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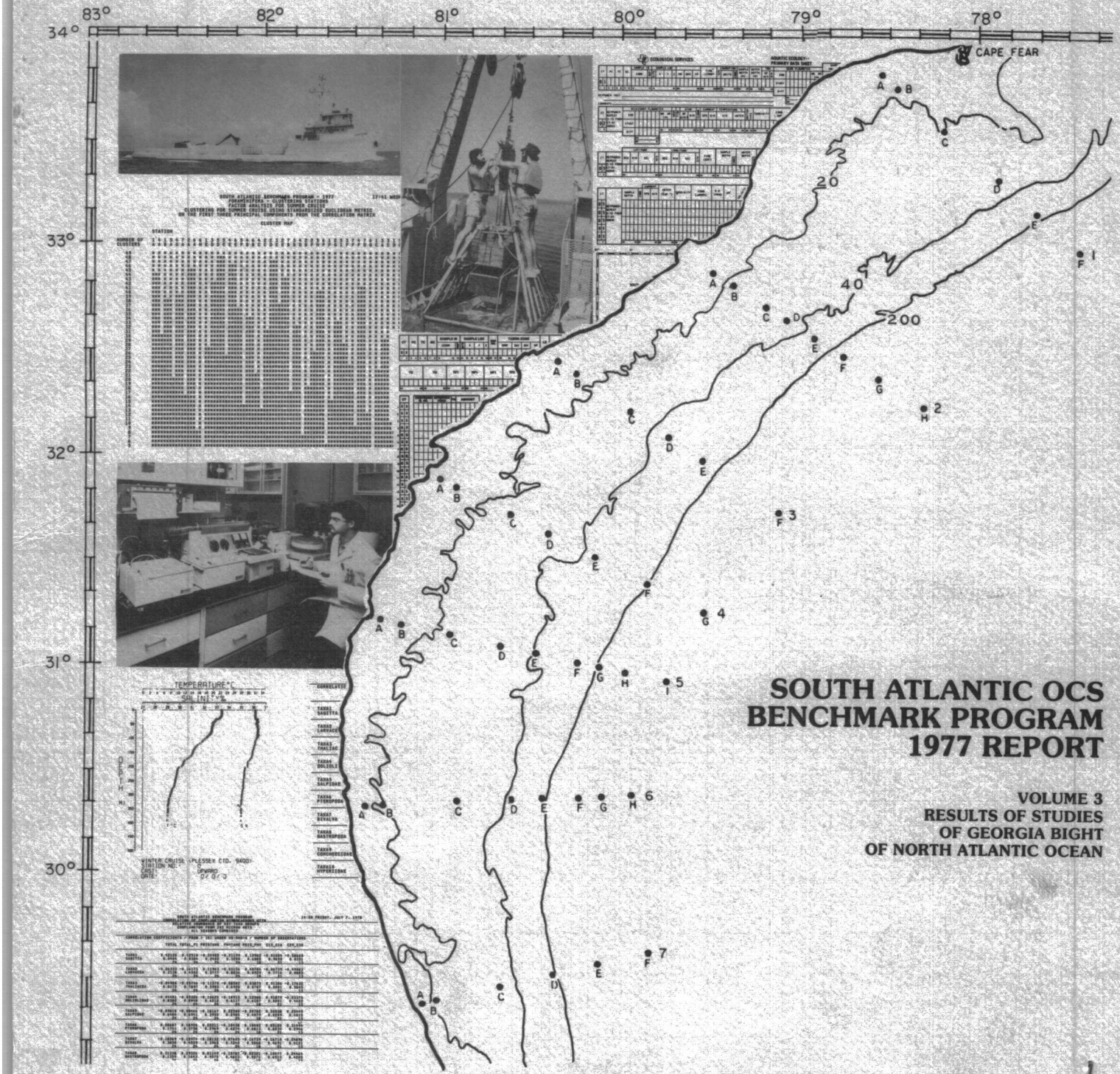

SOUTH ATLANTIC OCS BENCHMARK PROGRAM 1977 REPORT

VOLUME 3
RESULTS OF STUDIES OF GEORGIA BIGHT OF NORTH ATLANTIC OCEAN

Prepared by
TEXAS INSTRUMENTS
INCORPORATED

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hysical and chemical data on the composition of seawater collected in the western Atlantic ean between Cape Canaveral and Cape Fear were gathered to support data interpretation for e 1977 South Atlantic Benchmark Program. Salinity, temperature, dissolved oxygen, in-ganic nutrients, chlorophyll, and particulate and dissolved organic carbon were measured quarterly intervals at hydrographic stations occupied along seven transects on the con-inental shelf of Georgia Bight. It was apparent that the prevailing ocean conditions in is area were heavily influenced by freshwater runoff and Gulf Stream intrusions onto the ntinental shelf. The quarterly sampling scheme clearly defined the seasonal progression the shelf from the unusually cold winter of 1976/1977 through the normally hot summer of 77. Extreme cooling of the inner shelf in winter was followed by maximal warming during e summer. The middle- and outer-shelf regions exhibited lower annual temperature ranges 15° to 18°C. Concentrations of nutrients were normally high offshore in near-bottom ters close to or beyond the shelf break and again farther up on the shelf during Feb-ary and along some transects in May 1977. These waters had a persistent atom ratio cess of phosphorus and silicon over nitrogen. No significant land source for nutrients s detected, although some silicate was delivered to the nearshore areas by river runoff. e only process that provided new nutrients to the shelf was the upwelling of deep water. rticulate organic carbon and chlorophyll correlated well throughout the study area; peaks re observed in the extreme inner zone and on the southernmost transect near Cape Canavera ere persistent upwelling occurs in the wake of the cape. Dissolved oxygen on the con-nental shelf approached or exceeded saturation during all four seasons, while oxygen creased to 30 to 50% saturation at depth on the continental slope.

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Environmental Studies

VOLUME 3

RESULTS OF STUDIES OF GEORGIA BIGHT OF SOUTH ATLANTIC OCEAN

Final Report
Contract AA550-CT7-2

July 1979

Prepared by
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Dallas, Texas
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ABBREVIATIONS, ACRONYMS, AND SYMBOLS

Å	Angstrom unit
APDC	Ammonium pyrrolidindithiocarbamate
ANOV	Analysis of variance
~	Approximately
AAS	Atomic absorption spectroscopy
Ba	Barium
BOD	Biochemical oxygen demand
BMDP	Biomedical Computer Program, Series P
BLM	Bureau of Land Management
Cd	Cadmium
C	Celsius
Cm	Centimeter
Cr	Chromium
CTD	Conductivity/temperature/depth
Cu	Copper
°	Degree
DDDC	Diethylammoniumdiethyldithiocarbamate
DOC	Dissolved organic carbon
DO	Dissolved oxygen
÷	Divided by
eV	Electron volt
ESW	Enriched seawater
E	Extinction coefficient
ft	Foot
GC	Gas chromatography
GC-MS	Gas chromatography–mass spectroscopy
GSI	Geophysical Service Inc.
Ge(Li)	Germanium lithium
g	Gram
>	Greater than
HMWHC	High molecular weight hydrocarbon
HPLC	High-pressure liquid chromatography
hr	Hour
HAP	Hydrated antimony pentoxide
HCl	Hydrochloric acid
HF	Hydrofluoric acid
in.	Inch

ABBREVIATIONS, ACRONYMS, AND SYMBOLS (Continued)

ID	Inside diameter
Fe	Iron
kg	Kilogram
km	Kilometer
<	Less than
LM	Light microscopy
l	Liter
m/e	Mass-to-charge ratio
$\bar{x}$	Mean value
MW	Megawatt
m	Meter
MIBK	Methylisobutylketone
μg	Microgram
μl	Microliter
μm	Micrometer
μM	Micromole
mg	Milligram
ml	Milliliter
mm	Millimeter
min	Minute
M	Molar
MPN	Most probable number
M/V	Motor vessel
ng	Nanogram
nl	Nanoliter
nm	Nanometer
NBS	National Bureau of Standards
NEPA	National Environmental Policy Act
nmi	Nautical mile
NSI	Navigation Services Incorporated
NAA	Neutron activation analysis
HNO_3	Nitric acid
N	Nitrogen, North, normal
$n/cm^2/sec$	Number of neutrons per centimeter squared per second
n	Number of observations
OCS	Outer continental shelf
OCSESP	Outer Continental Shelf Environmental Studies Program
POC	Particulate organic carbon
$^0/00$	Parts per thousand

ABBREVIATIONS, ACRONYMS, AND SYMBOLS (Continued)

/	Per
%	Percent
P	Phosphorus
PNA	Polynuclear aromatic
PVC	Polyvinyl chloride
psi	Pounds per square inch
PDR	Precision depth recorder
PCA	Principal components analysis
PI	Principal investigator
PMS	Program management system
PHA	Pulse-height analyzer
QC	Quality control
RPD	Redox potential discontinuity
SAI	Science Applications Incorporated
SAC	Scientific Advisory Committee
sec	Second
SNR	Signal-to-noise ratio
Si	Silicon
SABP	South Atlantic Benchmark Program
SLCO	South Louisiana crude oil
SOP	Standard operating procedure
SRM	Standard reference material
SAS	Statistical Analysis System
SPM	Suspended particulate material
THF	Tetrahydrofuran
TAMU	Texas A&M University
TI	Texas Instruments Incorporated
K	Thousand
KeV	Thousand electron volt
X	Time (multiplication)
TOC	Total organic carbon
TM	Trace metal
UV	Ultraviolet
USGS	United States Geological Survey
V	Vanadium, volt
v/v	Volume to volume
wk	Week
w/v	Weight to volume
Zn	Zinc

CHAPTER 1

INTRODUCTION

by

Mallory S. May III
Texas Instruments Incorporated

SECTION 1
INTRODUCTION

The present concern about the rate of fossil-fuel consumption and dependency on import oil to supply current U.S. demands has resulted in a greater interest by the Federal Government and the petroleum industry in increased domestic production. The public and private sectors believe that the continental shelf, including the offshore area of the eastern United States, will be a major source of increased domestic production (Bell, 1975). Geophysical surveys have identified the Georges Bank off New England, the Baltimore Canyon extending offshore from the mid-Atlantic states, and the Southeast Georgia Embayment and Blake Plateau of the continental margin of the southern states as areas of greatest potential (Figure 3.1-1).

The Outer Continental Shelf (OCS) Lands Act of 1953 charges the Secretary of the U.S. Department of the Interior with responsibility for managing the economic development of the continental shelf of the United States beyond state jurisdiction. Furthermore, the 1969 National Environmental Policy Act (NEPA) makes the secretary responsible for protecting the environment of the continental shelf during the exploration and exploitation of resources. To obtain information on which to base decisions that will lead to orderly development of the resources while protecting the environment, the Bureau of Land Management (BLM), an agency of the Department of the Interior, established the Outer Continental Shelf Environmental Studies Program (OCSESP), sometimes called the marine environmental studies program. The OCSESP has four phases: a review and summary of present information as a basis for future decisions and study designs; multidisciplinary baseline studies for predevelopment characterization of the environment; special studies designed to answer specific questions; and environmental monitoring to detect changes as a result of the developmental actions. In November 1976, BLM contracted with Texas Instruments to perform the South Atlantic Benchmark Program (SABP) in 1977 as part of the planned series of studies for that area.

The SABP area of interest is the Georgia Bight, the marine portion of the Southeast Georgia Embayment, which is located off the coast of South Carolina, Georgia, and the northern part of Florida (Figure 3.1-2). The Georgia Bight, a marine basin located between Cape Fear to the north and Cape Canaveral to the south, is bordered on the west by the Coastal Plain and on the east by the Florida-Hatteras Slope. The basin's morphometry is undramatic out to the slope; no canyons, outcrops, or other topographical changes interrupt the seabed, which has a slope of <0.1%. Outcrops are located at the shelf edge of the Florida-Hatteras Slope and occasionally on the Slope.

The water of the Georgia Bight, bounded by the north-flowing Gulf Stream, is affected by seasonal changes of temperature, natural forces, and additions from the continent, Gulf Stream, atmosphere, and coastal water north of Cape Hatteras.

The basin is readily divided into three cross-shelf zones—nearshore, middle shelf, and outer shelf. The nearshore and middle-shelf bottoms are primarily composed of recent (nearshore) and relict sand of continental origin; the outer-shelf bottom is covered by carbonate sand of marine origin. The nearshore zone, which is greatly influenced by materials from the Piedmont and Coastal Plain drainage basins, is the zone of greatest temperature and salinity range and highest

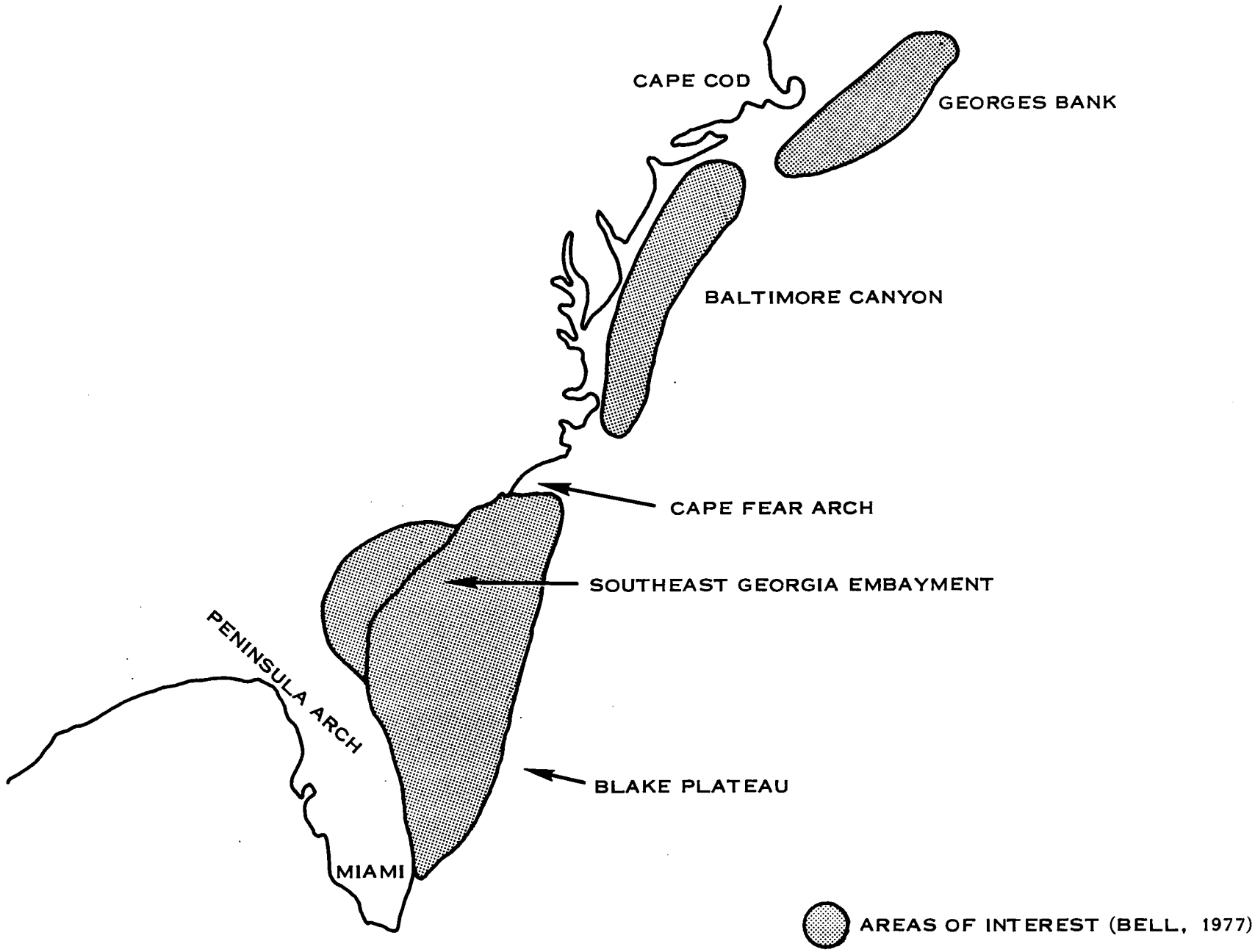

Figure 3.1-1. Areas of Greatest Petroleum Potential Along South Atlantic Continental Shelf

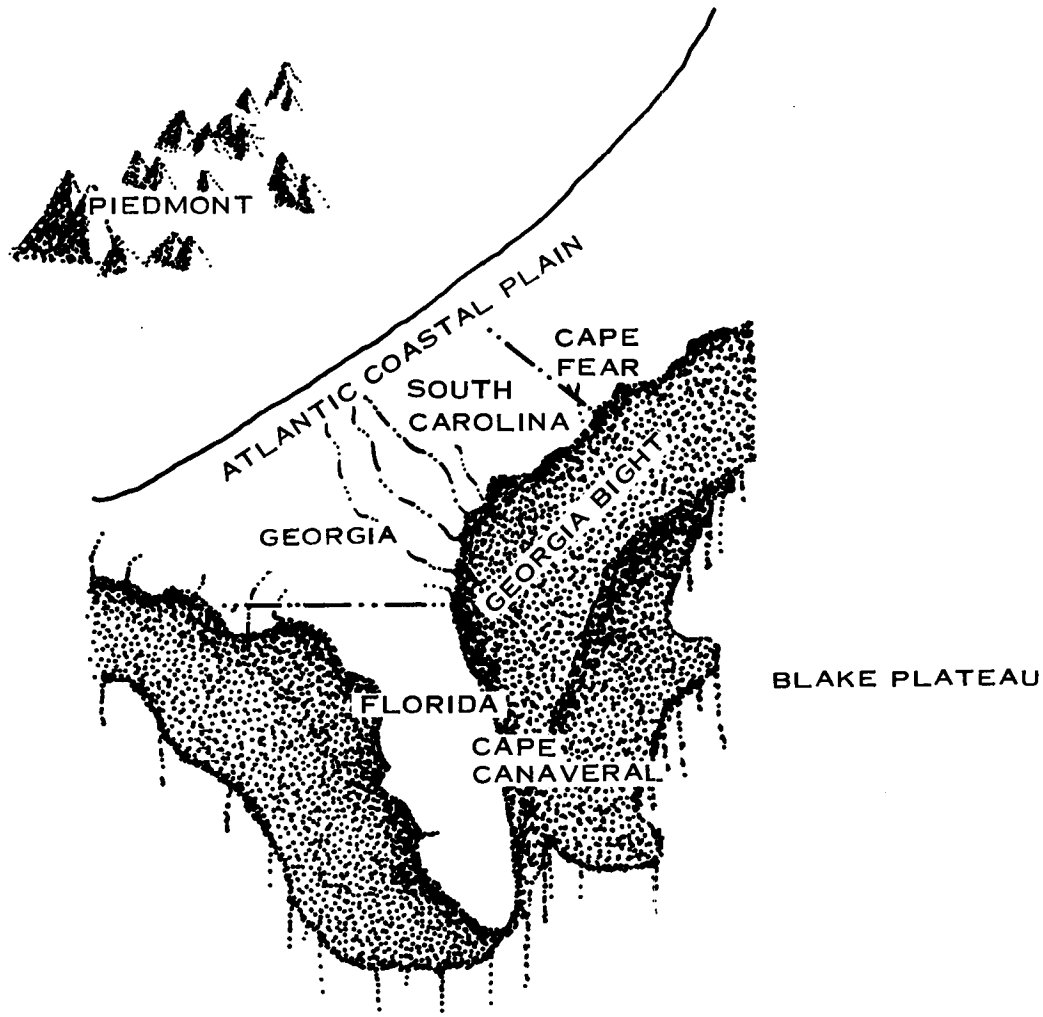

Figure 3.1-2. Morphometry of Southeast Georgia Embayment

turbidity. Upwellings from the slope transport cold water and nutrients onto the outer shelf. The middle shelf is a wide zone of transition between the nearshore and outer shelf through which cross-shelf transport occurs. The sediments of these three zones are constantly subjected to reworking forces; there appears to be a net transport of sediments toward the near shore.

Generally speaking, the water in the basin circulates counterclockwise, the western-boundary water moving south and the eastern-boundary water moving north. The southerly moving nearshore water is especially evident in the littoral drift and in the north-to-south erosion of the barrier-island beaches. Some gradient and wind forces result in temporary cross-shelf movements. Wind causes considerable movement of surface water from off shore to near shore. Bottom water moves from off shore to near shore; slope water upwells onto the margins of the outer shelf; and, occasionally, force regimes detach Gulf-Stream eddies that meander and mix on the outer shelf. The direction of the nearshore water changes with the tides.

Two major, biological communities distinguishable by differences in physicochemical conditions, transport process, and biota comprise the Georgia Bight: a narrow, nearshore community and an offshore community. Community distinctions become more discernible the farther the separation; e.g., the difference between a community 10 km offshore and a community 40 km offshore is more obvious than the difference between communities lying at 20 km and 25 km. There is also a difference in dependency on adjacent ecosystems: the nearshore community is more dependent on its adjacent estuarine habitat with its higher productivity and on passthrough materials from the Coastal Plain and Piedmont. Common characteristics of both communities are the patterns and changes in the distribution of the biota. Distribution is influenced by larval transport, migration, and habitat properties. The number and weight of organisms are greater nearshore than offshore, while the diversity of species is greater offshore. The changes in these community properties occur as cross-shelf gradients. Species composition and distribution undergo seasonal changes throughout the Bight without blurring the biomass and diversity gradients.

Even though the Georgia Bight is a rather homogeneous ecosystem, there are some dramatic features. Tropical benthic communities such as Grays Reef in the nearshore zone off the Georgia coast are patchily distributed on the shelf like oases dotting a desert. Reworked sands of former shorelines are an offshore crypt for Pleistocene fossils and prehistoric anthropogenic artifacts. The marine waters of the basin are a medium of expression for "nor'easters" and tropical storms. Commercial fisheries are limited to the nearshore zone; successful offshore fishing occurs at natural and artificial reefs and among schools of migrating Spanish mackerel and bluefish. High productivity is limited to the near shore, the reefs, and the nutrient-enriched outer-shelf water.

The Georgia Bight, then, is generally a monotonously homogeneous ecosystem having gradual cross-shelf gradients of slope, sediment texture, hydrographic properties, and community characteristics. A scuba diver traversing the seafloor from a barrier-island beach to the Florida-Hatteras slope would be unimpressed by changes in depth and sediment texture but would be aware of an increase in visibility and changes in the color, size, and shape of seastars, sanddollars, and crabs. Also, if an ichthyologist, the diver would observe a change in the distribution of the nearshore lizard fish and the offshore lizard fish. It is improbable that the diver would see sponges, soft corals, and reef fishes unless a path were chosen through a known hard-bottom community.

Until recently, information on the Georgia Bight was obtained from many single-purposed, provincial studies (Roberts, 1974), resulting in a mosaic of interpolations, hypotheses, and extrapolations about ecosystem attributes and areas but no overall, comprehensive description of habitats, components, and processes. During the past few years, BLM, as well as other agencies such as USGS, NOAA, and DOE, have sought a comprehensive understanding of the Bight's ecosystem. The SABP performed by Texas Instruments was intended to contribute to this goal for BLM; i.e., to provide synoptic, interdisciplinary information about the Georgia Bight before exploration and exploitation of its resources.

The SABP sampling design was the result of the needs of OCSESP and the recommendations of oceanographers and marine scientists from the public and private sectors, who conferred in Atlanta, Georgia, in October 1975 (Bureau of Land Management, 1976). The design was developed considering:

- Current knowledge about the region, e.g., habitats, unique or unusually productive areas (such as reefs), and physical and chemical processes
- Locations of lease blocks where oil exploration interest is high
- Historically successful study designs and techniques
- A desire for reference stations
- Acquisition of data that can be interpreted with statistical power (inference).

The design was a multitransect configuration (Figure 3.1-3) often used in investigations of marine environments to determine trends in nutrient concentration, community composition, hydrography sediment type, and other ecosystem characteristics. Typically, transects are aligned along the axis of an environmental gradient in such a manner that the various stations define the range of the gradient. Texas Instruments established 50 stations (Table 3.1-1) on seven transects crossing the shelf perpendicular to the shoreline. Each transect crossed the three shelf regimes—inner, middle, and outer. Transects 2, 5, and 6 were in regions of major interest to the oil industry; transects 3 and 4 were in areas where less environmental change is expected from oil- and gas-related activity; and transects 1 and 7 delineated the northern and southern limits of the region of interest. The nearshore stations were within the zone of riverine (fresh) water runoff; the outer stations were on the outershelf and upper slope in the area influenced by the Gulf Stream. The intervening stations were in the transitional, midshelf region.

The success and value of using transects to investigate marine habitats are well documented. They were used by Pinet and Frey (1977) in a study of organic carbon in the surficial sediments of the Georgia inner shelf; by Holm-Hansen et al. (1968) in a study of zooplankton, DNA, and chlorophyll *a* on the OCS of North Carolina; by Huang and Meinschein (1976) in an investigation of sterols in Gulf of Mexico surficial sediments; by Froelich et al. (1977) in the south Pacific along the East Pacific Rise; and by Oppenheimer et al. (1977) in the North Sea during a study of microorganisms and hydrocarbons in seawater and surficial sediments. Transect sampling designs have been used in biological studies on the continental margin in North Carolina (Cerame-Vivas and Gray, 1966), in zonation studies on the continental margin of Georgia and South Carolina (Rowe and Menzies, 1969), in a study of the faunal composition of the New England continental shelf (Haedrich et al., 1975), on the Pacific Continental Shelf (Fager, 1968), on the western Caribbean upper slope (Bullis and Struhsaker, 1970), in studies of the infauna of the Southeast Georgia Embayment (Frankenberg, 1971), and in studies of the association of marine microorganisms with detritus (Wiebe and Pomeroy, 1972). Sampling along transects is a standard design of geological, physical, and chemical oceanographers (Pilkey and Frankenberg, 1964; Duane et al., 1972; Blanton, 1971; Stefansson et al., 1971).

Sampling was conducted during four seasons of 1977. Each seasonal cruise (Table 3.1-2) included two legs—a water-column leg and a benthic leg. Water, zooplankton, and microbial samples were collected during the water-column leg to provide an interdisciplinary overview of the content and character of shelf water. Hydrocarbons, trace metals, organic carbon, micronutrients, and dissolved-oxygen concentrations, as well as salinity and temperature, were measured and indices of abundance of living biota determined through the measurement of chlorophyll *a* concentrations and the enumeration of zooplankton and microbes. The microbial community structure and metabolic use of hydrocarbons by microbes were determined by culturing techniques. From samples taken on the benthic leg, information was obtained on sediment texture, chemical constituents, and biotic assemblages of the seafloor. Accessory salinity and

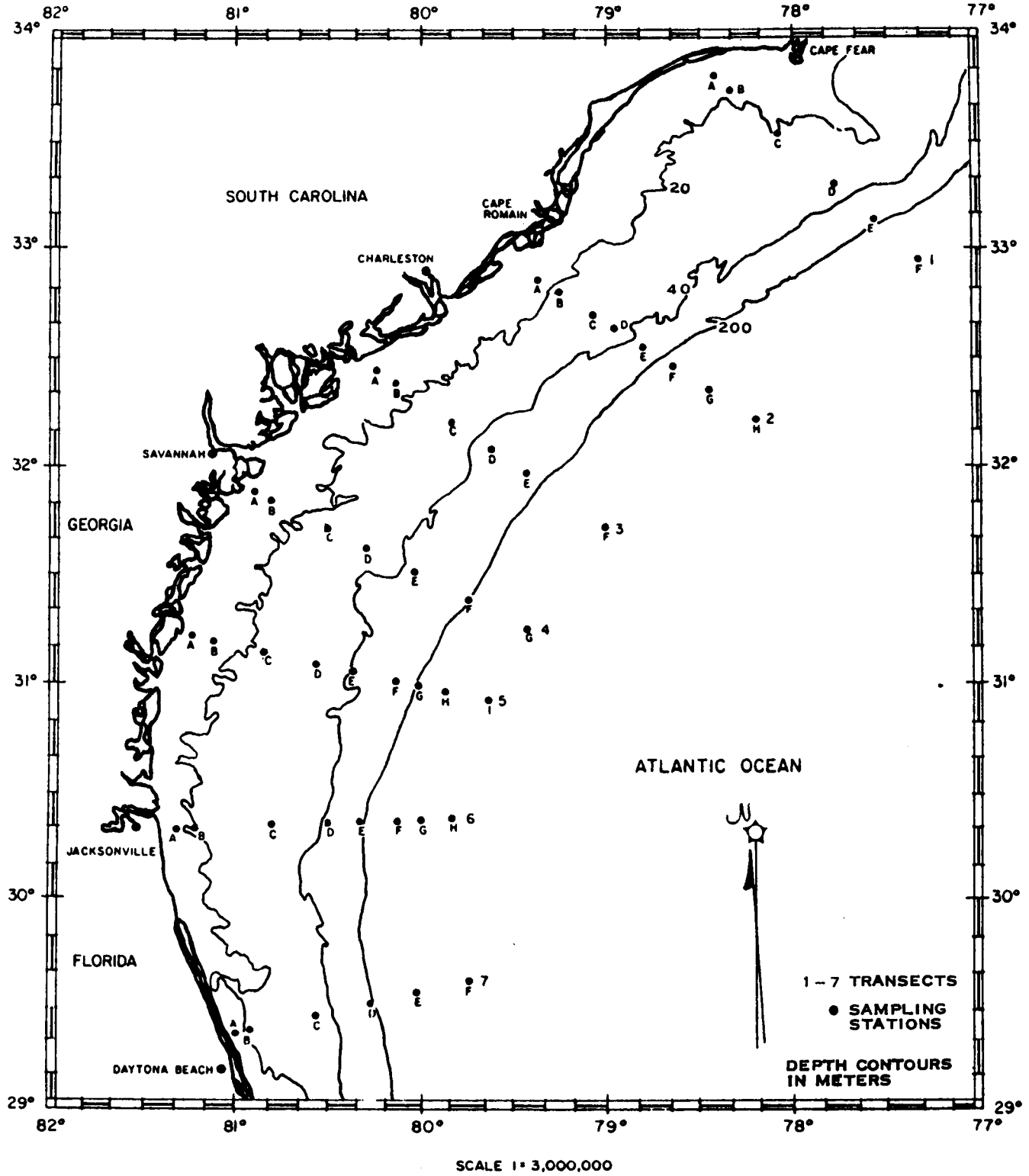

Figure 3.1-3. SABP Study Area, Showing Transects and Sampling Stations

Table 3.1-1. Station Locations

Station No.	Latitude (N)	Longitude (W)	Depth (m)
1A	33° 50′	78° 24′	11
1B	33° 47′	78° 21′	13
1C	33° 35′	78° 05′	18
1D	33° 20′	77° 46′	25
1E	33° 12′	77° 36′	44
1F	33° 01′	77° 21′	285
2A	32° 57′	79° 17′	12
2B	32° 54′	79° 12′	16
2C	32° 50′	79° 04′	22
2D	32° 45′	78° 56′	27
2E	32° 40′	78° 47′	37
2F	32° 36′	78° 39′	42
2G	32° 30′	78° 29′	218
2H	32° 20′	78° 11′	373
3A	32° 26′	80° 14′	9
3B	32° 23′	80° 09′	13
3C	32° 13′	79° 52′	22
3D	32° 05′	79° 38′	33
3E	32° 01′	79° 31′	46
3F	31° 46′	79° 05′	540
4A	31° 55′	80° 51′	8
4B	31° 53′	80° 46′	12
4C	31° 45′	80° 28′	16
4D	31° 40′	80° 16′	26
4E	31° 34′	80° 03′	38
4F	31° 27′	79° 46′	64
4G	31° 19′	79° 28′	495
5A	31° 13′	81° 13′	11
5B	31° 12′	81° 08′	11
5C	31° 08′	80° 50′	14
5D	31° 05′	80° 35′	25
5E	31° 03′	80° 26′	34
5F	31° 01′	80° 17′	40
5G	30° 59′	80° 08′	46
5H	30° 57′	79° 58′	183
5I	30° 54′	79° 44′	410
6A	30° 23′	81° 20′	17
6B	30° 23′	81° 15′	15
6C	30° 23′	80° 51′	26
6D	30° 23′	80° 36′	35
6E	30° 23′	80° 26′	39
6F	30° 23′	80° 18′	48
6G	30° 23′	80° 10′	134
6H	30° 23′	79° 57′	360
7A	29° 27′	81° 03′	20
7B	29° 28′	80° 57′	20
7C	29° 31′	80° 40′	18
7D	29° 34′	80° 22′	44
7E	29° 36′	80° 11′	185
7F	29° 38′	79° 53′	520

Table 3.1-2. Cruises of *M/V G.W. Pierce II*

		1977 Schedule			
		Water-Column Leg		Benthic Leg	
Cruise	Season	Departure (Port Everglades)	Arrival (Southport)	Departure (Port Everglades)	Arrival (Southport)
1	Winter	31 Jan	8 Feb	9 Feb	5 Mar
2	Spring	3 May	8 May	8 May	22 May
3	Summer	9 Aug	14 Aug	15 Aug	4 Sep[a]
Time-Series[b]	Summer	8 Sep	29 Sep	–	–
4	Fall	10 Nov	14 Nov	15 Nov[c]	29 Nov

[a]Arrived Brunswick, Georgia, to prepare for time-series cruise and effect repairs.
[b]Seven legs included in time-series cruise.
[c]Demonstration cruise, 21 November.

temperature data and samples from which to determine micronutrients and chlorophyll *a* concentrations were routinely collected at all benthic stations. Epifauna was collected to determine community structure, bioaccumulation of trace metals and hydrocarbons, and incidence of histological anomalies. Table 3.1-3 describes the sampling scheme for each cruise, including a time-series study of hydrographic factors and zooplankton distribution.

The interpretation of the SABP data that Texas Instruments collected is presented in this volume. The authors of the chapters are eminent scientists (Table 3.1-4) who were selected as principal investigators to discuss the results of the SABP because of their leadership in their respective disciplines and experience in the geographic area of interest. All techniques used to collect, prepare, and reduce the multidisciplinary data for this synthesis are described in Volume 2; original data are provided in Volume 6, microfiched for archiving.

Table 3.1-3. Sampling Scheme

Group	Sample Types	Transect	Station	Rationale
I	Quarterly collections for study of zooplankton tows; surface-film hydrocarbons and microbiology	1 2[a] 4 5[a] 6 7	D E E E D D	Central continental shelf stations on the northern most and southermost transects and on transects nearest potential oil activity
II	Hydrography (CTD), particulate trace metals, particulate and dissolved hydrocarbons, near-surface microbiology, microbiological oxygen demand, particulate and dissolved organic carbon	1 2[a] 3 4 5[a] 6 7	D[b] E, F D[b] D, E A, B[b], E[b], G[b] D D[b]	Hydrographic reference stations (group I and six additional stations for extended central and outer shelf coverage)
III	Sediment samples for granularity and chemistry: hydrocarbons, trace metals, total organic carbon	1 2[a] 5[a] 7	B, C, D, E, F B, C, D, E, F, G, H B, C, D, E, F, G, H, I B, C, D, E, F	Shelf and upper-slope stations on control transects (1 and 7) and transects of major oil industry interest
IV	Sediment samples for benthic biological community description and granularity: macroinfauna, foraminifera, total organic carbon	In winter and summer, all 50 stations; in spring and fall, as for group III		Emphasis placed in regions of oil industry interest
V	Epifaunal trawling or dredging	1 2[a] 3 4 5[a] 6 7	C[c], D B, D, E, F[c], H[c] B[c], D[c], E C, D, E[c], F A[c], C, D, G, I[c] B, C[c], E C, E, F[c]	Central and outer shelf stations on all transects with additional coverage in areas of oil-industry interest
VI	Time-series cruise			
	Hydrography	5[a] 6	E, F, G, H, I D, E, F, G, H	Outer continental shelf stations within range of Gulf Stream meanders to monitor short-term Gulf Stream intrusions
	Zooplankton	5[a] 6	E, I D, H	Zooplankton sampled on central shelf to detect short-term community variations

[a]Transects crossing regions of greatest future impact (2 and 5)
[b]Total trace metals measured at selected stations
[c]Sampled only on summer and winter cruises

Table 3.1-4. Principal Investigators

Investigator	Affiliation	Discipline
L.P. Atkinson*	Skidaway Institute of Oceanography	Nutrients, physical oceanography
R.T. Barber*	Duke University, Marine Laboratory	Organic carbon
P.R. Betzer	University of South Florida	Trace metals
B.C. Coull	University of South Carolina	Meiofauna
R.Y. George	University of North Carolina, Wilmington	Invertebrate epifauna
V.J. Henry*	Skidaway Institute of Oceanography	Geology
S.S. Herman	Lehigh University	Zooplankton
R.L. Lee	Skidaway Institute of Oceanography	Hydrocarbon
C.H. Oppenheimer	University of Texas	Microbiology
B.K. Sen Gupta	University of Georgia	Foraminifera
J.C. Staiger	University of Miami	Epibenthic fishes
K.R. Tenore	Skidaway Institute of Oceanography	Macroinfauna
M.R. Tripp	University of Delaware	Histology of epifauna
H.L. Windom*	Skidaway Institute of Oceanography	Trace metals

*Members of Scientific Advisory Committee.

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CHAPTER 2

HYDROGRAPHY, NUTRIENTS, CHLOROPHYLL, AND ORGANIC CARBON OF SOUTH ATLANTIC/GEORGIA BIGHT

by

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ABSTRACT

Physical and chemical data on the composition of seawater collected in the western Atlantic Ocean between Cape Canaveral and Cape Fear (Figure 3.1-3) were gathered to support data interpretation for the 1977 South Atlantic Benchmark Program. Salinity, temperature, dissolved oxygen, inorganic nutrients, chlorophyll, and particulate and dissolved organic carbon were measured at quarterly intervals at hydrographic stations occupied along seven transects on the continental shelf of the Georgia Bight. It was apparent that the prevailing ocean conditions in this area were heavily influenced by freshwater runoff and Gulf Stream intrusions onto the continental shelf. The quarterly sampling scheme clearly defined the seasonal progression on the shelf from the unusually cold winter of 1976/1977 through the normally hot summer of 1977. Extreme cooling of the inner shelf in winter was followed by maximal warming during the summer (the maximum annual temperature of approximately 25°C was observed). The middle- and outer-shelf regions exhibited lower annual temperature ranges of 15° to 18°C. Concentrations of nutrients were normally high offshore in near-bottom waters close to or beyond the shelf break and again farther up on the shelf during February and along some transects in May 1977. These waters had a persistent atom ratio excess of phosphorus and silicon over nitrogen. No significant land source for nutrients was detected, although some silicate was delivered to the nearshore areas by river runoff. The only process that provided new nutrients to the shelf was the upwelling of deep water. Particulate organic carbon and chlorophyll correlated well throughout the study area; peaks were observed in the extreme inner zone and on the southernmost transect near Cape Canaveral where persistent upwelling occurs in the wake of the cape. Dissolved oxygen on the continental shelf approached or exceeded saturation during all four seasons, while oxygen decreased to 30 to 50% saturation at depth on the continental slope.

A time series of observations to study any subsurface Gulf Stream intrusion onto the shelf at the southern end of the study area during September 1977 showed constancy for salinity, temperature, dissolved nutrients, and chlorophyll, indicating that there was probably no intrusion during the 21 days of observations.

SECTION 1
INTRODUCTION

A. PURPOSE

The physical and chemical composition of seawater was investigated to characterize the water mass and prevailing oceanographic conditions on the Georgia Bight continental shelf during the four seasons in 1977. The observations are meant to serve a supportive role for the intensive high-resolution biological and chemical analyses during the 1977 South Atlantic Benchmark Program. While physical conditions such as temperature and salinity will not be significantly affected by development of petroleum resources on the continental shelf, they are an integral part of the shelf ecosystem, which will be affected by petroleum development.

Hydrographic (temperature, salinity, and dissolved oxygen), inorganic nutrient (nitrate, phosphorus, and silicate), chlorophyll *a*, and particulate and dissolved organic carbon data were collected during the water-column leg of each seasonal cruise. Hydrographic, inorganic nutrient, and chlorophyll data were collected during the benthic leg of each seasonal cruise and during the time-series leg of the summer cruise.

It is important to use these data in an appropriate manner, considering that they are of limited value in assessing real-world processes. The processes regulating these properties have characteristic event scales of from one to several days; this response scale is equal to or less than the length of time required to cover the seven transects in each leg of the cruises. If an advective event had begun and developed fully during one cruise leg, the hydrographic data would have shown a spatial pattern along the grid, whereas the actual pattern in nature would have varied as a function of time. The existence of this temporal aliasing is a frequent problem in oceanography whenever a large grid or section is studied. It is important that the reader recognize that the horizontal maps are not synoptic, that the water-column leg required about 6 days and was run south to north, and that the benthic leg required about 20 days and was run north to south.

