer et al.

(1967) conducted bottom drift studies in the Tortugas shrimp grounds and found a predominant flow in a westerly-southwesterly direction.

Geostrophic Upwelling

Yentsch (1974) described a mechanism based upon the Rossby jet characteristics of the Gulf Stream whereby nutrients may be upwelled and transported from below the euphotic zone as a geostrophic flow to the left side of the direction of flow of the current. The flow of the Loop Current would be an analogous situation. Bogdanov et al. (1969) described an area of upwelling and high productivity off the southwest Florida shelf and a geostrophic upwelling would explain this phenomenon.

This type of process most likely occurs when the Loop Current is close to the shelf, flowing parallel with the continental slope. Based upon analysis of satellite data (Vukovich 1979; Geo-Marine 1980), it is probable that this is the prevalent mechanism for upwelling in the study area. Data collected during this program's four seasonal cruises also supports this conjecture. Figure 8-1 shows the position of the Loop Current relative to Transect A during the Fall 1980 Cruise. Cold, nutrient-rich water had upwelled (probably due to geostrophic upwelling) to the 80m isobath with penetration of the nutrient-rich waters into the 50m isobath. Woodward-Clyde Consultants and Skidaway Institute of Oceanography (1983), while studying the effects of Loop Current filaments, confirmed the source of the cold, nutrient-rich water data as being from off the shelf and below the subsurface salinity maximum. Figure 8-2 (from Woodward-Clyde Consultants and Skidaway Institute of Oceanography, 1983) depicts the deep water (from 160m) upwelling of colder, high nitrogen water from below the salinity maximum. Although this was related to a Loop Current filament (discussed later), the general results are the same. It may be supposed that the unsampled offshore hydrographic structure during portions of all four seasonal cruises were similar to that observed by Woodward-Clyde Consultants and Skidaway Institute of Oceanography (1983) -- although varying in intensity -- and strongly influenced the shelf near-bottom hydrographic environment.

A similar upwelling process which may be more intense than that noted above is described by Weatherly et al. (1977). When the Loop Current directly impinges

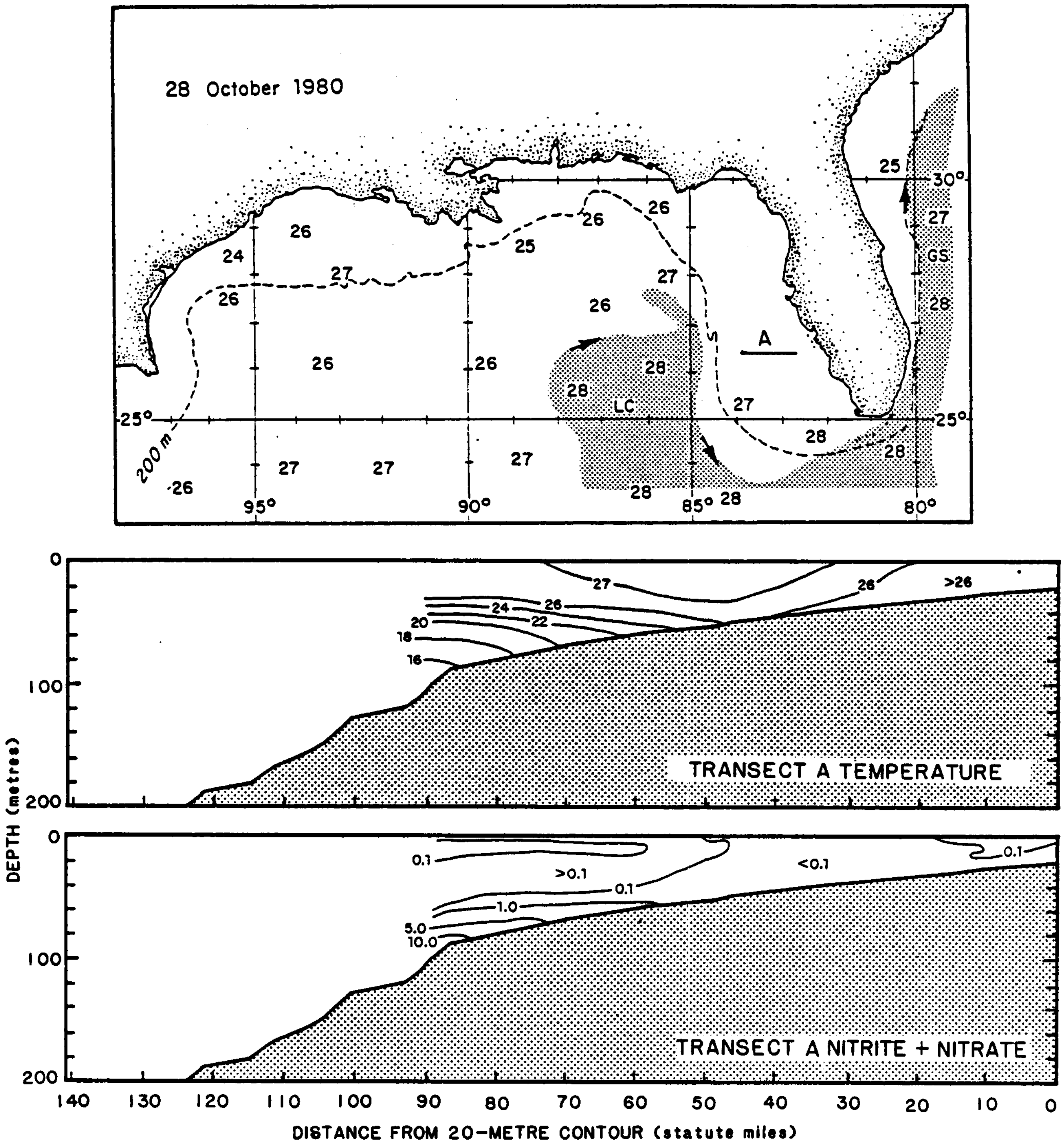

Figure 8-1. Fall Cruise 1980, Loop Current (LC) position relative to Transect A and associated hydrographic variables.

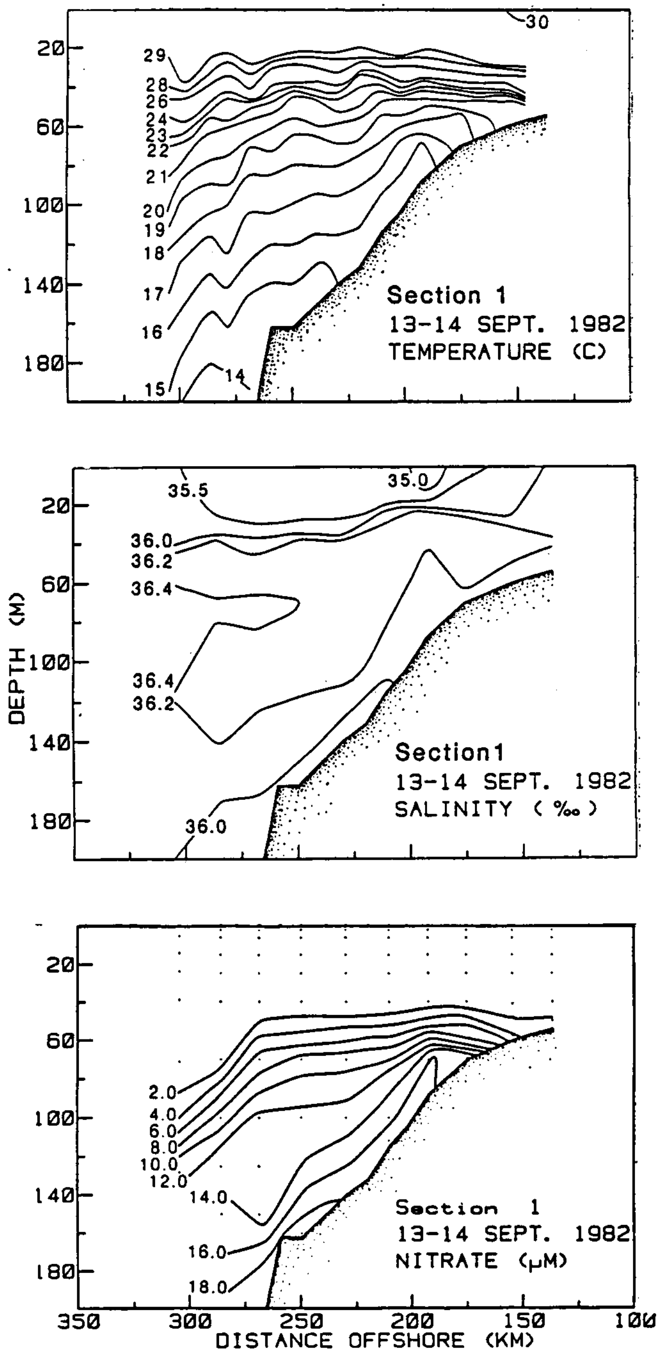

Figure 8-2. Hydrographic characteristics associated with upwelling, September 13-14, 1982 (after Woodward-Clyde Consultants and Skidaway Institute of Oceanography, 1983). See Figure 8-3 for transect location.

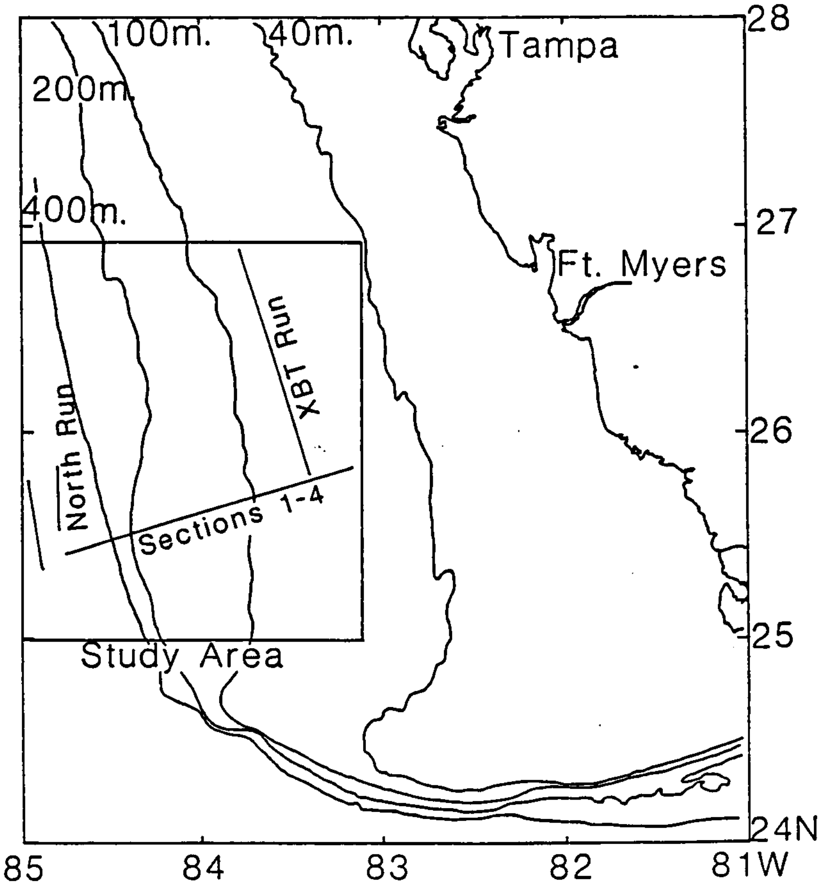

Figure 8-3. Location of sampling transects Summer Cruise, September, 1982 (after Woodward-Clyde Consultants and Skidaway Institute of Oceanography, 1983).

on the shelf slope and is flowing parallel with the shelf, frictional forces from the current's contact with the bottom creates an imbalance in the pressure gradient relative to the Coriolus effect. This causes a near-bottom flow in the shoreward direction as a topographic upwelling. Carder and Haddad (1979) have observed extreme bottom turbidities associated with this type of process suggesting near-bottom intrusion can be intense and penetrate to within the 40m isobath. Haddad (1982) has shown intrusions to be observable as a shoreward movement of the thermocline which can penetrate to within 3km of the coast, upwelling to the surface. This type of upwelling requires a larger amount of energy, and wind enhancement is certainly required for these extreme cases. This intense type of process was not observed during the four cruises and is likely to be a periodic event.

Eddy Impingement

Another Loop Current influence on the southwest Florida shelf that is intimately integrated into the previously described process is the impingement of Loop Current filaments or frontal eddies. An idealized Loop Current eddy consists of Loop Current water extending off the main Loop Current front, enclosing a cooler tongue of lower salinity waters, probably of shelf, shelf-edge, or upwelled origin. Vukovich et al. (1979) described these eddies as small meanders moving along the Loop Current boundary at average speeds of 28km/day with an average wavelength of 120km and a period of approximately 8 days.

Woodward-Clyde Consultants and Skidaway Institute of Oceanography (1983), studied Loop Current eddy structure, variability and processes extensively. The size and speed of the frontal eddies studied agreed well with that observed by Vukovich et al. (1979). Figure 8-4 depicts a frontal eddy penetrating the study area. It is apparent that the time scale for eddy movement is rapid and penetration can occur well within the 40 to 80m isobaths. Figures 8-5 and 8-6 show the hydrographic regimes across a frontal eddy that has penetrated onto the shelf. Based upon the time scales and observed results, it is likely that eddy penetration occurred in the study area during all of the seasonal cruises of the water column survey. The sampling scale and synopticity of the sampling precludes observing these relatively small scale events, but observations of low salinity lenses apparently associated with the

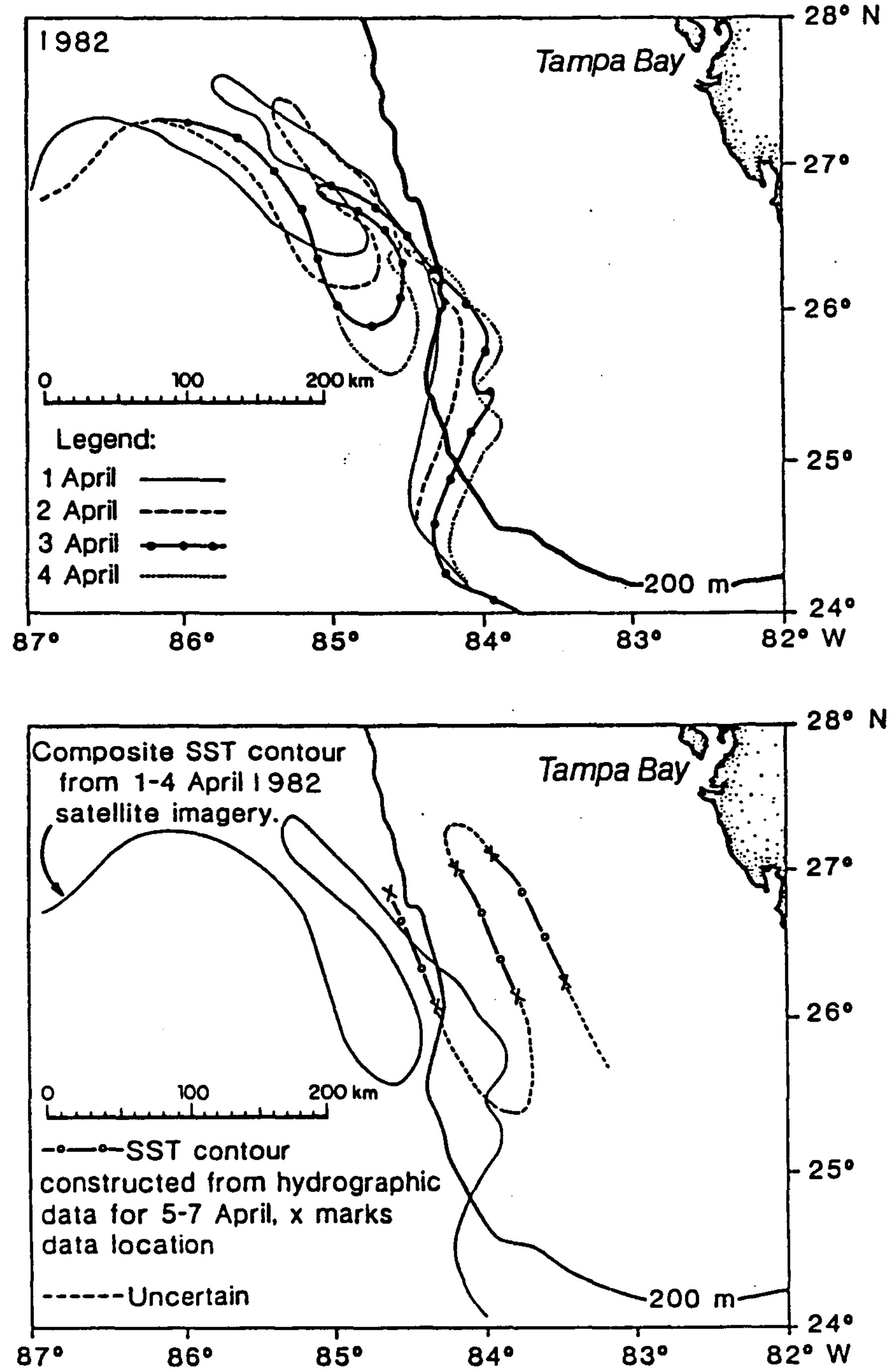

Figure 8-4. Time scale for impingement of Loop Current filament onto the shelf, April 1982 (after Woodward-Clyde Consultants and Skidaway Institute of Oceanography, 1984).

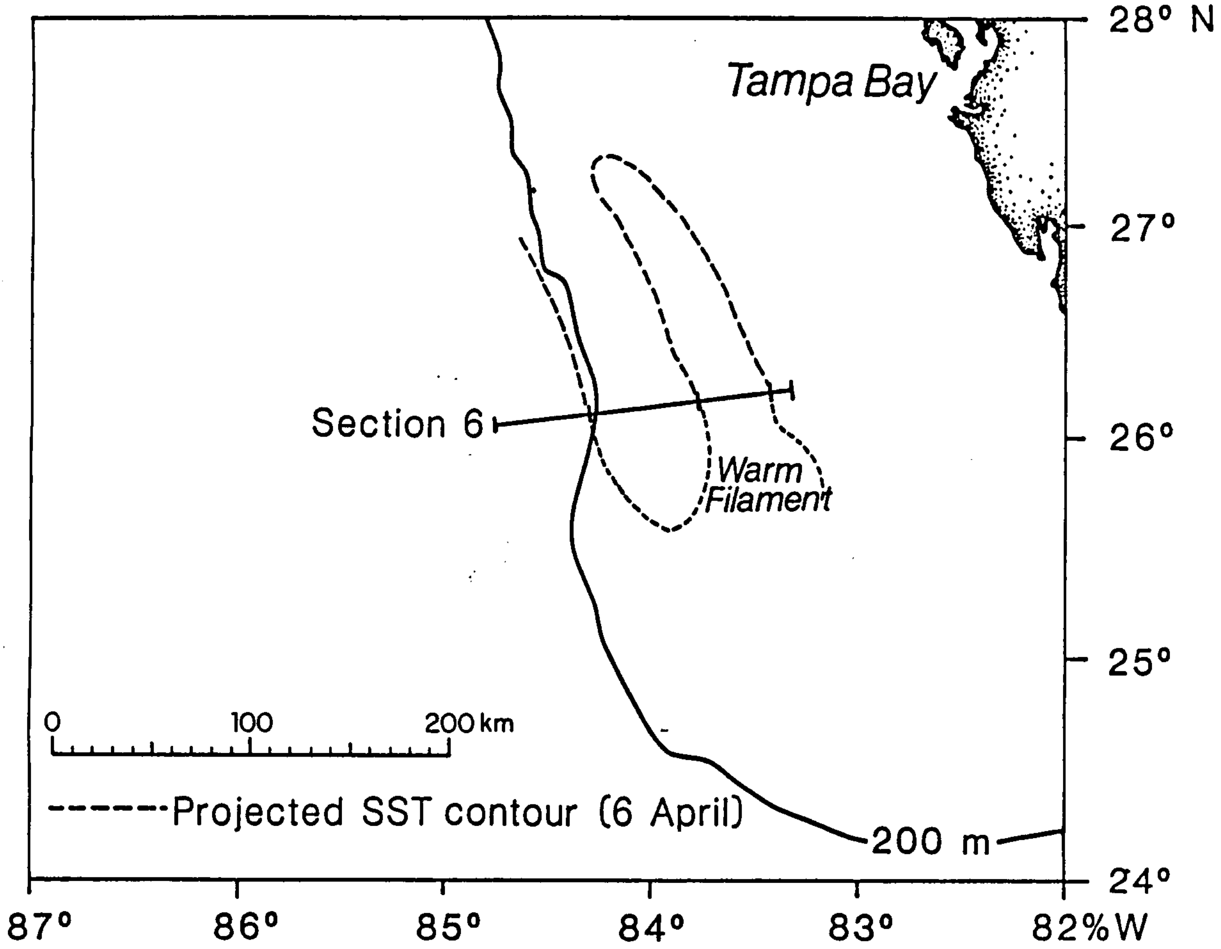

Figure 8-5. Position of frontal eddy and sampling Transect (Section 6) on April 6, 1982 (after Woodward-Clyde Consultants and Skidaway Instititute of Oceanography, 1983).

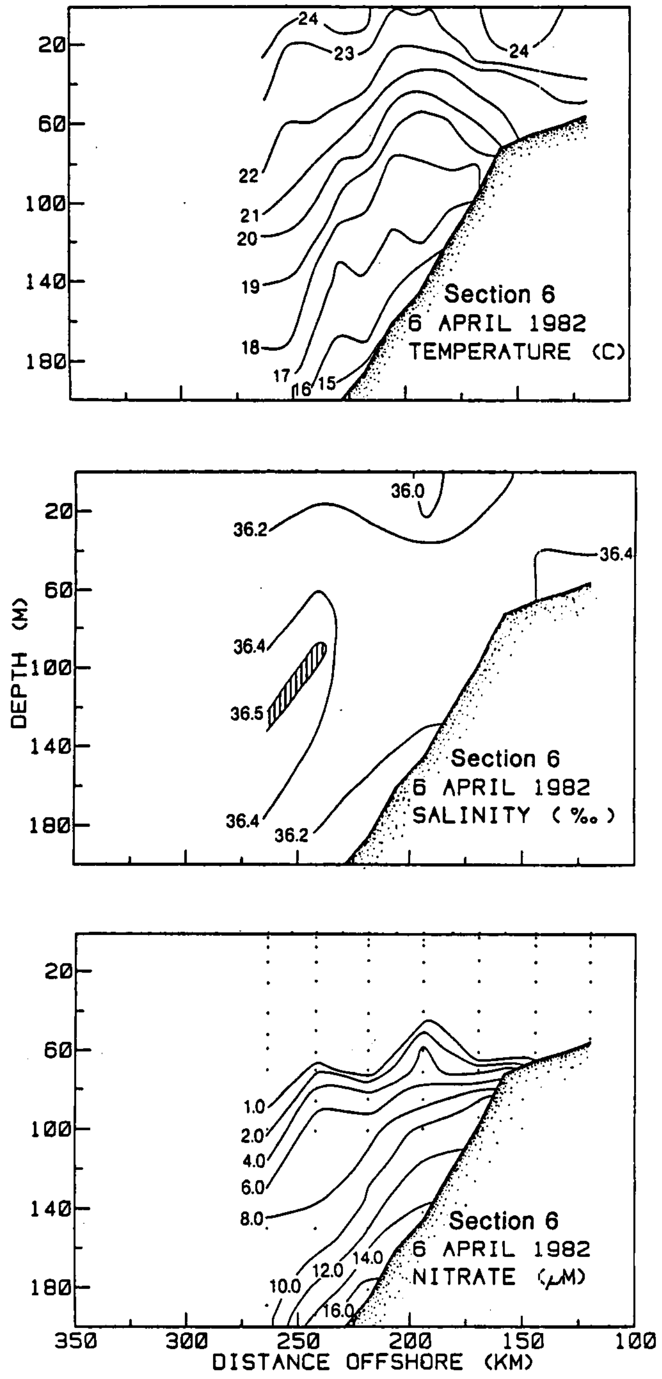

Figure 8- 6. Hydrographic characteristics associated with impingement of Loop Current filament onto the Shelf, April 6, 1982 (after Woodward Clyde Consultants and Skidaway Institute of Oceanography, 1983). See Figure 8-5 for Transect location.

eddies (Woodward-Clyde Consultants and Skidaway Institute of Oceanography, 1983) were made during all seasons and indicate at least remnants of Loop Current frontal eddies affecting the study area. It is likely that the low salinity pockets are coastally derived and entrained waters (i.e. carried down from the Mississippi) as described by Atkinson and Wallace (1975). This concept is open to speculation however, and individual low salinity pockets could be derived from any number of specific sources.

Satellite imagery for the Winter Cruise (Figure 8-7) depicts a Loop Current filament in the study area during the cruise period. Sampling of the offshore stations on Transects B and C took place within the time frame of the February 8, 1983, image (Figures 8-7b and 8-8). It is apparent, as one would expect, that the passage of an eddy in the area presents a dynamically changing water column. Transect B exhibited evidence of upwelling, while on Transect C the upwelling was suppressed (discussed further below). Woodward-Clyde Consultants and Skidaway Institute of Oceanography (1983) note that the water column can radically change within a 24-hour period as the filament affects a given location. It may be assumed that these filaments are not uncommon and constitute a major hydrographic influence on the outer portion of the southwest Florida shelf.

Cross Shelf Influences

The previous section primarily described geostrophic upwelling as a result of the Loop Current flowing parallel with the shelf edge. Another factor which must be considered is the east/west component of the current as it grows, meanders, spreads, and shrinks along the shelf break.

Filament impingement is certainly an example already discussed. As was observed in Figure 8-8, the lateral movement of an eddy onto the shelf can act to enhance or suppress the upwelling of cold, nutrient-rich water onto the shelf.

This same phenomenon can be expected as the Loop Current proper meanders east/west and on and off the shelf. Woodward-Clyde Consultants and Skidaway Institute of Oceanography (1983) found indications that toward-shelf movement of the Loop Current forced warm water onto the bottom layer, while the coldest

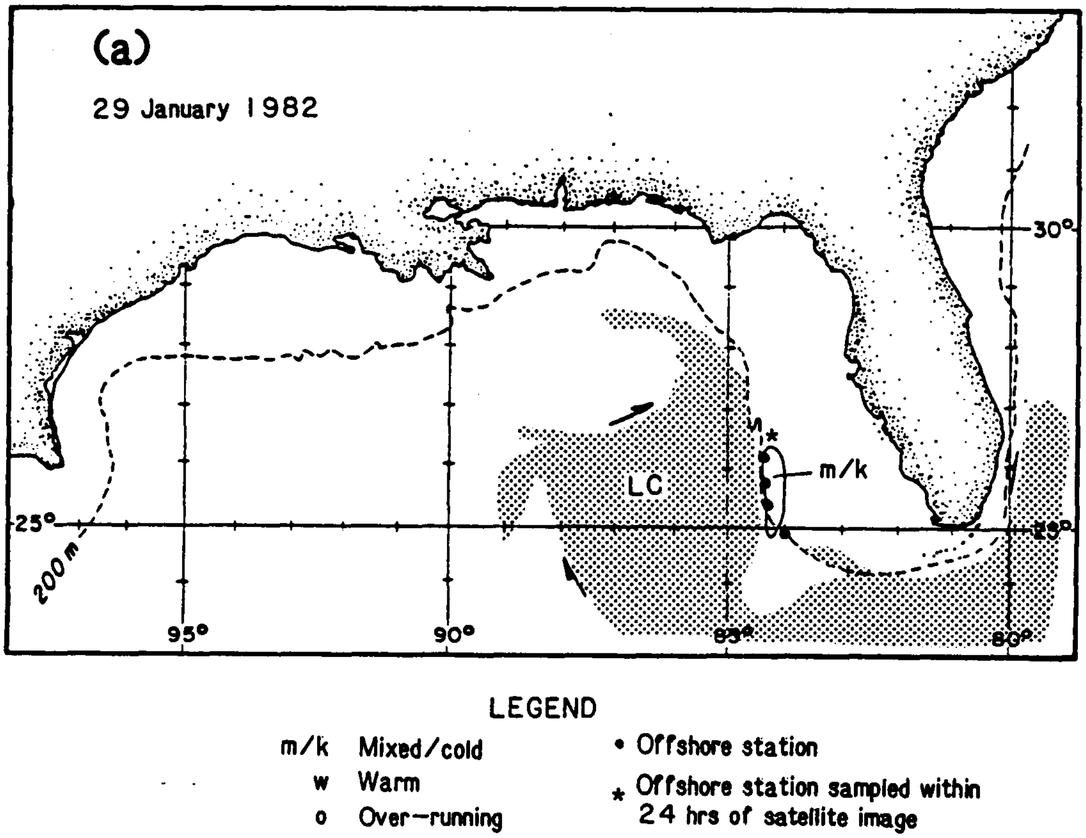

Figure 8-7. Loop Current (LC) positions during the Winter Cruise, as depicted by thermal imagery from the National Earth Satellite Service GOES satellite

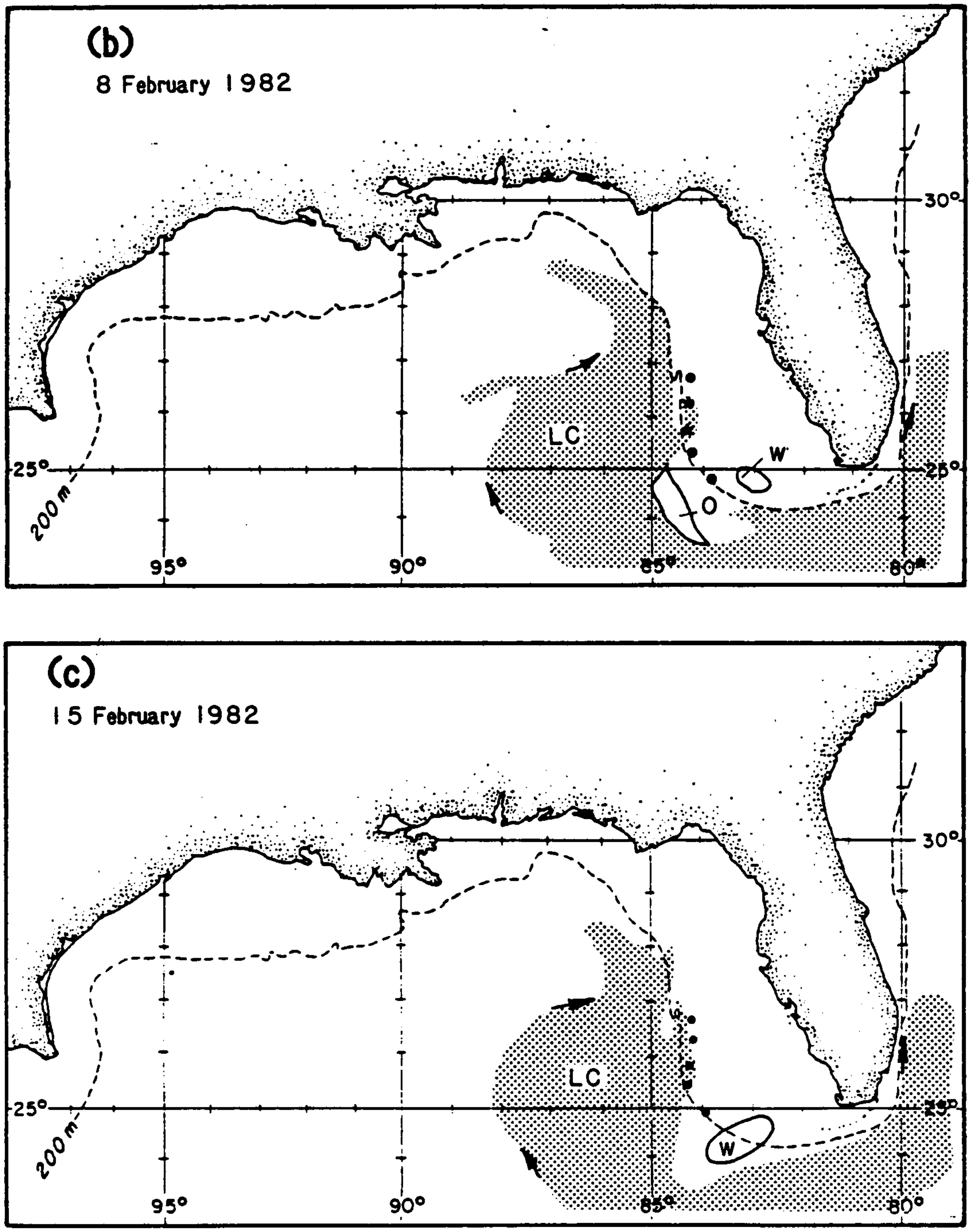

Figure 8-7 (Continued).

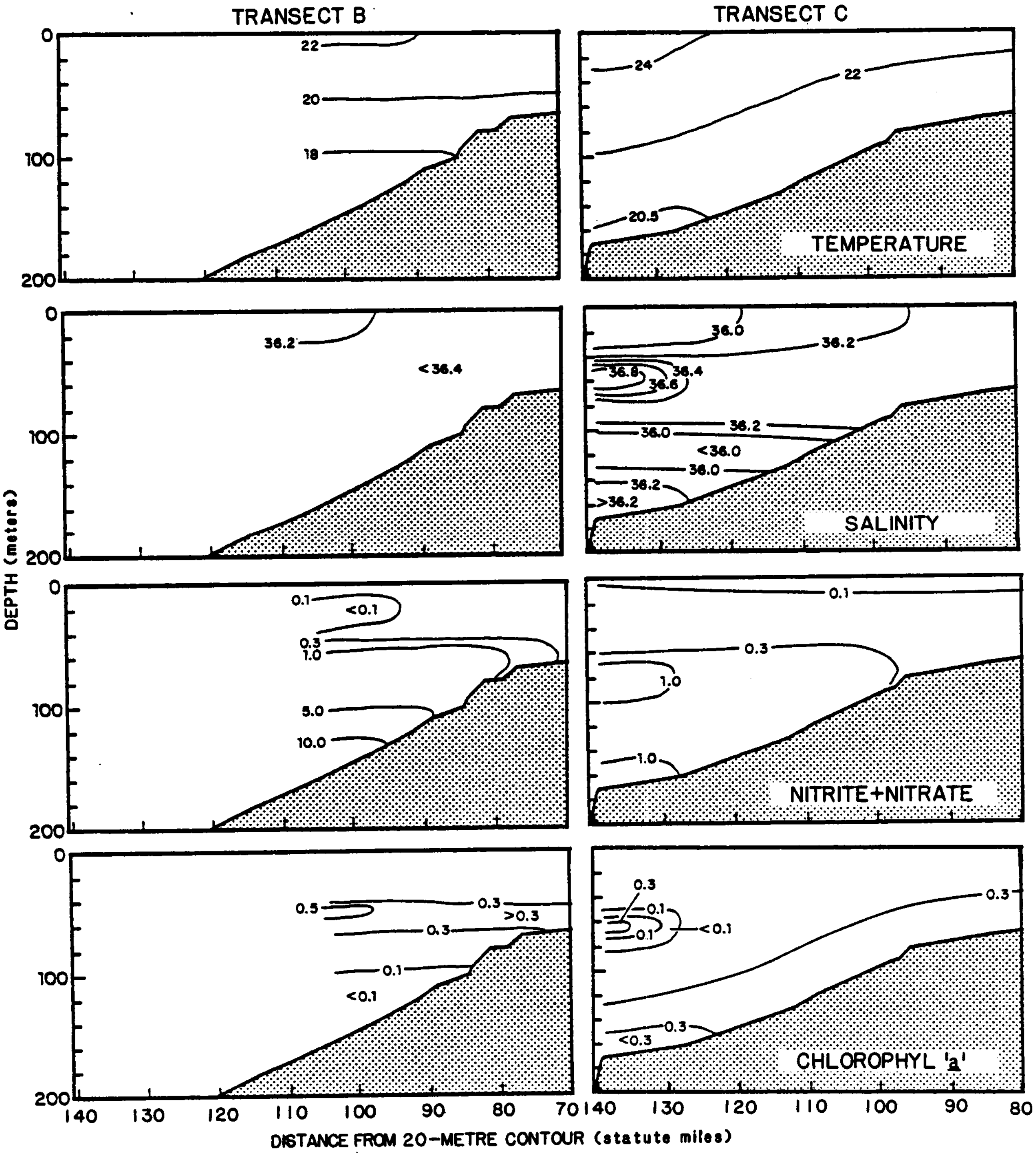

Figure 8-8. Winter Cruise 1982, Transects B and C: Shelf-edge hydrographic variables during a period of eddy impingement.

waters were found when the Current was furthest from the shelf. The forcing functions (both fine and mesoscale) driving the movement of the Loop Current are not understood. The time frame of east/west Current movement across the study area is not known, but could be mapped using thermal imagery analysis.

As with eddy impingement, movement of the Loop Current proper onto the shelf would also suppress upwelling of the colder nutrient-rich water. This could be considered an "El Nino" effect similar to that noted along the Peruvian coast. Peruvian coast upwelling is wind driven and provides the source for a rich biological assemblage. When those winds shift, warm low-nutrient waters impinge onto the upwelling zone and entire fisheries can disappear (Margalef 1975; Cushing 1981). Although the upwelling along the southwest Florida shelf is not nearly as intense, these Loop Current warm water impingements would certainly affect local biological production.

A process readily observable from thermal imagery is the development of large meanders over the southern portion of the study area. Vukovich et al (1979) determined that these meanders are created in conjunction with major gyre formation and separation from the Loop Current in more northern latitudes. They represent intrusions of shelf-water extending seaward as much as 400km. Vukovich et al. have shown that these shelf meanders can move as much as 300km in a cross-shelf direction in 20 days. This type of meander was observed during the seasonal sampling cruises and based on historical imagery (Geo-Marine 1980; Vukovich et al., 1979) is not uncommon. The effects of such gyre formation and meander development on shelf dynamics remains unknown. Figure 8-9 depicts a large meander progressing in an off-shelf direction during sampling of the outer shelf stations on Transects D and E during the Winter Cruise, 1982. When the offshore temperatures and nitrogen values from Transect E are compared with Transect A -- where no meander was present, and no frontal eddy was affecting the Transect -- an upwelling-related near-bottom temperature decrease of 4°C and a 5 μM increase in nitrite + nitrate was observed at Transect E (Figure 8-10). It is likely that meander generation served to upwell deeper, nutrient-richer water into the study area, particularly along Transects D and E, as the entrained shelf waters moved further offshore. Considering the regularity of meander formation and degradation,

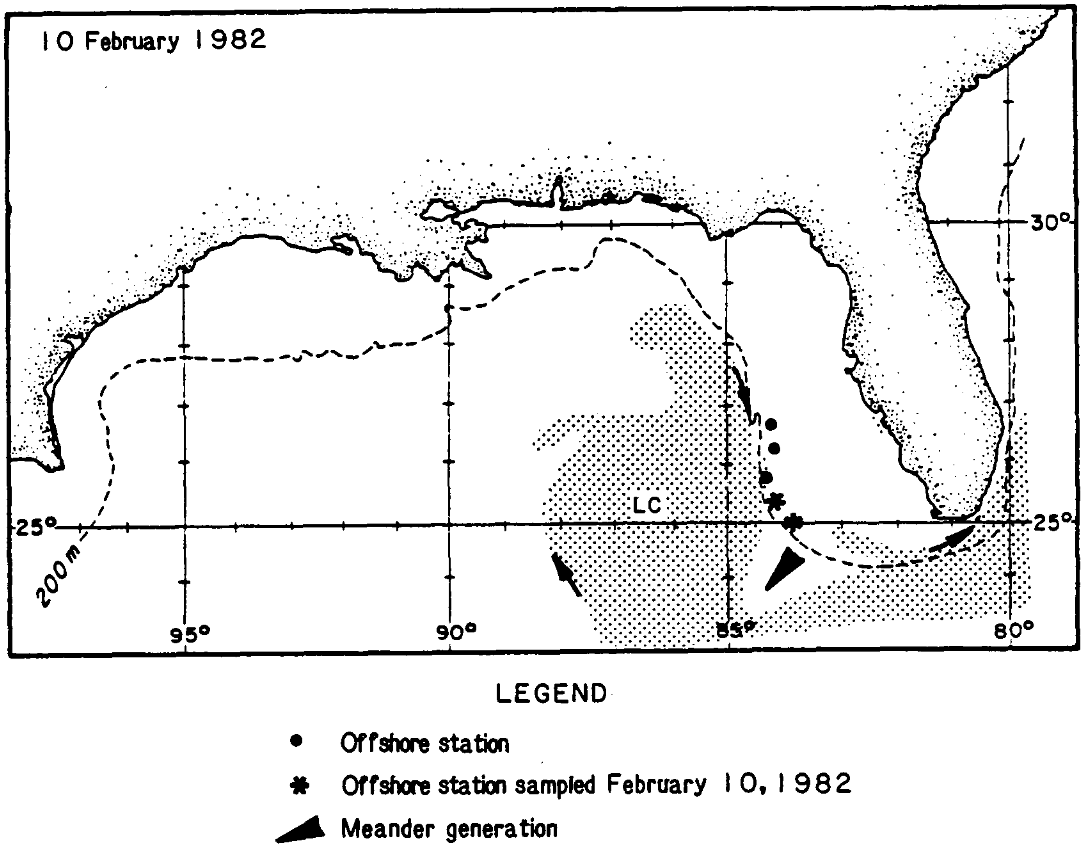

Figure 8-9. Loop Current (LC) position February 10, 1982, as depicted by thermal imagery from the National Earth Satellite Service GOES Satellite.

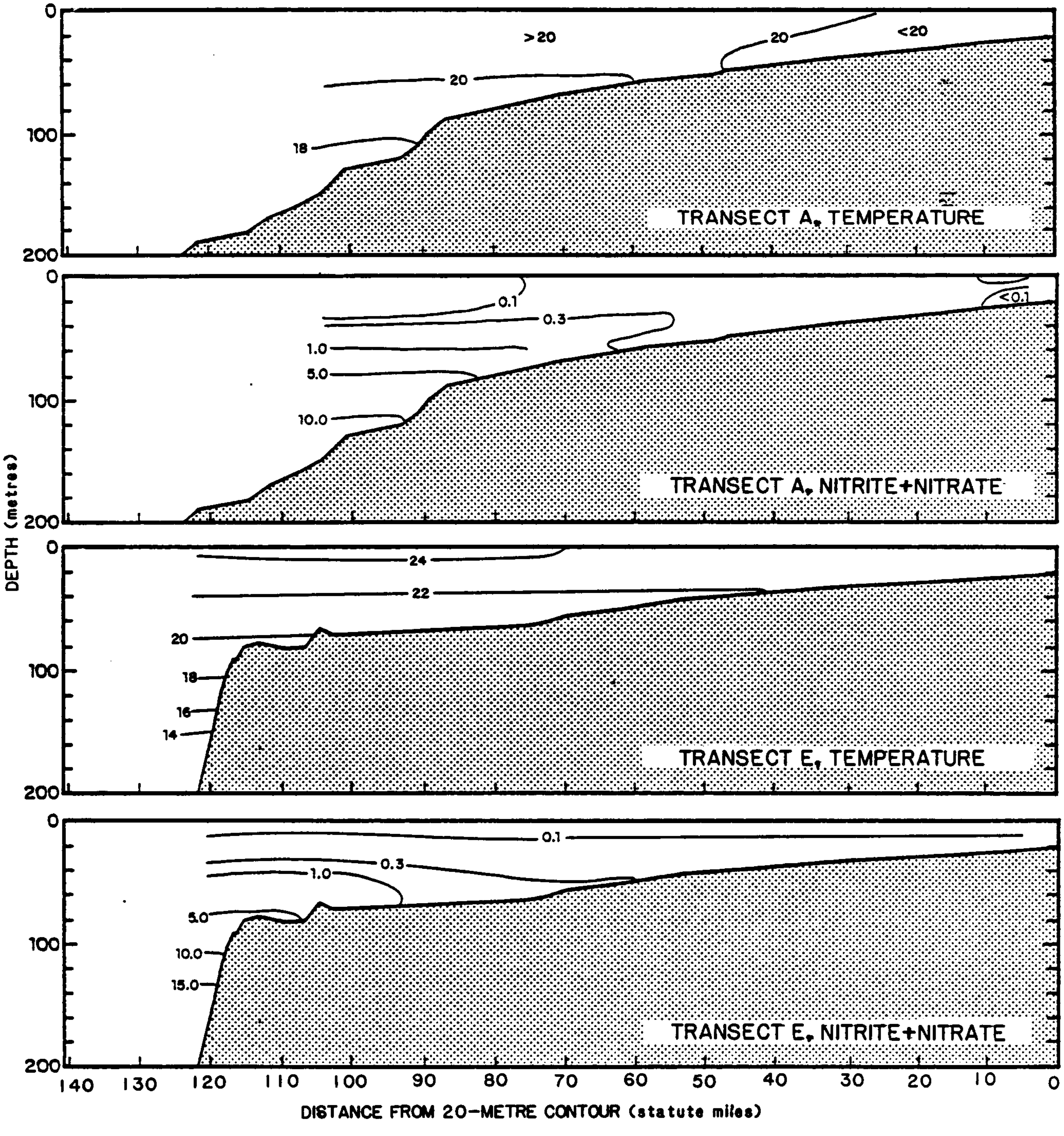

Figure 8- 10. Winter Cruise 1982, temperature (°C) and nitrite + nitrate (μM) distributions. Transect A sampled during period without meander or eddy influence; Transect E sampled during meander formation.

and the steep topography approaching Transect E, the potential for introducing cooler, nutrient-rich waters into this area are great.

Summary

The circulatory processes discussed above were observed during the four seasonal water column sampling cruises. Many other processes not yet discussed also impact the southwest Florida shelf study area. Winds can serve to depress or enhance the upwelling process. Tidal influence has an effect, as do alongshore currents, counter currents, and other circulation processes. As Woodward-Clyde Consultants and Skidaway Institute of Oceanography (1983) suggest, this needs further and intense study. Ocean/shelf interactions are difficult to model mathematically, primarily due to the numbers of variables and assumptions necessary. Although we are not be able to fully describe the processes, we can certainly observe the results. Figure 8-11 is a November 14, 1978, satellite Coastal Zone Color Scanner image of relative near surface chlorophyll concentrations within the study area. Chlorophyll concentrations reflect at least surface hydrographic patterns and water mass distributions (Hovis et al., 1980). Insertion of the image at this point is to impress upon the reader the tremendous variability and dynamics of the system. The transect locations and stations in the sample area are overlain to demonstrate that our sampling and contouring of data can only provide broad impressions and eliminate much of the inherent variability in the study area. This is acceptable, providing interpreters and resource managers utilize the data with that conceptual understanding.

8.1.1.2. Shelf/Near-shore Influences

Near-shore hydrographic influences on the southwest Florida shelf are subtle and difficult to define. Oceanic/Loop Current Circulation undoubtedly affects near-shore processes, but specific interactions are difficult to identify. In many continental shelf systems the 15 to 20m isobaths define a break between lower salinity, more productive, coastal waters and higher salinity, less productive, shelf waters. The southwest Florida shelf study area is most likely a deviation from this rule of thumb because of the great distance of the 15 to 20m isobaths from shore. Lower salinity influences were observed at the inner shelf stations during Spring and Fall Cruises, but actual salinity

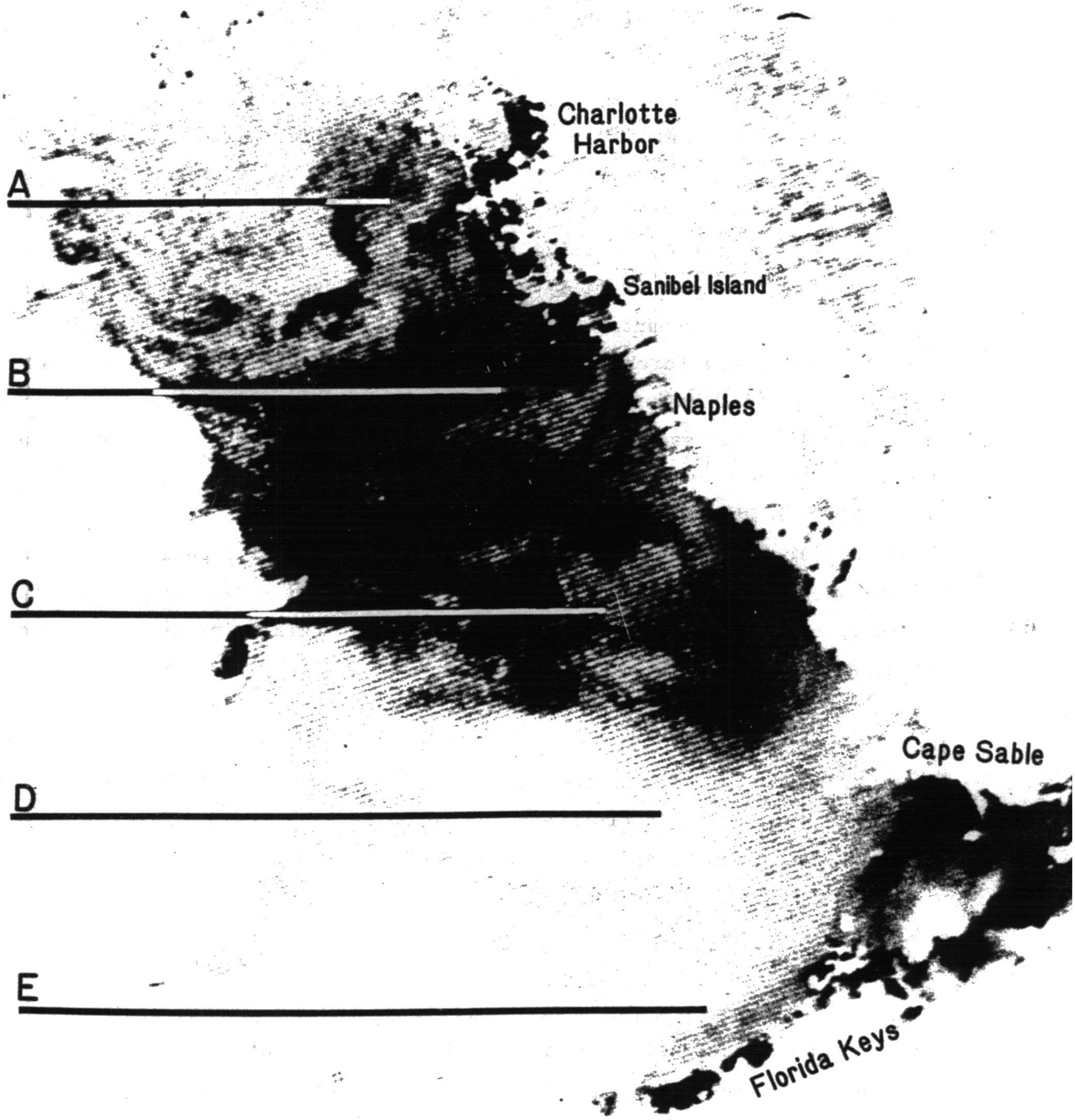

Figure 8-11. Coastal Zone Color Scanner image depicting surface chlorophyll structure in study area, November 14, 1978. (Darker shades indicate higher chlorophyll concentrations; study transect locations (A-E) approximate; after Haddad 1982.)

values were not below 35 o/oo. Transmittance values generally decreased near-shore, sometimes in conjunction with increased production, but greater turbulent mixing in the shallower waters also contributed to the overall transmittance decline. Summer and winter near-shore salinities (>36.4 o/oo) were generally higher than those offshore. This may have been an anomaly however, brought on by evaporative losses from a severe drought occurring in Florida at the time.

The question of Everglades input into the study area remains uncertain. The amount of freshwater and sheet flow penetrating the Everglades has been dramatically altered by channelization (Thomas, 1974). When considering the conceptual idea of the Everglades as a system, the logical influence to the southwest Florida shelf would be freshwater input. This type of influence was not observed however. Initial observations of yellow substance (Woodward-Clyde Consultants and Continental Shelf Associates, Inc., 1984) suggest this indicator of terriginous input to be below detectable limits of the methods. It could therefore be assumed that Everglades input of freshwater did not influence the study area.

Schmidt and Davis (1978) summarized water quality data from the Everglades National Park from 1879-1977. A salinity range of 26.7 o/oo to 39.2 o/oo was observed along the Florida Bay mainland in the 1930's, while hypersaline conditions (41-66 o/oo) were observed between 1973 and 1976. The effect of these high-salinity waters remains unknown. Hela (1956) suggested that these waters may at times be incorporated into the cyclonic eddy at the shoreward stage. The distinctness of these hypersaline barriers within the inner Florida Bay area has increased as a function of drainage rerouting in conjunction with development (Thomas, 1974). Zieman (1982) found surface concentrations of seagrass blades in the study area and determined their source to be the extensive seagrass beds within the shallow waters of Florida Bay. He has indicated that the exchange of material between the inshore grassbeds and the coastal shelf region is governed mainly by winds, with the predominant transport being westward from Florida Bay and the lower keys.

Contrary to the yellow substance observations, these other studies suggest that inner Florida Bay waters do influence the study area. Rather than freshwater input however, the influence may be more in the form of higher salinity, low-nutrient waters which would be governed by climatological events. There could be potential for a freshwater influence if proper conditions existed, but any Everglades runoff influence seems likely transient in nature.

Summary

Coastal influences, at least out to the water depths of the near-shore sampling stations, are noted occasionally. They do not appear to be as significant as in many other coastal areas however, and this may be due to the lack of freshwater input. The Charlotte Harbor estuarine system and coastal area south to the Everglades provide the potential for influence to the study area. Hydrographic variations during the seasonal cruises were slight however, with near-shore salinities ranging only from about 35.2 to 36.5 o/oo and chlorophyll concentrations never exceeding 1.5 mg/m^3. This does not suggest the system is static from a hydrographic (i.e. transport, water exchange, etc.) point of view, but it may mean the variability of the hydrographic parameters measured is not extreme.

8.1.1.3. Some Biological Implications

Many factors must be considered when discussing the southwest Florida shelf as an ecosystem. An ecosystem is defined as "A community of organisms, interacting with one another, plus the environment in which they live and with which they also interact," with the activities of the organisms "being influenced by physical conditions of the environment" (Abercrombie et al., 1974). Many of the physical factors have been measured and discussed for the study area. These processes are analogous to the climatology in land systems and are very important in determining the faunal/floral composition and ecological interactions within an area. The primary producers of an area form the basis for the food chain and often dictate the total productivity of the region.

Water Column Productivity

There are numerous methods in use for measuring primary production in the water column. One indirect method is the determination of chlorophyll concentrations. While this does not provide the necessary data to measure the rate of carbon exchange, an index for actual growth and health of the phytoplankton, it does provide a relative estimate of biomass (standing crop) within the system. The higher the chlorophyll concentration, the greater the biomass of phytoplankton present, and one could also assume a higher rate of primary production.

Two important parameters contribute significantly to the growth and maintenance of phytoplankton. Light availability is important on an individual species basis, different photoplankton species growing better at different light intensities. A nutrient source is also required to allow the trapped light energy to carry out its function in the growth process.

The lower limit for photosynthesis in the oceans has generally been considered as the depth to which 1% of the incident radiation reaching the water surface penetrates. As with any "biological limitation" this is not an ironclad rule and many plant species exist that grow below the 1% light level. Those waters above the 1% light level are considered the euphotic zone and the depth of the euphotic zone varies significantly between and within the world's oceans and marginal seas.

Previous workers, such as El Sayed et al. (1972), found the average depth of the euphotic zone (1% light attenuation level) in the Gulf of Mexico to be 74m. Chlorophyll a concentrations at the surface averaged 0.2 mg/m^3, but ranged from 0.05 to 0.3 mg/m^3. They also determined that maximum Chlorophyll a concentrations were subsurface and many maxima coincided with the depths of the euphotic zone. Woodward-Clyde Consultants and Skidaway Institute of Oceanography (1983) found the depth of the euphotic zone at approximately 65 to 70m during their offshore sampling of the southwest Florida shelf area. A limited number of light attenuation measurements were made during the Summer Cruise (1981). These are listed from the stations sampled, in Table 8-1. The 1% light level was noted between 50 to 70m and was not observed prior to bottom interception at several stations within that depth range. This depth of light penetration suggests quite clear waters. Transmittance values were generally greater than 85-90%, supporting the observation that exceptionally clear waters persist over much of the southwest Florida shelf.

Table 8-1. Percentage of surface incident light remaining at various water depths from selected southwest Florida shelf sampling stations (Summer Cruise 1981).

Sampling Depth (m)	Station Number/Depth						
	1 (24m)	20 (23m)	9 (56m)	28 (59m)	33 (146m)	35 (152m)	39 (159)
1.5	44	45	50	35	51	51	40
5	34	29	32	28	33		26
10	17	18	20	24	23	23	22
15	12	12	15	21	19		16
20	6	7	11	18	15	20	12
25	5	5	9	16	11		8
30			6	14	9	11	6
35			5	12	7		5
40			3	10	6	9	3
45			2	9	5		2
50			1*	8	4	7	1*
55				7	3		
60						4	
65							
70						1*	

*The one percent light attenuation level is generally considered the photic zone depth.

Throughout the study area, particularly at mid-shelf and outer shelf stations, Chlorophyll a concentrations in the mixed layers were oligotrophic in nature. Values of Chlorophyll a were often less than 0.1 mg/m^3 in the mid-shelf and outer shelf stations, with maximum values of greater than 1.0 mg/m^3 found at the inner shelf stations. Figure 8-12 depicts Chlorophyll a distributions on one representative transect during all four seasonal cruises. This provides a general impression of the variability across the region. It also becomes obvious that the chlorophyll maximum is subsurface and generally greater than 20m in depth. Woodward-Clyde Consultants and Skidaway Institute of Oceanography (1983) found the Chlorophyll a maximum as shallow as 2m and also found that the depth of the maximum did not always correspond to the depth of maximum C-14 uptake, although the C-14 uptake maximum was generally subsurface. They also noted that the Chlorophyll a maximum usually corresponded with the top of the nitracline. As with many phytoplankton communities, nitrogen availability appeared to be the limiting, or at least most obvious, nutrient relative to standing crop. Figure 8-13 depicts the NO_2-NO_3-N concentrations corresponding to Chlorophyll a in Figure 8-12. It is apparent that NO_2-NO_3-N concentrations of 1 µM upwelling into the euphotic zone (50 to 70m) significantly enhances the Chlorophyll a maximum and infers enhanced primary production. Figure 8-14 shows an example of nitrate and Chlorophyll a + pheaopigments data collected during the Year Two Modification Summer Loop Current Cruise (September 1982). It is apparent that the above conclusion may relate as a general observation for the outer and mid-shelf areas, but no statistical correlative analysis has been attempted.

Woodward-Clyde Consultants and Skidaway Institute of Oceanography (1983) have discussed the comparison between eddies affecting the southwest Florida shelf area and Gulf Stream eddies off the eastern Florida coast, relative to primary production. They found the following:

> *"Frontal eddies propagating along the cyclonic Gulf Stream front between Cape Canaveral, Florida and Cape Hatteras, North Carolina also cause upwelling and intrusion of nutrient-rich waters onto the outer southeastern continental shelf (Lee et al., 1981). During these events, surface mixed layer Chlorophyll a attains concentrations as high as 5 mg/m^3 or more, and primary production exceeds 5 $gC/m^2/day$. (Yoder et al., 1981a).*

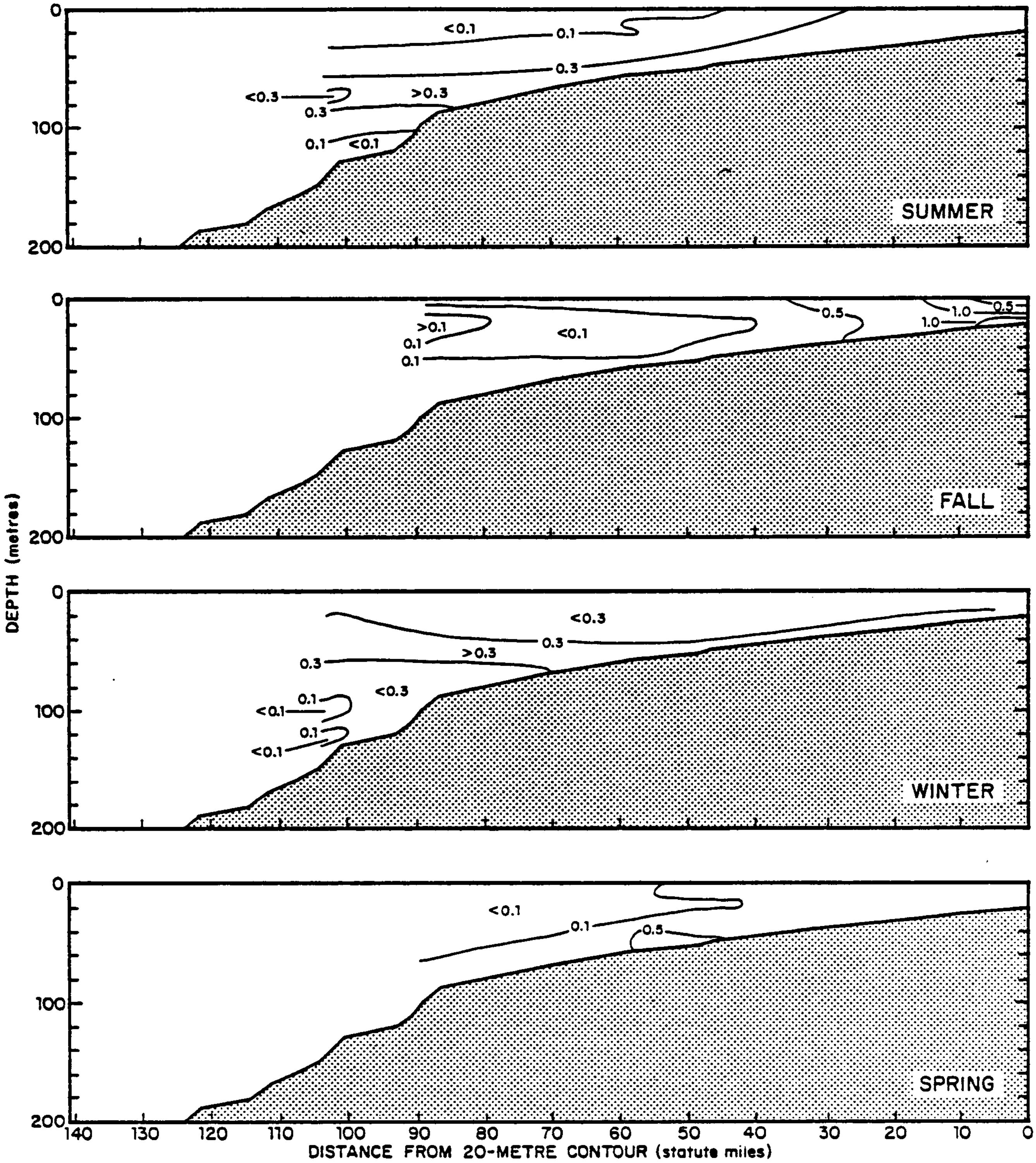

Figure 8-12. Seasonal chlorophyll a (mg/m^3) distributions on Transect A.