The sampling did resolve the seasonal pattern of shelf variability. The progression from the unusually extreme winter conditions to the intermediate spring to the extreme summer and back to the intermediate fall was the best description of changes in the entire Georgia Bight that has ever been obtained.

The following paragraphs review the present state of knowledge about the hydrography of the area in order to lay the foundation for understanding the data gathered during the 1977 South Atlantic Benchmark Program (SABP).

B. BACKGROUND

Using data gathered in earlier investigations (Atkinson, 1975, 1976), Atkinson (1978) summarized oceanographic processes determining the hydrographic character of the continental-shelf water of the Georgia Bight, identifying freshwater runoff into the coastal area and intrusions of the Gulf Stream up onto the shelf as the two most important processes affecting the composition of the shelf water. Atkinson included the seasonal variation in air temperature, coupled with spring and summer insolation and fall and winter radiational cooling, as processes

of lesser contribution to changes in the character of shelf water. Over the annual cycle, surface temperatures ranged from <14°C to >29°C. Higher temperatures occurred in the vicinity of the Gulf Stream during all seasons. During winter and spring, there was a definite offshore horizontal gradient in surface temperature. In spring, horizontal gradients were minimal except in the vicinity of the Gulf Stream. During summer, solar heating of surface waters further minimized horizontal temperature gradients. During fall, surface waters did not show temperature gradients throughout the entire Bight. During fall, spring, and summer, near-bottom horizontal temperatures decreased toward deeper water; by contrast, during winter, near-bottom temperatures increased toward deeper water. This temperature distribution arises because relatively cold, deep, Gulf Stream water moves onshore along the bottom during an intrusion process; during winter, this intrusion actually appears to bring warmer water to the shelf because the shelf water is relatively colder than the intruding Gulf Stream water. This process is very important because it brings new water onto the shelf, replacing that which was there and providing a source of fresh nutrients to the shelf.

The annual variation in temperature placed the highest average in nearshore waters at 12.3°C, in offshore surface waters at 6.4°C, and in shelf-break bottom waters at 4.2°C.

Surface salinities were lower near shore; in general, the 35 $^{o}/oo$ isohaline followed the 18-m (10-fathom) isobath. In the southern end of the study area south of 31°N latitude, the isohalines intersected the coast. Surface salinities were generally >36 $^{o}/oo$ for the shelf water; the higher values were to the south and the lower ones to the north at the same isobath.

The intrusion of deeper, nutrient-rich water onto the continental shelf was identified by looking at the near-bottom nutrient distribution. Since shelf nutrients are usually low because of phytoplankton uptake, higher concentrations of nitrate are especially indicative of intruded bottom water up onto the shelf. Typically, shelf-water nitrate concentrations were <1 μg-atom/l. In an intrusion, nitrate concentrations are higher, often reaching 10 μg-atoms/l. Farther offshore, near-bottom nitrate values increased, the only variant being where the increase started in the cross-shelf direction.

A strong thermocline caused by the intrusion of the cold Gulf Stream up onto the shelf existed in the outer-shelf waters during the fall. High nutrient concentrations were associated with this cold water. The area of maximum salinity often had values of 36.5 $^{o}/oo$ and occasionally 36.7 $^{o}/oo$. Nearshore salinities progressively decreased, and surface salinity near the shoreline was almost always less than bottom salinity.

Silicate and phosphate increased toward the shore from midshelf. Highest concentrations were usually at the surface. This too reflects the fresher-water outflow of these two nutrients. An oxygen minimum, usually <3.5 ml/l, was associated with the zone of high salinity.

Winter data showed the influence of strong winds and cooling on the study parameters. Nearly all the isolines were vertical, indicating the complete absence of vertical gradients in shelf waters. Temperature and salinity decreased toward the coast, reflecting atmospheric cooling and the influence of river runoff, respectively. In all vertical profiles, the colder deep water was found at the shelf edge. In spite of intense wind mixing, the profiles at the shelf break looked much like those seen in the fall.

The spring cruise was held while strong winter winds were ameliorating and the shelf was seasonably heating. Shelf-water temperatures were 18° to 21°C and exhibited little vertical structure. Coldest shelf waters were at the southern end of the study area and were caused by intrusion of colder Gulf Stream water.

The salinity maximum occurred well east of the shelf break at depths of 100 to 200 m. The slope of the isotherms in deeper water implied a counter-current (flowing counter to the Gulf Stream) near the shelf break in the northern part of the area. Nutrient concentrations revealed an especially intense active intrusion of deeper Gulf Stream water into the outer shelf waters in the northern section of the study area. Profiles showed a consistent dissolved-oxygen minimum at 100 to 200 m.

The area was dominated in summer by a southerly wind system, and there was a significant intrusion of colder water onto the entire shelf. Present at the shelf break was deep water having a temperature of 20°C and a nitrate concentration of 2 μM. In the southern section of the study area, a Gulf Stream eddy formed when the Gulf Stream intruded into the shelf waters and then was cut off from the main flow.

The horizontal effect of freshwater runoff and Gulf Stream intrusions is summarized in Table 3.2-1. Runoff (defined by the 35 $^{o}/oo$ isohaline) averages 56 km offshore in the north but <3 km in the south. Intrusions defined by nitrate concentrations of >1 μg-atom/l extend up onto the continental shelf an average of 20 km from the shelf break and much closer to shore in the southern than in the northern part of the Georgia Bight. The seasonal variability in the extent of the influence onto the shelf suggests that water-mass movement on this part of the continental shelf is dynamic and that transport of waterborne pollutants through the area must be equally dynamic.

During the fall of 1973, a special situation of lower salinity and lower density was observed midway on the shelf. It was hypothesized that this was the result of water that originated from the Mississippi River during periods of high freshwater runnoff (Atkinson and Wallace, 1975) being transported out of the Gulf of Mexico by the Gulf Stream. This behavior, if this hypothesis is correct, will also act as a pollutant transport mechanism into and out of the Georgia Bight.

The temperature-salinity relationships, examined through the use of standard T-S plots, are well defined and predictable from years of open-ocean research (see Sverdrup et al., 1942, for a summary) for each ocean and each depth in that ocean. For example, subsurface ocean water of 10°C always has a salinity of about 35 $^{o}/oo$ (Atkinson, 1978). The T-S relationship for subsurface waters is predictable. The Gulf Stream also has a narrowly defined T-S boundary. The shelf waters, however, are subject to seasonal effects because of the annual variation of precipitation and runoff and the combined effects of evaporation and precipitation. The seasonal variation of temperature and salinity on the nearshore shelf zone is schematically presented in Figure 3.2-1 (Atkinson, 1978). Freshwater runoff, bimodal with peaks in late winter and late summer, lowers salinities. During periods of slack runoff, insolation causes salinities to increase by surface evaporation; during the winter, the annual temperature cycle cools the shelf water. The temperature of the water increases as the air becomes warm and the duration of the insolation increases. The temperature peaks during summer, decreases during fall, and returns to lower temperatures during winter.

With an understanding of these processes, it is possible to proceed to a discussion and assessment of 1977 SABP data.

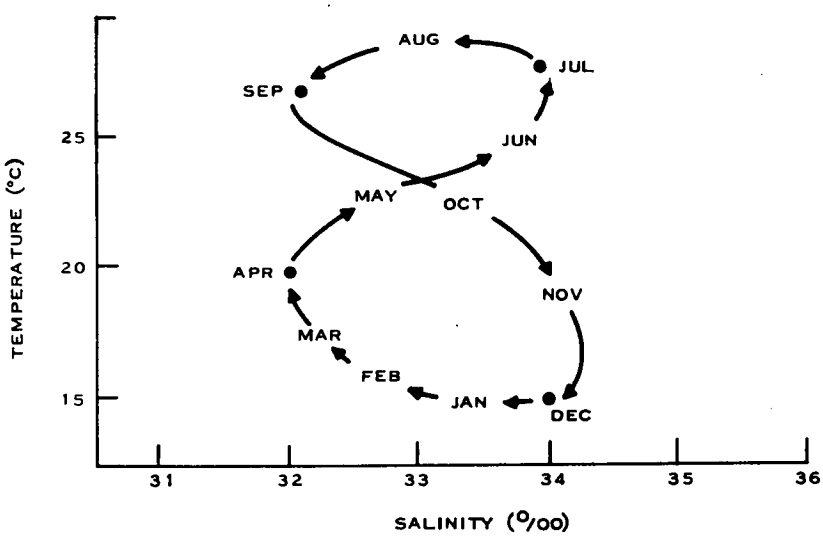

Figure 3.2-1. Seasonal Temperature: Salinity Schematic

Table 3.2-1. Horizontal Effects of Freshwater Runoff and Gulf Stream Intrusions on Continental Shelf of Georgia Bight

	Section	Avg Extent (km)	No. of Seasons
Offshore Extent of Runoff	I	56.5 ± 33.3	4
	II	42.3 ± 23.6	4
	III	33.8 ± 15.0	4
	IV	37.8 ± 23.0	4
	V	19.5 ± 1.3	4
	VI	2.7 ± 4.6	3
	All	33.4 ± 24.7	23
Inshore Extent of Intrusions	I	15.5 ± 17.2	4
	II	12.8 ± 10.5	4
	III	27.3 ± 9.5	4
	IV	11.5 ± 1.3	4
	V	13.5 ± 13.4	4
	VI	40.0 ± 30.8	3
	All	19.2 ± 16.6	23

SECTION 2
METHODS AND QUALITY CONTROL

A. ANALYTICAL METHODS

Sampling and analysis procedures are discussed in detail in Volume 2 of this report. During all four seasons, 12 hydrographic stations were occupied on the water-column leg of each cruise. On the benthic leg of each cruise during winter and summer, 50 hydrographic stations were occupied; 25 hydrographic stations were occupied during the benthic leg of the spring and fall cruises.

Water samples were collected in 10-l Niskin bottles or 7.5-l Go-Flo bottles. Temperature, salinity, dissolved oxygen, and chlorophyll *a* data were collected aboard the research vessel. Samples for analysis of nutrient concentration and particulate organic carbon were collected, frozen, and analyzed at TI's Environmental Chemistry Laboratory at the end of the research cruise. Samples for the analysis of dissolved organic carbon were collected and ampules sealed onboard and returned to the laboratory.

B. QUALITY CONTROL

Because the processes which govern the physical and chemical factors of seawater are basically understood, the internal consistency of these data can be evaluated to determine their overall suitability in adding to our knowledge of the study area.

1. Inorganic Nutrients

It is generally recognized that nitrate, phosphate, and silicate covary in a fixed manner, possibly established by the atom ratios of marine phytoplankton. This establishes the Redfield-Ketchum-Richards model (Redfield et al., 1963). It can be predicted that the nitrate nitrogen: phosphate phosphorus atom ratio in seawater will be 16:1. A simple quality-control check on the nutrient data involved regressing nitrate on phosphate to verify significant correlation and a 16:1 slope.

2. Particulate Organic Carbon

The quality of the particulate organic carbon data was verified by comparing the distribution of particulate organic carbon with the distribution of chlorophyll *a*. The filters that were used to collect the material for chlorophyll analysis and those used to collect particulate organic carbon samples had similar but not identical retention sizes; generally, POC increases over the detrital level will correlate with increases in chlorophyll *a*.

3. Chlorophyll *a*

Using chlorophyll *a* data alone and using a calculated chlorophyll *a*/living-POC ratio, chlorophyll *a* data were verified by comparison with previous data from the South Atlantic. In addition, behavior of chlorophyll *a* versus POC was examined using regression analysis (Huntman and Barber, 1977).

4. Dissolved Organic Carbon

In the dissolved organic carbon analyses for winter samples, a problem arose from high blank values. It was possible to calculate a mean blank value and thus arrive at a predicted but low confidence number for the DOC concentration. Since DOC distribution in the open ocean varies in a constant manner with depth and always within known bounds, it is easy to reach a judgment that the DOC numbers are not accurate. The dissolved organic carbon data were not intended to be and cannot be used as a primary index of hydrocarbon contamination since this contamination, if it is present, will be in the picogram or nanogram range rather than in the milligram range of the natural dissolved organic carbon. Potential petroleum contaminants will be up to a millionfold less abundant than the general DOC pool of seawater. Research into the composition of the DOC pool is of continuing interest; some first-class analytical work will be needed to solve the questions related to the composition and origin of this natural material. Since the natural material exceeds the petroleum-related compounds by such a large amount, serious analytical complications could result if there is even partial involvement of the natural organic matter in the extraction procedures. It seems that more qualitative analytical effort on the natural dissolved organic compounds would pay a large dividend in understanding, while it is not clear what use can be made of the quantitative data that are collected by the total organic carbon analyses.

5. Dissolved Oxygen

Dissolved-oxygen values were determined according to Strickland and Parsons (1972) and were reported in milligrams per liter of seawater, then converted to micromoles per kilogram of seawater and compared to the saturation values given by Kester (1975).

SECTION 3
RESULTS

Cruise tracks and station locations are presented in Volume 2. In this section, all horizontal plots of data are constructed using water-column and benthic data for both legs of each seasonal cruise plotted together. Data are not available for all benthic stations during all four seasons. The interested reader should examine the data set (Volume 6) to make a judgment as to the validity of contouring. The dashed lines in the plots indicate doubt concerning the positions of isolines.

A. TEMPERATURE DISTRIBUTION

As is normal in winter, inner-shelf temperatures were low and decreased to the north. Nearshore temperatures ranged from 4.7°C in the north to 14.8°C in the south. As Figure 3.2-2 indicates, the isotherms tended to parallel the coast, with midshelf temperatures varying from 10° to 20°C and outer-shelf waters ranging from 18° to 21°C. In winter (Figure 3.2-3), because of wind mixing, bottom temperatures were similar to surface temperatures on the inner shelf; this indicated that the Gulf Stream was to the east off transects 5 and 6 and to the west off transects farther to the north.

During spring (Figure 3.2-4), minimum surface temperatures were observed in outer-shelf waters in the southern sections. Bottom temperatures (Figure 3.2-5) also tended to confirm the presence of colder water at the shelf break. From these data, one can conclude that a shelf-edge cold eddy was present during the observation period at stations 7D and 7E and possibly at 6F, 6G, and 6H. Relative to winter, spring shelf waters had warmed considerably; the alongshore-nearshore gradient that had been 5° to 15°C was now 21° to 24°C, and the onshore-offshore gradient decreased to only 1° to 4°C.

The summer distribution of surface temperature (Figure 3.2-6) was usually rather monotonous. The low temperatures off Daytona Beach were not unusual and may have represented upwelling of subsurface Gulf Stream water. Bottom temperatures (Figure 3.2-7) indicated an intrusion of 18° to 19°C water on transects 4 and 5.

Fall cooling shows its effect in Figure 3.2-8. Isotherms again paralleled the coast, and horizontal thermal gradients were increasing. Near-bottom temperatures (Figure 3.2-9) indicated no significant Gulf Stream interaction with the shelf waters.

B. SALINITY DISTRIBUTION

The distribution of surface salinity is most useful in revealing distance to which runoff extends into the shelf waters but is not as useful an indicator of Gulf Stream water as is temperature.

Salinities of 30 $^{o}/oo$ were observed between Savannah and Brunswick during the winter cruise (Figure 3.2-10). The 35 $^{o}/oo$ isohaline, a good indicator of the extent of runoff, paralleled the coast to Jacksonville, then intersected the coast at Daytona Beach.

It is not possible to comment reliably on the minimum salinities at many of the inshore stations during the spring cruise (Figure 3.2-11) because, according to the study design, many of

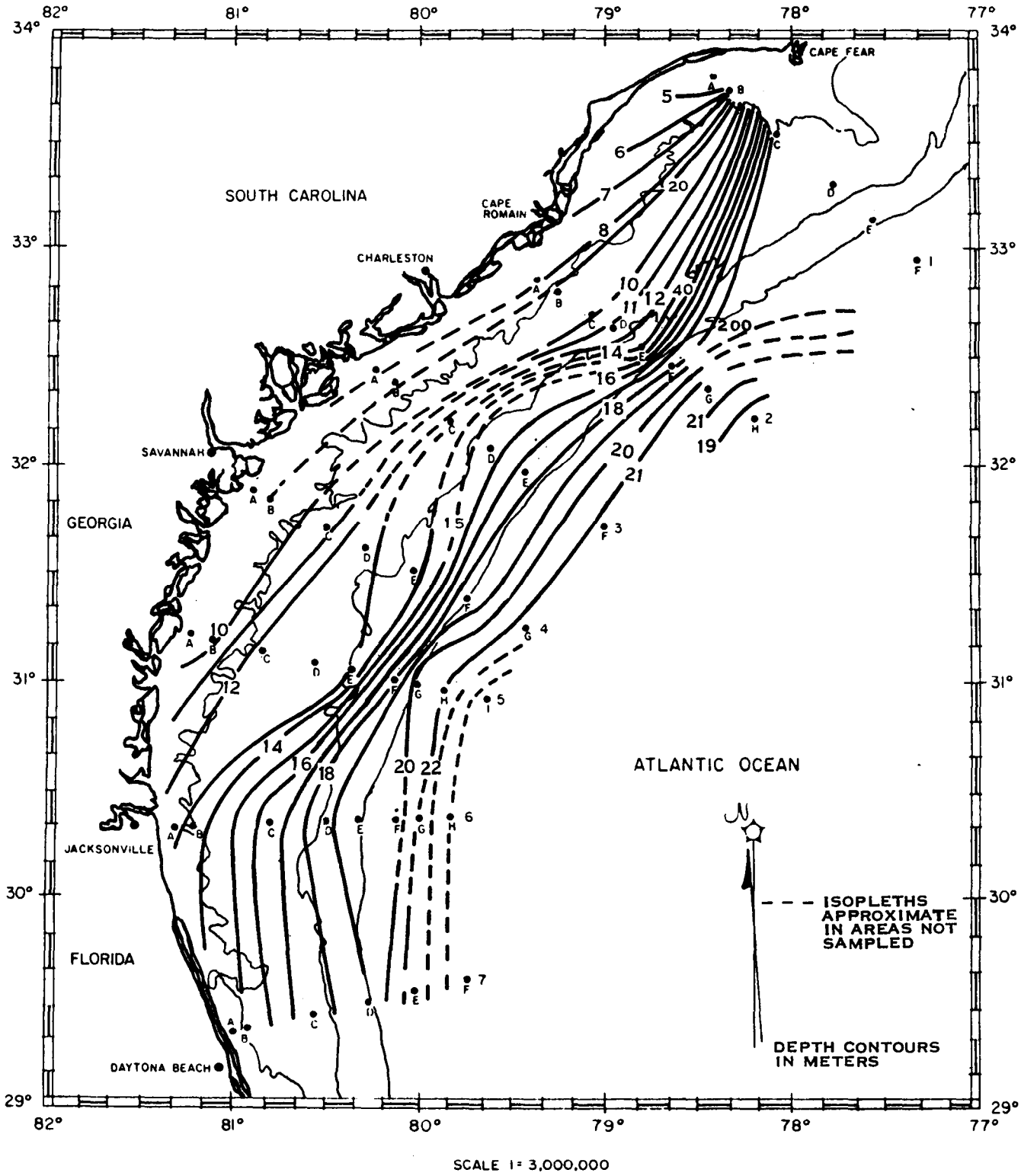

Figure 3.2-2. Surface Temperatures (°C), Winter 1977

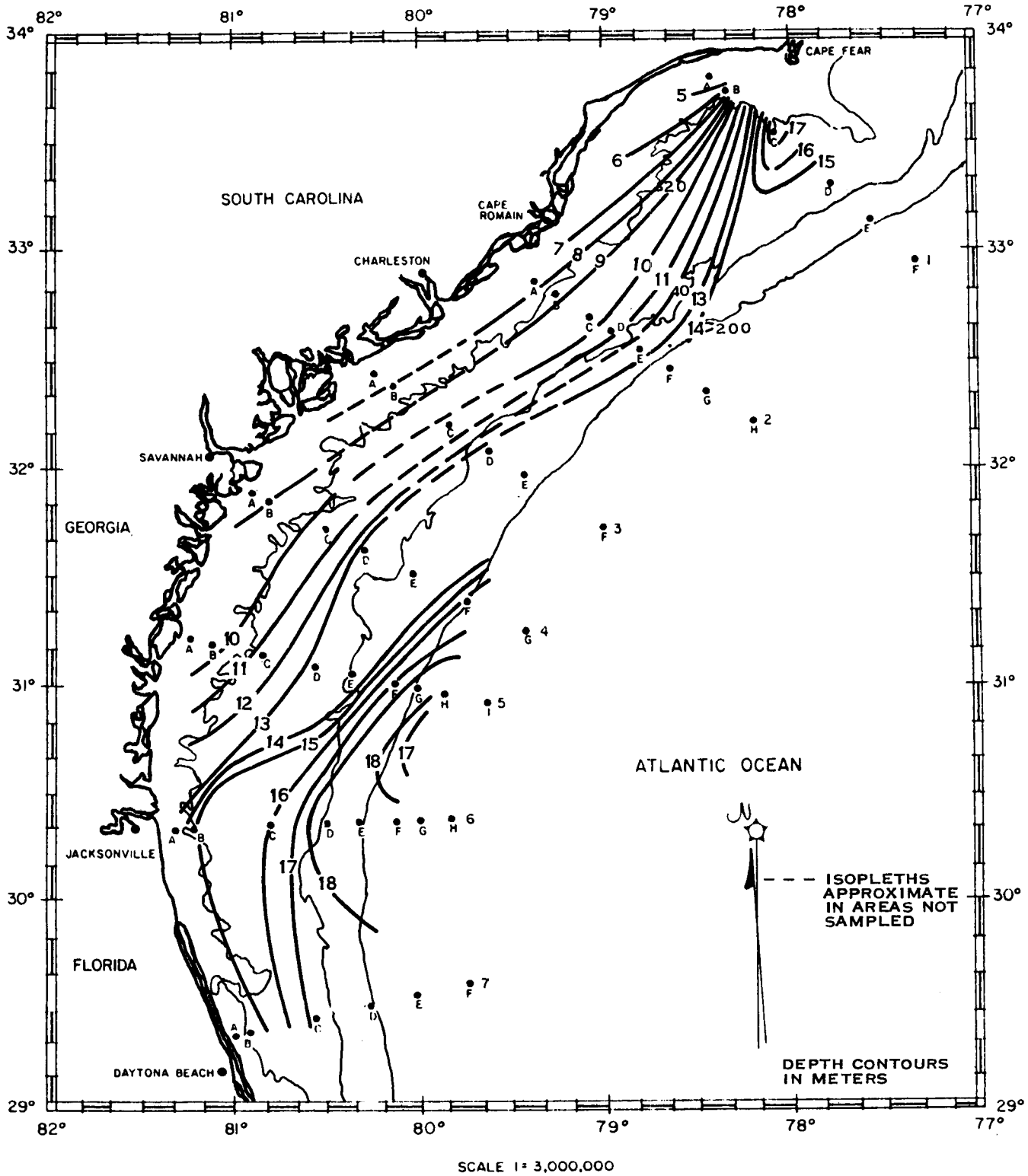

Figure 3.2-3. Near-Bottom Temperatures (°C), Winter 1977

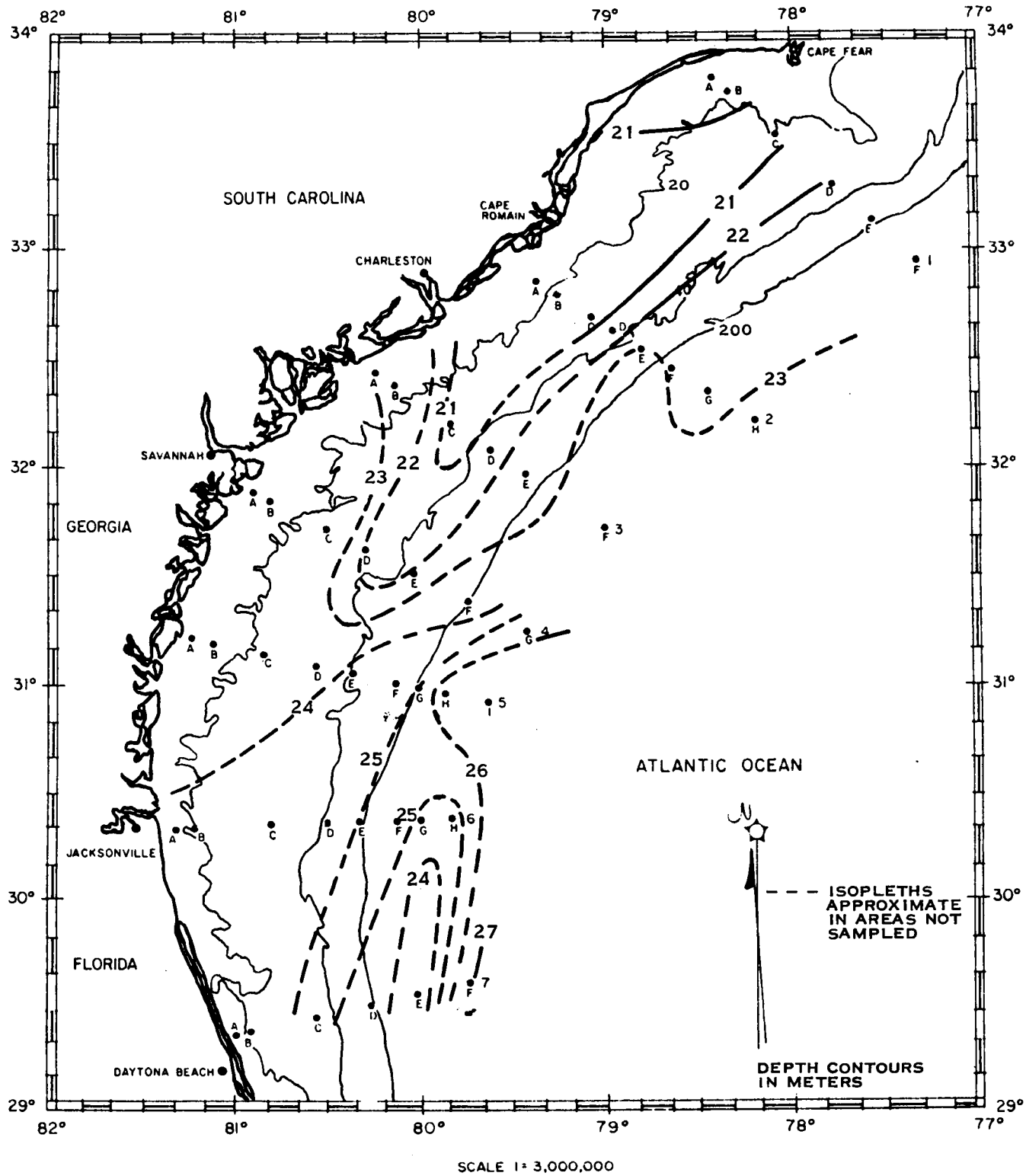

Figure 3.2-4. Surface Temperatures (°C), Spring 1977

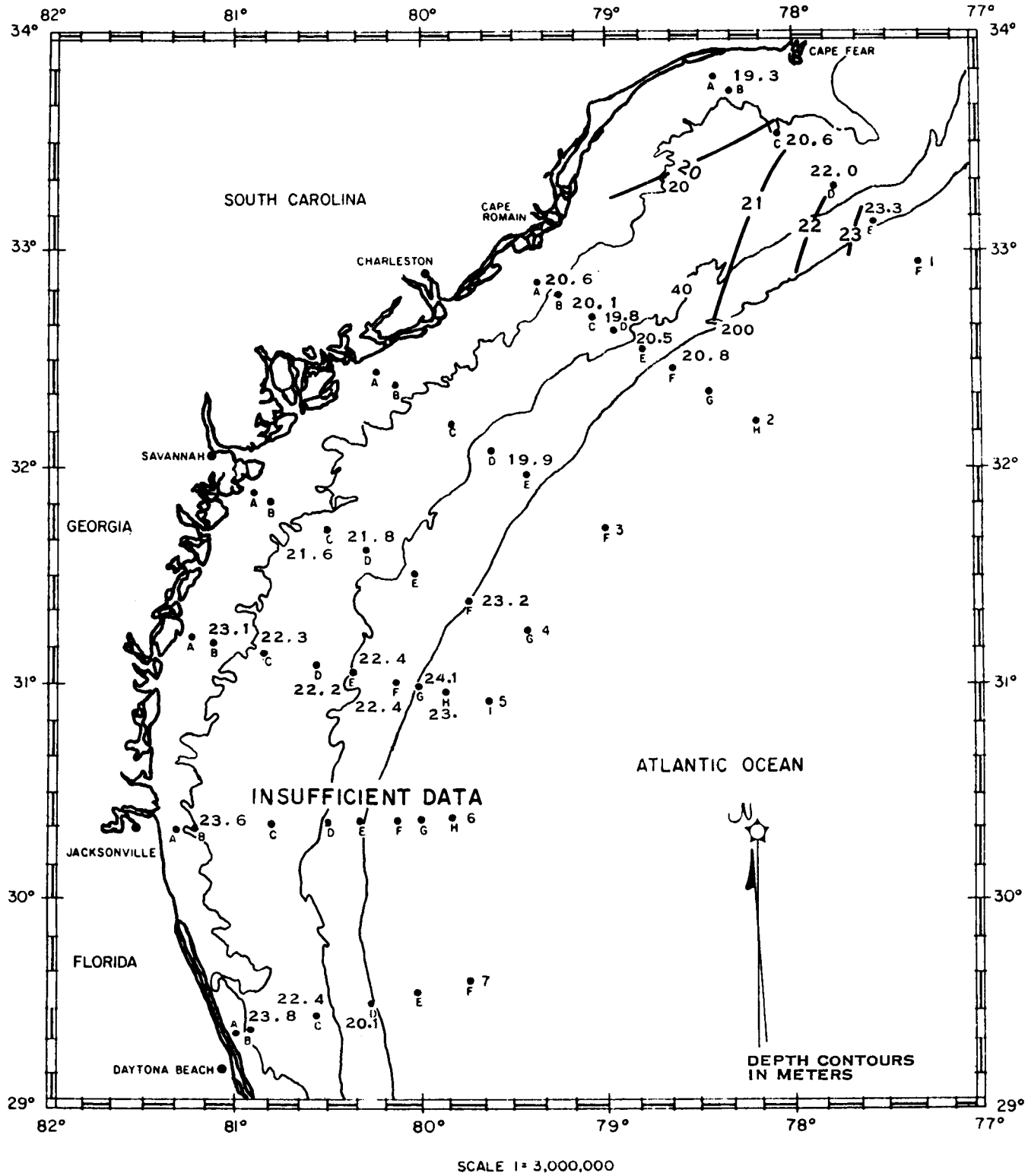

Figure 3.2-5. Near-Bottom Temperatures (°C), Spring 1977

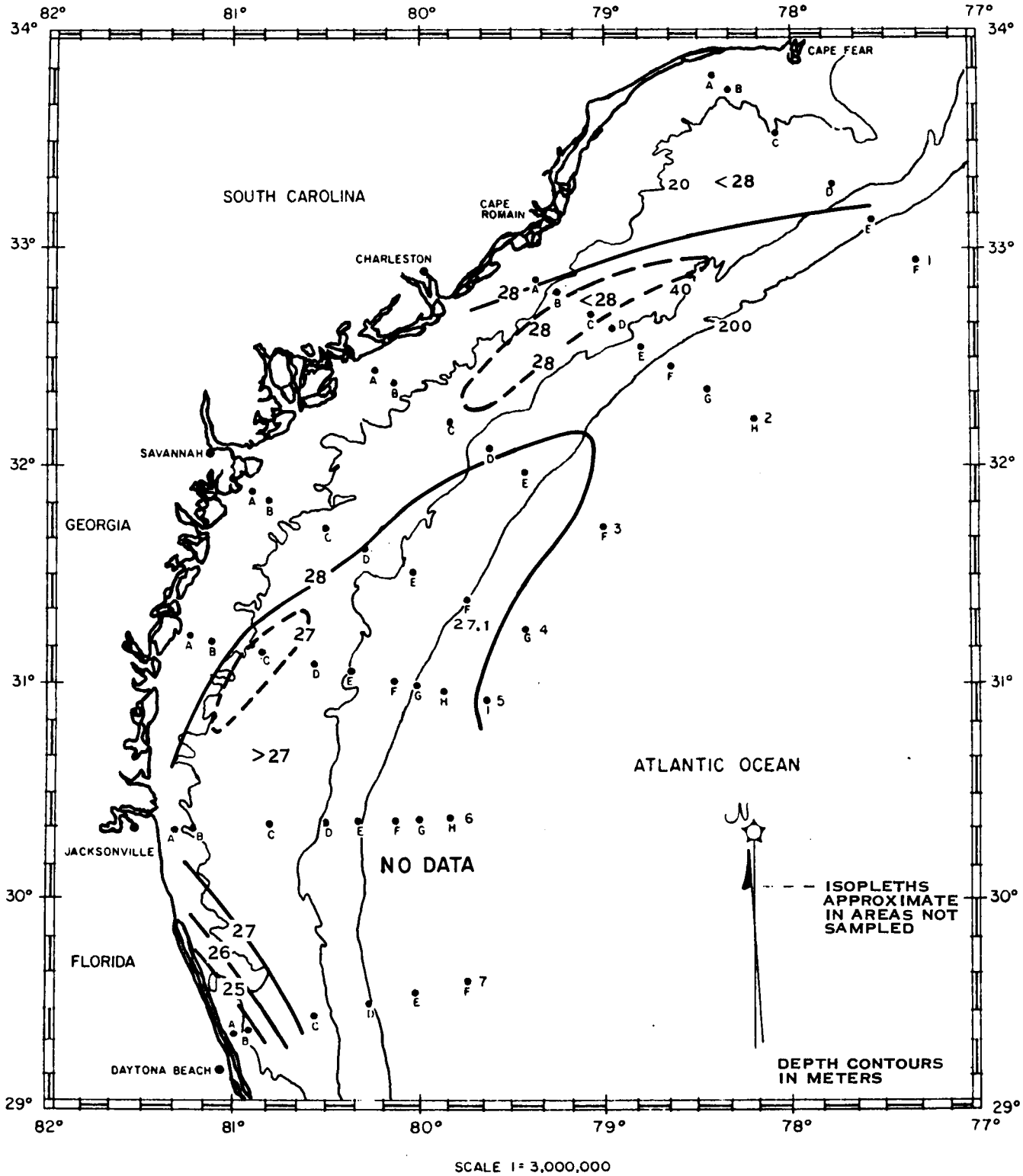

Figure 3.2-6. Surface Temperatures (°C), Summer 1977

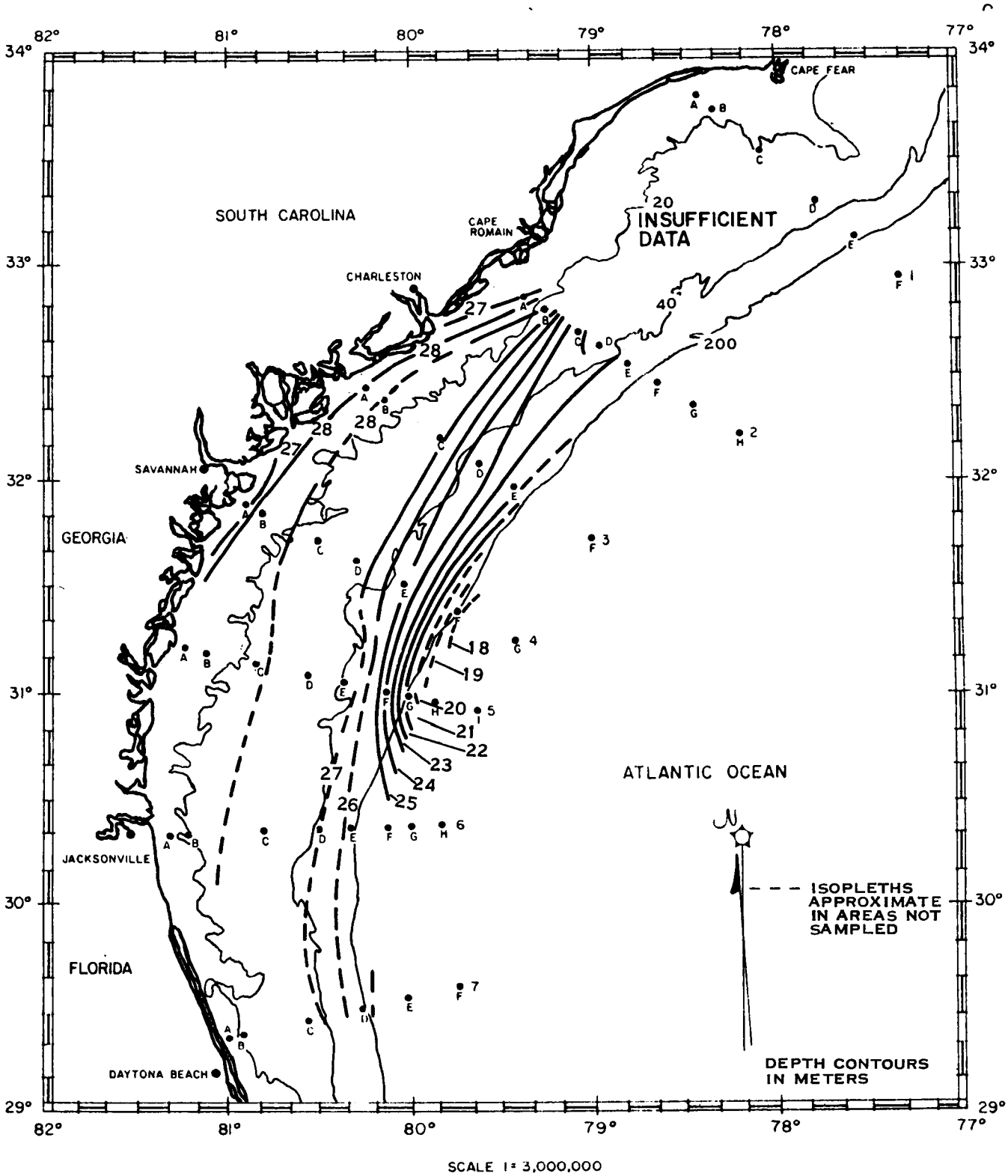

Figure 3.2-7. Near-Bottom Temperatures (°C), Summer 1977

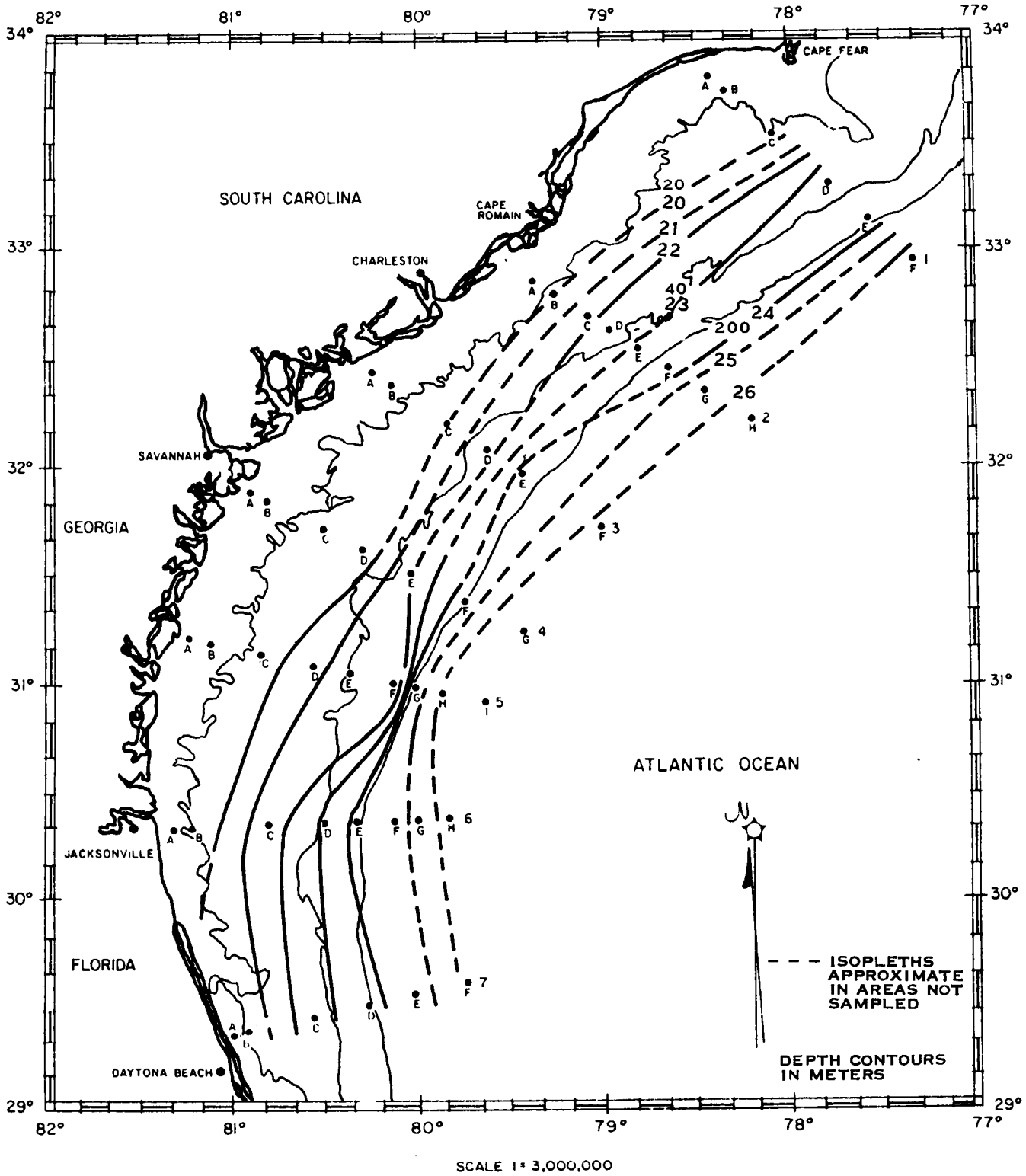

Figure 3.2-8. Surface Temperatures (°C), Fall 1977

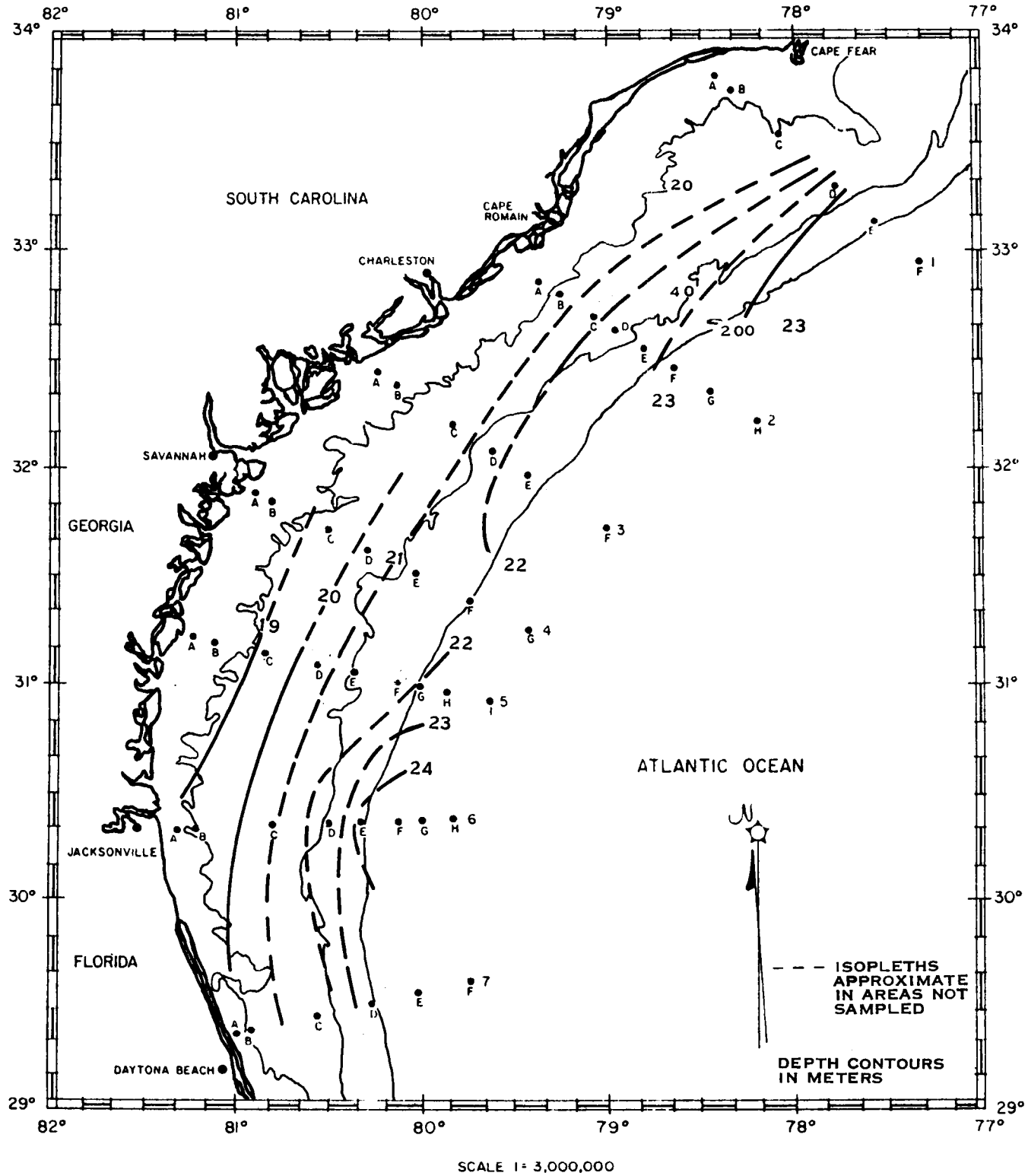

Figure 3.2-9. Near-Bottom Temperatures (°C), Fall 1977

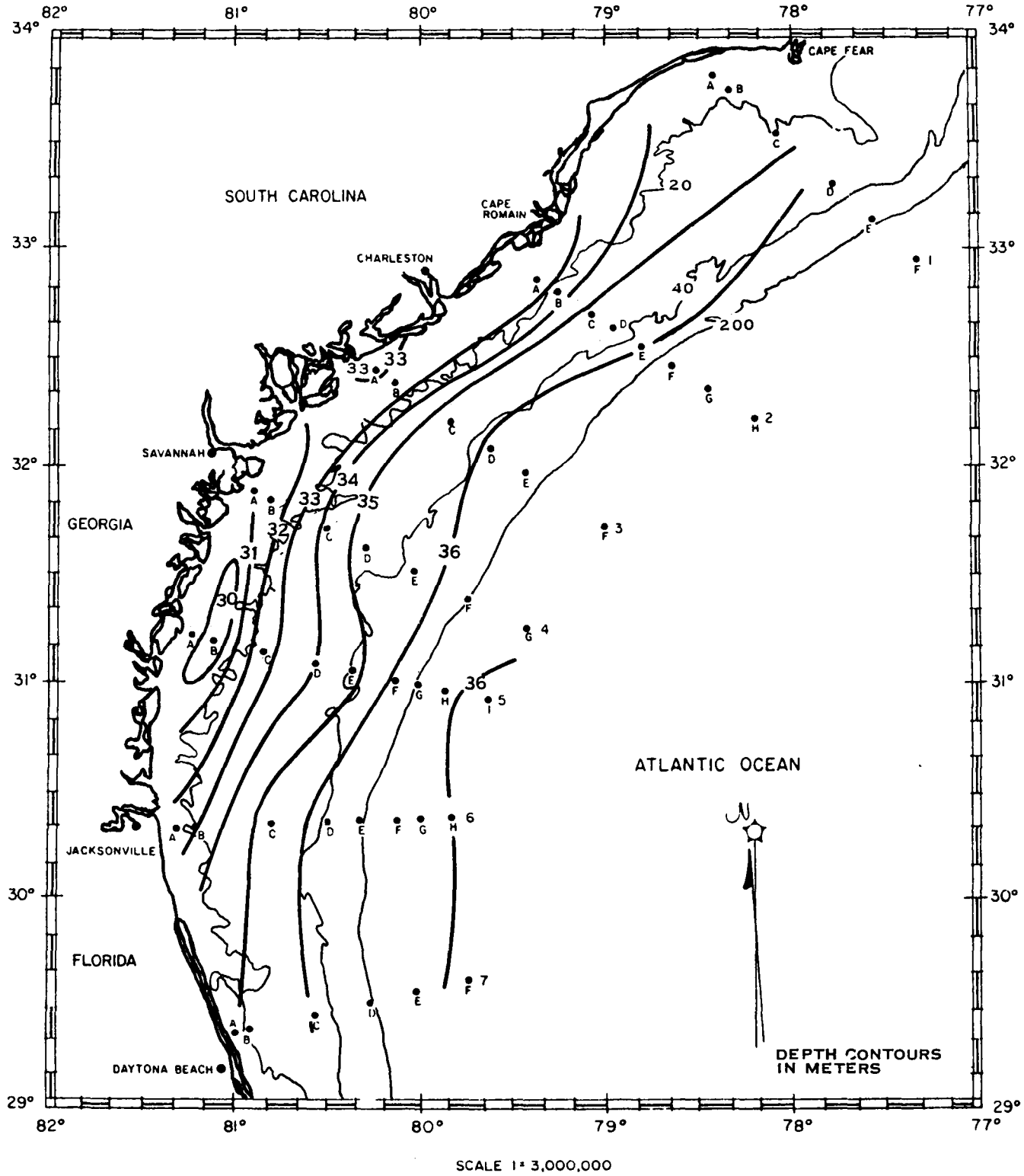

Figure 3.2-10. Surface Salinities (^{o}/oo), Winter 1977

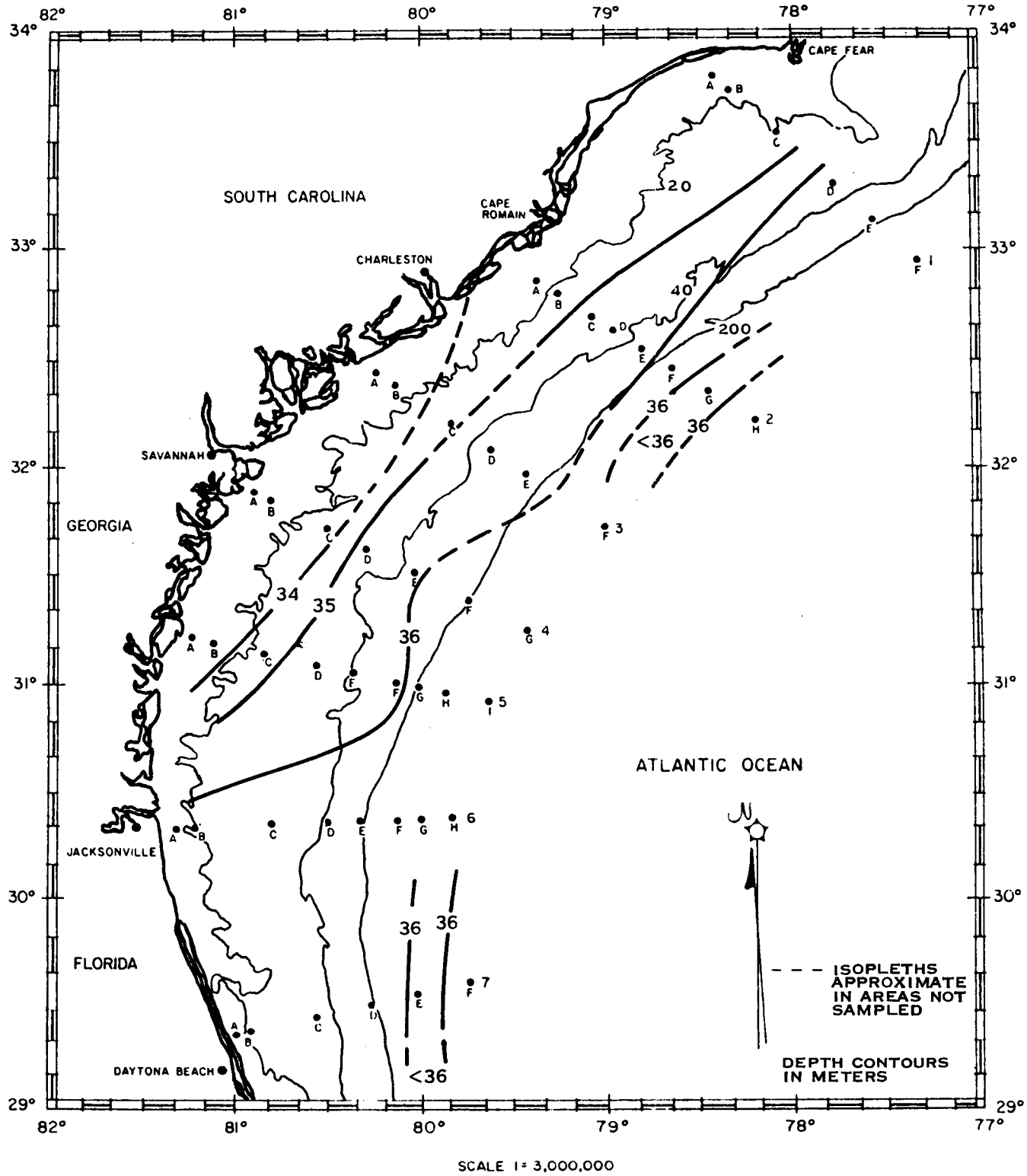

Figure 3.2-11. Surface Salinities (^{o}/oo), Spring 1977

these inshore stations were not to be sampled. The low salinities at 7E were possibly associated with a Gulf Stream eddy.

Summer was a time of low runoff. The 35 and 36 $^{o}/oo$ isohalines (Figure 3.2-12) were near the coast.

Fall was a time of minimum runoff and high surface salinities (Figure 3.2-13). Most of the mid- and outer-shelf water was 35 to 36.5 $^{o}/oo$; only nearshore stations exhibited less than 35 $^{o}/oo$.

C. RELATIONSHIPS

1. Nitrate Versus Phosphate

Figures 3.2-14 through 3.2-17 present data for the regressions of phosphate versus nitrate for the four seasonal cruises. Table 3.2-2 summarizes the regression data, showing that nitrate and phosphate were significantly correlated for all four seasons but that the predicted slope of the phosphate-versus-nitrate line was about 1:15 only for winter, spring, and fall. For summer, the slope of the relationship was determined to be about 1:30, which was clearly impossible. It was determined that the nitrate samples that had been diluted to be properly analyzed were the samples biasing the regression analysis; when these samples were corrected for the obvious dilution error, a slope closer to the 1:15 value was obtained. The corrected data are shown in Figure 3.2-16; uncorrected data are given in Appendix 3.2A, Volume 6. The reader is cautioned, however, that these data may contain additional errors and remain suspect. Because of the uncertainty of the summer nitrate data, this discussion is limited to winter, spring, and fall data.

The significant positive slope of approximately 1:15 for phosphate-versus-nitrate regressions for winter, spring, and fall indicated relatively typical nutrient-rich deep water at the bottom of the offshore stations. Table 3.2-3 shows, however, that the typically high nitrates were restricted to relatively great depths. The bottom intrusions that dominated the temperature, salinity, and advective fields had little nutrient impact in waters shallower than 50 m. Significantly, during spring and fall, the 1 μg-at/l values were restricted to depths exceeding 100 m.

The intercept of the phosphate-versus-nitrate regression (see Appendix 3.2B, Volume 6) is positive for phosphate at approximately 0.1 μg-at/l. The mean phosphate on the shelf is about 0.25 μg-at/l (Appendix 3.2B).

2. Nitrate Versus Temperature

Where nitrate concentrations were high, temperature-versus-nitrate regressions defined the domain in terms of temperature. The highest temperature at which nitrate values exceeded 1 μg-at/l can be seen in the print plots of the regressions in Appendix 3.2B of Volume 6. The winter temperature intercept was about 19°C; spring, approximately 21°C; and fall about 17°C. These observations emphasize that water colder than 22°C must intrude into the euphotic zone if there is to be quantitatively important nitrate transport into the shelf ecosystem. The maps of bottom temperature during the four seasons show this condition in the Georgia Bight. The nitrate-versus-temperature regressions show that there was very cold water in winter with zero nitrate; this condition was created when already nutrient-depleted water was locally cooled during winter. While water must be colder than 22°C if nitrate concentrations are to be high, this condition is not sufficient by itself.

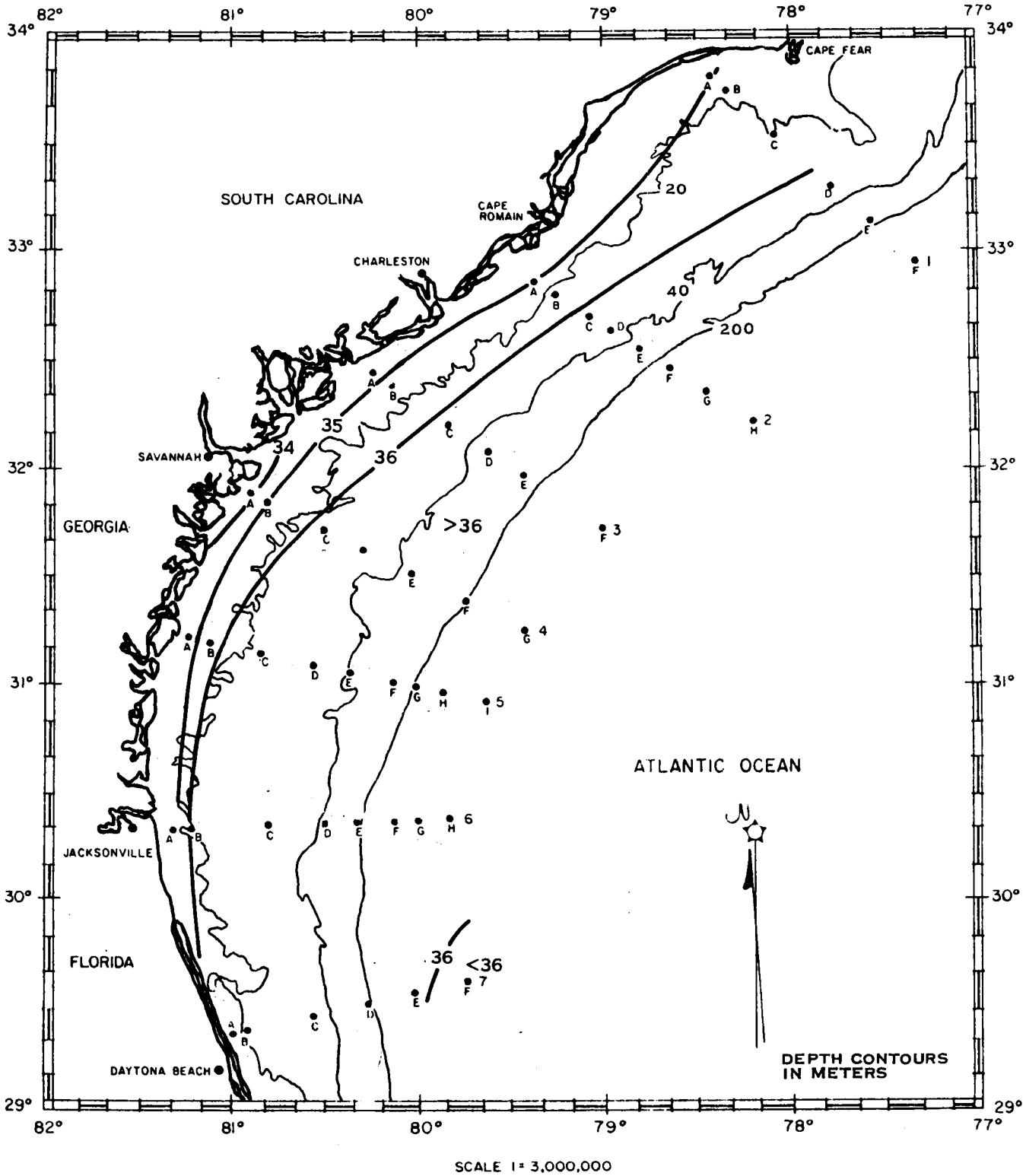

Figure 3.2-12. Surface Salinities (°/oo), Summer 1977

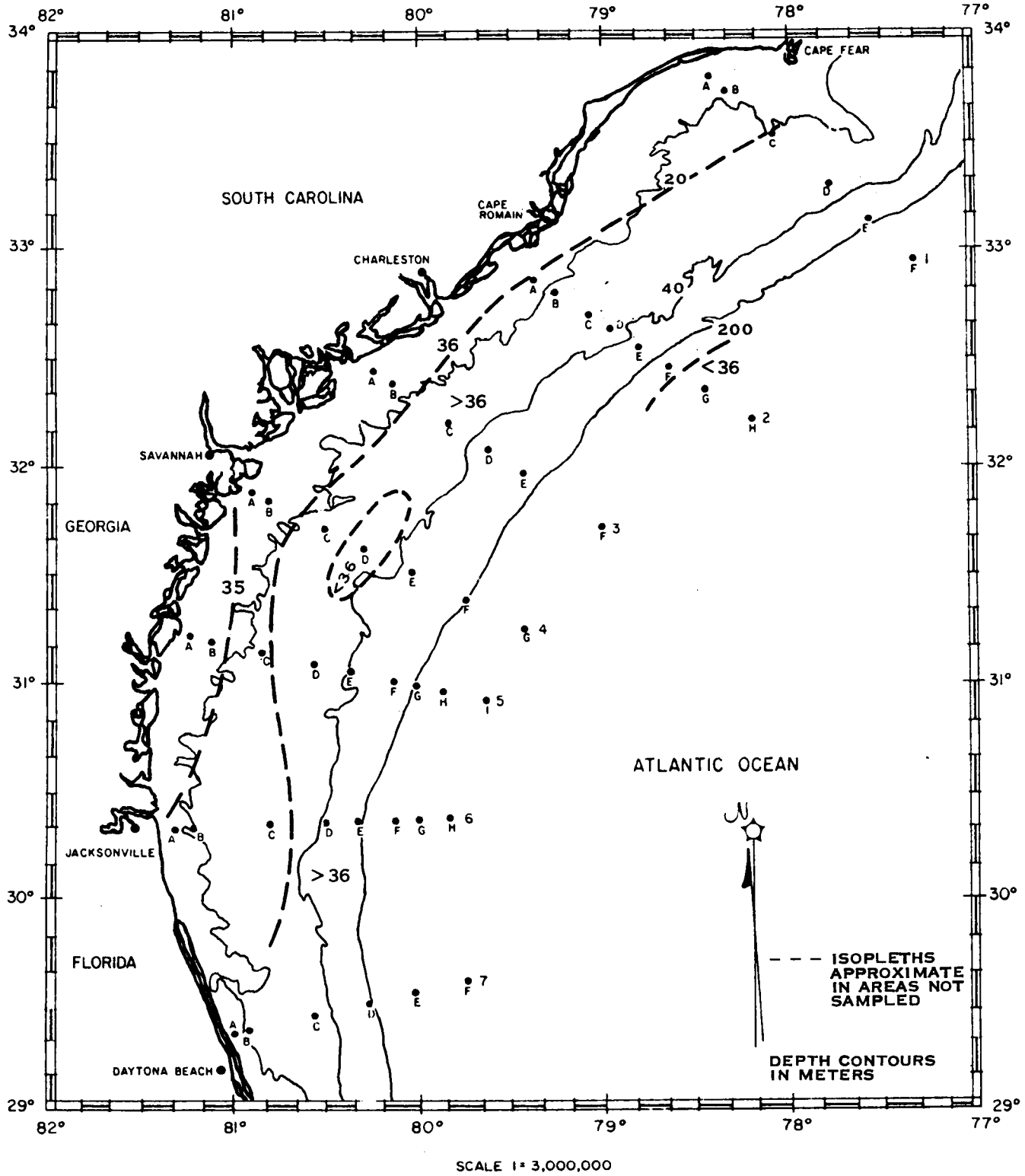

Figure 3.2-13. Surface Salinities (^{o}/oo), Fall 1977

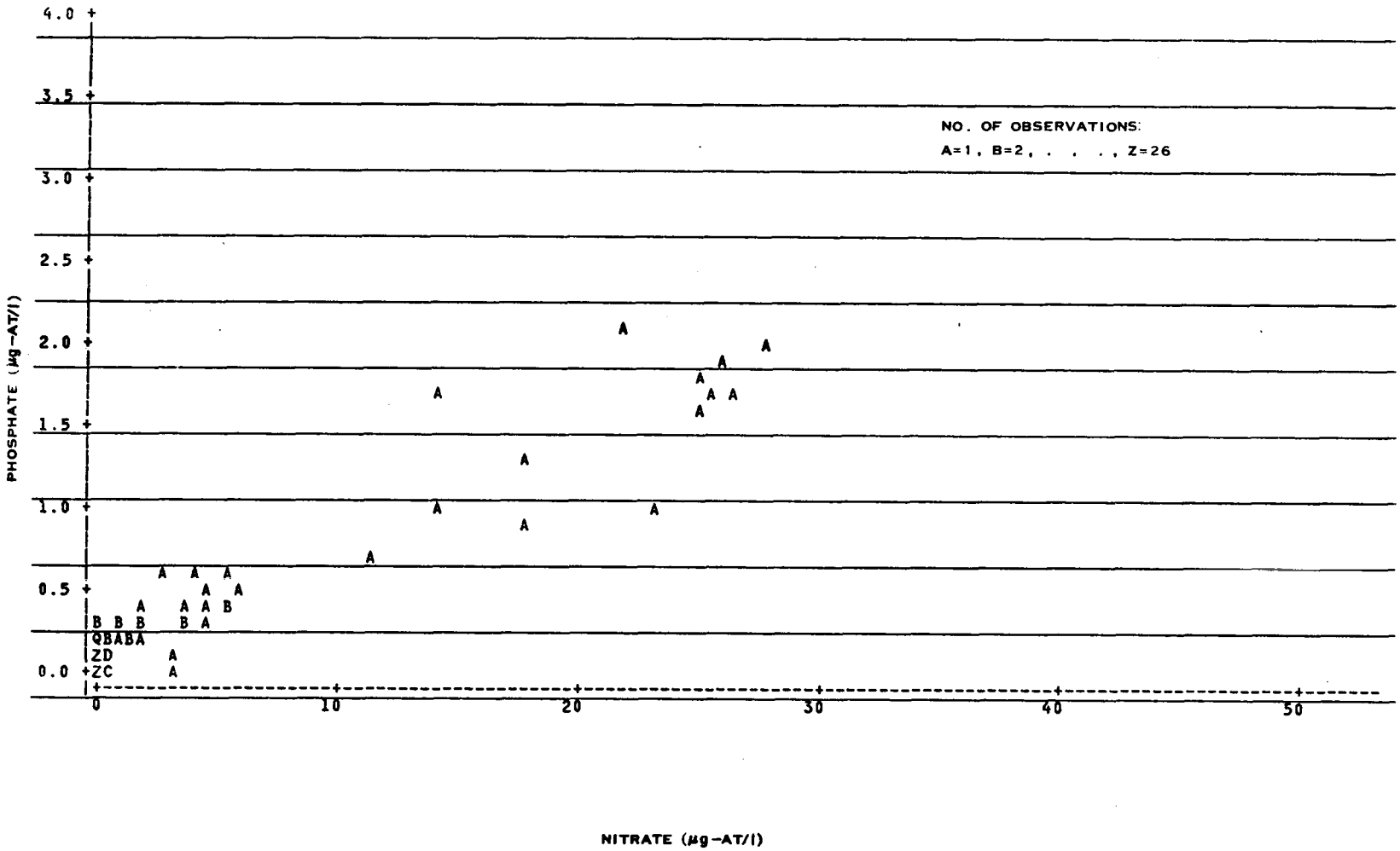

Figure 3.2-14. Phosphate Versus Nitrate, Winter 1977

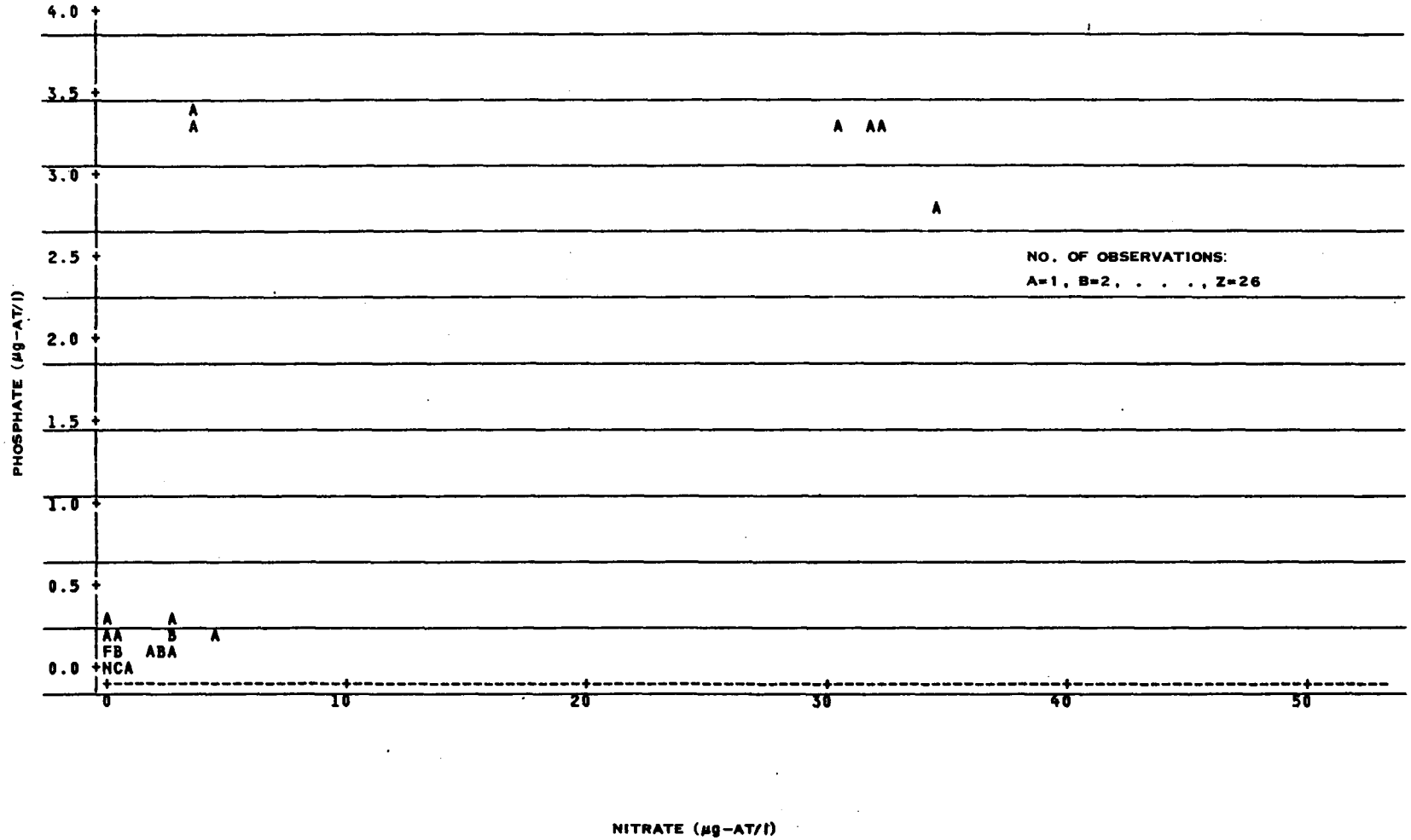

Figure 3.2-15. Phosphate Versus Nitrate, Spring 1977

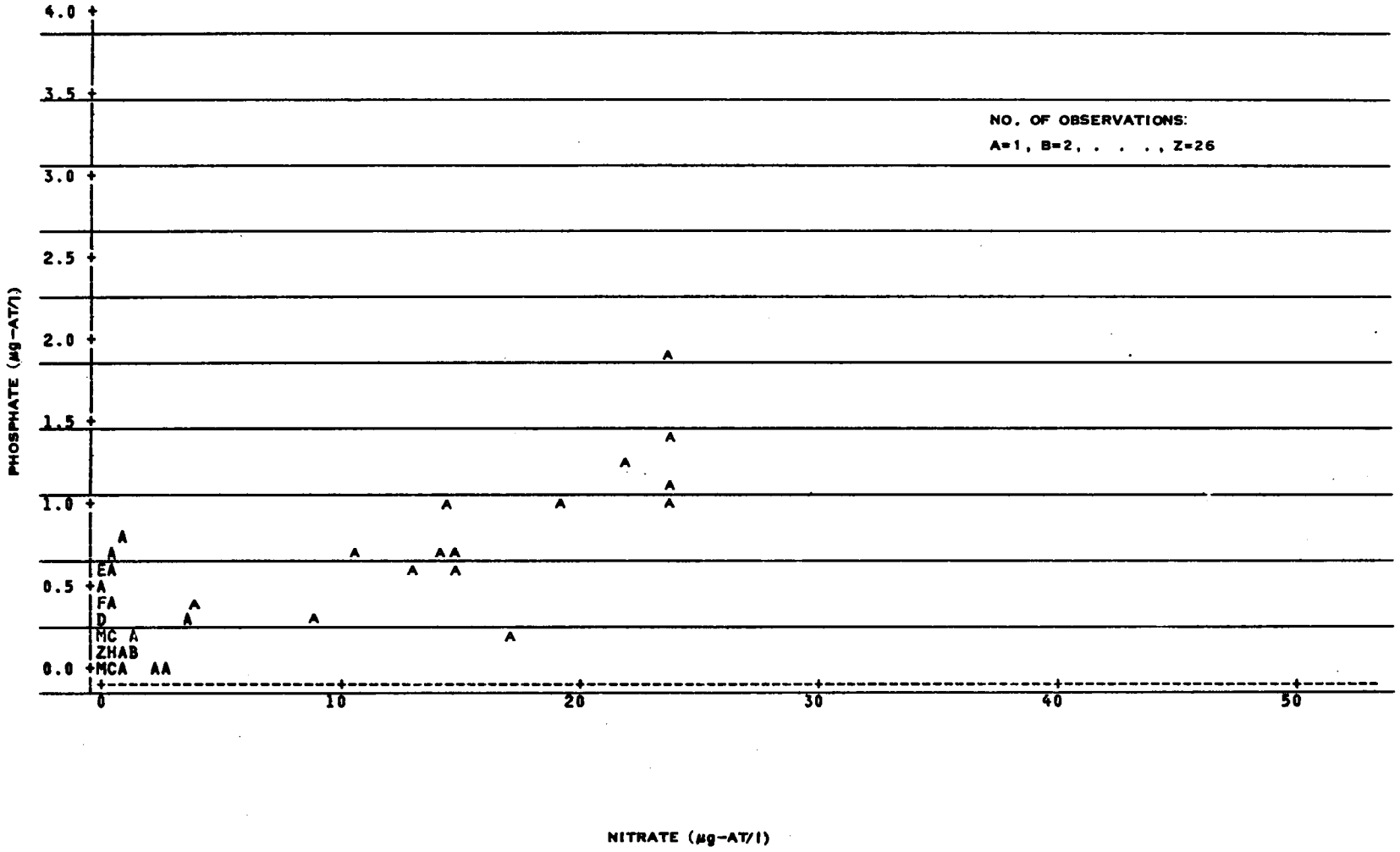

Figure 3.2-16. Phosphate Versus Nitrate, Summer 1977

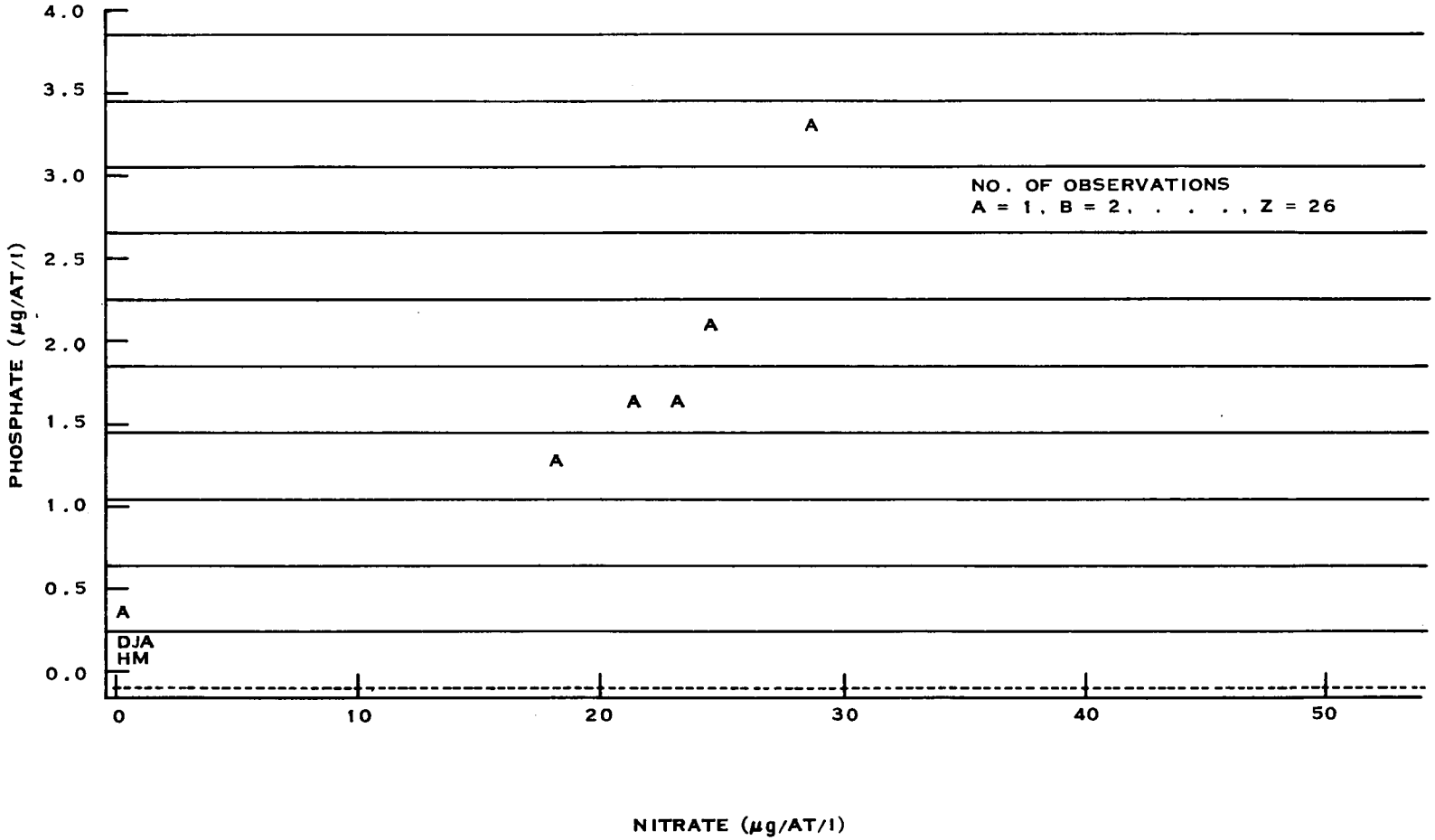

Figure 3.2-17. Phosphate Versus Nitrate, Fall 1977

Table 3.2-2. Phosphate-Versus-Nitrate Regression Data

Season	Regression Slope	N:P	Mean Phosphate (μg at/l)	Phosphate Intercept (μg at/l)	Correlation Coefficient (r^2)
Winter	0.066	15.2	0.28	0.09	0.91
Spring	0.10	10	0.27	0.07	0.68
Summer[a]	0.041	22.4	0.43	0.19	0.78
Fall	0.082	12.2	0.24	0.10	0.93

[a]Corrected data.

Table 3.2-3. Seasonal Variations in Bottom Nitrate on Transect 5

Station (depth in m)	Concentration (μg-at/l) Winter	Spring	Fall
5A (8)	0.0	–	–
5B (10)	0.1	0.2	0.2
5C (19)	0.1	0.2	0.2
5D (26)	0.2	0.0	0.2
5E (33)	0.0	0.2	0.2
5F (37)	0.1	0.0	0.2
5G (41)	0.6	0.0	0.4
5H (92)	4.6	0.4	0.6
5I (420)	26.5	30.4	21.4

The near-bottom distribution of nitrate (Figures 3.2-18 through 3.2-20) shows the results of advection of nutrient-rich, deeper Gulf Stream waters onto the shelf. Since nitrate is used by phytoplankton and the concentrations are reduced, its presence is a definitive indicator of recent Gulf Stream intrusion activity.

Winter samples exhibited relatively high nitrate concentrations at the shelf break at all locations except transect 5 off Brunswick (Figure 3.2-18). This pattern repeated itself in spring samples (Figure 3.2-19), although concentrations were relatively lower and no intrusion activity was visible on transects 1 or 2.

The fall data (Figure 3.2-20) indicated that there was no intrusion activity over the entire shelf.