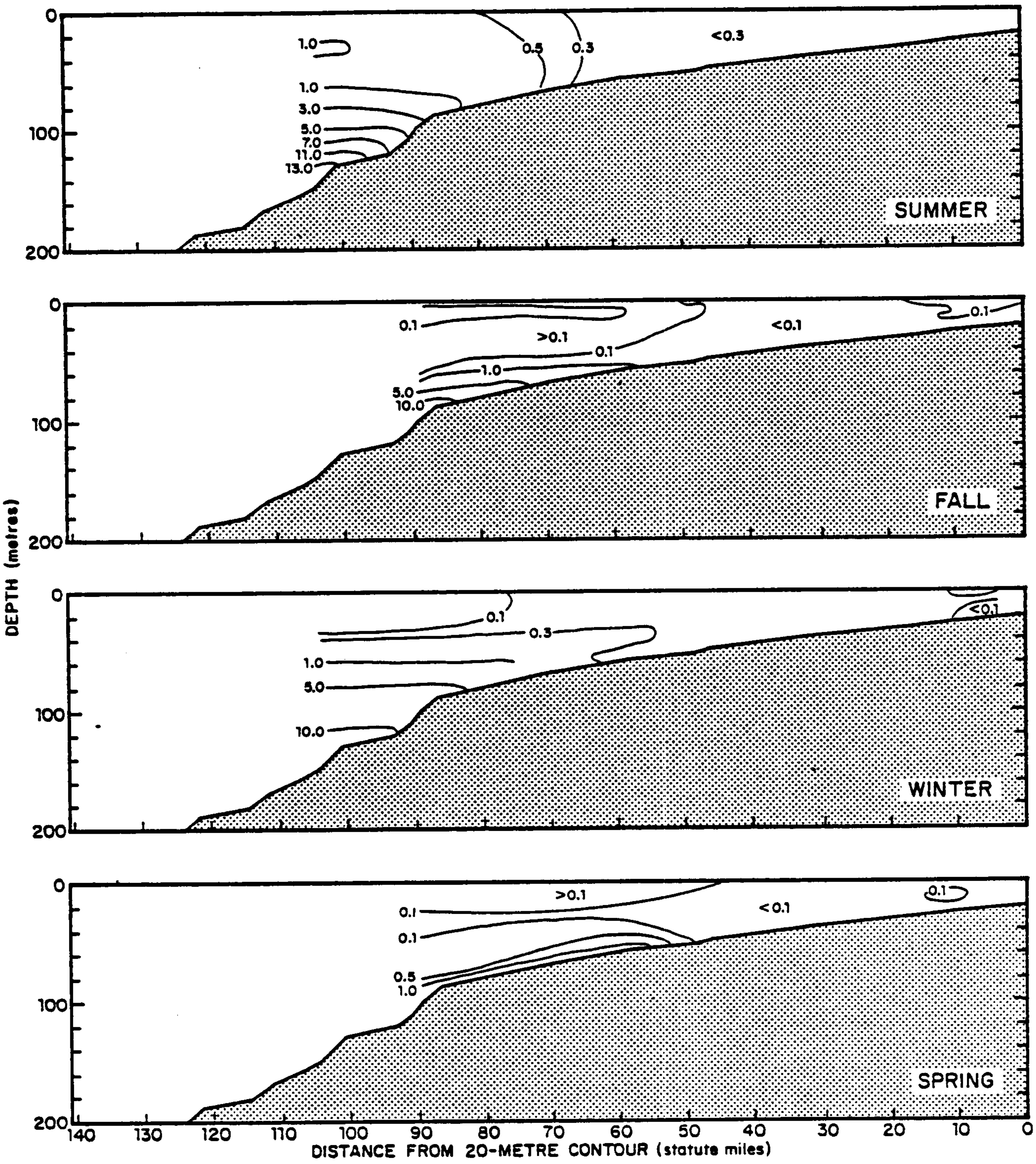

Figure 8-13. Seasonal nitrite + nitrate (μM) distributions on Transect A.

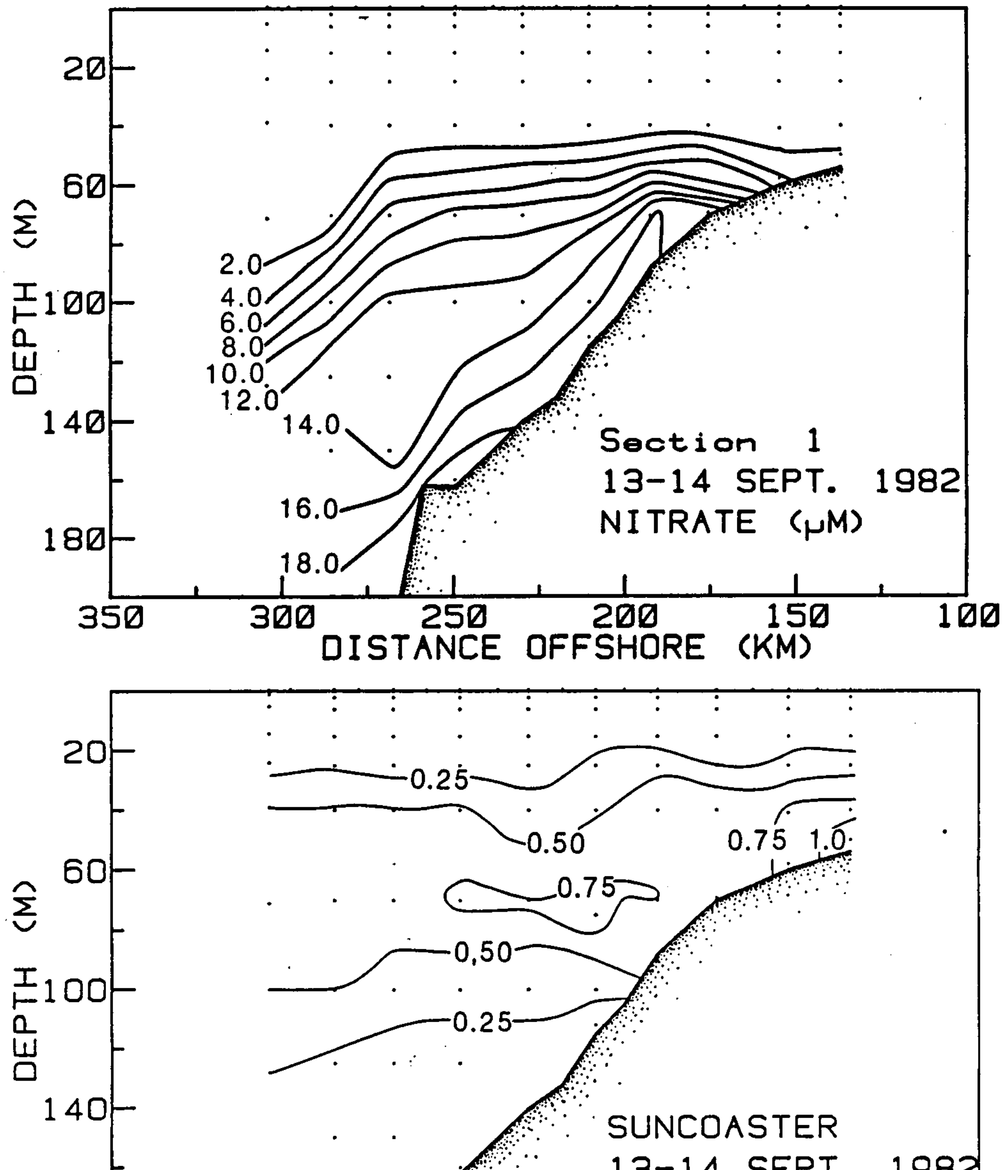

Figure 8- 14. Summer Cruise, 1982, Transect 1: nitrate (μM) and chlorophyll a + pheopigment a (mg/m^3) sections (after Woodward-Clyde Consultants and Skidaway Institute of Oceanography, 1983). See Figure 8- 3 for transect location.

> *Average production during upwelling events is about 1.8 gC/m²/day. During winter and spring, upwelling is the most important process controlling primary production on the outer southeastern shelf (Yoder et al., in press). The results of the spring Loop Current Cruise (April 1982) suggest that the effect of eddy-induced upwelling on primary production along the outer southwest Florida shelf is not as dramatic as on the outer southeastern shelf. Average outer shelf productivity at about 100 to 200m depths during the (Spring Loop Current) cruise was about 0.5 gC/m²/day, which is only about one quarter of that observed during similar events on the southeastern shelf. The most likely explanation for the difference between the two areas is the intensity of upwelling as evidenced by the depth of the top of the nitracline and the arguments in Section 3.2.1.7. During eddy-induced upwelling on the outer southeastern shelf, the top of the nitracline can come within 10 to 15m of the surface. Typically, the nitracline is within 20 to 25m of the surface during these events. In contrast, the top of the nitracline in the core of the Loop Current eddy during the Spring Cruise was only within 40 to 50m of the surface. Thus, most of the euphotic zone was not affected by nutrients upwelled by the eddy."*

It is apparent that nutrient availability within the euphotic zone is the measured variable governing phytoplankton biomass in mid and outer shelf regions. The nitracline, Chlorophyll a maximum, and euphotic zone depth suggest that "new" nutrients are only available to a select phytoplankton population. Transient perturbations may play an important role in upwelling nutrients higher into the photic zone. This was observed during the Spring Cruise on Transect E illustrated in Figures 8-15 and 8-16. In both figures the distance from shore relative to water depth has been compressed and the contour intervals reduced in order to provide visual impact to the role of upwelling. It is important to note that the upwelling was observed in all the measured parameters. That 20 to 24°C waters of 36.4 to 36.5 o/oo salinity and 1.0 to 3.0 µM NO_2-NO_3-N were characteristic of the upwelling, implies upwelling from depth was the source of this water mass. Winds during the Spring Cruise were from a southeasterly direction less than five knots during April 23-25 and from a north-northeast direction during April 26 - May 4 averaging five to 10 knots. This does not suggest wind-driven upwelling as the driving force.

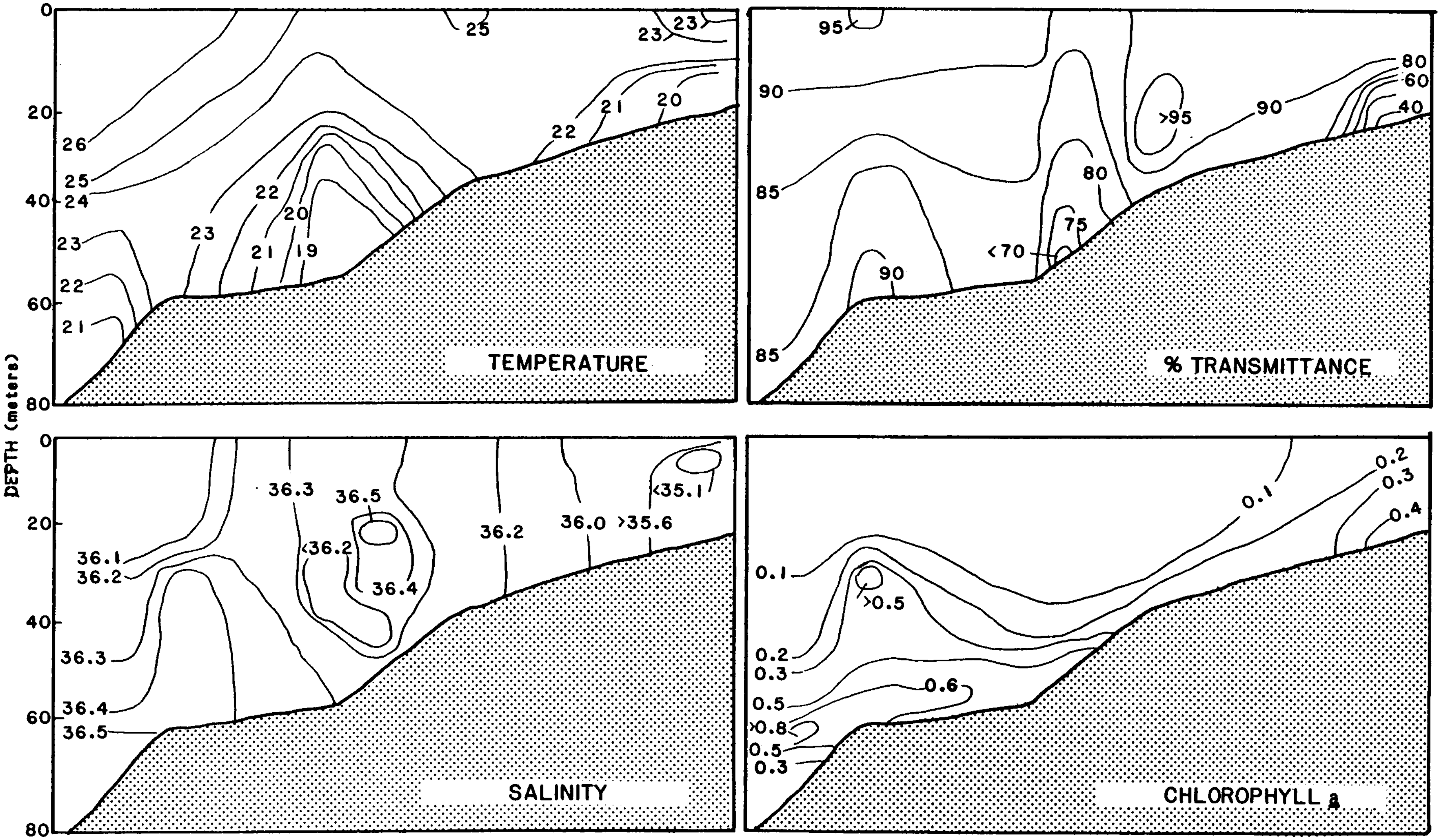

Figure 8-15. Spring Cruise 1981, Transect E: hydrographic characteristics (vertical scale exaggerated to emphasize water column structure).

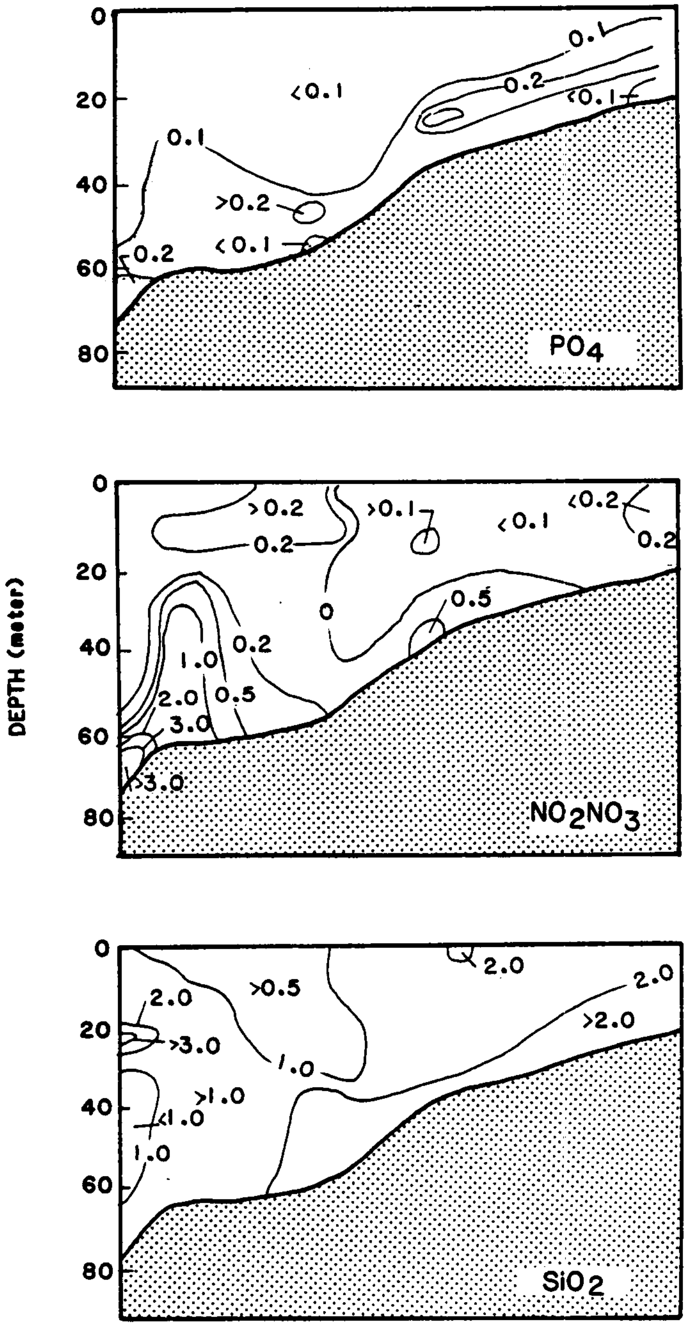

Figure 8-16. Spring Cruise 1981, Transect E: dissolved nutrient characteristics. (Vertical scale exaggerated to emphasize water column structure.)

One of the Loop Current-driven processes (Section 8.1.1.1) accounted for the needed energy to produce the upwelled water, although northeast winds could have enhanced the process. This was the only event of this magnitude actually observed during the southwest Florida shelf cruises and although the Chlorophyll a values (0.6 mg/m^3) are still low compared with other upwelling systems, the values are significant relative to those of surrounding waters. The fact that the upwelling was into the 30m depth range and within the 60m isobath is also important when considering the range of primary production in the photic zone. The physical parameters (i.e. temperature and salinity) indicate a surface-expressed frontal zone associated with this upwelling and the water column was affected to at least the 50m isobath. This is particularly noticeable in the near-bottom transmittance (approximately 70%) at the 50m isobath suggesting a turbulent frontal zone (Figure 8-15). The stage in development of the prominent frontal zone cannot be inferred from the data, nor can the frequency of these events. They are most likely on a rather variable time frame (hours to days) and can occur anywhere in the study area, from off the shelf to the 40 to 50m isobaths. Anytime nutrients of sufficient concentration penetrate above 50 to 70m depths vertically in the water column, or horizontally towards shore below the thermocline, utilization by phytoplankton is rapid and, unless the event is measured during its occurrence, the biological impact may not be observed.

The inner shelf processes affecting biological production are difficult to define. Chlorophyll a values for Transect D (Figure 4-52) provide an example of variability near-shore with values ranging from less than 0.3 mg/m^3 to greater than 1.0 mg/m^3 during the four seasonal cruises. If the Fall Cruise values are discounted (a redtide bloom may have been affecting the area at the time), inner shelf values were generally less than 0.5 mg/m^3. The NO_2-NO_3-N values corresponding to Chlorophyll a on Transect D (Figure 4-42) do not reveal a source of "new" nitrogen, but instead suggest regenerated nitrogen within the coastally-influenced water mass as the source. It is quite likely that coastally-derived water masses influence the inner shelf stations -- and occasionally the mid-shelf to outer shelf stations -- but frequency, depth of penetration, and their potential impact remain unknown.

During the four seasonal cruises, Chlorophyll a values on the inner shelf were generally low, suggesting a low biomass of phytoplankton. Transmittance values supported this conjecture (70 to 90% transmittance) although anomalies were observed. Transmittance values were unquestionably lower near-shore, but this is also attributable to shallow water mixing and not just biological production.

Summary

Upwelling is a major source of nutrients on the outer southwest Florida shelf. The primary contribution occurs when these nutrients are upwelled above the 1% light attenuation level at 50 to 70m water depths. Major physical processes of upwelling are discussed in Section 8.1.1.1.

Overall production from eddy-influenced upwelling, and most likely all forms of upwelling, are significantly lower on the southwest shelf than that occurring along Florida's Gulf Stream coast in the southeastern bight area. The mid-shelf area is affected by offshore events, but the inner shelf region would be very rarely affected. The inner shelf region is coastally-influenced -- but not significantly, when compared with other coastal regions. This, is of course, relative to the source of influences, with the Charlotte Harbor system and Everglades having the greatest potential for impact. In general the entire study area water column has a low standing crop (biomass) of phytoplankton and most likely a generally uniform planktonic food web. The water column in general is relatively stable and only mildly affected by seasonal climatological events. Variability is characteristically described by short term, transient events.

Benthic Community Considerations

When considering benthic communities developed across the southwest Florida shelf it is useful to address water column parameters in on onshore-offshore zonal configuration. Of course, in any ecosystem, bathymetry is an overriding factor to consider when approaching such a zonation. Figure 8-17 depicts the bathymetry of the study area. Several important factors are obvious. Between the 10 and 80m isobaths the average decrease in depth (onshore to offshore) is approximately 0.4m/km. From 80 to 220m the slope is approximately 2m/km, and from 220m and greater the slope is more than

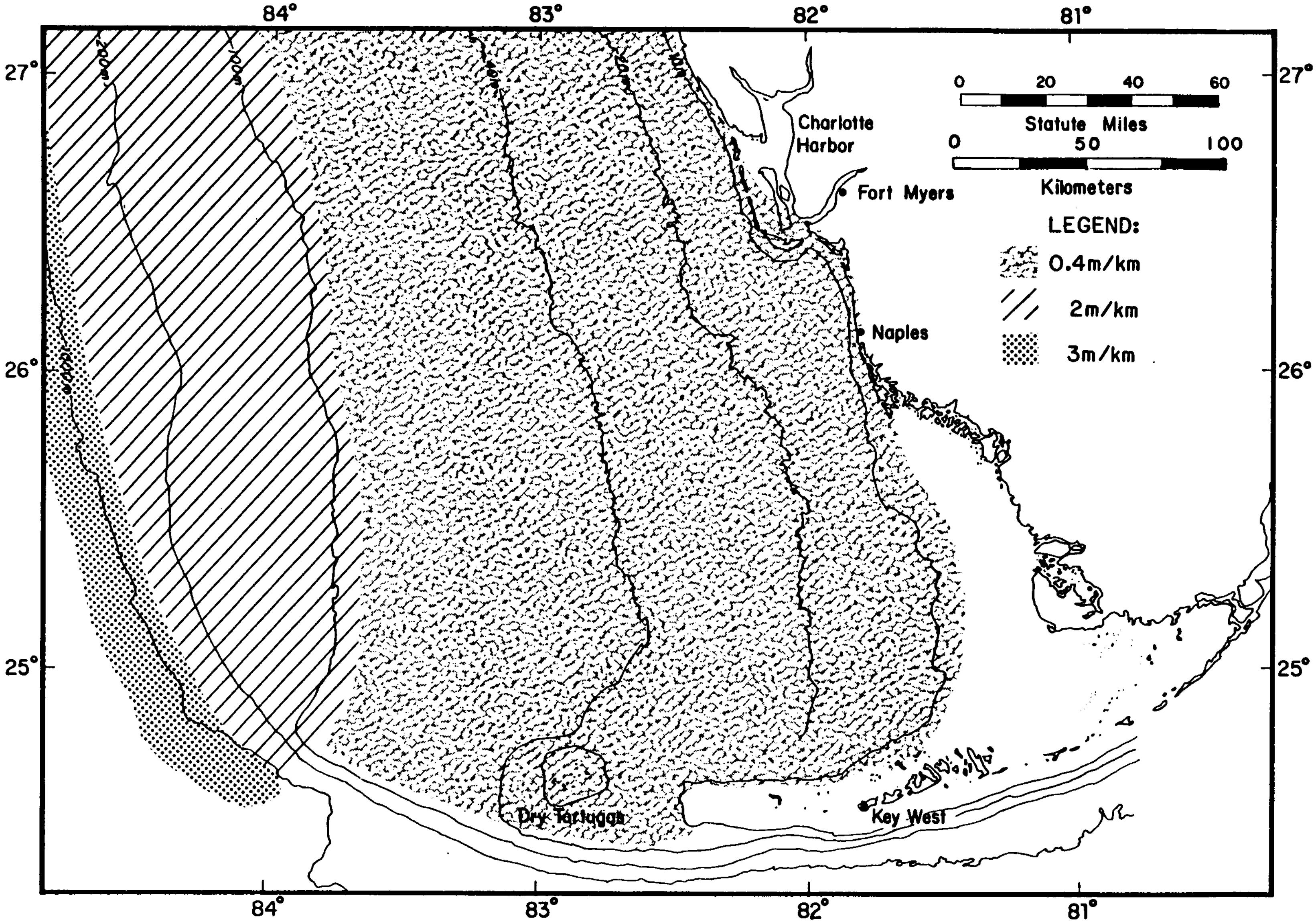

Figure 8-17. Shelf zonation based on increasing bottom slope (m/km) with distance offshore.

3m/km. This depth zonation is important to the energetics and influences within the water column and their possible effects on benthic communities.

When considering the development of horizontal (onshore to offshore) zonation in the water column, no statistical analyses were performed. Upper and lower bound data points were used, with depth, to develop "most likely zones of influence." Those parameters chosen for zonation, based on their potential influence on the benthic community, were temperature, salinity, 1% light attenuation depth, nitrate + nitrite concentrations, dissolved oxygen, transmittance, and upwelling zones.

Temperatures affecting the benthic community may be partitioned as above and below the thermocline and are variable, thus the zonation is given in temperature ranges (Figure 8-18). The temperature data also reflect seasonal climatic changes more than the other measured variables and this is seen near-shore. Figure 8-18 depicts the zonal temperature ranges. It is apparent that bottom temperatures decrease in variability in an offshore direction. The governing influence in temperature change offshore would be upwelling. The position of thermocline/bottom interception is more seasonal, with near-shore formation in spring and summer and retreats (mixing) offshore in fall and winter. Climatic and circulation processes each have the potential for.drastically altering the thermocline position.

Salinity (Figure 8-19) is more difficult to zone because of the lack of variability. It has been attempted because salinity often is important in benthic community distribution. Perhaps the most important consideration is the fact that the higher salinity intrusions occur off the shelf break at mid-depths and they intercept the bottom at water depths at 120 to 50m. Between 50 to 30m water depths, influence can be from either oceanic or coastal sources; for the inner shelf the influence is primarily coastal.

Based upon El Sayed et al., (1972), Woodward-Clyde Consultants and Skidaway Institute of Oceanography (1983), and selected data collected during the Summer Cruise (1981), the depth to which 1% of the surface light reaches the bottom is within the zone depicted in Figure 8-20 and shoreward of this zone.

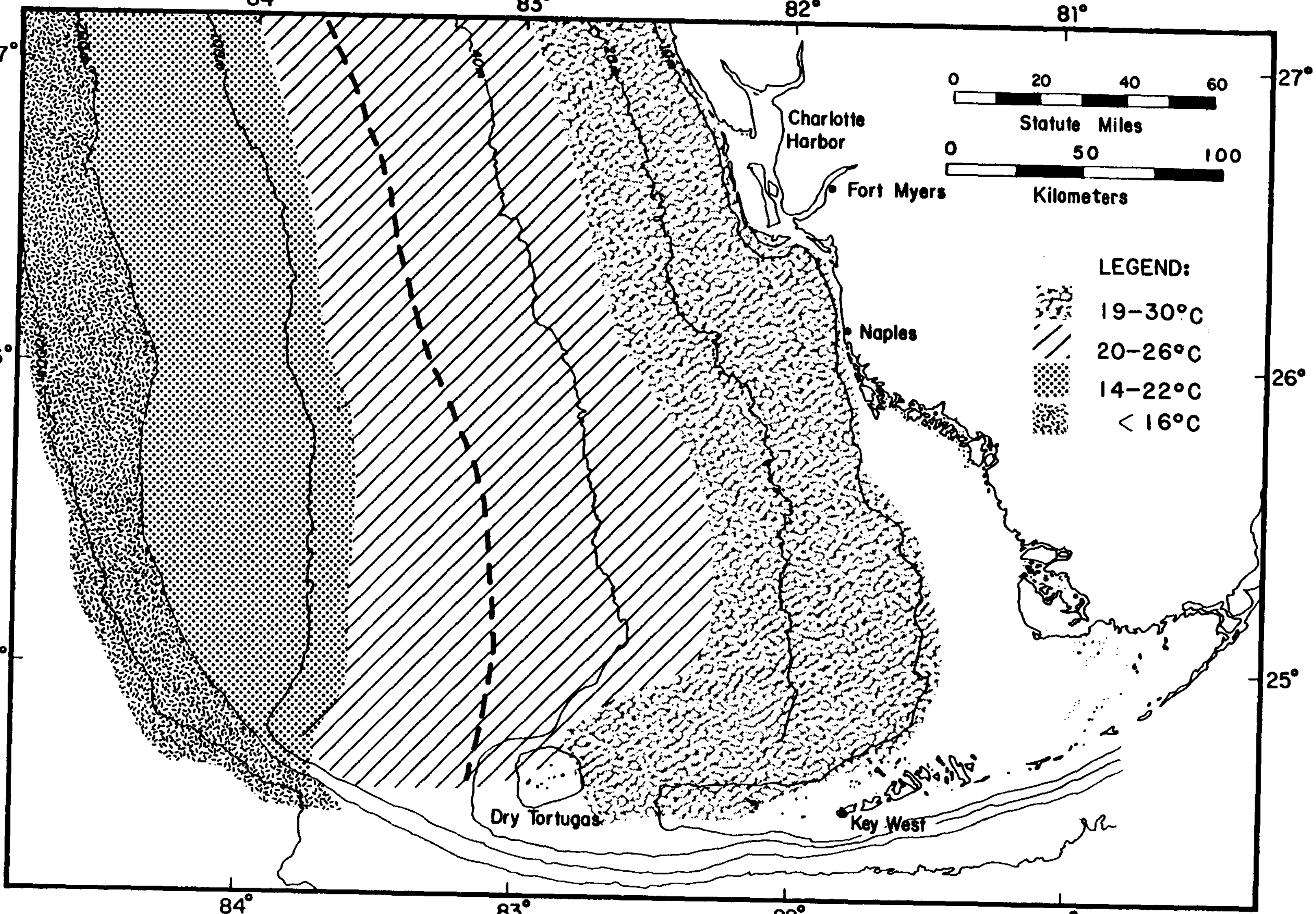

Figure 8- 18. Shelf zonation based on bottom water temperature (°C) ranges. Thermocline intercepted seafloor shoreward of dashed line during all cruises.

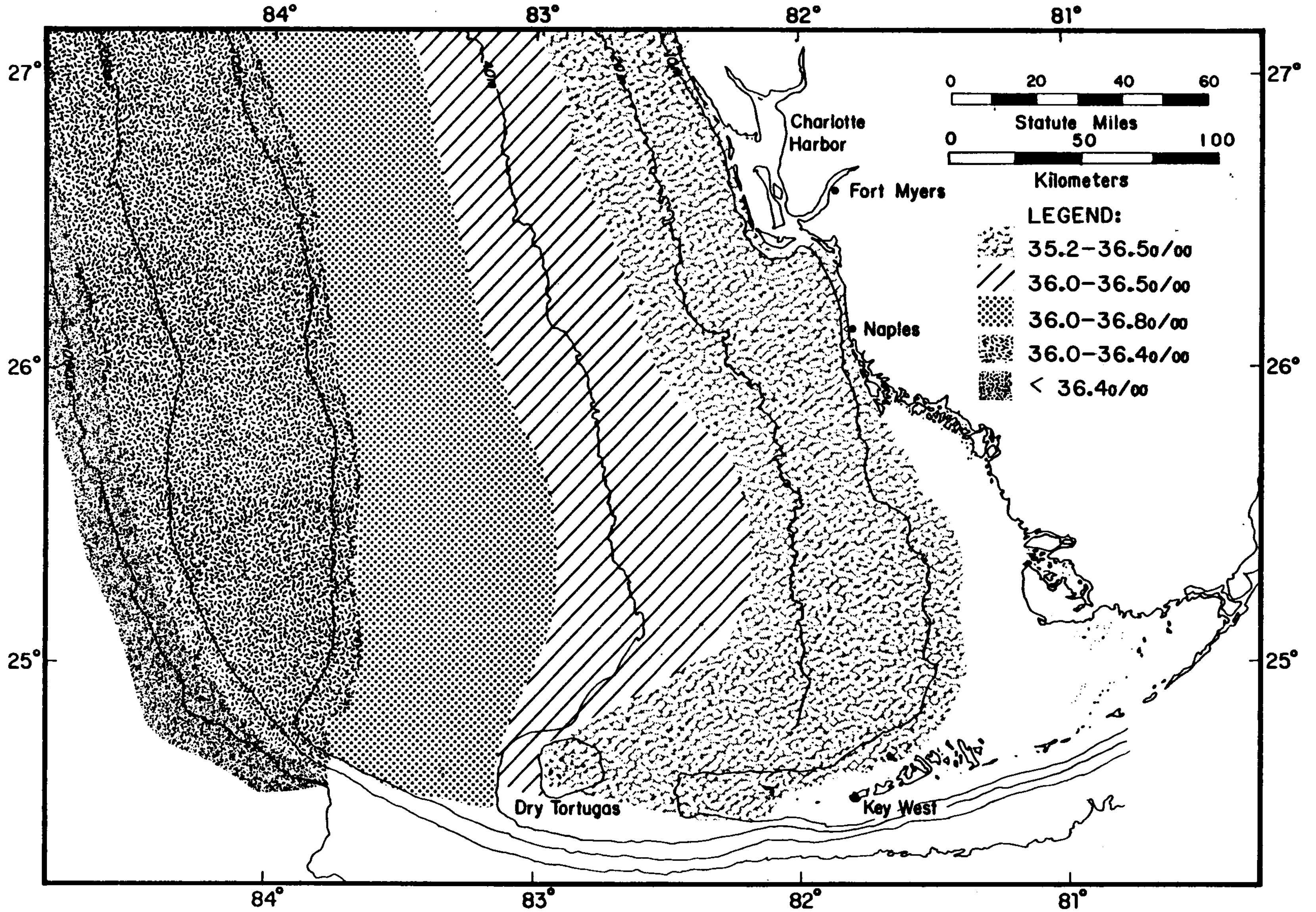

Figure 8-19. Shelf zonation based on bottom water salinity (o/oo) ranges.

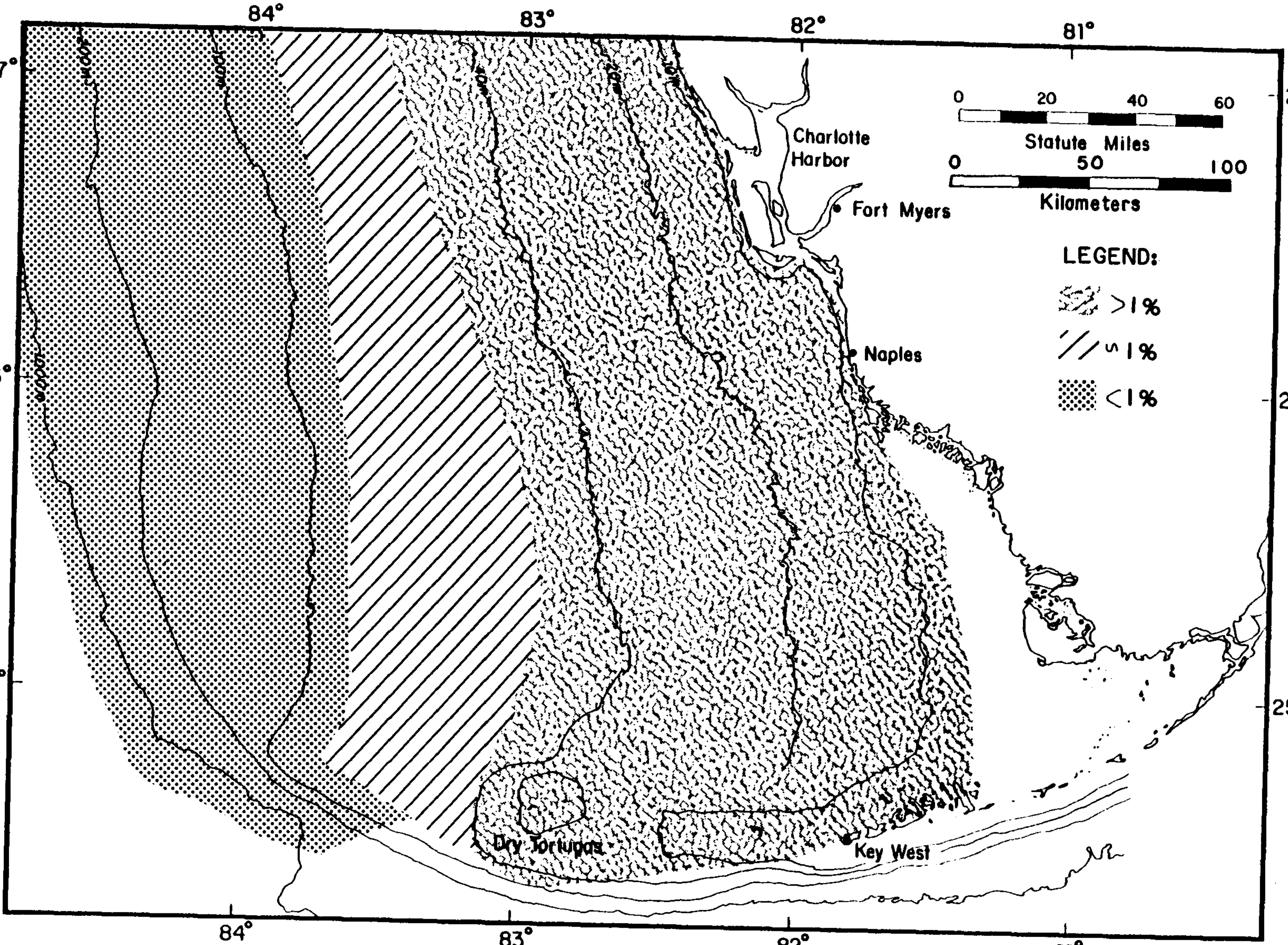

Figure 8-20. Shelf zonation based on one-percent light attenuation depth.

The specific zone depicted is that in which 1% depth varies due to water column properties.

Availability of dissolved oxygen in the water column is important to many benthic community inhabitants. Figure 8-21 shows near-bottom oxygen zones. Dissolved oxygen varied little except in the colder, deeper waters off the shelf that are often upwelled onto the shelf.

Transmittance was highly variable, reflecting both biological activity and suspended matter in the water column. Two grossly defined zones are apparent, based upon average transmittance values. These are depicted in Figure 8-22; the zonation is based upon coastal mixing influences and oceanic influences.

Nutrient concentrations are best represented by nitrite + nitrate. Figure 8-23 shows the zone of penetration for the 1 μM NO_2-NO_3-N along the bottom. This concentration level appears to contribute significantly to Chlorophyll a (phytoplankton biomass) concentrations in the water column, thus affecting light availability to the benthic community below. It also provides nutrients to the benthic floral community.

Finally, upwelling has been discussed as a primary influence on the outer shelf/mid-shelf study area. Based upon Woodward-Clyde Consultants and Skidaway Institute of Oceanography (1983) and the four seasonal cruises, zones of upwelling can be defined (Figure 8-24). Upwelling of cooler, nutrient-rich waters appears continuous to the 70 to 80m isobaths. Between the 70 to 40m isobaths, upwelling is more variable. Eddies have been observed to penetrate the 40m isobath, but their frequency of occurrence is unknown. Inside the 40m isobath upwelling would be rare, although in the summer -- during maximum thermocline development -- it could occur. It is possible that highly modified upwelled water could impinge within the 40m isobath.

8.1.2. Shelf Substrates

The west Florida shelf, occupying an area of some 78,000km^2 in the eastern Gulf of Mexico, is the only wholly carbonate continental margin in the United States. Despite its size and uniqueness, the geologic structure and recent

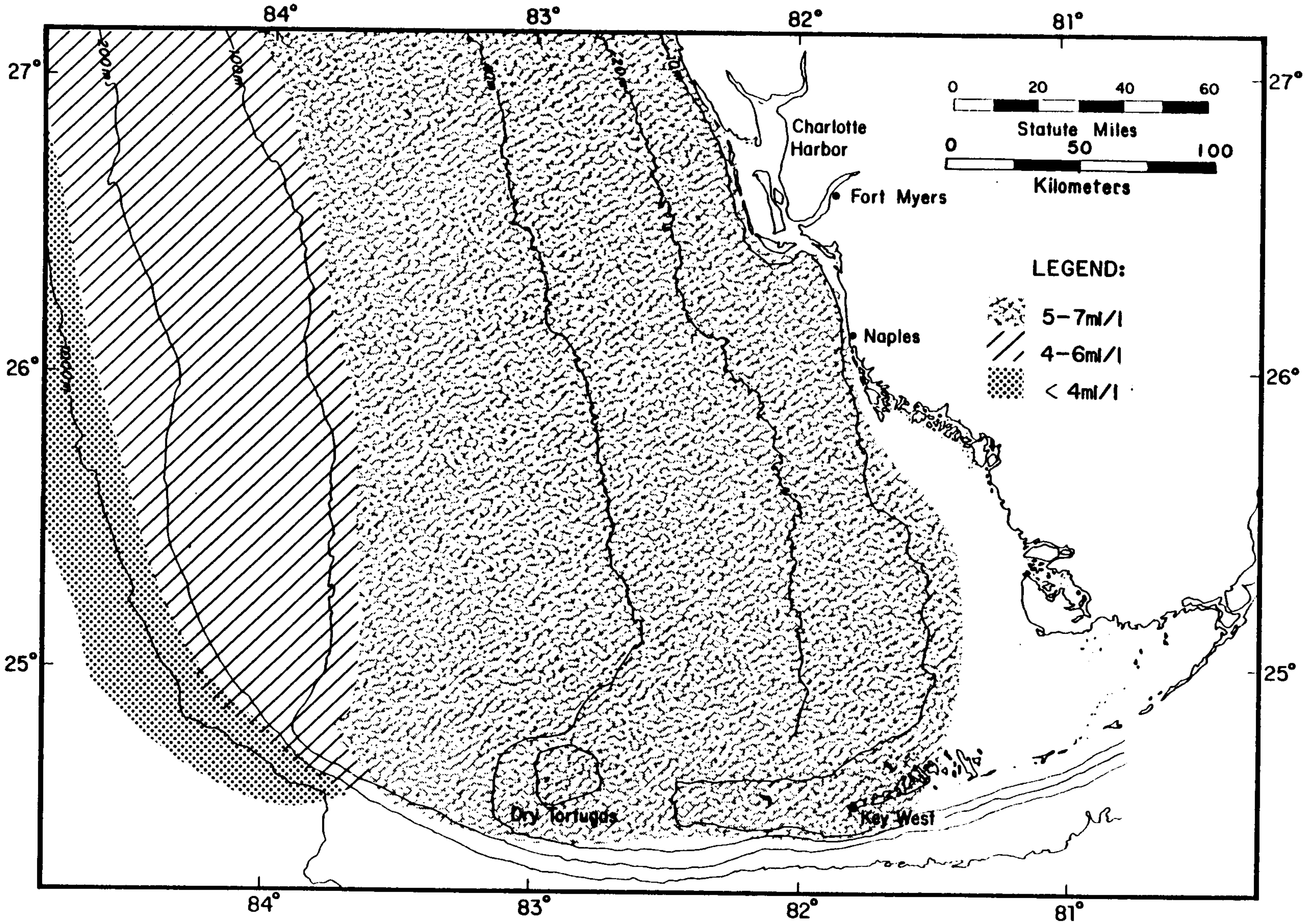

Figure 8-21. Shelf zonation based on near-bottom dissolved oxygen (ml/l) values.

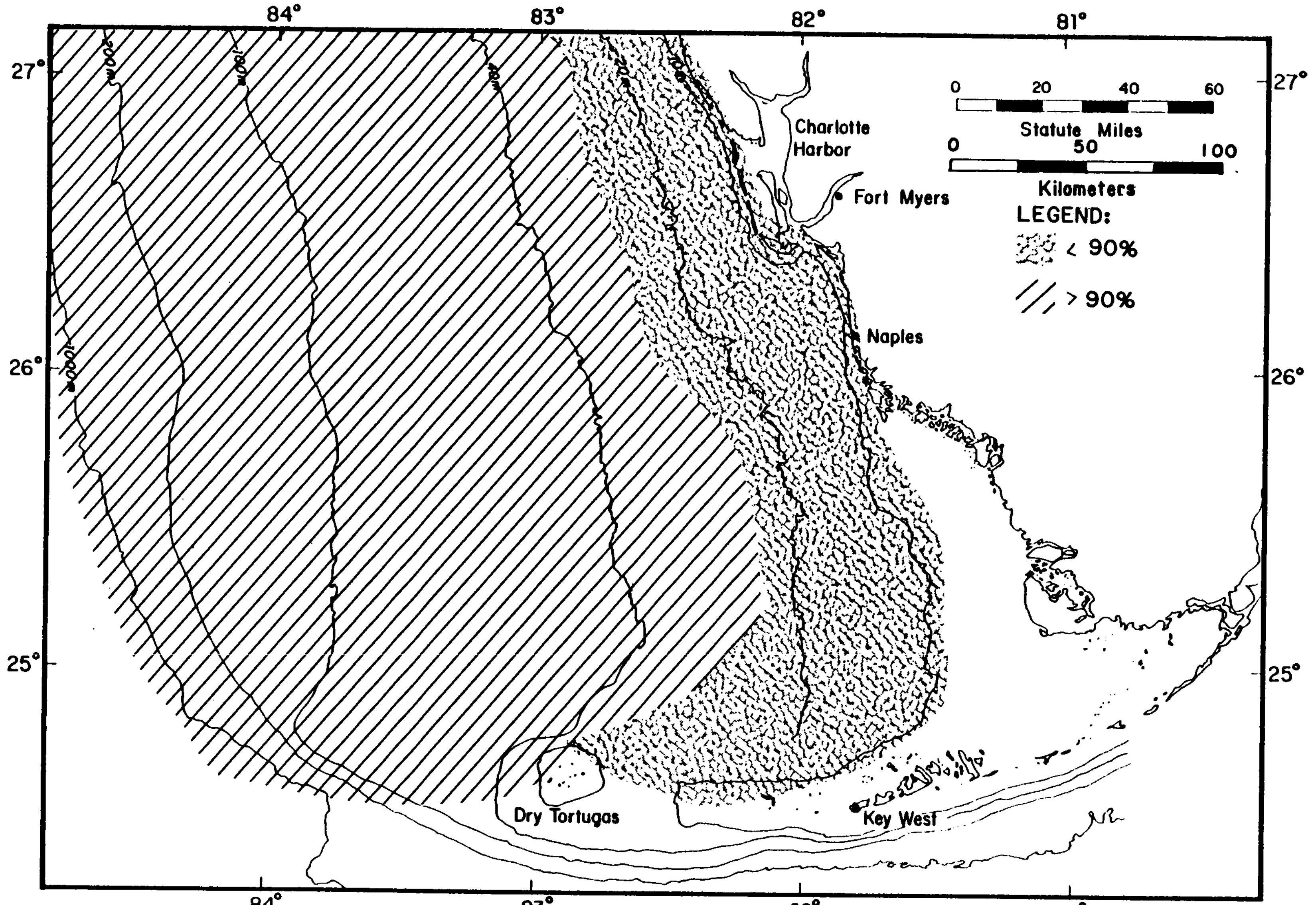

Figure 8- 22. Shelf zonation based on percent transmittance (devised from highly variable near-bottom values).

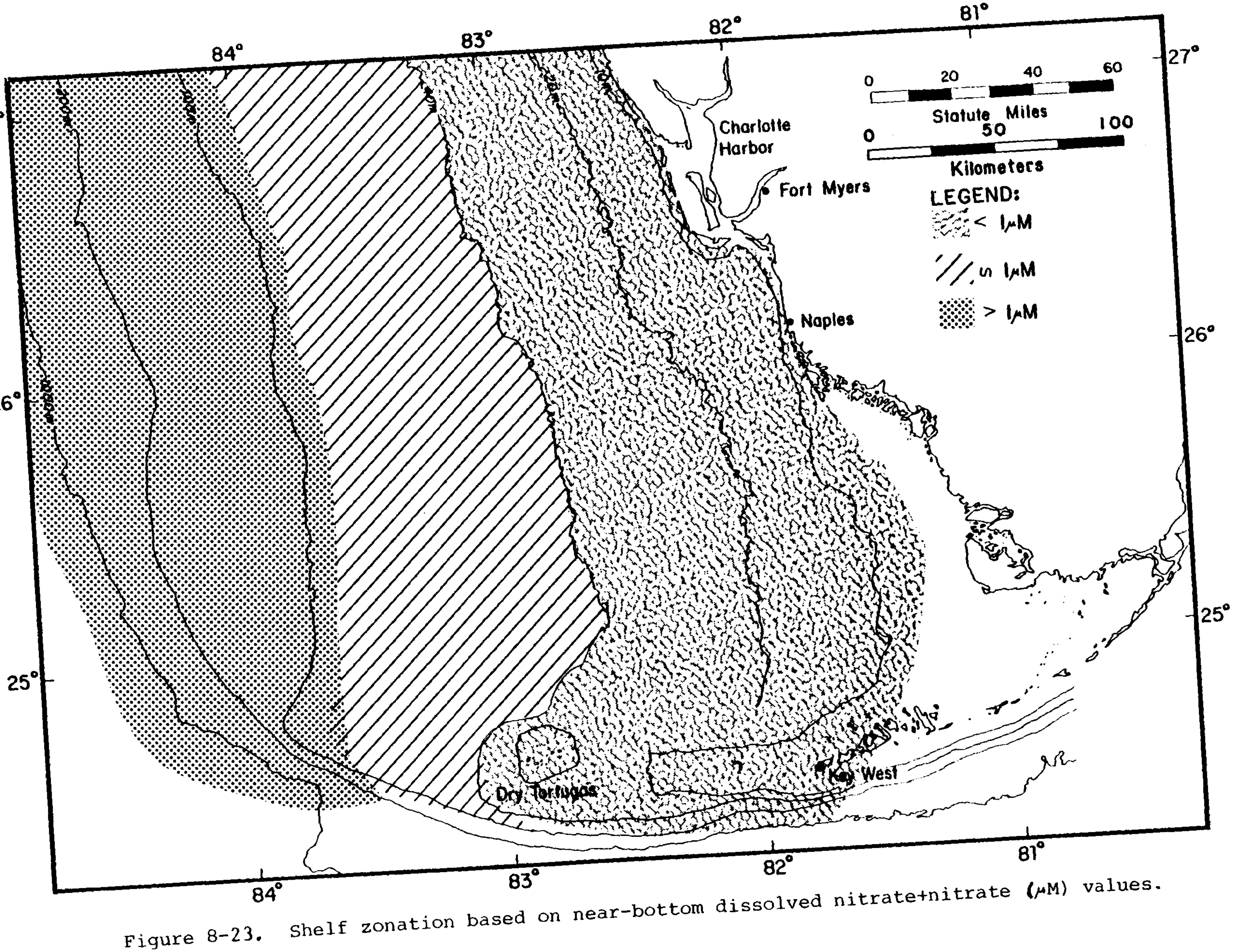

Figure 8-23. Shelf zonation based on near-bottom dissolved nitrate+nitrate (μM) values.

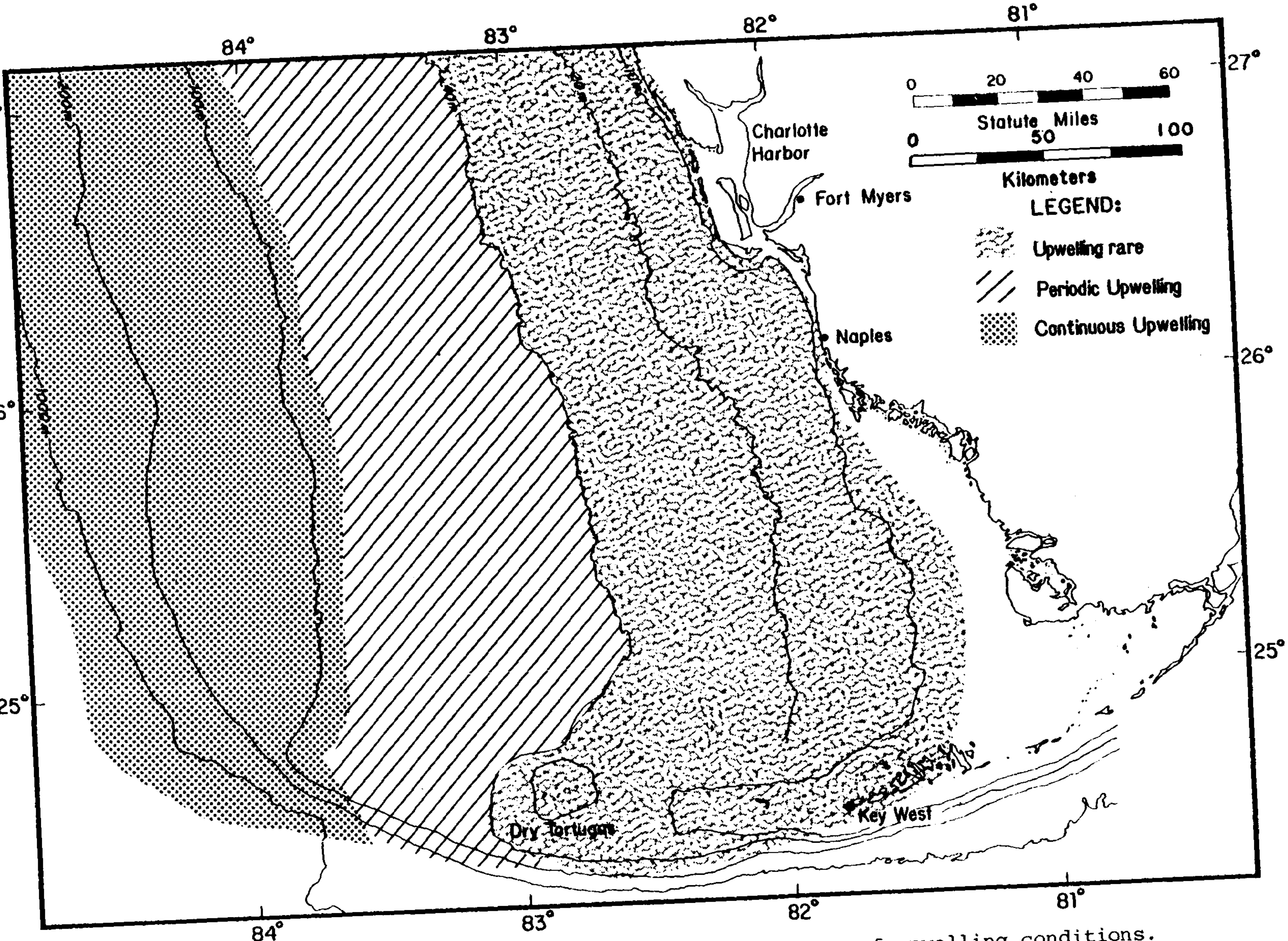

Figure 8-24. Shelf zonation based on probable frequency of upwelling conditions.

sedimentalogical history of the shelf remain only partly known. This section briefly summarizes our present understanding of these two topics.

8.1.2.1. Geologic Structure

Shallow geophysical studies performed as part of this program and reported in the Year One Final Report (Woodward-Clyde Consultants and Continental Shelf Associates, Inc., 1984 -- Section 2.0, Marine Geophysical Investigations) and a U.S. Geological Survey Open File Report by C. W. Holmes (1981) provide the following overview of shelf structure.

The present continental shelf and slope apparently overlie a karstic platform of probable Miocene age. The outer portion of this platform is covered by a lens of late Tertiary-Quaternary sediments, which thickens from the central shelf to a maximum of 150m at the upper slope break. A former north-trending double reef complex marks both the present shelf break and the inner shelf boundary. Both reef complexes are already partially buried and continue to be covered by more recent sedimentary material. A series of banks, crowned in shallower-water areas by coral growth (Dry Tortugas and Marquesas Keys), border the southern edge of the continental margin along the Florida Straits (Holmes, 1981).

The geographic distribution of the major geologic features described above is shown in Figure 8-25. Figure 8-26 provides a schematic vertical cross section across the shelf margin.

Our own studies defined the "Inner Shelf" as extending from the Florida coastline out to a water depth of about 40m. Side scan sonar data indicate that on the four northern study transects (A through D) the Miocene (?) bedrock is exposed or covered by a thin, mobile layer of sand with local, small scale outcrops of exposed bedrock. Further south on Transect E, finer grained silts overlie Holocene and Pleistocene sediments; no bedrock outcrops were seen. Holmes (1981) notes that the Florida Strait side of the Keys and the crests of the banks are veneered with sand. Immediately north of the banks, in the region protected by the topographic highs, finer grained silts are being deposited.

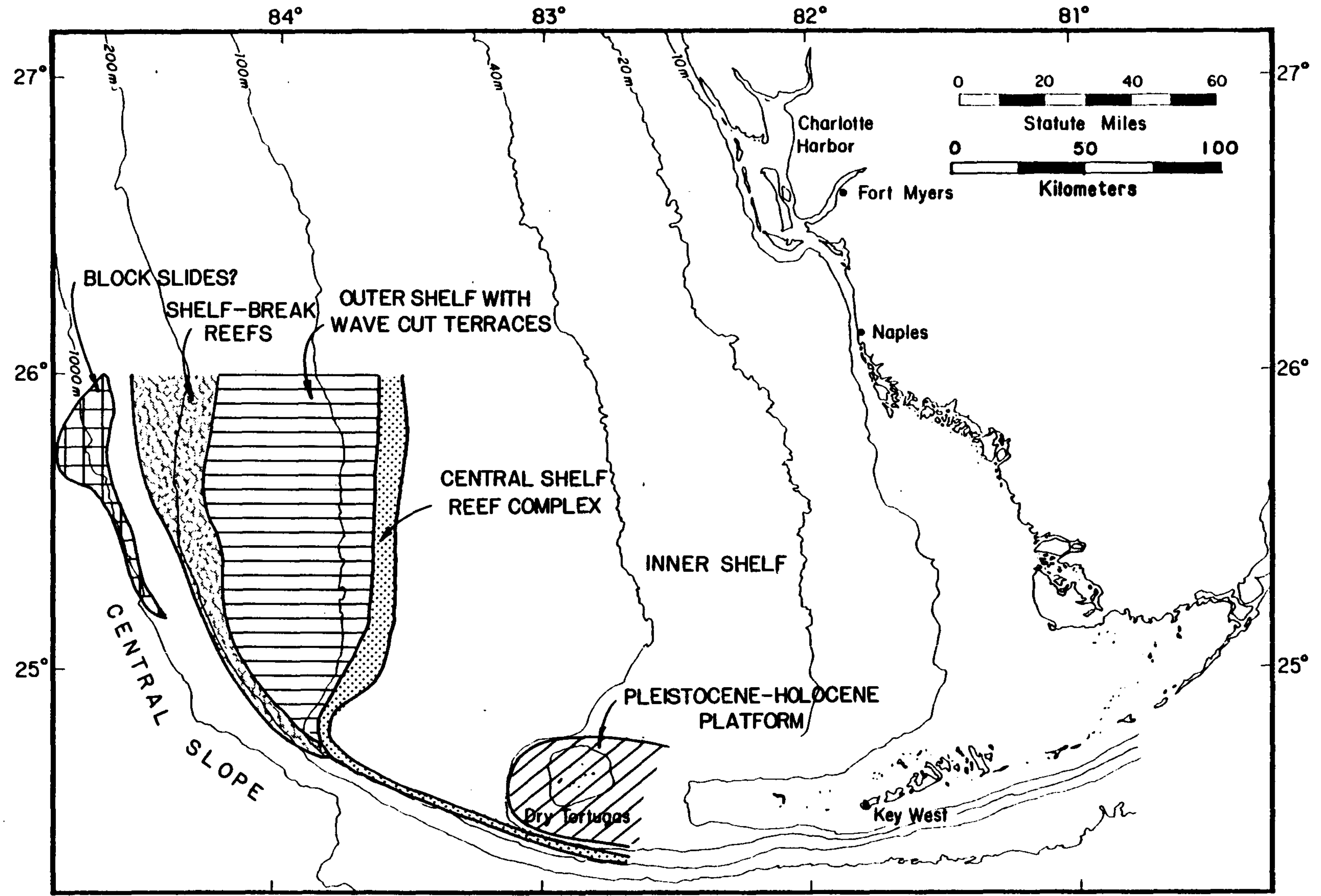

Figure 8-25. Major geologic features of the southwest Florida shelf (after Holmes, 1981)

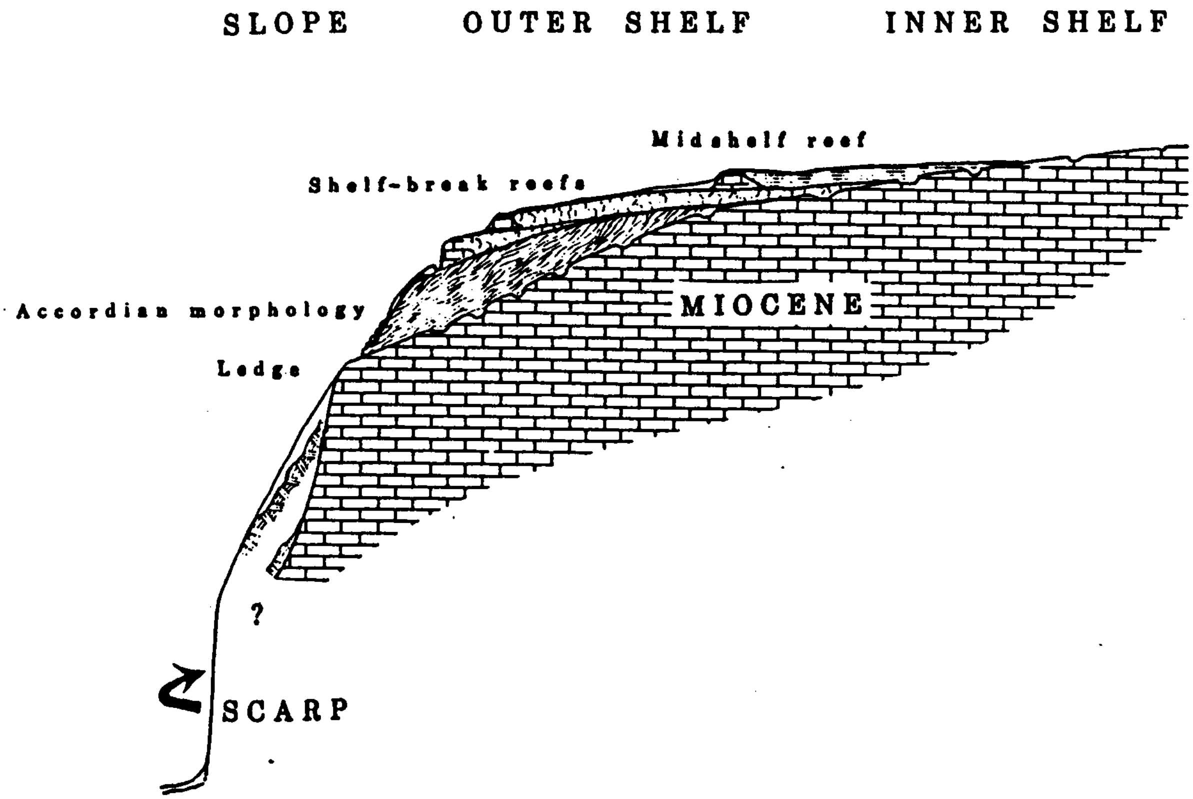

Figure 8-26. Diagramatic cross section of the southwest Florida shelf margin (after Holmes, 1981).