3. Salinity Versus Silicate

The Georgia Bight has two significant sources of silicate—the deep ocean and rivers. The silicate:salinity plot for the four seasons (Figure 3.2-21) demonstrates these sources and the

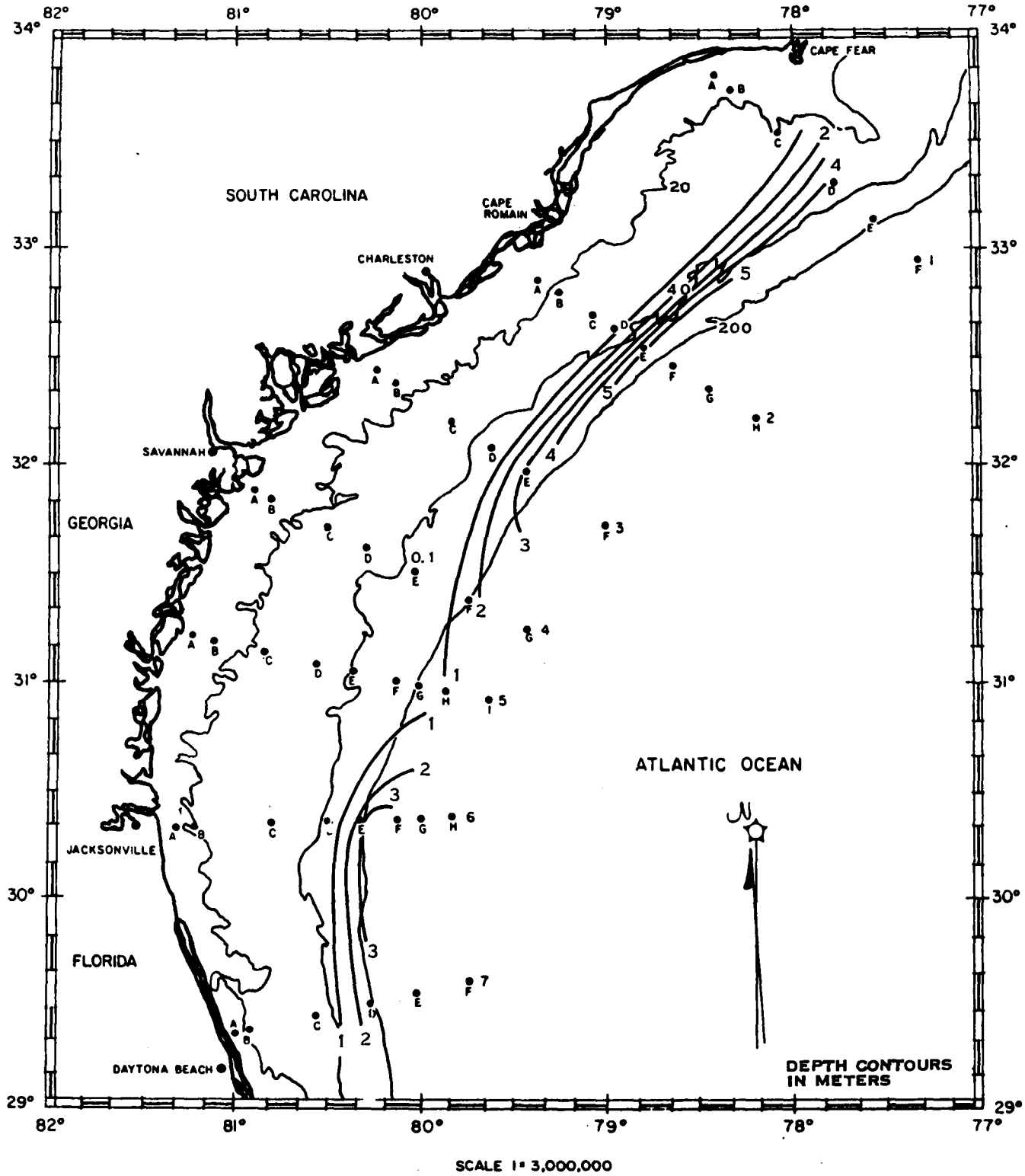

Figure 3.2-18. Bottom Nitrate Concentrations (μg-at/l), Winter Benthic Sampling Leg

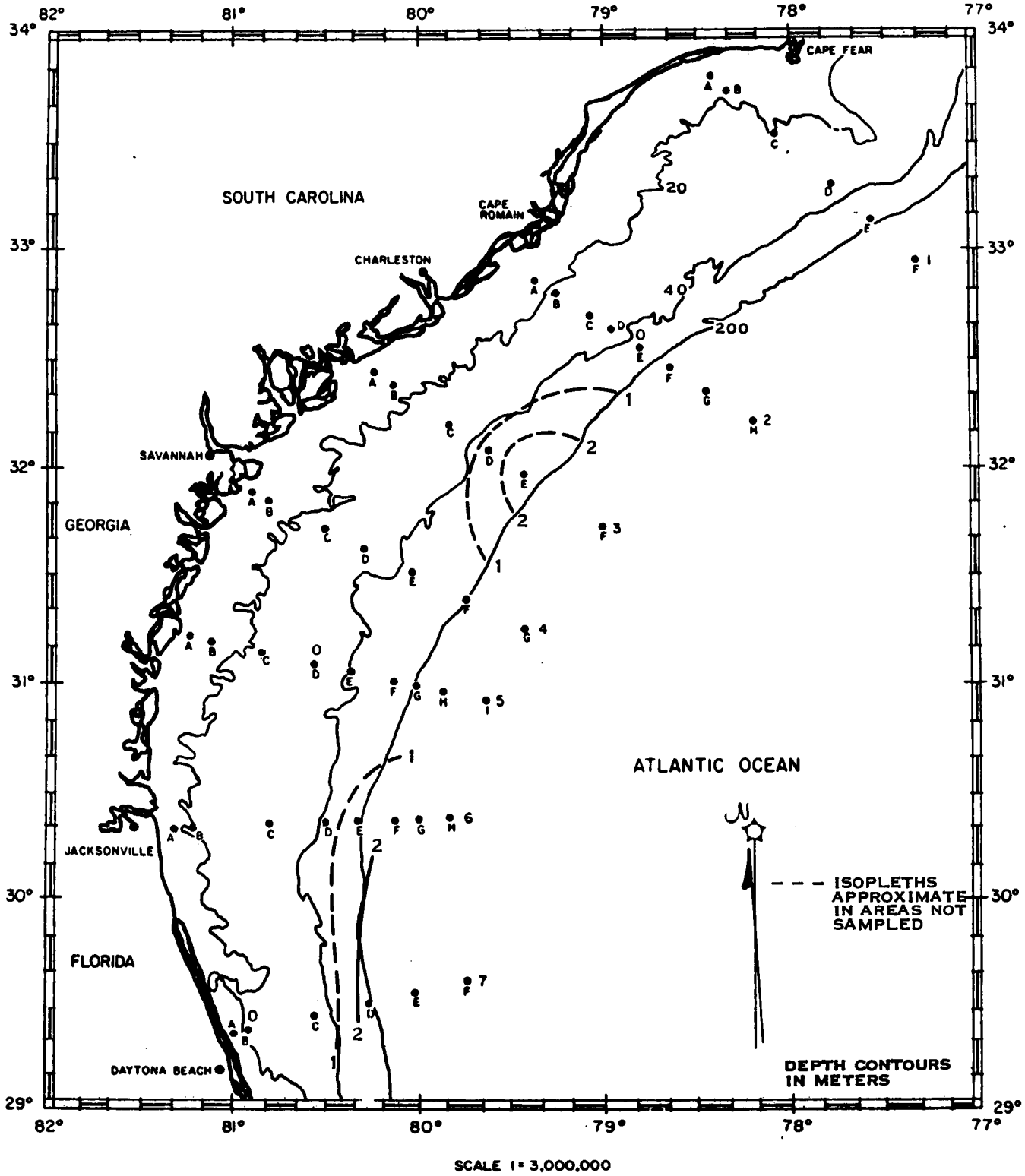

Figure 3.2-19. Bottom Nitrate Concentrations (μg-at/l), Spring Benthic Sampling Leg

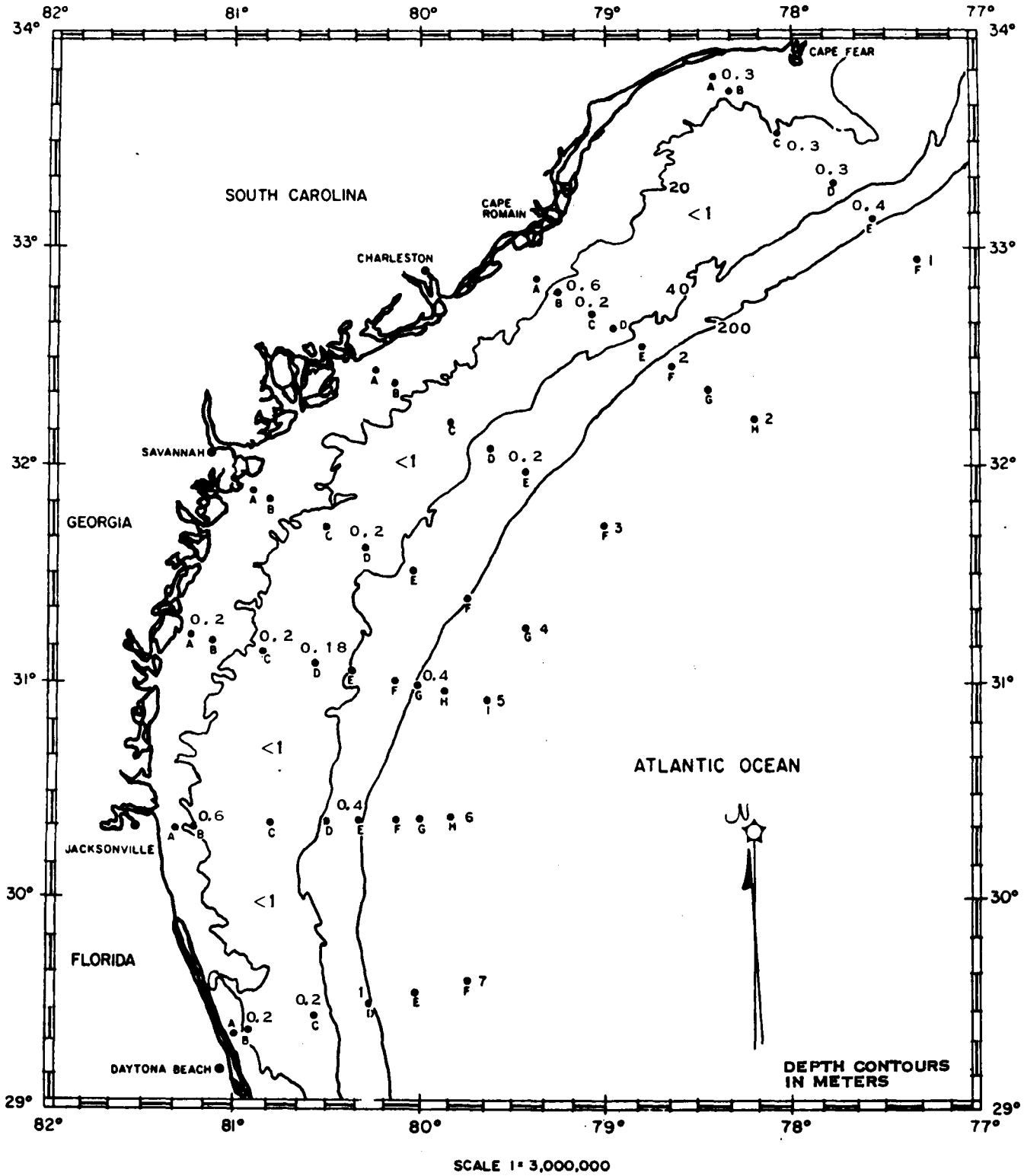

Figure 3.2-20. Bottom Nitrate Concentrations (μg-at/l), Fall Benthic Sampling Leg

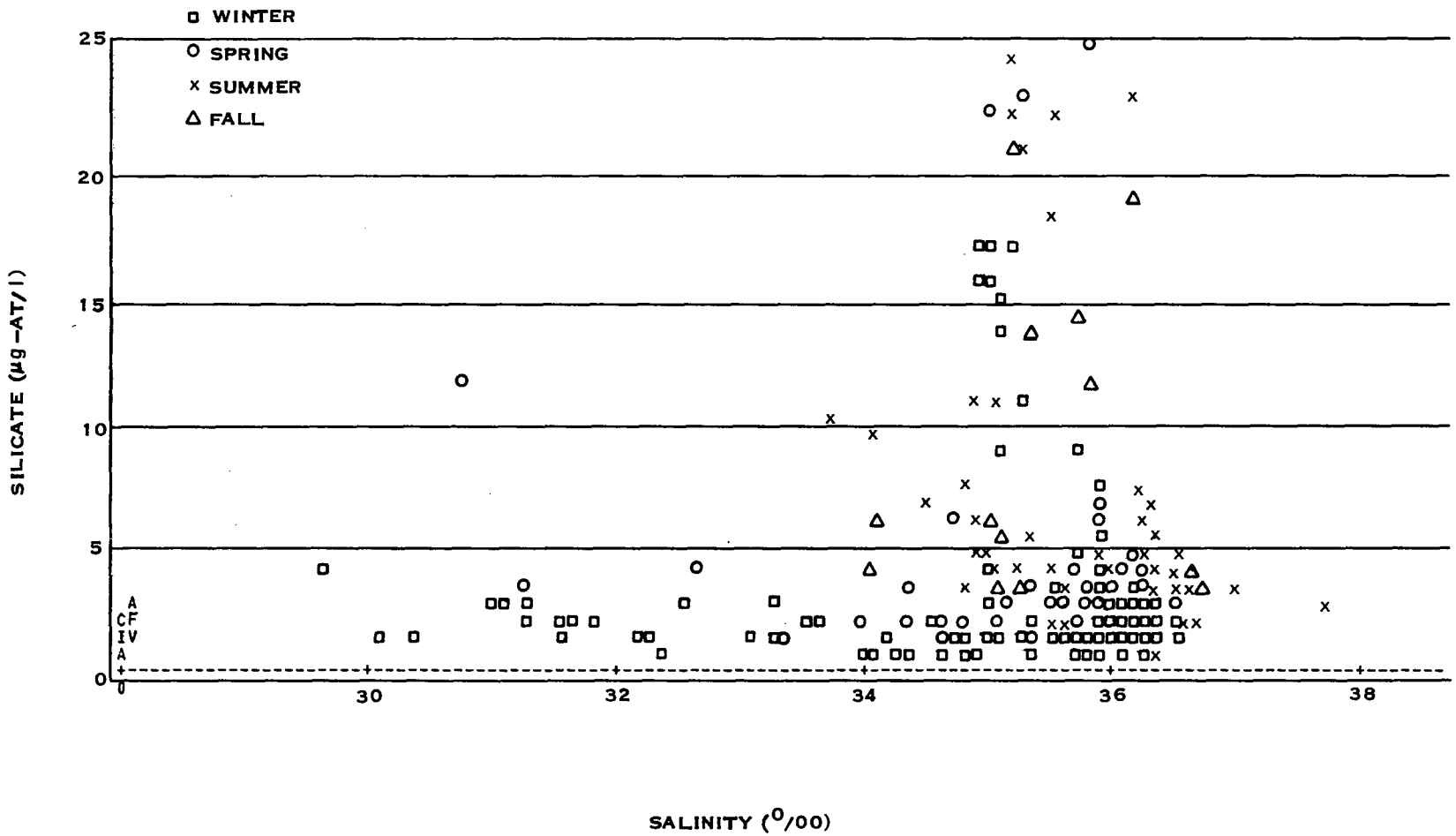

Figure 3.2-21. Silicate Versus Salinity, All Samples

effect. In winter, the low-salinity coastal waters had silicate concentrations reaching 3 μg-at/l, whereas high salinity deep-water concentrations reached 15 μg-at/l. During the spring cruise, concentrations were higher in both nearshore low-salinity waters and in the deeper high-salinity waters. During the summer cruise, no low-salinity waters were sampled, but high concentrations were encountered in the deeper waters. Fall observations were similar to those in summer; silicate concentrations were not high near shore because of reduced runoff.

4. Temperature Versus Salinity

A plot of temperature versus salinity is useful in checking the quality of the T-S data and interpreting the gross features of the waters. Figure 3.2-22 is a schematic derived from the individual seasonal T-S plots. Winter shelf water was coldest and freshest; water during the other seasons was warmer and more saline. The Gulf Stream water was relatively constant throughout the year.

5. Time-Series Regressions

The time-series stations were all on the outer shelf and therefore were expected to show no influence of runoff (e.g., high silicate at low salinity); indeed, there were no salinities less than 35.0 $^{o}/oo$ (Figure 3.2-23).

The variety of waters sampled during the time-series cruise is demonstrated in the nitrate: phosphate plot (Figure 3.2-24). Phosphate and nitrate concentrations varied from 0 to 2.4 and 30 μg-at/l, respectively. The apparent ratio of N:P, 16:1, was as expected and was higher than that observed on the other cruises.

The temperature:salinity diagram (Figure 3.2-25) clearly shows that the majority of the sampling was in waters having Gulf Stream characteristics. The few surface-water samples (those with temperatures above 26°C) exhibiting salinities of <36.0 $^{o}/oo$ could be considered to be slightly diluted with shelf water.

The phosphate:temperature plot (Figure 3.2-26) shows the typical increase in phosphate (and nitrate, since they are proportional) with decreasing temperature. If a subsurface Gulf Stream intrusion had occurred, low phosphate values would be expected at 15° to 23°C because, when deep, cold (8° to 10°C), nutrient-rich Gulf Stream water had ascended and intruded into the shelf waters, phytoplankton would have consumed the nutrient during the warming process. Since this was not observed, one may conclude that no Gulf Stream activity that would have significantly affected the outer shelf system in a chemical or biological sense occurred during the time-series cruise.

D. PARTICULATE ORGANIC CARBON AND CHLOROPHYLL

The behavior of POC versus chlorophyll *a*, shown in Figures 3.2-27 through 3.2-30 and summarized in Table 3.2-4, shows that the correlation coefficient was significant in spring, summer, and fall but was definitely not significant in winter. The intercept of the regression at some positive value of particulate carbon and at a zero chlorophyll value was an indication of the quantity of detrital particulate organic carbon or the amount of carbon not associated with chlorophyll *a*. In winter, the chlorophyll mean (Table 3.2-5) was high (2.16 μg/l), as was the POC mean (148 μg C/l). Based on these two values, the carbon:chlorophyll ratio was 69, which

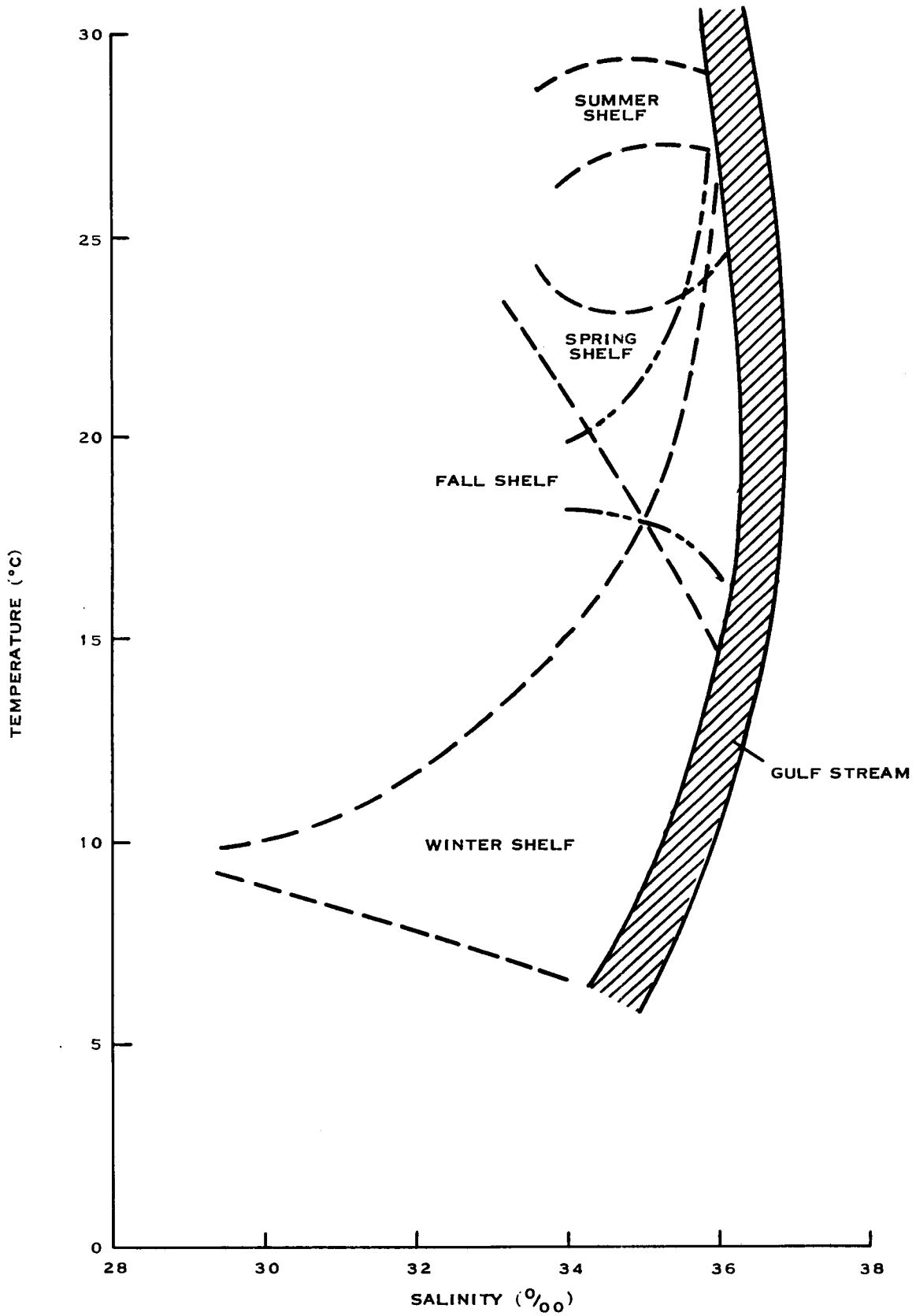

Figure 3.2-22. Temperature-Salinity Plot of Data Set

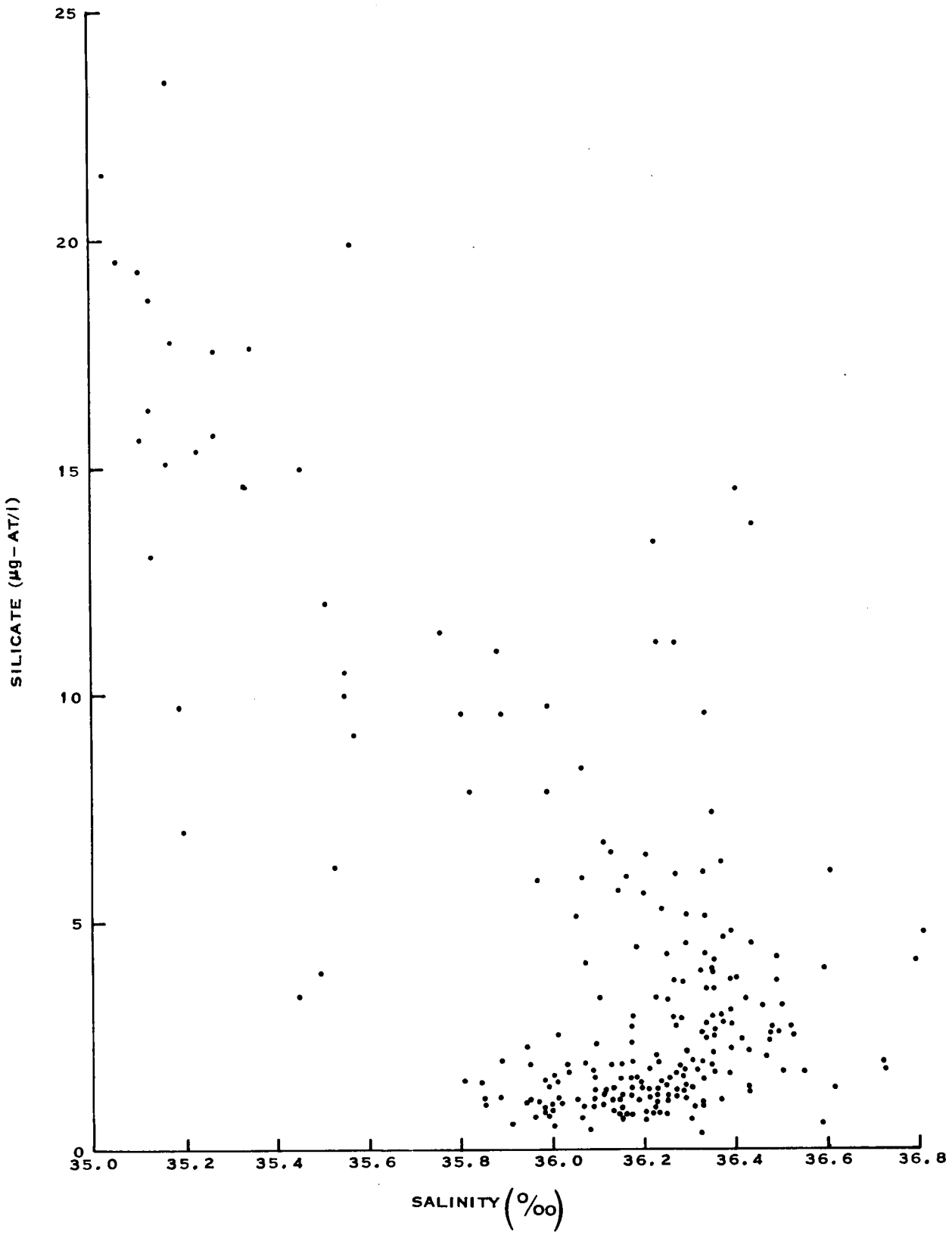

Figure 3.2-23. Silicate Versus Salinity, Summer Time-Series Cruise

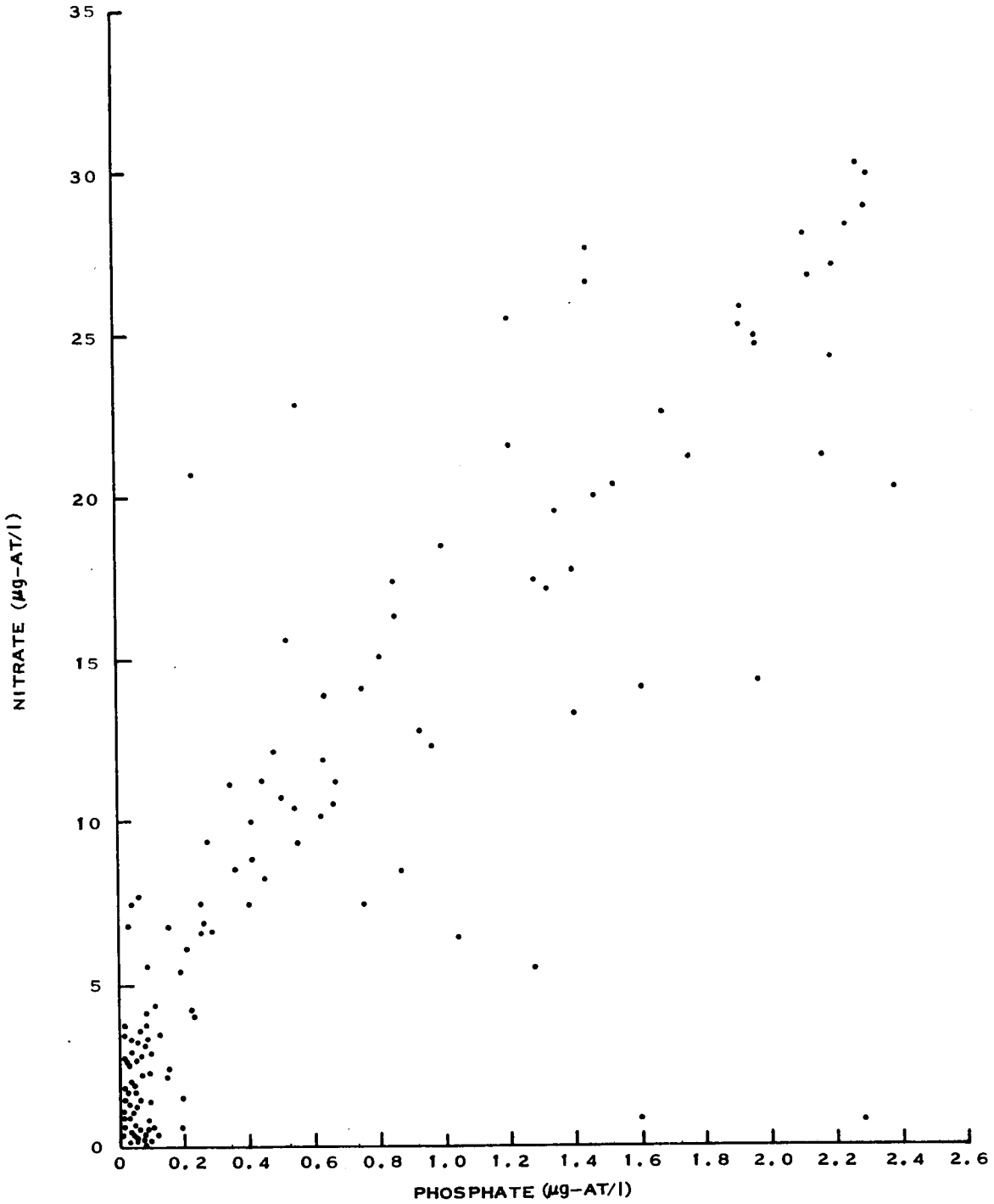

Figure 3.2-24. Nitrate Versus Phosphate, Summer Time-Series Cruise

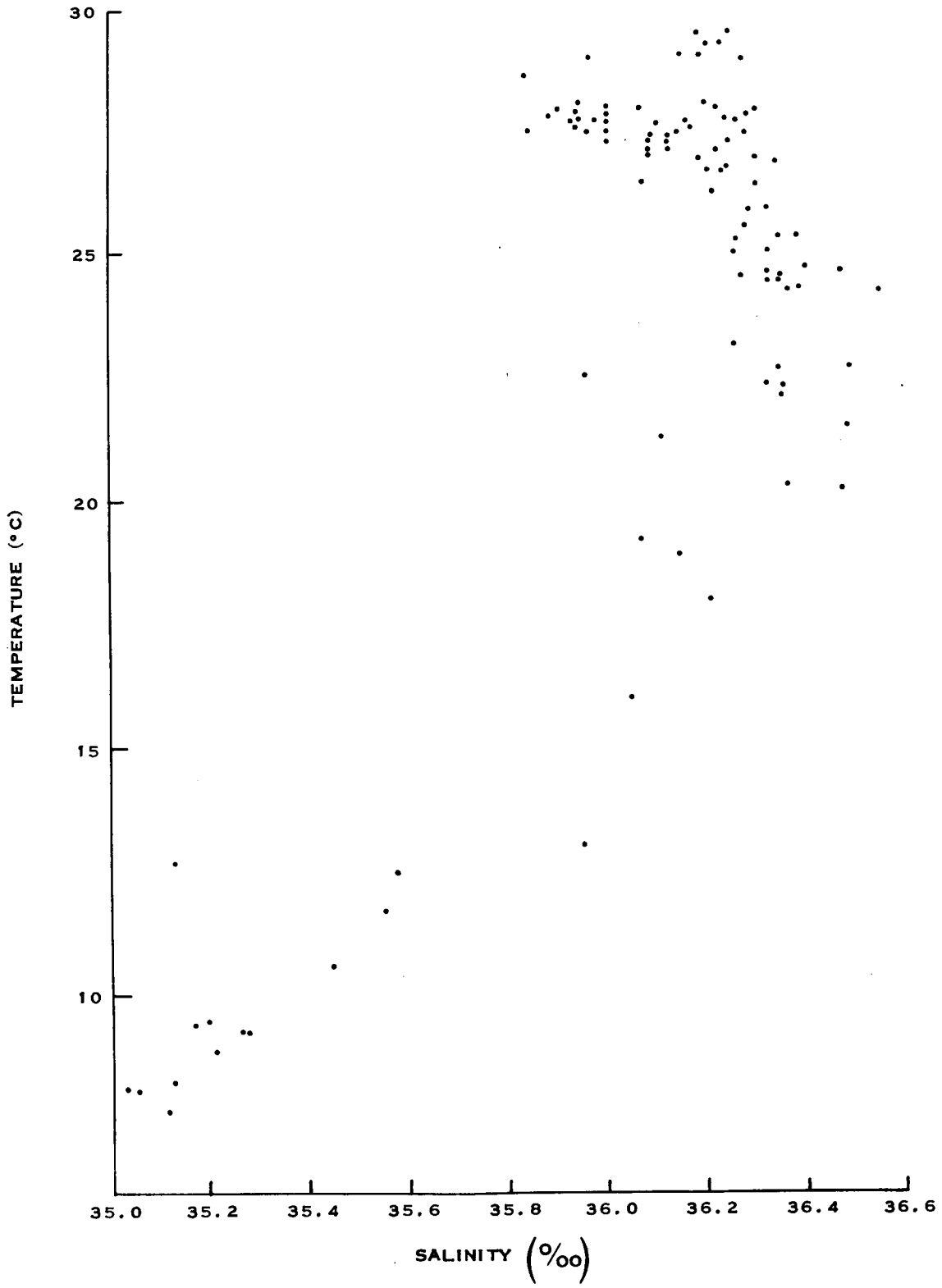

Figure 3.2-25. Temperature Versus Salinity, Summer Time-Series Cruise

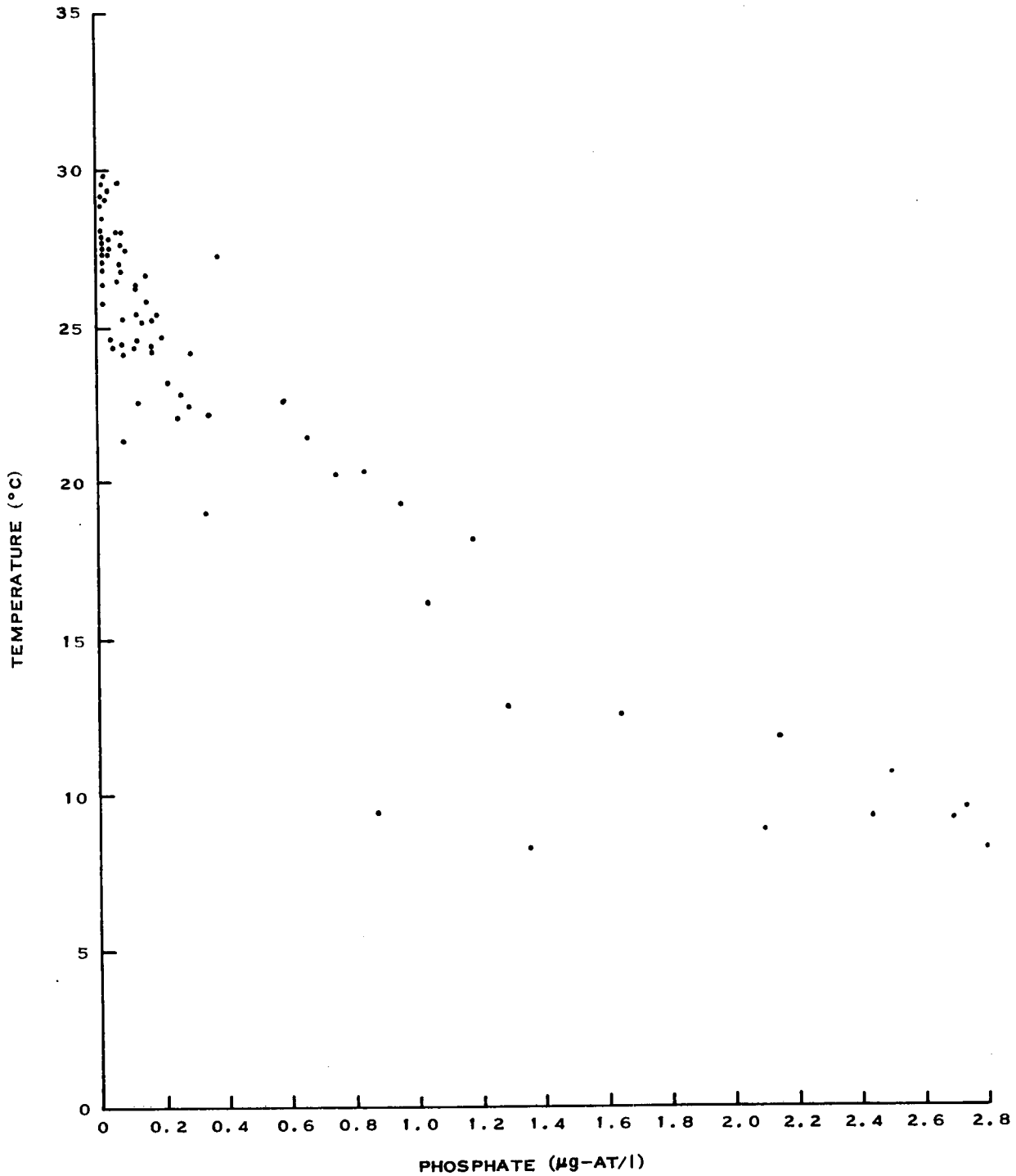

Figure 3.2-26. Temperature Versus Phosphate, Summer Time-Series Cruise

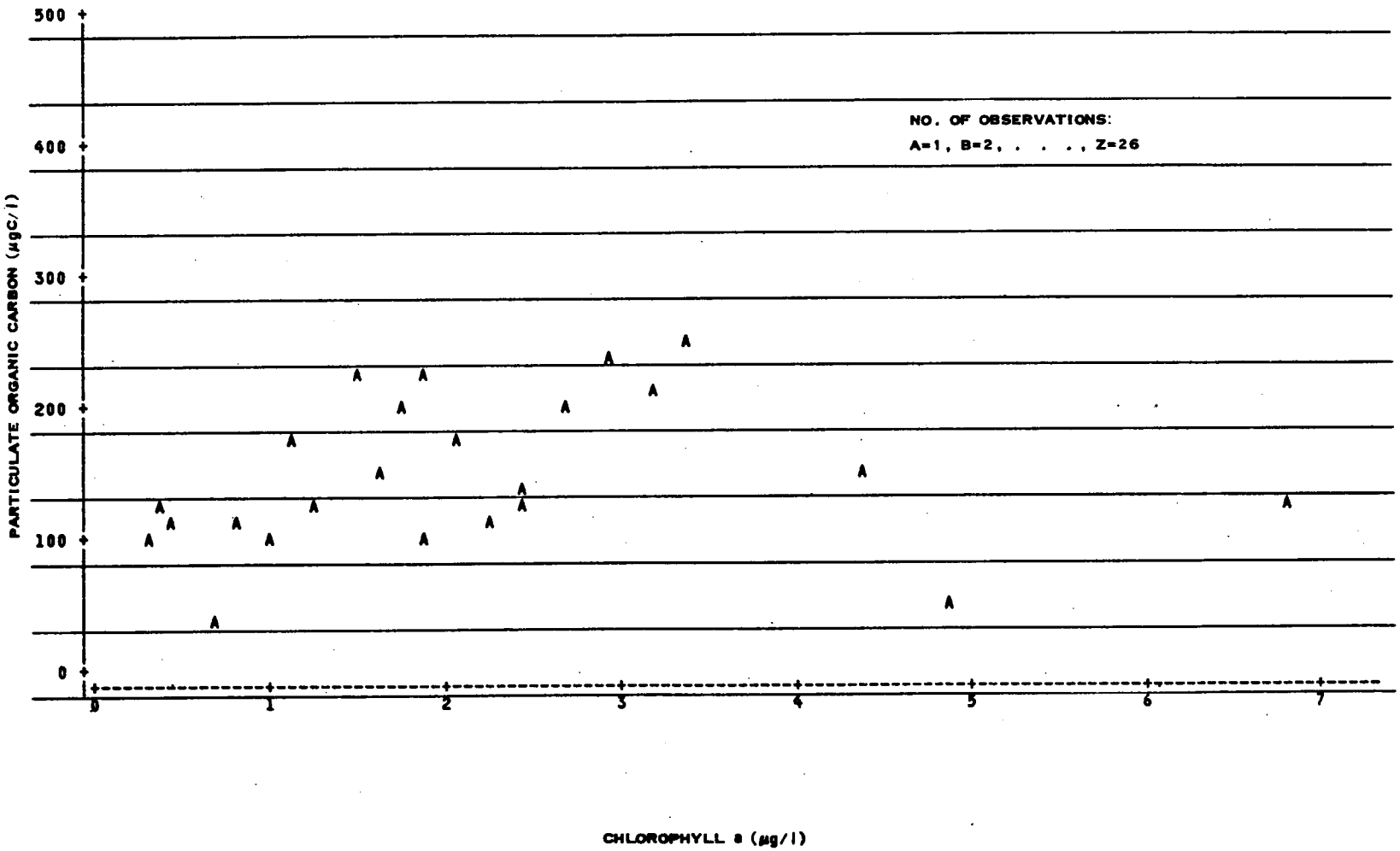

Figure 3.2-27. Chlorophyll Versus Particulate Organic Carbon, Winter 1977

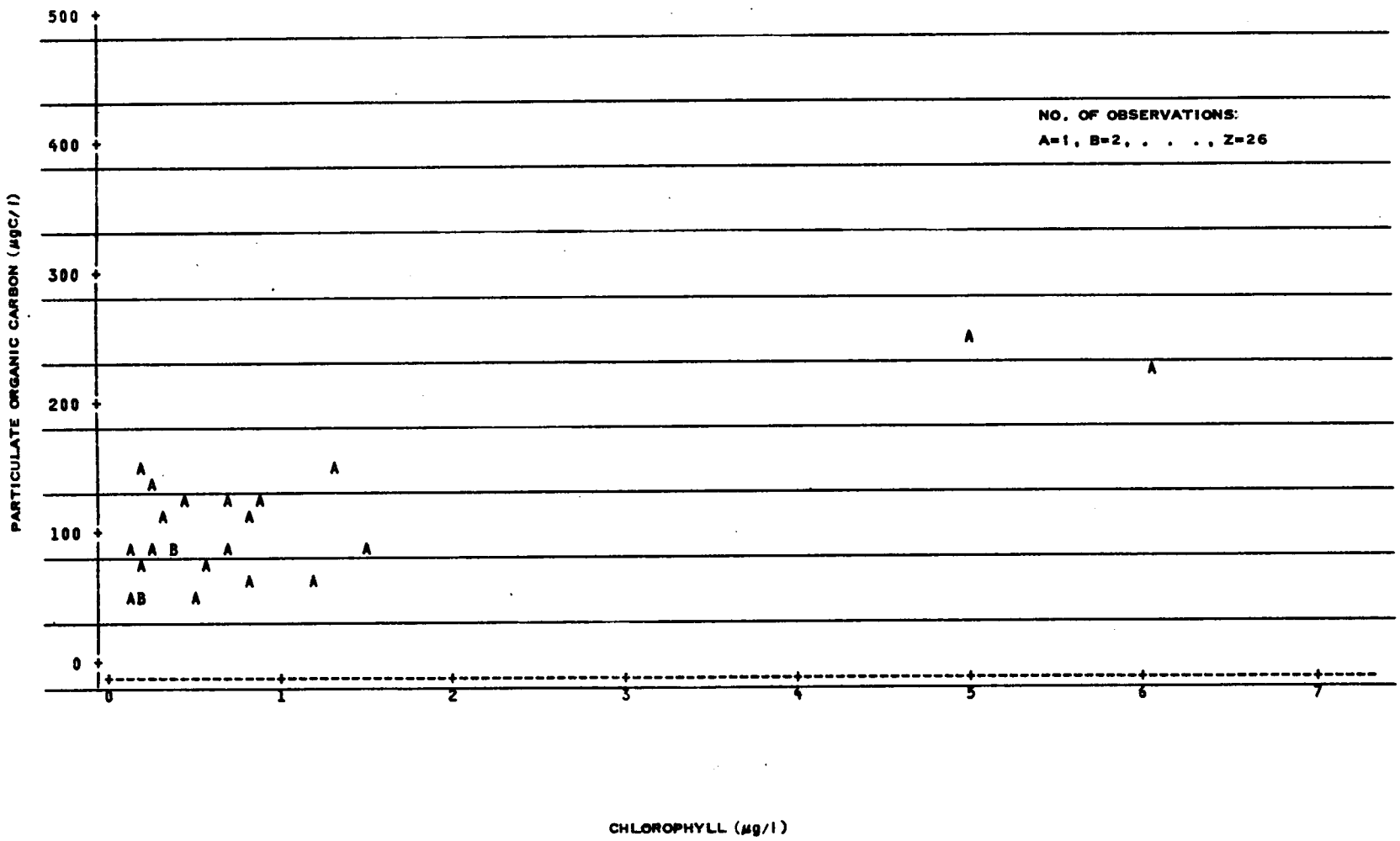

Figure 3.2-28. Chlorophyll Versus Particulate Organic Carbon, Spring 1977

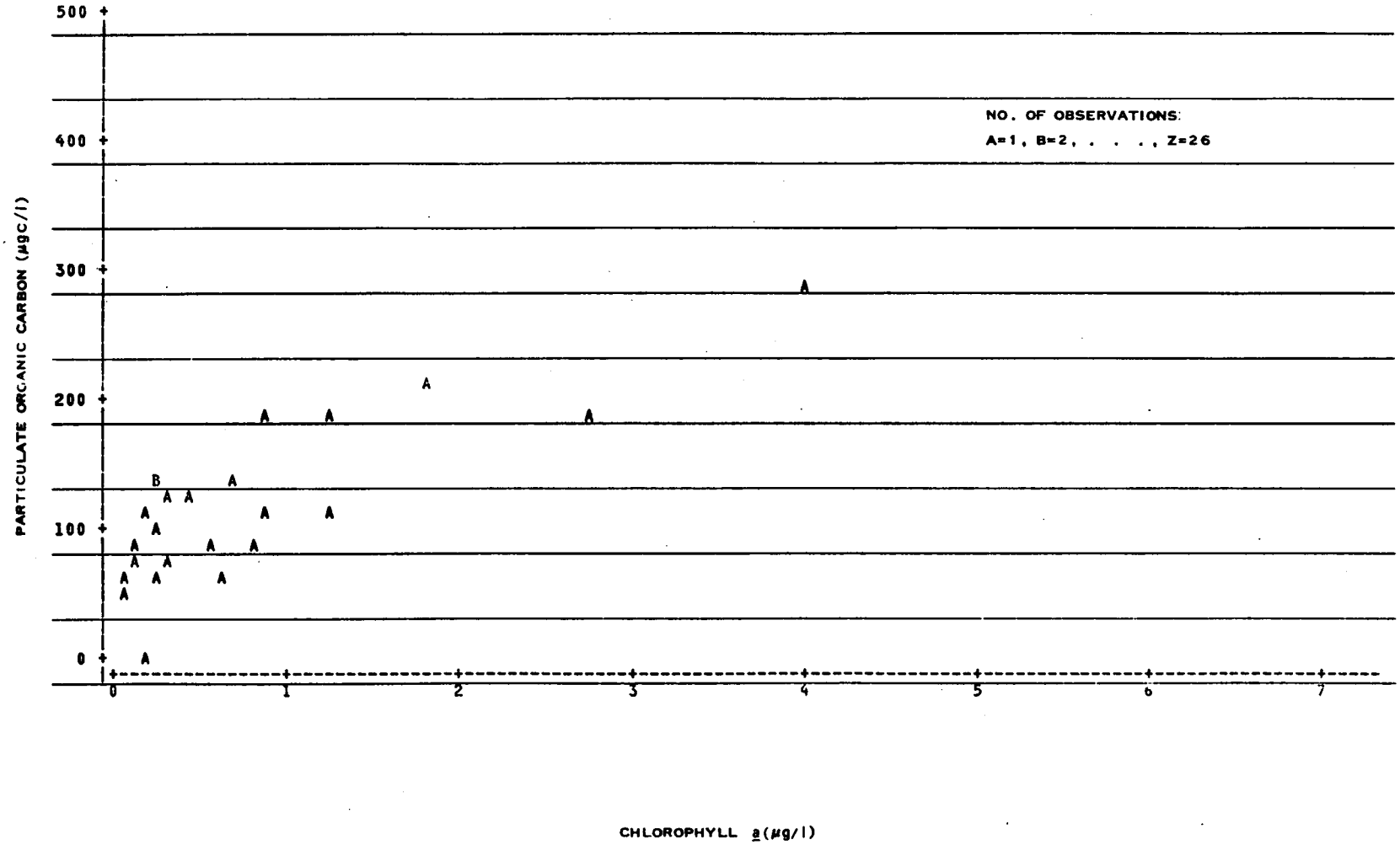

Figure 3.2-29. Chlorophyll Versus Particulate Organic Carbon, Summer 1977

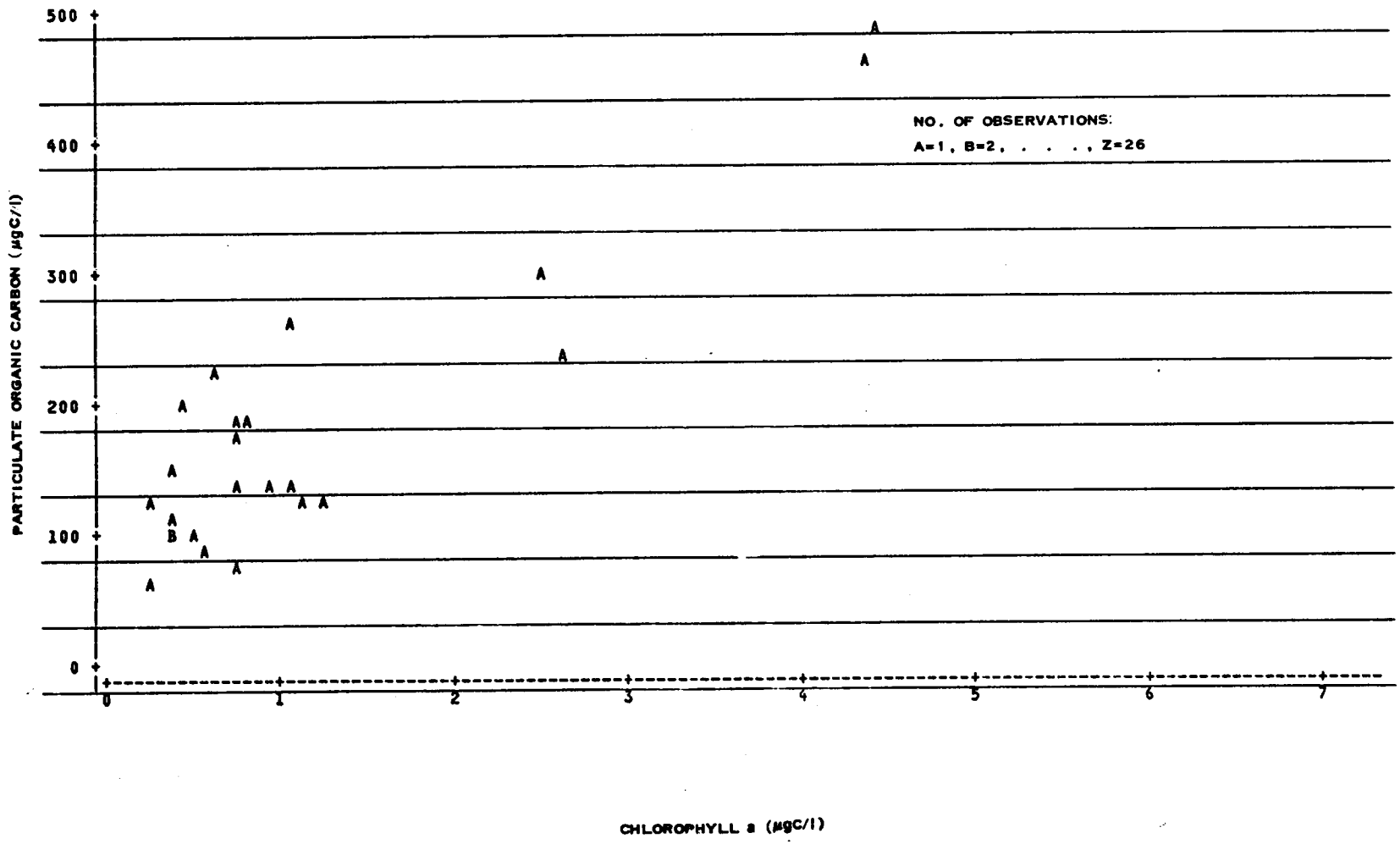

Figure 3.2-30. Chlorophyll Versus Particulate Organic Carbon, Fall 1977

Table 3.2-4. Particulate Organic Carbon Versus Chlorophyll *a*

Season	Mean POC (μg C/l)	POC Intercept[a] (μg/l)	Mean Chlorophyll *a* (μg/l)	Ratio C:Chl *a*	Correlation Coefficient (r^2)
Winter	148	139	2.16	5	0.01
Spring	105	78	0.95	30	0.60
Summer	117	53	0.76	90	0.66
Fall	179	84	1.14	95	0.81

[a]Detrital

Table 3.2-5. Mean Organic Carbon and Chlorophyll by Season

Season	Mean Chlorophyll *a* (μg/l)	Mean POC (μg C/l)	Mean DOC (mg C/l)
Winter	2.16	148	3.94
Spring	0.95	105	0.98
Summer	0.76	117	0.54
Fall	1.14	179	0.28

is characteristic of coastal waters. Unfortunately, the POC intercept was at 139 μg C/l; if the intercept is assumed to be nonliving detrital carbon and is subtracted from the mean POC, the carbon:chlorophyll ratio becomes 5. The low carbon:chlorophyll ratio and high POC intercept suggest the possibility of carbon contamination on the first cruise. However, on closer examination of the winter data (Figure 3.2-27), it is apparent that the regression analyses were prejudiced by three high chlorophyll *a* values obtained from station 3D surface and station 2E surface and bottom samples. If these three values are eliminated from the data and the regression analyses are redone, the correlation coefficient (r^2) is calculated to be 0.66, the mean POC to be 155.2 μg C/l, the POC intercept to be 85 μg C/l, and the chlorophyll mean to be 1.71 μg/l. Based on these data, the carbon:chlorophyll ratio is 91. If the intercept is assumed to be nonliving detrital carbon and is subtracted from the mean POC value, the organic carbon: chlorophyll ratio becomes 41, a value reasonable for productive coastal waters (Huntsman and Barber, 1977). Based on this rather basic analysis, it appeared there was an error in either the POC or chlorophyll data for these three data points during the winter cruise.

The POC-versus-chlorophyll regression shows a significant positive slope in all seasons, provided three data outliers of winter were neglected. The fact that the seasonal pattern of chlorophyll agreed well with previous studies in the South Atlantic (i.e., the highest mean value in winter and the lowest in summer) suggests that the problem with the winter data outliers was with the POC data for those three stations. If the POC data are correct for these three values—and assuming zero detrital POC—the ratio of living carbon to chlorophyll *a* ranges from 9.6 to 34, a value that, while not impossible, is difficult to accept.

The high chlorophyll *a* values are discussed in the Second and Third Quarterly Summary Reports (Texas Instruments Incorporated 1977a and 1977b). In the Second Quarterly Summary Report, bad analytical technique was suspected, but this was discounted in the Third Quarterly Summary Report and the high chlorophyll *a* values were postulated to result from "rather dense phytoplankton blooms" observed during the winter cruise. Holm-Hansen (1969), in presenting data on oceanic biomass profiles off Southern California, reported that a chlorophyll peak at 50 μm was not reflected in any of the corresponding particulate carbon, nitrogen, ATP, or DNA profiles. Holm-Hansen observed that the peak chlorophyll value was 0.22 μg pigment/l for his station 2 and the corresponding POC value was 48 μg C/l, giving a POC:chlorophyll ratio of approximately 200. The relevant parallel to this work is the increase in chlorophyll levels without observable increases in POC. Holm-Hansen reported that phytoplankton counts were the only indicator that accounted for the peak chlorophyll value. Thus, it appears that high chlorophyll levels can occur without the same increase in POC values.

The argument can be advanced that a similar effect occurred during the winter sampling at stations 2E and 3D. Unfortunately, there are no phytoplankton count data with which to verify this hypothesis. Salinity, temperature, chlorophyll *a*, POC, and nutrient data that are available for these samplings are presented in Table 3.2-6. Also given are calculated ratios for POC:chlorophyll *a*, N:Si, and N:P. These data show that nutrient enrichment was present at station 2E at a relatively high temperature of 13°C at the time of sampling. This is especially evident at the surface at station 2E where nitrate was 11.3 μg-at/l and phosphate was 0.68 μg-at/l, giving an N:P ratio of 16.6, a value indicating that preferential nutrient uptake had not occurred as of the time of sample collection. At station 2E bottom (water depth of sample, 34 m), data indicated uptake of nitrate in preference to phosphate (N:P = 9.6). At station 3D surface, both nitrate and phosphate were essentially nutrient-limited. This provides only indirect evidence with which to substantiate the hypothesis that a bloom state was responsible for the elevated chlorophyll *a* values and the abnormal POC:chlorophyll *a* ratios. These data, taken together, suggest that the behavior between POC and chlorophyll *a* present at the time of sample collection was anomalous when compared with data collected over the entire study area. Thus, it can be argued that neither POC nor chlorophyll *a* values were incorrect but that a unique occurrence was recorded at the time of sampling. Unfortunately, nothing more definitive can be said, and this must remain a hypothesis subject to subsequent confirmation or refutation. Because of this uncertainty, these data are not discussed further.

Table 3.2-6. Selected Hydrographic Data for Stations 2E and 3D

Station	Station Depth (m)	S (°/oo)	T (°C)	Chl *a* (μg/l)	POC (μg/l)	SiO_2 (μg-at/l)	NO_3 (μg-at/l)	PO_4 (μg-at/l)	POC:Chl *a* Ratio	N:Si Ratio	N:P Ratio
2E Surface	35	35.9	12.97	4.87	46.6	3.3	11.3	0.68	9.6	3.4	16.6
2E Bottom	35	36.1	13.17	6.83	121.6	1.7	4.6	0.48	17.8	2.7	9.58
3D Surface	42	36.4	17.16	4.36	148.6	0.7	0.1	0.2	34.1	0.14	0.5

Mean particulate organic carbon values for winter (without outliers), spring, summer, and fall were 155, 105, 117, and 179 μg C/l, respectively. The nonliving POC or detrital carbon was

55, 74, 45, and 46% of winter, spring, summer, and fall totals, respectively (Table 3.2-4 plus corrected seasonal data). The spatial pattern that emerges is a clear inshore maximum associated with high concentrations of chlorophyll.

Station 5A, a truly inshore station, was sampled repeatedly. The high POC and chlorophyll values, which improve the quality of the correlation coefficient in the carbon-versus-chlorophyll regressions, are always from station 5A. The richness of this station in terms of organic matter seems quite distinct from the rest of the stations in the study.

The seasonal pattern of chlorophyll abundance (Table 3.2-5) showed a peak in winter and a minimum concentration for the shelf as a whole in summer. This pattern supports the concept that intrusions and wake-stream upwelling are most strongly present in winter and are weakest in summer. The chlorophyll data showed that the inshore zone as sampled at station 5A had the entire shelf's chlorophyll maximum. The good correlation of chlorophyll and particulate organic carbon shows that the organic richness results mainly from phytoplankton growth, not from the runoff of detritus-laden water.

The mean DOC values by season (Table 3.2-5) showed a very large variation (from about 4.0 mg C/l in the winter to a low of about 0.30 in the fall). There is no possibility that this pattern is real, because it disagrees with other observed distributions.

E. DISSOLVED OXYGEN DISTRIBUTION

Table 3.2-7 shows the seasonal dissolved oxygen (DO) maximums and minimums, the stations and depths for which these data were determined, and the temperature (°C) and salinity (°/oo) at these stations. This general distribution indicated that shelf waters were well oxygenated, with supersaturation ranging from 11 to 24%, whereas waters beyond the continental break down the slope at depth may at times have been 51 to 69% undersaturated. Atkinson (1978) reported similar DO distributions.

Winter surface DO levels (Figure 3.2-31) were highest in the low-temperature areas in the north and were lower in the south. The concentration isolines paralleled the coast and followed surface isotherm patterns (Figure 3.2-2) reflecting temperature control of DO concentrations. Almost all surface waters in the study area were either at saturation or supersaturated; only at stations 3F and 4G was 6 to 8% undersaturation observed.

Winter bottom-water DO concentrations (Figure 3.2-32) again reflected the temperature control and showed the same general isotherm pattern (Figure 3.2-3); they were an inverse function of distance offshore, with a severe isoline gradient beyond the shelf break down the slope. They were mostly supersaturated at inshore stations, saturated in midshelf areas, and undersaturated in the deep water at the outermost stations.

Spring DO concentrations (Figures 3.2-33 and 3.2-34) were lower (generally in the 7.0 to 7.9 mg/l range at the surface and bottom) than those observed in the winter and were saturated or slightly supersaturated throughout the study area. Only the northernmost nearshore station (2B) had surface values exceeding 8.0 mg/l (13% supersaturation). Surface values lower than 7.0 mg/l were encountered at stations 5G, 5H, and 5I, correlating well with the position of the 26°C isotherm (Figure 3.2-4). These stations were 4 to 6% undersaturated. Bottom DO concentrations at the shelf break and down the slope were similar to winter concentrations and isoline locations.

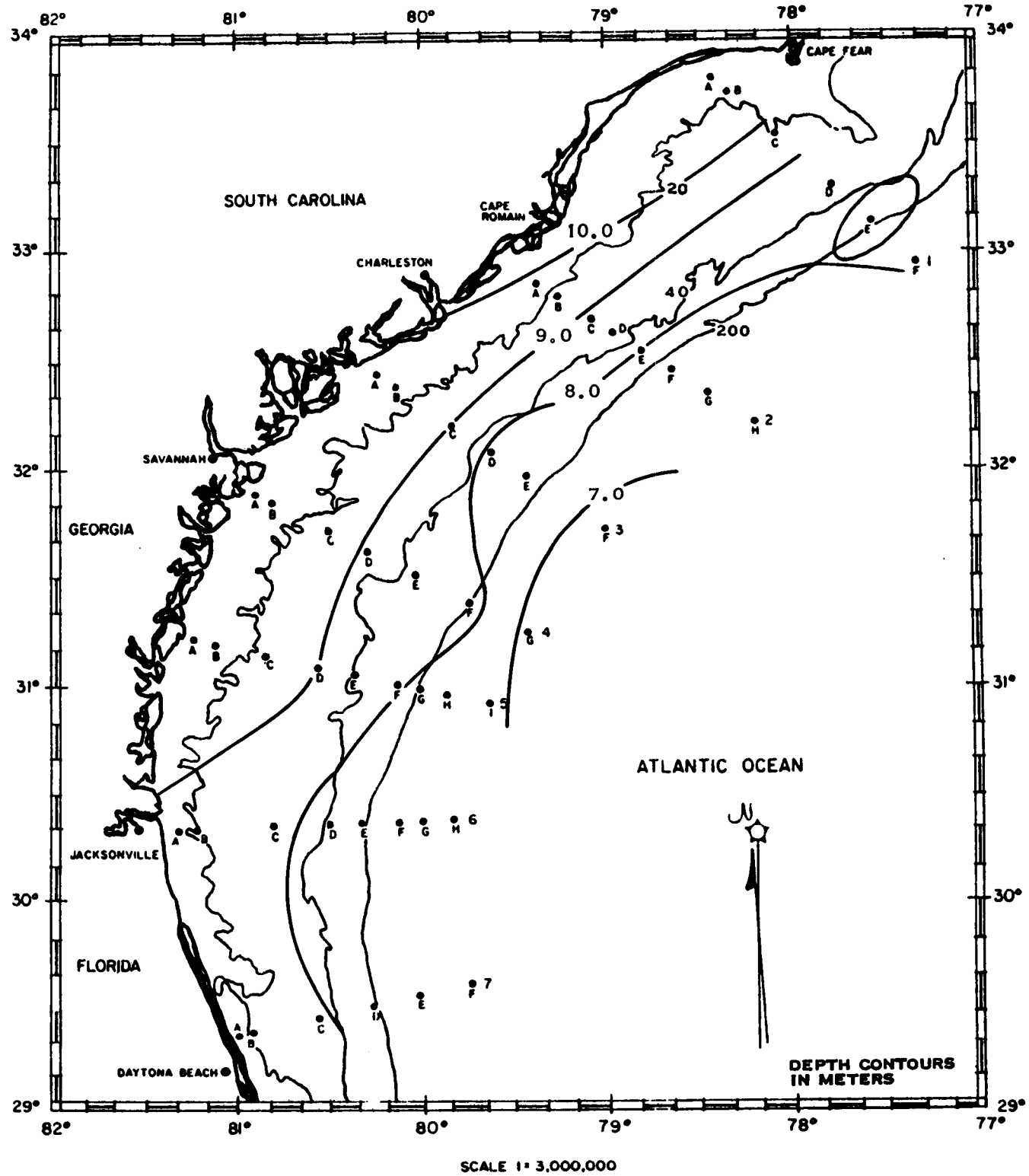

Figure 3.2-31. Surface Dissolved Oxygen Concentrations (mg/l), Winter 1977

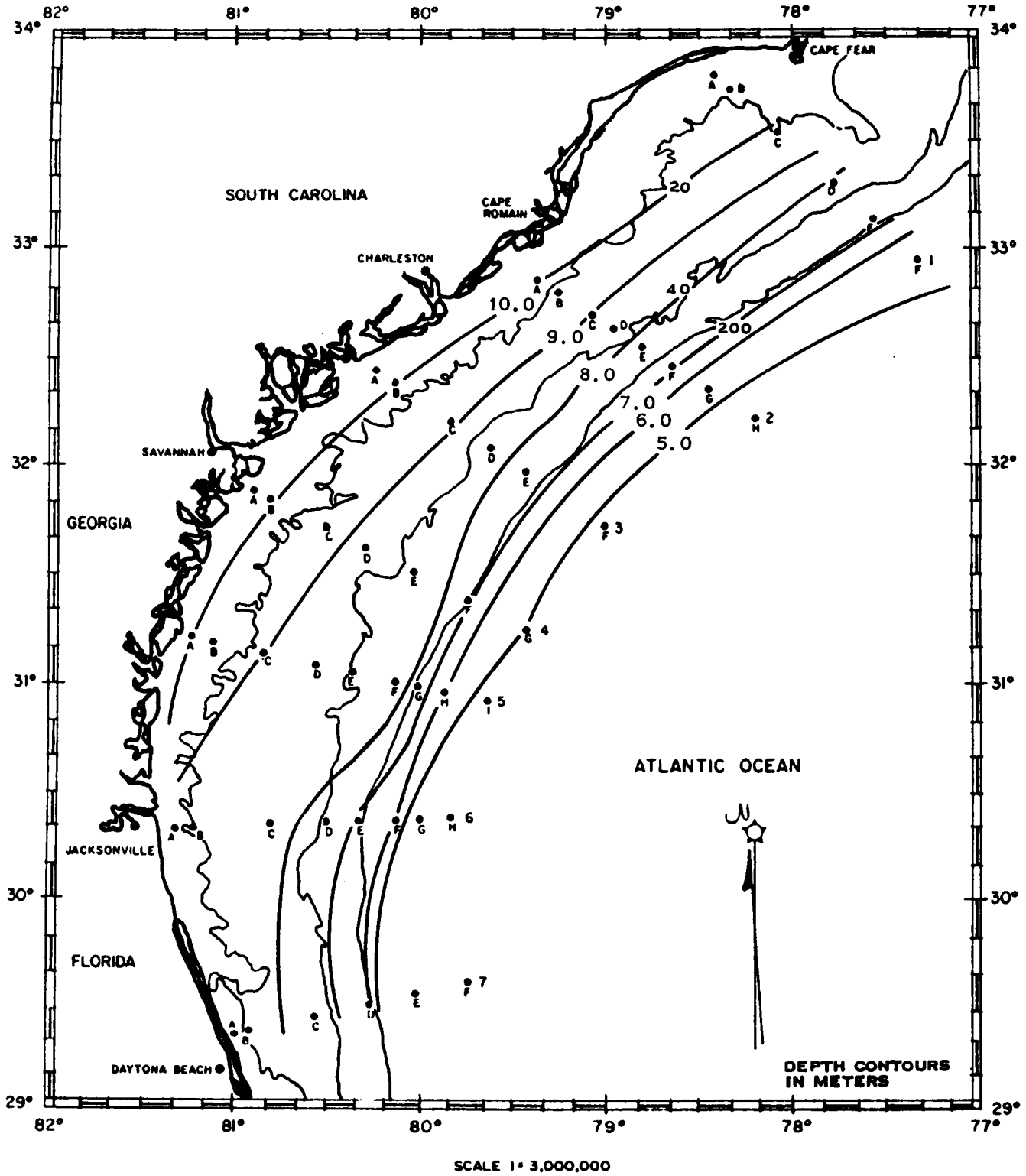

Figure 3.2-32. Bottom Dissolved Oxygen Concentration (mg/l), Winter 1977

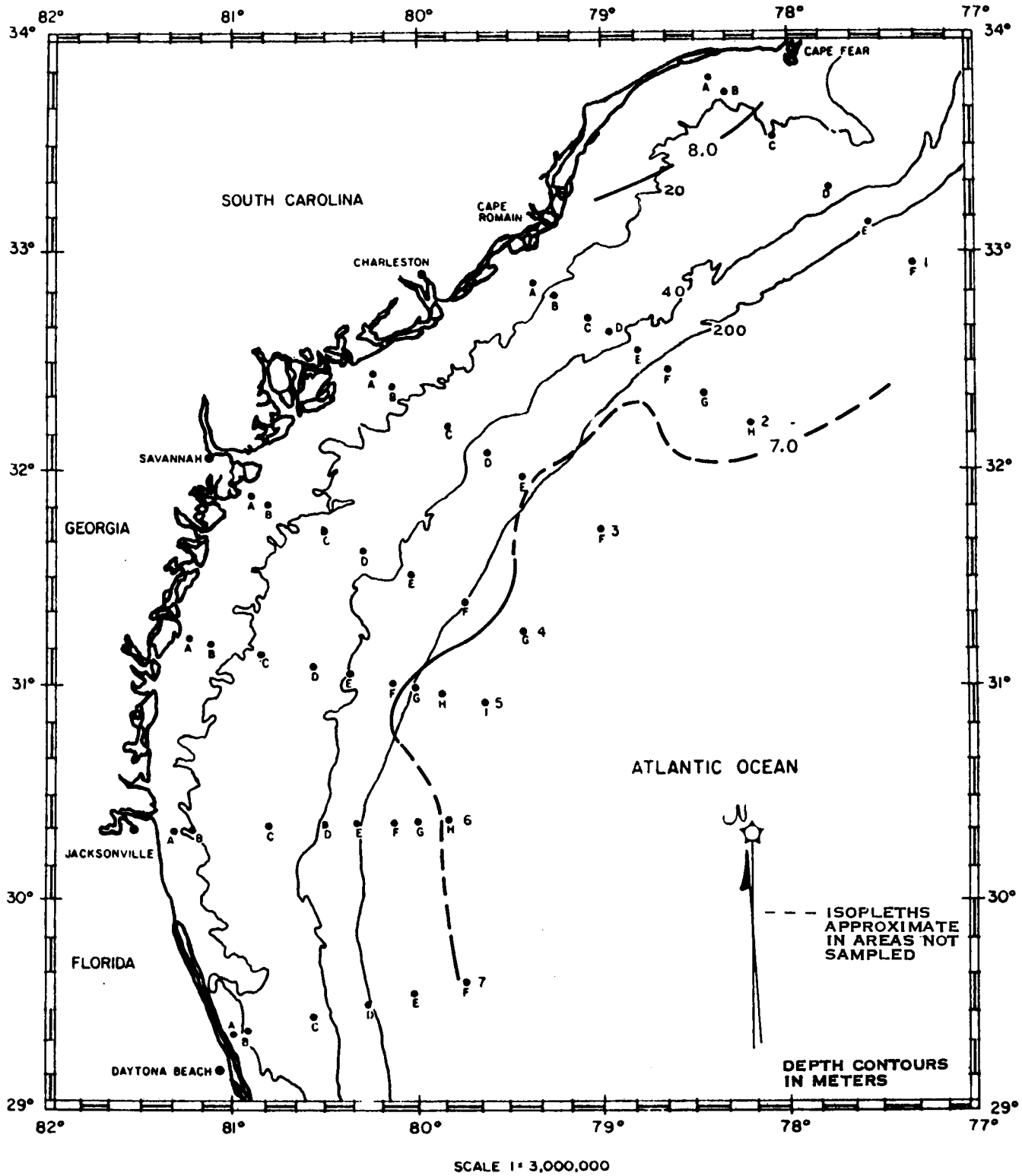

Figure 3.2-33. Surface Dissolved Oxygen Concentrations (mg/l), Spring 1977

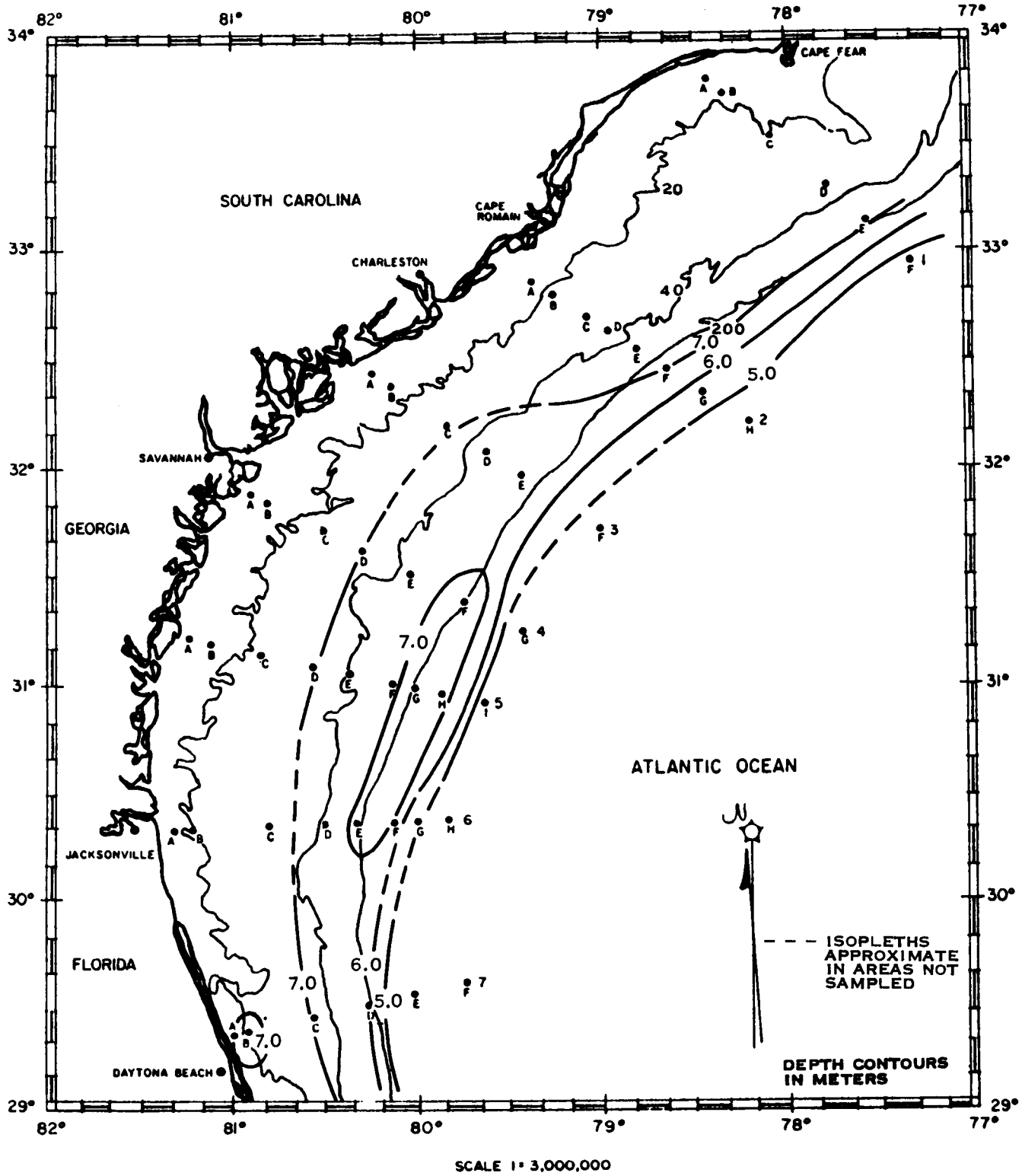

Figure 3.2-34. Bottom Dissolved Oxygen Concentrations (mg/l), Spring 1977

Table 3.2-7. Ranges of Dissolved Oxygen for Each Seasonal Cruise During 1977

Season	Station	Depth	Temperature (°C)	Salinity (°/oo)	Dissolved Oxygen (mg/l)
Winter					
Maximum	1A	Surface	4.7	34.42	11.8
Minimum	5I	Bottom	8.0	35.03	2.8
Spring					
Maximum	1B	Surface	21.1	34.00	8.2
Minimum	5I	Bottom	8.3	35.00	4.4
Summer					
Maximum	7D	Bottom	22.8	36.58	7.3
Minimum	5I	Bottom	–	35.20	4.3
Fall					
Maximum	1C	Bottom	19.0	36.01	8.8
Minimum	5I	Bottom	11.7	35.44	4.3

Values lower than 5.0 mg/l were encountered only in bottom waters at the outermost stations of each transect, giving 40 to 50% undersaturation.

The trend of decreasing dissolved oxygen concentrations continued during the summer (Figures 3.2-35 and 3.2-36) when DO generally was at levels of 7.0 to 6.0 mg/l and was essentially at saturation. This follows from the increase in shelf water temperature from winter through spring to a maximum during summer. Again, data for bottom waters at the deepest outermost stations showed DO concentrations of <5.0 mg/l that were 40 to 50% undersaturated.

Fall data showed that surface DO concentrations again become supersaturated as lower temperatures returned to the shelf area, increasing to more than 8.0 mg/l at nearshore stations and decreasing seaward where an outer-shelf station (5I) had 6.5 mg/l (Figure 3.2-37), which was at saturation. Bottom-water values again showed the isoline gradient at the shelf break and down slope (Figure 3.2-38); they were <5.0 mg/l at the deepest stations. The levels were undersaturated by 40 to 50%, as was observed for all four seasonal samplings. Fall isoline patterns generally conformed to the isotherm patterns discussed previously.

Correspondence between DO isolines and isotherms, as well as the seasonal DO variation exhibited throughout the four seasonal samplings, argues for temperature/salinity control of oxygen concentration in areas of the shelf where water-column mixing occurs. In areas where different water masses are found in the water column, oxygen has been removed by oxidation of organic material and has not been replaced because this deeper water has not been in contact with the atmosphere. This effect of two water masses in the Gulf Stream was originally discussed by Rossby (1936) and corresponds to the results of our investigation.