The area between the 40m and 70m isobaths (our "Middle Shelf") has a relatively smooth sea floor. A thin veneer of recent, unconsolidated sands overlies a wedge of late-Tertiary to Quaternary sediment that increases in thickness from 5m to 20m between the 40m and 70m isobaths. The recent overlying unconsolidated sediment layer thickens to 10m on Transect E.

Holmes' (1981) "Central Shelf Reef Complex" (Figure 8-25) occurs in water depths of 70 to 90m. This 10km wide biohermal complex appears to be a series of partially buried carbonate reef-like structures and is reflected in a zone of irregular sea floor topography. This feature was noted, either partially exposed or covered with a thin sand layer, on study Transects B through E. No evidence of reef-like structures was seen at these water depths on northernmost Transect A, however.

The "Outer Shelf" extends from the seaward edge of the Central Shelf Reef Complex to the limit of our survey area at the 200m isobath. This zone is only 10km wide on Transect E but widens rapidly northward to 65km on Transect A. Here the sea floor is generally covered with a sand veneer, although some extensive outcrops and associated live bottom assemblages were noted on Transects C, D, E and F (Volume 2, Figure 2-3).

Holmes (1981) noted a double-reef complex at the shelf break; the shallowest, partially buried reef or bioherm cresting at 130 to 150m water depth and veering landward north of latitude 25°10'N. This feature, named Howell Hook, is seen on Transect D. Evidence of shallow-buried bioherms was also seen further north on Transect C (water depths of 137 to 167m) and Transect B (water depths of 140 to 150m). On Transect C, the bioherm included numerous pinnacles of dead coral extending one to three meters above the sand covered sea floor. Although the bioherms on Transects B and C occur at the same general depth range as Howell Hook, the wide transect spacing does not allow direct correlation (Woodward-Clyde and Continental Shelf Associates, Inc., 1983).

8.1.2.2. Surficial Sediments

Prior to the present program, general accounts of sediments in the southern portion of the study area were published by Multer (1978), and in the more northerly portion, by Doyle and Sparks (1980), and Doyle and Feldhausen (1981).

Previous Studies

Doyle and Sparks' (1980) paper is based on results of the MMS-sponsored MAFLA study of the continental shelf off Mississippi, Alabama, and northern Florida. Their two most southerly sediment sampling transects extended due west from Charlotte Harbor and Cape Romano, respectively. Four sedimentary facies were defined in increasing water depths across the southwest Florida shelf (Figure 8-27a).

Adjacent to the shoreline is an exceedingly mature, very fine to fine quartz sand (West Florida Quartz Sand Band). Since the rivers of peninsular Florida carry little suspended load and even less bed load, these quartz clastics are apparently relict from an earlier time. Southerly longshore drift in the late fall and winter, and northerly drift the remainder of the year, apparently balance. The sediments tend to migrate back and fourth along the coast, but there is essentially no net drift.

Further offshore the quartz sand facies transitions into a carbonate sand facies (Carbonate Sand Sheet) that dominates the middle and outer shelf. The transition (Carbonate-Quartz Transition Zone) is gradual; the shoreward transition boundary is arbitrarily placed at 25% carbonate, the seaward transition boundary at greater than 75% carbonate. Sediment texture and carbonate constituents are both very patchily distributed. Patches of shell hash, foraminifera, lithothamnion algae, and even oolites, locally dominate. As expected, detrital heavy minerals are essentially absent from the carbonate facies.

Seaward of the carbonate sand facies (Figure 8-27a) lie the West Florida Lime Muds. This facies blankets the continental slope and consists largely of sand-sized planktonic foraminifera and finer grained carbonate nannoplankton (coccoliths).

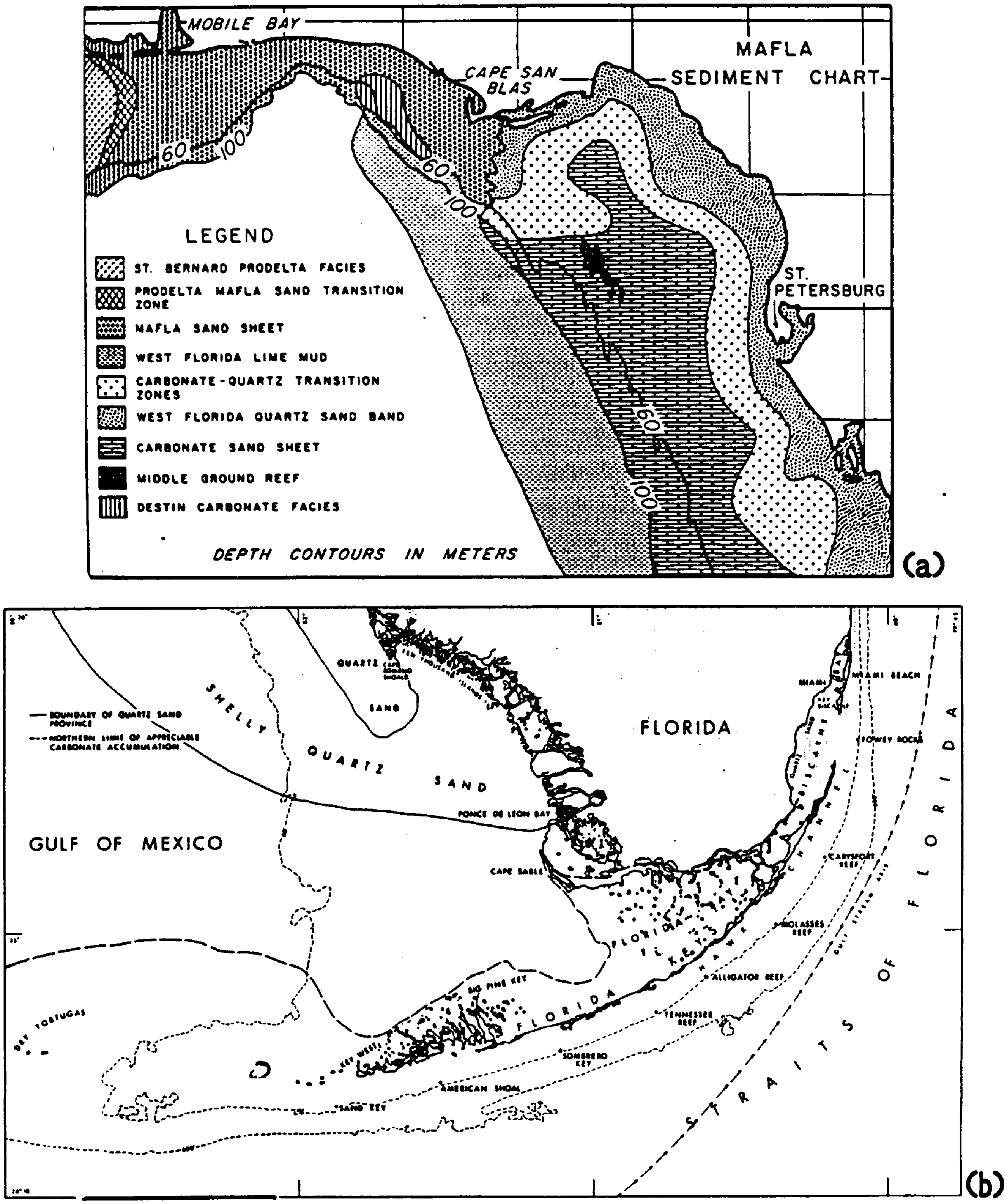

Figure 8- 27. Sedimentary facies of (a) northern (Doyle & Sparks, 1980) and (b) southern (Enos & Perkins, 1977) portions of the west Florida shelf.

Seasonal variability among replicate sediment samples was noted by Doyle and Sparks (1980) and statistically analyzed in a subsequent followup study by Doyle and Feldhausen (1981). In the later study, seasonal sediment texture changes confirmed at several stations were attributed to reworking of the bottom and sediment transport by hurricanes and winter frontal storm systems which sweep across the shallow shelf.

Multer (1978) and included references (for example, Enos and Perkins, 1977) indicate that further south, sedimentary facies boundaries turn east-west to parallel the continental shelf margin (Figure 8-27b). The band of coastal quartz sands dies out just south of Cape Romano. "Shelly quartz sand" -- probably equivalent to the Doyle and Sparks' carbonate-quartz transition zone lying outside the coastal quartz sands -- swings southeastward, intersecting the Florida shoreline at Cape Sable. Further offshore to the west, and southward towards the Florida Keys, carbonate accumulation becomes increasingly important (Figure 8-27b).

Present Study

Sediment samples for the present study were taken from box cores collected at the soft bottom stations on a seasonal basis. Grain size data were recorded among 14 size categories from less than 0.001mm, to greater than 4.0mm. Percent carbonate analyses were performed and six additional sediment variables were calculated: graphic kurtosis, mean grain size, median grain size, percent silt/clay, skewness, and inclusive graphic standard deviation. The results of some of these analyses have already been presented in Volume 2, Section 5.3.2 of this report.

Not all twenty-one sediment variables noted above were used in the subsequent weighted discriminant analyses of soft bottom biological assemblages and environmental variables (Section 8.2.2.2). Median grain size and percent silt/clay were dropped because of strong correlations with other variables and percent carbonate was dropped because of too many missing values. Principal Components Analysis (PCA) was run on the remaining data matrix to further reduce the total number of physical variables.

The first PCA axis explained 48.79% of the total variance among the remaining grain size variables. The factor matrix indicates that mean grain size and graphic kurtosis are both quite strong on Axis I, as well as most of the individual grain size categories, with the finer size categories opposing the negatively-signed coarser categories. This pattern indicates that Axis I is most strongly related to absolute grain size. A graphical representation of Axis I values is shown in Figure 8-28. PCA Axis I scores for mean grain size (higher scores representing finer grain sizes) are plotted for each of the soft bottom sampling stations and then contoured. While the contouring remains open to interpretation, the general east-west pattern of coarser- and finer-grained sediments is somewhat reminiscent of the facies map reproduced in Figure 8-27b (Enos and Perkins, 1977).

Axis II explains 20.67% of the total variance, and is characterized by the fine sand grand size categories weighting strongly in the positive direction, with all other grain size categories on the positive side of the axis, coarser sediments weighting most strongly. This is a commonly observed pattern that could describe a "stable fine sand environment." Such an environment is dominated by fine sand in a stable, moderate current that does not allow desposition of fines, yet is not strong enough to remove fine sand particles.

Axis III explains another 7.75% of the total variance. This axis was labelled "Standard Deviation Factor" as the coarse graphic standard deviation completely dominates. Axis IV explains 5.46%, and is equally dominated by the graphic kurtosis and the most coarse grain size category (corresponding to gravel). Finally Axis V (6.11%) was labelled after skewness values that completely dominated the axis. At this point, 87.77% of the total variance had been explained by the first five principal components, and Axis V was chosen as the PCA cutoff point.

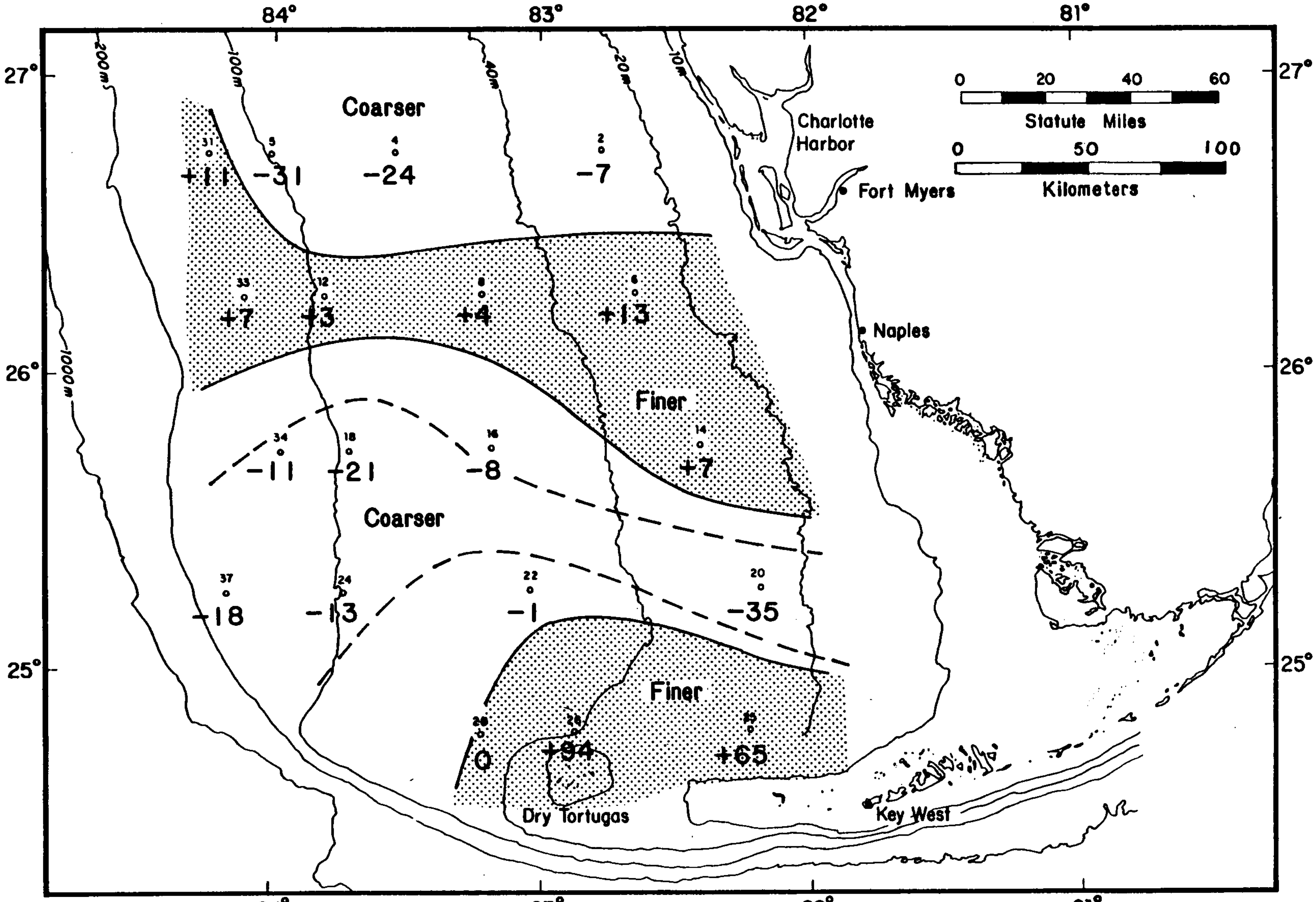

Figure 8-28. Contour plot of PCA Axis I scores for GRAIN SIZE (higher scores finer grain sizes). See text for additional explanation.

8.2 BENTHIC BIOLOGY

8.2.1 Live Bottom Communities

Distribution and zonation patterns of live bottom biota have been discussed in Section 6.4. This section reviews the shelfwide distribution of biota and attempts to relate distributional patterns to environmental variables.

8.2.1.1 Summary of Shelfwide Distribution Patterns

Figures 8-29 and 8-30 summarize the distribution of assemblages delineated by television transect surveys. Seven live bottom assemblages were defined: 1) an Inner Shelf Live Bottom Assemblage I located primarily in 20 to 27m depths on Transects C and D; 2) an Inner and Middle Shelf Live Bottom Assemblage II located in 25 to 75m depths on Transects A, B, C, and D; 3) a Middle Shelf Algal Nodule Assemblage located in depths of 62 to 108m, primarily on Transects B, D, E, and F; 4) the *Agaricia* Coral Plate Assemblage located in 64 to 80m depths on Transect E; 5) an Outer Shelf Crinoid Assemblage located in depths of 118 to 168m on Transects B, C, and (especially) D; 6) an Outer Shelf Low-Relief Live Bottom Assemblage located in depths of 125 to 185m on Transects C and D and 108 to 198m depths on Transect E; and 7) an Outer Shelf Prominences Live Bottom Assemblage located in 136 to 169m depths on Transect C. In subsequent sampling efforts, all assemblages except the last one were represented by at least one station.

Quantitative slide analysis (QSA) of photographs at selected stations allows a refinement of these assemblage delineations (Figure 8-31). A group of inner and middle shelf stations in depths of 20 to 58m support mixed sponge/seasonal algae assemblages, with the degree of algal vs. sponge contribution to total cover varying widely but not in a consistent shelfwide pattern. These assemblages occur on hard bottom covered by a thin veneer of sand or (occasionally) on scattered low-relief outcrops. The Middle Shelf Coralline Algal Nodule Assemblage is the same as that delineated in the television transect surveys. However, QSA shows a north-south gradient within the zone, with stations in the southern portion of the 60 to 80m depth range exhibiting

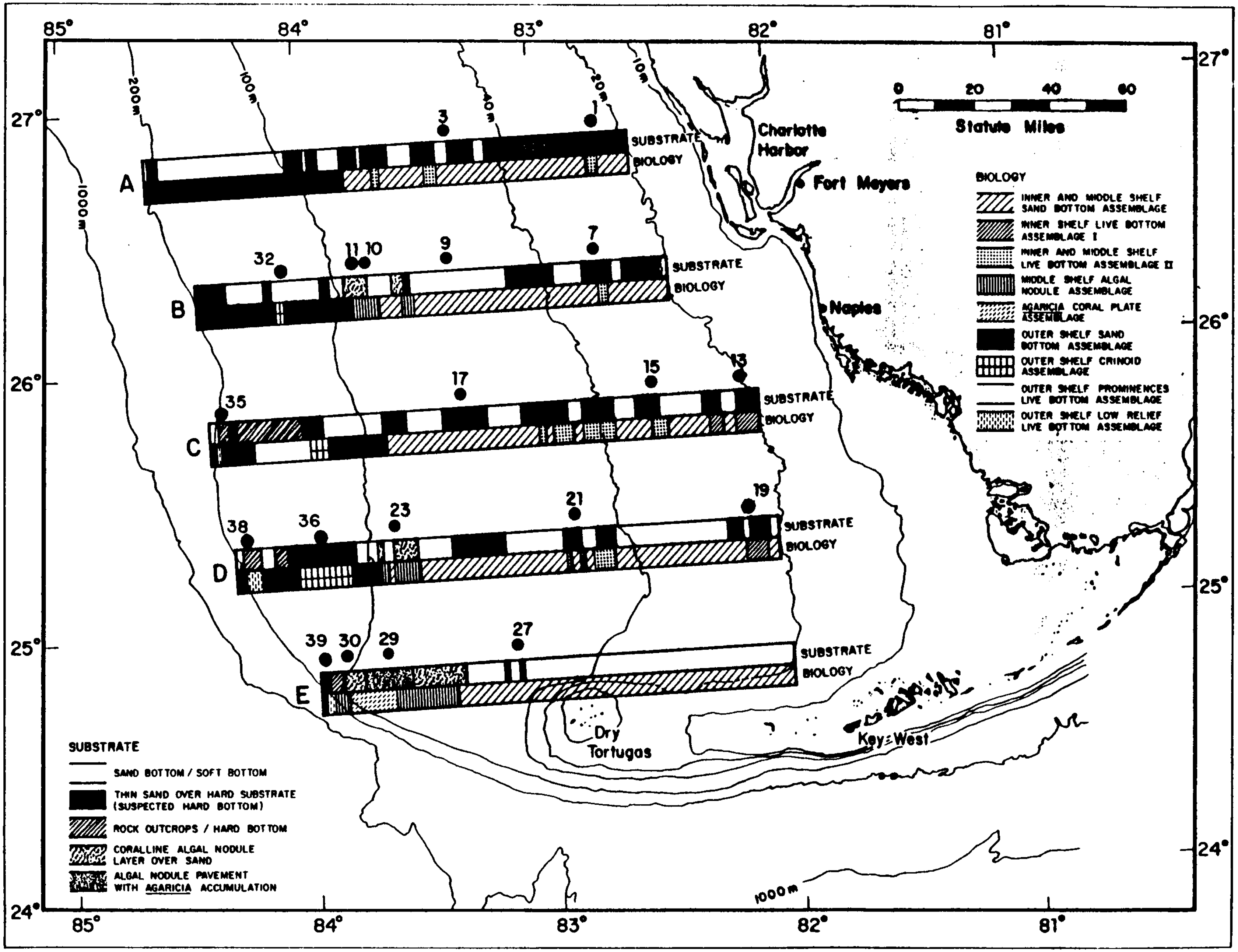

Figure 8-29. Live-bottom sampling stations relative to generalized substrate and biological assemblage distributions

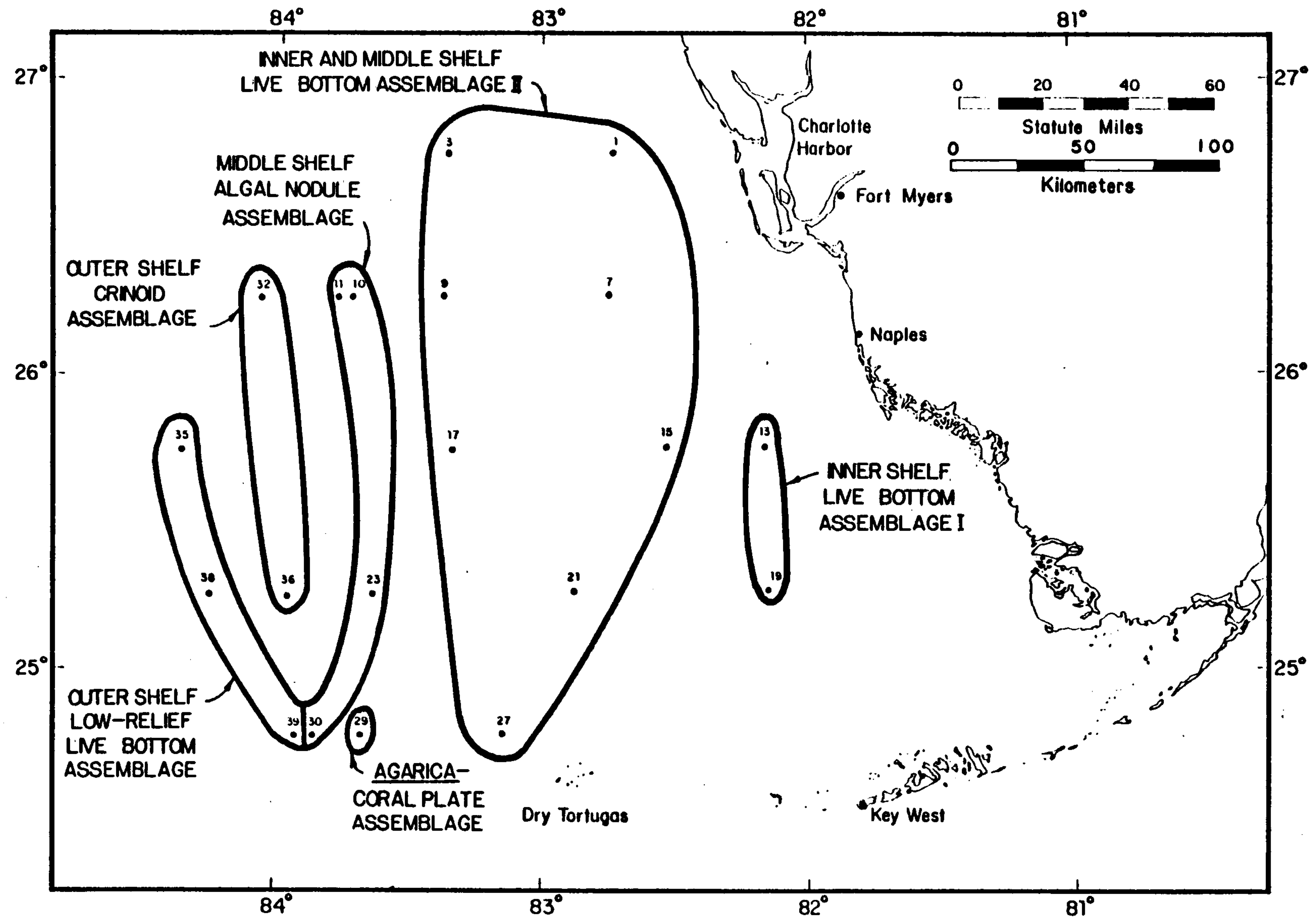

Figure 8-30. Groupings of live bottom stations on the basis of television transect surveys.

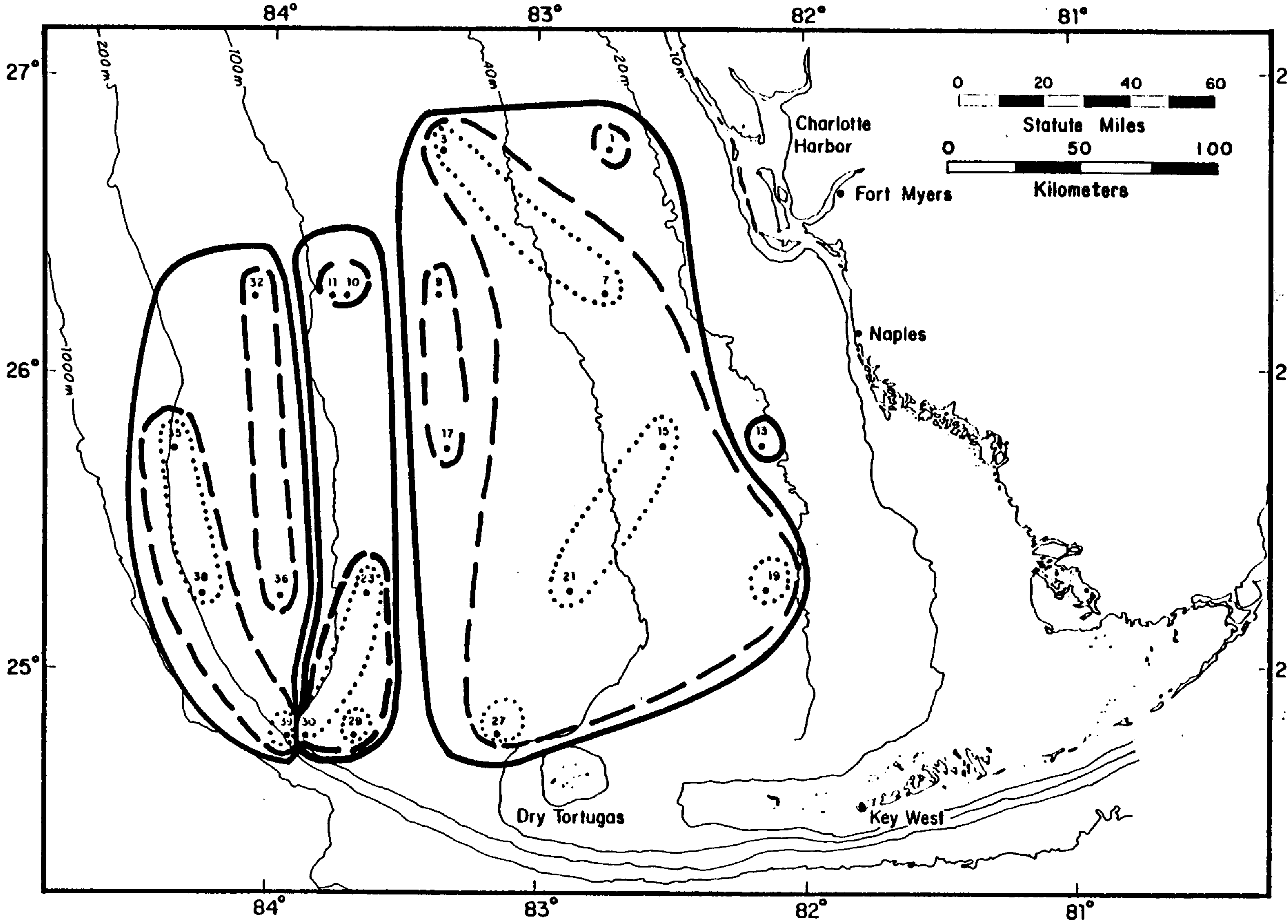

Figure 8-31. Live bottom station groupings based on examination of quantitative slide analysis (QSA) data.

higher levels of cover by coralline and crustose perennial red algae (*Peyssonnelia* spp.) and the leafy green alga *Anadyomene menziesii*. The *Agaricia* Coral Plate Assemblage denoted in television transects is similar to the southern Middle Shelf Algal Nodule Assemblage stations (23 and 30). The Outer Shelf Crinoid Assemblage and the Outer Shelf Low-Relief Live Bottom Assemblage emerge as similar in QSA results; both support a sparse suspension-feeding assemblage dominated by crinoids and small sponges. Unidentified deepwater green algae were also observed at the deep shelf-edge stations (35, 38, and 39).

Figures 8-32 and 8-33 summarize the results of cluster analyses of dredge and trawl collections, respectively. Both data sets delineated major inshore and offshore groupings. The inshore group of stations generally exhibited some subclustering relatable to depth and/or distance from shore. Within the offshore group of stations, triangle dredge cluster analysis grouped the coralline algal nodule and *Agaricia* coral plate stations as similar and identified a north-south gradient in assemblage composition, as noted above for the QSA results. Otter trawl cluster analysis, in contrast, grouped the two northern coralline algal nodule stations with the deeper stations (in the case of Station 11) or with the inshore stations (both Stations 10 and 11).

8.2.1.2 Relationships between Live Bottom Assemblages and Environmental Variables

Shelfwide distribution and zonation patterns presumably reflect spatial and seasonal variations in the suite of environmental variables that can affect the establishment, maintenance, growth, survival, and reproduction of live bottom epibiota. The relationships between environmental variables and live bottom assemblages are examined from two approaches in the following sections. First, relationships between the station groupings produced by cluster analyses and specific environmental variables (e.g., water column temperature, salinity, transmissivity, and nutrient values) measured at each station on the biological sampling cruises are examined using weighted discriminant analysis. This is followed by a more general discussion of environmental factors possibly influencing assemblage composition.

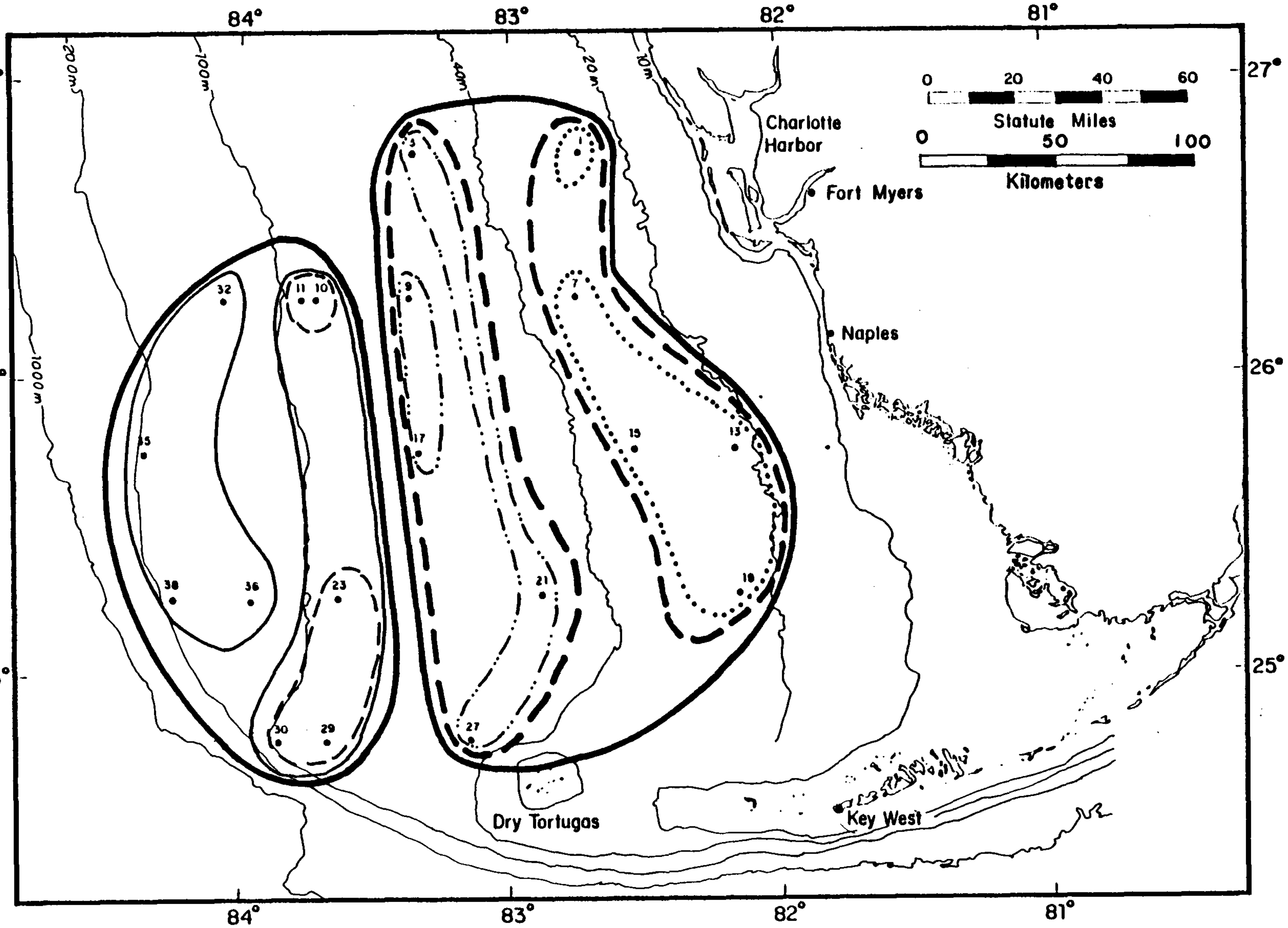

Figure 8-32. Station groupings from cluster analysis of triangle dredge data, all cruises.

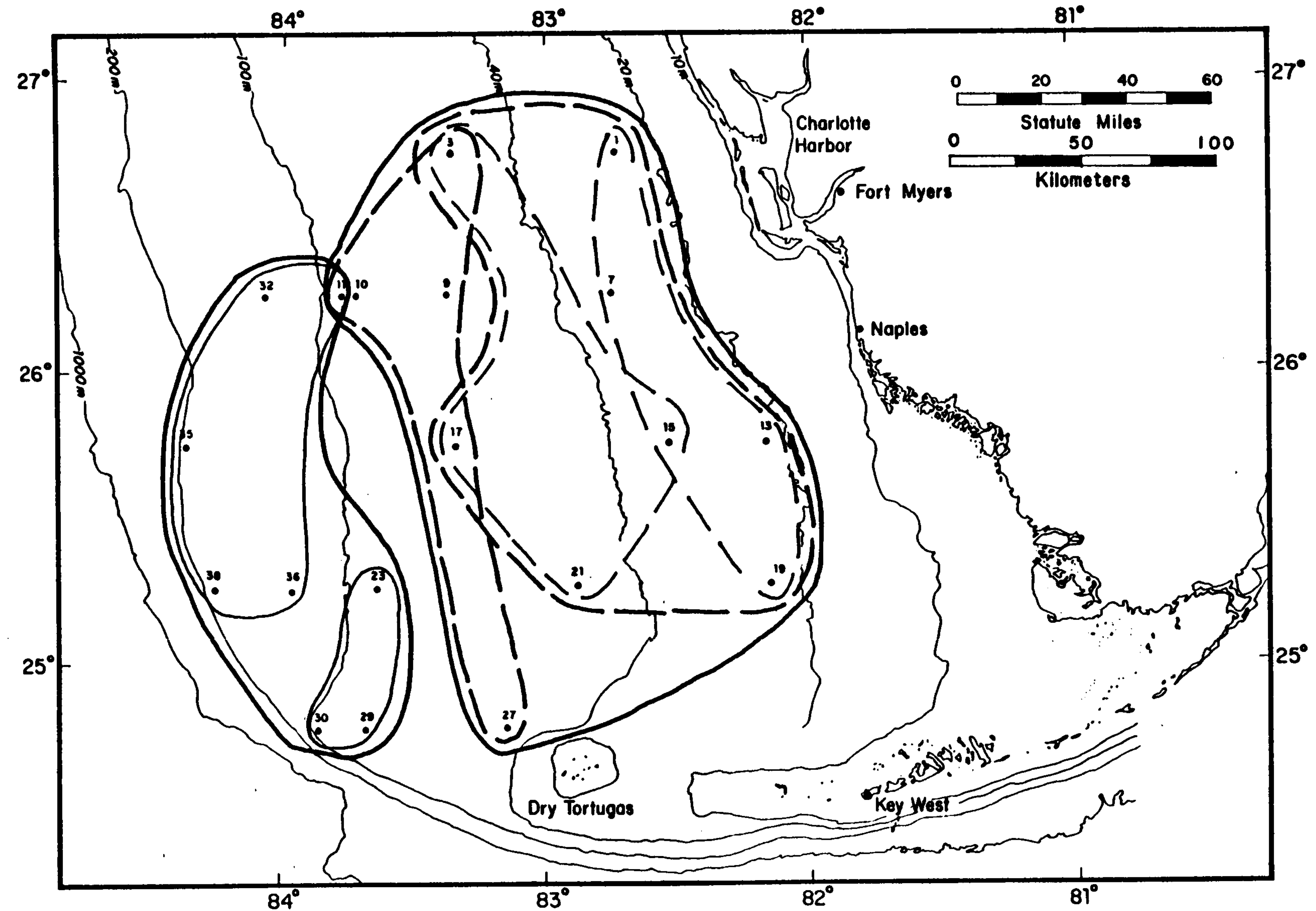

Figure 8-33. Simplified station groupings from cluster analysis of live bottom otter trawl data, all cruises combined. (Some stations appear in more than one cluster due to seasonal changes in species composition.)

8.2.1.2.1 Weighted Discriminant Analysis

The purpose of using weighted discriminant analysis in the interpretation of biological and environmental data from live bottom stations was to determine which environmental variable(s) could best explain the observed station groupings. Stations were initially grouped using normal cluster analyses (Section 6.4.3). A suite of physical environmental variables was available from measurements taken at each station on (ideally) each cruise. The problem, then, was to find axes in multidimensional environmental space along which station groups were separated (discriminated) to the greatest possible extent.

A separate weighted discriminant analysis (see Section 3.0 for specific details of methodology) was run for each season and for all seasons (cruises). For both triangle dredge and otter trawl data the analyses for the individual seasons produced poor results and little consistency. Therefore, only the results of the "all cruises" analyses are presented below.

Environmental Data Selection and Estimation of Missing Values -- The environmental variables originally considered for inclusion in the weighted discriminant analysis were: station depth; temperature, salinity, dissolved oxygen, and transmissivity; chlorophyll *a* and phaeopigment values; and concentrations of the water column nutrients nitrate, nitrite, phosphate, and silicate. Only bottom readings were considered relevant for all water column parameters measured.

For the two Year Two cruises, water column data were not obtained for all stations. Consequently, the data base contained too few bottom measurements to allow weighted discriminant analyses. The missing values for these parameters were interpolated from the Year Two modification report (Woodward-Clyde Consultants and Skidaway Institute of Oceanography, 1983) water column profiles. No profiles were available for dissolved oxygen and phaeopigment data and these parameters were therefore not included in the weighted discriminant analyses. Similarly, the interpolated values for chlorophyll were therefore not compatible with the measured values from the first two cruises and consequently were also eliminated from the analyses. The profile for inorganic nitrogenous nutrients was drawn from the value of nitrites plus nitrates. Thus, nitrite values were added to nitrate values for the measured data to create a statistic compatible with the interpolated statistic. Other missing values were estimated using the EAP estimation program (see Section 3.4.3.2).

Thus, for the weighted discriminant analyses of all surveys combined, the environmental parameters used were DEPTH, NITRITE + NITRATE, PHOSPHATE, SILICATE, SALINITY, TEMPERATURE, and TRANSMISSIVITY.

Table 8-2 lists the values for each environmental parameter included in the analyses for each seasonal sampling date at each station.

Triangle Dredge Data: Results and Interpretation -- Station groups used in the weighted discriminant analysis of triangle dredge data are shown in Figure 8-34. The groups were chosen on the basis of the cluster analysis results for all seasons combined (Figure 8-32), but some subjective judgement was used in deciding on the level of similarity/dissimilarity to define particular groupings. Some knowledge of other results from QSA was also employed in the process. For example, the groupings of Stations 9 and 17, Stations 10 and 11 vs. 23, 29, and 30, and Station 1, although not all at the same level of dissimilarity, were chosen because these particular station groupings were also evident in the QSA data.

The first discriminant axis explained 97.5% of the variance in discriminant space (Table 8-3). The contribution of each environmental variable to Axis I was determined using coefficients of separate determination. The coefficients of separate determination for Axis I show that DEPTH, PHOSPHATE, and NITRATE + NITRITE were most strongly related to the axis with values of 73.3, 13.7, and 7.1, respectively. Axis II explained 1.7% of the total variance; NITRATE + NITRITE and PHOSPHATE were most strongly related to this axis, with coefficients of 48.4 and 22.9, respectively. Axes I and II together explained 99.2% of the total variance in discriminant space.

Table 8-2. Values of environmental parameters used in the weighted discriminant analysis of live bottom station data.

Station/ Cruise	Parameter*						
	DEPTH	NITNAT	PHS	SIL	SWS	TEH	TRA
1/Fall	24.0	0.22	0.110	1.36	35.99	26.6	78.0
1/Spring		0.01	0.040	1.60	35.92	20.2	90.0
1/Summer		0.20	0.100	3.00	36.20	29.0	87.0
1/Winter		0.10	0.100	2.00	36.40	19.0	85.0
3/Fall	50.2	0.62	0.140	3.21	35.82	26.3	92.0
3/Spring		0.01	0.040	1.90	36.31	19.4	86.5
3/Summer		0.10	0.100	2.00	36.20	22.0	93.0
3/Winter		0.30	0.200	3.00	36.40	20.0	86.4
7/Fall	30.4	0.04	0.000	3.10	35.93	26.0	78.0
7/Spring		0.22	0.080	2.20	36.00	20.6	89.5
7/Summer		0.30	0.100	3.00	36.20	25.0	90.0
7/Winter		0.20	0.100	2.00	36.40	19.0	90.0
9/Fall	55.5	1.00	0.180	2.95	36.07	23.8	83.0
9/Spring		1.83	0.090	1.70	36.39	20.2	91.0
9/Summer		0.30	0.200	3.00	36.30	21.0	90.0
9/Winter		0.20	0.100	2.00	36.40	20.0	90.0
10/Fall	71.3	1.66	0.120	3.42	36.20	20.9	80.0
10/Spring		1.61	0.150	1.50	36.40	20.4	92.5
11/Fall	77.0	7.37	0.610	5.28	36.07	18.2	92.0
11/Spring		1.77	0.100	1.20	36.39	20.4	94.0
11/Summer		1.00	0.300	4.00	36.30	18.0	90.0
11/Winter		2.00	0.300	3.00	36.30	18.0	90.0
13/Fall	19.6	0.28	0.120	5.72	36.09	25.6	62.0
13/Spring		0.28	0.100	1.70	35.87	22.1	81.5
13/Summer		0.20	0.100	2.00	36.40	30.0	88.0
13/Winter		0.30	0.100	2.00	36.50	22.0	92.0
15/Fall	31.5	0.09	0.600	3.13	35.98	26.6	73.0
15/Spring		0.33	0.080	2.70	36.09	20.7	86.5
15/Summer		0.20	0.100	2.00	36.30	27.0	88.0
15/Winter		0.20	0.100	1.00	36.50	22.0	92.0
17/Fall	58.5	4.36	0.260	6.07	35.98	24.6	73.0
17/Spring		0.27	0.070	2.30	36.24	19.0	90.0
19/Fall	22.5	0.00	0.070	0.19	36.17	25.3	74.0
19/Spring		0.27	0.080	0.80	35.71	22.0	78.5

Table 8-2. Continued.

Station/ Cruise	Parameter*						
	DEPTH	NITNAT	PHS	SIL	SWS	TEH	TRA
21/Fall	44.2	0.68	0.060	2.62	36.01	26.2	80.5
21/Spring		0.20	0.060	2.70	36.06	19.2	90.0
21/Summer		0.20	0.100	3.00	36.20	23.0	90.0
21/Winter		0.30	0.200	2.00	36.50	20.0	88.0
23/Fall	70.0	3.68	0.270	2.76	36.37	21.6	88.0
23/Spring		2.33	0.145	2.35	36.36	19.6	90.0
23/Summer		3.00	0.500	4.00	36.20	19.0	90.0
23/Winter		1.00	0.300	2.00	36.30	19.0	88.0
27/Fall	53.5	0.50	0.090	1.92	35.77	26.1	84.0
27/Spring		0.17	0.130	2.60	36.24	18.7	69.5
29/Fall	62.5	2.97	0.250	1.85	36.47	22.9	88.5
29/Spring		1.81	0.140	1.30	36.46	23.3	90.0
29/Summer		2.00	0.200	2.00	36.30	20.0	92.0
29/Winter		4.00	0.400	2.00	36.40	20.0	93.0
30/Fall	76.1	3.88	0.340	2.00	36.50	21.8	85.0
30/Spring		3.86	0.240	1.95	36.51	20.4	87.0
32/Summer	137.0	10.00	0.700	6.00	36.00	16.0	90.0
32/Winter		10.00	0.800	4.00	36.30	16.0	90.0
35/Summer	159.0	9.00	0.500	4.00	36.40	16.0	90.0
35/Winter		1.00	0.100	2.00	36.20	20.0	92.0
36/Summer	127.0	9.00	0.700	5.00	36.20	17.0	90.0
36/Winter		4.00	0.600	3.00	36.30	17.0	88.0
38/Summer	159.0	13.00	0.800	6.00	36.20	17.0	90.0
38/Winter		10.00	0.600	3.00	36.30	17.0	88.0

*Parameters:
DEPTH = mean station depth (m)
NITNAT = nitrate + nitrite concentration (μM), bottom reading
PHS = phosphate concentration (μM), bottom reading
SIL = silicate concentration (μM), bottom reading
SWS = salinity (parts per thousand), bottom reading
TEH = temperature (°C), bottom reading
TRA = transmissivity (%), bottom reading

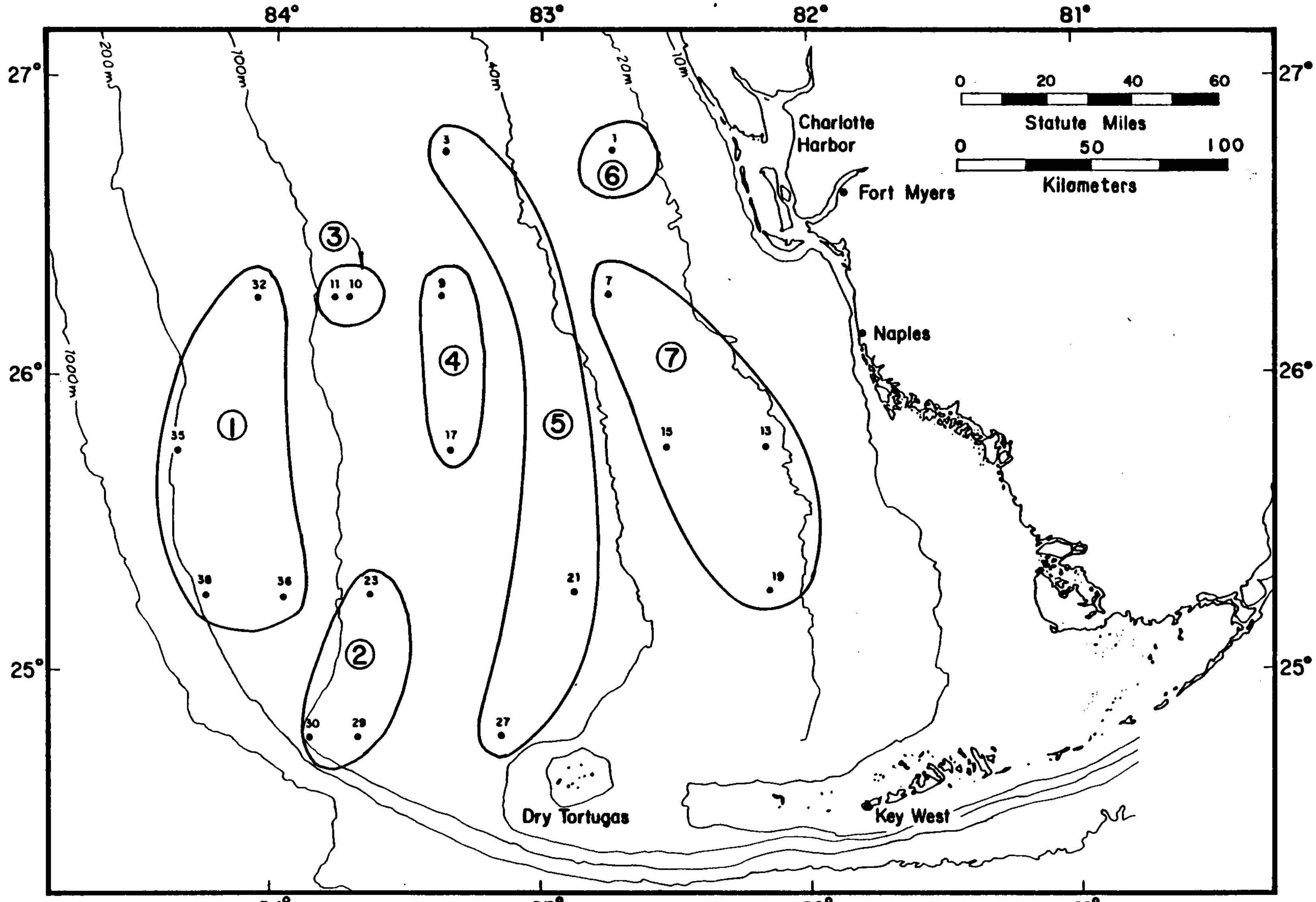

Figure 8-34. Station groupings derived from cluster analysis of triangle dredge samples, for use in weighted discriminant analysis.

Table 8-3. **Results of weighted discriminant analysis of triangle dredge data from live-bottom stations.**

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SW FLORIDA SHELF ECOSYSTEMS STUDY.
WEIGHTED DISCRIMINANT ANALYSIS: TRIANGLE DREDGE -- LIVE BOTTOM; ALL CRUISES COMBINED.

PERCENT OF TOTAL GROUP SEPARATION EXPLAINED BY EACH AXIS

              AXIS     PCT      CUM PCT

                1      97.5      97.5

                2       1.7      99.2

                3       0.7      99.9

                4       0.0     100.0

                5       0.0     100.0




          COEFFICIENTS OF SEPARATE DETERMINATION


                     DISCRIMINANT AXES

                        AXIS1   AXIS2   AXIS3   AXIS4   AXIS5
 VARIABLE


 . DEPTH                 73.3     2.8     4.0     0.9     2.3

 . NITRATE+NITRITE        7.1    48.4     3.0    11.8    27.1

 . PHOSPHATE             13.7    22.9     0.3    35.3     9.1

 . SILICATE               2.2     2.8     4.9    49.7     0.3

 . SALINITY               1.8     1.2    79.9     1.3     4.3

 . TEMPERATURE            1.6    11.8     1.2     0.2    13.2

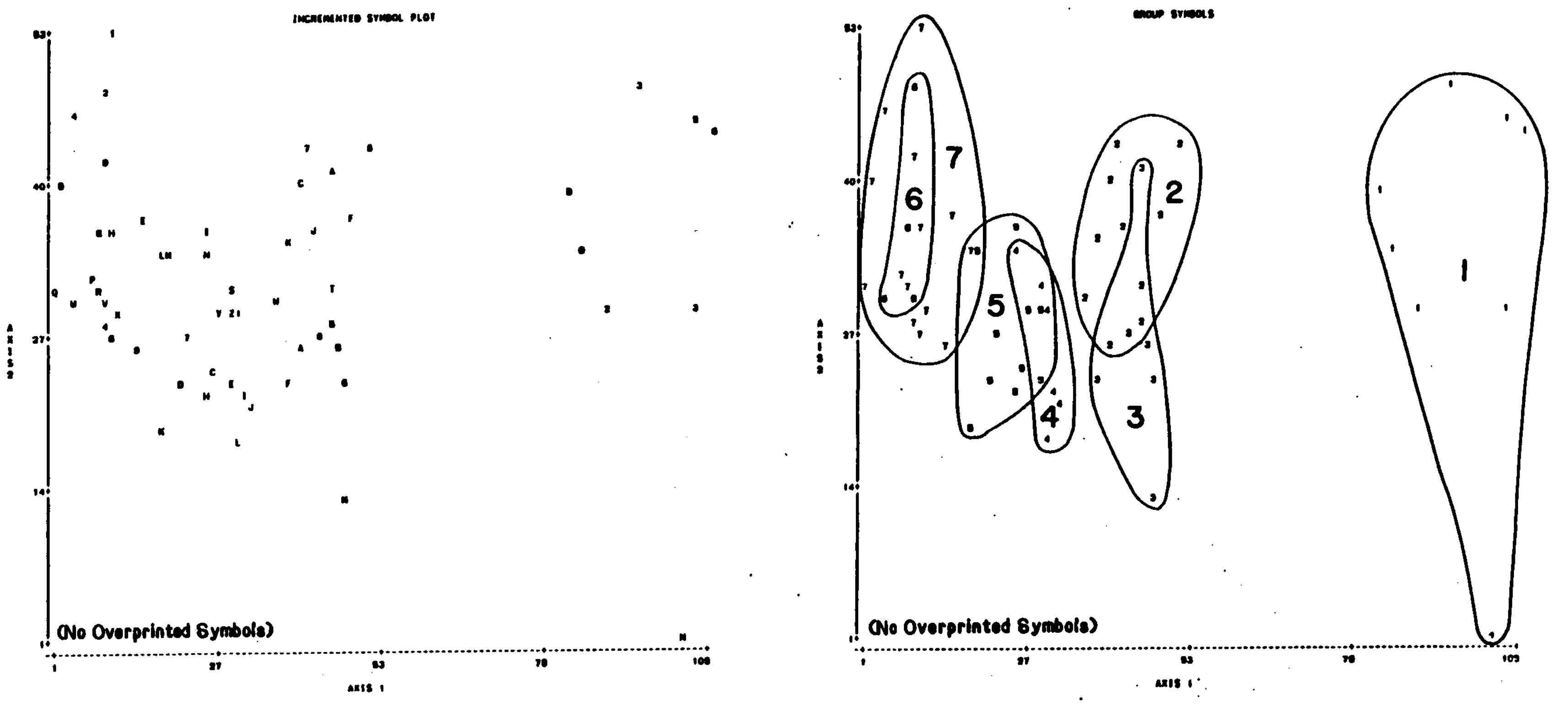
 . TRANSMISSIVITY         0.3    10.0     6.7     0.7    43.6
```

Figure 8-35 shows a plot of all stations/seasons on the first two discriminant axes and provides a key for identification of all points for reference in the discussion of discriminant analysis plots. Figure 8-35 also shows a plot of the station groupings on the first two discriminant axes. Axis I easily separates the Group 1 (deep, offshore) stations from all remaining stations, with lesser degrees of separation between most other groups. Groups 2 and 3 (the northern and southern subclusters within the group of mid shelf algal nodule/pavement stations) are not separated along Axis I. Axis II separates Groups 2 and 3 and provides additional separation between Group 3 vs. Groups 6 and 7.

Figure 8-36 shows the same plot with ordinal values for DEPTH replacing each station's group number. The values, which range from 1 to 9 denoting increasing depth, were derived by dividing the full range of depth values into nine equal subranges and replacing each original value with the number corresponding to the subrange into which it fell. The plot is best interpreted by looking for consistent trends in the ordinal DEPTH values in the direction of either axis. The plot confirms what one would intuitively conclude from examination of the station group maps (e.g., Figure 8-32): the groupings correspond largely to depth zones. Group 1 stations were those at the greatest depths, whereas Group 7 stations were at shallow depths, etc. Depth cannot "explain" the distinction between Groups 2 and 3 (Stations 10 and 11 vs. 23, 29, and 30) or Groups 6 and 7 (Station 1 vs. Stations 7, 13, 15, and 19).

Figure 8-37 shows a similar plot for PHOSPHATE, which was also related to Axis I. Although PHOSPHATE also easily distinguishes the deep, offshore stations (Group 1), discrimination among the other station groups on the basis of PHOSPHATE appears to be poor. PHOSPHATE was also correlated with Axis II but appeared to contribute little to the separation of any groups along the axis. Within-group and seasonal variability in PHOSPHATE (e.g., the wide spread within Group 1) was larger than between-group variability.

Figure 8-38 shows the Axis I vs. Axis II plot with ordinal values for NITRATE + NITRITE shown for each station/season. NITRATE + NITRITE scored high on Axis II and appears to contribute most to the discrimination of Group 2 vs. 3 (i.e., the two groups of mid shelf, algal nodule/pavement stations) and Group 3 vs.



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SW FLORIDA SHELF ECOSYSTEMS STUDY.
WEIGHTED DISCRIMINANT ANALYSIS:  TRIANGLE DREDGE  -- LIVE BOTTOM; ALL CRUISES COMBINED.
SYMBOL TABLE FOR INCREMENTED SYMBOL PLOT.

      SYM ID        SYM ID        SYM ID        SYM ID        SYM ID        SYM ID        SYM ID        SYM ID
       1  1 3 19     9  2 2 13     H  1 3 18     P  1 3 07     X  2 2 07     6  1 4 18     E  2 2 03     M  2 2 11
       2  1 3 01     A  1 3 11     I  1 3 27     Q  1 3 13     Y  2 3 21     7  1 3 03     F  1 3 18     N  2 3 28
       3  2 3 32     B  1 4 13     J  1 3 23     R  2 3 13     Z  1 4 27     8  1 4 10     G  2 3 11
       4  1 4 18     C  1 3 20     K  1 4 28     S  1 3 08     1  1 4 08     9  2 3 07     H  1 4 03
       5  2 2 38     D  2 2 38     L  2 3 18     T  2 2 23     2  2 3 36     A  1 4 23     I  2 3 08
       6  2 3 38     E  2 2 18     M  1 3 21     U  1 4 01     3  2 2 38     B  1 4 11     J  2 2 08
       7  2 3 20     F  1 4 30     N  1 3 17     V  2 3 01     4  1 4 07     C  2 2 03     K  1 4 21
       8  1 3 30     G  2 2 01     O  2 2 32     W  2 2 20     5  2 3 23     D  2 2 21     L  1 4 17

NOTE:  SYM=SYMBOL; ID=YEAR-CRUISE-STATION;

       YEAR 1, CRUISE 3 = FALL CRUISE (OCTOBER 25-NOVEMBER 23, 1980); YEAR 1, CRUISE 4 = SPRING CRUISE (APRIL 22-MAY 8, 1981);
       YEAR 2, CRUISE 2 = SUMMER CRUISE (JULY 18-AUGUST 8, 1981); YEAR 2, CRUISE 3 = WINTER CRUISE (JANUARY 28-FEBRUARY 18, 1982).
```

Figure 8-35. Incremented symbol plot and station group plot from weighted discriminant analysis of triangle dredge data. Plots show the positions of all stations/seasons and groups on the first two discriminant axes. Groups correspond to station groups shown in Figure 8-34.

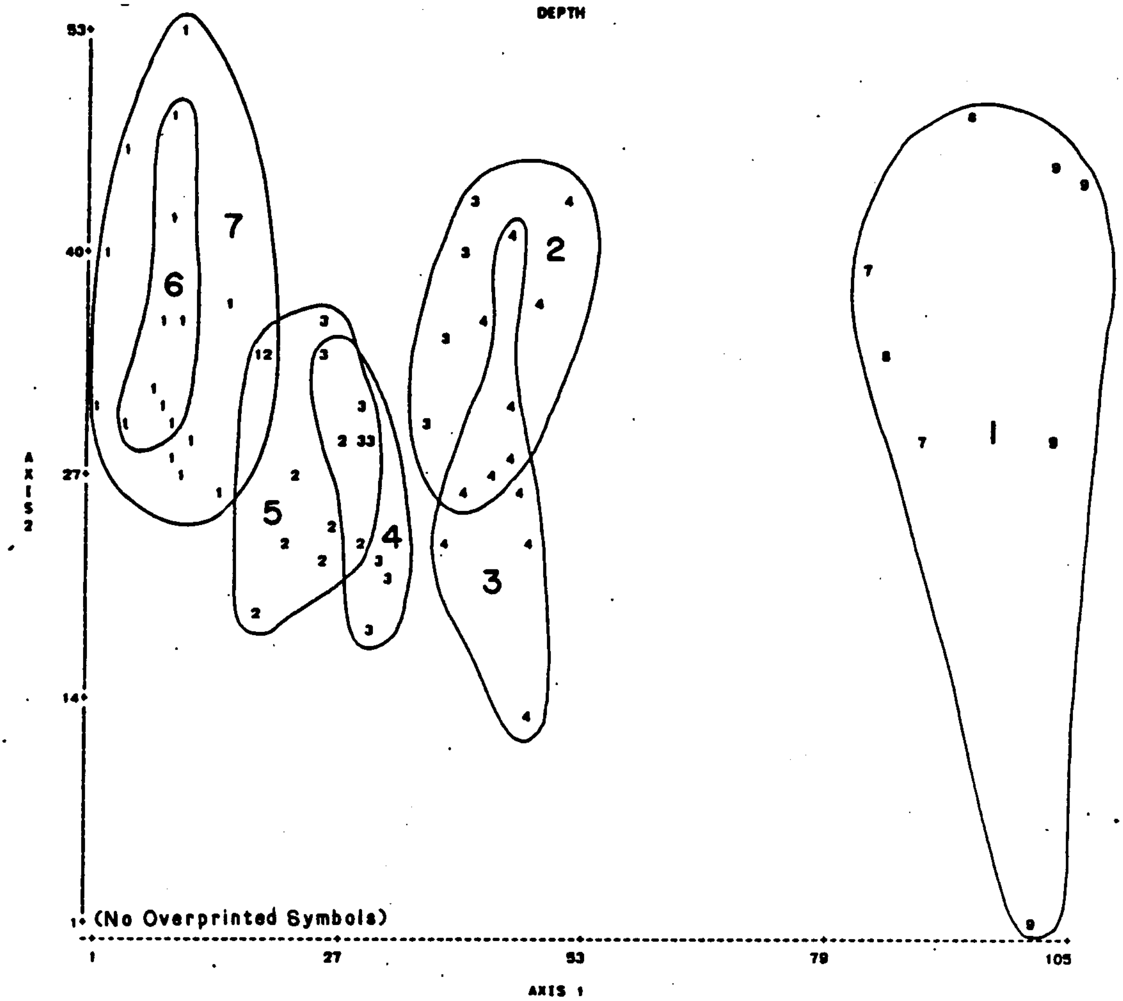

Figure 8-36. Weighted discriminant analysis triangle dredge data. Ordinal DEPTH values for each station/ season plotted on the first two discriminant axes. Higher values indicate greater depths.

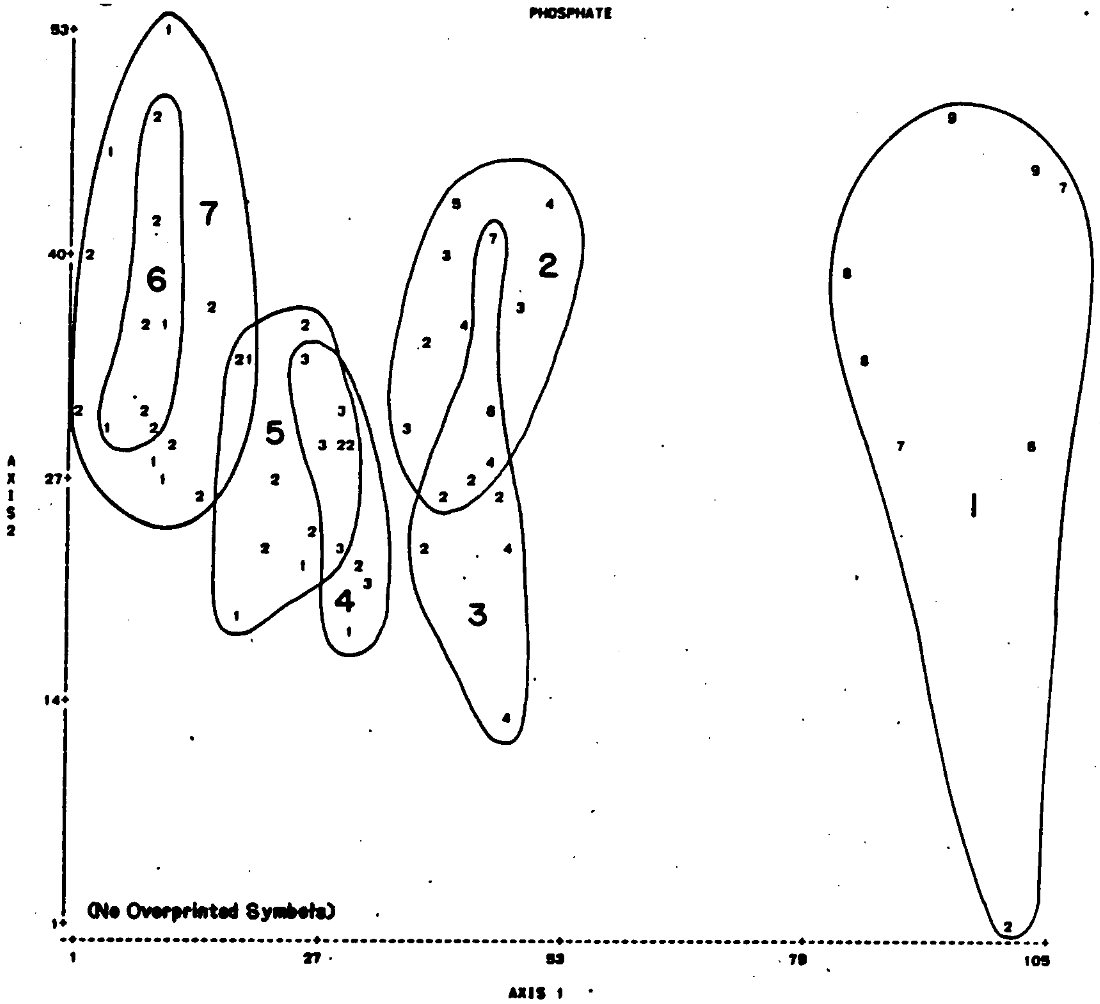

Figure 8-37. Weighted discriminant analysis, triangle dredge data. Ordinal PHOSPHATE values for each station/season plotted on the first two discriminant axes. Higher values indicate higher phosphate concentrations.

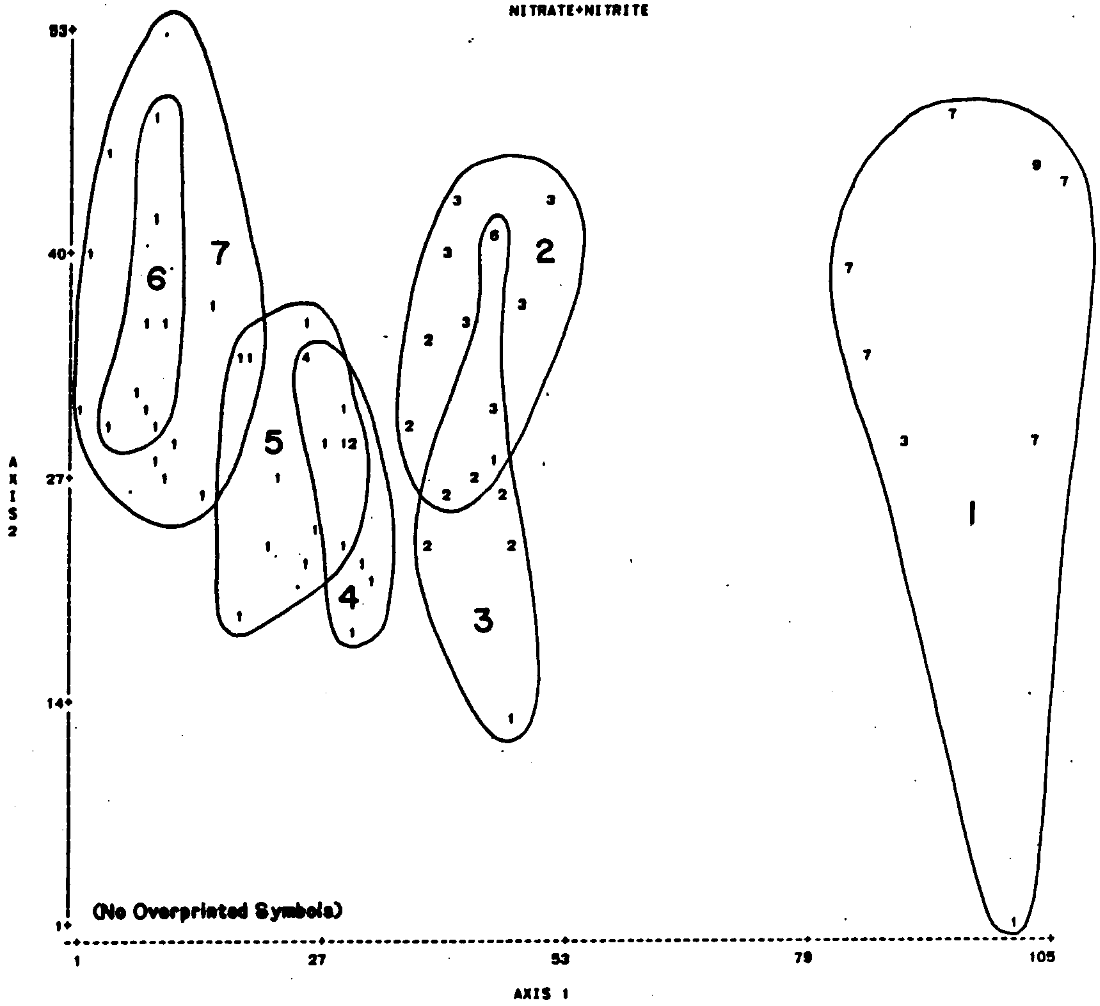

Figure 8-38. Weighted discriminant analysis, triangle dredge data. Ordinal NITRATE + NITRITE values for each station/season plotted on the first two discriminant axes. Higher values indicate higher nitrate+nitrite concentrations.

Groups 6 and 7 along that axis. NITRATE + NITRITE also contributes to the separation of Group 1 vs. all other groups and Groups 2 and 3 from all other groups on Axis I. Within-group variability was again high at the deep offshore stations; both NITRATE + NITRITE and PHOSPHATE were uncharacteristically low at Station 35 (Group 1) on the Winter Cruise.

Although TEMPERATURE weighted only weakly on both of the first two axes (plot not shown), it appears to contribute to the overall discrimination of the deep Group 1 stations from all other station groups. Bottom temperature was generally lower and less variable at the deep offshore stations than at shallower stations.

These results indicate that of the variables included in the analysis, depth was the one best able to discriminate station groupings derived from triangle dredge cluster analysis. There was some evidence to suggest that near-bottom nutrient levels (nitrate and nitrite; phosphate) can also be used to discriminate station groupings. The best separation was clearly between Group 1 and all other groups; Group 1 stations were at much greater depths than any other stations and were exposed to higher nutrient (nitrate, phosphate) levels and lower temperatures than other stations. As discussed later, depth per se cannot be invoked as a causative agent in the development of the biological assemblages of the shelf; rather, it is a correlate of several potentially influential environmental variables included in this analysis, such as nitrate and nitrite, phosphate, and temperature. In addition, it is likely to be correlated with several other variables (e.g., light level, temperature _range_, substratum, etc.) that were not included in this analysis. In the absence of long-term average measurements of such variables (in contrast to the point measurements in this study), depth discriminates the assemblages effectively because it is a correlate of time-averaged environmental conditions. A discussion of environmental conditions (whether correlated with depth or not) and their likely influence in determining the makeup of live bottom biological assemblages of the shelf is provided in Section 8.2.1.2.2.

Otter Trawl Data: Results and Interpretation -- Station/season groups used in the weighted discriminant analysis of trawl data are listed in Table 8-4.

Table 8-4. Station/season groupings derived from otter trawl cluster analysis for use in weighted discriminant analysis.

Group 1

Station 1 - Summer
Station 13 - Summer

Group 2

Station 1 - Spring, Fall, Winter
Station 2 - Spring, Summer, Fall
Station 13 - Spring, Fall, Winter
Station 19 - Spring, Fall
Station 15 - Spring

Group 3

Station 3 - Summer, Winter
Station 15 - Summer, Fall, Winter
Station 17 - Spring
Station 21* - Spring, Summer, Winter
Station 29 - Spring

Group 4

Station 3 - Spring, Fall
Station 9 - Spring, Summer, Fall, Winter
Station 10 - Spring, Fall
Station 11 - Spring, Fall
Station 17 - Fall
Station 27 - Spring, Fall
Station 7 - Winter

Group 5

Station 23 - Spring, Summer, Fall, Winter
Station 29 - Summer, Fall, Winter
Station 30 - Spring, Fall

Group 6

Station 32 - Summer

Group 7

Station 11 - Summer, Winter
Station 32 - Winter
Station 35 - Summer, Winter
Station 36 - Summer, Winter
Station 38 - Summer, Winter

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*No otter trawl was obtained at Station 21 on the Fall Cruise.

As discussed in Section 6.4.3.2, cluster analysis of otter trawl data exhibited more seasonal variation than did triangle dredge cluster analysis. This is reflected in the groups listed in Table 8-4.

Discriminant Axis I explained 92.6% of the variance in discriminant space, and was most strongly related to DEPTH and NITRATE + NITRITE (coefficients of determination = 53.4 and 22.9, respectively) (Table 8-5). Axis II explained 4.9% of total variance, and was dominated by NITRATE + NITRITE (37.1) and SALINITY (38.8). Axes I and II together explained 97.5% of the total variance in discriminant space.

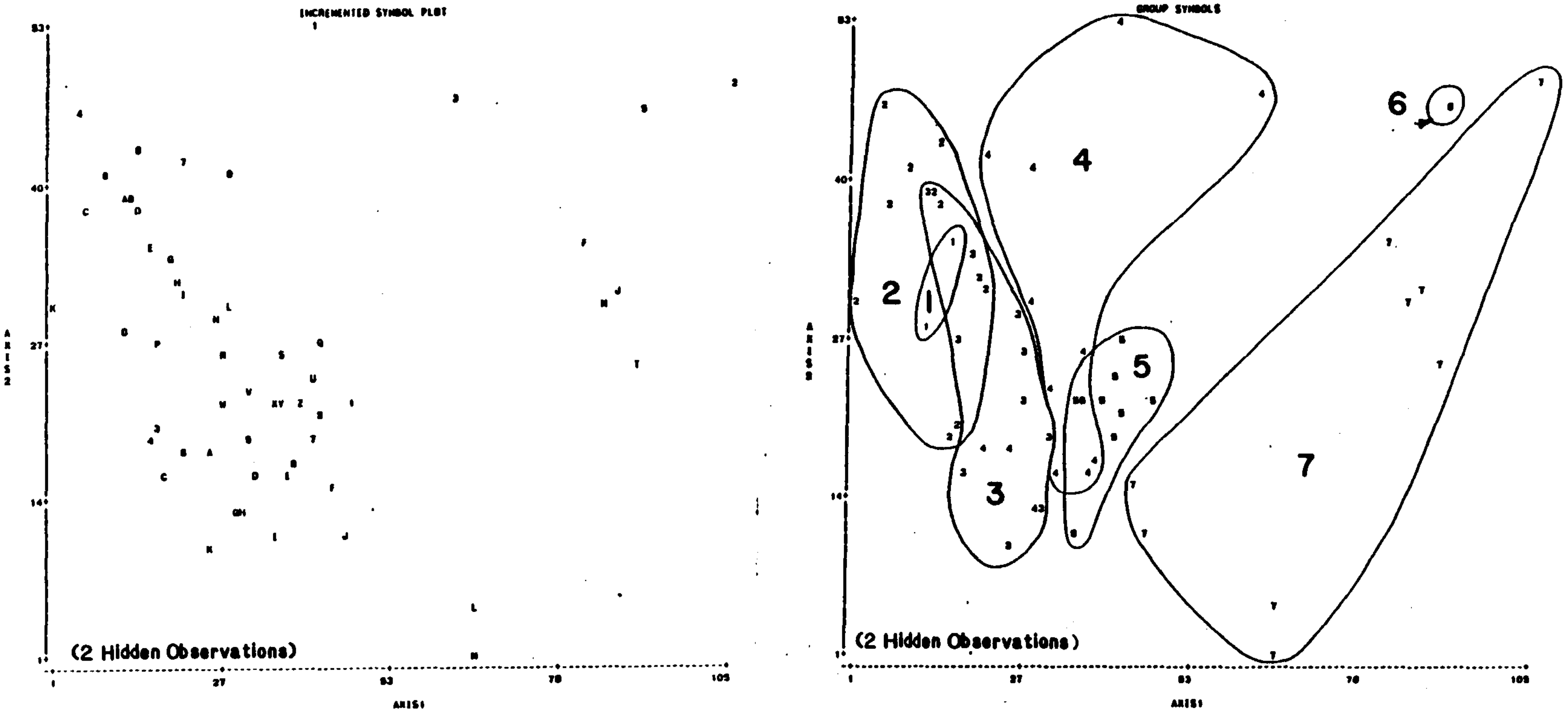
Figure 8-39 provides a plot of all individual stations/seasons on the first two discriminant axes for reference in discussion of the discriminant analysis plots. Figure 8-39 also shows a plot of the station groupings on the first two discriminant axes. Axis I best separates Groups 6 and 7 from the remaining groups, among which a less consistent degree of separation is evident. A large amount of scatter within station groups is evident along Axis II; the axis also provides additional separation of Group 5 vs. 1 and Group 6 vs. Groups 1, 3, and 5.

Figure 8-40 shows ordinal values for DEPTH on the Axis I vs. Axis II plot; the variable scored highly on Axis I. DEPTH provided some separation between Groups 3, 4, 5, 6, and 7. Unlike the triangle dredge results, the trawl clustering produced results that placed several stations in more than one group, depending on season; this variation could obviously not be explained by depth, which did not vary with season. Thus, for example, the separation of Summer Cruise results for Station 32 (= Group 6) or the Summer Cruise results for Stations 1 and 13 (= Group 1) must be explained by some other variable(s).

Figure 8-41 shows the NITRATE + NITRITE overlay for the same discriminant axes. The variable scored moderately high on both Axes I and II; its main effect in the analysis was to discriminate Groups 5, 6, and 7 from remaining groups and to discriminate Group 5 from Groups 6 and 7. A large amount of variation within Group 7 is evident; the two Station 11 points in the lower left portion of the station grouping clearly are more typical of the values in Group 4, where

Table 8-5. Results of weighted discriminant analysis of otter trawl data from live-bottom stations.

```
SW FLORIDA SHELF ECOSYSTEMS STUDY.
WEIGHTED DISCRIMINANT ANALYSIS:  OTTER TRAWL -- LIVE BOTTOM: ALL CRUISES COMBINED.

PERCENT OF TOTAL GROUP SEPARATION EXPLAINED BY EACH AXIS

               AXIS       PCT      CUM PCT

                 1       92.6       92.6

                 2        4.9       97.5

                 3        1.6       99.1

                 4        0.8       99.8

                 5        0.1      100.0

             COEFFICIENTS OF SEPARATE DETERMINATION

                       DISCRIMINANT AXES

                         AXIS1   AXIS2   AXIS3   AXIS4   AXIS5
 VARIABLE


 1. DEPTH                 53.4     7.8     1.0    34.8     0.5

 2. NITRATE+NITRITE       22.9    37.1    13.3     4.7    10.3

 3. PHOSPHATE              2.8     6.1    27.5     1.0    58.0

 4. SILICATE              11.8     4.4    37.8    12.8     0.3

 5. SALINITY               0.7    38.8     9.1    20.2    23.4

 6. TEMPERATURE            3.8     5.5     7.8     0.5     0.7

 7. TRANSMISSIVITY         4.6     0.3     3.5    26.1     6.8
```



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SW FLORIDA SHELF ECOSYSTEMS STUDY.
WEIGHTED DISCRIMINANT ANALYSIS:  OTTER TRAWL -- LIVE BOTTOM; ALL CRUISES COMBINED.
SYMBOL TABLE FOR INCREMENTED SYMBOL PLOT.

            SYM ID         SYM ID         SYM ID         SYM ID         SYM ID         SYM ID
             1  1 3 17      B  1 3 13      L  1 3 09      V  1 4 09      6  1 4 29      G  2 3 09
             2  2 2 38      C  1 3 01      M  2 3 32      W  2 2 03      7  1 3 30      H  2 3 03
             3  1 3 11      D  1 4 01      N  1 4 21      X  1 3 29      8  1 4 27      I  2 3 23
             4  1 4 19      E  2 2 01      O  2 2 13      Y  2 2 29      9  2 3 07      J  2 2 11
             5  2 2 32      F  2 2 36      P  2 2 15      Z  1 4 23      A  1 4 03      K  2 3 21
             6  1 3 07      G  1 4 07      Q  1 3 23      1  2 2 23      B  1 4 11      L  2 3 36
             7  1 3 27      H  1 4 15      R  2 2 21      2  1 4 30      C  2 3 15      M  2 3 35
             8  1 4 13      I  2 2 07      S  1 3 10      3  2 3 13      D  2 2 09
             9  1 3 03      J  2 3 38      T  2 2 35      4  2 3 01      E  1 4 10
             A  1 3 15      K  1 3 19      U  2 3 29      5  1 4 17      F  2 3 11

NOTE:  SYM=SYMBOL; ID=YEAR-CRUISE-STATION;

       YEAR 1, CRUISE 3 = FALL CRUISE (OCTOBER 25-NOVEMBER 23, 1980); YEAR 1, CRUISE 4 = SPRING CRUISE (APRIL 22-MAY 5, 1981);
       YEAR 2, CRUISE 2 = SUMMER CRUISE (JULY 18-AUGUST 5, 1981); YEAR 2, CRUISE 3 = WINTER CRUISE (JANUARY 28-FEBRUARY 15, 1982).
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Figure 8-39. Incremented symbol plot and station group plot from weighted discriminant analysis of otter trawl data from live bottom stations. Station/season groups are those listed in Table 8- 4.

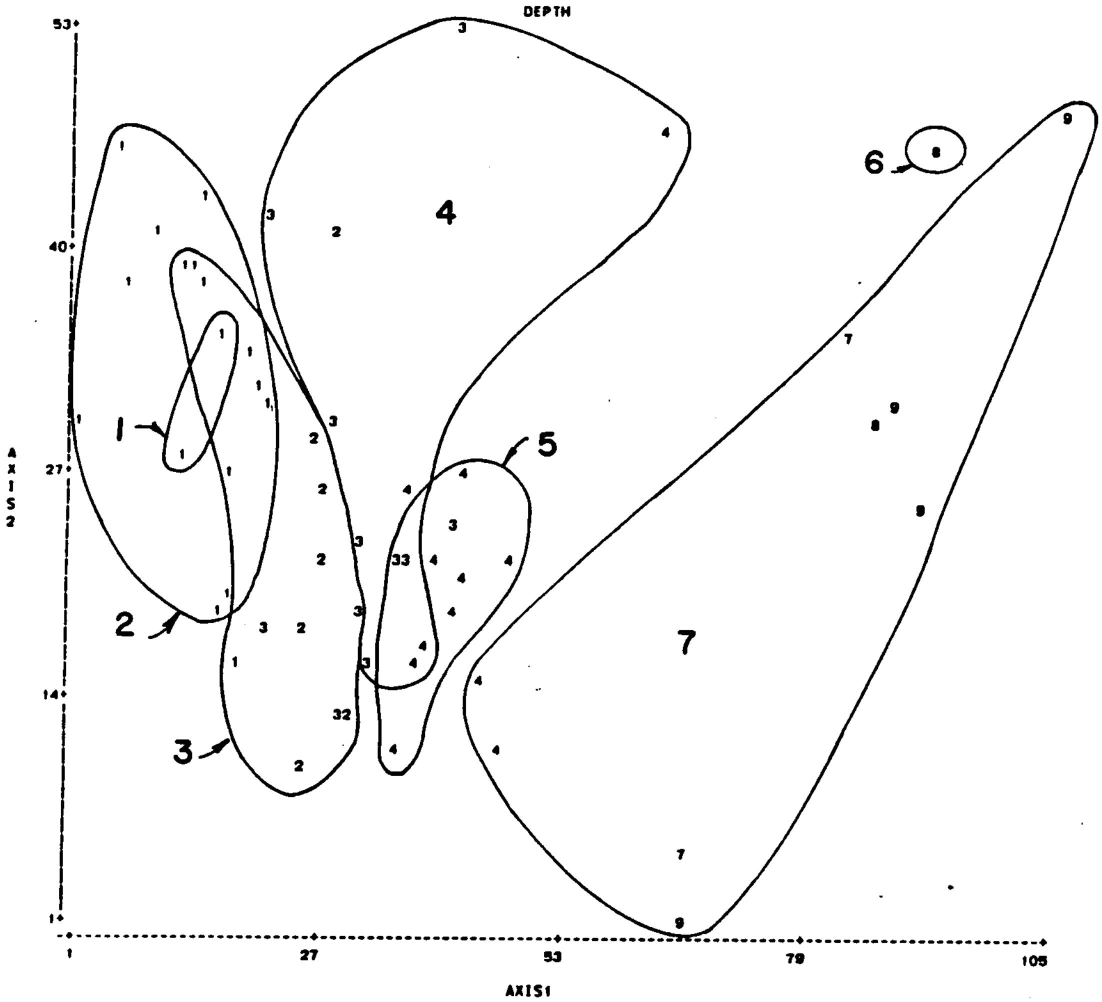


Figure 8-40. Weighted discriminant analysis, live bottom otter trawl data. Ordinal DEPTH values for each station/season plotted on the first two discriminant axes. Higher values indicate greater depths.

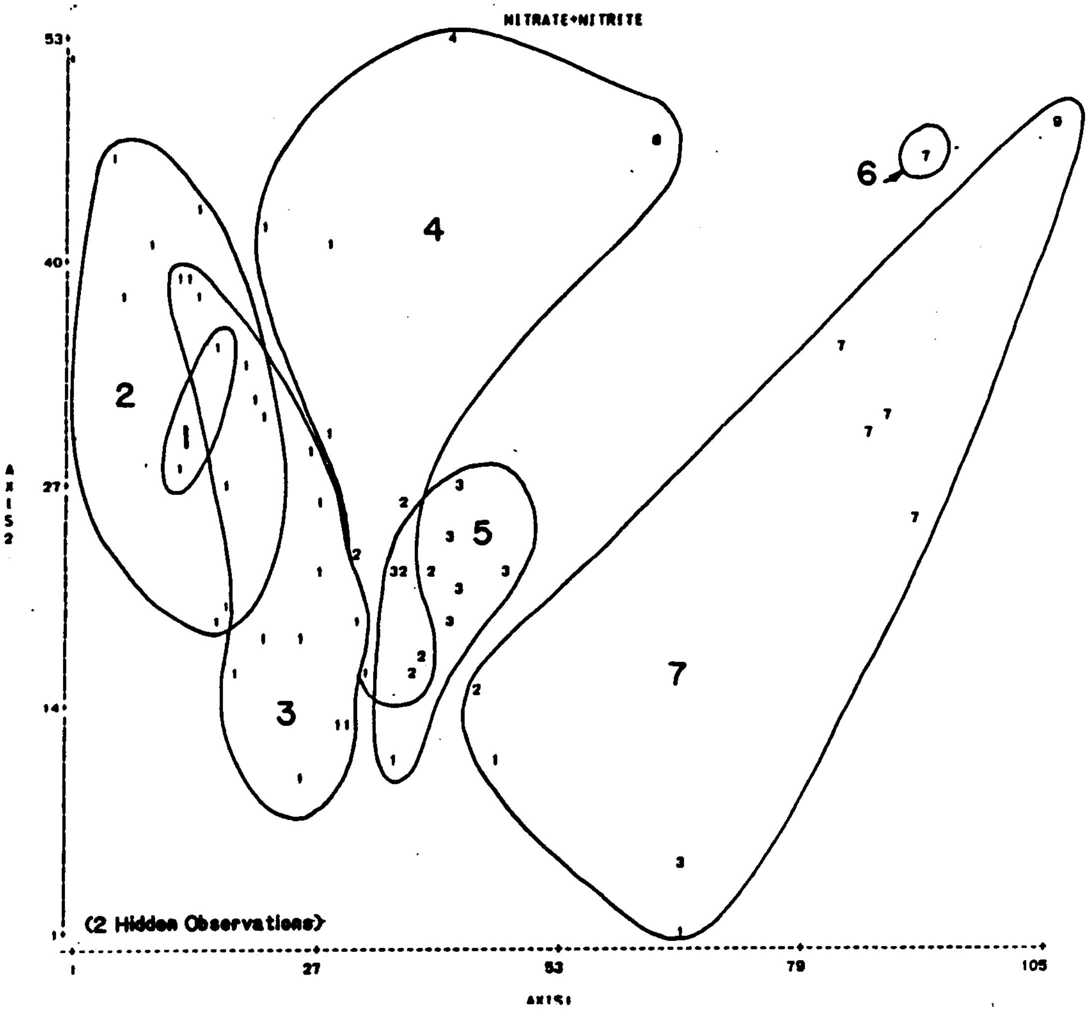


Figure 8-41. Weighted discriminant analysis, live bottom otter trawl data. Ordinal NITRATE + NITRITE values for each station/ season plotted on the first two discriminant axes. Higher values indicate higher nitrate + nitrite concentrations.

the two other Station 11 points occur. Seasonal variation in NITRATE + NITRITE was also evident at Stations 35 and 36 (the two points near the base of the Group 7 cluster), which had low nutrient levels on the Winter Cruise. NITRATE + NITRITE levels could not explain the separation of Station 32 Summer Cruise results (Group 6) from those at other deep stations/seasons (Group 7).

Figure 8-42 shows the plot of ordinal SALINITY values on the first two discriminant axes. SALINITY scored moderately high on Axis II, but little group separation was evident along that axis. SALINITY appears to account for the separation between Group 6 vs. Group 7; SALINITY was relatively "low" (by a few tenths of a part per thousand) at Station 32 on the Summer Cruise (Group 6).

The results of the weighted discriminant analysis using otter trawl data indicate that depth and nitrate + nitrite levels are the variables best able to discriminate among station groupings. Depth, per se, was not as useful a discriminator as in triangle dredge-based analyses because otter trawl clustering placed some stations in different groups depending on season. Of these seasonal groupings, only one (Station 32, Summer Cruise = Group 6) could be associated with a specific environmental difference--reduced salinity. However, the meaningfulness of this association is doubtful, because the salinity was still 36.00°/°°, only slightly lower than typical salinity values at the other outer shelf stations. Nutrient levels were not as successful in this analysis as the corresponding triangle dredge analysis in separating station groups, with the exception of the deep, outer shelf stations which were subject to higher nutrient levels.

8.2.1.2.2 General Discussion of Environmental Factors

The formal discriminant analysis identified depth, and possibly nutrient (nitrate and nitrite) levels, as factors that could "explain" the observed station groupings of live bottom assemblages on the southwest Florida shelf. The usefulness of depth as a discriminator among station groupings probably reflects consistent relationships between depth and the long-term values of a suite of environmental variables such as temperature, salinity, light, substratum, sediment movement, food inputs, and inorganic nutrient levels, that are typically

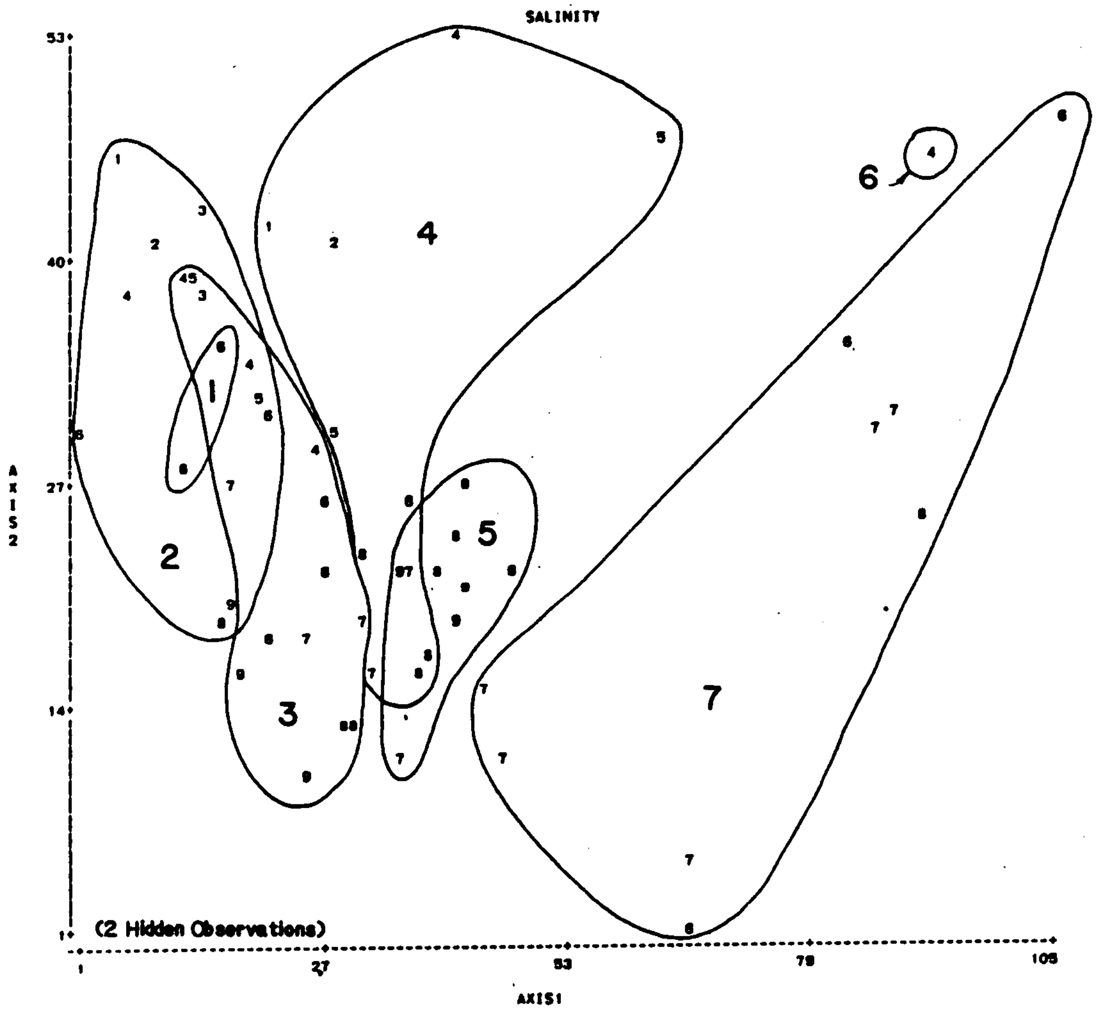


Figure 8-42. Weighted discriminant analysis, live bottom otter trawl data. Ordinal SALINITY values for each station/season plotted on the first two discriminant axes. Higher values indicate higher salinity.

associated with zonation patterns of hard bottom biota (Sheppard, 1982; Bright, 1983; Fricke and Schuhmacher, 1983). The analysis has several shortcomings: 1) relatively few environmental variables were included, and others that one might expect to exert a major influence on biological assemblages were not available or not included; 2) the parameter values were determined at single points in time and therefore may not represent the average conditions to which the organisms are exposed; 3) the use of station groups derived from cluster analysis of all taxa combined is likely to obscure organism-environment relationships for different phyletic groups such as algae, crustaceans, corals, etc; and 4) causal relationships can only be inferred, rather than firmly established, on the basis of these statistical associations between environmental variables and station groupings. This section attempts to address the first three problems and improve the resulting view of environment/organism relationships for live bottom assemblages by considering a broader range of environmental variables, their temporal consistency, and their likely effects on particular groups of organisms. The problem of inferring causal relationships remains; it can best be addressed in the future by conducting laboratory and field experiments and collecting more process-oriented data from live bottom areas.

Individual species have distributional ranges that are determined by tolerances to ranges of abiotic environmental variables, dispersal abilities, and biotic interactions. Although shelfwide distributional patterns of particular species and the factors controlling these patterns are of interest, the major emphasis in this section is on the inferred relationships between environmental parameters and the major phyletic groups and functional types that predominate in different live bottom habitats across the shelf.

Temperature

Temperature exerts a profound influence on all organisms via its effects on metabolic processes. Different organisms have different tolerances to absolute temperature values and to short-term temperature changes. In addition, within these limits, many organisms have thermal optima for survival, growth, and/or reproduction. Because the temperature regime to which benthic epibiota are exposed varies with depth and latitude, shelfwide changes in the species composition of these assemblages can be explained in part as a consequence of the overlapping tolerance ranges of those species. Of more interest is the relationship between the temperature regime and the general characteristics of epibiotal assemblages on the shelf.

Near-bottom temperature values for live bottom stations have been presented in Table 8-2. Although some effect of latitude is noticeable (i.e., stations at similar depths at lower latitudes are 1 to 2°C warmer), temperature is most strongly related to depth. The general relationship of temperature to depth is summarized in Figure 8-43, which also includes data for soft bottom locations sampled. The highest maximum temperatures (30°C) occur at the shallowest (about 20m depth) stations, but the temperature range (8° to 10°C) of locations at 20 to 50m depths is fairly consistent. At stations at 50 or 60m and up to 90m depths, the temperature range is markedly lower (about 4° to 6°C) and minimum temperatures are about 17° to 18°C. Although stations deeper than 100m were only sampled twice (Summer and Winter Cruises), it appears that the temperature range is still significant at these depths and minimum bottom temperature is generally less than 18°C. Geostrophic upwelling of cold, deep water due to passage of the Loop Current along the shelf edge is in part responsible for the generally consistent low temperatures observed at the outer shelf stations. In addition, impingement of Loop Current filaments onto the shelf can cause temperature anomalies (e.g., penetration of warm surface Loop Current water to the bottom at Station 35 on the Winter Cruise) (see Section 4.0).

Although temperatures consistently lower than 18°C are likely to prevent the establishment of any active coral reef development at depths greater than about 90m, such development is highly unlikely anyway because light levels are too low to support hermatypic coral growth. The occurrence of hermatypic corals below about 100m is rare, even where temperatures are probably not limiting (Fricke and Schuhmacher, 1983). Temperatures across the remainder of the shelf in the study area are not likely to restrict coral reef development as such temperatures are common in Caribbean reef environments.

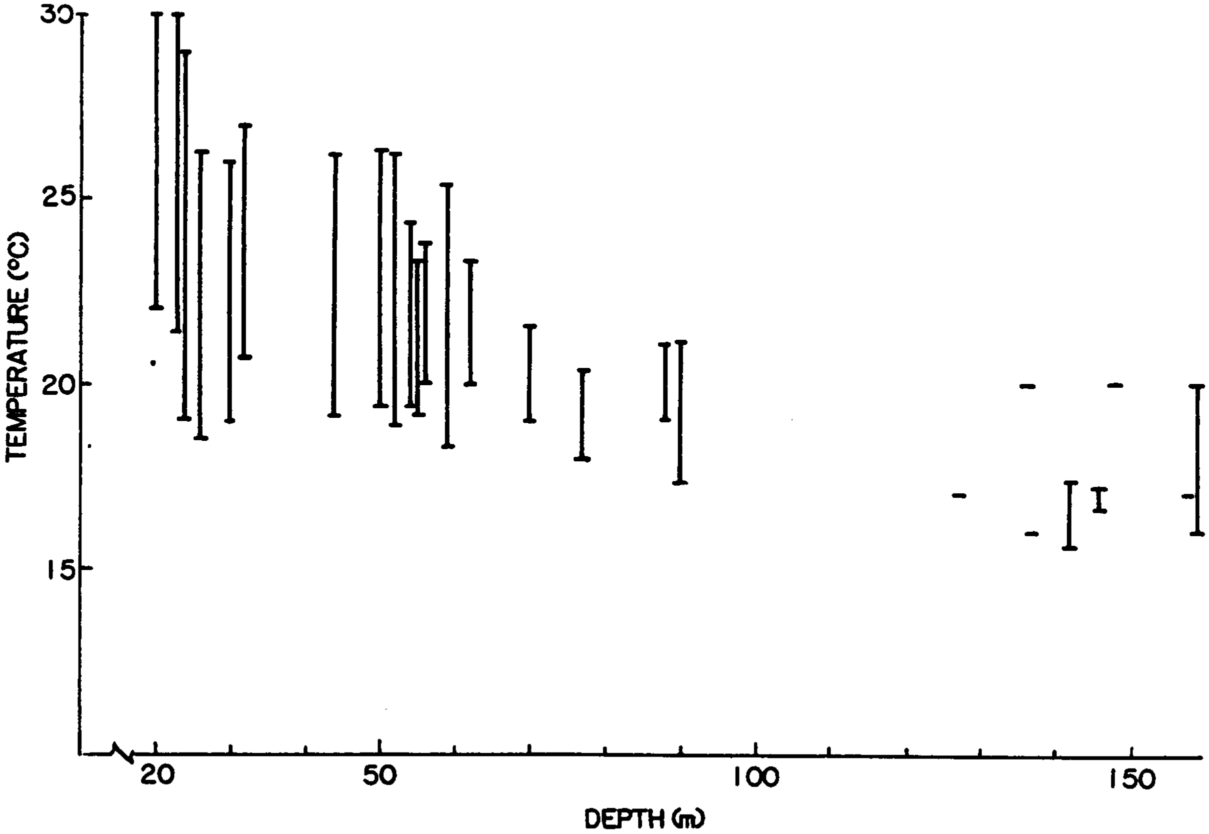


Figure 8-43. Bottom temperature range (°C) for live and soft bottom stations sampled during all four seasons (stations at >100 m. depth, sampled on the summer and winter cruises only also included).

Seasonality of algal growth and production is likely to be related to the ambient temperature range. QSA results indicate distinct seasonal patterns of abundance (percent cover) at inner shelf stations, and a higher contribution of perennials (e.g., Halimeda, Peyssonnelia, Anadyomene) at mid shelf (60 to 80m) depths. However, there is no general relationship between annual temperature range and the observed range in percent cover (Figure 8-44). When individual algal groups are considered, only the red algae show a strong relationship between annual temperature range and the range of algal abundance (Figure 8-45). A weaker relationship is noted for the green algae (Figure 8-46); among the mid shelf stations where temperature range was relatively low, those at which Anadyomene menziesii was the dominant green alga show little algal seasonality, but Station 11 (which had no Anadyomene) does not fit the relationship. Brown algae were never abundant at middle and outer shelf locations where one would expect their seasonality to be less pronounced.

Miller and Richards (1979) have discussed the general relationship between temperature and the composition of live bottom fish assemblages in the South Atlantic Bight. They observed that tropical (no growth at 18°C; mortality at 16 to 18°C) species may be prevented from establishing themselves on the outer shelf because of periodic intrusions of deep, cold Gulf Stream water. Off northeastern Florida, where the shelf is narrow and winter temperatures are relatively mild, this results in restriction of tropical and subtropical-tolerant species to the inner shelf, but farther north, colder conditions force the submergence of these species to an intermediate, mid shelf depth. On the southwest Florida shelf, winter temperatures are considerably milder than those observed in the shallow South Atlantic Bight (viz., 18° to 20°C vs. 12° to 16°C at 20 to 40m depths; Marine Resources Research Institute, 1982) and thus are not likely to restrict the penetration of tropical and subtropical species inshore. However, occasional severe cold fronts can penetrate in shallow locations and kill or injure tropical fish and invertebrate species associated with hard ground or patch reefs (Bullock and Smith, 1979; Bohnsack, 1983).

In summary, the inferred effects of temperature on live bottom assemblages of the southwest Florida shelf include: 1) restriction of tropical-tolerant species to depths shallower than about 90m; 2) probable episodic mortalities

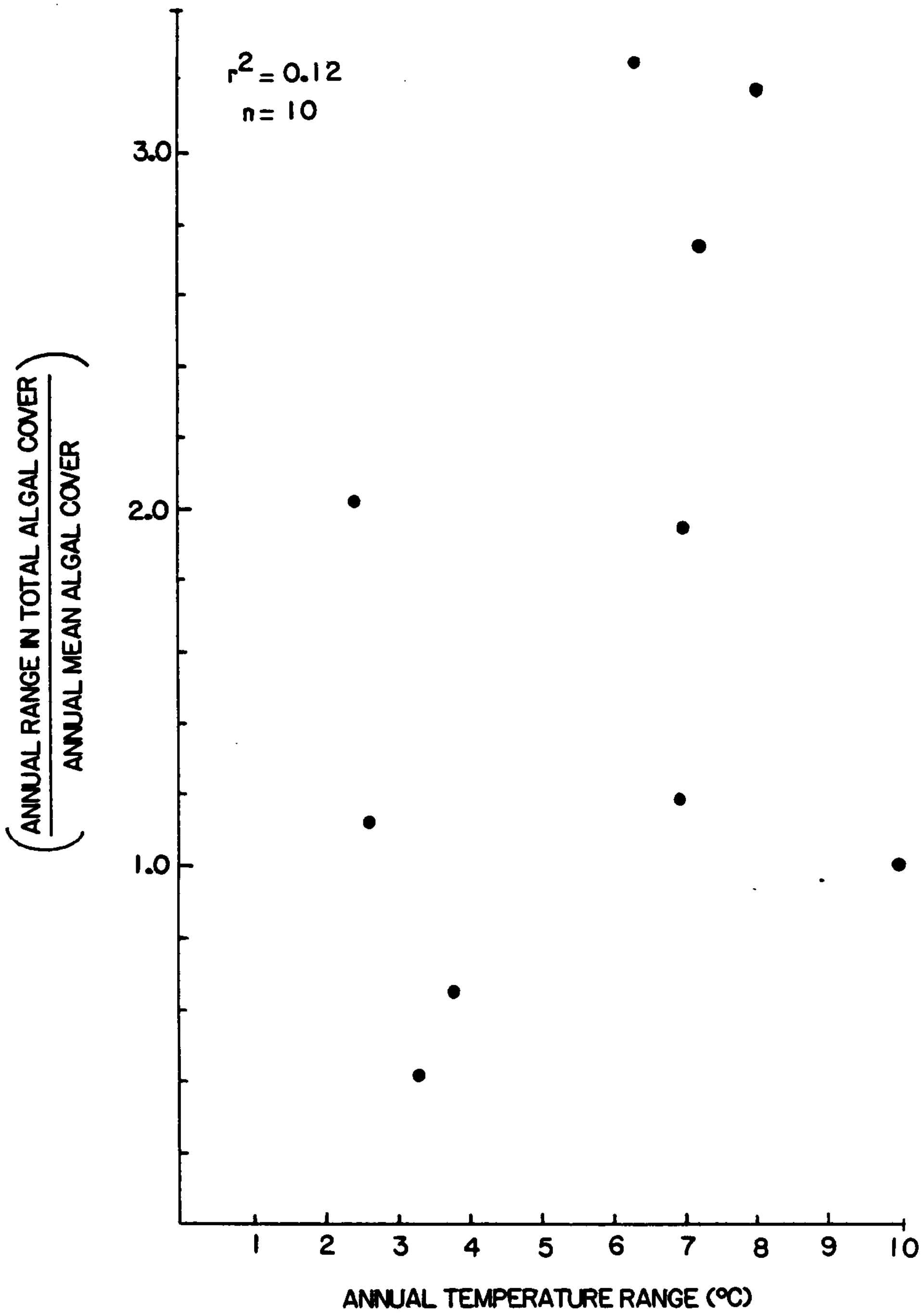


Figure 8-44. Relationship between annual range in algal cover and annual temperature range at live bottom stations sampled during all four seasons.

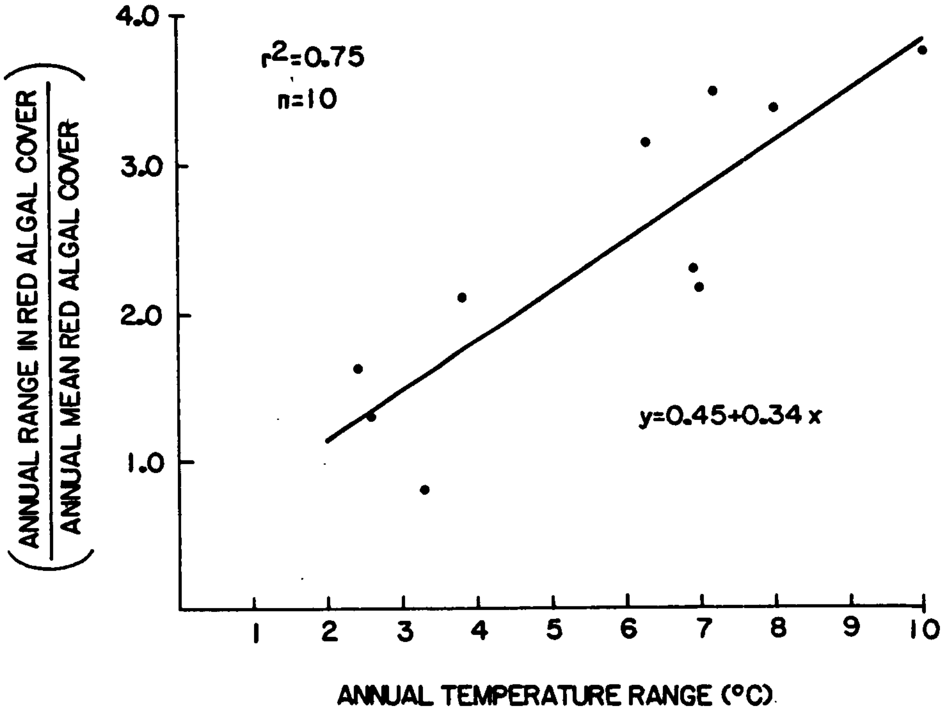


Figure 8-45. Relationship between annual range in red algal cover and annual temperature range at live bottom stations sampled during all four seasons.

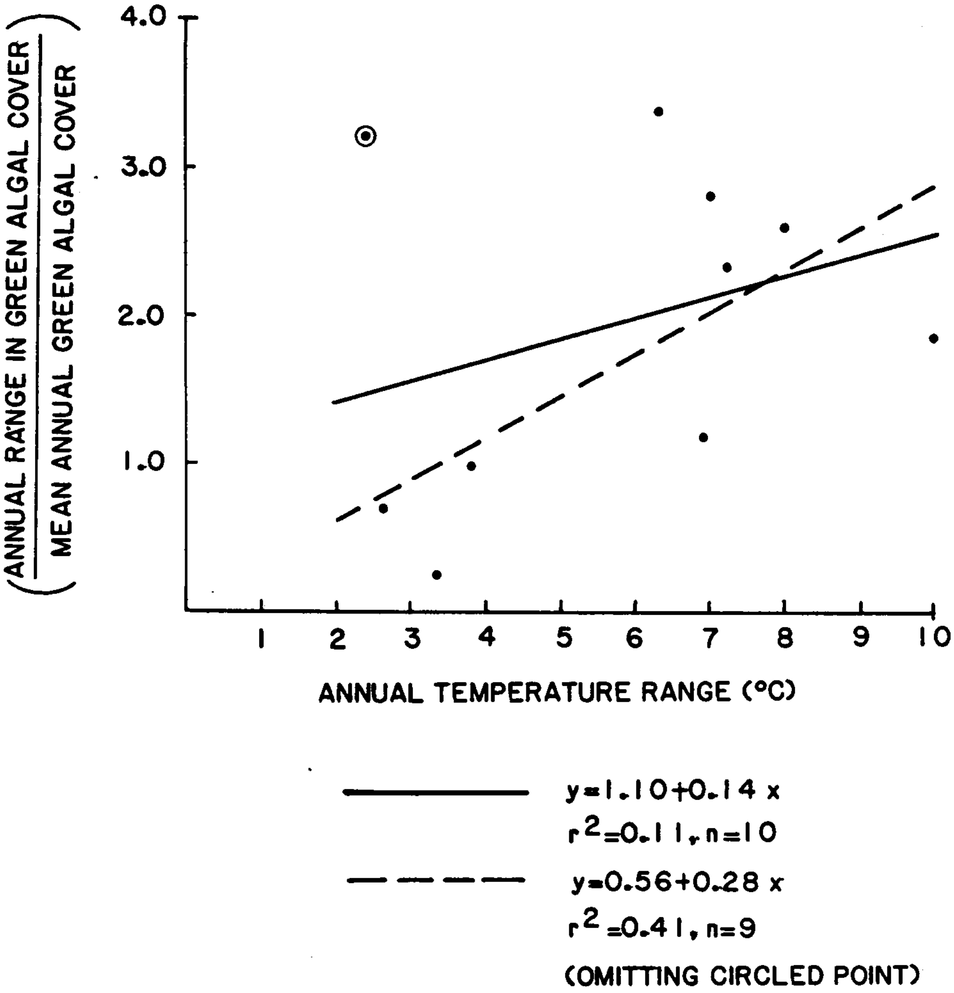


Figure 8-46. Relationship between annual range in green algal cover and annual temperature range for live bottom stations sampled on all four seasonal cruises.

of tropical and or subtropical tolerant species at shallow locations, due to occasional severe winter cold fronts; and 3) regulation of seasonal algal abundance, especially at inner shelf locations.

Light

The major influences of light levels on biological assemblages of the shelf are mediated by algae, including the symbiotic zooxanthellae harbored by hermatypic corals. Decreasing light levels with depth establish a lower limit for hermatypic coral development and probably determine (in part) the shelfwide abundance patterns of benthic algae. Both algae and hermatypic corals can provide emergent structure that in turn provides microhabitats for a variety of associated cryptic fauna.

Few data were collected concerning light levels, due to equipment malfunction. Figure 8-47 shows light penetration curves for Stations 1 (24m) and 35 (159m) and illustrates two points. In clear offshore waters, the 1% light level commonly taken as coinciding with the maximum depth of the photic zone occurs at approximately 70m (probably varying by 10m or so based on other profile results). More extensive and sophisticated determinations of light penetration conducted as part of the Year Two modification (Woodward-Clyde Consultants and Skidaway Institute of Oceanography, 1983) suggested the 1% light level occurs at 65 to 70m in the area. Second, light penetration is reduced in shallow, nearshore waters, probably because of suspended particulate matter. Transmissivity data provide additional information concerning turbidity levels. Stations can be divided into three (arbitrary) groups on the basis of transmissivity sampling:

1) stations that always exhibited transmissivity values in the 80s to over 90% (Stations 3, 9, 10, 11, 21, 23, 29, 30, 32, 35, 36, and 38);

2) stations that exhibited at least one value in the 70% to 80% range (Stations 1, 7, 15, 17, and 19); and

3) stations that exhibited at least one value in the 60% to 70% range (Stations 27 and 13).

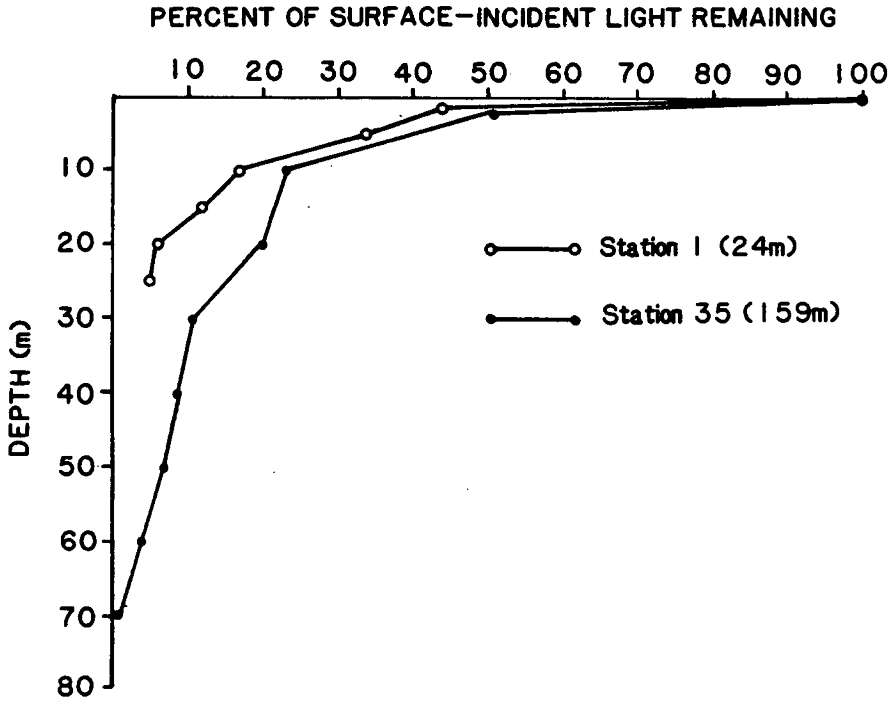


Figure 8-47. Light penetration curves for two live bottom stations at different depths.

Although the first two groups correspond to depth zones (62 to 159m and 22 to 58m, respectively), the third does not. Station 13 was the shallowest station (20m), but Station 27 was located at 54m depth. The low transmissivity values noted at Station 27 probably reflect its proximity to fine (easily resuspended) substrates immediately to the east (see Section 5.0). Elevated near-bottom chlorophyll a values and anomalously high silicate values for soft bottom Station 25, located farther east of Station 27 on Transect E, also suggest possible resuspension events (Section 4.0). Similar elevated near-bottom chlorophyll values were also observed at the shallow inshore stations on some transects. Although Carder and Haddad (1979) observed high near-bottom turbidity (low transmissivity) on the outer southwest Florida shelf during the MAFLA study, no major reductions in transmissivity at outer shelf stations were noted in the present study. Carder and Haddad (1979) attributed their results to direct erosive effects of Loop Current penetration onto the outer shelf.

The importance of these transmissivity and light data lies not in deriving any absolute values for light levels at the bottom but rather in the recognition that progressively shallower locations (and those adjacent to fine soft bottom substrates) are likely to be exposed to periodic reductions in incident light due to resuspension of bottom sediment.

Because hermatypic corals exhibit light-enhanced calcification (Goreau and Goreau, 1959), their bathymetric ranges reflect, in part, relationships between coral morphology and light capture abilities (Fricke and Schuhmacher, 1983), but photoadaptation (Bak, 1976; Dustan, 1982) is a complicating factor and consequently the overall influence of light levels on zonation patterns of corals is not well established (Sheppard, 1982). Plate-like forms such as Agaricia spp. (which were abundant in a limited area in 60 to 80m depths in the southwest corner of our study area) are adapted to low light levels and have been reported from depths at the lower limit (about 100m) of hermatypic coral occurrence in Caribbean environments (Lang, 1974; Van Den Hoek et al., 1978). Leptoseris, an agariciid genus, has been reported from 145m depths in the Red Sea (Fricke and Schuhmacher, 1983). Agaricia also occurs in shallower habitats, but generally on steep vertical surfaces (Van Den Hoek et al., 1978) or under sheltering ledges (Hubbard and Pocock, 1972), and its distribution partly reflects poor clearance abilities for coarse sediment particles (Hubbard and Pocock, 1972). As discussed later (see section concerning "Substratum, Sedimentation, and Sediment Movement"), sedimentation and/or sediment movement is likely to exert important influences on establishment of hermatypic coral colonies on the shelf due to the general lack of high-relief emergent substrate. Agaricia, by virtue of its morphology and adaptation to low light, is apparently able to take advantage of the relatively sediment-free environment created by the algal nodule "pavement" that occurs in deep (60 to 80m) water in the southwest corner of the study area. Although near-bottom turbidity could significantly reduce light levels at shallower depths, it is unlikely that changing light levels can be invoked to explain the lack of other major growths of hermatypic corals on the shelf.