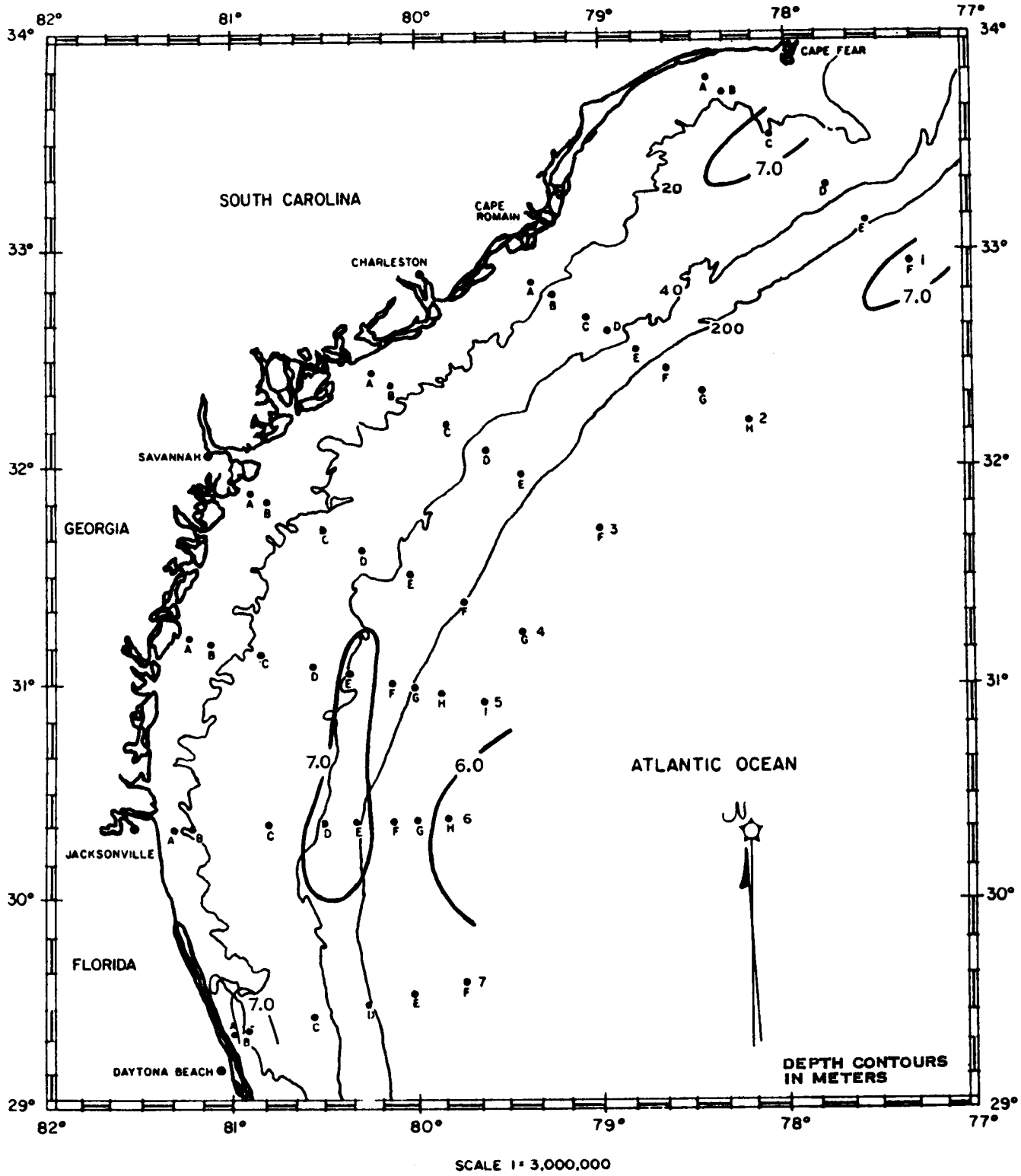

Figure 3.2-35. Surface Dissolved Oxygen Concentrations (mg/l), Summer 1977

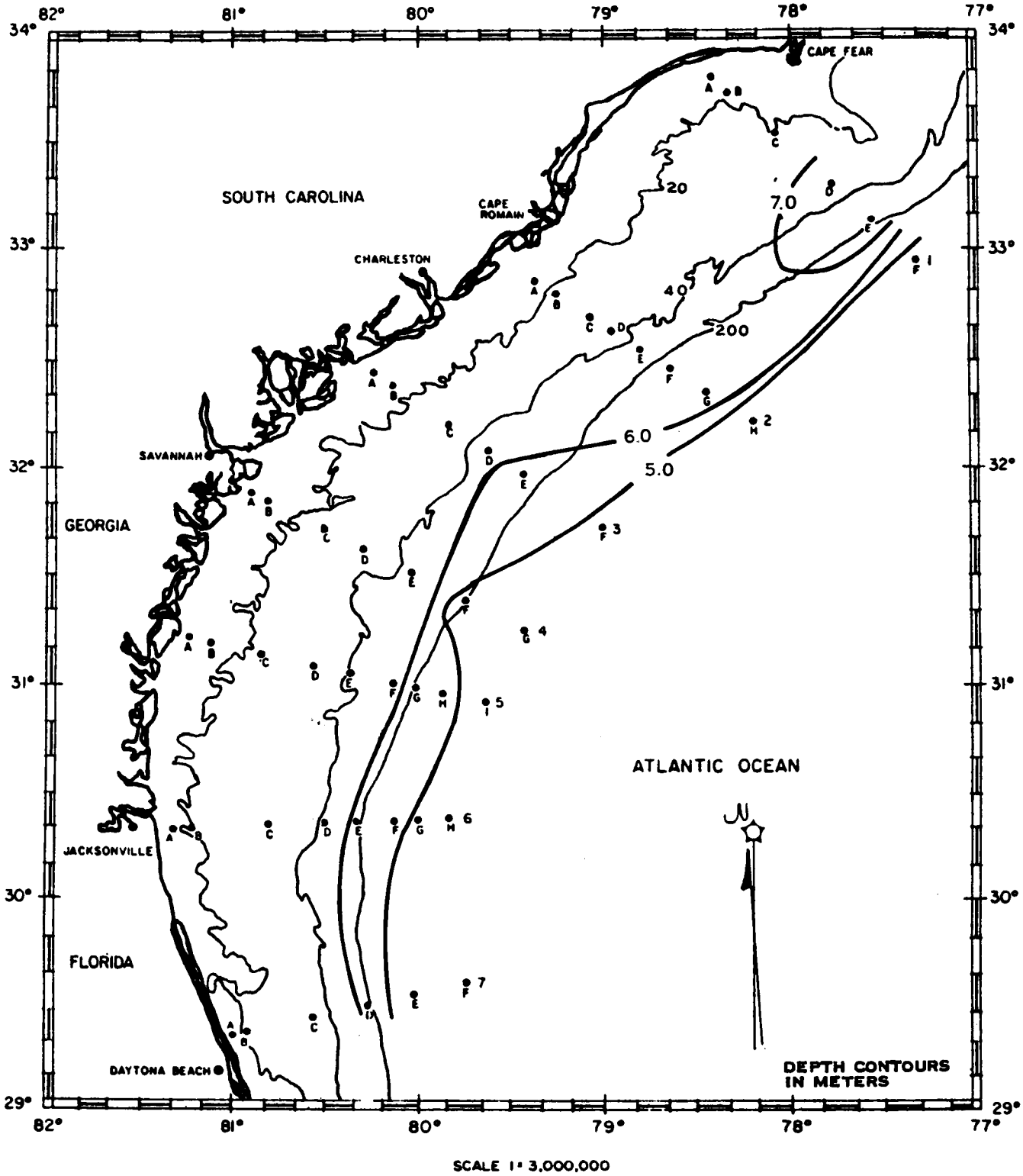

Figure 3.2-36. Bottom Dissolved Oxygen Concentrations (mg/l), Summer 1977

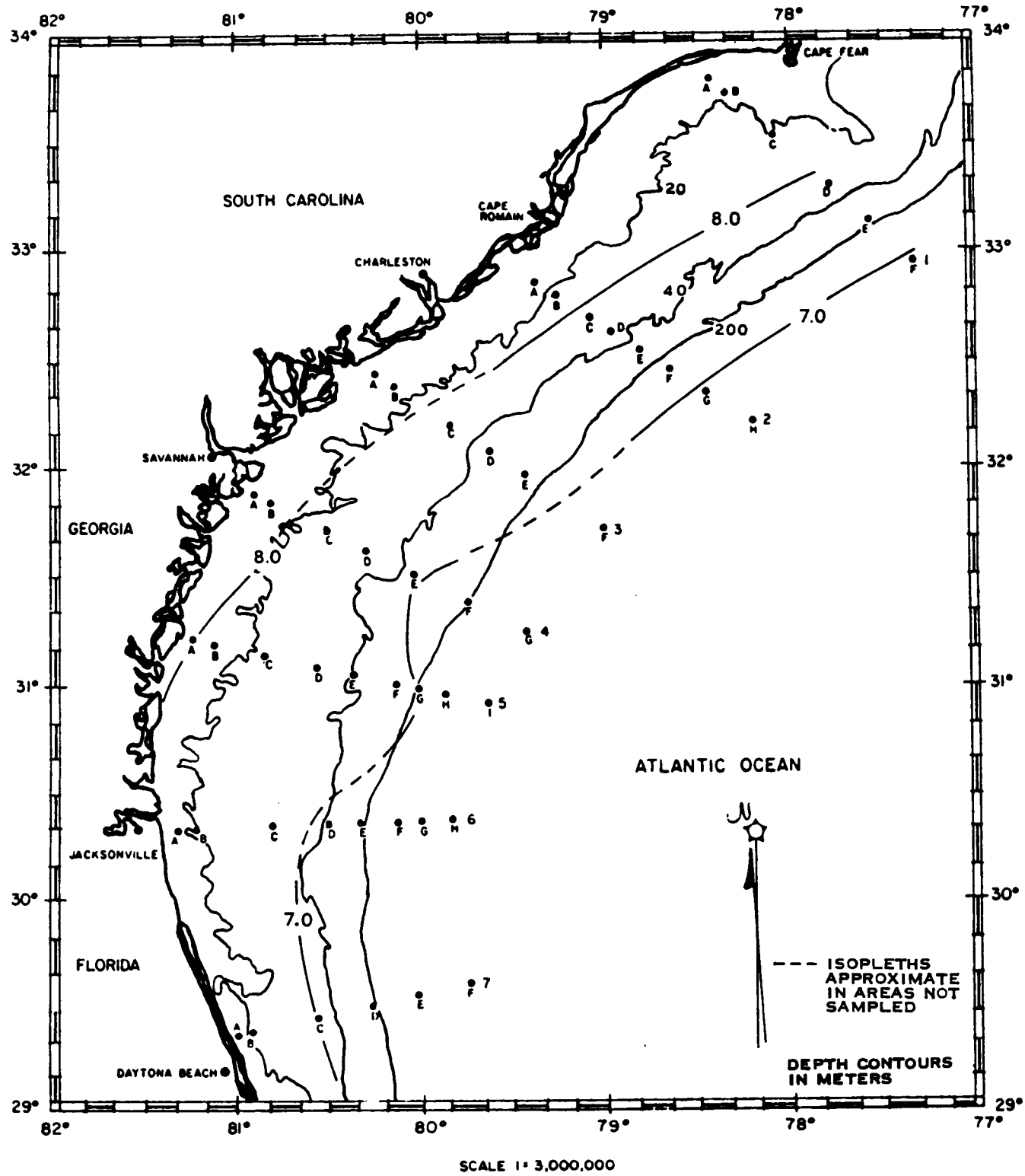

Figure 3.2-37. Surface Dissolved Oxygen Concentrations (mg/l), Fall 1977

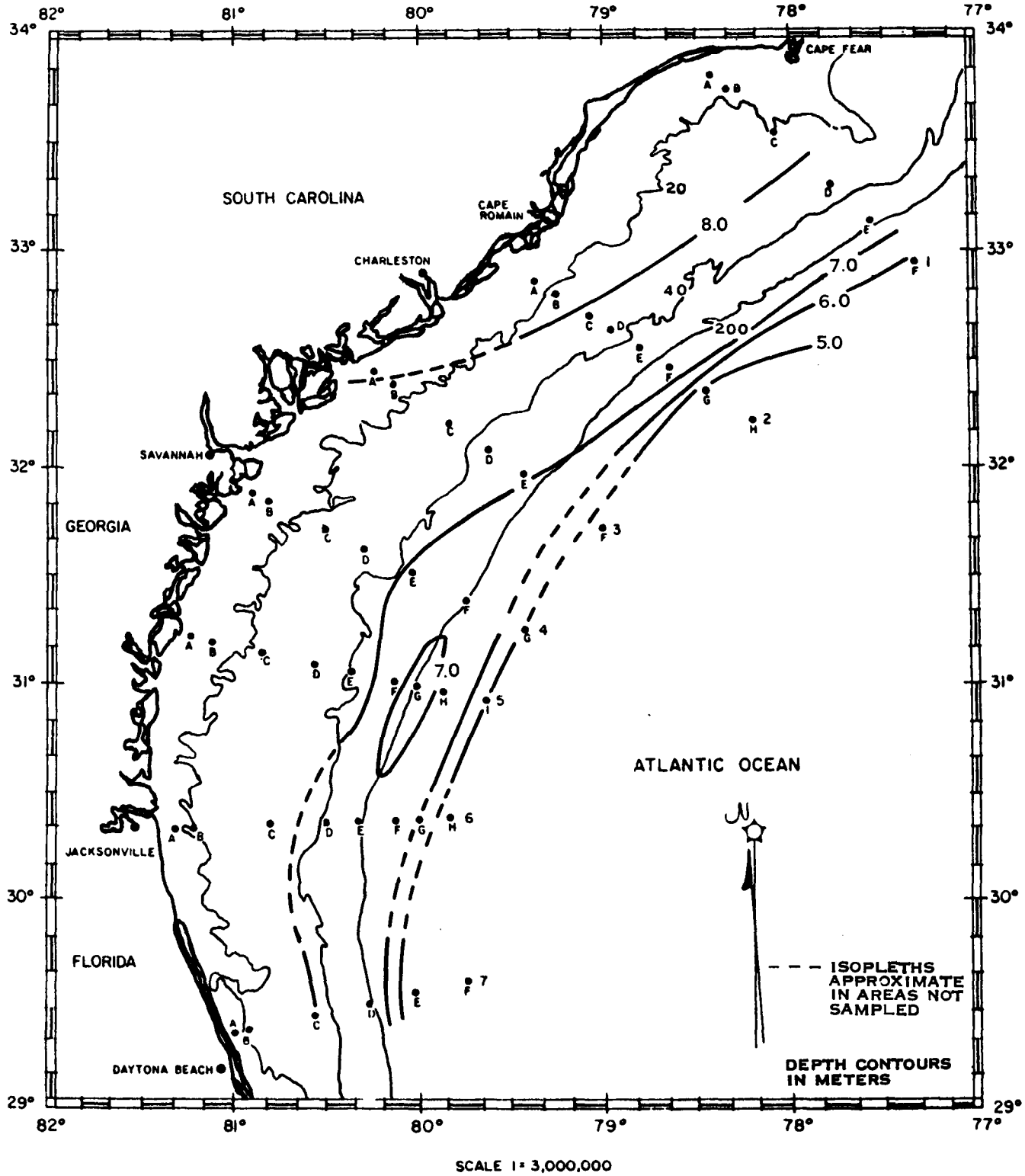

Figure 3.2-38. Bottom Dissolved Oxygen Concentrations (mg/l), Fall 1977

SECTION 4
DISCUSSION

A. OBSERVATIONS WITH RESPECT TO MEAN CONDITIONS

The Georgia Bight, being a broad shallow shelf east of a large landmass, is particularly responsive to weather that may come off the North American continent. This is especially true in winter when the shelf waters are either occasionally cooled by cold fronts from the continent or are warmed by intrusions of Gulf Stream waters. During the summer, the only source of colder waters–the Gulf Stream intrusions–does not affect the whole shelf. Thus, monthly temperature ranges are much greater in winter than in summer.

Since the data in this report will be used as a baseline with which to compare future observations and determine trends, it is important to determine if the observations were made under what may be called "mean conditions."

The winter cruise was not made during mean conditions. The mean winter temperature for the inshore waters off Savannah is 14°C and the standard deviation is 1°C (Atkinson, 1978); clearly, the observed temperatures of 9°C during the winter 1977 SABP sampling fell well below the mean minus the standard deviation. It is certain, then, that the data from the first cruise were collected during an abnormally cold winter and should not be construed as being normal, at least in the oceanographic sense. The other cruises appeared to be normal, at least with respect to surface temperatures (Atkinson, 1978).

B. GULF STREAM AND FRESHWATER DISTRIBUTIONS

The chemical and biological state of the various parts of the Georgia Bight system is dependent primarily on the presence, absence, or mixture of runoff and Gulf Stream water. Runoff carries the soluble and suspended load from the continent to the shelf waters. The Gulf Stream either contributes surface water, which carries essentially no suspended material and no nutrients, or deeper water, which has high nutrient concentrations and forms the significant source of "new nutrients" for the region. The presence of these waters also implies a degree of vertical stability, since the runoff-influenced shelf waters are of lower salinity, resulting in a halocline, and the subsurface Gulf Stream waters are colder, resulting in a thermocline. Figures 3.2-39 through 3.2-42 illustrate the distribution of these two water types. The distribution of fresh water was determined by the position of the 35.5 $^{o}/oo$ isohaline; the shelf waters would have approximately that salinity if no runoff were present. The distribution of subsurface intrusions of Gulf Stream water was determined by the position of the 1 μg-at/l nitrate isopleth when intrusions are not present. An exception to these criteria was used for the summer cruise: the 23°C isotherm was used instead of nitrate data.

During the year, the extent of penetrations into the shelf varies considerably. The freshwater distribution, of course, is primarily dependent on the runoff rates. Maximum offshore penetration was seen during winter and spring. Subsurface Gulf Stream intrusions–which are controlled by a variety of forces including wind, shelf-water densities, and Gulf Stream dynamics–occurred to some degree throughout the year.

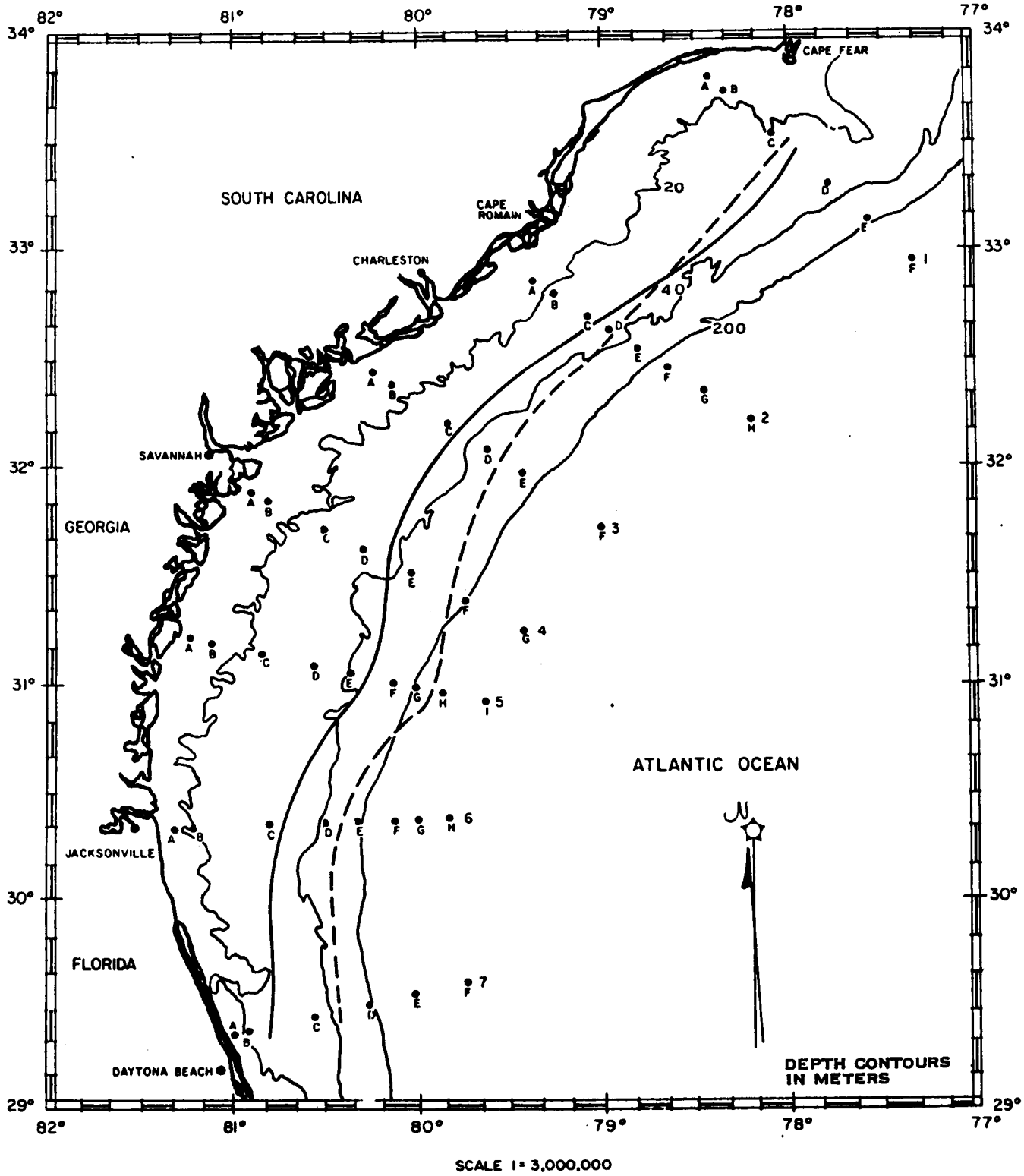

Figure 3.2-39. Approximate Offshore Extent of Freshwater Runoff (Solid Line) and Onshore Extent of Subsurface Gulf Stream Intrusions (Dashed Line), Winter 1977

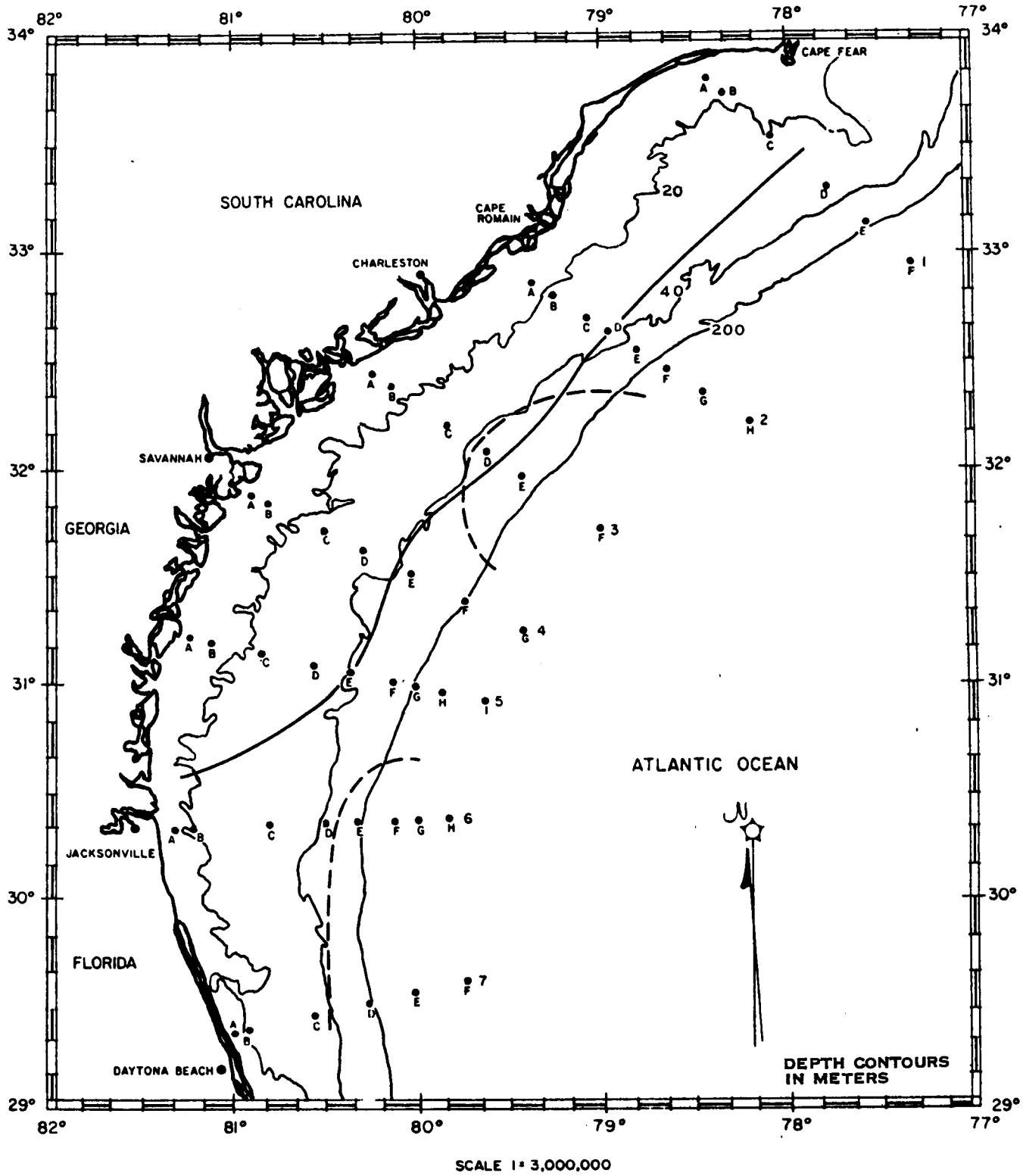

Figure 3.2-40. Approximate Offshore Extent of Freshwater Runoff (Solid Line) and Onshore Extent of Subsurface Gulf Stream Intrusion (Dashed Line), Spring 1977

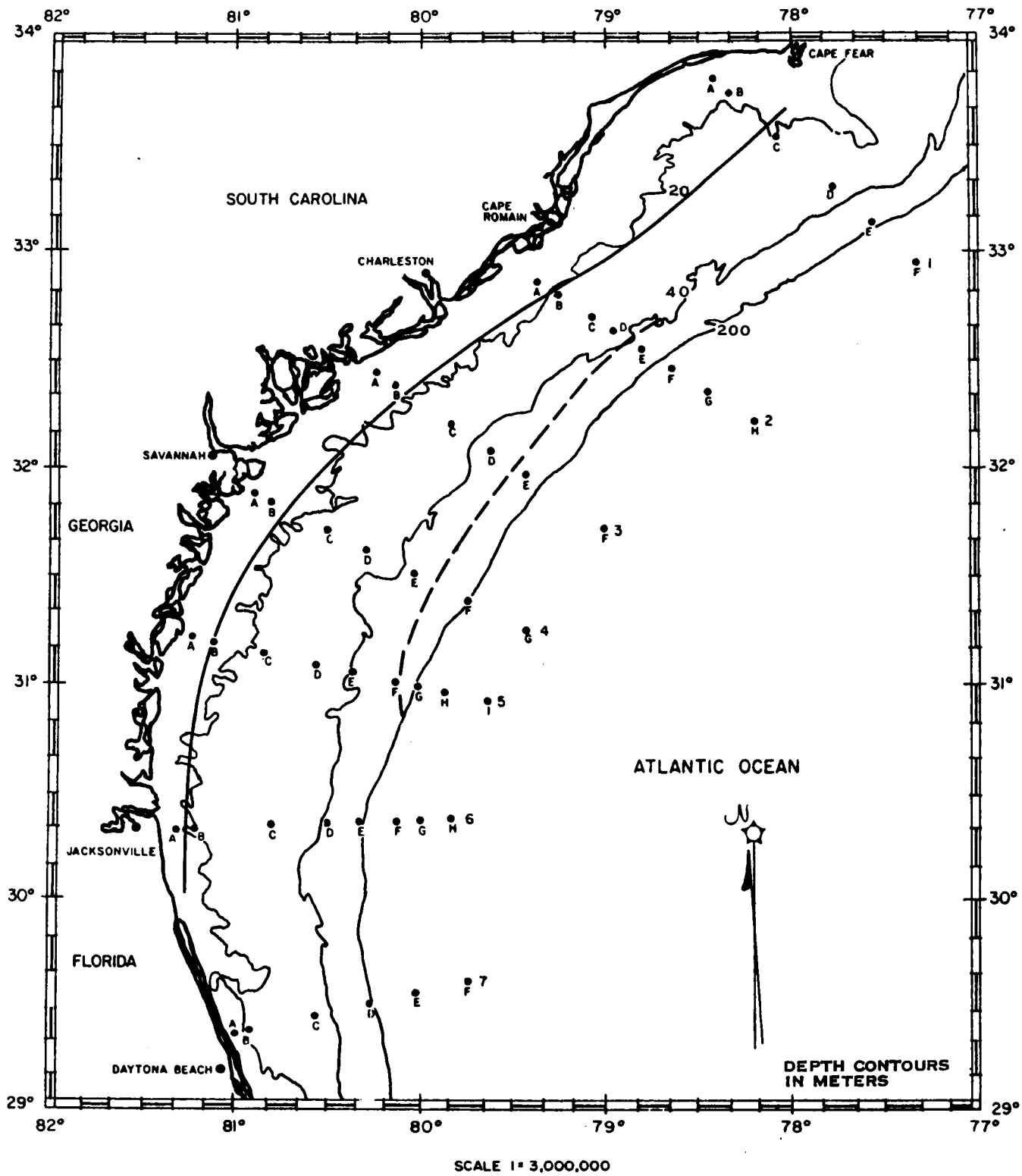

Figure 3.2-41. Approximate Offshore Extent of Freshwater Runoff (Solid Line) and Onshore Extent of Subsurface Gulf Stream Intrusion (Dashed Line), Summer 1977

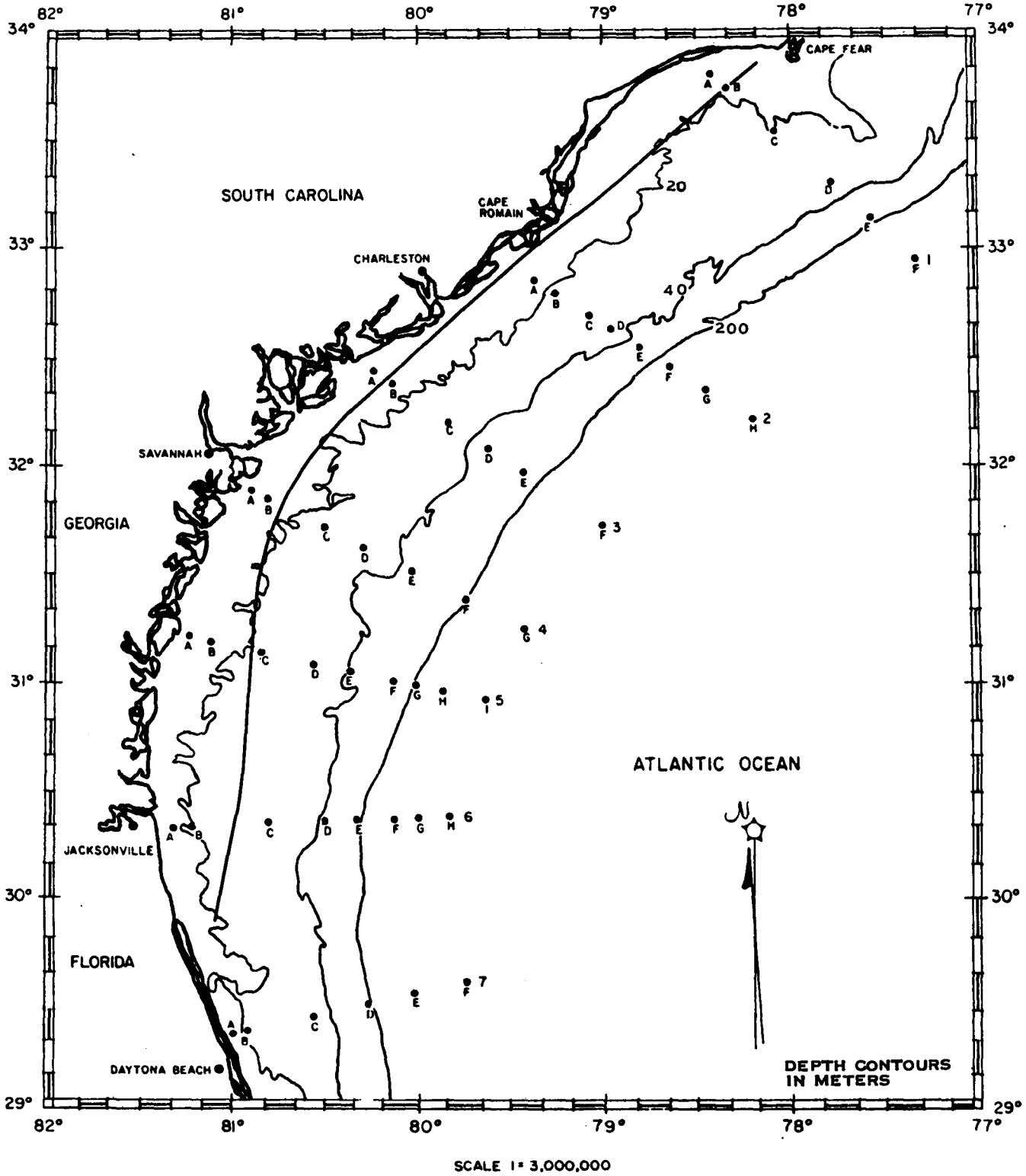

Figure 3.2-42. Approximate Offshore Extent of Freshwater Runoff (Solid Line), Fall 1977

C. SEASONAL DIFFERENCES

The hydrographic, nutrient, carbon, and chlorophyll data collected on the four cruises characterize well the oceanic environment that existed on the South Atlantic continental shelf at the time of the quarterly cruises. The seasonal differences were strong on the shelf, so the entire suite of data is best discussed chronologically. The dominance of the seasonal signal in the inner and middle shelf of the Georgia Bight is, in itself, an important finding.

1. Winter

The absence of persistent warming in the midshelf bottom waters off Georgia may reflect, in part, weaker alongshore advective transport that gives the midshelf bottom water a longer residence time to give up its heat and come into closer temperature equilibrium with the atmosphere. Also, the cooling of the bottom inner shelf and midshelf during the abnormally cold winter of 1977 would have a large effect on the hard-bottom animals with tropical affinities. An impressive amount of inorganic nutrients was present in the surface waters during the benthic sampling leg of the winter cruise; nitrate concentrations were >1 μg-at/l at stations 1D, 2E, 3D, 4G, and 5I. The results indicate a very narrow band of upwelling or intense mixing in the northern region at midshelf and at the shelf break on transects 4 and 5. This phenomenon was not observed on the water-column leg of the winter cruise: the only nitrate value exceeding 1 μg-at/l at the surface was at station 2E. Nutrient injection and uptake events occur over several days, and only time-series observations can resolve these short-lived events.

Chlorophyll concentrations were high during the winter in a pattern very similar to that of the high nitrate concentrations. Of the stations sampled on the water-column leg, only 5A and 5B were not in the midshelf region. Of the 10 midshelf stations, seven had chlorophyll concentrations exceeding 2 μg/l. While these data suggest that the entire shelf was undergoing a bloom, the much better onshore/offshore coverage of the 50 stations of the benthic leg showed that the bloom was actually quite narrow (although very long and persisting for at least 1 to 2 weeks).

2. Spring

During spring sampling, the entire shelf region had uniformly warmed to between 20° and 22°C. The strong inner-shelf cooling and offshore warming pattern was not present. Nutrients in the surface waters were uniformly low at this time; 4E on both legs had the only value exceeding 1 μg-at/l. The only surface chlorophyll concentration that was >2 μg/l was at the extreme inner station, 5A. It is clear that the nutrient-depleted, oligotrophic character of the shelf had been reestablished after the strong winter mixing.

3. Summer

During the summer cruise, some vertical temperature stratification was evident throughout the mid- and outer shelves. Most surface temperatures were between 27° and 28°C; bottom temperatures were slightly lower. The summer nitrate data remain suspect because of an error that cannot be corrected with absolute confidence in the results.

The chlorophyll pattern gives good insight into the dynamics of this region. Stations 1A, 4A, 5A, and 6A had chlorophyll concentrations exceeding 2 μg/l; 6E was the only other station having a concentration this high. The high chlorophyll concentrations in the summer period were associated with lowered salinities. It is clear that the shallow, well mixed, inner-shelf zone is quite distinct from the remainder of the shelf. Bottom regeneration of nutrients and thorough mixing must contribute to this enrichment, although the SABP data emphasize that runoff from land is a major factor in the enrichment of the inner zone only. The carbon: chlorophyll ratio at the inner-shelf stations indicates that the organic enrichment results mainly from *in situ* phytoplankton growth and not from the export of organic detritus from the estuaries.

4. Fall

The vertical temperature stratification was weaker during fall, and differences were <1°C from surface to bottom. The entire shelf had cooled from summer temperatures of approximately 27° to 28°C.

Nutrients were very low throughout the entire shelf. Surface nitrate concentrations were <1 μg-at/l, and bottom concentrations from below 100 m were <1 μg-at/l with one exception: station 7D had a concentration of 1.02 μg-at/l at 44 m—the sole place in the entire Georgia Bight where a significant quantity of new nutrient was being supplied to the upper 100 m during fall. The nutrient depletion of the surface waters remains the dominant factor determining the biological character of the region.

Concentrations of chlorophyll exceeding 2 μg/l were present only at stations 5A, 5B, and 6B. The inner-shelf bloom apparently persists throughout the year.

SABP data indicated that the gradient between the inner zone and midshelf is quite close inshore during certain periods. Station 5B (10 m) sometimes had midshelf conditions and sometimes was enriched like station 5A (8 m), emphasizing that two different oceanographic regimes can exist over a short depth range. It is clear that the sampling plan used in this study revealed well the midshelf and outer-shelf conditions but not the inner-shelf conditions. Only one station, 5A, was consistently in the enriched, biologically active inner shelf. A single station in this zone cannot possibly describe the gradients or ranges that prevail there.

D. SEASONAL RANGES

Table 3.2-8 summarizes the observed 1977 seasonal range by nearshore, midshelf, and outer-shelf stations. Nearshore surface and bottom temperatures and salinities exhibited the widest seasonal ranges. The widest seasonal range for nutrients was at the outer-shelf stations. For chlorophyll *a*, the widest seasonal ranges were in the midshelf area. The particulate organic carbon seasonal range did not exhibit a characteristic areal preference, but ranged from 90 to 160 μg C/l for the entire area, with a suggestion of the widest range in nearshore surface waters. The nearshore sector had the widest dissolved-oxygen seasonal ranges, undoubtedly a reflection of the wide range in temperatures also observed there. However, the outer-shelf near-bottom values also were high, indicative of water-mass differences and not temperature differences.

Table 3.2-8. Seasonal Ranges, All Transects

Stations	Depth	Temperature (°C)	Salinity (°/oo)	Silicate (μg at/l)	Nitrate (μg at/l)	Phosphate (μg at/l)	Chlorophyll *a* (μg/l)	Particulate Organic Carbon (μg C/l)	Dissolved Oxygen (μg/l)
Near shore (A, B)	Surface	4.7–28.3	29.65–36.25	0.30–9.65	00.00–00.54	0.00–0.78	2.73–4.99	92–254	6.4–11.8
Near shore (A, B)	Bottom	4.6–29.0	30.20–36.30	0.30–9.41	00.00–00.61	0.00–0.61	3.35–6.05	121–226	6.2–11.8
Midshelf (C, D, E)	Surface	10.5–27.8	34.05–36.45	0.20–3.19	00.00–0.39	0.00–0.55	0.07–4.87	23–117	6.1–10.3
Midshelf (C, D, E)	Bottom	11.0–28.5	34.25–36.45	0.20–9.41	00.00–5.40	0.00–0.39	0.18–6.83	33–152	6.1–10.3
Outer shelf (F, G, H, I)	Surface	17.5–27.0	36.20–37.00	0.42–20.0	00.00–17.0	0.00–0.94	0.27–2.96	37–117	5.4–8.3
Outer shelf (F, G, H, I)	Bottom	4.6–21.0	35.05–37.17	7.50–22.6	13.9–46.6[a]	0.08–2.84	0.04–1.11	64–090	2.8–7.7

[a]Suspect

SECTION 5
CONCLUSIONS

From the foregoing discussion, it is clear that the original objective of this aspect of the 1977 SABP has been adequately fulfilled. With the exception of few anomalies, the data set presents a coherent picture of the water mass and oceanographic features of the study area.

The seasonal influence on temperature and salinity distributions in the study area has been graphically and dramatically demonstrated. The winter of 1977 was atypical, but the three seasons that followed fell into the boundaries of what has been previously reported for this region.

The high-nitrate bottom waters off the shelf break down onto the continental slope were expected. Their seasonal presence indicates that they are sometimes supplied by Gulf Stream intrusions. This is the only significant source of new nutrients to the shelf.

The nearshore zone of high productivity is extremely narrow and acts as a filter for nutrients supplied to the area by river runoff. The nutrients are rapidly depleted from the water, even though the influence of fresh water is farther onto the shelf.

Lower surface temperatures and higher nutrient and chlorophyll values identified a persistent upwelling feature. This appeared to be an established feature along transect 7 around the midshelf stations and should be reflected by higher productivity and sediment organic material than at surrounding stations not influenced by it.

The time-series cruise during the summer did not reveal an intrusion of the Gulf Stream onto the shelf.

Emerging from the results of the hydrographic, nutrient, chlorophyll, and organic carbon data analysis are the following recommendations:

- Use XBTs (expendable bathythermographs) as backup to the CTD.
- Run the time series more opportunistically; i.e., seek the area in which the process of interest is at work.
- Use less sparse station spacing for the water-column leg.

SECTION 6

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CHAPTER 3

HYDROCARBONS IN WATER, SEDIMENT, ZOOPLANKTON, BENTHIC FAUNA, AND DEMERSAL FISHES OF SOUTH ATLANTIC/GEORGIA BIGHT

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ABSTRACT

This is a report of a 1-year study of the hydrocarbons in surface film, water, zooplankton, benthic macrofauna, and sediments of the South Atlantic outer continental shelf.