Many gorgonians, like hermatypic stony corals, harbor symbiotic zooxanthellae but are also capable of feeding on animal prey or particulate organic matter (Lasker, 1981). Light levels have been suggested as a factor influencing gorgonian zonation and may be responsible for the general restriction of symbiont-containing gorgonians to relatively shallow depths (Goldberg, 1973). Reduced feeding rates with increasing depth (Lasker et al., 1983) should accentuate the decline in net photosynthetic rates with depth to restrict gorgonian distribution. In the present study, several species of gorgonians were abundant at the shallowest (20m) station (Station 13); subsequent sampling under Year Three of this program has identified abundant gorgonian assemblages at shallower depths.

Light levels and seasonal changes in light are also likely to be important factors determining the abundance and species composition of algal assemblages on the shelf. The success of a particular species will depend in part on its photosynthetic action spectrum and photoadaptation to ambient light levels (Vooren, 1981; Dustan, 1982). Although the level of 1% light penetration is commonly taken as the lower boundary of the euphotic zone, some algal production obviously occurs at greater depths. In our study, unidentified "green algae" were noted on outcrops at deep (150 to 160m) shelf-edge stations where light levels should be quite low. However, small amounts of crustose red algae and a green algal film have been noted at even greater depths (167 to 174m) on rocks collected off Discovery Bay, Jamaica (Lang, 1974).

Salinity and Dissolved Oxygen

Near-bottom salinities were consistently oceanic at all stations (Table 8-2) and are therefore not likely to be important controlling variables for live bottom biota within the depth range examined.

As expected in a generally oligotrophic shelf environment with no major riverine particulate inputs, dissolved oxygen levels (Section 4.0) were generally high. Slightly lower values (4 to 5 ml/l) of near-bottom dissolved oxygen, indicative of deeper water from below the salinity maximum, were observed at the deep, outer shelf stations, but these values are still near saturation for the temperatures and salinities involved (Riley and Chester, 1971). Dissolved oxygen levels are therefore not likely to exert a major influence on epibiotal assemblages present.

Particulate Organic Matter Inputs

Live bottom assemblages comprise both autotrophic and heterotrophic elements. A major feature of several characteristic organisms, including hard corals (Goreau and Goreau, 1959), gorgonians (Lasker, 1981), sponges (Wilkinson, 1983), and ascidians (Sybesma et al., 1981), is that many harbor symbiotic algae within their tissues so that both heterotrophic and autotrophic nutrition are possible within the same organism. The relative importance of these nutritional modes varies with the organism (Porter, 1976) and with ambient conditions (Reed, 1983). In hard corals and gorgonians, heterotrophic nutrition involves capture of small prey items such as crustacean zooplankton. However, non-living particulate organic matter (POM) is likely to represent a significant primary or supplemental food source for suspension-feeding epibiota such as sponges and ascidians, and deposited organic material can also serve as primary food for the abundance of associated motile invertebrates such as deposit-feeding crustaceans.

There are several potential sources of POM for live bottom epibiota, including: 1) autochthonous production of benthic algae; 2) phytoplankton/detritus from the water column; 3) terrigenous material from river runoff; and 4) resuspended bottom sediment (actually a secondary source, because this material must originate from one of the first three sources). The relative importance of these sources of POM should vary with depth and location. There is little evidence for any significant terrigenous POM inputs within the study area; sediments are almost entirely biogenic $CaCO_3$, and hydrocarbon analyses (see Section 5.4) indicate that most of this organic matter is of marine biogenic origin, with some fine outer shelf terrigenous material probably being derived from the Mississippi River. Phytoplankton production is presumed to be low, except when the Loop Current generates upwelling of nutrient-rich water onto the shelf (see Section 4.0; also Woodward-Clyde Consultants and Skidaway Institute of Oceanography, 1983). Excluding for the moment these nutrient enrichment effects, POM deposition rates from phytoplankton production can be expected to decrease with increasing depth due to mineralization of organic matter as it settles through the water column (Hargrave, 1980). However, the greatly enhanced primary production associated with upwelling or intrusions is likely to produce pulses of POM deposition to the benthos that should far exceed ambient POM deposition rates, resulting in an enrichment of the outer and middle shelf (Hanson et al., 1981). In the present study, elevated chlorophyll _a_ levels, probably reflecting nutrient enrichment, were noted in the water column (subsurface maxima within the photic zone) on the outer shelf and near the bottom at middle shelf stations (Section 4.0). Reed (1981, 1983) has attributed enhanced _Oculina_ growth and higher diversity of associated biota at a shelf-edge _Oculina_ reef off the east coast of Florida to shelf-edge upwelling of nutrient-rich water, though a mechanism for these effects (enhanced primary production and higher POM deposition?) has not been established (the shelf-edge _Oculina_ do not contain zooxanthellae). Reed (1983) also noted a predominance of deposit-feeding pagurids among the crustaceans present at the deep reef (80m) in contrast to the higher proportion of suspension feeders noted at the shallower reefs (6m).

Sheppard (1982), in a discussion of environmental factors affecting coral populations on reef slopes, discounted the importance of POM as a major influence on zonation--partly because distinct trends in POM levels or rates of POM input are not evident within particular reef environments. However, when the shelf as a whole is considered, significant differences in POM input are likely, and these should be a significant influence on the productivity and composition of benthic assemblages on the shelf. Deposition of phytoplankton production and resuspension of bottom sediments (including in situ benthic microalgal production) are likely to be the major POM inputs to the benthos, and Loop Current intrusions are likely to provide the largest pulses of POM deposition. The relative importance of various POM sources and the magnitude of POM deposition in relation to benthic respiratory demand could be assessed in future work using sediment traps and in situ respirometry.

Inorganic Nutrient Levels

Levels of inorganic nutrients, including nitrate, nitrite, phosphate, and silicates, could directly and/or indirectly influence the characteristics of live bottom assemblages. Direct effects could be mediated by benthic macroalgae, which are major structural and trophic components of the biota associated with hard substrates. Possible indirect effects on POM deposition due to enhanced phytoplankton production in the water column have been mentioned above.

Nitrogenous nutrients (particularly nitrates) are considered the most likely major limiting nutrients for benthic macroalgal production in marine systems and are probably limiting to water column primary production in the absence of Loop Current-induced nutrient enrichment in the study area (see Section 4.0). Silicates can be limiting to diatoms (Parsons et al., 1977).

A clear pattern of nutrient levels on the shelf emerges from the water column data, at least for nitrates and phosphates; no major trends in silicates are evident (see Section 4.0). Most of the shelf benthic environment is exposed to consistently low nitrate and phosphate levels, but the near-bottom environment of the outer shelf is exposed to much higher nitrate and phosphate concentrations characteristic of deeper Loop Current water. Two related processes bring nutrient-rich water onto the outer shelf. First, passage of the Loop Current along the shelf edge presumably generates geostrophic upwelling of cold, deep water onto the shelf (see Section 4.0). Second, the formation of Loop Current filaments generates upwelling of deep, nutrient-rich Loop Current water within a cold core of Continental Edge Water (Woodward-Clyde Consultants and Skidaway Institute of Oceanography, 1983). Of the two processes, the former is probably relatively common, whereas the formation of frontal eddies is assumed to be relatively infrequent and episodic. These processes would be of little consequence if the penetration of the nutrient-rich layer were restricted to depths beyond the lower light limits of benthic algae. On the outer shelf, nutrient enrichment is apparently responsible for the observed subsurface chlorophyll maxima in the water column (e.g., Transect C, Winter and Spring Cruises). In the benthic environment, as shown in Figure 8-48, the nutrient-enrichment effect extends inshore to about 55m depths, where several middle shelf stations (e.g., 11, 23, 29, and 30) exhibited order-of-magnitude higher near-bottom nutrient levels than shallower stations. It is within the 60 to 80m depth range, which is within the photic zone and within the range of the nutrient-rich bottom layer, that the coralline algal nodule (or pavement) substrate predominates, other crustose red algae are abundant, and (at southern stations) the leafy green alga Anadyomene menziesii occurs at high densities. Nitrate levels were higher on the average at the southern (23, 29, and 30) than northern (10 and 11) stations within this depth range (as reflected in the usefulness of NITRATE + NITRITE as a discriminator between these station groups in the triangle dredge discriminant analysis), but there was no consistent relationship between average nitrate levels and the abundance of Anadyomene. Although a variety of factors, including light, substrate, currents and sediment movement, competition with other algae, and grazing are likely to affect the shoreward extent of this algal-dominated zone and the abundance of particular algae within it, the sharp shoreward reduction in average nitrate and phosphate levels at 50 to 60m depths could be a contributing factor. Various crustose coralline algae, including species of Lithothamnium and Lithophyllum that are apparently responsible for the formation of algal nodules in the area, frequently occur at a range of depths in tropical Caribbean reefs (Bak, 1976; Adey, 1978), which are generally exposed to low inorganic nutrient levels. Grazing effects and competition with fleshy and/or filamentous algae, which overgrow the prostrate crustose forms, are cited as important factors determining the relative abundance of these crustose algae along depth

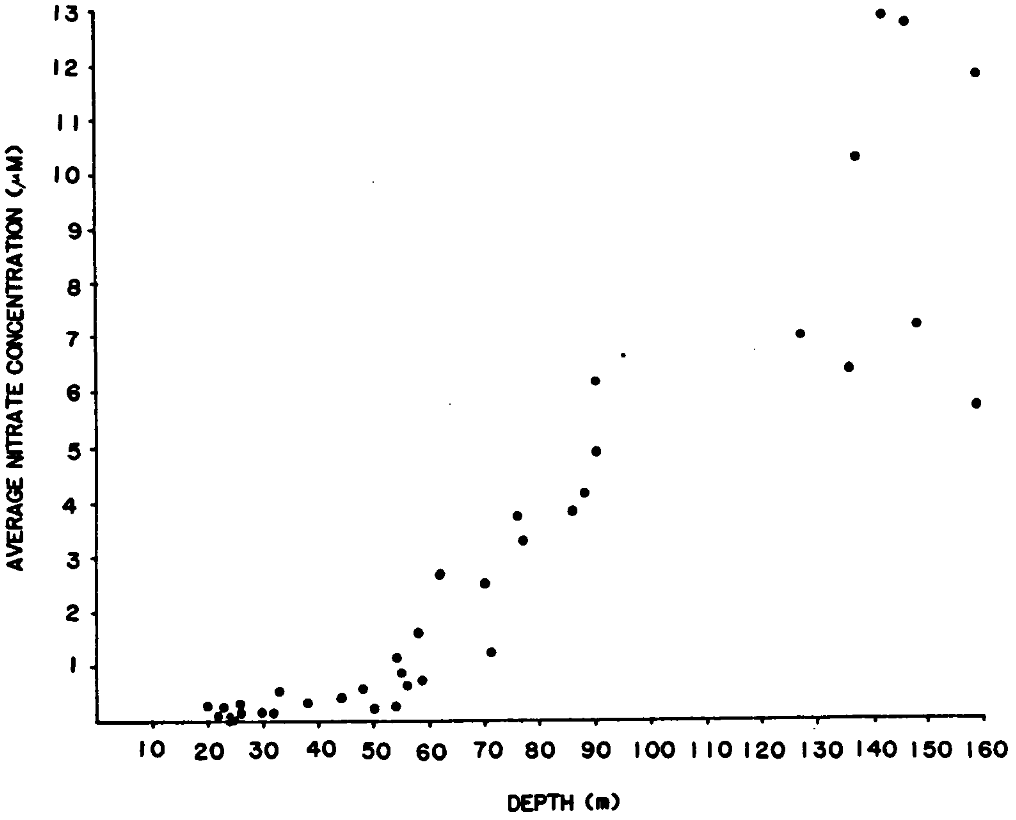


Figure 8-48. Relationship between station depth and average near-bottom nitrate levels for live and soft bottom stations.

gradients (Connor and Adey, 1977). There are no distinct seasonal trends in nutrient levels at inner shelf stations, suggesting that nutrient levels are not a major influence on algal seasonality on the inner shelf. However, light, temperature, and inorganic nutrient levels can interactively affect the production and biochemical composition of benthic macroalgae (Lapointe and Tenore, 1981; Rosenberg and Ramus, 1982). The potential importance of nutrient levels as factors influencing the shelfwide zonation pattern of particularly abundant algae could be investigated by factorial laboratory and in situ experimentation.

Substratum, Sedimentation, and Sediment Movement

Live bottom assemblages occur on emergent or thinly covered hard substrates or on biogenic surface rubble layers. The distribution and characteristics of available substratum on the shelf influences the distribution and characteristics of live bottom assemblages that have developed there. In addition, substrate characteristics determine the mobility of sediment in response to normal currents and storm-related bottom disturbance; sediment mobility can have differential effects on the settlement, growth, and survival of epibiota.

The southwest Florida shelf consists of a broad carbonate platform overlain by varying thicknesses of late Tertiary-Quaternary sediments (Holmes, 1981). Shallow nearshore sediments are quartz sands (Gould and Stewart, 1955), which give way to calcareous sands within the present study area. The distribution of emergent and thinly-covered hard bottom is patchy and reflects in part the position of previous shorelines and ancient shallow reefs (Neurauter, 1979; Holmes, 1981). On the inner shelf (<40m depths), the veneer of overlying sands is relatively thin and patch reefs, outcrops, and thinly-covered hard bottom are relatively common (the latter being by far the most common). Beyond about 40m depths, the wedge of unconsolidated sediments increases in thickness due in part to the impounding effect of a shallow, buried mid shelf "reef complex" at about 70 to 90m depths that was probably formed about 10,000 yr BP during a hiatus in sea level rise (Holmes, 1981). The surface expression of this ridge is most pronounced on the southernmost transect (Transect E), where Station 29 (which supports the *Agaricia* coral plate assemblage) is located on a distinct topographic elevation. The progressive increase in the proportion of "sand" substrate (vs. "thin sand over hard bottom") on Transects C, D, and E reflects a greater thickness and greater inshore penetration of the wedge of unconsolidated sediments in the southern part of the study area and a corresponding lack of live bottom (especially on Transect E). The increased thickness of the sand veneer at mid shelf depths is also reflected in a relative lack of live bottom there; all four of the stations in 50 to 60m depths were located in very small patches, and live bottom assemblages at 60 to 80m depths are associated with coralline algal nodules (or pavement) over a thick sand base. At greater depths, shell rubble provides a substrate for some live bottom epibiota such as stalked crinoids (e.g., at Station 38). The major high-relief emergent hard bottom consists of a series of shelf-edge pinnacles that are probably drowned remnants of ancient calcareous algal reefs (Holmes, 1981). In addition to the emergent hard bottom, the shelf is characterized by several different types of bedforms (e.g., sand waves) that are indicative of different levels and frequencies of disturbance by storms (Neurauter, 1979).

Sessile epibiota require a firm substrate for attachment. In the case of many corals and sponges, this means emergent hard bottom; for some epibiota (e.g., the crinoids at outer shelf stations), surface rubble or debris may suffice. In tropical coral reef systems, bare sand patches can limit the lower depth extent of corals even where other conditions are favorable (Van Den Hoek et al., 1978). The need for a stable sediment-free surface is probably most critical for larvae, and this may prevent the establishment of live bottom biota on sand-covered hard substrates. In rocky intertidal and shallow subtidal environments, the rate at which available substratum is provided by physical or biological disturbance can exert a profound influence on the composition of epibiotal communities. In the benthic environment of the southwest Florida shelf, most epibiota occur on hard substratum that is covered by a thin veneer of sand. Bare substratum must occasionally be generated (e.g., by shifting sediments), and the frequency and duration of periods of exposure of bare patches should be critical variables in determining rates of colonization by sessile epibiota.

In addition to the requirement for a stable emergent substratum, corals exhibit different degrees of tolerance to ambient sedimentation and sediment movement (Hubbard and Pocock, 1972). Sediment particles can be cleared from coral surfaces by a variety of passive mechanisms and active processes, and the distribution of different species in the field often reflects in part the effects of differential sediment clearance abilities (Hubbard and Pocock, 1972; Fisk, 1981). Species such as *Oculina diffusa*, *Isophyllia sinuosa*, and *Manicina areolata*, for example, which were common at several inner shelf stations, are competent at removing a wide range of sediment particle sizes, whereas the plate-like *Agaricia* sp. is generally inefficient at moving coarse sediments and is typically found in sheltered habitats where sedimentation of coarse particles is low (Hubbard and Pocock, 1972). Aside from the high-relief hard bottom located near the shelf edge (too deep to support hermatypic corals), the algal crust which has developed in the southwest portion of the study area (60 to 80m depths) provides the best emergent substratum for development of extensive hermatypic coral growths. As discussed below, the occurrence of the algal crust in the area is itself suggestive of an environment that is not exposed to frequent bottom disturbance, and this is an additional favorable condition for *Agaricia* development.

The shallow (<40m depths) inner and middle shelves are probably subject to more periodic bottom disturbance than the outer shelf, and this represents a stress to the live bottom organisms colonizing available substratum. As discussed above, transmissivity and chlorophyll *a* data suggest resuspension events are more likely to be observed at shallow than deep stations, as one might expect given the decline with depth of boundary shear stress exerted by surface waves (Sternberg and Larsen, 1975). In addition, Neurauter (1979) has discussed the roles of different types of disturbance events in the formation of bedforms on the west Florida shelf. Giant to large-scale bedforms in <20m depths are probably generated by major storms other than hurricanes, while those in depths of 20 to about 80m are apparently generated by the passage of hurricanes; the outer shelf exhibits a relatively flat contour with occasional large-scale bedforms that may reflect strong currents (direct impingement of the Loop Current?) or remnants of wave-cut terraces cut during periodic hiatuses in sea level rise (Neurauter, 1979; Holmes, 1981). Additional evidence for the potential effects of direct Loop Current impingement was provided by

Carder and Haddad (1979), who observed dramatic reduction in near-bottom transmissivity on the outer shelf. Both Bullock and Smith (1979) and Woodley et al. (1981) have described significant effects of major disturbances due to storms on shallow hard ground communities or reefs. These effects can include burial by sediment and direct damage to epibiota, and the extent of damage depends on depth and the morphology of the organisms (Woodley et al., 1981).

Periodic disturbance by wave-induced currents may facilitate the development of some assemblages. Although encrusting coralline algae can grow in a wide bathymetric range of habitats, formation of algal nodules is apparently associated with moderate depths. For example, nodules are found at depths of about 45 to 70m on the East and West Flower Garden Banks (Hogg, 1975) and at similar depth ranges on other banks in the northern Gulf of Mexico (Rezak and Bright, 1983). Although algal clumps can grow on bits of shell debris or other nuclei, periodic rolling of the growths is necessary for the formation of spheroid or ovoid shapes (Bosellini and Ginsburg, 1971). At the lower end of the depth range of the coralline algae, the reduced ability of surface wave-induced currents to periodically move the growths tends to result in discoidal or amoeboid growths, or even flattened algal crusts or pavements such as those noted in the southwest corner of our study area. McMaster and Conover (1966) have noted that the maximum orbital velocities produced by surface waves are generally not high enough to move nodules at these depths. Bosellini and Ginsburg (1971) suggest two likely mechanisms for the rolling of the nodules: 1) storm waves; and 2) sediment movement per se (i.e., sand waves). Nodules in our study area and at the East and West Flower Garden Banks (Hogg, 1975) are frequently noted at the troughs of sand waves; Bosellini and Ginsburg (1971) suggest that movement of these sand waves provides a mechanism for rolling incipient nodules. In either case, there is likely to be a "window" of disturbance level that can produce nodular growth--too little movement and a crust or pavement forms; too much movement and the nodules could be buried or washed away. The depths of stations at which the algal pavement is present (Stations 29 and 30) are comparable to those of other stations where only nodules are present (Stations 10, 11, and 23). The difference partly reflects a north-south trend of overall increasing nodule/algal density in the 60 to 80m depth range (cause unknown), but may also indicate lower frequencies of wave-induced bottom disturbance at the southernmost stations in this depth range.

Biotic Variables

In addition to different tolerance ranges to physical environmental variables exhibited by different organisms, biological capabilities and biotic interactions could play important roles in determining the shelfwide distribution of live bottom epibiota. Important biological considerations include: 1) dispersal and colonization abilities; 2) trophic and/or habitat associations; 3) competition; and 4) predation. Because the biota of the southwest Florida shelf is relatively unstudied (aside from taxonomy), the importance of specific processes and interactions in determining observed spatial and temporal patterns is largely speculative at this time.

Dispersal and colonization abilities have been cited as important factors influencing the makeup of epibiotal communities, particularly those that are subject to periodic disturbance that results in the provision of unoccupied space (Dayton, 1971; Jackson, 1977; Peckol and Searles, 1983). In live bottom habitats, one may expect periodic sediment movement to result in burial of some organisms and exposure of new space for colonization. The extent to which such disturbance produces an epibiotal community of predictable composition depends on a variety of factors, including the magnitude, timing (season), and frequency of disturbance, the tolerances of different epibiota, interactions among epibiota, and the colonizing ability of different groups. Filamentous algae are frequently the first colonizers of newly exposed space on subtidal hard bottoms (Smith, 1975; Schuhmacher, 1977), followed by other algae (e.g., crustose coralline algae), bivalves, barnacles, and other solitary invertebrates (Schuhmacher, 1977) prior to the longer-term development of colonial coral, sponge, and bryozoan populations. Sediment stabilization by algal mats can facilitate colonization by corals and other organisms that are relatively sensitive to sediment movement (Fisk, 1981). Solitary attached organisms such as bivalves and barnacles are often inferior space competitors in the long term and persist by an opportunistic strategy that makes rapid use of newly exposed space (Jackson, 1977).

In the present study, the only major indication of disturbance was a bloom of unidentified blue-green algae which formed a filmy covering on emergent hard bottom at Station 13 (20m depth) on the Summer Cruise. No mass mortalities were evident, however, so it is not clear whether the bloom was a product of disturbance similar to that produced by a 1971 red tide bloom that affected shallow patch reefs off Tampa (Smith, 1975). Several authors have cited coralline algae as good colonists or pioneering species that persist in the long term only in the absence of intense grazing--although some grazing can apparently be beneficial by resulting in selective removal of competing fleshy and filamentous algae (Adey, 1978; Van Den Hoek et al., 1978). The predominance of sponges as major contributors to total epibiotal cover at most stations, however, suggests a lack of severe or frequent disturbance, because sponges are not early colonists but generally prevail over other colonial forms in the long term (Jackson and Winston, 1982).

Because live bottom is patchily distributed on the shelf, the species richness of assemblages at particular locations should reflect in part the effects of patch size. Live bottom patches may be regarded as habitat "islands" in a "sea" of thick sand, and the size of these islands determines the probabilities of colonization and extinction of particular species (MacArthur and Wilson, 1967; Smith, 1979). Unfortunately, no measure of total patch size was available for sampling stations, and there are no clear relationships between species richness and either the percent live bottom across stations or the linear extent of live bottom patches along survey transects (data not shown). However, even mid shelf stations of apparently small size (e.g., Stations 9, 17, and 27) were not depauperate in species richness. It would be of interest to compare species richness for locations of known patch size within a particular depth range. However, a consistent relationship might not be expected because there is no single large pool of potential colonists for hard bottom habitat islands, a major limitation in the application of the theory of island biogeography to these areas.

The abundance and diversity of major structural elements of live bottom assemblages such as macroalgae, sponges, and corals should influence the abundance and diversity of associated mobile fauna by providing a variety of habitat space and food sources. Many invertebrate species collected in dredge samples (e.g., the ubiquitous ophiuroid Ophiothrix angulata; alpheid shrimps, etc.) are ectocommensal on or closely associated with sponges, which generally harbor a variety of invertebrates (Westinga and Hoetjes, 1981). There is, however, no consistent relationship between average biotic cover or average sponge cover and the species richness of crustaceans, molluscs, or ophiuroids (data not shown). The search for such trends and relationships in the data is confounded by the wide range of depths encompassed (i.e., few stations at a given depth) and the problem of sampling adequacy (individual seasonal samples cannot be considered adequate in assessing total taxonomic richness).

It is often presumed that the distribution of sessile epibiota reflects in part the outcome of previous competitive interactions, even though proof can be elusive (Bradbury and Young, 1983). The predominance of colonial forms among hard bottom biota is attributed to their superior competitive abilities (Jackson, 1977). Perennial algae possess a similar advantage in preempting space (Peckol and Searles, 1983). Sponges are generally good competitors for space and tend to dominate many surfaces in the long term in the absence of disturbance (Jackson and Winston, 1982). In competitive ("aggressive") interactions with corals, sponges tend to perform better with increasing depth (Suchanek et al., 1983). Although sensitivity of some sponges to UV radiation may restrict them from shallow habitats in some instances (Wilkinson, 1981), the explanation for the general predominance of sponges in greater depths and corals in shallower depths remains unexplained (Lang et al., 1975; Wilkinson, 1983). Within the present study area, sponges and/or algae dominate cover at most live bottom stations (Figures 8-49 and 8-50); the lack of extensive coral cover is more likely a result of poor tolerance of hermatypic corals to sedimentation and sediment movement than to competitive interactions. The trends shown in these figures do not necessarily reflect competitive interactions for available space between sponges and algae; they may instead reflect different abilities to use different types of available substrate. Although algae constituted seasonal (e.g., summer) cover dominants at several inner shelf (<40m depth) stations, their dominance was usually associated with an increase in absolute cover--i.e., they were able to colonize space not previously occupied by other biota (debris, rubble, thicker sand veneer?). The transition from

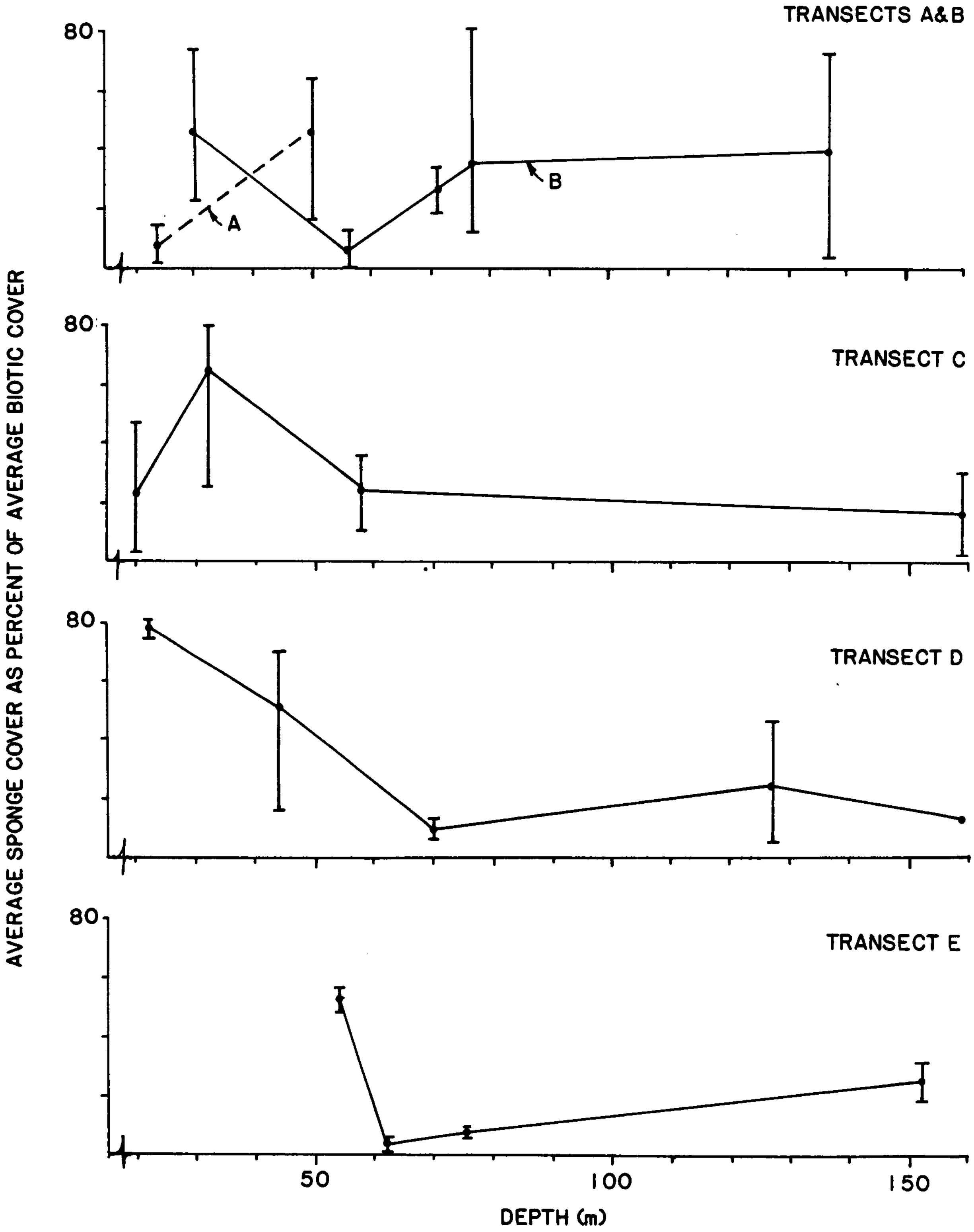


Figure 8-49. Contributions of sponge cover to total biotic cover at live bottom stations along study Transects A through E.

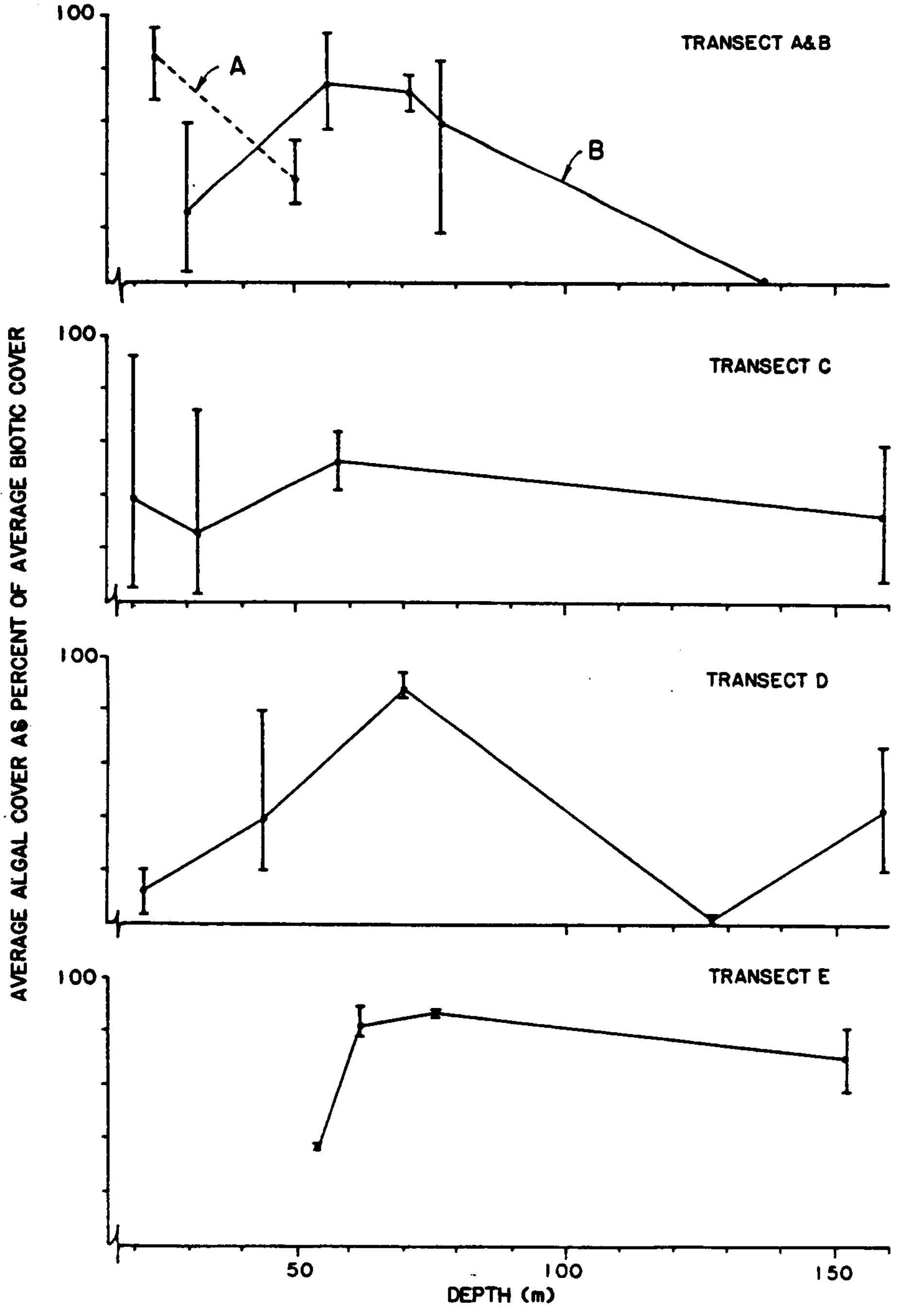


Figure 8-50. Contribution of algal cover to total biotic cover at live bottom stations along study Transects A through E.

sponge to algal dominance exhibited at mid shelf stations (50 to 80m depths) (Figures 8-49 and 8-50) reflects in part a thickening of the sand veneer; coralline algal nodules and rubble (or an algal pavement at Stations 29 and 30) apparently serve as better substrates for perennial algal growth than for sponges. At deeper outer shelf stations (e.g., Station 38), crinoids (and small sponges) can dominate by utilizing a surface layer of shell rubble. Hypotheses concerning the role of space competition in determining the areal composition of epibiotal communities generally assume that space is equally available or usable by potential competitors. On the southwest Florida shelf, hard bottom habitat varies in quality (emergent hard bottom; hard bottom covered with varying thicknesses of sand; algal rubble; shell rubble; algal pavement, etc.) and this should probably be considered as a determinant of epibiotal relative abundance patterns before competition is invoked as an explanation.

Grazing/predation is another factor that is of potential importance in regulating the composition and dynamics of epibiotal assemblages (Paine, 1966; Paine and Vadas, 1969; Carpenter, 1981). The most dramatic effects of intense grazing are those resulting from episodic population outbreaks of coral-eating starfish (Acanthaster planci) on some tropical reefs (Pearson, 1981). With the exception of such major episodic disturbances, the most important grazers are frequently echinoids such as the long-spined tropical urchin Diadema antillarum, which can be a major controlling influence on reef structure in some Caribbean reefal environments (Sammarco, 1980; Carpenter, 1981) and is the major echinoid grazer at the Florida Middle Ground (Hopkins et al., 1977). Grazing by Diadema and by fishes can prevent dominance by crustose coralline algae or facilitate their success by removing competitors (Connor and Adey, 1977; Wanders, 1977). The predominance of coralline algae at the deep fringes of some Caribbean reefs has been attributed to either a decline in grazer abundance or a dietary switch by Diadema to living coral tissue at depth (Bak and Van Eys, 1975). Within the present study area, Diadema antillarum was captured only in the southwestern portion of the area at Stations 15, 23, and 29; it was only captured in one sample each at Stations 15 and 23. Both leafy and prostrate crustose algae are abundant at Stations 23 and 29, and these may serve as food sources for Diadema; however, its effect on the algal and coral community there is unknown. A variety of other primarily herbivorous echinoids occur at other live bottom stations. Common species include Arbacia punctulata, Stylocidaris affinis, Lytechinus variegatus carolinus, Genocidaris maculata, Eucidaris tribuloides tribuloides, and Clypeaster subdepressus. Several of these urchins also consume encrusting epibiota such as sponges and bryozoans (Serafy, 1979) and could have significant effects on the composition of epibiotal assemblages.

8.2.2 Soft Bottom Communities

Shelfwide distribution and zonation patterns of soft bottom biota have been discussed in Section 7.4. The following discussion briefly reviews shelfwide patterns and then attempts to relate them to environmental variables.

8.2.2.1 Summary of Shelfwide Distribution Patterns

Infauna: Box Core Data -- Figure 8-51 shows the groupings of stations from normal cluster analysis of infaunal data from box core sampling. Two major station clusters were evident: a group of deep (90 to 150m) offshore stations and a second group of nearshore and intermediate stations. Subclustering by depth was evident within the offshore group. Within the other major cluster, stations were also grouped primarily into depth ranges, but the shallow (23m) Station 20 grouped with intermediate depth (50 to 60m) stations. Stations 25 and 26, which were located in an area of fine (silt-sized) carbonate sediments, were somewhat unique in composition but clustered more closely with the nearshore (20 to 30m) stations than with those in intermediate depths.

Examination of data concerning faunal densities and indices of community structure for the infauna provided additional information concerning shelfwide patterns. The deep, offshore stations generally exhibited low faunal densities and low to moderate diversity (Shannon-Weaver H') and equitability (Pielou's J') values; Station 37 was unusual in exhibiting extremely high density during one sampling period and in having very low diversity and equitability. A group of mid and inner shelf stations (4, 16, 20, 22, and 28) exhibited high diver-

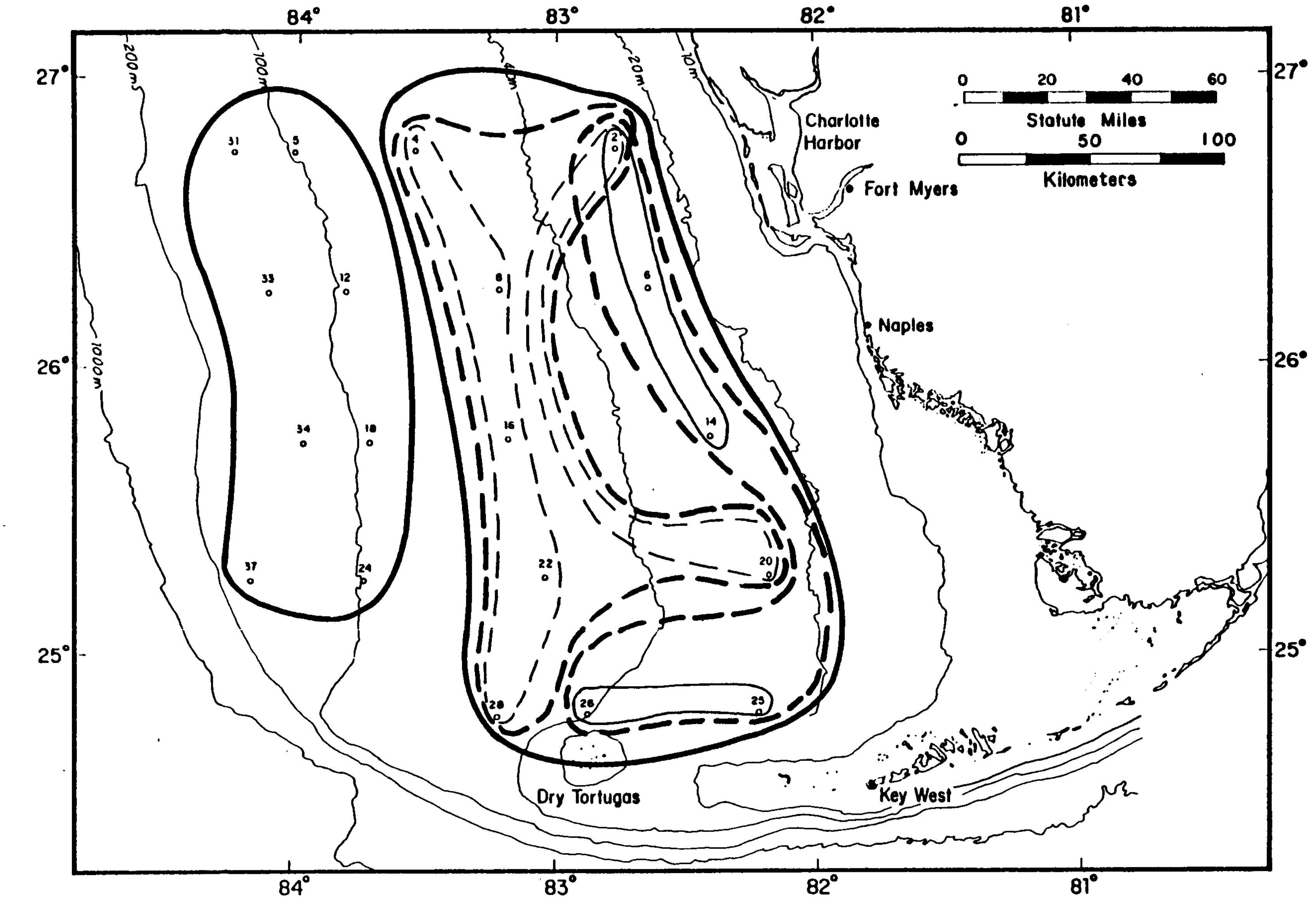


Figure 8-51. Station groupings based on cluster analysis of box core infaunal data, all cruises combined.

sity values, and three of these (4, 16, and 20) had very high equitability. Stations 25 and 26 exhibited low species richness and low diversity.

Epibiota: Otter Trawl Data -- Figure 8-52 shows groupings of stations from normal cluster analysis of data from otter trawl sampling. Three major station/season groupings were evident. The first consisted of the deep Stations 31, 33, 34, and 37 and Summer Cruise samples from Stations 5, 12, and 24; the second, most or all seasonal cruise samples at the mid shelf Stations 4, 5, 8, 12, 16, 18, 22, 24, and 28; and the third, the shallow, nearshore Stations 2, 6, 14, 20, and 25 with the addition of the somewhat deeper Station 26 and the Fall Cruise sample for Station 4. Bathymetric zonation was evident within the the mid shelf cluster; within the nearshore group, Stations 25 and 26 grouped closely, as they did in the cluster analysis of box core data.

8.2.2.2 Relationships between Soft Bottom Assemblages and Environmental Variables

Variations in the abundances and community composition of infauna and epibiota associated with soft bottom habitats on the shelf presumably reflect the influences of a suite of environmental variables that can affect larval settlement, survival, growth, and reproduction of soft bottom biota. Organism-environment relationships were investigated in our study by both principal coördinates analysis and weighted discriminant analysis. Although the approaches of these two techniques are different, they provide similar results concerning possible controlling environmental variables; to be consistent with live bottom data interpretation, only the weighted discriminant analysis results are presented here, followed by a more general discussion of environment-organism relationships.

8.2.2.2.1 Weighted Discriminant Analysis

The purpose of using weighted discriminant analysis was to determine which environmental variables could best discriminate the station groupings derived from normal cluster analysis of box core infaunal and otter trawl data. Specifics of methodology are provided in Section 3.0.

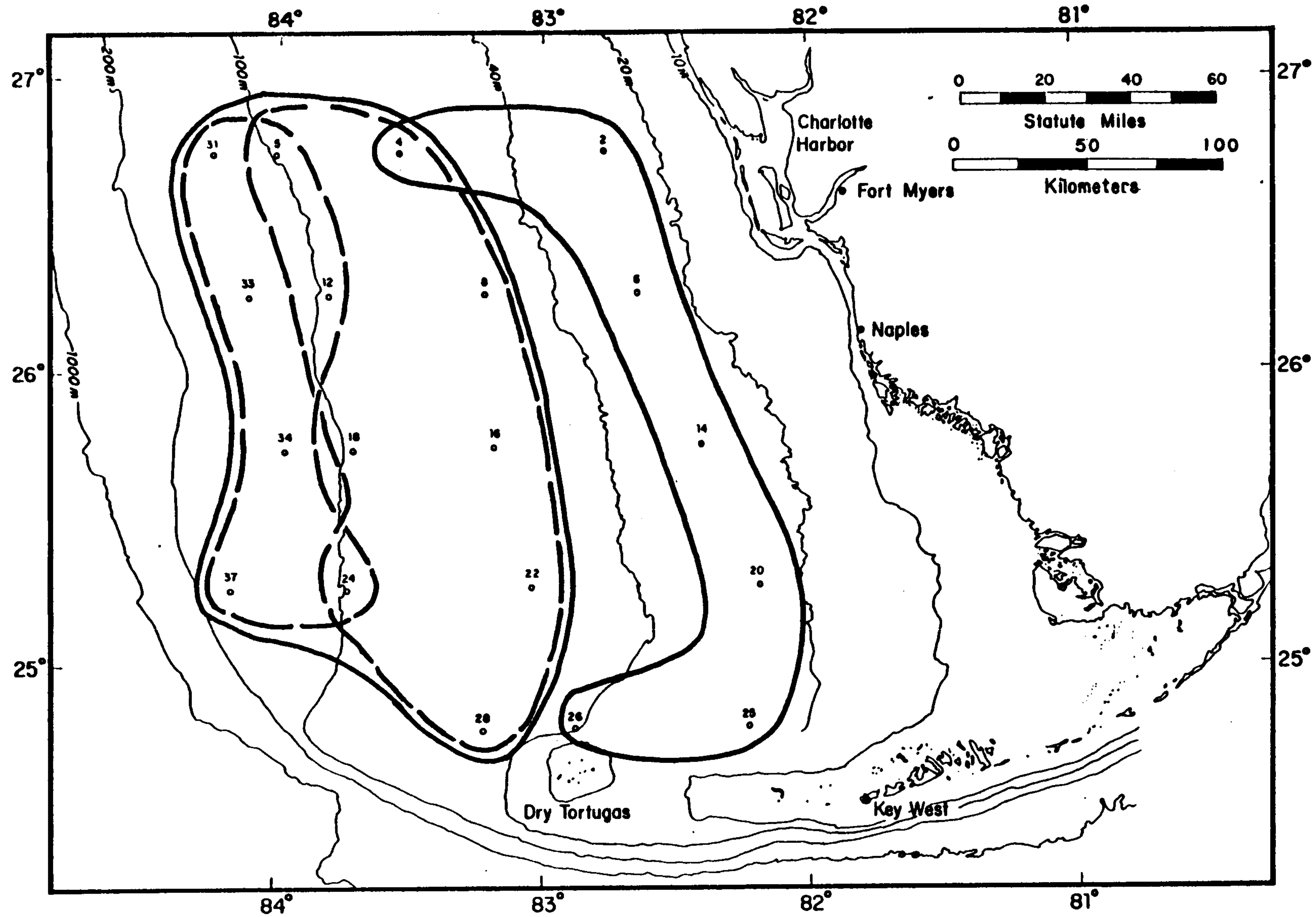


Figure 8-52. Simplified station groupings based on cluster analysis of soft bottom otter trawl data, all cruises combined.

A larger number of environmental variables were available for use in this analysis than for the comparable live bottom analysis, because: 1) sediment grain size parameters were determined at all soft bottom stations, and 2) the deletion of water column sampling at some stations on the Year Two cruises affected mostly the live bottom station data sets. Nevertheless, some variables had to be deleted from consideration (or missing values estimated). Following this process of environmental data selection and missing value estimation, the dimensionality of the data set was reduced by conducting principal components analysis (PCA).

Environmental Data Selection and Estimation of Missing Values

Environmental variables initially considered for inclusion in the analysis encompassed a wide range of sedimentary and hydrographic parameters. The "first cut" was to restrict consideration of water-column variables to the near-bottom values. Several parameters (e.g., chlorophyll a values--fluorometric and acidification methods; Hydrolab dissolved O_2 and temperature values; sediment percent carbonate values) had to be deleted because of too many missing values; for other variables, the EAP estimation program (see Section 3.4.3.2) could be used to estimate the few missing values. Other parameters had to be deleted because of high correlations with other variables--e.g., median sediment grain size (correlated with mean grain size); percent silt-clay in sediments (correlated with percentages in silt-clay size fractions). The list of variables available following these initial deletions is shown in Table 8-6.

Principal Components Analysis

PCA was used to reduce the dimensionality of the data set, which was necessary for both the analysis and interpretation of the data. This analysis projects the multivariate data (e.g., 18 grain size parameters for each sediment sample) into multidimensional space and constructs fewer, new axes in that space so as to summarize the original information by fewer variables. The multidimensional coordinates of each point are then replaced by its scores on each of the PC axes. Separate PCAs were conducted using two variable subsets: the grain siz variables and the nutrient variables.

Table 8-6. Environmental variables considered for inclusion in the weighted discriminant analysis of data from soft bottom stations, prior to reduction of the data set by principal components analysis.

Variable	Explanation
DEPTH	Station depth (m)
TEMPERATURE	Near-bottom temperature (°C)
SALINITY	Near-bottom salinity (°/₀₀)
DISSOLVED OXYGEN	Near-bottom DO values (ml/l)
TRANSMISSIVITY	Near-bottom transmittance (%)
NITRATE	Near-bottom nutrient value (μM)
NITRITE	Near-bottom nutrient value (μM)
PHOSPHATE	Near-bottom nutrient value (μM)
SILICATE	Near-bottom nutrient value (μM)
CHLOROPHYLL	Near-bottom chlorophyll _a_, trichromatic method
GSAM	Mean sediment grain size
GSAKG	Sediment graphic kurtosis
GSASR	Sediment graphic standard deviation
GSASK	Sediment graphic skewness
GSA01-GSA14	Sediment grain size categories

PCA: Sediment Variables -- Results of the PCA for sediment grain size variables allowed a reduction of the data set from 18 variables to 5. Those variables included 14 individual grain size classes, plus mean grain size, and measures of sorting, skewness, and kurtosis. The results are not presented here but are summarized as follows. The first PCA axis explained 48.79% of the total variance in the grain size variables. The factor matrix indicated that mean grain size (GSAM) and graphic kurtosis (GSAKG) were all quite strong on Axis I, as well as most of the grain size categories, with the finer categories (GSA07-GSA14) opposing the negatively-signed coarser categories (GSA01-GSA06), on Axis I. This pattern indicates that Axis I is most strongly related to absolute grain size; the Axis I scores entered the weighted discriminant analysis as a new variable labeled "SEDIMENT SIZE FACTOR."

Axis II explained 20.67% of the total variance, and was characterized by the fine sand grain size categories (GSA06-GSA08) weighting strongly in the positive direction, with all other grain size categories on the positive side of the axis, coarser sediments weighting most strongly. The variable defined by the scores for Axis II was labeled "FINE SAND FACTOR."

Axis III explained another 7.75% of the total variance. This axis was labeled "STANDARD DEVIATION (SD) FACTOR" as the coarse graphic standard deviation (GSASR) completely dominated.

Axis IV explained 5.46%, and was equally dominated by the graphic kurtosis (GSAKG) and the most coarse grain size category, GSA01 (corresponding to gravel). The axis was labeled "GRAVEL/SD/KURTOSIS FACTOR."

Finally, Axis V (5.11%) was labeled "SKEWNESS FACTOR" as GSASK completely dominated the axis. At this point, 87.77% of the total variance had been explained by the first five principal components, and Axis V was chosen as the cutoff point.

PCA: Nutrients -- The PCA for nutrient variables was much simpler. Nitrate and phosphate were quite strong on Axis I (66.6% of total variance); Axis I was labeled "NITRATE/PHOSPHATE FACTOR." Axis II (32.63%) was completely dominated by nitrite; hence Axis II was labeled "NITRITE FACTOR."

In summary, all grain size variables were represented in the weighted discriminant analysis by the first five principal components, labeled "SEDIMENT SIZE FACTOR," "FINE SAND FACTOR," "SEDIMENT SD FACTOR," "GRAVEL/SD/KURTOSIS FACTOR," and "SKEWNESS FACTOR." The nutrient variables were represented by the first two principal components, labeled "NITRATE/PHOSPHATE FACTOR" and "NITRITE FACTOR". Table 8-7 summarizes the environmental variables available for the weighted discriminant analyses following those reductions in the data set.

Weighted Discriminant Analysis of Box Core Data

Station groupings for the weighted discriminant analysis were selected from the "all cruises" cluster analysis results. The results for the four seasonal cruises clustered closely for most stations; only Station 2 exhibited high enough between-cruise variability to be categorized into two different groups (Figure 8-53).

Results of the weighted discriminant analysis of the box core data are summarized in Table 8-8. Axis I explains 69.7% of the variance in discriminant space; DEPTH and the SEDIMENT SIZE FACTOR weighted highly on this axis as indicated by the coefficients of separate determination. Axis II explains an additional 22.0% of the variance and is most strongly related to the SEDIMENT SIZE FACTOR and DEPTH. Axis III explains a much smaller percentage (6.9%) of the variance and is apparently related to the FINE SAND FACTOR and (to a lesser extent) the SEDIMENT SD FACTOR and DEPTH. These first three axes explain 98.6% of the variance in discriminant space.

Figure 8-54 shows a plot of all stations/seasons on the first two discriminant axes and provides a key to the identity of each point for use in the subsequent discussion of the other plots; station groupings used in the analysis are shown also.

Table 8-7. Environmental variables (including PCA-derived variables) used in weighted discriminant analysis of data from soft bottom stations.

Variable	Explanation
DEPTH	Station depth (m)
TEMPERATURE	Near-bottom temperature (°C)
SALINITY	Near-bottom salinity (°/₀₀)
DISSOLVED OXYGEN	Near-bottom DO values (ml/l)
TRANSMISSIVITY	Near-bottom transmittance (%)
SILICATE	Near-bottom nutrient value (μM)
NITRATE/PHOSPHATE FACTOR	Axis I scores from nutrient PCA
NITRITE FACTOR	Axis II scores from nutrient PCA
CHLOROPHYLL	Near-bottom chlorophyll a, trichromatic method
SEDIMENT SIZE FACTOR	Axis I scores from sediment PCA
FINE SAND FACTOR	Axis II scores from sediment PCA
SEDIMENT SD FACTOR	Axis III scores from sediment PCA
GRAVEL/SD/KURTOSIS FACTOR	Axis IV scores from sediment PCA
SKEWNESS FACTOR	Axis V scores from sediment PCA

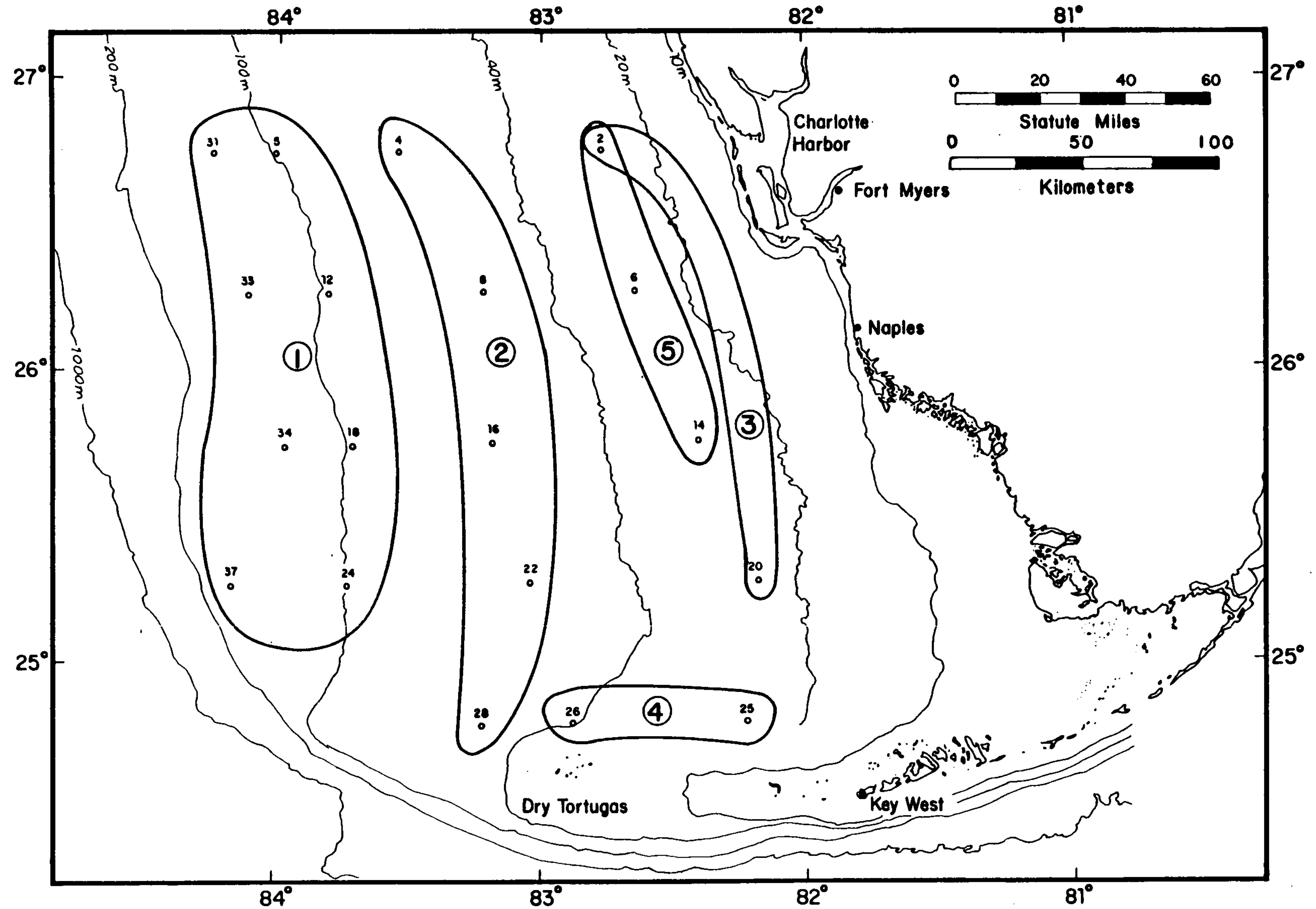
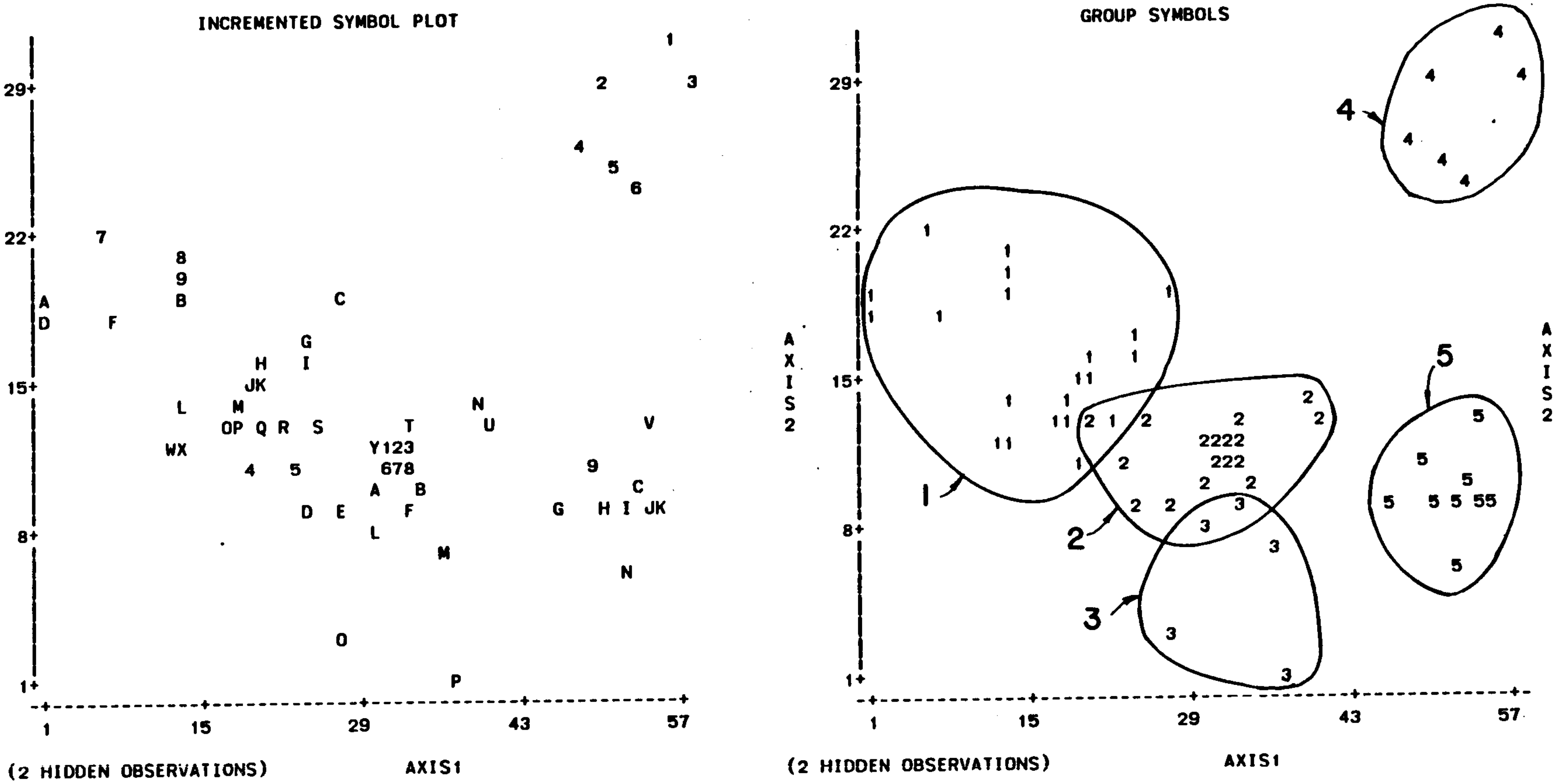


Figure 8-53. Stations groupings used for weighted discriminant analysis of box core infaunal data. The two seasonal samples at Station 2 clustered with different stations, resulting in an overlap.