Biogenic hydrocarbons, including n-alkanes and polyolefinic hydrocarbons, were the primary components in almost all samples from the study area (frontispiece). The major saturated hydrocarbons were: C_{19}, surface film; C_{15}, dissolved in water; C_{17}, particulates in water; pristane, zooplankton; C_{17}, sediment; and pristane, benthic macrofauna. Important hydrocarbons in the unsaturated/aromatic fraction were squalene and the polyunsaturated olefin 21:6. Hydrocarbon concentrations in the sediment averaged 0.6 μg/g, and most samples were in the 0.1- to 1.0-μg/g range. One station off Daytona Beach, Florida, had very high concentrations of biogenic hydrocarbons in the sediment, which were correlated with high organic carbon and a high silt/clay content. Small amounts of aromatic hydrocarbons, including biphenyl, phenanthrene, naphthalene, and pyrene, were detected in some sediment samples. Water and biological samples generally showed an absence or only traces of aromatic hydrocarbons. Unresolved complex mixtures were not observed in hydrocarbons from most samples. Particulate and dissolved hydrocarbons averaged 0.4 μg/l and 0.5 μg/l, respectively, with highest concentrations occurring in the spring. Hydrocarbon concentrations during some seasons correlated with chlorophyll. Hydrocarbon concentrations in fish varied from 75 μg/g for the offshore lizard fish *Synodus poeyi* to 8 μg/g for the sand perch *Diplectrum formosum*. In benthic macrofauna, pristane, C_{17}, and C_{15} were the major saturated components of the saturated hydrocarbons and squalene the major component of the unsaturated/aromatic fraction.

In summary, most of the water, sediment, and biota samples of the South Atlantic OCS area appeared to contain little or no petroleum hydrocarbons.

SECTION 1
INTRODUCTION

This chapter reports on the distribution of hydrocarbons in the outer continental shelf area off the southeastern United States. This region (Figure 3.1-3), which was studied in 1977 under the South Atlantic Benchmark Program (SABP), is a potential oil and gas production area, so it was necessary to determine the extent of hydrocarbons in water, sediment, and biota before development for use as a guide to subsequent leasing and assessment of environmental impact. In addition to determining concentrations and types of hydrocarbons in water, sediment, and biota, an attempt was made to correlate the hydrocarbon concentrations with several biological, chemical, and physical parameters. Where available, hydrocarbon concentrations in samples from the South Atlantic area were compared with those from other OCS study areas.

Hydrocarbons in the marine environment are derived from a variety of sources, both anthropogenic and natural. Some of the thousands of hydrocarbons found in fossil fuels are similar to those biosynthesized by marine plants and animals, the so-called biogenic hydrocarbons. Distinguishing between anthropogenic hydrocarbons and biogenic hydrocarbons when both are at very low levels remains a difficult analytical problem that is addressed throughout this chapter.

Only a few determinations have been made of hydrocarbons in offshore waters and sediments of the area between Cape Hatteras and Cape Canaveral. The National Academy of Sciences (1975), in reporting data on hydrocarbons in the water column, showed no collections from this region. Swinnerton and Lamontagne (1974) reported concentrations of low molecular weight hydrocarbons in ocean waters off the southeastern United States; concentrations (in nl/l) averaged 45 for methane, 1.0 for ethane, 4.7 for ethylene, 0.1 for propane, and 0.5 for propylene. Brown and Huffman (1976) reported hydrocarbon concentrations in surface waters of this region ranging from 5 to 17 μg/l and in near-surface samples ranging from 1 to 3 μg/l. Paraffinic hydrocarbons comprised most of the hydrocarbon fraction with less than 20% aromatics. Levy (1977), reporting on tar distribution in the Atlantic off the southeastern United States, found tar concentrations of 0.1 to 0.01 mg/m^2 on the surface; he suggested that the source of this tar was oil being lost by tankers going from Venezuela and the Middle East to North America and Europe and its subsequent transport into the Gulf Stream and, consequently, into the waters of the continental shelf.

In continental slope and continental shelf areas, hydrocarbon concentration in the sediment generally is in the range of 1 to 100 μg/g (Farrington and Meyers, 1975); concentrations in inshore areas are generally much higher. Farrington and Tripp (1977) reported on the hydrocarbon analysis of sediments from 31°N: the concentration of hydrocarbon was 1.2 μg/g with no aromatics detected; the concentration was 5.1×10^{-3} μg/g for n-C_{17} and 32×10^{-3} μg/g for n-C_{29}. Pyrene and fluoranthene have been isolated from manganese nodules collected on Blake Plateau (30°N, 78°W; Thomas and Blumer, 1964).

There have also been a few preliminary studies of plankton off the southeast coast of the United States (Lee, unpublished data) in which the major hydrocarbon in the phytoplankton was found to be the polyunsaturated olefin, 21:6, identified in a number of phytoplankton species (Blumer et al., 1971; Lee and Loeblich, 1971); pristane was the major hydrocarbon in the copepod *Eucalanus* sp., which is a common zooplankter in these southeastern offshore waters, and there was only a trace of the polyunsaturated 21:6 hydrocarbon (Lee, unpublished data).

SECTION 2
METHODS AND MATERIALS

The SABP area of study was 20 to 150 km from the coast and included the marine waters between Cape Hatteras and Cape Canaveral. There were from six to nine sampling stations, inshore to offshore, on each of seven transects. (The study area is described in more detail in Chapter 1 of this report.)

Surface-film hydrocarbons were collected with a Teflon disk sampling device. A Bodman sampler collected 90 l of near-surface (1 m) and near-bottom waters. The water was filtered through glass-fiber filters. Hydrocarbons extracted from the filters are referred to as particulate hydrocarbons; hydrocarbons extracted from water passing through the filter are referred to as dissolved hydrocarbons.

Zooplankton samples were collected with bongo frames fitted with either 202-μm or 505-μm mesh Nitex nets towed obliquely from near bottom to near surface. Subsamples were taken from these two nets and frozen until analyzed for hydrocarbons.

Bottom sediments were collected with a stainless-steel box corer and subcores taken for hydrocarbon analysis. Trawls and dredges were used to collect macroepifauna and demersal fishes.

Further details on the methods of collection and the materials used in analyzing hydrocarbons in the samples are presented in Volume 2 and in Appendix 3.3 of Volume 6. The analytical methods involved extraction, saponification, silica-gel chromatography, high-pressure liquid chromatography (HPLC), and gas-liquid chromatography using high-resolution glass capillary column techniques. From each sample, two fractions were obtained: a saturated hydrocarbon fraction eluted with petroleum ether from silica gel (referred to as fraction 1, or F1); and an unsaturated aromatic fraction eluted with 50% benzene in petroleum ether from silica gel (referred to as fraction 2, or F2). These fractions were separately analyzed. Aliphatic and aromatic hydrocarbons having retention indices in the range of 1,400 to 3,200 were determined. Approximately 8% of the samples were analyzed by gas-liquid chromatography coupled with mass spectrometry. Characteristic mass spectra and retention index data were accumulated for the resolved hydrocarbon components.

Acceptable process blanks were obtained in nearly all cases. Trace amounts of organics were frequently present but were not sufficient to interfere with the interpretation of the data from the actual samples. Gas-liquid chromatograms of the representative process blanks that were run with water, sediment, and biota samples appear in Volume 6 (Appendix 3.3I). Recovery of hydrocarbon standard from spiked samples (Table 3.3-1) was generally >70% and, therefore, quite acceptable.

Recoveries and recovery distribution for the HPLC step in the analytical method are given in Table 3.3-2 for 25 different compounds tested. The average recovery for all compounds was 88% through this step. As can be seen from data in these two tables, given a BLM performance criterion of >70% recovery, this requirement was generally met for fraction 1 (saturated) hydrocarbons when extracted from zooplankton, water, and sediment; marginally met for

particulates; and extremely difficult to meet for macrofauna samples. For fraction 2 (aromatic) hydrocarbons generally acceptable recoveries were usually obtained. Amounts of total resolvable components generally found by gas-liquid chromatography for different samples and the usual detection limits for an individual component are given in Table 3.3-3.

Table 3.3-1. Recovery of Hydrocarbons From Spiked Samples

		Percent Recovery for Type of Sample [a]				
Fraction	Component	Zooplankton	Water	Particulate	Sediment	Macrofauna
1	n-C_{16}	73 ±12	78 ±4	65 ±30	89 ±28	58 ±22
	n-C_{17}	89 ±19	79 ±8	71 ±36	79 ±30	51 ±24
	Pristane	83 ±2	79 ±11	71 ±31	93 ±26	69 ±29
	Phytane	78 ±19	84 ±15	74 ±36	94 ±17	56 ±26
	Androstane	86 ±22	83 ±10	73 ±31	83 ±30	65 ±22
	n-C_{20}	85 ±20	82 ±3	70 ±36	103 ±35	59 ±25
	n-C_{22}	85 ±19	80 ±2	66 ±31	78 ±25	60 ±24
	n-C_{26}	76 ±23	89 ±6	75 ±2	76 ±14	63 ±30
	n-C_{28}	76 ±25	83 ±3	61 ±9	56 ±24	52 ±25
	Cholestane	76 ±21	83 ±2	62 ±25	67 ±19	55 ±19
	n-C_{30}	79 ±23	90 ±3	62 ±22	64 ±23	66 ±23
	n-C_{32}	76 ±23	81 ±3	57 ±10	62 ±22	57 ±17
2	1,3–Dimethylnaphthalene	68 ±33	58 ±0	55 ±14	79 ±22	90 ±38
	9,10–Dihydrophenanthrene	76 ±43	78 ±10	68 ±10	83 ±15	90 ±41
	Phenanthrene	82 ±45	75 ±10	80 ±17	102 ±17	88 ±38
	Pyrene	60 ±40	71 ±14	75 ±16	81 ±12	69 ±34

[a]Data given as mean ±1 standard deviation

Table 3.3-2. Recovery of Hydrocarbons From μ-Styragel HPLC Column

Compound	Retention Index[a]	% Recovery in Given Fraction 1	2	3	4	5	6	Total
C_{32}	3200	37	45					82
C_{30}	3000	8	78					86
C_{28}	2800		82					82
Cholestane	2834		10	91				101
C_{26}	2600		95					95
C_{22}	2200		74					74
C_{21}	2100		76					76
C_{20}	2000		77					77
$C_{20:1}$	1989		105					105
C_{19}	1900		70					70
Phytane	1913		72	4				76
C_{18}	1800		62	10				72
$C_{18:1}$	1790		62	10				72
Pristane	1710		66	10				76
C_{17}	1700		55	41				96
C_{16}	1600		6	88				94
C_{15}	1500			76				76
Androstane	1993				100			100
3, 6-Dimethylphenanthrene	1986				96	3		99
Pyrene	2091					112		112
Phenanthrene	1756					100		100
9, 10-Dihydrophenanthrene	1664					86		86
Fluorene	1561					77		77
Acenaphthene	1460					56	6	62
1, 3-Dimethylnaphthalene	1404					50	8	58
						Average		88

[a]Determined on an SE-30 column

Table 3.3-3. Detection Levels

Type of Sample	Concentration of Total Resolvable Hydrocarbons	Detection Limit
Water, surface film (mg/m^2)	0.05 to 1.0	0.0001
Water, dissolved (μg/l)	0.2 to 1.0	0.002
Water, particulates (μg/l)	0.1 to 1.0	0.002
Sediment (μg/g)	0.1 to 1.0	0.001
Macrofauna (μg/g)	5 to 100	0.02
Zooplankton (μg/g)	50 to 500	0.1

SECTION 3
RESULTS

A. SURFACE-FILM HYDROCARBONS

Surface-film samples collected during the winter cruise showed high concentrations of hydrocarbons with patterns similar to the oil of the ship. Subsequent cruises were in calmer weather and more precautions were taken to prevent contamination. Table 3.3-4 summarizes the surface-film data collected in summer and spring.

Figure 3.3-1 shows the gas-liquid chromatograms for hydrocarbons from a summer surface-film sample (653) collected at station 5B. Generally, there was a smooth distribution of n-alkanes in F1, with a maximum at C_{19} and an odd:even ratio close to unity. Pristane and phytane were minor components except at station 6D in the spring. Some samples showed only minor amounts of unresolved components. The F2 hydrocarbons (Section 2 of this chapter) generally had <10% of the total hydrocarbon. The n-alkane series C_{23} to C_{29} in the surface-film hydrocarbons had an odd:even ratio of approximately 1.5, suggesting some terrestrial input since longer-chain alkanes are important in the waxes of land plants.

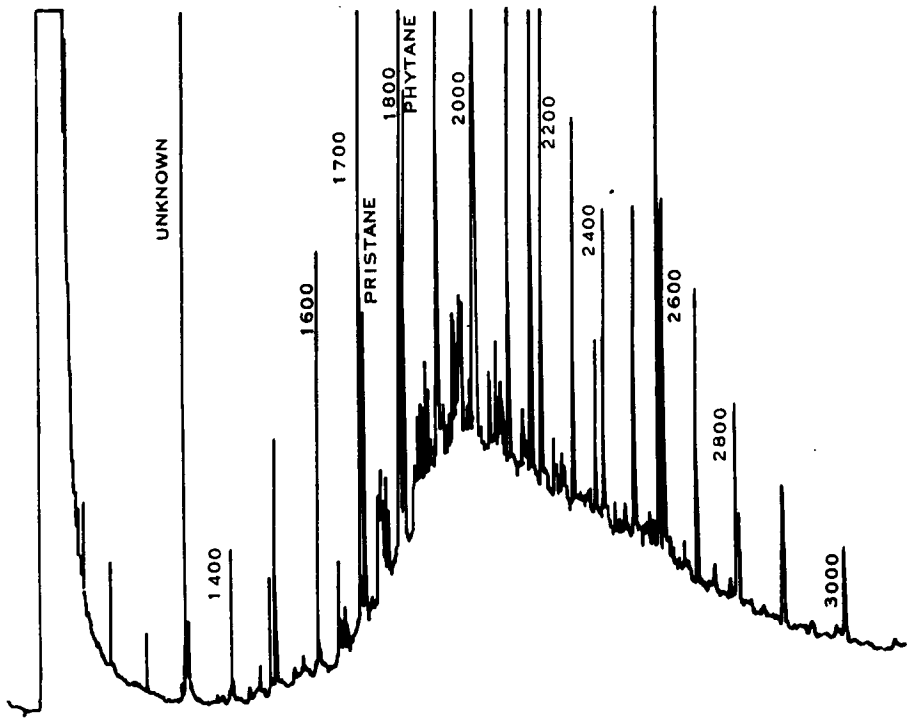
B. PARTICULATE HYDROCARBONS IN WATER

Except at station 7D, total hydrocarbon concentrations for particulates during winter, spring, summer, and fall averaged 0.5, 0.7, 0.2, and 0.1 μg/l, respectively, in near-bottom waters and 0.4, 0.8, 0.3, and 0.1 μg/l, respectively, in near-surface waters (Table 3.3-5). Thus, concentrations of particulate hydrocarbons were higher in winter and spring than in summer and fall. The peak in spring samples may be of some significance.

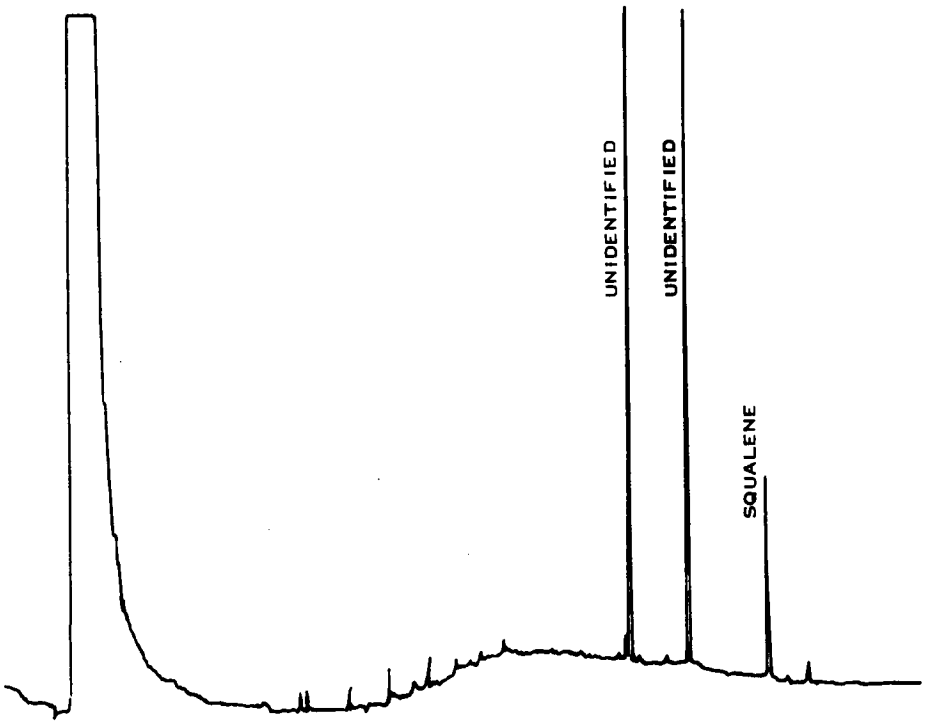
The concentration of dissolved and particulate hydrocarbons in summer samples is shown in Figure 3.3-2. Gas-liquid chromatographs of almost all samples showed an absence or only a trace of an unresolved complex mixture.

Figure 3.3-3 is a typical gas-liquid chromatogram for particulate hydrocarbons (near-surface/near-bottom sample 670). In the saturated hydrocarbon fraction there are two series of peaks, one having a maximum at the C_{17} alkane and the second having a maximum at the C_{28} alkane. The hydrocarbons of F2 were resolved and showed little or no unresolved complex mixture; aromatic hydrocarbons were generally absent or in trace amounts in this fraction. In some samples, aromatic hydrocarbons included biphenyl, fluorene, and pyrene (Table 3.3-6). Biogenic olefinic hydrocarbons (e.g., the polyunsaturated 21:6 hydrocarbon and squalene) were the major components of F2.

The concentrations of near-surface particulate hydrocarbons at station 7D were 36.9, 0.2, 1.5, and 0.1 μg/l for winter, spring, summer, and fall samples, respectively. The winter samples at 7D appeared to be grossly contaminated and showed a high content of plasticizers, silicones, and petroleum. These industrial compounds may have leached from O-rings, etc., during the initial filling of the sampler.



SURFACE FILM 653-0-0 F1



SURFACE FILM 653-0-0 F2

Figure 3.3-1. Gas Chromatograms of Surface-Film Sample 653, Fractions 1 (Top) and 2 (Bottom), Station 5B, Summer 1977

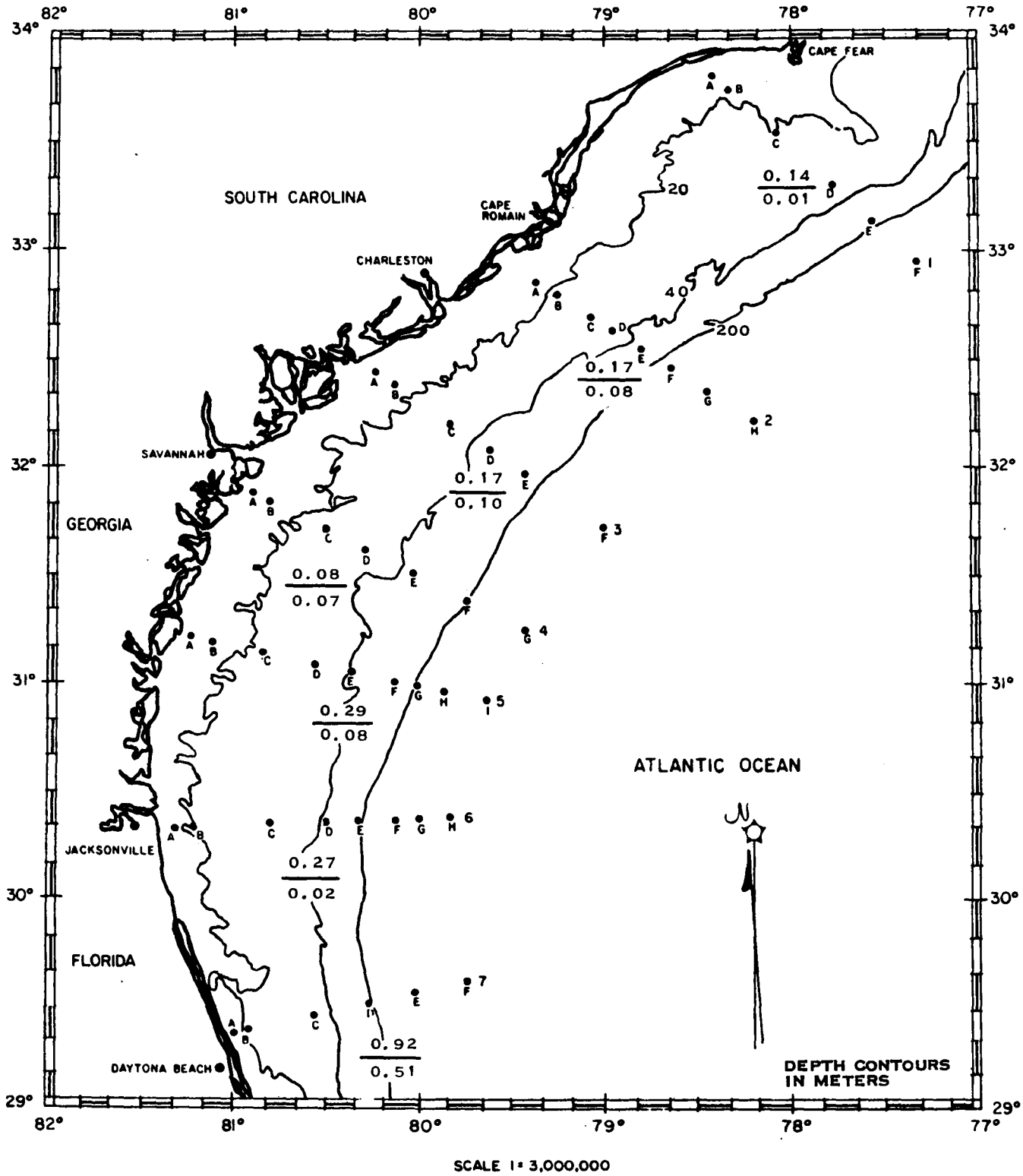
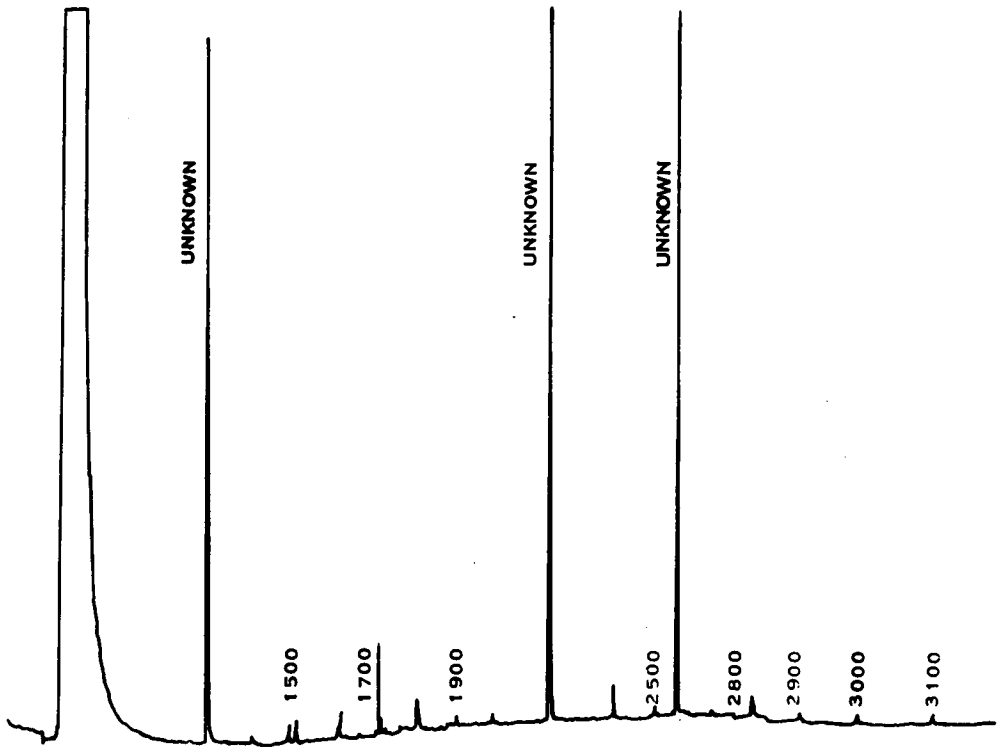
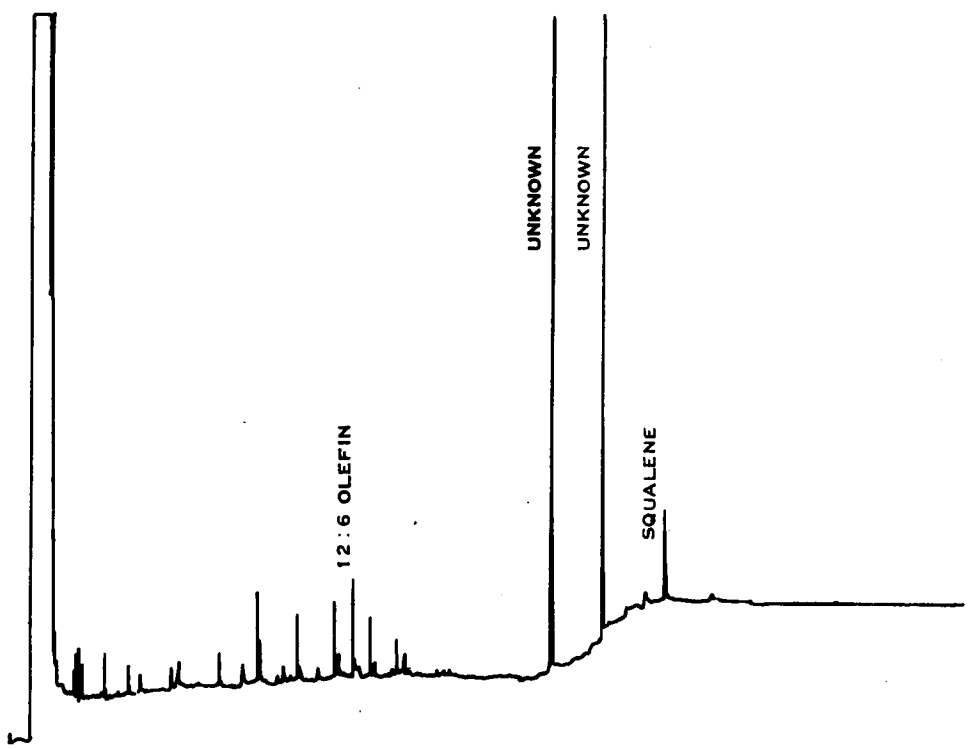


Figure 3.3-2. Dissolved (Top Number) and Particulate (Bottom Number) Saturated Hydrocarbons (μg/ℓ) in Near-Surface Waters, Summer 1977



670-2-0 F1



670-2-0 F2

Figure 3.3-3. Gas Chromatograms of Particulate Material Sample 670, Fractions 1 (Top) and 2 (Bottom), Collected Near Bottom, Summer 1977

Table 3.3-4. Surface-Film Hydrocarbons

Season	Station	F1	F2	Phytane	Pristane	C_{15}	C_{17}	C_{19}
		Concentration (mg/m^2)						
Spring	2E	0.17	0.01	0.004	0.002	–	0.004	0.013
	4E	0.28	0.01	0.007	0.003	–	0.005	0.017
	5G	0.23	0.01	–	0.004	–	0.008	0.025
	6D	0.33	0.01	0.008	0.015	–	0.010	0.040
	7D	0.66	0.04	0.018	0.009	–	–	–
Summer	2E	0.13	0.09	0.001	0.001	0.001	0.002	0.004
	4E	0.15	0.02	0.001	0.001	0.001	0.002	0.005
	5B	0.23	0.06	0.002	0.001	0.001	0.002	0.006
	6D	0.34	0.04	0.001	0.001	0.001	0.002	0.007
	7D	0.52	0.24	0.001	0.001	0.001	0.002	0.006

Table 3.3-5. Hydrocarbons in Water

Season	Sample Type	Station	Depth[a]	F1	F2	Pristane	C_{17}	C_{15}
				Concentration ($\mu g/l$)				
Winter	Dissolved	1D	B	1.20	0.42	0.009	0.018	0.02
		1D	S	0.68	0.80	0.011	0.017	0.03
		2E	B	0.30	0.06	0.008	0.020	0.03
		2E	S	0.30	0.08	0.003	0.010	0.01
		3D	B	0.31	0.12	0.004	0.010	0.01
		3D	S	0.17	0.09	0.006	0.020	0.02
		4D	B	0.25	0.09	0.003	0.010	0.02
		4D	S	0.40	0.03	0.007	0.010	0.01
		5E	B	0.15	0.25	0.003	<0.002	0.01
		5E	S	0.24	0.03	0.003	0.01	0.01
		6D	B	0.26	0.31	0.006	0.012	0.01
		6D	S	0.18	0.02	0.003	0.008	0.01
		7D	B	6.4	0.34	0.23	0.03	0.03
		7D	S	7.5	15.0	0.02	0.48	0.39
	Particulate	1D	B	0.13	0.25	0.005	0.007	0.005
		1D	S	0.06	0.21	0.003	0.008	0.004
		2E	B	0.05	0.35	0.006	0.006	0.004
		2E	S	0.07	0.22	0.006	0.011	0.007
		3D	B	0.06	0.11	0.006	0.014	0.01
		3D	S	0.03	0.26	0.004	0.005	0.006
		4D	B	0.16	0.17	0.010	0.028	0.01
		4D	S	0.03	0.10	0.003	0.008	–
		5E	B	0.04	0.12	0.005	0.005	0.005
		5E	S	0.70	0.28	0.026	0.044	0.03
		6D	B	0.05	1.30	0.009	0.009	0.007
		6D	S	0.20	0.24	0.021	0.030	0.02
		7D	B	0.37	0.24	0.006	0.010	0.001
		7D	S	2.92	34.0	0.010	0.024	0.02

[a]B = near bottom; S = near surface

Table 3.3-5. Hydrocarbons in Water (Continued)

Season	Sample Type	Station	Depth[a]	Concentration (μg/l) F1	F2	Pristane	C_{17}	C_{15}
Spring	Dissolved	1D	B	0.26	0.36	0.002	0.004	0.019
		1D	S	0.29	0.16	0.004	0.008	0.014
		2E	B	0.21	0.18	0.006	0.008	0.013
		2E	S	0.18	0.16	0.005	0.007	0.009
		3D	B	0.19	0.17	0.004	0.007	0.007
		3D	S	0.24	0.12	0.006	0.008	0.008
		4D	B	0.73	0.20	0.005	0.009	0.011
		4D	S	0.15	0.34	0.005	0.009	0.011
		5E	B	0.21	0.18	0.005	0.008	0.014
		5E	S	0.18	0.40	0.005	0.007	0.014
		6D	B	0.19	0.80	0.002	0.004	0.011
		6D	S	0.37	0.24	0.004	0.010	0.012
		7D	B	0.21	0.09	0.005	0.007	0.009
		7D	S	0.18	0.11	0.004	0.007	0.010
	Particulate	1D	B	0.26	0.25	0.016	0.019	–
		1D	S	1.00	0.13	0.031	0.033	0.008
		2E	B	0.42	0.03	0.01	0.01	–
		2E	S	0.09	0.009	0.008	0.007	–
		3D	B	1.43	0.31	–	0.028	–
		3D	S	0.08	0.16	–	–	–
		4D	B	0.54	0.09	0.005	0.015	–
		4D	S	1.41	0.68	0.111	0.117	–
		5E	B	0.21	0.15	0.005	0.008	–
		5E	S	0.13	0.04	–	0.005	–
		6D	B	0.20	0.04	0.009	0.008	–
		6D	S	0.87	0.58	0.037	0.056	–
		7D	B	0.63	0.66	0.020	0.025	0.004
		7D	S	0.10	0.13	0.006	0.007	–
Summer	Dissolved	1D	B	0.11	0.14	0.002	0.003	0.019
		1D	S	0.14	0.11	0.004	0.004	0.033
		2E	B	0.19	0.13	–	0.009	0.048
		2E	S	0.17	0.10	0.003	0.004	0.031
		3D	B	0.04	0.41	–	–	0.009
		3D	S	0.17	0.22	–	0.003	0.029
		4D	B	0.23	0.11	–	0.044	0.030
		4D	S	0.08	0.24	0.002	0.001	0.008
		5E	B	0.16	0.03	0.005	0.005	0.030
		5E	S	0.29	0.25	0.010	0.009	0.060
		6D	B	0.12	0.12	–	–	0.020
		6D	S	0.27	0.19	0.004	0.004	0.043
		7D	B	0.10	0.15	–	0.002	0.015
		7D	S	0.92	2.85	0.025	0.035	0.086
	Particulate	1D	B	0.12	0.09	–	–	–
		1D	S	0.01	0.07	–	0.003	–
		2E	B	0.06	0.08	–	–	–
		2E	S	0.08	0.04	–	0.006	–
		3D	B	0.03	0.09	–	–	–
		3D	S	0.10	0.05	0.003	0.028	0.005

[a]B = near bottom; S = near surface

Table 3.3-5. Hydrocarbons in Water (Continued)

Season	Sample Type	Station	Depth[a]	Concentration (μg/l) F1	F2	Pristane	C_{17}	C_{15}
Summer (cont)	Particulate (cont)	4D	B	0.01	0.03	–	–	–
		4D	S	0.07	0.02	–	0.004	0.002
		5E	B	0.03	0.13	0.002	0.002	–
		5E	S	0.08	0.07	0.001	0.005	–
		6D	B	0.08	0.14	0.003	0.007	0.002
		6D	S	0.02	0.03	0.001	0.002	0.001
		7D	B	0.09	0.04	–	–	–
		7D	S	0.51	1.03	0.002	0.014	0.001
Fall	Dissolved	1D	B	0.09	0.18	0.002	0.003	0.016
		1D	S	0.09	0.19	0.001	0.002	0.016
		2E	B	0.11	0.07	0.002	0.002	0.020
		2E	S	0.09	0.14	0.002	0.003	0.027
		3D	B	0.06	0.05	0.003	0.002	0.010
		3D	S	0.11	0.03	0.003	0.002	0.015
		4D	B	0.17	0.07	–	0.001	0.011
		4D	S	0.76	11.6	0.014	0.028	0.176
		5E	B	0.15	0.62	0.002	0.003	0.018
		5E	S	0.12	0.12	0.002	0.002	0.020
		6D	B	0.07	0.08	0.001	0.002	0.008
		6D	S	0.09	0.25	0.002	0.002	0.011
		7D	B	0.27	0.58	0.007	0.009	0.038
		7D	S	0.21	4.90	0.002	0.004	0.020
	Particulate	1D	B	0.04	0.01	0.001	0.003	–
		1D	S	0.03	0.03	0.001	0.002	–
		2E	B	0.02	0.03	0.002	0.006	0.001
		2E	S	0.01	0.11	–	0.002	–
		3D	B	0.03	0.03	0.005	0.006	0.003
		3D	S	0.01	0.02	–	0.003	–
		4D	B	0.09	0.19	0.007	0.008	–
		4D	S	0.04	0.02	0.004	0.004	0.004
		5E	B	0.02	0.01	0.002	0.001	–
		5E	S	0.18	0.01	0.003	0.002	0.003
		6D	B	0.11	0.04	0.004	0.003	0.011
		6D	S	0.04	0.01	0.004	0.004	0.003
		7D	B	0.05	0.01	0.001	0.003	0.002
		7D	S	0.05	0.03	0.001	0.004	0.001

[a]B = near bottom; S = near surface

Table 3.3-6. Aromatic Hydrocarbons and Miscellaneous Chemicals Found in Fraction 2 by GC-MS Analysis

Retention Index	Molecular Weight	Tentative Identification	Major Characteristic Ions m/e (Relative Intensity)	Occurrence in Sample Type[a] Mac.	Zoo.	Sed.	Wat.	Part.
1170	128	Naphthalene	128(100), 127(12), 41(12), 102(11)	+	0	++	++	0
1346	–	Silicone	341(100), 73(57), 342(35), 325(28)	+	0	+	+	+
1347	154	Biphenyl	154(100), 153(42), 152(30), 155(14)	0	0	++	++	++
1400	168	Methylbiphenyl	168(100), 167(92), 165(40), 91(39)	0	0	+	0	0
1450	220	Di-t-butylcresol	205(100), 220(25), 206(18), 177(15)	0	0	+	0	0
1500	170	Trimethylnaphthalene	155(100), 170(85), 159(32), 169(29)	0	0	+	0	0
1522	–	Silicone	281(100), 73(65), 147(46), 327(28)	0	0	+	+	+
1550	166	Fluorene	165(100), 166(99), 82(40), 163(23)	0	0	0	0	+
1550	188	Chlorobiphenyl	188(100), 152(50), 190(32), 153(24)	0	0	0	++	0
1600	182	Diphenylethane	91(100), 65(19), 92(7), 51(5)	0	0	+	0	0
1610	184	Tetramethylnaphthalene	169(100), 184(87), 154(36), 170(32)	0	0	+	0	0
1664	180	Methylfluorene	180(100), 179(85), 89(63), 178(58)	0	0	+	0	0
1690	222	Dichlorobiphenyl	222(100), 224(70), 152(56), 155(17)	0	0	0	++	0
1695	–	Silicone	73(100), 355(68), 221(61), 281(57)	0	0	+	+	+
1700	196	Trimethylbiphenyl	181(100), 196(60), 166(42), 167(38)	0	0	+	0	0
1743	178	Phenanthrene	178(100), 176(20), 151(17), 179(16)	+	+	++	+	+
1860	–	Silicone	73(100), 147(48), 221(45), 281(25)	0	0	+	+	+
1870	–	Silicone	327(100), 156(62), 253(32), 249(30)	0	0	+	+	0
1880	192	Methylphenanthrene	192(100), 191(64), 189(35), 91(27)	0	0	+	0	0
1880	238	1,1-bis (ethylphenyl)ethane	223(100), 238(43), 224(20), 181(20)	0	0	+	0	0
1968	206	Dimethylphenanthrene	206(100), 191(71), 189(42), 190(29)	0	0	+	0	0
2013	–	Silicone	73(100), 148(52), 281(42), 135(39)	0	0	+	+	+
2072	202	Pyrene	202(100), 200(28), 100(22), 101(18)	0	0	++	++	++
2171	–	Silicone	73(100), 221(68), 281(67), 147(65)	0	0	+	+	+
2180	–	Silicone	135(100), 197(35), 73(29), 136(15)	0	0	+	0	0
2329	–	Silicone	73(100), 221(76), 147(68), 281(57)	0	0	+	+	+
2374	–	Dioctyladipate	129(100), 57(35), 70(23), 55(23)	+	++	++	++	++
2415	228	Chrysene	228(100), 114(70), 229(63), 112(62)	0	0	+	0	0
2479	–	Silicone	73(100), 221(83), 281(81), 147(68)	0	0	+	+	+
2499	–	–	91(100), 207(75), 129(65), 206(40)	0	0	0	0	+
2512	–	Dioctylphthalate	149(100), 69(68), 167(41), 41(31)	+	+	+	+	+
2518	–	–	91(100), 207(73), 129(67), 206(38)	0	0	0	0	+
2533	–	–	91(100), 207(80), 129(71), 206(40)	0	0	0	0	+
2624	–	Silicone	73(100), 221(95), 147(75), 281(68)	0	0	+	+	+
2737	–	Silicone	73(100), 221(87), 147(66), 281(57)	0	0	+	0	0
2780	252	Perylene	252(100), 207(56), 45(43), 130(40)	0	0	+	0	0
2781	–	Silicone	73(100), 147(38), 221(32), 207(14)	0	0	+	+	+
2808	–	Squalene	69(100), 81(48), 41(17), 68(17)	+	++	++	++	+
2824	–	Silicone	197(100), 135(50), 259(30), 198(20)	0	0	+	0	0
2921	–	Silicone	73(100), 147(47), 221(16), 207(11)	0	0	0	+	+
3068	–	Silicone	73(100), 147(40), 221(9), 74(8)	0	0	0	+	+

[a]0 = not found; + = low levels; ++ = relatively high levels.