Table 8-8. Results of weighted discriminant analysis of box core infaunal data from soft-bottom stations.

```
SW FLORIDA SHELF ECOSYSTEMS STUDY.
WEIGHTED DISCRIMINANT ANALYSIS:  BOX CORE SAMPLES -- SOFT BOTTOM; ALL CRUISES COMBINED.

PERCENT OF TOTAL GROUP SEPARATION EXPLAINED BY EACH AXIS

               AXIS        PCT      CUM PCT

                 1         69.7      69.7

                 2         22.0      91.7

                 3          6.9      98.6

                 4          1.4     100.0


             COEFFICIENTS OF SEPARATE DETERMINATION

                      DISCRIMINANT AXES
                                   AXIS1   AXIS2   AXIS3   AXIS4
   VARIABLE


  1. CHLOROPHYLL                     1.0     1.6     0.2     1.3

  2. DEPTH                          52.8    13.4    14.3     0.6

  3. DISSOLVED OXYGEN                1.8     5.0     0.1     3.0

  4. SILICATE                        0.7     2.6     0.9     1.0

  5. SALINITY                        2.8     0.1     0.0     4.6

  6. TEMPERATURE                     3.0     0.3     4.8     4.8

  7. TRANSMISSIVITY                  0.1     9.0     2.2     0.7

  8. SEDIMENT SIZE FACTOR           18.4    44.7     1.5     0.1

  9. FINE SAND FACTOR                8.2     4.4    46.6     6.9

 10. SEDIMENT SD FACTOR              0.7     1.6    18.4    22.4

 11. GRAVEL/SD/KURTOSIS FACTOR       0.7     7.2     2.0     4.2

 12. SKEWNESS FACTOR                 0.4     2.0     1.6     0.7

 13. NITRATE/PHOSPHATE FACTOR        9.4     7.0     6.8    43.4

 14. NITRITE FACTOR                  0.1     1.0     0.6     6.3
```



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SW FLORIDA SHELF ECOSYSTEMS STUDY.
WEIGHTED DISCRIMINANT ANALYSIS:  BOX CORE SAMPLES -- SOFT BOTTOM; ALL CRUISES COMBINED.
SYMBOL TABLE FOR INCREMENTED SYMBOL PLOT.
AXIS1 VS. AXIS2 PLOTS.

 SYM ID        SYM ID        SYM ID        SYM ID        SYM ID        SYM ID        SYM ID
  1  1 3 25     A  2 3 37     J  1 3 18     S  1 3 04     2  1 3 22     B  2 2 18     K  1 4 14
  2  1 3 26     B  2 2 31     K  1 3 24     T  2 2 22     3  1 3 26     C  2 2 06     L  2 3 20
  3  1 4 25     C  1 3 12     L  2 3 05     U  1 4 08     4  1 4 18     D  2 3 16     M  1 4 20
  4  1 4 26     D  2 2 37     M  1 3 05     V  1 3 06     5  2 2 04     E  1 4 04     N  1 4 02
  5  2 2 25     E  2 3 34     N  1 3 08     W  1 4 05     6  2 3 28     F  1 3 20     O  2 2 20
  6  2 3 25     F  2 2 34     O  2 3 24     X  2 2 05     7  2 2 28     G  2 3 06     P  1 3 02
  7  2 3 33     G  2 3 12     P  1 4 24     Y  1 3 18     8  1 4 28     H  2 2 14
  8  2 2 33     H  1 4 12     Q  2 3 04     Z  2 3 22     9  2 3 14     I  1 3 14
  9  2 3 31     I  2 2 12     R  2 2 24     1  1 4 22     A  1 4 16     J  1 4 06

NOTE:  SYM=SYMBOL; ID=YEAR-CRUISE-STATION;

       YEAR 1, CRUISE 3 = FALL CRUISE (OCTOBER 25-NOVEMBER 23, 1980); YEAR 1, CRUISE 4 = SPRING CRUISE (APRIL 22-MAY 5, 1981);
       YEAR 2, CRUISE 2 = SUMMER CRUISE (JULY 18-AUGUST 5, 1981); YEAR 2, CRUISE 3 = WINTER CRUISE (JANUARY 28-FEBRUARY 15, 1982).
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Figure 8-54. Incremented symbol plot and station group plot from weighted discriminant analysis of box core infaunal data. Plots show the positions of all stations/seasons and groups (from Figure 8-53) on the first two discriminant axes.

Figure 8-55 shows the same Axis I vs. Axis II plot with ordinal values for DEPTH replacing each corresponding point. These numbers were derived by subdividing the range of actual DEPTH values into nine equal subranges and replacing the original values with the number of the subrange (1 to 9) into which they fell. As the plot shows, Groups 1 and 2 are easily discriminated from each other and from the remaining groups on the basis of DEPTH; these groups consist of the offshore and mid shelf stations, respectively. Groups 3, 4, and 5, however, encompass similar depth ranges and those groupings cannot be "explained" by DEPTH.

Figure 8-56 shows a similar plot for ordinal values of the SEDIMENT SIZE FACTOR, which weighted highly on Axis II and somewhat less on Axis I. This factor most effectively separates Groups 3, 4, and 5 from each other. Sediments were very coarse (mean grain size was generally 0.4 to 0.5mm) at the Group 3 stations (2 and 20), very fine (silt sized) at Group 4 stations (25 and 26), and intermediate at Group 5 stations (6 and 14). The clustering of Station 2 with Station 20 (as Group 3) on the Fall Cruise vs. with Stations 6 and 14 (Group 5) on the Spring Cruise clearly reflects differences in sediment composition at the station. Fall Cruise sediments from Station 20 were coarse (scoring "1" on the SEDIMENT SIZE FACTOR; mean grain size was 0.43mm), whereas those sampled on the Spring Cruise were less so (scoring "3"; mean grain size 0.15mm). The results suggest that different sediment patches or habitats were sampled on the two cruises.

Although no Axis III plots are shown here, the axis appears to most effectively separate Group 5 stations from Groups 3 and 4 stations. The FINE SAND FACTOR, which weighted highly on Axis III, effectively distinguishes the Group 5 stations (2, 6, and 14) from all others; these stations were characterized by a relatively high proportion of sediments in the fine sand size categories.

Summary -- The weighted discriminant analysis of box core infaunal data shows that depth and grain size are the environmental parameters that, in combination, best distinguish among the station groupings derived from cluster analysis. Although a general depth-related zonation pattern is evident, the pattern is complicated at nearshore stations by variations in sedimentary parameters.

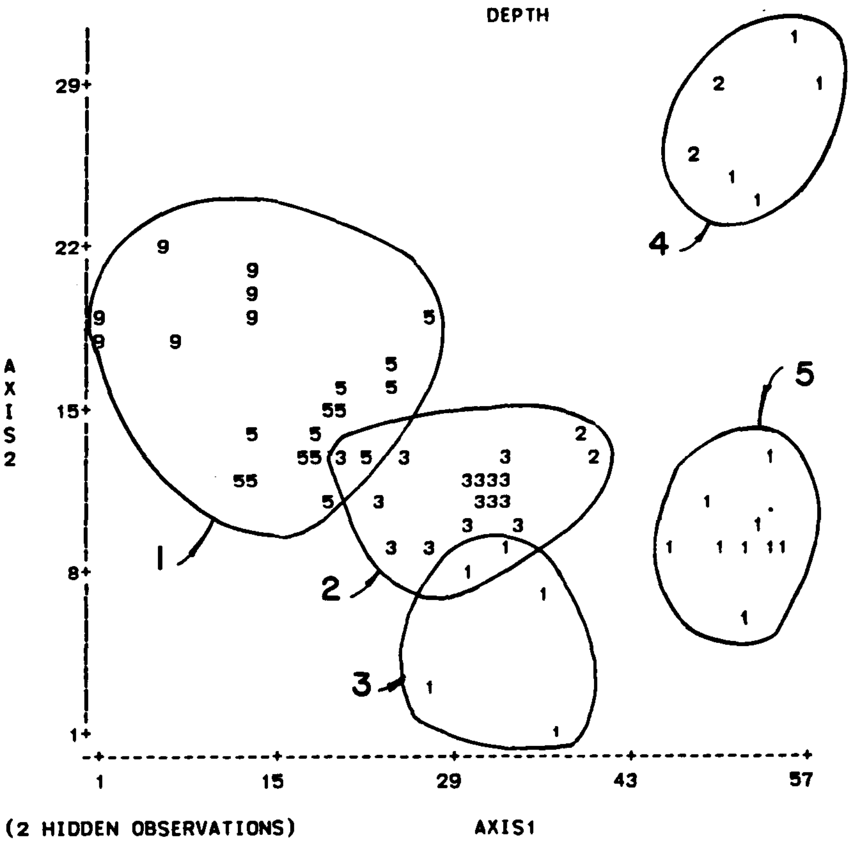


Figure 8-55. Weighted discriminant analysis, box core infaunal data. Ordinal DEPTH values of each station/season plotted on the first two discriminant axes. Higher values correspond to greater depths.

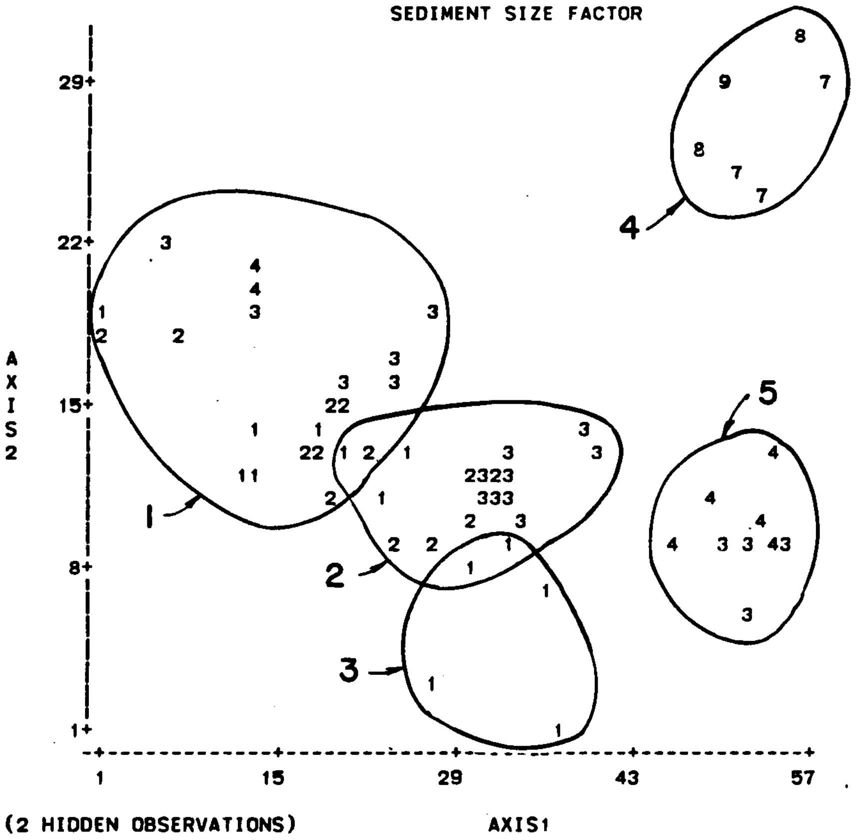


Figure 8-56. Weighted discriminant analysis, box core infaunal data. Ordinal values of the SEDIMENT SIZE FACTOR for each station/season point plotted on the first two discriminant axes. Higher values indicate finer sediments.

Stations 25 and 26 in the inner portion of Transect E are located in an area of silt-sized carbonate sediments and support a distinctive infaunal assemblage. Nearshore stations (2, 6, 14, and 20) are all in comparable water depths but are characterized by different sedimentary parameters; coarse sand predominated at Stations 2 (Fall Cruise) and 20, whereas mean grain size was lower and fine sand content higher at Stations 2 (Spring Cruise), 6, and 14. The difference in the clustering of Station 2 between cruises (i.e., with Station 20 in the Fall Cruise and with Stations 6 and 14 on the Spring Cruise) appears to reflect sampling of different sediment patches on the two cruises.

Figure 8-57 provides an illustration of the relationship between station depth, sediment grain size, and groupings of infaunal assemblages. The plot shows the mean (over all cruises) scores of each station on the SEDIMENT SIZE FACTOR (= Axis I from the sediment PCA), with station groupings superimposed. Highly positive scores on this factor indicate very fine sediments (silt-clay range); thus, the map is similar to Figure 5-24, which shows mean silt/clay percentages. The only area of very fine sediments is in the vicinity of Stations 25 and 26, but there is also a band of fine sediments (fine sand) extending across the shelf, primarily along Transect B. For the nearshore stations, sediment grain size appears to be of more importance in determining the characteristics of the infaunal assemblage than is depth (or, more likely, environmental variables correlated with depth). This is supported by other results of cluster analyses that were not included in the weighted discriminant analysis. For example, in analyses of individual cruises, Stations 2 and/or 20 (both in 20 to 30 m depth) tended to cluster with mid shelf stations rather than with the other shallow stations (6, 14, and 25)--presumably a reflection of sediment grain size differences among the nearshore stations. In addition, the between-cruise difference in the infaunal assemblage at Station 2 clearly reflects differences in sediment grain size parameters. Although Figure 8-57 suggests that depth (or depth-related environmental variables) are more important than grain size variables in determining the characteristics of the infaunal assemblage at mid or outer shelf stations, this would be an overly simplistic conclusion. Station 8, which was located in the cross-shelf band of relatively fine sediments, clustered apart from other mid shelf stations on both individual cruise analyses in which it was included. Station 4, which had

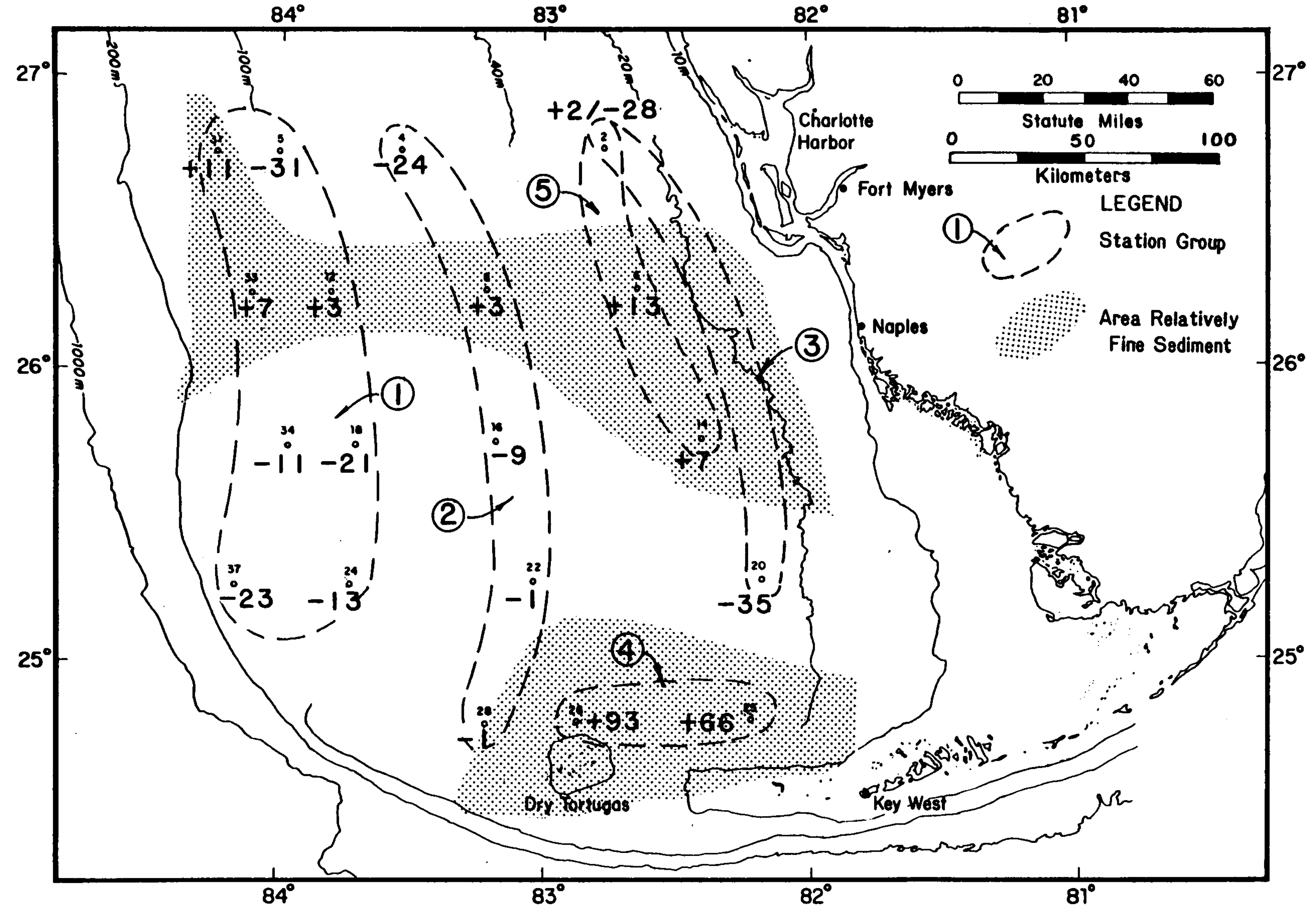


Figure 8-57. Soft-bottom station groups used in discriminant analysis and PCA scores for SEDIMENT SIZE FACTOR. PCA values are station means for all cruises except for Station 2, where sharply different Spring (+2) and Fall (-28) cruise values are both cited.

the most coarse sediments within the mid shelf station grouping, clustered with the deeper Station 5 (which had similarly coarse sediments) on the Fall Cruise and also emerged as somewhat distinct from other mid shelf stations on the Summer Cruise. Even among the deepest offshore stations, sediment grain size appeared to be responsible for some subclustering. Thus, for example, Station 37 was most dissimilar to Stations 31 and 33 in both Summer and Winter Cruise analyses, reflecting the relatively coarse grain size at Station 37. Because of the limited number of "major" station groupings chosen for the weighted discriminant analysis, some of these more subtle relationships between environmental (particularly sedimentary) variables and infaunal assemblages are not indicated by the results of the analysis.

Weighted Discriminant Analysis of Soft Bottom Otter Trawl Data

Station/season groupings used in the weighted discriminant analysis of otter trawl data are listed in Table 8-9. Because different seasonal samples from particular stations did not always cluster together, some stations appear in more than one group used in the analysis.

Results of the weighted discriminant analysis are summarized in Table 8-10. Axis I explained 79.9% of the variance in discriminant space and appeared highly related to DEPTH (as indicated by its high coefficient of separate determination). Axis II explained 16.4% of the variance and appeared to be related weakly to several parameters: TEMPERATURE, TRANSMISSIVITY, DISSOLVED OXYGEN, NITRITE FACTOR, and SEDIMENT SIZE FACTOR. Axis III explained only 2% of the variance and is not discussed further.

Figure 8-58 shows a plot of all stations/seasons on the first two discriminant axes with a key to identify each point; station/season groupings are also shown for future reference.

Figure 8-59 shows the same plot with ordinal values for DEPTH replacing each point. As indicated by the high score of DEPTH on Axis I, DEPTH provides a high degree of discrimination between the station groupings. Its main effects are to separate Groups 1, 2, and 3 from Groups 4, 5, 6, 7, and 8 and Groups 4

Table 8-9. Station/season groupings used in weighted discriminant analysis of otter trawl data from soft bottom stations.

Group 1

Stations 31, 33,34, and 37 — Winter Cruise

Group 2

Station 37 — Summer Cruise

Group 3

Stations 5, 12, 24, 31, 33, and 34 — Summer Cruise

Group 4

Stations 5, 12, and 24 — Spring, Fall, and Winter Cruises
Station 18 — Spring and Fall Cruises
Station 28 — Winter Cruise

Group 5

Stations 8, 16, and 22 — All cruises
Station 4 — Spring, Summer, and Winter Cruises
Station 28 — Spring, Summer, and Fall Cruises

Group 6

Station 20 — Fall Cruise
Station 25 -- Winter Cruise

Group 7

Stations 25 and 26 — Spring and Fall Cruises
Station 2 — Spring Cruise

Group 8

Stations 6 and 14 — All cruises
Stations 2 and 4 — Fall Cruise
Station 20 — Spring, Summer, and Winter Cruises
Station 25 — Summer Cruise

Table 8-10. **Results of weighted discriminant analysis of otter trawl data from soft bottom stations.**

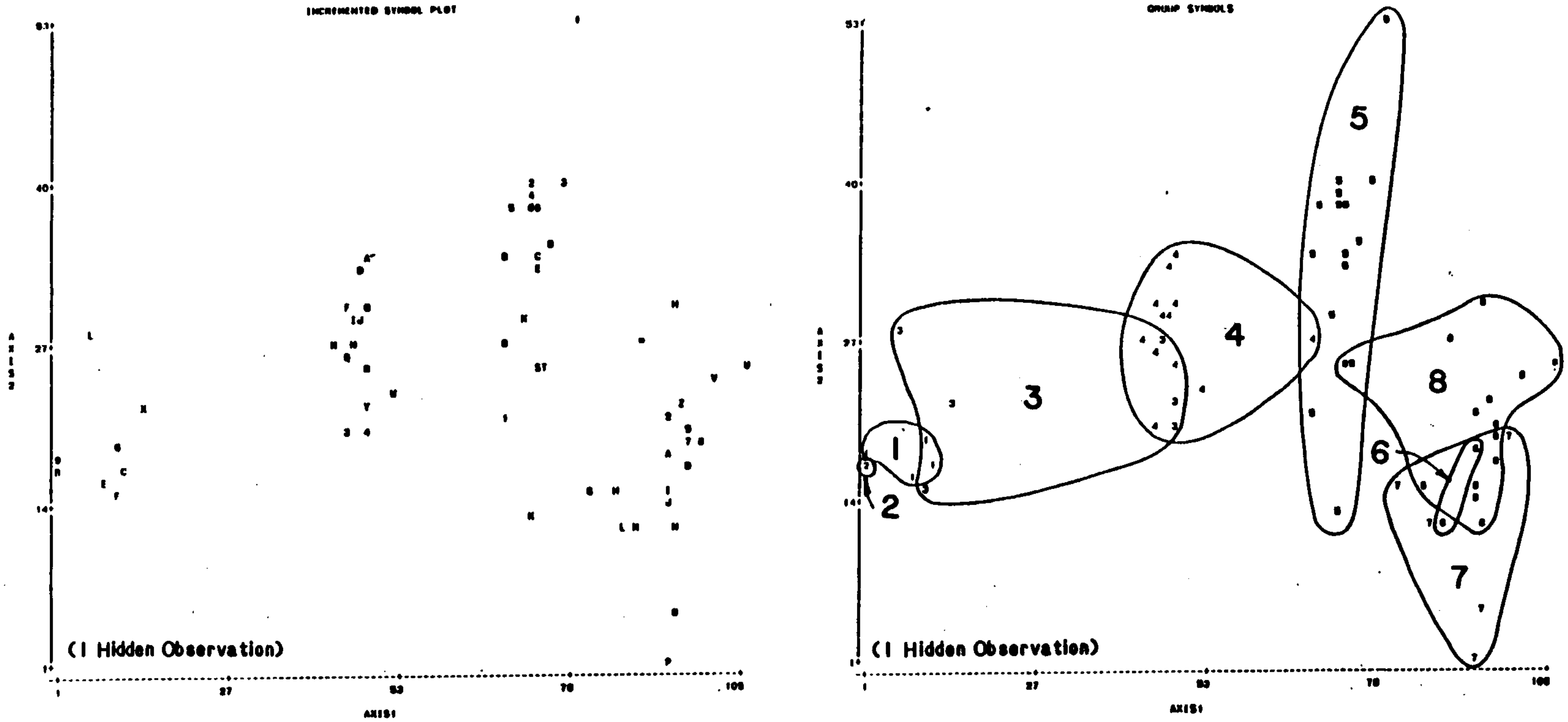
SW FLORIDA SHELF ECOSYSTEMS STUDY.
WEIGHTED DISCRIMINANT ANALYSIS: OTTER TRAWL -- SOFT BOTTOM (OTS): ALL CRUISES COMBINED.

PERCENT OF TOTAL GROUP SEPARATION EXPLAINED BY EACH AXIS

AXIS	PCT	CUM PCT
1	79.9	79.9
2	16.4	96.2
3	2.0	98.3
4	0.8	99.0
5	0.6	99.6

COEFFICIENTS OF SEPARATE DETERMINATION

	DISCRIMINANT AXES				
VARIABLE	AXIS1	AXIS2	AXIS3	AXIS4	AXIS5
1. CHLOROPHYLL	1.4	1.0	0.8	14.7	1.0
2. DEPTH	80.0	0.5	0.5	1.1	2.5
3. DISSOLVED OXYGEN	3.0	16.6	8.6	5.2	5.8
4. SILICATE	0.5	2.2	0.3	3.2	0.6
5. SALINITY	0.2	3.6	1.9	0.4	0.8
6. TEMPERATURE	1.0	23.2	3.9	13.8	0.6
7. TRANSMISSIVITY	0.4	17.3	1.1	1.8	1.2
8. NITRATE+NITRITE/PHOSPHATE FACTOR	8.2	3.2	4.0	2.2	39.2
9. NITRITE FACTOR	0.4	12.6	0.8	0.5	1.8
10. SEDIMENT SIZE FACTOR	0.4	12.1	34.1	7.4	3.9
11. FINE SAND FACTOR	0.1	3.7	4.2	5.5	20.3
12. SEDIMENT SD FACTOR	1.0	3.3	25.9	43.3	0.0
13. GRAVEL/SD/KURTOSIS FACTOR	3.3	0.0	0.5	0.3	5.6
14. SEDIMENT SKEWNESS FACTOR	0.0	0.7	13.3	0.5	16.7



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SW FLORIDA SHELF ECOSYSTEMS STUDY.
WEIGHTED DISCRIMINANT ANALYSIS:  OTTER TRAWL -- SOFT BOTTOM; ALL CRUISES COMBINED.
SYMBOL TABLE FOR INCREMENTED SYMBOL PLOT

          SYM ID          SYM ID          SYM ID          SYM ID          SYM ID          SYM ID
           1  1 3 16       B  2 2 28       L  2 2 33       V  2 2 20       6  2 3 31       G  1 4 26
           2  2 3 18       C  1 4 22       M  1 4 12       W  1 3 05       7  1 4 14       H  2 2 25
           3  1 4 04       D  1 4 18       N  2 2 05       X  2 2 31       8  1 4 02       I  1 3 06
           4  2 3 22       E  2 2 16       O  2 3 28       Y  2 2 12       9  2 3 37       J  1 4 06
           5  2 2 04       F  1 4 05       P  2 3 20       Z  2 2 14       A  1 3 20       K  1 4 08
           6  1 4 16       G  1 3 12       Q  2 3 05       1  1 3 28       B  2 2 37       L  1 3 26
           7  2 3 04       H  2 3 06       R  2 3 24       2  2 3 14       C  2 3 34       M  2 3 25
           8  2 2 22       I  1 3 24       S  1 3 04       3  2 3 12       D  1 4 20       N  2 2 06
           9  1 3 08       J  1 4 24       T  1 3 22       4  2 2 24       E  2 3 33       O  1 3 25
           A  1 3 18       K  1 4 28       U  1 3 02       5  1 3 14       F  2 2 34       P  1 4 25

NOTE:  SYM=SYMBOL; ID=YEAR-CRUISE-STATION;

       YEAR 1, CRUISE 3 = FALL CRUISE (OCTOBER 25-NOVEMBER 23, 1980); YEAR 1, CRUISE 4 = SPRING CRUISE (APRIL 22-MAY 5, 1981);
       YEAR 2, CRUISE 2 = SUMMER CRUISE (JULY 18-AUGUST 5, 1981); YEAR 2, CRUISE 3 = WINTER CRUISE (JANUARY 28-FEBRUARY 15, 1982).
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Figure 8-58. Incremented symbol plot and group symbol plot from weighted discriminant analysis of soft bottom otter trawl data.

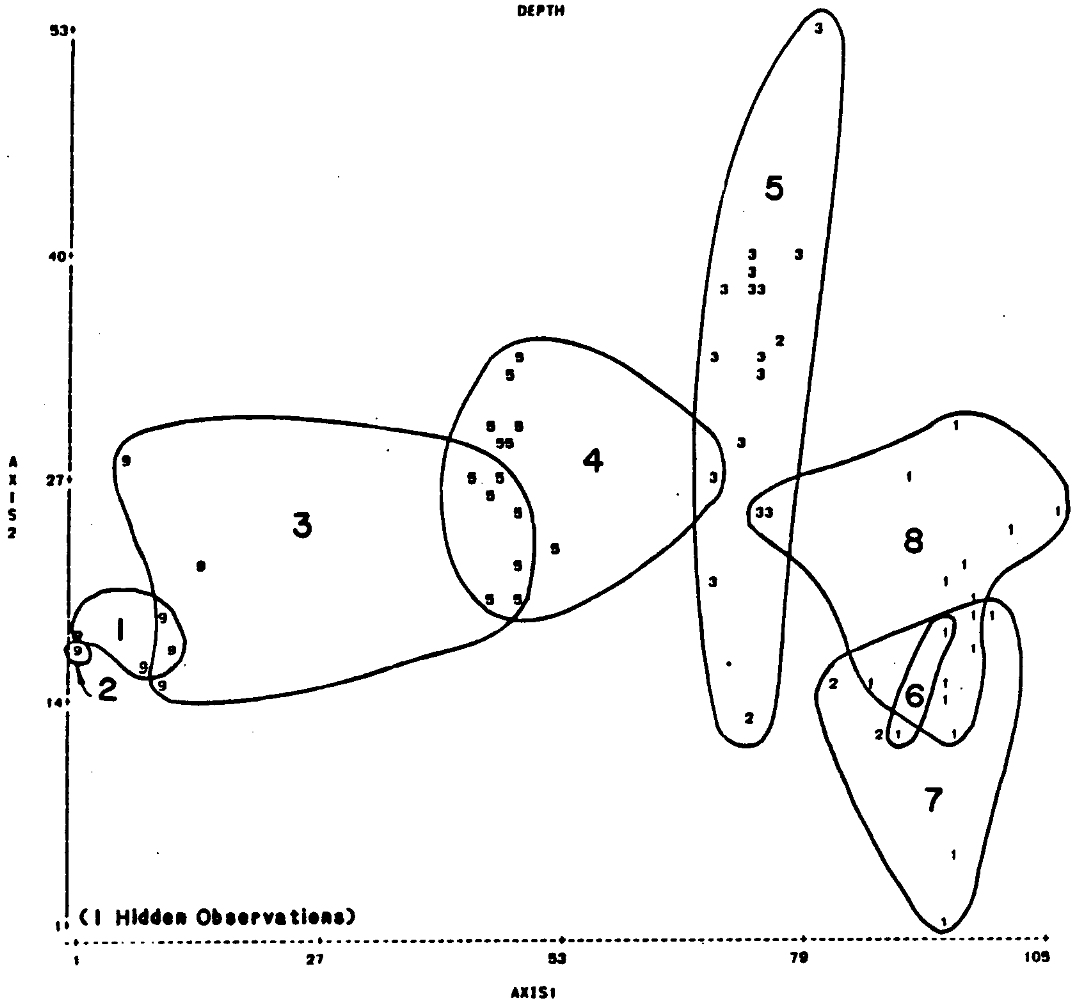


Figure 8-59. Weighted discriminant analysis, soft bottom otter trawl data. Ordinal DEPTH values for each station/ season point plotted on the first two discriminant axes. Higher values indicate greater depths.

and 5 from Groups 6, 7, and 8. As Table 8-9 indicates, Groups 1, 2, and 3 consist of offshore stations and Groups 4 and 5 consist of mid shelf stations (with some overlap between the groups). Because DEPTH did not vary with season yet the cluster groupings of some stations did, DEPTH cannot "explain" some of the groupings. Depth provides little discrimination between and among Groups 1, 2, and 3 or Groups 6, 7, and 8, which encompass different seasonal station groupings. Although most groups encompassed a relatively narrow range of depths, Group 3 included stations in 80 to 90m depths (Stations 5, 12, and 24--Summer Cruise) as well as those in 130 to 150m depths (Stations 31, 33, and 34--Summer Cruise). Also, within Group 8, Station 4 (Fall Cruise) was uncharacteristically deep (55m vs. 20 to 30m for others in the group).

Figure 8-60 shows the Axis I vs. Axis II plot with ordinal values for TEMPERATURE replacing each station/season point. Although this variable was the one that scored highest on Axis II, it appears to contribute little to the separation of any groups along the axis. Other variables that scored relatively high on Axis II also provide little additional insight (plots not shown).

Summary -- The weighted discriminant analysis of otter trawl data from soft bottom stations provided little insight into possible controlling variables in comparison to the similar analysis of box core infaunal data. The results are more comparable to those of the live bottom otter trawl analysis, although for the soft bottom trawls, nutrient variables did not emerge as good discriminators. Although the groupings derived from cluster analysis can be broadly characterized as depth-related, "seasonal" difference in the collections at some stations resulted in cluster groupings that could not be "explained" by depth gradients. The other environmental variables included in the analysis provided little or no additional insight into possible factors controlling community composition at these stations. As discussed previously in connection with live bottom otter trawl results (see Section 6.5), part of the apparent seasonal variability in trawl collections is probably attributable to sampling inadequacy.

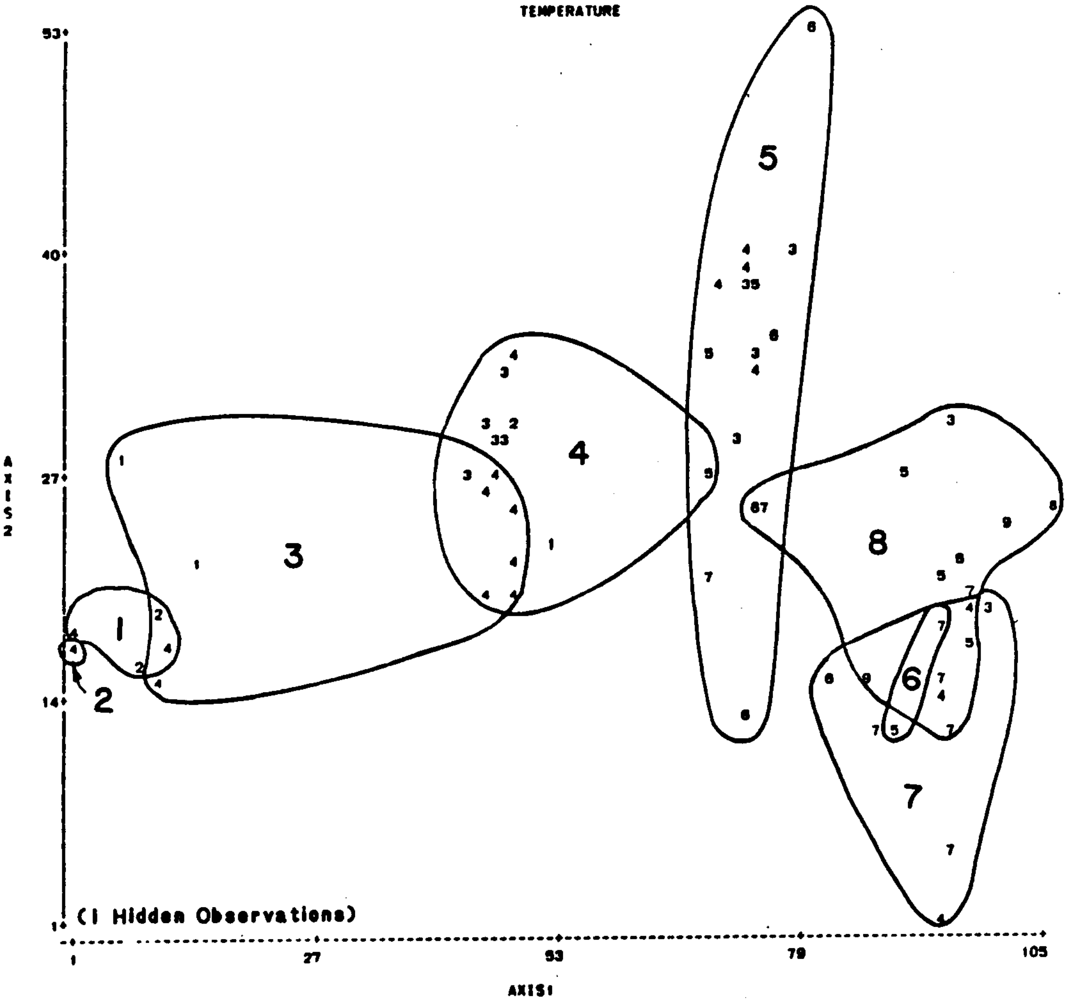


Figure 8-60. Weighted discriminant analysis, soft bottom otter trawl data. Ordinal TEMPERATURE values of each station/season point plotted in the first two discriminant axes. Higher values indicate higher temperature.

8.2.2.2.2 General Discussion of Environmental Factors

The weighted discriminant analysis identified depth and sediment grain size variables as environmental features that differed among station groupings emerging from cluster analysis box core data. In the soft bottom trawl data, only depth discriminated the station groupings.

As discussed previously, depth per se has little explanatory value; its importance in the discriminant analysis is presumed to reflect depth-related trends in environmental variables such as temperature, light, nutrients, substratum, etc. Shelfwide patterns in these variables have been discussed in Section 8.2.1.2.2 and that discussion is not repeated here except insofar as the variables provide additional insight into soft bottom assemblages.

The predominance of depth in the trawl discriminant analysis probably reflects shelfwide temperature patterns that are not adequately characterized by the isolated "point" measurements in our study. Most of the species collected in trawls were fishes. Miller and Richards (1979) have discussed the role of temperature in limiting the bathymetric distribution of fishes on the continental shelf off the southeastern United States. Shelfwide distribution patterns are considered reflections of the minimum temperature tolerance of the particular fish species: for tropicals, no growth at 18°C and mortality at 16° to 18°C; for subtropicals, no growth at 15°C and mortality at 13° to 15°C. Consistent temperatures of 18°C or more are most likely to predominate at mid shelf depths in our study area. Upwelling of deep Loop Current water onto the outer shelf results in occasional temperature anomalies, as noted for the South Atlantic Bight (Miller and Richards, 1979). The inshore penetration of tropical forms is greater in our study area than in the South Atlantic Bight due to overall higher temperatures. However, occasional cold fronts differentially affect the nearshore populations (Bohnsack, 1983), and seasonal inshore-offshore movements of some fish species as reflected in the variability in species composition of trawl catches are probably temperature-related.

Although not evident in the discriminant analysis of trawl data, substratum characteristics are also important determinants of community composition of fishes and epibenthic crustaceans (Williams, 1958; Topp and Hoff, 1972; Huff and Cobb, 1979). Distinctive assemblages are generally associated with major substrate (sediment) types in the Gulf (Chittenden and McEachran, 1976; Bright, 1983). Although the shelf is in general characterized by coarse carbonate sands, finer sediments predominate in certain areas, particularly at the inshore end of Transects E (Stations 25 and 26) and B (near Station 6). Stations 25 and 26 are located in the area of the Tortugas pink shrimp grounds, and Station 6 is in the area of the Sanibel grounds (Station 14 is just south of the latter). Species typical of these areas included the pink shrimp *Penaeus duorarum*, the shoal flounder *Syacium gunteri*, the dwarf sand perch *Diplectrum bivittatum*, and tomtate *Haemulon aurolineatum*. There were apparently enough other species in common with the other nearshore stations (2 and 20) so that major distinct sediment-related station groupings did not emerge in the trawl data (as they did in the box core data). Also confounding the results was the occurrence of live bottom within soft bottom stations; as noted in individual station characterizations in Section 7.3, many stations exhibited a mixed assemblage of epifauna having either sand bottom or live bottom ("reef") substratum affinities. However, those stations characterized by the highest "live bottom" character were mid to outer shelf stations (see Section 7.4.2) that were in Groups 4 and 5 in the trawl discriminant analysis. The analysis suggests that there is bathymetric zonation of trawl-collected macroepibiota, but certain groupings are more likely to be indicative of differences in substratum characteristics than of depth per se.

The emergence of grain size related parameters as important determinants of infaunal assemblage composition is in accord with results of other benthic studies of continental shelf habitats (Texas Instruments, Inc., 1978; Flint and Rabalais, 1981) and with the known importance of sediment parameters for infauna. Sediment serves as both habitat and food source for many of these organisms, and substrate affinities can reflect effects of grain size variables on tube-building activities, motility, and feeding type (Meadows and Campbell, 1972; Gray, 1974; Rhoads, 1974; Fauchald and Jumars, 1979).

Continental shelf habitats are typically characterized by low infaunal abundances and high diversity in comparison to estuarine habitats (Flint and

Rabalais, 1981). The lack of highly characteristic "dominant" species that have typically been used to characterize bottom communities (Thorson, 1957) makes it difficult to link variations in sediment composition with specific differences in the composition of infaunal communities. One approach to this problem has been to reclassify all infaunal species into functional groups or "guilds" whose distributions presumably reflect variations in sediment composition (Jumars and Fauchald, 1977; Fauchald and Jumars, 1979; Maurer and Leathem, 1981). The major drawback in such an approach is the lack of specific knowledge concerning the feeding modes of many species, which necessitates some supra-specific level groupings and other educated guesswork. Rather than reclassify all species or the most abundant species by station, we have characterized the life habit/feeding mode of species that were highly characteristic of particular station groupings from cluster analysis. The classifications were based on Fauchald and Jumars (1979), Maurer and Leathem (1981), and unpublished data of Vittor and Associates, Inc., who are presently reanalyzing infaunal data from the MAFLA surveys (K. Shaw, personal communication, 1984). The results are shown in Table 8-11. Although no simple pattern emerges, the table shows some interesting points. It appears that the silty carbonate sediments associated with Stations 25 and 26, and to a lesser degree with Stations 6 and 14, are characterized more by tube-dwelling surface deposit feeders and burrowing subsurface deposit feeders in contrast to areas of coarser sediment, which are more typified by free surface dwelling scavengers, carnivores, and surface deposit feeders. Results of Maurer and Leathem (1981) show a positive relationship between the abundance of burrowing subsurface deposit feeders and the percent of fine sediments for infauna on Georges Bank. Preliminary unpublished results of Vittor and Associates, Inc. for MAFLA infaunal data also suggest that coarser mid shelf sediments are likely to support more motile surface deposit feeders and scavengers than are fine muddy sediments. Species such as Mediomastus californiensis, Paraprionospio cristata, and Sigambra tentaculata which were characteristic of Stations 25 and 26, are typical of muddy deltaic sediments in the northern Gulf of Mexico (Vittor and Associates, Inc., unpublished).

Not shown in Table 8-11 is Synelmis albini, the overall most abundant polychaete collected during this study. This polychaete was generally the most

Table 8-11. Feeding type and motility classifications of infaunal species that were characteristic of particular station groupings from cluster analysis.

Group (Stations)	Species*	Feeding Type**	Motility***
1 (Stations 5, 12, 18, 24, 31, 33, 34, & 37)	*Aplacophora* sp. B (solenogaster)	S	M
	Callianassa marginata (crustacean)	S	M
	Glycera oxycephala (Glyceridae)	C	M
	Prionospio cirribranchiata (Spionidae)	F-S	D
	Spiophanes wigleyi (Spionidae)	F-S	D
	Aricidea simplex (Paraonidae)	B	M
2 (Stations 4, 8, 16, 22, & 28)	*Exogone lourei* (Syllidae)	H	M
	Magelona sp. A (Magelonidae)	S	D
	Spiophanes bombyx (Spionidae)	F-S	D
3 [Stations 2 (Fall) & 20]	*Ancistrosyllis hartmanae* (Pilargidae)	C	M
	Cirrophorus branchiatus (Paraonidae)	S	M
	Ehlersia cornuta (Syllidae)	H	M
	Protodorvillea kefersteini (Dorvilleidae)	C	M
4 (Stations 25 & 26)	*Magelona cf. cincta* (Magelonidae)	S	D
	Paraprionospio pinnata (Spionidae)	F-S	D
	Prionospio cirrifera (Spionidae)	F-S	D
	Sigambra tentaculata (Pilargidae)	C	M
5 [Stations 2 (Spring), 6, & 14]	*Aricidea philbinae* (Paraonidae)	B	M
	Cyclaspis sp. A (cumacean)	F-S	M
	Rutiderma licinum (ostracod)	?	M
	Synchelidium americanum (amphipod)	F-S	M
4 & 5 (Stations 2, 6, 14, 25, & 26)	*Aricidea wassi* (Paraonidae)	B	M
	Lumbrineris ernesti (Lumbrineridae)	C	M
	L. verrilli (Lumbrineridae)	C	M
	Magelona pettiboneae (Magelonidae)	S	D
	Mediomastus californiensis (Capitellidae)	B	M
	Owenia fusiformis (Oweniidae)	F-S	D
	Prionospio cristata (Spionidae)	F-S	D

*Family designation is included for polychaetes but not for other groups.

**Feeding type designations: S = surface deposit feeding; B = subsurface deposit feeding; C = carnivore/scavenger; F-S = filter feeding and/or surface deposit feeding; and H = herbivore (microphagous).

***Motility designations: M = motile; D = discretely motile (generally indicates semi-permanent tubes or burrows); and S = sessile (none included in this table).

abundant (or among the most abundant) species at middle and outer shelf stations (4, 5, 12, 16, 18, 22, 24, 25, 28, 31, 33, 34, and 37) but was not abundant at nearshore stations (2, 6, 14, and 20). The species, like other pilargid polychaetes, is considered a burrowing scavenger/carnivore, and its general distribution pattern suggests that sediment type is less influential than are depth-related factors for this species.

The silt-sized carbonate sediments on the inner end of Transect E present an unusual situation for infauna. Most fine sediments are organic-rich (Longbottom, 1970; Hargrave, 1972), and areas of fine sediment in temperate shelf environments are frequently colonized by a low-diversity assemblage of opportunistic tubicolous polychaetes (Rhoads and Boyer, 1982). Although Stations 25 and 26 in this area exhibited low infaunal diversity, faunal abundances were low and no species was dominant.

Other environmental factors that are likely to influence the abundance and community composition of infauna include the shelfwide variation in POM inputs and in situ micro- and macro-algal production. The magnitude of benthic production in different benthic environments is probably related to differences in ambient POM deposition rates (Rowe, 1971; Hargrave, 1980; Wangersky and Wangersky, 1981), which should vary as functions of water depth and primary production in overlying water column. The generally low infaunal standing crop of the southwest Florida shelf is a consequence of the oligotrophic quality of the overlying waters, as has been suggested for Gulf of Mexico deep-sea benthos (Rowe, 1971). Because there is no major riverine influence on the area, interaction of the Loop Current with the shelf system is probably the major forcing function of water column primary productivity (Woodward-Clyde Consultants and Skidaway Institute of Oceanography, 1983). As discussed in Section 8.2.1.2.2, nutrient enrichment due to Loop Current-induced geostrophic upwelling may reach the photic zone as far inshore as 50m depths, but the highest nutrient (e.g., nitrate) levels are observed on the outer shelf. Without data concerning the overall frequency and extent of upwelling effects and of episodic Loop Current frontal eddies, it is not possible to predict the overall pattern of primary productivity and, more importantly, of resulting POM deposition to the benthos. Hanson et al. (1981), working with a similar upwelling/intrusion system off the southeastern United States, suggested that nutrient enrichment by Gulf Stream intrusions results in enhanced benthic productivity on the middle shelf, compensating for a decreased supply rate of terrigenous and marsh-derived POM with increasing distance from shore. In the present study, it is tempting to interpret an observation such as the dramatic increase in faunal density at Station 37 on the Winter Cruise as resulting from benthic enrichment by a pulse of POM deposition, but the suggestion is purely speculative at this time. The increased faunal density at Station 37 was largely due to a population "boom" of the orbiniid polychaete Haploscoloplos sp., part of a general pattern of elevated winter abundance for this species at middle and outer shelf stations. The reason for the magnitude of population increase of Station 37 is not known.

Many infaunal species are selective deposit feeders or microphagous herbivores, and surface primary production by microalgae is presumably an important controlling variable for these species. We presently have no data concerning benthic chlorophyll levels, or even of general indicators of nutritional value such as organic carbon or nitrogen content.

The presence of macroalgae at soft bottom stations could presumably affect abundance and diversity of infauna by providing direct food source, source of autochthonous POM, and microhabitats. Stations that had the highest incidence of macroalgae in bottom photographs (Stations 4, 16, 20, and 28) were also those exhibiting high taxonomic richness and diversity, though supporting only moderate infaunal densities. The mid shelf stations are the most likely to support a perennial algal assemblage which should constitute a more consistent food supply and microhabitat for cryptofauna.

8.2.3 Live Bottom vs. Soft Bottom Comparisons

With the exception of the otter trawl collections, the sampling methodology and suite of organisms collected at live vs. soft bottom stations were necessarily different, precluding direct comparisons. However, general trends and observations within each data set can be compared.

8.2.3.1 General Observations

Taxonomic Richness -- In both live and soft bottom station collections, maximal taxonomic richness was observed at stations in the 30 to 60m depth range. Figures 8-61 and 8-62 illustrate this general pattern for triangle dredge and box core infaunal data, respectively; because all stations were not sampled on the same number of cruises, the results shown are average numbers of taxa collected per sampling cruise at each station. In the triangle dredge collections, average taxonomic richness was highest at Stations 17, 3, 21, and 7, respectively. When triangle dredge and trawl collections at live bottom stations are considered, total taxonomic richness (i.e., all taxa collected on all cruises at a given station) was highest at Stations 3, 7, and 21; sponge taxonomic richness was highest at Stations 15 and 21; molluscan taxonomic richness was highest at Station 3; and the number of fish taxa collected was highest at Station 9. All of these are in 30 to 60m depths. At soft bottom stations, the average number of taxa collected per sampling cruise was highest at mid shelf Stations 28, 16, 22, and 4, respectively (Figure 8-62); these stations also had the highest number of total taxa collected over all cruises. These stations, along with Station 20, generally also exhibited high diversity and equitability as well (see Figures 7-4 and 7-5). Otter trawl results from soft bottom stations indicate highest taxonomic richness at Stations 16 and 22; the number of fish taxa collected was highest at Stations 12, 16, 22, and 28.

In both data sets, the deep (>100m) offshore stations were generally characterized by low taxonomic richness (Figures 8-61 and 8-62). In the box core data, these outer stations also exhibited generally moderately low diversity values (see Figure 7-4).

Only otter trawl samples were obtained at both live and soft bottom stations, and fishes constituted the largest single contributing group. Therefore, fish data from the otter trawls provide an overall view of trends in taxonomic richness across the shelf. Figure 8-63 shows the general pattern for the number of combined live and soft bottom otter trawl fish taxa; only stations that were sampled on all four cruises (except Station 21, three cruises) are included. The highest number of fish taxa was generally obtained at stations

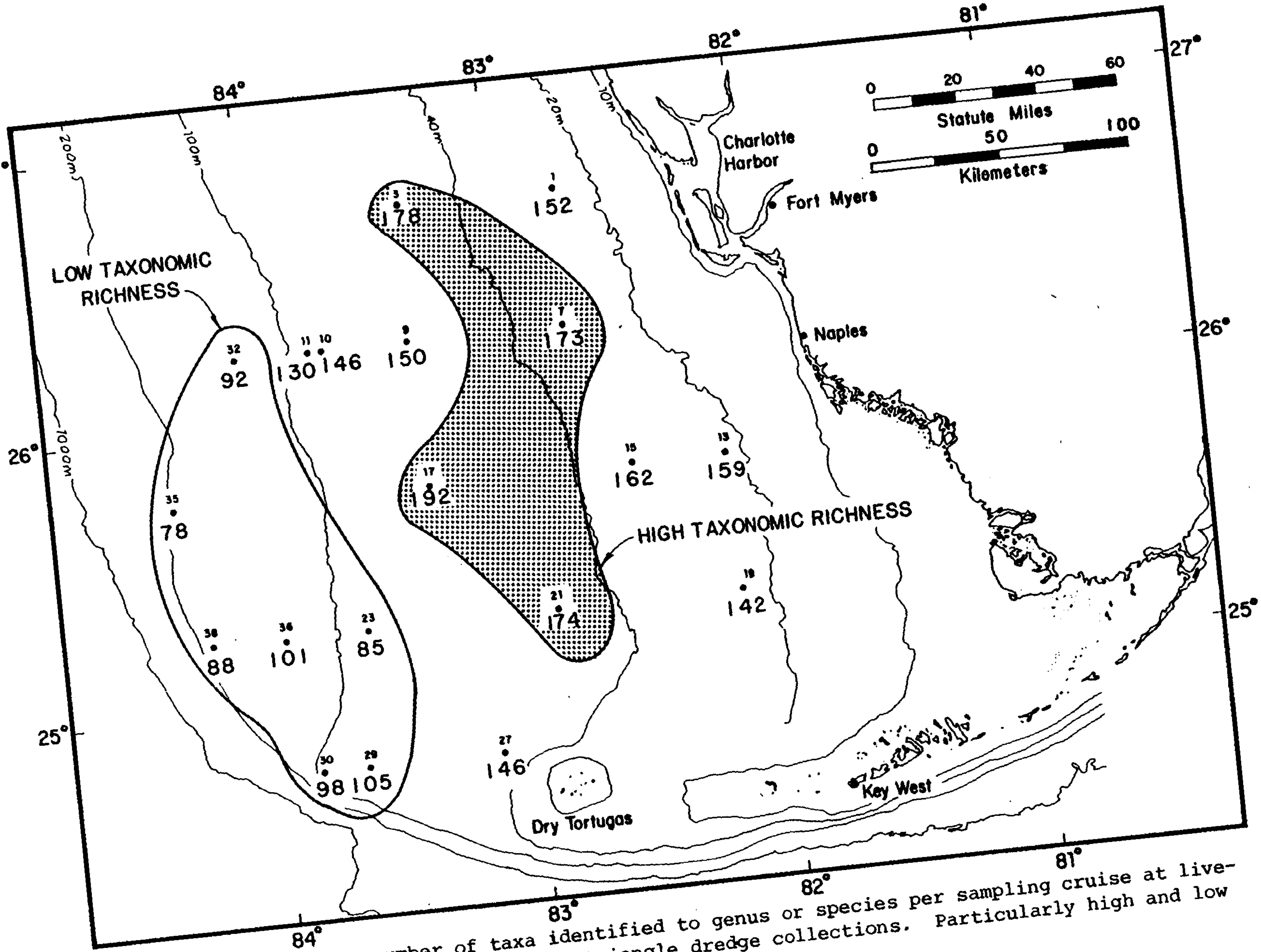


Figure 8-61. Average number of taxa identified to genus or species per sampling cruise at live-bottom stations, based on triangle dredge collections. Particularly high and low values are indicated.

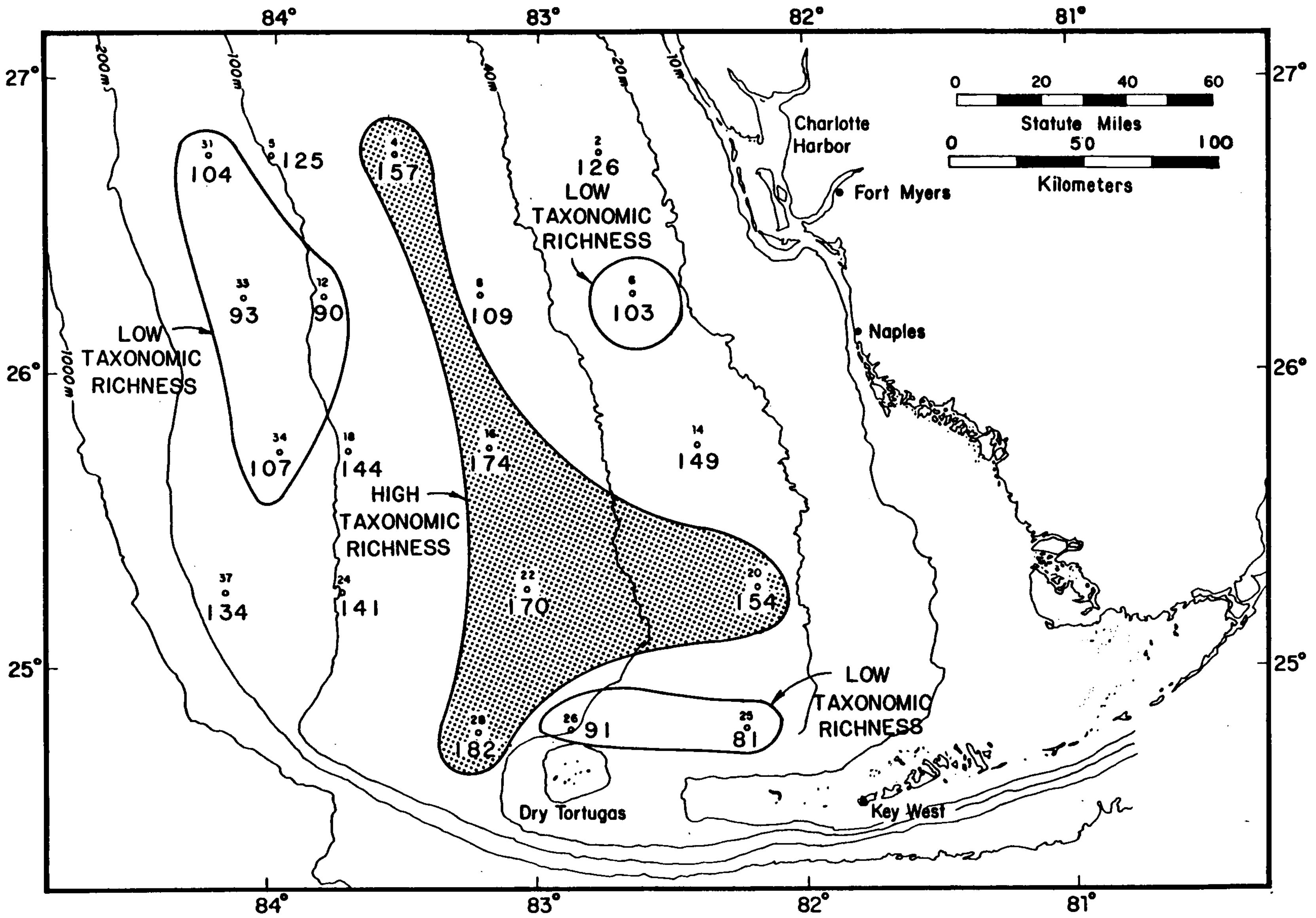


Figure 8-62. Average number of infaunal taxa (identified to genus or species) collected per sampling cruise by box core sampling at soft bottom stations. Particularly high and low values are indicated.

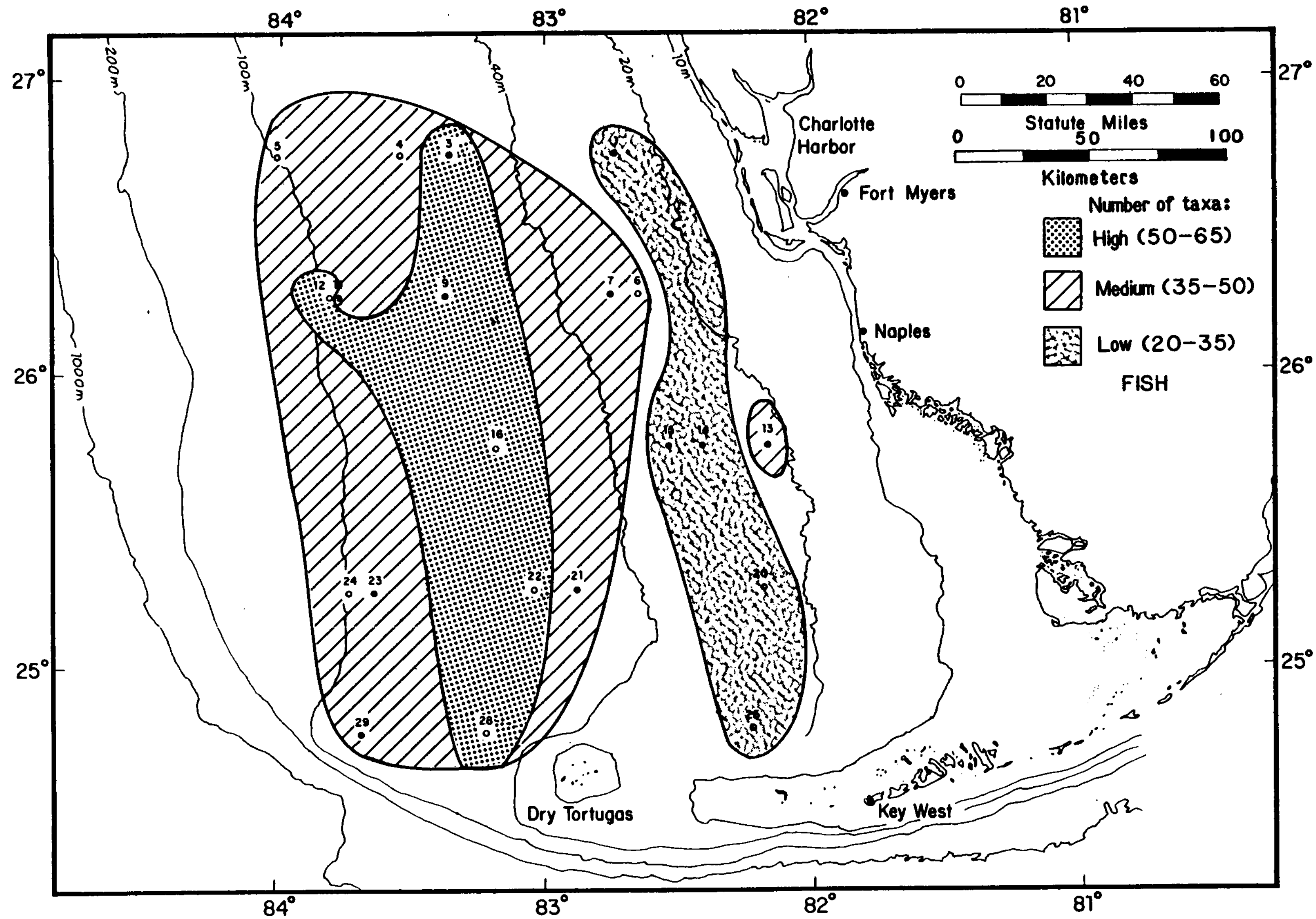


Figure 8-63. Shelfwide variation in taxonomic richness of fishes collected in otter trawls at live and soft bottom stations. Only stations sampled on all four cruises are included.

in 50 to 60m depths (except Station 12, 90 m). Low taxonomic richness was observed at most inner shelf (20 to 30m depths) stations, and even lower numbers would probably have been observed at the deep (>100m) stations had they been sampled on all cruises; the per-cruise catch at these stations was relatively low.

The factors responsible for controlling shelfwide patterns in taxonomic richness and diversity of the benthos are not known, though the existence and causes of such patterns have been the subject of considerable debate in the literature (Rex, 1981). Estuarine and nearshore areas (which were not encompassed in Years One and Two sampling) are exposed to environmental (temperature, salinity, dissolved oxygen, etc.) variability that constitutes a stress for many marine organisms and consequently the number of species that can adapt to such conditions is limited (Sanders, 1969) and the speciation rate of nearshore marine benthic communities is believed to be lower than that of offshore, shelf communities (Jablonski et al., 1983). Although none of our stations can be considered "nearshore" or estuarine, environmental variability and the chances of major disturbance (e.g., storm-related) are likely to decrease markedly within the 20 to 60m depth range of the inner shelf. Stations in the 40 to 60m depth range mark the limit of inshore penetration of numerous outer shelf species, and this overlap of inner and outer shelf species probably accounts in part for the mid shelf maximum in taxonomic richness and diversity.

Density/Abundance -- At live bottom locations, the highest percent cover estimates were noted in the southwest portion of the study area in 60 to 80m depths (Figure 6-4); cover at those stations consisted primarily of crustose cryptonemialid red algae and leafy green algae (*Anadyomene menziesii*). In addition, several inner shelf stations (Stations 15 and 21, especially) exhibited high cover values consisting primarily of sponges (see Figure 6-5). The deep (>100m) offshore stations generally supported a sparse epibiota; even when percent cover was high (e.g., Station 39, Summer Cruise), the biota consisted of a thin encrusting layer of (presumably) little biomass. At soft bottom stations, the highest infaunal abundances were noted at shallow (Stations 6 and 14) and deep (Station 27) extremes (see Figure 7-3) and no shelfwide trend was evident. However, the dramatically elevated density value at Station 37 on the Winter Cruise was not typical of other deep stations, nor of Station 37 on the previous cruise. The cause for the elevated density is not known.

Distinct seasonal abundance patterns were much more readily discernible in the live bottom data set, primarily reflecting the importance of algae as major contributors to the epibiota. Infaunal organisms can also be expected to undergo seasonal abundance patterns but are to some extent buffered from direct seasonal influences such as temperature variations in the water column.

Different environmental factors are presumed to regulate shelfwide abundance patterns of live and soft bottom biota, though such relationships remain largely speculative at this time. The availability of hard substratum for attachment, inorganic nutrients (for macroalgae), suspended POM (for suspension feeders), temperature, and light levels are likely to be primary influences on the abundances of live bottom epibiota. Sediment grain size characteristics, rates of POM deposition, and temperature are likely to be the major influences on infaunal abundance.

Other Comparisons -- The southernmost Transect E exhibited some distinct assemblages in both data sets. Sediment thickness was higher in the inner (eastern) portion of the transect (which traverses the Tortugas pink shrimp grounds), thereby precluding the occurrence of live bottom. The fine, silty carbonate sediments in this area supported an infaunal assemblage that was low in diversity and equitability, though moderate in faunal density, and which exhibited a distinct taxonomic composition in cluster analyses. The outer (western) end of Transect E exhibited the *Agaricia*-coral plate assemblage over an algal nodule pavement, which precluded the development of an infaunal assemblage. The *Agaricia*-coral plate assemblage was uniquely characterized by a well-developed community of deepwater hermatypic corals and abundant leafy green algae (*Anadyomene menziesii*); the development of this assemblage is presumably favored by the low-sediment regime of the coralline algal pavement, a moderate temperature regime, and enhanced inorganic nutrient levels due to Loop Current-induced upwelling on the outer shelf.

8.2.3.2 Shelfwide Cluster Analysis of Live Bottom and Soft Bottom Trawl Data

To evaluate the overall similarities of trawl-collected biota from live vs. soft bottom stations, an additional cluster analysis was conducted using the combined data set for both types of stations and all cruises. Only taxa (identified to genus or species level) that occurred in 14 or more station/season samples were included; this truncation was necessary to reduce the size of the data set for analysis. Of 1,370 total genus- or species-level taxa available, 126 were thereby included in the analysis, representing about 9% of the total number of taxa and 44% of the total number of station/season occurrences. The 126 taxa included 39 fishes, 32 crustaceans, 18 sponges, 12 echinoderms, 9 molluscs, 5 bryozoans, 5 algae, 3 cnidarians, and 3 ascidians. It should be noted that soft bottom stations were represented primarily by fishes and crustaceans in this analysis, whereas live bottom stations were represented by a wider range of groups.

The results are too voluminous and complex for easy visual presentation, but can be summarized as follows. The two major groupings of stations/seasons were:

1) All live bottom stations/seasons except: the deep offshore Stations 32, 35, 36, and 38 (both seasons) and Stations 1 and 13 (Summer Cruise); plus soft bottom Station 20 (Winter Cruise); and

2) All soft bottom stations/seasons except: Station 20 (Winter Cruise); plus the deep offshore live bottom Stations 32, 35, 36, and 38 (both cruises) and Stations 1 and 13 (Summer Cruise).

Further subclustering within these primarily reflected depth-related groupings as noted in the separate live and soft bottom cluster analyses and is not discussed further here.

Two-way species/station occurrence tables were examined to determine the basis for the "crossover" clustering of live bottom Stations 32, 35, 36, and 38 with the soft bottom station group. Two contributing factors are: 1) the occurrence at these four stations of the crinoid *Comactinia meridionalis*, which was also characteristic of deep soft bottom stations; and 2) the absence of several live bottom epibiota more characteristic of shallower stations, including several sponges (*Cinachyra alloclada*, *Placospongia melobesioides*, *Niphates erecta*), ascidians (*Didemnum candidum*), bryozoans (*Amathia convoluta*, *Celleporaria albirostris*, *C. magnifica*, *Steganoporella magnilabris*), and echinoderms (*Arbacia punctulata*, *Ophiolepis elegans*). Because soft bottom stations were also characterized partly by the absence of such taxa, the cluster analysis tended to group the deep live bottom stations with them. Also, the deep live bottom stations supported a number of sponges that were not identifiable to genus or species and were therefore not included in this analysis; if these sponges had been included, the dissimilarity of deep live vs. soft bottom stations would have been emphasized.

Examination of the two-way tables provides some explanation for the grouping of Summer Cruise results for live bottom Stations 1 and 13 with the soft bottom group. As noted in the live bottom cluster analysis of otter trawl data, Summer Cruise results for these two stations were somewhat distinct from the others. Both samples were represented by a relatively species-poor catch, and the absence of several typical live bottom taxa may have overemphasized similarity to soft bottom stations. The bryozoan *Celleporaria magnifica* and the echinoid *Lytechinus variegatus carolinus* were among the "missing" taxa; at Station 13, the bivalve *Laevicardium pictum* and the arrow crab *Stenorhynchus seticornis* were conspicuously absent, among others. All of these taxa and most of the others that were conspicuously missing from Summer Cruise trawl results for Stations 1 and 13 were present in dredge samples from the same cruise, suggesting a sampling inadequacy problem.

Grouping of Winter Cruise results for soft bottom Station 20 with the live bottom stations appears to reflect the presence of several sponge species (e.g., *Aiolochroia crassa*, *Geodia neptuni*, *Haliclona compressa*, *Anthosigmella varians*) in the Station 20 trawl for that cruise. As noted in the individual soft-bottom station descriptions in Section 7.3, many soft bottom stations included areas of live bottom, at least as indicated by trawl collections. The occurrence of some live bottom biota at soft bottom stations was apparently not frequent enough to cause major cross groupings of live and soft bottom stations in this cluster analysis, however.

Although the combined cluster analysis therefore generally grouped stations by their live or soft bottom characteristics, several features show an overall similarity of stations within depth zones. For example, the misclassified, deep live bottom Stations 32, 35, 36, and 38 clustered most closely with the deep soft bottom Stations 31, 33, 34, and 37. In addition, the misclassified soft bottom Station 20 (Winter Cruise) clustered most closely with the nearby live bottom Station 19. The live bottom Stations 1 and 13 (Summer Cruise), which grouped with soft bottom stations, were most closely related to soft bottom Stations 20 and 25, both located in comparably shallow depths. Aside from the distinguishing live bottom attached epibiota, stations within depth ranges appear similar, as one would expect. Several of the more abundant fishes and crustaceans, for example, were ubiquitously distributed within particular depth ranges. Lyons and Camp (1982) showed generally depth-related groupings from cluster analysis of dredge and trynet samples encompassing both soft and live bottom habitats (no visual ground-truth was obtained) in the overlapping Hourglass Study Area; their analysis included mostly crustaceans, fishes, and echinoderms.

8.2.4 Summary

Shelfwide and seasonal patterns in the composition of live and soft bottom assemblages and the abundance of the component biota presumably reflect the influence of a suite of environmental variables on the recruitment, survival, growth, and reproduction of benthic organisms. The relationships between environmental variables and the distribution of biotic assemblages (derived from cluster analysis) were investigated using weighted discriminant analysis. Environmental variables available for the discriminant analysis of data from live bottom stations included station depth and hydrographic variables (temperature, salinity, dissolved oxygen, transmissivity, and inorganic nutrients). Several sediment grain size variables were also available for inclusion in the soft bottom discriminant analysis. In both analyses, station depth emerged as a major discriminating "variable"; the usefulness of depth as a discriminator is believed to reflect depth-related trends in environmental variables such as temperature, light, nutrients, substratum quality, and POM inputs. Even though several of these depth-correlated variables were included in the discriminant analysis, depth per se was a better discriminator, probably because it integrates environmental conditions over time. Depth as a correlate of time-averaged environmental conditions has more explanatory value than do "point" measurements of those environmental variables.

Substratum and inorganic nutrient variables provided additional insight into station groupings in the discriminant analyses. Sediment grain size variables emerged as significant discriminators of soft bottom station groupings, reflecting the recognized importance of sediment characteristics as determinants of its suitability as a habitat and food source for deposit-feeding infauna. Inorganic nutrient (nitrate, phosphate) levels emerged as potential influences on the distribution of live bottom assemblages, though the causal mechanism for such influences is not known; several direct or indirect pathways of influence are possible.

The weighted discriminant analyses have several shortcomings as tools for the interpretation of shelfwide and seasonal trends in the biological data:

1) Relatively few environmental variables were available for the analysis, and others that one might expect to exert major influences on the biota were either unavailable or not included. For example, data concerning light levels, rates of deposition and nutritional quality of POM inputs, sediment thickness (for live bottom), and sediment nutritional quality (e.g., nitrogen content for soft bottom infauna) should have significant explanatory value.

2) Values for environmental parameters were determined at single points in time (i.e., on each cruise) and may therefore not be representative of average or long-term environmental conditions to which organisms are exposed. In addition, without long-term measurements (e.g., by in situ recording thermograph for temperature), the occasional environmental extremes may never be encountered.

3) Station groupings were derived from cluster analysis of combined phyletic groups, whereas it is very likely that different environmental conditions influence particular phyletic or nonphyletic functional groups to different degrees. Light and inorganic nutrient levels are of far more direct importance as regulating variables for algae than for crustaceans and fishes, for example. Different polychaetes can be expected to show spatial distributions in relation to sediment types that accord with their feeding/motility types (Maurer and Leathem, 1981).

In addition, it is difficult to establish causal relationships on the basis of coinciding patterns in environmental vs. biotic variables. Correlations among environmental variables and the variety of direct and indirect environmental influences that can be postulated complicate the interpretation of discriminant analysis results. However, the problem of inferring causal relationships in the natural environment is an inherent feature of all descriptive or observational field studies that is best resolved by conducting laboratory and/or field experiments, which are beyond the scope of the present study.

Two peculiarities of the physical environment of the southwest Florida shelf have important influences on the distribution of assemblages and the abundance of biota. The first is the Loop Current, which passes southward along the shelf edge and generates geostrophic upwelling of cold, nutrient-rich water onto the outer shelf. The enhancement of inorganic nutrient levels is important when it extends into the photic zone--either in the water column on the outer shelf or in the benthic environment of the middle shelf (50 to 80m depths). Enhanced water column productivity due to nutrient enrichment is well documented and could provide substantial POM inputs to outer and middle shelf benthos; these POM inputs are potential food sources for surface deposit-feeding infauna and suspension-feeding sessile epibiota. In addition to the more consistent geostrophic upwelling generated by the passage of the Loop Current, periodic instrusion of Loop Current filaments could have significant effects on the termperature and nutrient regimes and on POM inputs to the benthic environment. The second peculiarity is the existence of a north-trending subsurface reef complex in 70 to 90m depths, which is most prominent on the southernmost Transect E, where the <u>Agaricia</u> coral plate assemblage occurs. East of this topographic elevation, unconsolidated sediments (including the fine silty sediments of the Tortugas pink shrimp ground area) accumulate to varying thicknesses over the consolidated hard bottom. Farther north along the mid-shelf buried reef complex, live bottom is increasingly sparse due to the submergence of the feature beneath the increasingly thick veneer of unconsolidated sediments. Live bottom assemblages at these 50 to 80m depths consist primarily of organisms associated with coralline algal nodules (or pavement) over a thick sand substrate; percent cover of the nodules and of associated biota also declines toward the north from Transect E to Transect A.

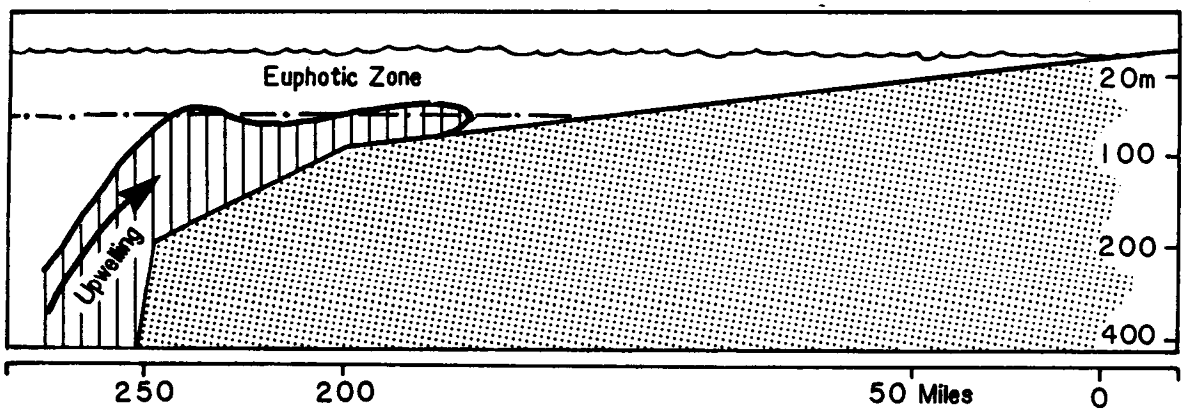
8.3 AN ADDENDUM: SPECULATIONS

Having reached this point in our data analysis and synthesis -- and fully recognizing that significant information gaps (particulate organic matter (POM), dissolved organic matter (DOM), zooplankton, intermediate carnivores, most fish) and most details remain to be studied -- some broader speculations concerning the general nature and driving mechanisms (forcing functions) of the southwest Florida shelf ecosystem begin to emerge. Some of these speculations are summarized in graphic form and presented in the figures that follow.

8.3.1 Regional Trends

Objectively established regional shelf trends are listed in the upper portion of Figure 8-64, while the lower portion outlines some speculations on significant differences between generally offshore verses generally onshore shelf conditions. Possible "limiting factors" controlling biological production across the shelf are also suggested.

Overall, environmental conditions may be most "stable" (temporaly uniform) over the middle shelf. Areas closer to shore are subject to more frequent perturbation due to shallower water, increasing effects of storms and waves, and possible land influences. Areas close to the shelf-break on the other hand, while deeper and less disturbed by storms, are instead subject to the upwelling effects of Loop Current intrusions. Water temperatures, dissolved nutrients, oxygen, primary production, even turbidity, can all change rather abruptly at apparently irregular intervals.



REGIONAL TRENDS

← Increasing Bottom Slope ——————

← More Constant Near–bottom Temperature /Salinity ——————

← Decreasing Near–bottom Dissolved Oxygen ——————

← Less Light Reaches Sea Floor ——————

← Increasing Water Clarity ——————

← Bottom Less Disturbed by Storms ——————

← Increasingly Frequent Upwelling Events ——————

← Increasing Near–bottom Dissolved Nutrients ——————

SPECULATIONS

OFFSHORE	ONSHORE
Primary Production Pulses	Low Primary Production
Increased POM/DOM from Subsurface Plankton	Minimal POM/DOM from Land Runoff
Less Disturbed Bottom, Thicker Sand Veneer, Self–edge Attachment Sites	Unstable Shifting Sand Veneer
Available Substrate & Depth (Light) Limited	Bottom Disturbance & Food Limited

Figure 8-64. Southwest Florida shelf ecosystem, a summary of regional trends and some speculations.

8.3.2 Trophic Relationships

Figure 8-65 provides a speculative, diagramatic synthesis of trophic (food-web) relationships within the overall southwest Florida shelf ecosystem. The general form of the diagram follows Mann (1982); conventional symbols are used to indicate primary producers, consumers, and abiotic storage compartments.

Primary production at offshore locations comes largely from the subsurface phytoplankton maximum or attached benthic macroalgae. Phytoplankton growth depends on "pulses" of upwelled, nutrient-rich Loop Current-related water, penetrating the uphotic zone under appropriate seasonal temperature conditions. Benthic algae probably also benefit from the upwelling, but are more likely limited by available light and suitable substrates for attachment. Both of these primary producer groups undoubtedly contribute significant amounts of particulate organic matter (POM) and dissolved organic matter (DOM) to the shelf ecosystem. The POM/DOM probably support associated bacterial populations which together with zooplankton, zooplankton faeces pellets (which speed delivery of organic matter to the seafloor) and the attached benthic algae, help support the live and soft bottom benthic animal assemblages. Many of these benthic organisms are either epifaunal filter feeders taking food from the water column, or infaunal scavengers, removing organic matter from the sediments.

The energy transfer pathways outlined above are probably the most important ones within the overall shelf ecosystem. The key components in offshore production would be the subsurface phytoplankton and benthic biota. We can speculate that potential "limiting factors" include the frequency of Loop Current upwelling events (providing nutrients), adequate available light, and suitable substrates for attachment. Secondary pathways for energy transfer would include the meio- and micro-faunas living within the bottom sediments, intermediate carnivores (chaetognaths, ctenophores, juvenile fish, etc.), and both demersal and pelagic fish species (Figure 8-65).

The shelf ecosystem at more onshore locations -- away from Loop Current influences, yet still too far offshore to be much affected by land influences -- exhibits rather different characteristics (Figure 8-64). Because of low

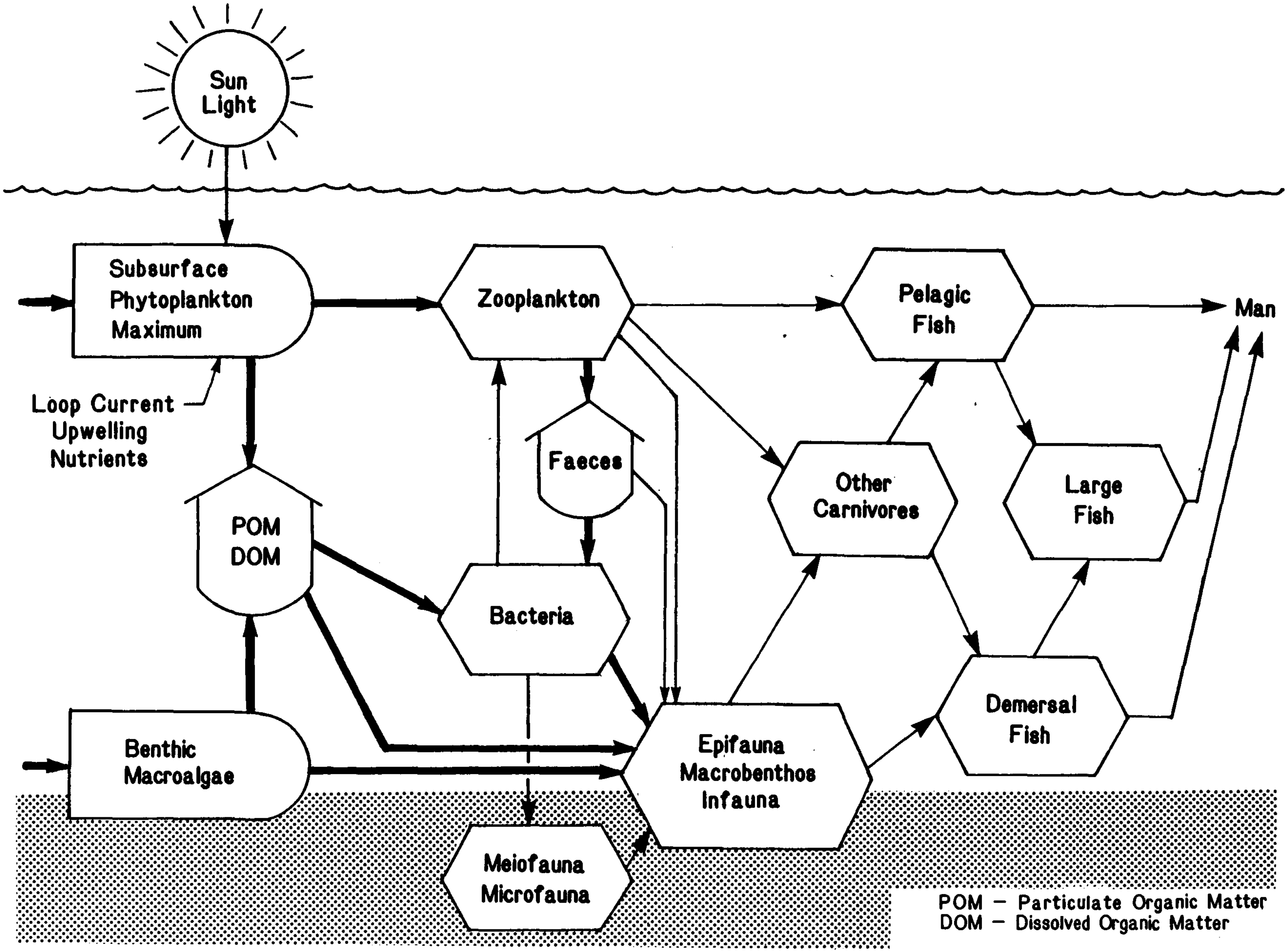


Figure 8-65. Hypothetical schematic food web for the southwest Florida shelf ecosystem, emphasizing the roles of the subsurface phytoplankton maximum, benthic macroalgae and macrobenthos (developed after Mann, 1982).

nutrient availability, from either land runoff or upwelling, primary production is probably lower than further offshore. Light is certainly not a limiting factor here, unless too much light, or near-bottom sediment resuspension and turbidity, is a problem. POM and DOM are also probably low, again reflecting minimal influences from the land. While little terrigenous sediment presently reaches the "onshore" shelf, resuspension and reworking of the existing sand veneer by waves and storm action probably results in unstable, shifting bottom conditions. One can speculate that the species composition and abundance of benthos at such locations, will reflect the length of time since last disturbance of the bottom and the species available for recolonization at (and since) that time.

At these more onshore location lower levels of primary production and POM/DOM availability might result in the communities being food-limited. The availability of suitable substrates and sites for attachment may also limit benthic community development and production. It must be emphasized that ecosystem conditions probably change again at sites still closer to the southwest Florida shoreline and the Florida Keys, where a whole range of influences (and influxes) not seen further offshore will be developed.

If indeed middle shelf conditions are less variable than those found at either near-shore, or shelf-edge stations, then this would be the region most likely to yield the greatest numbers of both demersal and pelagic fish. The data presented in Figure 8-63 support this suggestion. MMS-sponsored studies in the south Atlantic bight, where a comparable situation occurs (periodic Gulf Stream intrusions and geostrophic upwelling), also confirmed that fish abundance and biomass were generally highest and least subject to seasonal variation on the middle shelf (Marine Resources Research Inst., 1982).

Figures 8-66 and 8-67 present hypothetical trophic relationships in greater detail for shelfwide live bottom and soft bottom benthic community types, respectively. Distinctions between the two systems include the presence of zooxanthellae as primary producers associated with certain live bottom epibenthic suspension feeders, and the major role of infaunal deposit feeders in the soft bottom system.

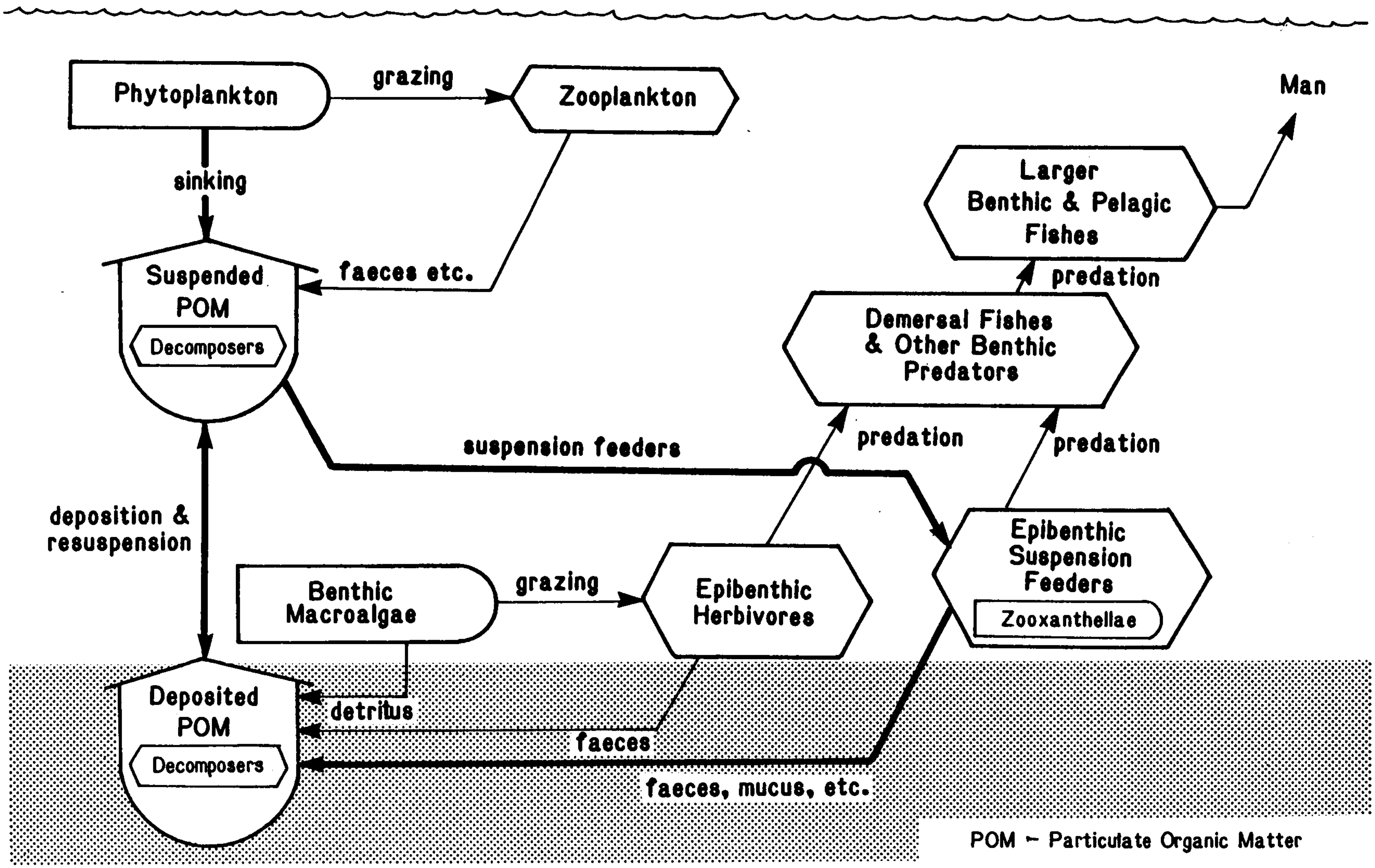


Figure 8-66. Hypothetical schematic food web for southwest Florida shelf live bottom benthic ecosystem.

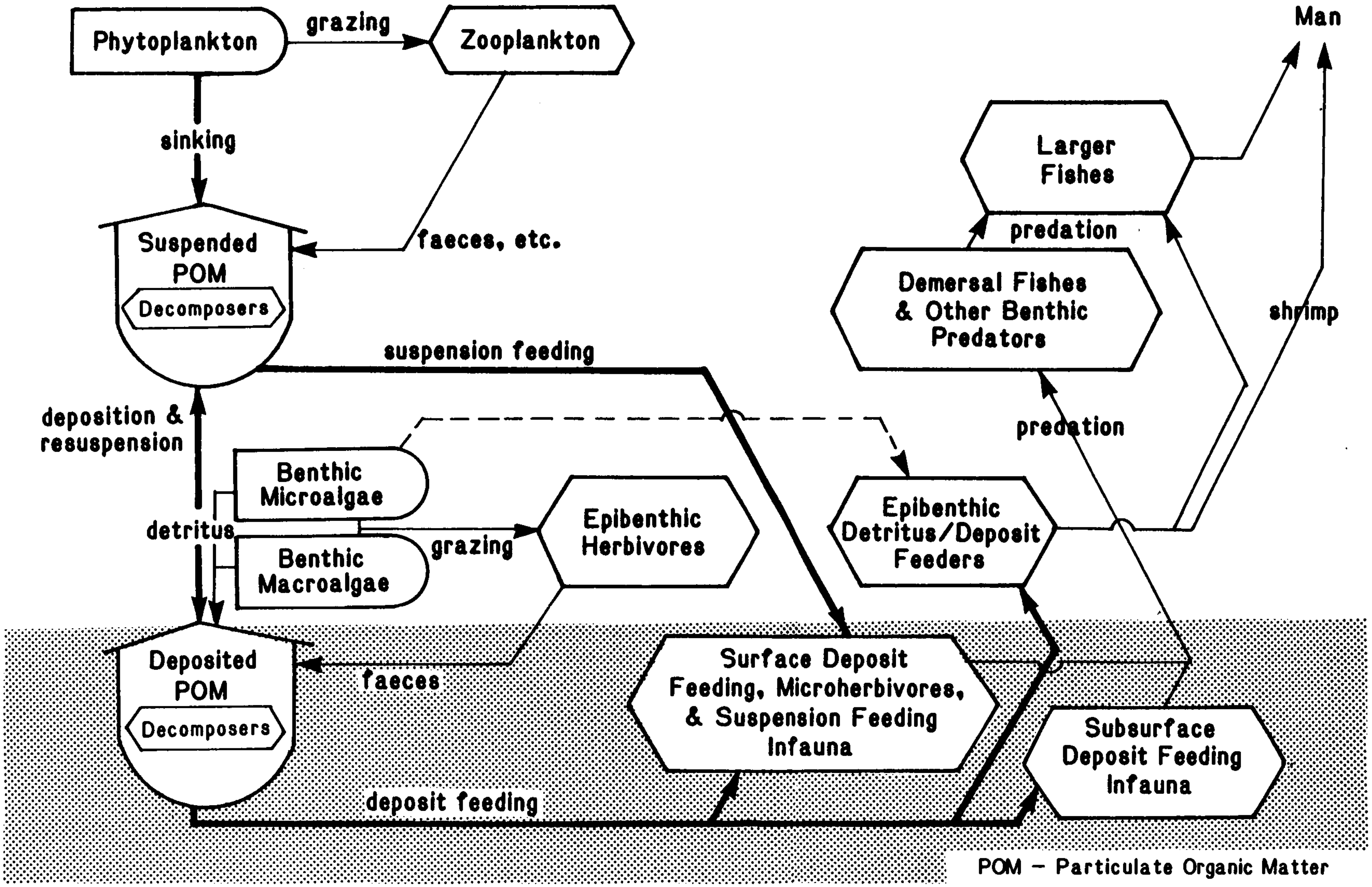


Figure 8-67. Hypothetical schematic food web for southwest Florida shelf soft bottom benthic ecosystem.

8.3.3 Benthic Community Distribution Patterns

In addition to the generalized food webs described above, three "state transition" models have been developed for the inner, middle, and outer shelf benthos (Figures 8-69 through 8-70, respectively). The purpose of these models is to portray the importance of substrate type and sediment movement as determinants of the benthic community types that develop across different portions of the southwest Florida shelf.

In each model, the principal substrate types occurring across relevant portions of the southwest Florida shelf are shown in the left-hand column. Note that the "transitions" between types reflect both spatial differences in distribution of substrate types and temporal changes due to sediment movement and/or algal nodule formation. Depending on such factors as substrate suitability, adjacent species populations, availability of propagules, larvae and colonizers, time since last disturbance, etc., a distinctive community type (indicated in the middle column) develops on each different substrate. Periodic burial by sediment or exposure of hard bottom surfaces will, of course, modify the community through time. The right-hand column in each figure indicates the specific benthic assemblages (described earlier in this report) that characterize each different substrate/community-type combination.

Since the data base remains limited, the models are rather generalized. They do, however, permit predictions to be made concerning the types of communities and assemblages most likely to be encountered on different substrate types within the inner, middle, and outer regions of the southwest Florida shelf.

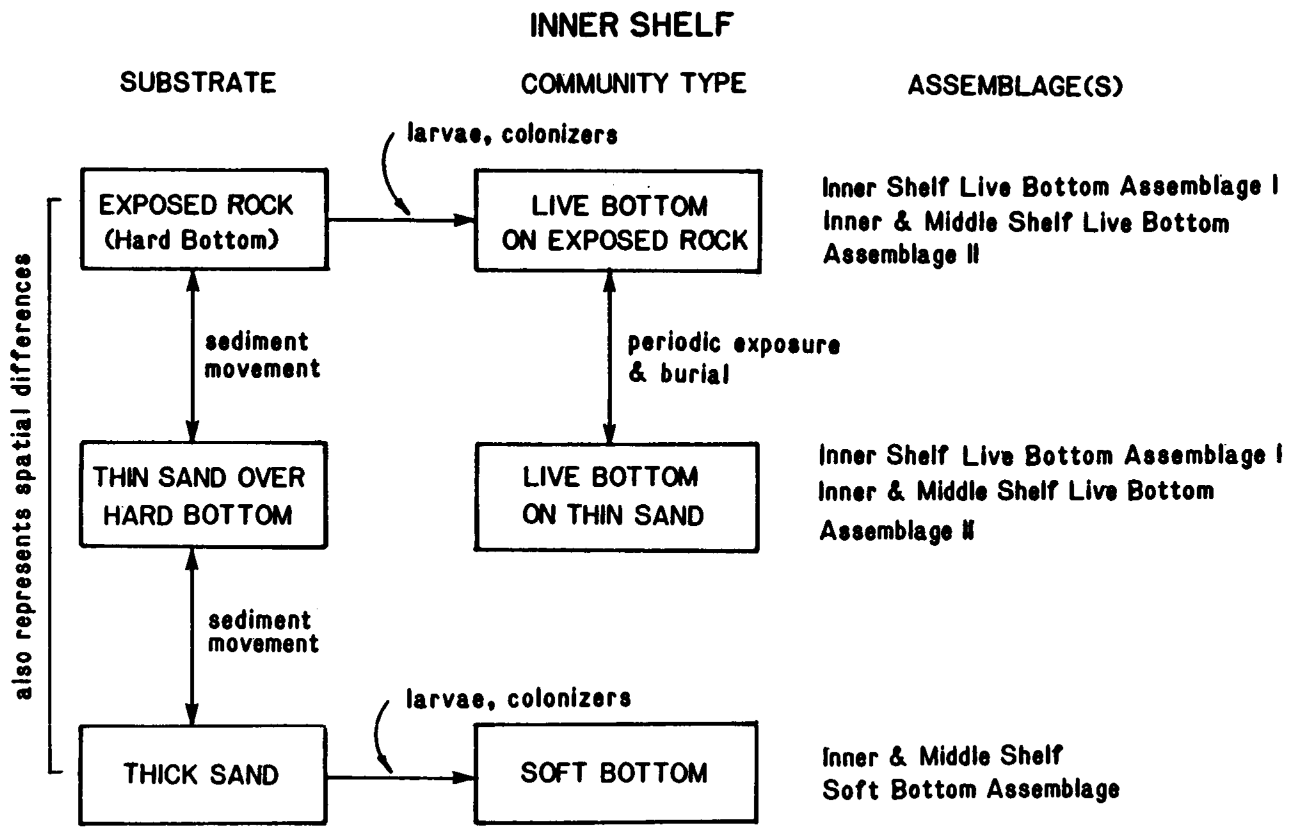


Figure 8-68. Southwest Florida inner shelf: hypothetical relationships among substrates, community types, and specific benthic species assemblages. See text for additional explanation.

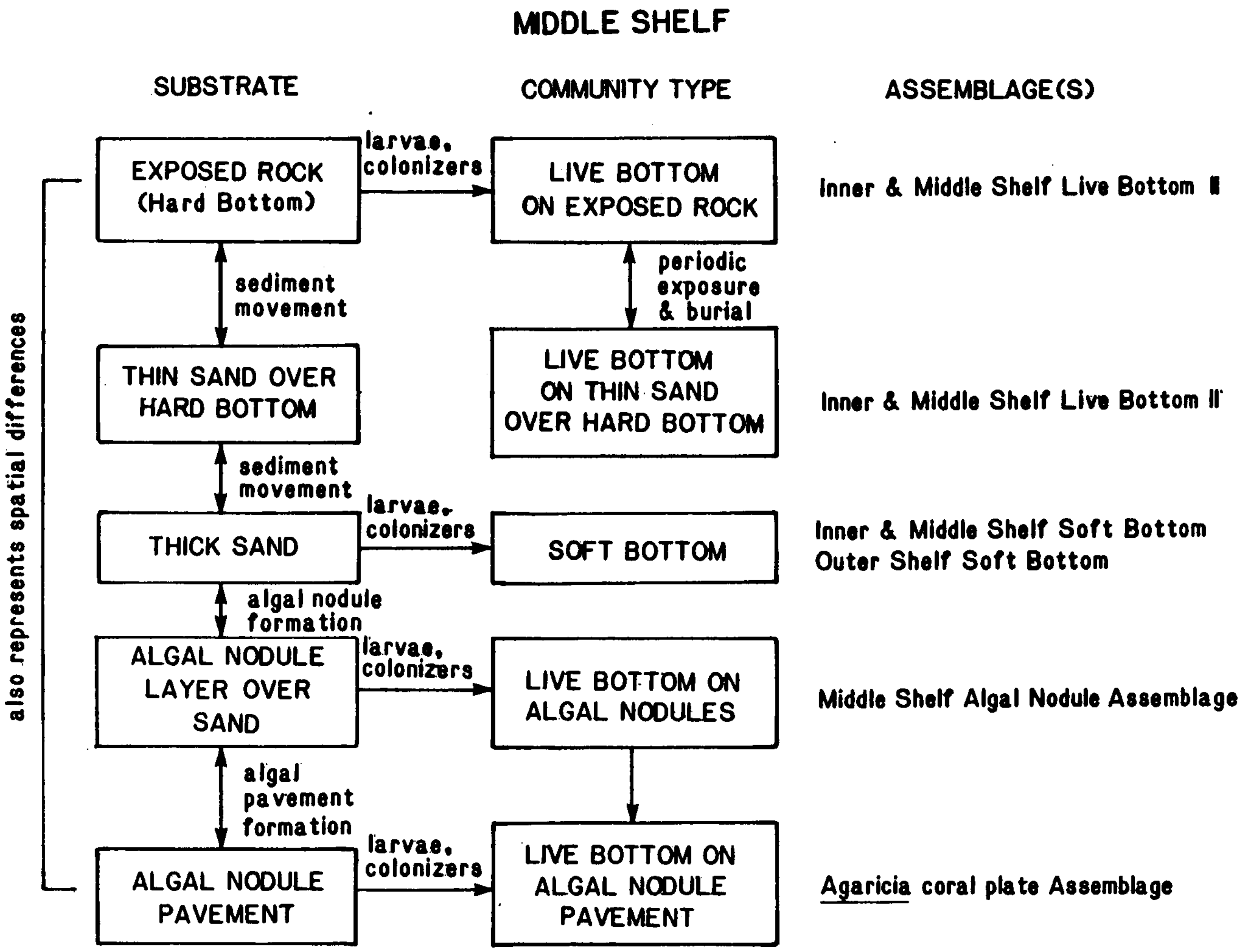


Figure 8-69. Southwest Florida middle shelf: hypothetical relationships among substrates, community types, and specific benthic species assemblages. See text for additional explanation.

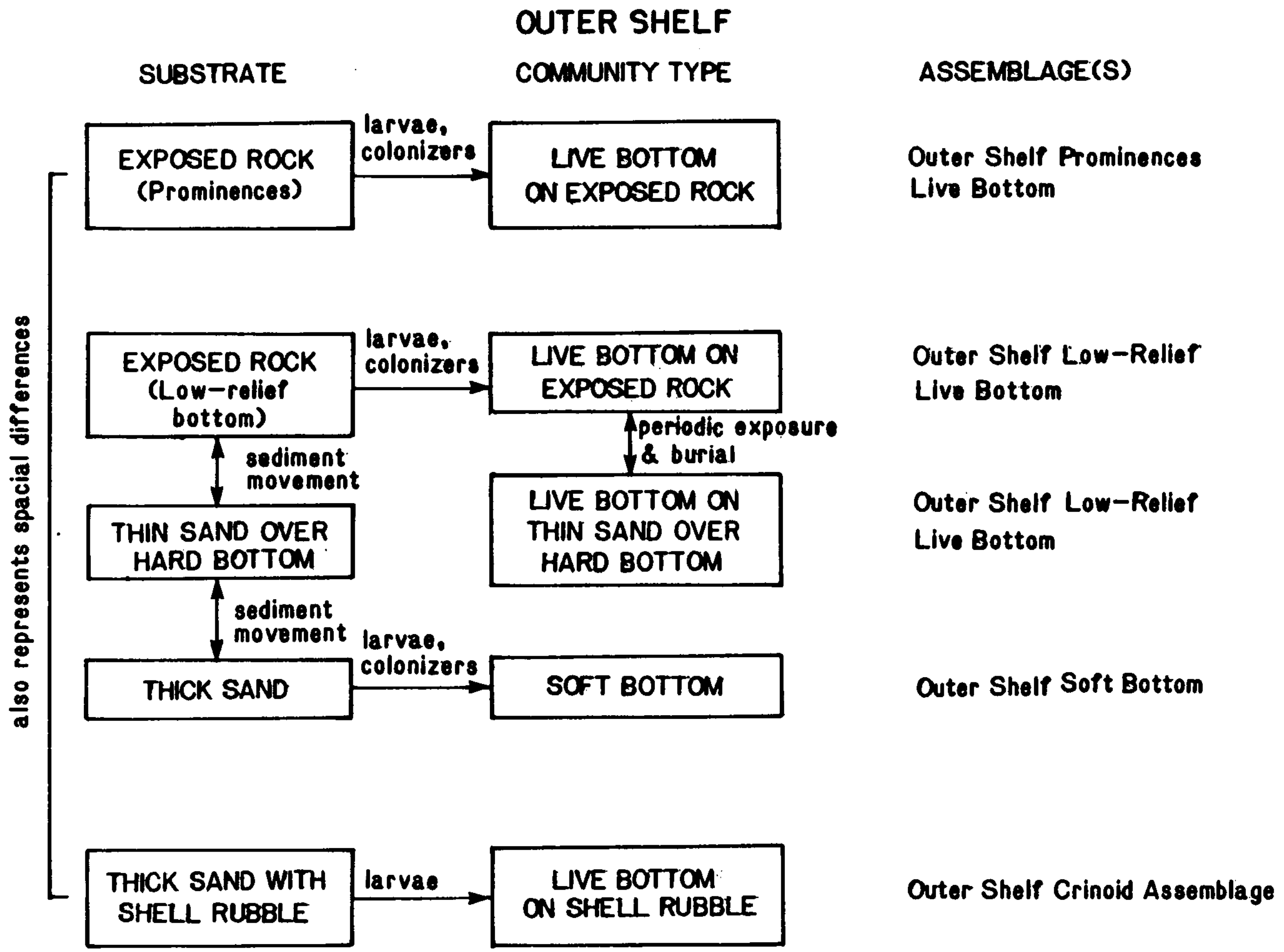


Figure 8-70. Southwest Florida outer shelf: hypothetical relationships among substrates, community types and specific benthic species assemblages. See text for additional explanation.

9.0 POTENTIAL OCS DEVELOPMENT IMPACTS

9.1 INTRODUCTION

The most recent annual Gulf of Mexico Summary Report summarizes the prior leasing history of the southwest Florida shelf and presents a wide range of current information on OCS oil and gas activities throughout the Gulf of Mexico Region (OCS Oil and Gas Information Program, MMS, 1984; see earlier editions in the series also).

All of Florida's west coast submerged territory was at one point under lease. Only three leases presently remain active however (East Bay - Getty/Exxon; Apalachicola to Naples, offshore - Coastal Petroleum Company), all other rights having reverted back to the State. A total of 19 exploratory wells have been spudded in Florida State waters, but there has been no production.

Several federal OCS oil and gas lease sales were conducted for tracts within the Eastern Gulf of Mexico Planning Area prior to the initiation of "areawide" sales in May 1983. These included Lease Sales 5 (1959), 32 (1973), 41 (1976), 65 (1978), 66 (1981), 67 (1982), and 69-Part II (1983). The first federal areawide sale for the Eastern Gulf of Mexico Planning Area, Lease Sale 79, was conducted in January 1984. Sale 79 attracted more interest than anticipated, with industry attention focused on the Pulley Ridge and Destin Dome leasing areas (MMS, 1984). The current 5-year offshore leasing schedule, extending through June 1987, calls for a second Eastern Planning Area Sale in November 1985.

Figure 9-1 indicates the locations of three categories of federal OCS leases within and adjacent to the southwest Florida shelf study area: (1) active leases from pre-May 1983 lease sales; (2) active leases from 1984 lease sales; (3) expired or relinquished leases (MMS, 1984, Visual No. 1).

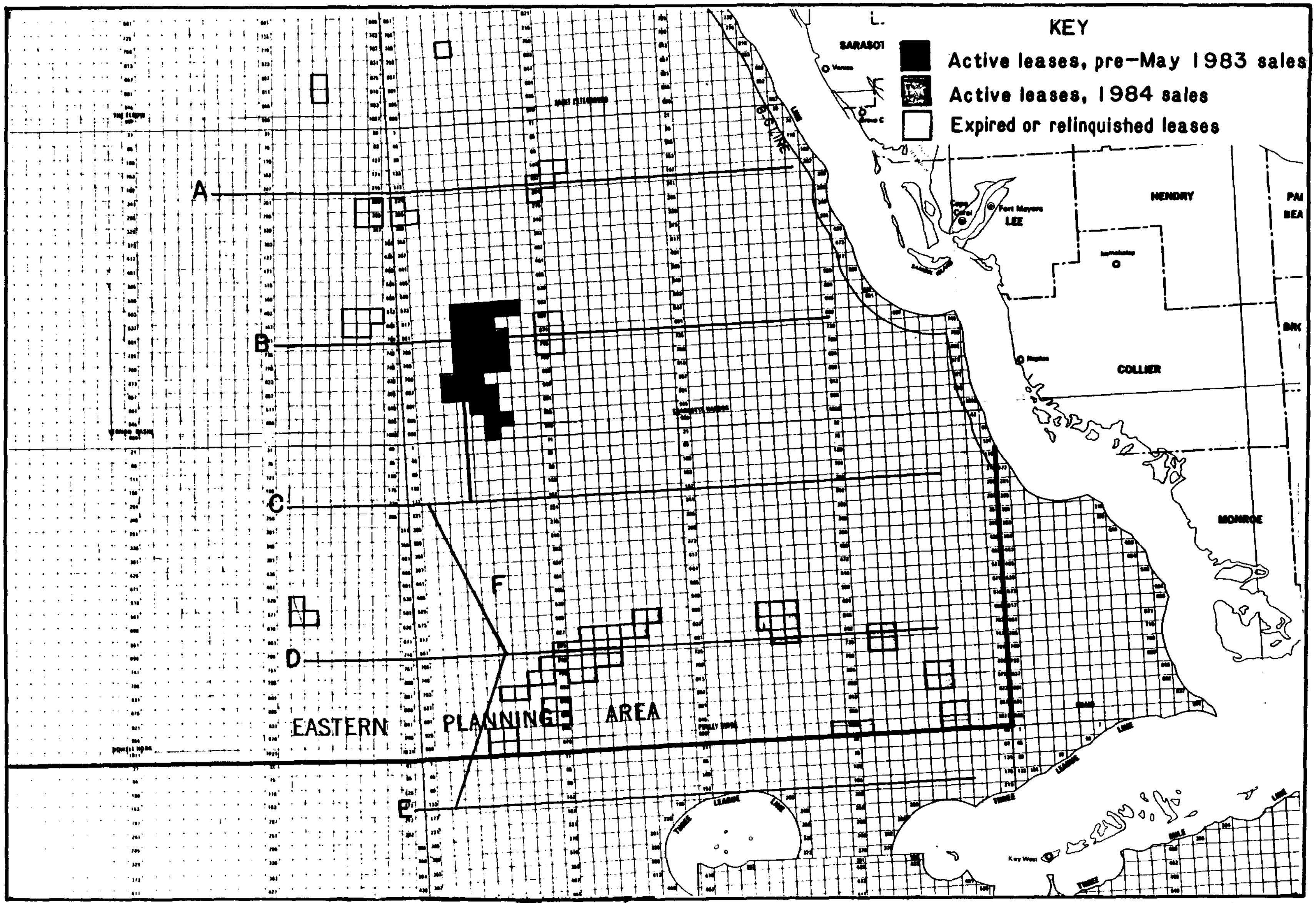


Figure 9-1. Southwest Florida shelf OCS oil and gas lease tracts and Year One and Two study transects (A-F ; after MMS, 1984).

9.2 GENERALIZED OIL AND GAS DEVELOPMENT ACTIVITIES

This section briefly describes the principal types of activities associated with OCS oil and gas exploration and development that are most likely to produce impacts on the local marine environment (Figure 9-2).

9.2.1 Lease Exploration

Exploratory drilling within a lease block is the initial activity which could impact the biota of the southwest Florida shelf. Sources of potential impact include the placement of the drilling platform and/or anchoring of the platform; the discharge of drilling muds, drill cuttings, and cooling water; and other minor discharges including sanitary wastes and deck drainage.

9.2.1.1 Rig Emplacement

Initial geophysical surveys are performed to determine geologic hazards, bottom stability, cultural resources, and other conditions which bear on the choice of exploratory drillsite locations. Within the present study region, the location of buried channels and karst features, minor near-surface faults, rock outcrops, and sea floor depressions, as well as live bottom biota distribution would need to be reviewed. Subsequently, a mobile drilling platform (jack-up, drillship, or semi-submersible) would be moved to the selected location. Depending on the type of platform utilized, it is positioned by either lowering of the legs (jack-up) or anchoring (semi-submersible and drillship).

Physical effects on the bottom, especially from dredging operations in areas which had been formerly polluted, can mobilize hydrocarbons, trace metals, etc. as sediment is disturbed and resuspended. Such disturbance can also change the nature of the bottom, bringing up flocculent sediment (which is a better absorber of pollutants) and breaking up cemented bottom surfaces.

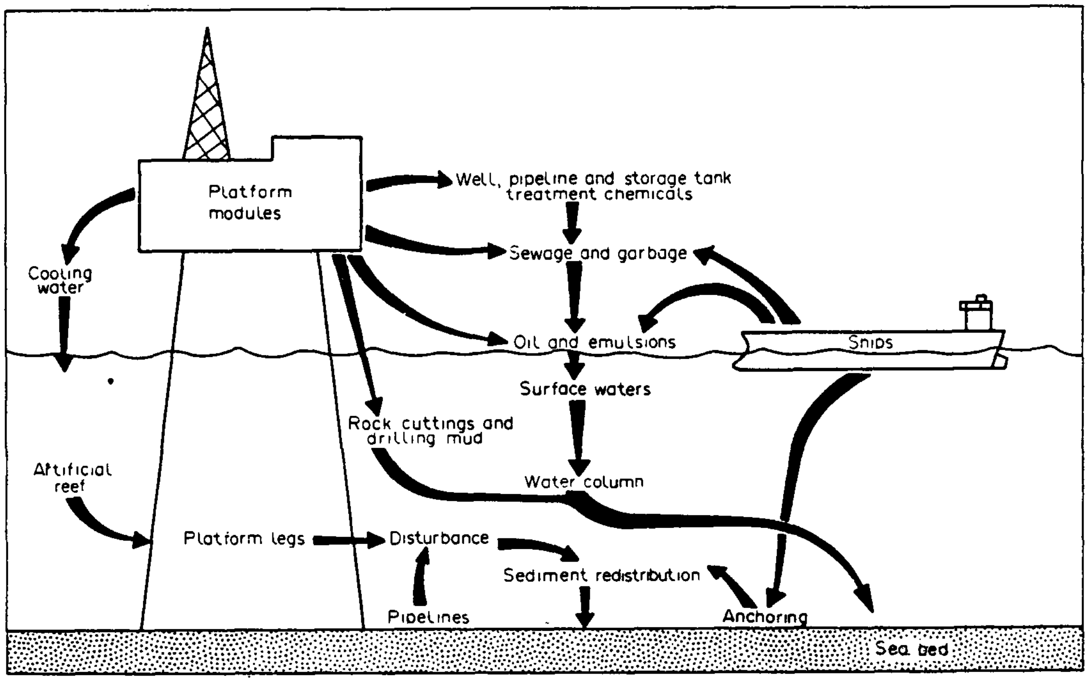


Figure 9-2. Potential pathways for various biological effects of oil and gas development (Dicks, 1982). Additional pathways include atmospheric imputs from flare stacks and fires, release of produced waters, and export through "reef" species food chains.

9.2.1.2 Drilling Mud and Cuttings

The potential affects of discharging drilling muds and cuttings into marine environments have been extensively studied. Recent reviews include those of the National Research Council (NRC), 1983) and Duke and Parrish (1984).

Drilling muds are used in the drilling operation to cool and lubricate the drilling bit and drill pipe, to remove formation cuttings, to insure controlled and efficient drilling through maintenance and integrity of the borehole, and to minimize corrosion. Generally, the drilling muds are separated from the cuttings (which are continuously discharged during actual drilling operations) and recirculated through the borehole. The drilling muds must be discharged periodically to meet changing conditions encountered at greater depths in the borehole. Discharges of drilling fluids without cuttings generally occur eight to ten times during the drilling of an offshore well (Offshore Operators Committee, 1976).

Cuttings are composed of small pieces of the drilled formation rock and range in size from microns to a few centimeters (Gettleson and Laird, 1980). Large cuttings have been found to fall directly to the sea floor. Drilling muds adhering to the cuttings wash free as the cuttings descend to the bottom. Fine cuttings and muds generally form a visible plume which disperses from a discharge pipe (Ayers et al., 1980b). In areas where bottom current velocities are high, drill cuttings do not accumulate on the bottom but are either entrained into the sediments or dispersed over a large area (Ray and Meek, 1980). In contrast, cutting piles have been observed in areas of low bottom current velocities (Zingula, 1975). Piles of cuttings as large as 30m in diameter and 1m in height have been observed at drilling rigs where discharges were near the surface in areas of low current velocity. In similar low velocity areas, piles up to 1 to 3m in height and 19 to 22m in diameter have been observed at drilling rigs where discharges were shunted to within 10m of the bottom. these accumulations of cuttings would most likely smother the existing benthic biota but provide new substrates for future colonization.

Drilling muds and cuttings sometimes contain hydrocarbons and toxic metals such as chromium. Barium (and its trace metal contaminants, such as lead, zinc, cadmium and chromium), while widely used as a drilling mud additive, is though to be of low solubility (NRC, 1983). The bentonite clay used in drilling muds absorbs hydrocarbons more strongly than other sediment components. Cuttings normally bear little hydrocarbon load but are essentially inseparable from mud. There can be a release over time of some of the absorbed hydrocarbons and trace metals.

9.2.1.3 Cooling Water

Sea water is often pumped through engine jackets on the drilling rig for once-through cooling of the engines. The volume of water utilized in this manner varies depending on the type of drilling rig. This water does not come in contact with anything other than the engine jacket, therefore, temperature is the only property of the water which changes during this operation. The average temperature increase of the discharged cooling water is 6 to 8°C.

9.2.1.4 Blowouts and Chronic Spills

Both oilwell blowouts and chronic spills of oil can occur during exploratory drilling although extensive precautions are required to minimize such events. Either event would increase the hydrocarbon load in the water and some hydrocarbons could be added to bottom sediments. Pollutants could be released again if the sediments are disturbed.

9.2.2 Oilfield Development and Production

The principal differences between lease exploration and oil field development are in the much larger scale and longer time-frame of the later.

Platform placement will cause bottom disturbance, but on the positive side, the artificial reef effect due to the platform's presence attracts sessile biota and fish to the site (see Section 9.4.3). Resulting increases in sediment organic content can tend to concentrate pollutants (polycyclic aromatic or chlorinated hydrocarbons) closer to the platform (J.N. Butler and J.R. Payne, personal communication, 1984).

In addition to drilling muds and cuttings, cooling water, sanitary wastes and deck drainage, and blowouts and chronic spills -- all noted above -- field development results in the generation of produced water.

9.2.2.1 Produced Water

Produced water is commonly mixed with the oil and gas which is extracted from a reservoir formation. The ion ratios of this produced water generally differ from the ion ratios found in the sea water at the production site. Appreciable concentrations of the cations sodium, magnesium, and calcium and the anions chloride, sulfate, carbonate, and bicarbonate are generally found in the produced waters. The concentrations of the total dissolved constituents vary over a wide range, generally from a few milligrams per liter to over 300,000 milligrams per liter.

Metals generally found in produced water include calcium, magnesium, potassium, strontium, aluminum, boron, barium, iron, and lithium. Other metals such as chromium, copper, manganese, nickel, tin, titanium, and zirconium are present in low concentrations. Concentrations of the trace metals, with the exception of copper, chromium, manganese, and strontium, are not substantially different from concentrations typically found in sea water.

Oil and grease in the produced water are removed by a treatment system on the production platform. Trace residues are discharged with the production water. Rapid dilution of the produced water upon discharge decreases the concentration of these hydrocarbons around the drilling platform and it is unlikely that they would produce any significant impacts.

9.2.2.2 Pipeline Activities

The majority of offshore production platforms in the Gulf of Mexico transfer their oil and gas to land-based facilities for treatment and/or shipment. This requires the installation and maintenance of pipelines and pumping facilities.

9.2.2.3 Increased Boat Traffic

The installation, development and servicing of offshore production platforms will lead to increases in boat traffic of various types. This in turn increases the probability of minor fuel spills, release of bilge water, sanitary wastes, etc.

9.2.2.4 Spills

Increased offshore development and production can be expected to lead to increased probabilities of spills, blowouts, pipeline leaks, discharges of ballast and bilge water from increased supply/work boat and tanker traffic, etc. All of these events can potentially increase total hydrocarbon and pollutant input to the water column and eventually to marine sediments. Effects associated with pipelines and tanker discharges may be noted long distances from actual oil and gas production sites.

Information on the potential for oil spills on the southwest Florida shelf, and their potential trajectories and land-falls should they occur, are available from at least four sources:

- Empirical studies of circulation using surface drift bottles (Williams et al., 1977) and Woodhead surface drifters (Parker et al., 1979)
- Empirical distributional studies of crude oil residues -- pelagic tar/tar balls (FIO/USF, 1981, 1982)
- Theoretical oil spill risk analysis and oil spill trajectory analysis performed by the U.S. Geological Survey (Lanfear, Smith and Slack, 1979; Lanfear and Samuels, 1981; LaBelle, 1982).
- Ongoing MMS Eastern Gulf of Mexico physical oceanography research programs.

9.3 OCS DEVELOPMENT IMPACTS TO SOUTHWEST FLORIDA SHELF OFFSHORE AND COASTAL ENVIRONMENTS

9.3.1 Southwest Florida Shelf Environmental Review

9.3.1.1 Water Column Environment

Results of the present study indicate that the southwest Florida shelf is oligotrophic (see Volume 2, Section 4.4.4.6). This classical subtropical-tropical situation is characterized by low dissolved nutrient levels and high water temperatures and salinities. The Loop Current dominates circulation in the eastern Gulf of Mexico and also has pronounced effects on the circulation of the southwest Florida shelf (Section 8.1.1).

Outer continental shelf waters were very oligotrophic during the periods sampled. Nitrate concentrations were low, as were chlorophyll concentrations, within the top 40 to 60m of the water column. The nutrient and chlorophyll concentrations were similar to those reported for the oligotrophic central waters of the Gulf of Mexico, suggesting that there is no real distinction between outer continental shelf and open Gulf of Mexico surface waters. This situation contrasts with that of other continental shelves where there is a distinct difference in nutrient and chlorophyll properties compared with offshore waters. Most of the primary productivity within the water column was associated with a mid-depth chlorophyll maximum layer which ranged from 40m to 60m in depth. This pattern is also similar to that reported for the open Gulf of Mexico (R.L. Iverson, personal communication, 1982).

There is strong support for the applicability of the enrichment model proposed by Riley to explain the occurrence of water containing high nutrient concentrations near the bottom along continental shelf edges. Salinity, temperature, density, and nitrate isopleths all suggest an advective upwelling of nutrient-rich water along the shelf edge in southwest Florida waters associated with Loop Current activity. Benthic sampling studies documented the presence of extensive beds of several species of bottom-dwelling macroalgae. These populations are living at low light-levels in 60 to 100m of water and are found within the region of upwelled nitrate.

Phytoplankton data for the eastern Gulf of Mexico indicate that diatoms dominate inshore coastal areas while dinoflagellates often dominate open Gulf of Mexico waters, particularly in terms of species richness. Steidinger (1973) also found that phytoplankton species composition in coastal areas fluctuates throughout the year. Seasonal peaks vary geographically and from year to year. Data on succession and seasonality are difficult to interpret but maximum productivity occurred during the spring and summer.

Zooplankton constitute a major link between phytoplankton primary production and higher trophic levels in the pelagic food web. Patchy distribution of zooplankton makes abundance estimation difficult. Copepods are the most abundant zooplankters. Common neritic species in the Gulf of Mexico include the calanoids *Euchaeta marina*, *Neocalanus gracilis*, *Scolechithrix danae*, *Candacia pachydactyla*, *Undinula vulgaris*, *Eucalanus attenuatus*, and *Acartia tonsa*, and the cyclopoids *Copilia mirabilis* and *Corycaeus* spp. Euphausiids, chaetognaths, ctenophores, cnidarian medusae, salps, pteropods, and a variety of meroplanktonic larvae also contribute to the neritic zooplankton assemblage in the Gulf of Mexico (United States Department of the Interior, 1978).

Ichthyoplankton, especially larvae of commercial fish, are a component of the zooplankton which is of incipient economic value. Houde et al., (1979) reported the ichthyoplankton of the eastern Gulf of Mexico to be abundant and diverse. Larval species characterizing the eastern Gulf of Mexico include *Syacium papillosum*, *Decapterus punctatus*, and *Diplectrum formosum*. Houde (1975) reported higher mean abundance of ichthyoplankton at stations greater than 50m in depth. Similarly, Houde et al., (1979) reported significantly higher ichthyoplankton species richness at depths greater than 50m than at shallower depths.

9.3.1.2 Southwest Florida Shelf Benthic Environment

Substrate analyses from this study (Volume 2, Section 5.0) permit identification of three distinct sediment types in the study area. Soft bottom areas in the northeastern portion of the study area (Station 2 for example) are dominated by the quartz clastics facies. Fine grained carbonate mud is found in the southern portion of the study area (Stations 25 and 26 for example) adjacent to the Florida Keys. The remaining soft bottom sites within the study area are dominated by carbonate sand.

Hydrocarbons

Surficial sediment hydrocarbon analyses from this study identified low levels of biogenic hydrocarbons at all soft bottom sample sites. Anthropogenic hydrocarbons were found at a single site (Station 12) and were attributable to inputs of clay particles carried south by the Loop Current from the northern Gulf of Mexico and Mississippi River areas. Overall, it was concluded that the southwest Florida shelf carbonate sediments contain low levels of hydrocarbons from biogenic sources. Possible hydrocarbon contamination from offshore oil and gas development activities should be readily distinguishable against these virtually "pristine" background conditions.

Trace Metals

Previous work on central and northwest Florida shelf surficial sediments (Alexander et al., 1977; Presley et al., 1975; Trefry et al., 1978) has shown these areas to have very low trace metal concentrations. The primary factor contributing to these low concentrations is the dominance of carbonate in these areas. Results from this study confirmed that low trace metal concentrations are also typical of the southwest Florida shelf, for the same reasons. As with hydrocarbons, possible increases in trace metal concentrations due to offshore oil and gas development activities should be readily distinguishable above present "pristine" background conditions.

Biota

Onshore-offshore zonation of biological assemblages across the west Florida shelf has been suggested by several previous workers (Collard and D'Asaro, 1973; Defenbaugh, 1976; Lyons and Collard, 1974). Collard and D'Asaro (1973) suggested two faunal provinces but found no clear-cut boundaries between them. The two provinces were shallow shelf assemblages, which had Carolinian affinities, and deep shelf assemblages, which had West Indian affinities. Defenbaugh (1976) identified three biotal zones on the west Florida shelf: an inner shelf, intermediate shelf, and outer shelf assemblage, respectively. Lyons and Collard (1974) suggested four zones in this same region: Shallow Shelf (10 to 30m); Middle Shelf I (30 to 60m); Middle Shelf II

(60 to 140m); and Deep Shelf. More recently, Lyons and Camp (1982) confirmed the designation of the Shallow Shelf (10 to 30m) and Middle Shelf I (30 to 60m) zones based on multivariate analysis of much of the biological data from the Hourglass Cruises.

Soft Bottom Biota -- Results of the present study indicate that bathymetric zonation is characteristic of both the epifauna and macroinfauna from soft bottom areas of the southwest Florida shelf. Cluster analysis of the epifaunal data showed distinct bathymetric groupings, indicating onshore-offshore differences in species distributions. Analyses of the macroinfauna data also showed distribution patterns related to bathymetry and sediment grain size parameters. No obvious patterns of latitudinal or bathymetric dispersion were found for the epiflora, however.

Analysis of television observations revealed that offshore middle shelf stations were characterized by an Outer Shelf Sand Bottom Assemblage. This epifaunal assemblage is characterized by asteroids, crinoids, chinoids, ophiuroids, sea pens, anemones, crustaceans, and scattered hexactinellid sponges. An Inner and Middle Shelf Sand Bottom Assemblage, which is dominated by algae, asteroids, bryozoans, chinoids, holothuroids, sea pens, and scattered hard corals and sponges, characterizes the inshore middle shelf and inner shelf stations.

Live Bottom Biota -- Results of this study indicate the presence of three live bottom biotal zones in the study area. The outer portion of the middle shelf zone is dominated by small coralline algae, algal nodules, or *Agaricia* coral plates. A distinct inshore middle shelf zone, distinguished by the presence of sponges, is also evident from analysis of the live bottom data. Inner shelf stations are characterized by algae, ascidians, large or small gorgonians, hard corals, hydrozoans, and sponges. The depth ranges noted for these three zones confirm the bathymetric delineations presented by Lyons and Collard (1974).

9.3.2 Southwest Florida Shelf Offshore Development Impacts

9.3.2.1 Exploratory Phase

The types of rigs used during exploration are usually either floating or bottom-supported types: jack ups, submersibles, semi-submersibles, drilling ships, and drilling barges. Disruption of the seabed in the immediate vicinity of the drilling rig is likely. Some local habitat may be destroyed and biological communities may be smothered. Disturbances would be limited to 1 to 2km (or less) surrounding the rig. Because of the biological stipulations placed on lessees working specific lease blocks, damage to sensitive benthic habitats and communities can probably be avoided (BLM, FEIS 67/69). If the drilling activities occur adjacent to reef tracts or other live bottom communities, anchor damage from ships attending the drilling rigs and from the floating rigs themselves, may have the greatest potential for causing environmental damage. Davis (1977) demonstrated the extent of damage to a high-profile reef in south Florida subjected to only a moderate amount of pressure from recreational boating.

Drilling Mud & Cuttings Impacts

A major concern during offshore drilling operations is the disposal of drilling muds and cuttings. Drilling muds are comprised of barite, bentonite, lignosulfonates, lignites, and a minor amount of other compounds. The possible release of barium, chromium, lead, and hydrocarbons (the latter only if the drilling muds are oil-based, which is generally prohibited under EPA-NPDES permits for each OCS region) may have serious effects on benthic communities (Reviewed in Symposium on Research on Environmental Fate and Effects of Drilling Fluids and Cuttings, Proceedings. January 21-24, 1980, Lake Buena Vista, Florida; and by NRC, 1983).

The fate of drilling mud discharges from wells has been monitored on several occasions. Drilling muds are released at or near the surface of the water column at unshunted wells. Typically, two plumes have been associated with unshunted bulk discharges. The heavier fraction of the discharged drilling muds descends immediately to the bottom, leaving the less dense fraction in the water column (Ayers, et al., 1980a; Houghton et al., 1980; Ray and Meek, 1980). This upper plume has been found to spread over the thermocline (Continental Shelf Associates, Inc., 1978). Tracking studies of the water column plume have shown transmissivity to be the only hydrographic parameter altered beyond the immediate vicinity of the discharge source (Ayers, et al., 1980a). Trocine and Trefry (1981) observed a 10^6 dispersion factor for total drilling solids within 2,000m of discharge near the Flower Garden Banks in the northwestern Gulf of Mexico.

In one recent study (Tanner Bank, Southern California) that specifically examined the behavior of released drilling muds from an oil rig, Ray and Meek (1980) report:

> *"The exploratory drilling operation required 85 days to reach a total depth of 3,419m. During this time a total of 315 cubic meters of cuttings were produced .... the first two days cuttings were deposited directly on the seabed. Subsequently, mud circulation was established and all cuttings were returned to the platform for disposal .... Total bulk mud discharge was 2,460 bbl .... Mud and cutting discharges had little effect on water quality, with the exception of percent transmittance. At a maximum discharge rate of 754 bbl/hr, transmittance was still affected at 1,000m. Within 200m of the discharge, total suspended solids were approaching background levels. Metal concentrations in all discharges approached background levels in 100 to 150m ...."*

The fate of the released drilling mud was undetermined in this study, thus possible physiochemical and biological effects (Figure 9-3) remained unknown. The study does show, however, that the immediate effects of releasing drilling muds would probably be both localized and relatively minor.

Thompson and Bright (1980) subjected seven species of corals to three concentrations of whole drilling muds for 96 hours in aquaria maintained 2 to 3m underwater off Key Largo, Florida. They found that all species exhibited polyp retraction; specimens of three species died following exposure to 1,000µl/1 of mud. One certain effect of drilling mud and cuttings disposal would be an increase in turbidity, at least on a local and short-term scale.

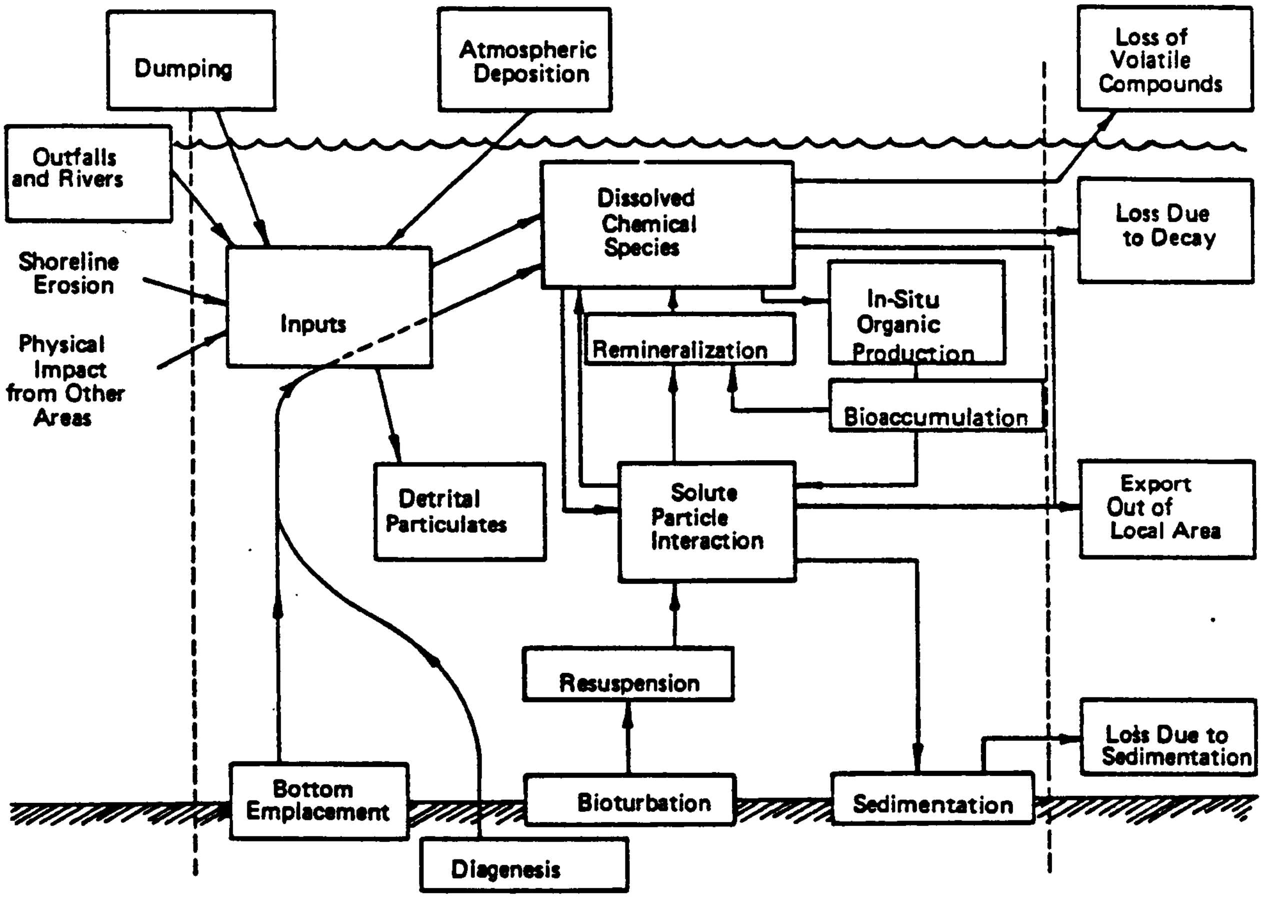


Figure 9-3. Possible transformations of a pollutant in the water column (MMS, 1982).

Increased turbidity (typically caused by dredging operations) has been shown to damage or destroy benthic communities in tropical waters (see for example, Sverdloff, 1971; Johannes, 1972; Voss, 1973).

Primary concerns of the impact of drilling fluids on benthic systems have centered around: (1) smothering of sessile invertebrates, (2) changes in community structure due to decreased hard bottom availability, (3) burial of infauna inhabiting sand cover, and (4) decreased algal growth due to increased turbidity (Marine Resources Research Institute and Coastal Resources Division, 1981). Smothering of sessile invertebrates and coverage of emergent rock are probably the most severe potential impacts on live bottom assemblages. Petrazzulo (1981) determined that no substantial reduction in benthic macro-infaunal abundance would occur at distances greater than 1,000m from an exploratory drilling rig. Increased turbidity in areas such as the southwest Florida shelf, may affect macroalgal production and filter-feeding sessile invertebrates. An additional concern is settling of clay size particles from drilling muds over a typically carbonate sand substrate. In addition to smothering the infauna within the sediments, settlement of benthic larvae may be inhibited (Tagatz and Tobia, 1978; Tagatz et al., 1978).

Impact from oil and gas operations on the biota of the southwest Florida shelf is difficult to assess since it may be mitigated or intensified through the complex interactions of the components of the biota. For example, a decrease in the abundance of one species may result in changes of abundances of other species due to microhabitats or trophic interactions, e.g., predation. However, it is possible to speculate on potential impacts which might occur as a result of drilling activities.

Discharged drilling muds, which are typically fine-grained sediments, may alter the predominant grain size of a small area (probably within a radius of <2km). With the exceptions of Stations 25 and 26, sediments at the soft bottom stations were predominantly sand. Changes in the grain size composition of the sediments in the vicinity of a drilling operation might affect the structure of the infaunal assemblage through burial, as well as change the suitability of the sediment for recruitment. The addition of trace metals and petroleum hydrocarbons, during production activities, to sediments that presently have very low concentrations of these substances may also affect the biota. Deposition of discharged drilling muds on live bottom areas would decrease the availability of hard substrate. This decrease could alter the structure of the live bottom community in the immediate vicinity of the drilling operation.

Turbidity will be increased in the vicinity of drilling operations. Since turbidity is often higher inshore, the impact of decreased light penetration will probably be less nearer to the coast; however, the proximity of the bottom to the discharge source may increase this impact since dilution and dispersion will be less in shallower water. The inner and middle shelf live bottom assemblages are probably more adapted to greater fluctuation of abiotic factors (temperature, salinity, turbidity, sedimentation) than outer shelf live bottom assemblages; however, this fact does not insure that the assemblages would be able to withstand the turbidity and sedimentation added by drilling discharges. Increased turbidity would most likely affect algae and corals by reducing primary productivity (production by symbiotic zooxanthellae in the case of corals). In offshore areas (Agaricia Coral Plate Assemblage and Outer Shelf Crinoid Assemblage), the potential for dilution and dispersion of discharged drilling muds is greater, but the biota and benthic macroalgae will be more sensitive to decreased light penetration since they are adapted to a very clear water environment. This impact can, potentially, be alleviated to some extent by locating drilling operations away from live bottom areas. Detrimental changes due to drilling mud discharges are generally localized near the drilling operation (Ecomar, 1980).

Agaricia corals are extremely susceptible to sedimentation; hence discharges of drilling muds near the Agaricia Coral Plate Assemblage (see Volume 3, Section 6.0) would be detrimental. Hubbard and Pocock (1972) examined the capabilities of various scleractinian corals with respect to sediment rejection and found Agaricia to be capable of rejecting only fine-grained sediments. Since this coral is only found in clear water environments, where sedimentation is generally low, increased sedimentation in the vicinity of this assemblage could jeopardize the health of this community.

Suspension feeders may also be susceptible to increased loads of sediment in the vicinities of drilling operations. Particles of discharged drilling muds will not be of nutritive value to suspension feeders, but will increase the load for filtering. Although this may not affect organisms which routinely ingest large quantities of sediments, e.g., bivalves, other organisms may expend large quantities of energy handling particles which provide no nutrition.

9.3.2.2 Production Phase

Oil Spill Impacts

Once oil is in the marine environment, its behavior, fate, and effects on biota are extremely unpredictable (Figure 9-4). Water temperature, salinity, sea state, weather conditions, age of the oil, its composition and solubility, and the treatment the oil receives during clean-up have all been shown to affect its toxicity (see, for example, Straughan, 1972; Evans and Rice, 1974; Malins, 1977; Wolfe, 1977). Evaporation, dilution, dissolution, mixing, biodregration, and absorption are some of the processes that alter the composition and toxicity of oils. In general, crude oil is less toxic to marine biota than refined hydrocarbons. The toxicity tends to be proportional to the aromatic content. Oil slicks probably have less of an effect offshore than in coastal waters where they often become stranded and coat the seabed, smothering the benthic communities. Hershner and Lake (1980) showed that a substantial portion of a coastal salt marsh was destroyed following an oil spill. Other effects noted were delayed plant growth/development the following spring, increased plant density, and reduced plant biomass per stem.

Following an oil spill, a variety of general effects to organisms can be expected:

- Direct kill of animals by oil coating or asphyxiation.
- Organisms may die through direct contact poisoning.
- Exposure to water soluble fraction (WSF) of oils may cause deaths.
- Sedentary forms appear more susceptible than mobile species or life stages.

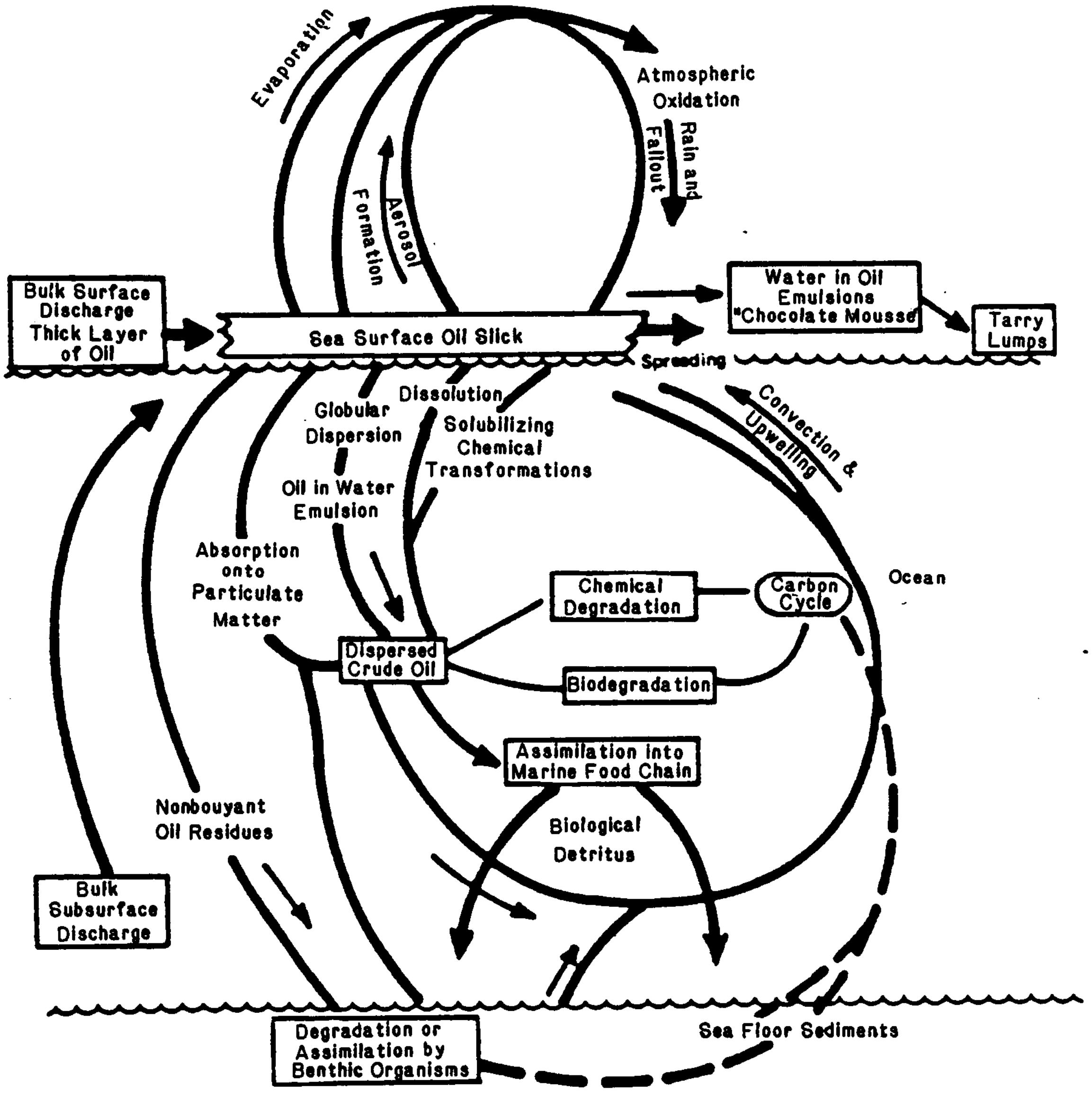


Figure 9-4. Processes Affecting the Fate of Spilled Oil (Jordan and Payne, 1980).

- Juveniles of a species tend to be adversely affected to a greater extent than adults.
- Incorporation of sublethal amounts of oil within tissues may lead to the inability to survive diseases or other stresses.
- Some hydrocarbon derivatives are potentially carcinogenic.
- Sublethal doses of oil and its derivatives may lead to the disruption of normal physiological processes and affect behavior (Blumer, 1970).

The existence of a subsurface chlorophyll maximum layer on the outer edge of the continental shelf, with its associated phytoplankton productivity, suggests that accidental input of hydrocarbons to the sea surface may not primarily affect phytoplankton productivity through toxic effects. The primary effect would be through reduction of light energy if enough material were to accumulate on the sea surface.

Pipeline Dredging Impacts

Among various oil-related development activities, trenching operations associated with pipelaying are most likely to cause environmental disturbances. Pipelines in less than 200 feet (60m) of water are usually buried to minimize their potential as an obstruction on the sea floor (Gowen et al., 1980). Dredging activities greatly increase the turbidity in the local environment and depending on the flushing characteristics of the basin, may have long-term effects. Benthic biota may be smothered or their feeding mechanisms interfered with. Any pollutants associated with the sediments, such as hydrocarbons and heavy metals, will become resuspended and reintroduced into the pelagic environment. Sensitivity to these pollutants by larval and juvenile fishes, crustaceans, and molluscs has been extensively documented by Morton (1971) and Stern and Stickle (1978). Feeding and molting rates may decrease, orientation become disrupted, respiration impaired, and predator avoidance affected. Dredge spoils may also interfere with bottom trawl fishing, cause excessive gear loss, and effectively eliminate an area from fishing (Carstens, 1977).

Dredging activities near-shore will have greater effects than those offshore. Sensitive and unique habitats (i.e., wetlands, mangroves, seagrass beds) occur all along the southwest Florida coast (Figure 9-5). These sites are important

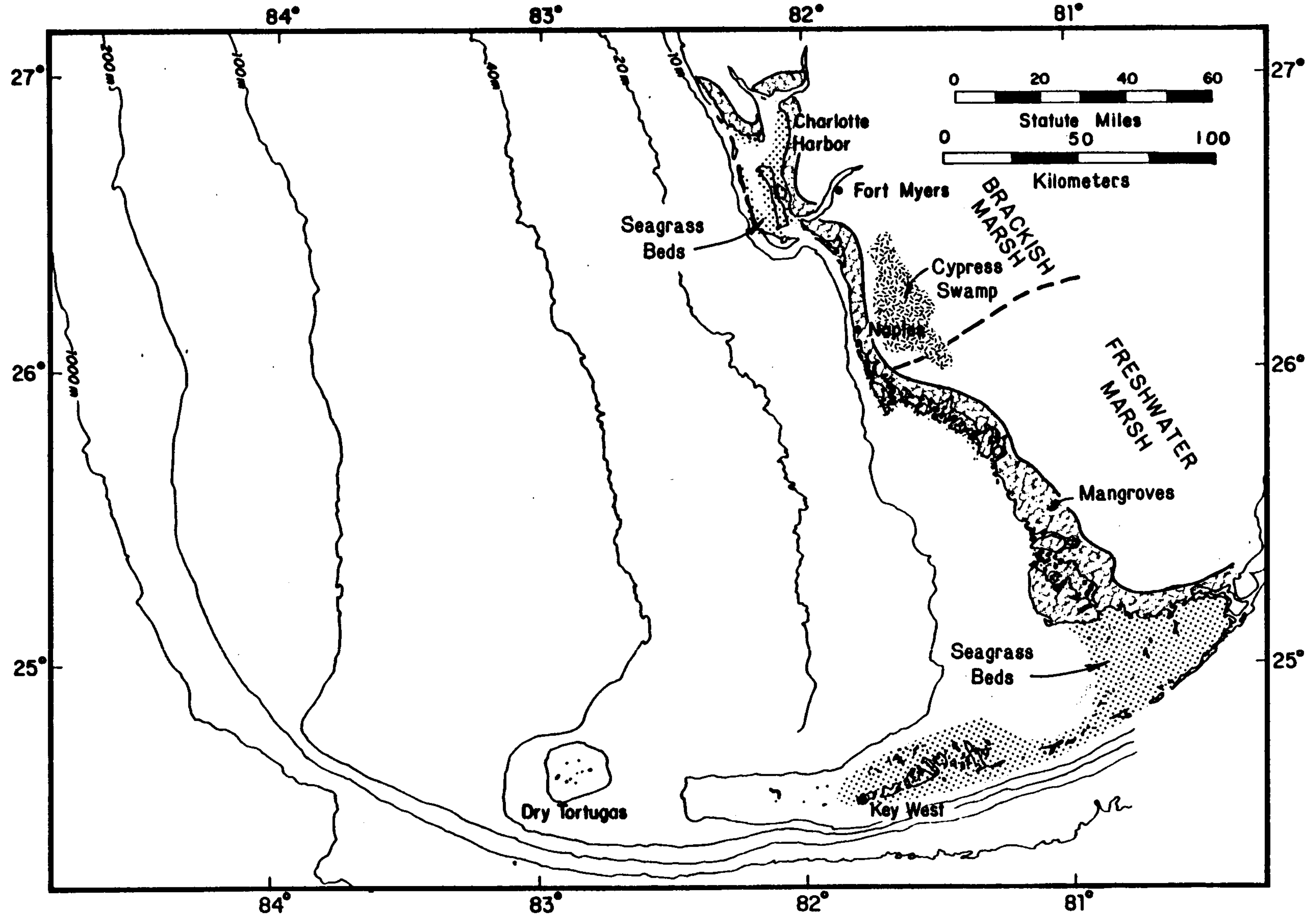


Figure 9- 5. Southwest Florida shelf: approximate distribution of principal near-shore coastal vegetation types (after USFWS, 1981).

nesting and nursery grounds. Small areas of biological significance (i.e., shellfish and grass beds) are distributed throughout the coastal environment. Because of their shallowness, and often limited tidal flushing, resuspended material tends to remain in suspension in the vicinity of the dredging. Often this material has a high organic content which can trigger phytoplankton blooms. Blue-green algae in particular respond to an increase in carbon and nutrient sources by large increases in their numbers. Eutrophication in the coastal zone results in lower dissolved oxygen content in the water, at times below the physiological tolerances of fish, shrimp, and crabs. Clupeids and eugraulid, fishes and adult crustaceans are notably sensitive to low oxygen levels (Thorhaug et al., 1978; Eisler, 1979). Surface sediments in coastal Florida waters probably contain greater concentrations of hydrocarbons and heavy metals than sediments further offshore. In industrial centers like the Tampa Bay area, these types of pollutants are carried into the marine environment via sewage runoff, and riverine discharges. Ship traffic is responsible for introducing hydrocarbons which end up in the sediments. Dredging activities release these contaminants, many of which adversely affect marine life. For example, feeding behavior of blue crabs is inhibited by the water soluble fraction of crude oil at concentrations as low as 0.03 ppm (D. Pearson, Batelle NW Laboratory, Sequoia, WA, personal communication, 1982). Fishing on the continental shelf is conducted primarily with otter and beam trawl gear. The finfish sought are highly mobile and not dependent on specific small areas for feeding, shelter and reproduction. Thus they can more easily avoid the dredging and pipelaying activities. Commercial fishermen are concerned with the potential obstruction caused by pipelines, offshore platforms, the ganglines that connect them, and the debris from trenching activities. Nets can hang up and tear; otter trawl doors may hook under the pipelines. Pipelines themselves may be damaged by trawl gear, especially beam trawl equipment (Gowen et al., 1980).

Loss of fishing area is a commonly voiced complaint by the fishing industry. Several recent studies suggest that this is not a really serious problem. Mackay (1979) calculated that the total fishing area in the North Sea that was eliminated because of pipeline right-of-ways was 0.2-0.92% of the area fished. Similarly, Olsen (1977) estimated that only 73 to 364 acres per square mile (11.4 to 56.9%) were lost along the pipeline route to Georges Bank. Gowen et al. (1980) compared the amount of sediment disturbed by surf clamming, scallop dredging, and otter trawling with that of dredging associated with pipeline laying. The effects of fishing on the sediment far exceeded that of pipeline laying.

Summary

In summary, local disturbances from pipeline installation and operation are likely. Leaks or spills from ruptured pipelines will rarely occur and will be relatively small in size. Nearshore habitats are more sensitive to impacts than offshore ones and the effects are likely to be more severe. Adverse effects to the fishing industry are not expected to be extensive, provided some care is taken to route pipelines in such a way as to avoid prime fishing areas.

Accidental oil spills from tankers or the normal discharge of their ballast waters are two major sources of oil pollution in marine waters. Most of the releases are small, only 3% of the spills in the Gulf of Mexico exceeded 50 barrels during 1974-1979 (BLM, FEIS 67/69). The effects of a single spill are therefore minor and localized in most cases. If the spill is large and occurs near the coast, then the effects upon biota may be considerable as described for the DELIAN APPOLON grounding in Tampa Bay in 1970. The repeated, small-scale releases of petroleum products in harbors and ports probably has a larger effect on populations and habitats than the occasional large spill at sea. Chronic sublethal effects of oil in the coastal zone of southwest Florida have not been studied in any comprehensive manner, however, and suspected biological effects must be extrapolated from other better known areas.

9.4 SPECIAL REGIONAL CONCERNS

9.4.1 Biologically Sensitive Areas Offshore

Much of the southwest Florida shelf is comprised of unconsolidated soft sediments and characterized by relatively low productivity. Scattered areas of apparently more productive "live bottom" habitats also occur. The MMS defines such locales as those which contain corals, sea fans, sea whips, sponges, bryozoans, anemones, etc. growing on rock outcrops, and providing an irregular topography that can be utilized by fishes, crustaceans, molluscs and turtles. Coral reef communities of Florida are described in general terms by Smith (1971), while Bright and Japp (1976) present data on these habitats along the southwest Florida shelf. The coordinates of some reefs and banks are well known (i.e., Florida Middle Grounds, Howell Hook, the reef tracts associated with the Florida Keys). Prior to the study reported here, however, little information was available that identified the location and described the communities of "live bottom" areas within proposed OCS lease areas south of 26°N latitude.

Recognizing both the relative scarcity and ecological importance of "live bottom" areas on the southwest Florida shelf, the federal government has imposed biological stipulations on industry, should they commit to exploratory drilling on certain lease tracts. There are 77 lease tracts seaward of Tampa-Charlotte Harbor that have been designated as biologically sensitive areas. To mitigate against possible harm to these areas, lessees are to provide bathymetric maps and sea floor photographic surveys. Maps must show any "live bottom" areas within a 1,820m radius of the proposed exploration and production activity site. If lessees follow the directives of the stipulations, significant negative impacts to these biologically sensitive areas will most likely be avoided (MMS 1981).

In the event of an oil spill or blowout at a platform site near a reef area, the reef may become coated with oil and exposed to the water soluble fraction (WSF) of that oil. Populations of sessile organisms may be seriously injured or killed. Peters et al. (1981) showed how No. 2 fuel oil became incorporated into the tissues of a coral, Manicina areolata, and resulted in impaired reproductive tissue, loss of zooxanthellae, and atrophy of muscle tissue. Loya and Rinkevich (1980) provide a review of the effects of oil and water soluble fractions of oil on reefs. Fishes and other mobile species may be able to avoid the acute impacts of an oil spill on their home ranges, but loss or damage to their feeding and shelter areas may lead to abandonment of these sites. While these individuals are seeking new reef habitats, they will probably be more vulnerable to predation.

9.4.2 Recolonization and Recovery of Live Bottom Areas

No data concerning recolonization or recovery rates for defaunated or damaged benthic habitats in the southwest Florida shelf study area are presently available. Some such measurements are being carried out as part of the ongoing Year Four and Year Five programs (R. Avent, MMS, personal communication, 1985). A preliminary assessment can be made on the basis of other studies conducted on the west Florida shelf and in the South Atlantic Bight.

Smith (1975) described recolonization of patch reefs that were decimated by a "red tide" kill in summer 1971. The reefs are located in 13 to 10m water depth near Sarasota, Florida. Over 77% of the resident fish species were eliminated immediately following the red tide, and populations of hard and soft corals, echinoderms, crustaceans, molluscs, and benthic algae sustained heavy mortalities. Blue green algae rapidly colonized decimated areas, followed by filamentous red and brown algae; although there was a second disturbance (Hurricane Agnes) the following summer, most benthic algae present before the red tide had apparently recolonized within the first year. Irregular fish censuses during the five years following the red tide revealed that: (1) the number of fish species returned to approximately the pre-impact level within about 16 months; and (2) species composition of the reef fish community approached that of the pre-impact community with one to two years. Recolonization by some epifaunal species was much slower, however, with several common and conspicuous reef species such as the spiny lobster (*Panulirus argus*), Atlantic deer cowrie (*Cypraea cervis*), the alcyonariam corals *Muricea elongata* and *M. laxa*, and two ophiuroids, *Astrophytum muricatum* and *Ophiothrix suensoni*, still absent nearly three years after the red tide.

Marine Resources Research Institute (1984) assessed the potential for colonization of newly submerged hard substratum (e.g., platform legs) and recovery of defaunated hard bottom areas in the South Atlantic Bight by (1) monitoring colonization of fouling plates over the course of one year, and (2) comparing epibiotal community composition on artificial reefs that had been in place for 3.5 to 10 years. The fouling plates were rapidly colonized by sessile (barnacles and hydroids) and motile (amphipods) epibiota. There were some seasonal variations in colonization, and community composition on the plates did not converge to any "climax" state within the one-year interval. The artificial reef study showed that epibiotal community composition was more consistent on the artificial reefs than on the one-year colonization plates -- suggesting that establishment of a fairly consistent epibiotal community on defaunated hard substratum may take several years. Even the 10-year artificial reef lacked large, sessile epibiota (certain sponges and hard corals) typical of natural hard bottom areas in the same vicinity. Thus, recovery of live bottom areas following a severe disturbance could take 10 years or more. A disturbed area might also recover in the sense of achieving a persistent community composition different from the one present before the impact occurred.

These studies provide only a general indication of the timespan that may be needed for recovery of live bottom areas following a disturbance resulting from oil and gas related activities on the southwest Florida shelf. The conditions obtaining in the wake of such a disturbance would not necessarily be like those following a red tide kill or deployment of an artificial reef. In the event that drilling is conducted on the southwest Florida shelf, the impacts on, and recovery of, nearby live bottom areas could be determined through a monitoring program.

9.4.3 Commercial Fisheries

Offshore exploration and development of oil and gas leases on the southwest Florida shelf probably will have an insignificant effect on the commercial fishing industry, unless a major oil spill event occurs. The oil and gas industry has coexisted with the fishing industry in offshore waters of Louisiana and Texas for more than 30 years. During 1977-1980, the U.S. port reporting the greatest tonnage of fisheries products landed was Cameron, Louisiana. Three other ports in Louisiana and Mississippi ranked among the countries top ten in commercial fishery landings (U.S. Dept. of Commerce, 1981). Although an adverse affect of OCS activities on the fishing industry is not expected, a brief review of the Florida commercial fishing industry follows.

The following statistics for commercial fishing in 1979 (BLM, FEIS 67/69) are characteristic for the region: Florida landings were 108.5 million pounds, valued at $90.8 million (17% of the value of the catch for the entire Gulf region). Shrimp are the most valued species for the industry, the 1979 catch was valued at $377 million for the entire Gulf. The Florida shrimp catch comprises about 15% of the total Gulf catch, and in 1980 was worth $44.3 million (Fisheries Management Plan, 1981a). Another commercially valuable species is the spiny lobster. Commercial landings of lobster in Florida were worth $11.6 million in 1979; 86.1% of the catch was landed in ports on the west coast of Florida (Fisheries Management Plan, 1981b). A small stone crab fishery is very important locally in southwest Florida in the Ten Thousand Islands region and Florida Bay. That catch had an ex-vessel value in 1979 of $3.8 million (Fisheries Management Plan, no date). Aside from shellfish, a United States and Cuban reef-fish fishery exists along the southwest Florida shelf. This fishery primarily targets red snapper and grouper. In 1978, these species accounted for 75% of the domestic catch and 85% of its value. Ex-vessel value of the domestic catch of reef-fish on the Florida southwest coast in 1978 was reported as $8.6 million (Fisheries Management Plan, 1981c). The three major fishing ports, based on total landings and value of the 1979 (BLM, FEIS 67/69) catch are:

Location	Landings ($\times 10^6$ lbs)	Ex-vessel Value ($\times 10^6$ \$)
Key West	16.5	25.9
Fort Myers	15.9	17.8
Apalachicola	10.4	10.1

General concerns voiced by commercial fishermen with respect to OCS activities are that drilling may hurt them financially because: (1) some productive fishing areas may be set aside exclusively for oil and gas development, (2) gear loss may result from hang-ups on uncovered pipelines and other oil-related structures in deep water, (3) an oil spill may taint their catch or foul their nets, and (4) waters in nursery grounds may become polluted (George Tamm, personal communication, 1983). In all likelihood, the greatest threat to the commercial fishing industry comes from the expected onshore development. Construction activities in the coastal, and even the adjoining upland areas, may have an effect on offshore fishing. Shrimp, lobster, crabs, and numerous species of reef-fish rely on the shallow estuarine waters of the southwest Florida coast as critical nursery grounds (see, for example, Costello and Allen, 1966; Allet et al., 1980; Davis and Dodrill, 1980; Bert et al., 1978; Stone et al., 1979). The pink shrimp (*Penaeus duorarum*), for example, spawn in the Dry Tortugas area, but larvae are swept into Florida Bay where they metaphorphose into juveniles. Juvenile pink shrimp are found in and amongst the mangrove islands and salt marshes throughout the brackish waters of the Everglades National Park, where they feed along the shoreline (George Tamm, personal communication, 1983). Any long-term change in surface hydrology that has an impact on the influx of freshwater and nutrients passing through the expansive marshes of southwest Florida is likely to affect the production of postlarval penaeid shrimp (Allet et al., 1980: Fisheries Management Plan, 1981a).

9.4.3.1 Fish Related Impacts

This study did not involve major sampling efforts directed toward commercially important fishes, and none of the most frequently collected fish species in our study are of commercial importance in the area. However, many fishes typically associated with hard or live bottom habitats serve as prey for commercially valuable fishes such as groupers (*Mycteroperca* spp., *Epinephelus* spp.) and red snapper (*Lutjanus campechanus*), which were not frequently collected in our samples.

Several investigators have reported high fish abundance, biomass, and species richness associated with live bottom areas (Marine Resources Research Institute, 1982, 1984; Darcy and Gutherz, 1984). In our study, the highest fish species richness (per trawl) was noted on the middle shelf at live bottom Stations 9, 10, 17, 21, and 27 and at soft bottom Stations 8, 16, 22, and 28, which exhibited some live bottom character. We did not specifically evaluate fish biomass or abundance because the trawl samples were unreplicated and the data were felt to be semi-quantitative at best.

Live bottom attracts fish species that use the habitat for feeding and/or shelter. Some species, such as sheepshead (*Archosargus probatocephalus*), graze directly on sessile live bottom epibiota (Marine Resources Research Institute, 1984). Others, such as sand perch (*Diplectrum formosum*) and tomtate (*Haemulon aurolineatum*) forage for infaunal prey in surrounding sand bottom areas. Still others, such as twospot cardinalfish (*Apogon pseudomaculatus*) and jackknife-fish (*Equetus lanceolatus*) may feed on water column animals, including nocturnally emerging benthic crustaceans (Marine Resources Research Institute, 1984). Of the two most frequently collected fish species at our sampling stations, the fringed filefish (*Monacanthus ciliatus*), is considered a plant/detritus feeder (Randall, 1983), and the dusky flounder (*Syacium papillosum*) is considered a generalized benthic carnivore (Toop and Hoff, 1972).

Oil and gas drilling activities could affect fishes associated with live bottom areas in several ways. Bottom disruption due to rig, platform, or pipeline emplacement, anchor deployment and retrieval, etc., may destroy or reduce habitat for those species that use an area for shelter. Bottom disruption and burial/sedimentation effects (e.g., due to deposition of discharged drilling muds and cuttings) on sessile epibiota could reduce food sources for species feeding on live bottom epibiota. Infaunal abundance and species composition might be affected by deposition of drilling muds and cuttings, and this could affect feeding by live bottom dwellers that feed on surrounding sand bottom. All of these effects should be local in scope and are not likely to have any overall effect on populations of commercially important fish species on the shelf.

Placement of drilling rigs and production platforms could also have beneficial effects in that additional habitat would be provided where there is currently little or no vertical relief. Studies by Gallaway and Lewbel (1982) and Boland et al. (1983) have summarized fish communities associated with oil and gas production platforms in the northwestern Gulf of Mexico. The platforms provide shelter and potential food (sessile and motile epibiota that colonize platform legs) for a great variety of demersal and pelagic fishes.

A major oil spill contacting coastal estuarine habitats would present the most serious potential threat to shelf fish populations, because many fishes use estuarine/near-shore areas as spawning or nursery grounds (U.S. Department of the Interior, Minerals Management Service, 1983).

9.4.3.2 Shellfish Related Impacts

Few commercially important shellfish species were frequently collected in our study. Some pink shrimp (*Penaeus duorarum*) were obtained from soft bottom Stations 6 (in the Sanibel grounds area) and 25 (in the Tortugas grounds area). Rock shrimp (*Sicyonia brevirostris*) were collected at several live and soft bottom stations, primarily in 40 to 60m depths. Neither spiny lobster (*Panulirus argus*), nor stone crab (*Menippe mercenaria*) were collected, as these are primarily near-shore species. Major harvest areas for the latter three species are outside the immediate study area: most rock shrimp landings are from the northeastern Gulf of Mexico, whereas most spiny lobster and stone crab harvesting occurs in shallow near-shore waters off Monroe and Collier counties (southwest Florida), respectively (U.S. Department of the Interior, Minerals Management Service, 1983).

Pink shrimp and most other common panaeids on the west Florida shelf are nocturnally active, generalized benthic carnivores that are preferentially associated with calcareous sand and shell rubble substrate (Huff and Cobb, 1979). Oil and gas exploration and development activities may adversely affect shrimp populations through localized habitat alteration due to placement of drilling rigs and platforms and deposition of drilling muds and cuttings. Such impact would be localized in the vicinity of a rig or platform and would be unlikely to have any overall effect on shrimp populations. As noted for fishes, oil spills that contact estuarine bays and marshes present the most serious potential impact to these shellfish populations because these areas are used as spawning and/or nursery grounds.

9.4.4 Recreational Fisheries

Oil and gas exploration and development activities on the southwest Florida shelf are expected to have a positive effect on recreational fisheries (BLM, FEIS 67/69). Emplacement of drilling structures will create artificial reefs and lure fishes to known spots where their populations can be more readily exploited by recreational fishermen. Evidence has long supported this claim (Randall, 1963; Turner et al. 1979; Continental Shelf Assoc., Inc., 1982; Putt, 1982), although there is still debate whether the structures act merely to lure fish or whether the access to new "live bottom" habitat results in an increased productivity of fish populations also (Stone, 1978).

Since very few exploratory wells have been drilled off the Florida Gulf coast, data supporting this idea come principally from studies in Louisiana, California, and Texas. Stone et al. (1979) did show that Florida populations of fishes will readily make use of a newly constructed artificial reef. There is no reason to expect that the fishes of the Florida shelf would behave any differently to the emplacement of oil rigs (Dugas et al., 1979). Turner et al. (1969) reported that oil platforms have a mature successional community of organisms associated with them in as few as five years after emplacement. Further, they note that fishing success near oil platforms off the California Coast is two to three times better than that reported from natural reefs in these same areas.

9.4.4.1 Offshore Structures as Artificial Reefs

Gallaway (1980) summarized the results of investigations of pelagic, reef, and demersal fishes associated with the Buccaneer Field, located approximately 50km offshore from Galveston, east Texas. Production platforms and other structures served as artificial reefs around which fish aggregated. Structure-associated fish were either seasonal transients or residents. The transients appeared to be attracted to the structures intrinsically, while residents included those dependent on the structure-associated fouling community for both food and cover and those apparently attracted to the structures for cover alone. Beyond a radius of a few meters from the produced brine outfalls, Gallaway discerned no cause and effect relationship between produced brine discharge from production platforms and composition of fish communities. He attributed this to a rapid dilution and dispersion of discharged brine.

Gallaway (1980) also summarized studies of the fouling community of the Buccaneer Field and the effects of produced brine discharge on this community. The community was diverse and abundant, composed of two main components: (1) shelled organisms, and (2) "mat" producing organisms. During all seasons, fouling community biomass was lower near the bottom than near the water surface. Produced brine discharge had a detrimental influence on biomass and production rate of the fouling community within a vertical distance about 1m and a horizontal distance about 10m from the point of impact of discharged brine with the water surface.

Harper (1977) described the distribution and abundance of benthic meio- and macrofauna in the Buccaneer Field. There was no clear relationship between proximity to production platforms and meiofaunal abundance in sediment samples. Benthic macrofaunal population density appeared depressed within a radius of 50m from the production platforms as compared to the surrounding area. Harder substrate near production platforms may have been unsuitable habitat as compared to soft muddy sands observed elsewhere in the field, but Harper was not able to rule out possible effects of contaminants from metal debris below the platforms or produced brine discharge as possible causes.

Another study of the structure-associated fouling community of Buccaneer Field (Fotheringham, 1979) indicated that energy accumulated within the fouling community was exported to components of the adjacent marine ecosystem along three major pathways. The most apparent pathway was through grazing fish. Gut content analyses of 191 fish representing 27 species indicated that the spadefish (*Chaetodipterus faber*), sheepshead (*Archosargus probatocephalus*), crested blenny (*Hypleurochilus geminatus*), cocoa damselfish (*Pomacentrus variabilis*), and cubbyu (*Equetus acuminatus*) feed extensively on fouling organisms. A second pathway linked the fouling community to the benthic fauna living beneath the platforms, which was apparently enriched by consumption of barnacles and other invertebrates dislodged from the platform legs by wave and current stresses, abrasion by boats, and foraging fish. Several fouling species, which did not occur on the structures themselves, were found on dislodged barnacle shells and gastropod shells occupied by hermit crabs. Thus, accumulation of biomass beneath the structures is apparently increased by the presence of these shells. The third pathway linked the fouling community to planktivorous fish and invertebrates through the release of planktonic larvae by fouling organisms. A significant difference ($p < 0.05$) was found in the proportion of these larvae in the total plankton between stations within Buccaneer Field and those at a control site 8km east of the field.

It is apparent from the studies described above (Gallaway, 1980; Harper, 1977; Fotheringham, 1979) that the impacts of the Buccaneer Field can be classified into those associated with the presence of the structures themselves and those associated with the Buccaneer Field contaminants from a number of sources. The presence of the structures contributed to scouring of surficial sediments and provided artificial reef substrate upon which a fouling community developed and to which a variety of fishes and other motile organisms were attracted or otherwise aggregated. The studies further suggest that future assessments of impacts of offshore gas and oil production operations should concentrate on the components of the marine ecosystem in and around the production platforms and associated structures. The Buccaneer Field investigation was unable to detect impacts beyond 100m from production platforms. Studies that do not include sampling in close proximity to the point sources of gas and oil field contaminants are not likely to detect significant impacts, when compared to regional background levels of contaminants in the marine ecosystem (Caillouet, 1982).

9.5 SAMPLE STATION SPECIFIC IMPACTS

This concluding portion of Section 9.0 briefly outlines the types of OCS development-related impacts that would be of greatest potential significance and concern at each of the 39 individual sampling stations examined during this study. A summary listing of potential OCS development-related impacts, compiled from the discussions presented above, is provided in Table 9-1. General substrate characteristics at each sampling station are reviewed in Volume 2, Section 5.0. Live bottom and soft bottom species assemblages present at each site are described in Volume 3, Sections 6.0 and 7.0, respectively. These data, combined with the development activities presented in Table 9-1, have been used to examine those specific impacts most likely to be of concern at individual sampling stations.

Table 9-1. Summary of potential impacts associated with southwest Florida shelf OCS exploration and development activities.

Activity/Source	Potential Impacts
(1) Anchoring Drill Rigs & Boats	Bottom disturbance Breakup of algal pavement Smothering benthos Increased turbidity & Reduced photosynthesis
(2) Rig-associated Boat Traffic	Increased potential for local air & water pollution & possible collisions with sea turtles & manatees
(3) Discharge Sewage, Garbage, Deck Drainage	Local water pollution
(4) Discharge Cooling Waters	Locally increased ambient water temp.
(5) Discharge Drill Cuttings	Smothering benthos Increase in hard substrate for epifaunal attachment Release of mud additives, heavy metals, hydrocarbons
(6) Discharge Drilling Muds	Burial of hard substrate Smothering of benthos Increased turbidity & reduced photosynthesis Clogging respiratory/feeding structures Release of mud additives, heavy metals, hydrocarbons
(7) Discharge Produced Waters	Discharge of brine, oil and grease, trace metal residues Local changes ambient ion ratios
(8) Oil Spills from Rigs, Tankers & Pipelines	Shoreline impacts Oil coating on birds & turtles; asphyxiation Acute & chronic toxic effects Shading, reduced photosynthesis, potential toxicity due to dispersants
(9) Emplaced Drilling Structures	Artificial reef effects -- attachment surfaces, increased shelter, food supply Increased fishing opportunities
(10) Pipeline Installation	Dredging, bottom disturbance Smothering of benthos Increased turbidity & Reduced photosynthesis Resuspension of polluted sediments
(11) Onshore Development	Loss of coastal habitat Dredging impacts Water, energy requirements Increased potential for pollution Increased urbanization

A summary of potential impacts for each live bottom sample station is presented in Table 9-2, and for each soft bottom station in Table 9-3. Six separate impact criteria are considered for each individual station summary. Four criteria represent general categories of OCS development-related concerns drawn together from Table 9-1. These concerns reflect an individual sampling station's likely susceptibility to: (1) bottom disturbance; (2) burial/sedimentation; (3) added hard substrate; and (4) toxic pollutants, respectively. In addition, each station's relative habitat "value," and potential recovery rate following possible disturbance, are considered. Further explanation of the terms used in the station impact summaries is presented below.

9.5.1 Relative Habitat Value

As a group, all live bottom stations are regarded as significantly more susceptible to development impacts than soft bottom stations. The "relative habitat value" criterion is therefore based on the distinctiveness and abundance of any live bottom assemblage present at each sample station -- the species richness and apparent abundance of epibiota, and the spatial extent of the live bottom patch. Live bottom Stations 29 and 30, with the *Agaricia* coral plate assemblage, are considered to be unique, rich, live bottom areas and are ranked highest (Rank A). The soft bottom stations are considered the least distinctive and support relatively sparse epibiota (Rank F); however, soft bottom Stations 8, 16, 22, and 28 exhibited species-rich trawl collections that included many typical live bottom species, so these four stations are assigned a slightly higher value (Rank E). Of the remaining live bottom stations, Stations 13, 15, 21, and 23 are considered to be the most important in terms of percent cover and species richness (Rank B).

9.5.2 Susceptibility to Impacts

The four general categories listed here represent a summary of the various impacts presented in Table 9-1. Further explanations of each susceptibility category are outlined below.

Table 9-2. Impact Summary Table for Live Bottom Sampling Stations.

Station	Relative Habitat "Value"	Likely Susceptibility to				Relative Recovery Rate
		Bottom Disturbance	Burial/ Sedimentation	Added Hard Substrate	Toxic Pollutants	
1	C	Moderate	Moderate	Moderate	Yes	Slow
3	D	Moderate	Moderate	Moderate	Yes	Slow
7	C	Moderate	Moderate	Moderate	Yes	Slow
9	D	Moderate	Moderate	Moderate	Yes	Slow
10	C	High	Moderate	Moderate	Yes	Slow
11	C	High	Moderate	Moderate	Yes	Slow
13	B	Moderate	Moderate	Moderate	Yes	Slow
15	B	Moderate	Moderate	Moderate	Yes	Slow
17	D	Moderate	Moderate	Moderate	Yes	Slow
19	C	Moderate	Moderate	Moderate	Yes	Slow
21	B	Moderate	Moderate	Moderate	Yes	Slow
23	B	High	Moderate	Moderate	Yes	Slow
27	D	Moderate	Moderate	Moderate	Yes	Slow
29	A	High	High	Moderate	Yes	Very Slow
30	A	High	High	Moderate	Yes	Very Slow
32	D	Moderate	Moderate	Moderate	Yes	Slow
35	C	High	Moderate	Moderate	Yes	Moderate
36	C	Moderate	Moderate	Moderate	Yes	Slow
38	C	Moderate	Moderate	Moderate	Yes	Slow
39	C	High	Low	Low	Yes	Slow

See text for explanation of terms.

Table 9-3. Impact Summary Table for Soft Bottom Sampling Stations.

		Likely Susceptibility to				
Station	Relative Habitat "Value"	Bottom Disturbance	Burial/ Sedimentation	Added Hard Substrate	Toxic Pollutants	Relative Recovery Rate
2	F	Low	Moderate	High	Yes	Rapid
4	F	Low	Moderate	High	Yes	Rapid
5	F	Low	Moderate	High	Yes	Rapid
6	F	Low	Moderate	High	Yes	Rapid
8	E	Low	Moderate	High	Yes	Rapid
12	F	Low	Moderate	High	Yes	Rapid
14	F	Low	Moderate	High	Yes	Rapid
16	E	Low	Moderate	High	Yes	Rapid
18	F	Low	Moderate	High	Yes	Rapid
20	F	Low	Moderate	High	Yes	Rapid
22	E	Low	Moderate	High	Yes	Rapid
24	F	Low	Moderate	High	Yes	Rapid
25	F	Low	Moderate	High	Yes	Rapid
26	F	Low	Moderate	High	Yes	Rapid
28	E	Low	Moderate	High	Yes	Rapid
31	F	Low	Moderate	High	Yes	Rapid
33	F	Low	Moderate	High	Yes	Rapid
34	F	Low	Moderate	High	Yes	Rapid
37	F	Low	Moderate	High	Yes	Rapid

See text for explanation of terms.

Bottom Disturbance

For example, anchor and rig emplacement and removal. This is presumed to have the greatest potential for impact where epibiota occur on exposed rock (e.g., at Station 39) or a surface layer of algal nodules (Stations 10, 11, and 23), algal nodule pavement (Stations 29 and 30), or shell rubble (Station 35). The rest of the live bottom stations would be affected, but less severely, and soft bottom stations even less so.

Burial/Sedimentation

For example, release of drilling muds and cuttings. This would be most damaging at Stations 19 and 30, where the agariciid corals are sensitive to sedimentation. There would be little effect at Station 39 because of the steep slope and likely strong currents at shelf edge. Other live bottom stations could be impacted to various degrees, but are classified here as moderate. The soft bottom stations are also considered to be susceptible, not so much because of burial but because of possible changes in sediment texture, an important determinant of infaunal community composition. Fine drilling mud particles would be an atypical substrate over much of the shelf, except perhaps at Stations 25 and 26, where carbonate muds predominate. Cuttings particles can range up to several centimeters in size and these too would be atypical almost anywhere on the shelf.

Effect of Added Hard Substrate

For example, anchors, platform legs, cuttings piles, etc. The impact would be greatest where there is currently no emergent hard bottom (for prominent epibiota) -- that is, at the soft bottom stations. There would be significant effects at all live bottom stations, though the impact would be least where there is already considerable relief, such as at Station 39.

Effects of Toxic Pollutants

For example, components of drilling muds, spilled oil, or other wastes. We have no information to suggest differential sensitivity of live and soft bottom biota. Presumably, significant impacts could result at any station if the exposure level were high enough.

9.5.3 Relative Recovery Rate

This is very speculative at this time and is intended to be used in a comparative sense only. Most infaunal species have short generation times and high growth rates in comparison with large, sessile epibiota (e.g., sponges, hard corals) typical of live bottom areas. Moreover, most of the shelf is covered by sand bottom, whereas the distribution of live bottom is patchy; therefore, the availability of suitable larvae and colonists for a defaunated soft bottom area is likely to be greater than for a live bottom area. We speculate that the formation of the algal nodule pavement and the large *Agaricia* coral plates could take longer than would regrowth of other epibiota such as sponges and gorgonians. Finally, recovery of crinoids attached to shell rubble at Station 35 may be somewhat more rapid than recovery of sessile epibiota attached to rock outcrops of thin sand over hard substrate. The shell rubble should be readily and frequently moved under natural conditions by strong near bottom currents; this suggests the crinoids may be quick to recolonize such areas after a disturbance.

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Steven Hess, Ph.D. Candidate (University of Miami, Biological Oceanography) -- Cephalopoda

Walter C. Jaap, B.S. (University of Miami, Biology, 1970) -- Scleractinian corals.

Louis Kornicker, Ph.D. (Columbia University, Geology, 1957), U.S. National Museum of Natural History -- Myodocopa Ostracoda

Rafael Lemaitre, M.S. (Florida International University, Environmental and Urban Systems, 1981) -- Decapod Crustacea

Arthur J. J. Leuterman, Ph.D. (Texas A&M University, Oceanography, 1979) -- Bryozoa

Jennifer Wheaton Lowry, B.S. (Marshall University, Zoology, 1970) -- Octocorallia

Patsy A. McLaughlin, Ph.D. (George Washington University, Zoology, 1972) -- Anomuran Crustacea and Cirripedia

Charles G. Messing, Ph.D. (University of Miami, Biological Oceanography, 1979) -- Crinoidea

Paula M. Cowles Mikkelsen, B.S. (Bates College, Biology, 1976) -- Mollusca

John E. Miller, III, B.A. (University of South Florida, Zoology, 1971) -- Echinoidea and Holothuroidea

Douglas Morrison, M.S. (University of Miami, Biology, 1981) -- Scleractinian corals.

Thomas H. Perkins, M.S. (University of South Florida, Zoology, 1972) -- Polychaeta

Edward J. Petuch, Ph.D. (University of Miami, Biological Oceanography, 1980), U.S. National Museum of Natural History -- Mollusca; also contributed Appendix B-11, on zoogeographical patterns.

Shirley A. Pomponi, Ph.D. (University of Miami, Biological Oceanography, 1977) -- Porifera

James F. Quinn, M.S. (University of Miami, Biological Oceanography, 1977) -- Mollusca (Turridae)

John L. Taylor, Ph.D. (University of Florida, Biology, 1971) -- Polychaeta

Ronald B. Toll, Ph.D. (University of Florida, Biological Oceanography, 1982) -- Cephalopoda

Steven Trine, B.S. (University of Miami, Zoology, 1976) -- Scleractinian corals

Richard L. Turner, Ph.D. (University of South Florida, Biology, 1977) -- Asteroidea and Ophiuroidea

James A. Vallee, Ph.D. (University of Miami, Marine Biology, 1965), Pacific Bio-Marine Laboratory, Inc. -- Ascidiacea

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.