Table 3.3-7. Dissolved and Particulate Hydrocarbons Correlated With Chlorophyll *a* and Organic Carbon (Particulate and Dissolved) in Bottom and Surface Samples

Season	Sample Depth[a]	Significant Correlations	Probability[b]
Winter	S	F1 particulate hydrocarbon versus chlorophyll	0.04
Summer	S	Particulate pristane versus DOC	0.01
Fall	S	F1 dissolved hydrocarbon versus chlorophyll	0.001
		F1 dissolved hydrocarbon versus POC	0.001
		Total particulate hydrocarbon versus chlorophyll	0.001
		F1 particulate hydrocarbon versus DOC	0.02
		Total particulate hydrocarbon versus POC	0.01
Winter	B	Total dissolved hydrocarbon versus POC	0.01
		F1 dissolved hydrocarbon versus POC	0.01
		Dissolved pristane versus chlorophyll	0.001
Fall	B	Total dissolved hydrocarbon versus chlorophyll	0.0001
		Total dissolved hydrocarbon versus POC	0.0001
		F1 dissolved hydrocarbon versus chlorophyll	0.003

[a]S = near surface; B = near bottom.

[b] Let R denote the sample correlation coefficient, and r denote the calculated value of the sample correlation coefficient. Then

$$\Pr\left\{|R|>|r|\right\} = p$$

can be thought of as a measure of the degree of agreement between the data collected and the hypothesis of no correlation. This measure can take values between zero and one, with small values of p (generally less than 0.10, 0.05, or 0.01) indicating poor agreement and higher values indicating better agreement. More technically,

$$\Pr\left\{|R|>|r|\right\} = p$$

is the probability, before collection of data, of obtaining a value of the statistic R without a sign greater than the observed value of r without a sign, given that the assumption of no correlation represents the true state of nature.

Table 3.3-7 indicates significant correlations between particulate hydrocarbons and chlorophyll and organic carbon (particulate and dissolved) in bottom and surface samples. Correlations omitted from this table because of their lack of significance and the data used for the correlations appear in Volume 6 (Appendix 3.3A) of this report. Total particulate hydrocarbons, fraction 1 particulate hydrocarbons, and particulate pristane correlated in some seasonal samples with chlorophyll, dissolved organic carbon, and particulate organic carbon. Since significant correlations were not observed in all seasonal samples, the relationships may not be important. A second explanation for the lack of significance during some seasons may be that there are different origins for particulate hydrocarbons during different periods (e.g., subsequent to, during, and after a phytoplankton bloom).

Table 3.3-8 presents significant correlations between particulate hydrocarbons and zooplankton hydrocarbons. In some seasonal samples, total particulate hydrocarbons and F1 particulate hydrocarbons correlated with total zooplankton hydrocarbons and F1 zooplankton hydrocarbons. These correlations suggest that some of the particulate hydrocarbons are derived from zooplankton, possibly through the zooplankton feces.

Table 3.3-8. Dissolved and Particulate Hydrocarbons Correlated With Zooplankton Hydrocarbons

Season	Sample Depth[a]	Net Size (μm)	Significant Correlations	Probability[b]
Winter	S	202	Total dissolved hydrocarbon versus total zooplankton hydrocarbon	0.02
Winter	S	202	Total dissolved hydrocarbon versus F1 of zooplankton hydrocarbon	0.002
Winter	S	202	Total dissolved hydrocarbon versus zooplankton pristane	0.002
Winter	S	202	F1 dissolved hydrocarbon versus total zooplankton hydrocarbon	0.03
Winter	S	202	F1 dissolved hydrocarbon versus F1 zooplankton hydrocarbon	0.01
Winter	S	202	F1 dissolved hydrocarbon versus zooplankton pristane	0.003
Winter	S	202	Dissolved pristane versus total zooplankton hydrocarbon	0.03
Winter	B	202	F1 dissolved hydrocarbon versus F1 zooplankton hydrocarbon	0.04
Winter	B	202	Total dissolved hydrocarbon versus total zooplankton hydrocarbon	0.02
Winter	B	202	Total dissolved hydrocarbon versus F1 zooplankton hydrocarbon	0.002
Winter	B	202	F1 dissolved hydrocarbon versus F1 zooplankton hydrocarbon	
Spring	B	202	Total dissolved hydrocarbon versus total zooplankton hydrocarbon	0.03
Spring	B	202	Total dissolved hydrocarbon versus F1 zooplankton hydrocarbon	0.0001
Spring	B	202	F1 dissolved hydrocarbon versus F1 zooplankton hydrocarbon	0.0001
Spring	B	202	Dissolved pristane versus zooplankton pristane	0.002
Spring	B	202	Total particulate hydrocarbon versus total zooplankton hydrocarbon	0.04
Spring	B	202	Total particulate hydrocarbon versus F1 zooplankton hydrocarbon	0.001
Spring	B	202	F1 particulate hydrocarbon versus total zooplankton hydrocarbon	0.002
Winter	S	202	Total dissolved hydrocarbon versus total zooplankton hydrocarbon	0.001
Winter	S	202	Total dissolved hydrocarbon versus F1 zooplankton hydrocarbon	0.004
Winter	S	202	F1 dissolved hydrocarbon versus total zooplankton hydrocarbon	0.02
Winter	S	202	F1 dissolved hydrocarbon versus total F1 zooplankton hydrocarbon	0.02
Winter	S	202	Dissolved pristane versus zooplankton pristane	0.05
Summer	S	505	Total dissolved hydrocarbon versus total zooplankton hydrocarbon	0.04
Summer	S	505	Total dissolved hydrocarbon versus F1 zooplankton hydrocarbon	0.04
Summer	S	505	Total particulate hydrocarbon versus total zooplankton hydrocarbon	0.04
Summer	S	505	Total particulate hydrocarbon versus F1 zooplankton hydrocarbon	0.03
Summer	S	505	F1 particulate hydrocarbon versus total zooplankton hydrocarbon	0.05
Summer	S	505	F1 particulate hydrocarbon versus F1 zooplankton hydrocarbon	0.05
Fall	S	505	Total particulate hydrocarbon versus total zooplankton hydrocarbon	0.03
Fall	S	505	F1 particulate hydrocarbon versus total zooplankton hydrocarbon	0.001

[a]S = near surface; B = near bottom

[b] Let R denote the sample correlation coefficient, and r denote the calculated value of the sample correlation coefficient. Then

$$\Pr \ |R|>|r| \ = p$$

can be thought of as a measure of the degree of agreement between the data collected and the hypothesis of no correlation. This measure can take values between zero and one, with small values of p (generally less than 0.10, 0.05, or 0.01) indicating poor agreement and higher values indicating better agreement. More technically,

$$\Pr \ |R|>|r| \ = p$$

is the probability, before collection of data, of obtaining a value of the statistic R without a sign greater than the observed value of r without a sign, given that the assumption of no correlation represents the true state of nature.

C. DISSOLVED HYDROCARBONS IN WATER

Except at station 7D, concentrations of total dissolved hydrocarbons during winter, spring, summer, and fall averaged 0.4, 0.4, 0.4, and 0.3 μg/l, respectively, in near-surface waters and 0.5, 0.6, 0.4, and 0.4 μg/l, respectively, in near-bottom waters (Table 3.3-5). At most stations, concentrations ranged from 0.1 to 1.0 μg/l. A series of n-alkanes from C_{14} to C_{30} was observed in the saturated hydrocarbon fraction, with C_{14} and C_{15} as the principal components, as shown in the gas-liquid chromatogram. Figure 3.3-4 (near-bottom sample 032). The ratio of odd-chain-length:even-chain-length alkanes was generally almost unity.

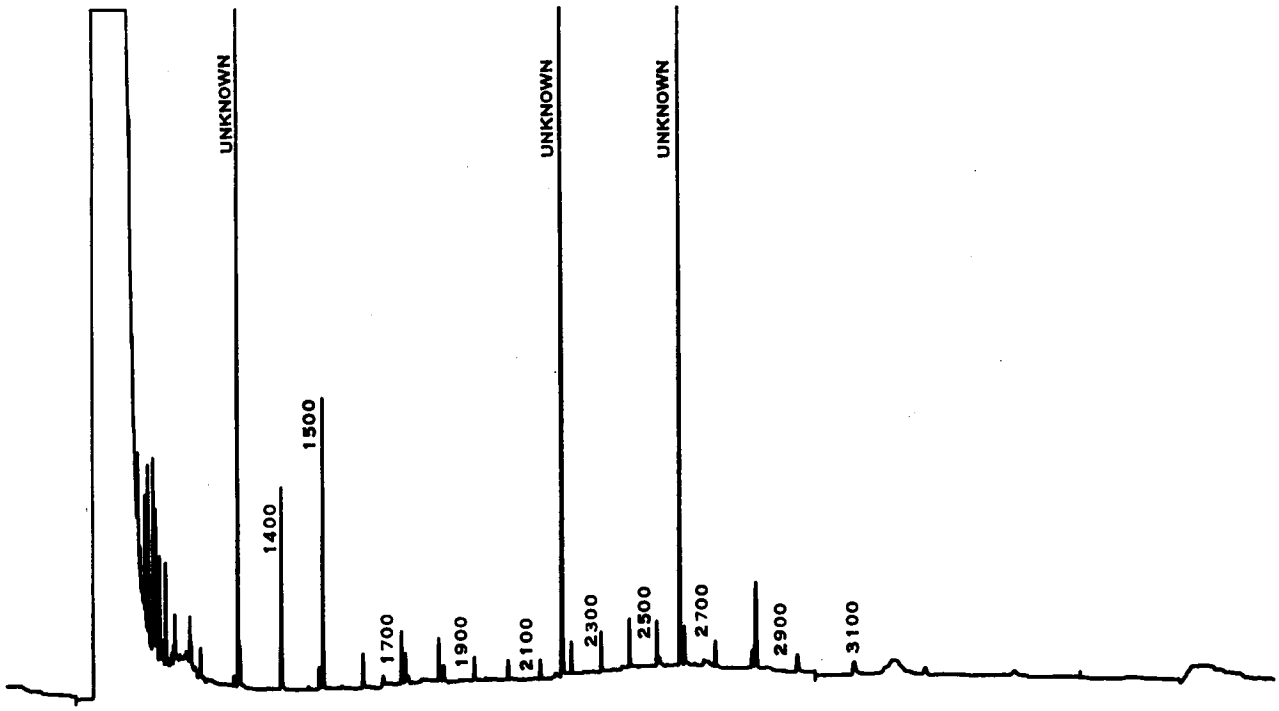
The gas-liquid chromatograms of the various samples showed well-resolved peaks with little or no unresolved complex mixtures. Fraction 2 showed biogenic olefins and only traces of aromatic hydrocarbons, with the exception of station 7D in the winter; the major biogenic hydrocarbon was squalene, and the aromatic hydrocarbons identified in some samples included naphthalene, biphenyl, and pyrene (Table 3.3-6). Generally, dissolved hydrocarbon concentrations were much higher than particulate hydrocarbon concentrations (Figure 3.3-2). In near-surface waters at station 7D, dissolved hydrocarbon concentrations were 22.5, 0.3, 3.8, and 5.4 μg/l in winter, spring, summer, and fall, respectively; the winter sample was grossly contaminated, as discussed previously, but the higher concentrations observed in later seasonal cruises suggest that this station was influenced by primary productivity during other seasons.

In some seasonal samples, total dissolved hydrocarbons, F1 dissolved hydrocarbons, and dissolved pristane correlated with particulate organic carbon, dissolved organic carbon, and chlorophyll (Table 3.3-7). Also in some seasonal samples, total dissolved hydrocarbons, F1 dissolved hydrocarbons, and dissolved pristane correlated with total zooplankton hydrocarbons, F1 zooplankton hydrocarbons, and zooplankton pristane (Table 3.3-8). Phytol, a long-chain alcohol found in chlorophyll, is converted to pristane during the metabolism of chlorophyll by zooplankton; this would explain a relationship of pristane to zooplankton hydrocarbons.

D. ZOOPLANKTON HYDROCARBONS

Table 3.3-9 summarizes zooplankton hydrocarbons found in samples from the various stations. Saturated hydrocarbons in zooplankton collected in 202-μm and 505-μm nets averaged 181 and 132 μg/g, respectively. Pristane, the major component of the saturated hydrocarbon fraction, was generally >30% of the total, with the straight-chain alkanes C_{15} and C_{17} being major components. Figures 3.3-5 and 3.3-6 are gas chromatograms of the hydrocarbons from zooplankton collected during winter in 202-μm and 505-μm nets at stations 1D and 2E, respectively. The F2 hydrocarbons were predominantly squalene and the polyunsaturated 21:6 hydrocarbon.

The averages and ranges of concentrations for zooplankton from all stations in each season are presented in Table 3.3-10. Summer and fall concentrations were generally an order of magnitude higher than those in the winter and spring. As already discussed, particulate hydrocarbons showed a reverse relationship; i.e., highest concentrations in winter and spring.



W7DB WATER 32-15 F1

Figure 3.3-4. Gas Chromatogram of Seawater Sample 035, Fraction 1, Collected at Station 7D, Near Bottom, Winter 1977

Table 3.3-9. Zooplankton Hydrocarbons

Season	Net Size (μm)	Station	Concentration (μg/g) F1	F2	Pristane	C_{17}	C_{15}
Winter	202	1D	28	110	0.7	0.1	1.0
		2E	14	47	5.9	0.1	0.4
		4E	9	12	3.9	0.3	0.8
		5E	28	120	12.6	0.3	1.3
		6D	28	29	14.9	1.2	1.1
		7D	175	40	55.1	36.3	9.4
	505	1D	14	10	4.6	0.3	2.1
		2E	11	22	3.7	0.2	0.9
		5E	9	11	4.9	0.3	0.9
		6D	14	15	2.8	0.4	0.5
Spring	202	1D	3	65	42.6	0.6	10.0
		2E	9	38	7.3	0.3	0.7
		4E	34	45	15.0	–	1.7
		5E	39	68	24.5	0.3	2.0
		6D	64	–	52.7	0.8	4.6
		7D	23	228	18.1	0.5	2.6
	505	1D	55	48	17.7	0.8	14.5
		2E	21	12	5.9	0.1	0.9
		4E	65	83	29.2	0.4	7.8
		5E	51	49	25.0	1.0	2.3
		6D	56	161	25.7	2.1	5.7
		7D	3	16	1.7	0.1	0.5
Summer	202	1D	173	1.0	46.2	9.1	29.3
		2E	65	2.0	21.4	1.8	8.4
		4E	127	1.0	25.1	4.0	12.9
		5E	2,538	3.0	69.5	20.8	17.5
		6D	67	0.1	14.4	13.6	5.1
		7D	130	1.0	44.4	11.6	1.3
	505	1D	147	1.0	30.0	5.1	39.1
		2E	99	1.0	13.8	3.2	10.1
		4E	554	4.0	55.3	16.4	67.4
		5E	145	1.0	38.7	10.0	24.5
		6D	286	2.0	34.4	28.5	22.5
		7D	942	3.0	56.7	27.3	21.5
Fall	202	1D	98	0.2	60.0	4.9	9.6
		2E	150	1.0	32.2	3.4	15.5
		4E	60	0.2	33.4	1.9	7.8
		5E	75	0.2	37.4	4.1	8.2
		6D	73	0.2	36.2	0.4	13.6
		7D	338	2.0	35.2	13.4	11.2
	505	1D	67	0.2	34.4	2.2	13.5
		2E	71	0.2	32.0	1.8	10.9
		4E	411	6.0	26.4	4.0	7.8
		5E	63	–	26.7	0.9	12.8
		6D	74	2.0	24.5	1.5	6.8
		7D	65	0.2	8.0	3.1	8.0

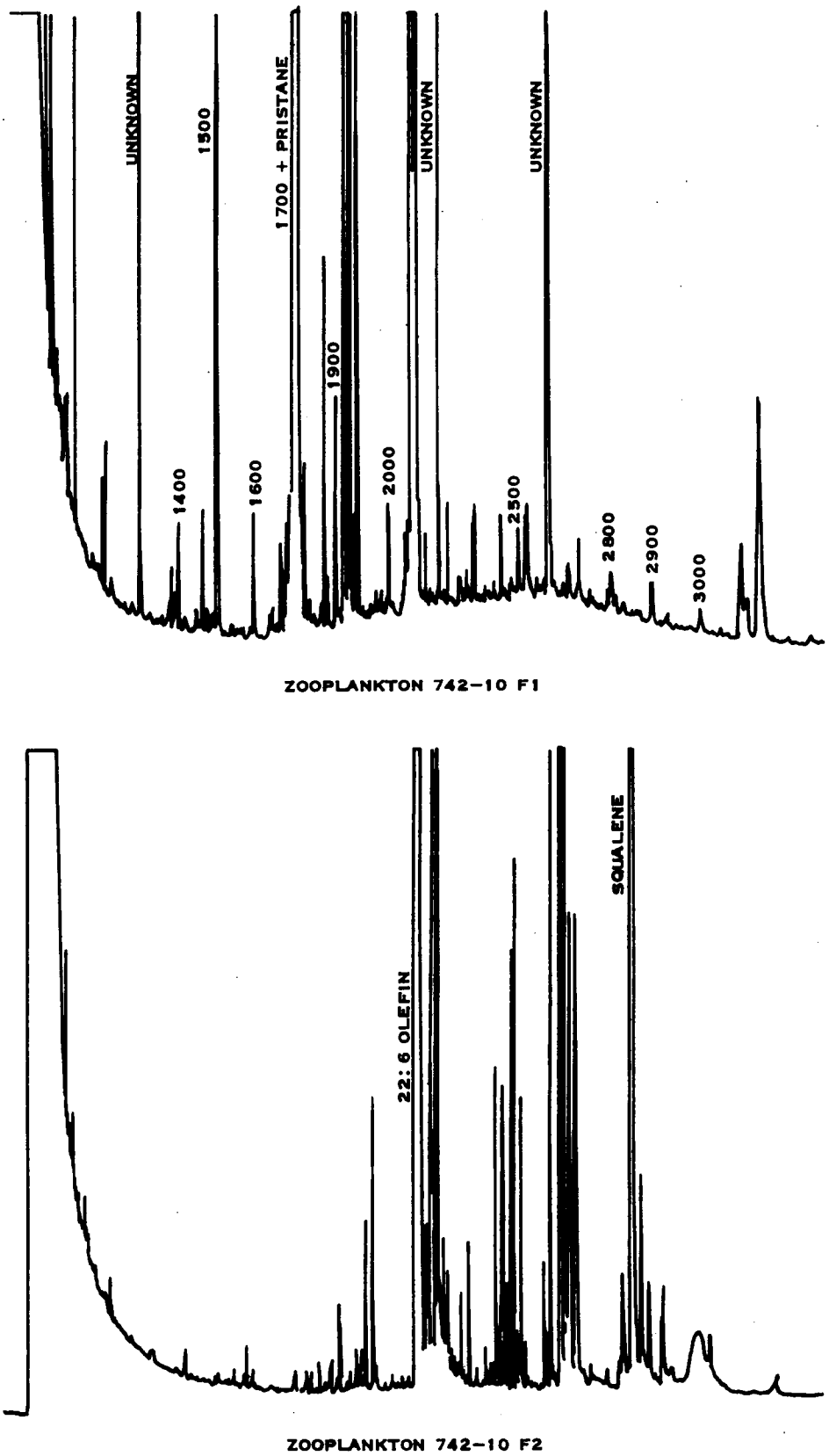
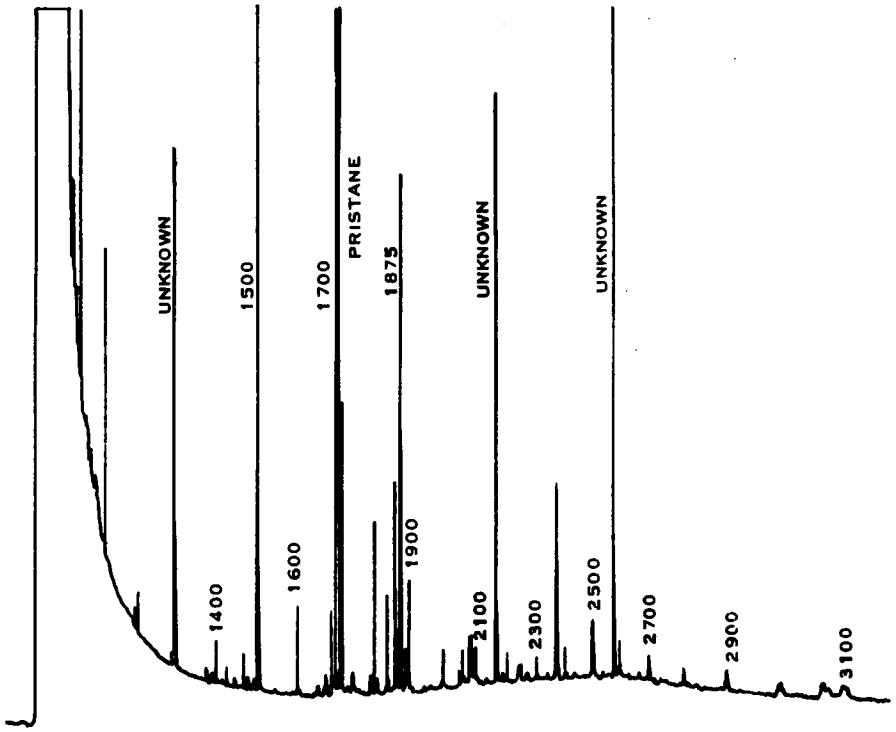
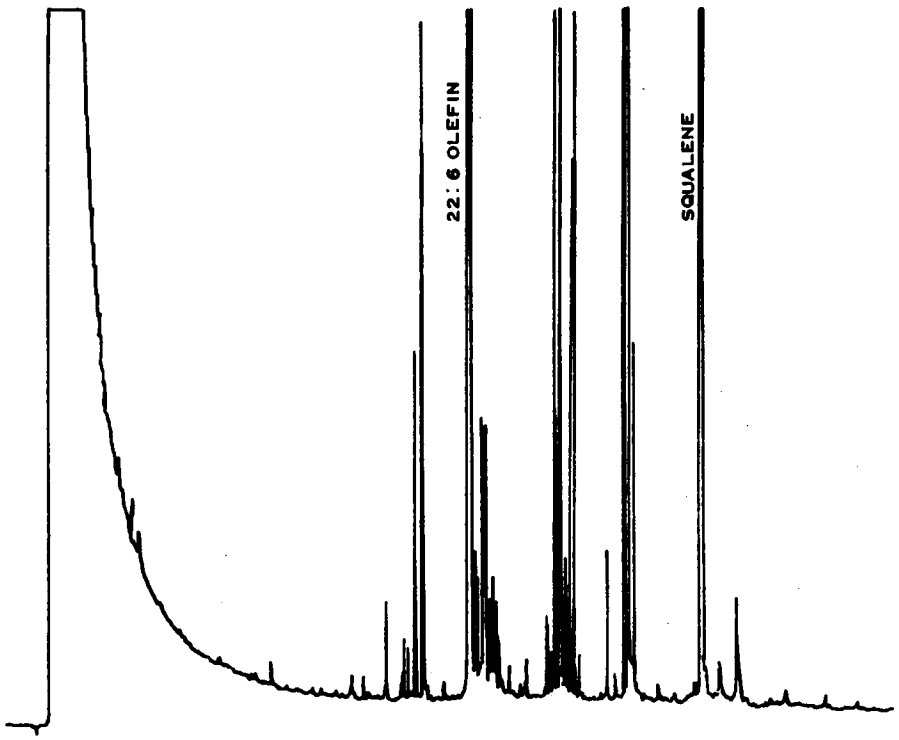


Figure 3.3-5. Gas Chromatograms of Zooplankton Sample 074, Fractions 1 (Top) and 2 (Bottom), Collected in 202-μm Net at Station 1D, Winter 1977



ZOOPLANKTON 62–10 F1



ZOOPLANKTON 62–10 F2

Figure 3.3-6. Gas Chromatograms of Zooplankton Sample 062, Fractions 1 (Top) and 2 (Bottom), Collected in 505-μm Net at Station 7D, Winter 1977

Table 3.3-10. Hydrocarbon Concentrations in Zooplankton Samples

Season	Net Size (μm)	Concentration (μg/g) F1 Average (Range)	F2 Average (Range)	Total
Winter	202	47 (9–175)	60 (12–110)[a]	107
	505	12 (9–14)	15 (10–22)[a]	27
Spring	202	29 (3–64)	89 (38–22)[a]	118
	505	42 (3–65)	62 (12–161)[a]	104
Summer	202	516 (65–2,538)	1 (0.1–3.0)	517
	505	362 (99–942)	2 (1–4)	364
Fall	202	132 (73–338)	0.6 (0.2–2.0)	133
	505	114 (63–411)	1.7 (0.2–6.0)	116

[a] F2 data contain a predominance of biogenic olefins masking aromatic compounds.

GC-MS data collected on winter and spring F2 zooplankton hydrocarbon samples showed major interference by relatively large amounts of biogenic olefins. The biogenic olefins often overload the glass capillary columns, causing unsatisfactory resolution or obscuring traces of aromatic hydrocarbons having similar retention times.

The HPLC cleanup step inserted into the analytical method between the analyses of Cruises 2 and 3 samples removed biogenic olefins and produced accurate data on aromatic hydrocarbons for Cruises 3 and 4. However, F2 hydrocarbon data for Cruises 1 and 2 are prejudiced on the high side by the presence of nonaromatic biogenic olefins.

To more easily analyze aromatic hydrocarbons, if present, biogenic olefinic hydrocarbons were removed from summer and fall F2 hydrocarbons by passage through Styragel columns (Table 3.3-6). The low F2 content of summer and fall samples, relative to winter and spring samples, indicated that most of the zooplankton F2 was composed of biogenic olefins, although traces of aromatic hydrocarbons such as phenanthrene were detected in a few samples (Table 3.3-6).

The concentration of total zooplankton hydrocarbons, F1 hydrocarbons, and pristane during certain seasons correlated with the abundance of the copepods *Paracalanus* and *Clausocalanus* (Table 3.3-11). Species of *Paracalanus* were important major zooplankters in 202-μm net samples from most stations. *Sagitta*, decapods, and copepods accounted for >50% of the zooplankton in 505-μm net samples from all stations (often up to 80% at many stations). The abundance of the decapods and copepods *Centropages* and *Eucalanus* correlated with the concentration of zooplankton pristane.

E. SEDIMENT HYDROCARBONS

Hydrocarbon concentrations were very low in all sediment samples except those from stations 7D and 7E. The average for all stations for four seasons was 0.6 μg/g and the range was 0.04 to 2.2 μg/g, with most samples being in the 0.1- to 1.0-μg/g range. A summary of the sediment hydrocarbon data showing the standard deviations for replicate samples is presented in Table 3.3-12.

Table 3.3-11. Relative Abundance of Various Zooplankton Groups Correlated With Zooplankton Hydrocarbons

Season	Net Size (μm)	Significant Correlations	Probability [a]
Winter	202	*Paracalanus* versus total zooplankton hydrocarbon	0.04
	202	*Paracalanus* versus F1 zooplankton hydrocarbon	0.05
	202	*Paracalanus* versus zooplankton pristane	0.0004
	202	*Clausocalanus* versus total zooplankton hydrocarbon	0.03
	202	*Clausocalanus* versus zooplankton pristane	0.001
	202	*Clausocalanus* versus zooplankton C_{15}/C_{16}	0.03
Summer	202	*Paracalanus* versus total zooplankton hydrocarbon	0.04
	202	*Paracalanus* versus F1 zooplankton hydrocarbon	0.04
	202	*Paracalanus* versus zooplankton pristane	0.02
All seasons	505	*Sagitta* versus F1 zooplankton hydrocarbon	0.001
	505	Gammaridae versus total zooplankton hydrocarbon	0.002
	505	Polychaeta versus zooplankton C_{29}/C_{30}	0.002
	505	Hydromedusa versus zooplankton C_{15}/C_{16}	0.04
	505	Decapoda versus zooplankton pristane	0.05
	505	Copepoda versus zooplankton pristane	0.02
	505	*Centropages* versus zooplankton pristane	0.001
	505	*Eucalanus* versus zooplankton pristane	0.05

[a] Let R denote the sample correlation coefficient, and r denote the calculated value of the sample correlation coefficient. Then,

$$\Pr\{|R|>|r|\} = p$$

can be thought of as a measure of the degree of agreement between the data collected and the hypothesis of no correlation. This measure can take values between zero and one, with small values of p (generally less than 0.10, 0.15, or 0.01) indicating poor agreement and higher values indicating better agreement. More technically,

$$\Pr\{|R|>|r|\} = p$$

is the probability before collection of data, if obtaining a value of the statistic R without a sign greater than the observed value of r without a sign, given that the assumption of no correlation represents the true state of nature.

The concentrations of saturated hydrocarbons during each of the four seasons along the different transects are shown in Figure 3.3-7. The major saturated component was generally the C_{17} alkane. Other important F1 components were C_{18}, pristane, and phytane. The average ratio of odd-numbered alkanes to even-numbered alkanes was 2; the average ratio of pristane to phytane was 1.5, with many sediment samples having ratios of unity or less. There was little or no unresolvable complex mixture in most sediment samples.

Figures 3.3-8 through 3.3-14 are representative gas-liquid chromatograms of sediment hydrocarbons found at stations 2G, 5D, 5G, 7D, and 7E. Generally, F2 hydrocarbons were biogenic olefinic hydrocarbons such as squalene or the polyunsaturated 21:6 hydrocarbon.

Figure 3.3-15 indicates the concentrations of unsaturated/aromatic hydrocarbons (F2) during each of the four seasons along the different transects. Low levels of aromatic hydrocarbons could be detected in some sediment samples by gas-liquid chromatography coupled with mass spectrometry, but the presence of aromatic hydrocarbons could not be determined on

Table 3.3-12. Sediment Hydrocarbons

Season	Station	Concentration (μg/g) F1	F2	Pristane	Phytane	C_{17}
Winter	1B	0.36	0.21	0.012	0.016	0.013
	1C	0.42	0.12	0.006	0.012	0.014
	2F	0.22	0.06	0.002	0.002	0.013
	5A	1.50	0.94	0.003	0.003	0.007
	5B	0.31	0.10	0.006	0.004	0.009
	5C	0.16	0.09	0.008	0.003	0.014
	5D	0.29	0.60	0.007	0.005	0.016
	5E	0.15	0.08	0.004	0.003	0.010
	5F	0.31	0.14	0.006	0.004	0.012
	5G	0.48	0.12	–	–	0.008
	5H	0.35	1.58	0.003	0.002	0.005
	7D	0.44	0.27	0.009	0.003	0.016
	7E	0.90	0.86	0.101	—	0.007
	7F	0.42	0.20	0.008	0.002	0.013
Spring	1B[a]	0.55 ±0.22	0.23 ±0.08	0.005	0.038	0.017
	1C[a]	0.23 ±0.03	0.21 ±0.11	0.005	0.010	0.021
	2B	0.52	0.12	0.021	0.014	0.023
	2F	0.27	0.14	0.008	0.007	0.014
	5B	0.59	0.39	0.017	0.004	0.017
	5C	1.59	0.68	0.036	0.024	0.051
	5D	0.36	0.49	0.021	0.011	0.036
	5E	0.10	0.27	–	–	0.011
	5F	0.46	0.71	0.008	0.011	0.014
	5G	0.15	0.15	–	–	0.009
	5H	0.20	0.25	0.009	0.005	0.013
	5I	1.50	0.34	0.008	0.011	0.013
	7B	0.09	0.23	–	–	0.007
	7C	0.19	0.24	–	–	0.007
	7D	7.16	0.32	0.001	0.001	0.010
	7E	1.44	6.77	–	0.014	0.140
	7F	0.42	0.18	0.024	0.007	0.036
Summer	1B	0.27	0.21	0.002	0.016	0.016
	1C	0.11	0.07	0.002	0.004	0.010
	1D	0.64	0.18	0.006	0.007	0.026
	1E	0.22	0.07	0.008	–	0.026
	1F	0.15	0.10	0.001	0.003	0.002
	2B[a]	0.20 ±0.15	0.12 ±0.06	0.004	0.003	0.002
	2C	0.21	0.13	0.011	0.005	0.025
	2D	0.18	0.08	0.005	–	0.010
	2E	0.11	0.08	0.001	0.003	0.005
	2F	0.05	0.05	0.001	–	0.007
	2G	0.28	0.13	0.001	0.002	0.004
	5B[a]	0.44 ±0.11	0.14 ±0.07	0.004	0.002	0.010
	5C[a]	0.37 ±0.18	0.18 ±0.07	0.007	0.001	0.019
	5D[a]	0.16 ±0.06	0.12 ±0.06	0.006	0.003	0.011
	5E[a]	0.10 ±0.01	0.11 ±0.07	0.002	0.002	0.009
	5F[a]	0.12 ±0.05	0.13 ±0.04	0.002	0.003	0.006
	5G[a]	0.33 ±0.12	0.07 ±0.02	0.002	0.002	0.006
	5H[a]	0.52 ±0.34	0.37 ±0.13	0.002	0.002	0.003
	5I[a]	0.25 ±0.23	0.45 ±0.57	0.003	0.002	0.004
	7B[a]	0.39 ±0.32	0.19 ±0.05	0.002	0.003	0.015
	7C[a]	0.43 ±0.16	0.45 ±0.26	0.005	0.003	0.022
	7D[a]	0.43 ±0.33	0.19 ±0.07	0.002	0.001	0.011
	7E[a]	3.11 ±0.90	1.28 ±0.80	0.164 ±0.24	0.004	0.007

[a] Represents calculated values of six individual samples. All other samples are single analyses of a single pooled sample composed of six individually collected samples (Volume 2).

Table 3.3-12. Sediment Hydrocarbons (Continued)

Season	Station	F1	F2	Concentration (μg/g) Pristane	Phytane	C_{17}
Fall	1B	0.15	0.05	0.004	0.007	0.006
	1C	0.19	0.10	0.002	0.002	0.008
	2B	0.84	0.08	0.014	0.003	0.029
	2F	0.24	0.13	0.004	0.001	0.007
	5B	0.02	0.02	0.001	–	0.002
	5C	0.07	0.06	0.001	–	0.003
	5D	0.09	0.05	0.004	0.002	0.008
	5E	0.11	0.68	0.007	0.001	0.001
	5F	0.02	0.04	–	–	0.001
	5G	0.21	0.12	0.001	0.002	0.005
	5H	0.21	0.14	0.001	0.001	0.002
	7B	0.30	0.14	0.002	0.002	0.010
	7C	0.33	0.26	0.003	0.002	0.021
	7D	0.88	0.66	0.003	0.007	0.023
	7E	2.51	1.19	0.026	0.026	0.007
	7F	0.27	0.29	0.004	0.001	0.004
	7G	0.58	0.86	0.006	0.001	0.005

the basis of gas-liquid chromatography alone because of their low concentrations and the presence of biogenic olefinic hydrocarbons. The major aromatic hydrocarbons detected were biphenyl, phenanthrene, naphthalene, and pyrene (Table 3.3-6)—and there were trace amounts of perylene, chrysene, dimethylphenanthrene, methylphenanthrene, trimethylbiphenyl, methylfluorene, tetramethylnaphthalene, diphenylethane, trimethylnaphthalene, and methylbiphenyl in some samples. Silicones and plasticizers were also detected in some samples.

Two dozen sets of replicate sediment samples were analyzed, and the results are summarized in Table 3.3-13. Because of very low levels of individual components, the levels of total resolved components were determined, as well as the ratios of pristane/C_{16}, C_{15}/C_{16}, and C_{29}/C_{30}. The use of C_{16} instead of C_{17} is preferred for ratios because C_{17}, like C_{15}, is often a major biogenic n-paraffin and, hence, is not as good a petroleum indicator as C_{16}. The relative standard deviations were generally <50%, which is quite low for replicate sediment sampling. Even more significant, the standard deviation of the means of all the sets was also unexpectedly low. This would indicate that the sediments from the entire sample area except stations 7D and 7E were remarkably uniform in terms of hydrocarbon content. Correlations of hydrocarbons in sediments with sediment characteristics, TOC, and near-bottom particulate hydrocarbons are presented in Table 3.3-14.

F. HYDROCARBONS FOR EPIFAUNA AND RESIDENT DEMERSAL FISHES

Hydrocarbon data for the 14 species of benthic invertebrates and 38 species of fish collected during the four seasonal cruises are presented in Table 3.3-15 and 3.3-16; in cases in which replicate samples were analyzed from one station, standard deviations are given.

Three invertebrate species—*Loligo pealei* (squid), *Sicyonia brevirostris* (rock shrimp), and *Holothuria imperator-arenico* (sea cucumber)—were collected during all four seasons, and squid and rock shrimp were collected at several stations during each season. Three species of fish—*Synodus foetens* (inshore lizard fish), *Urophycis regius* (spotted hake), and *Diplectrum formosum* (sand perch)—were collected during all seasons at most stations.

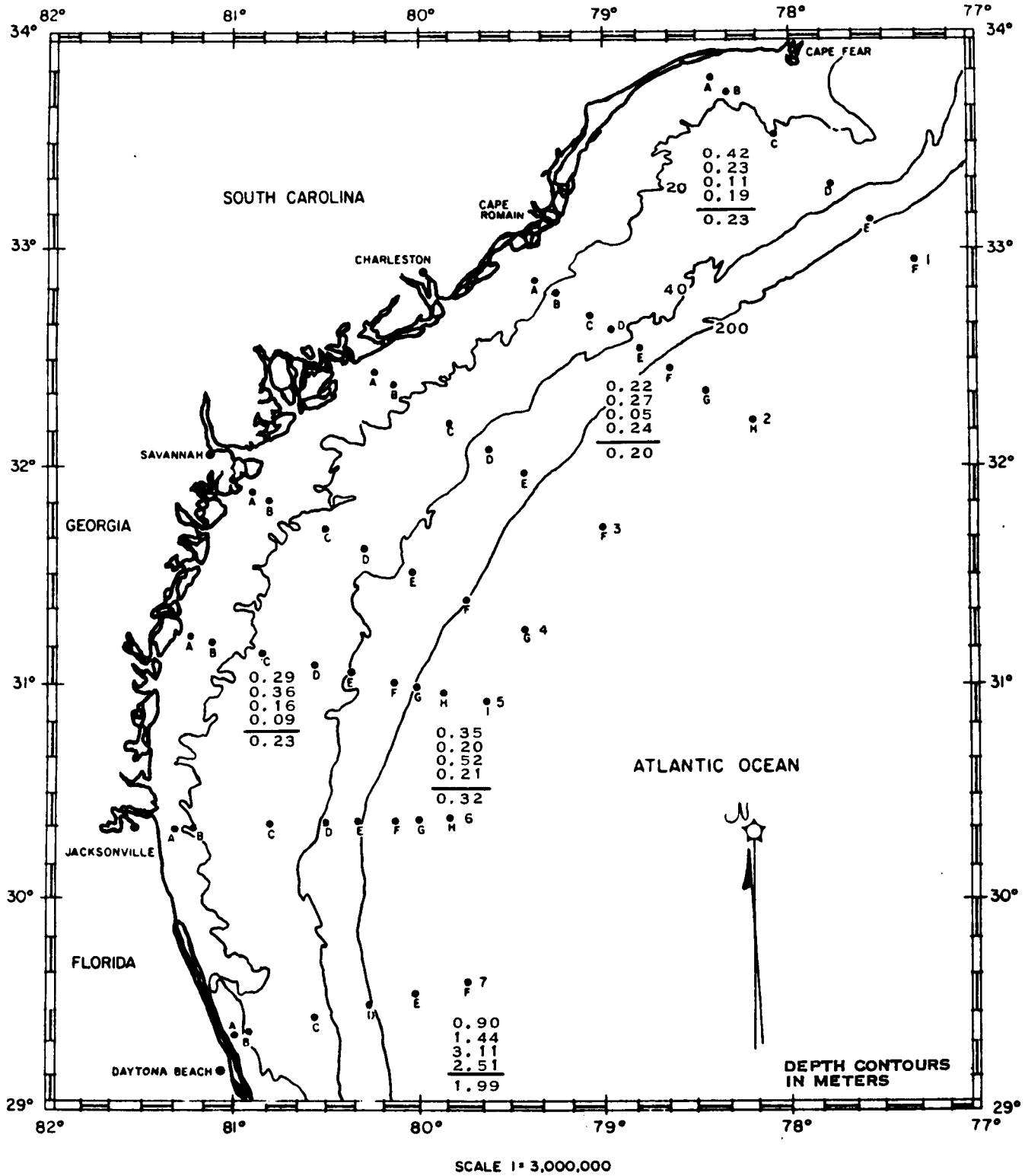


Figure 3.3-7. Saturated Hydrocarbons (μg/g) in Sediment Collected During Four Seasons at Stations 1C, 2F, 5D, 5H, and 7E (Order of Values: Winter, Spring, Summer, Fall, Average)

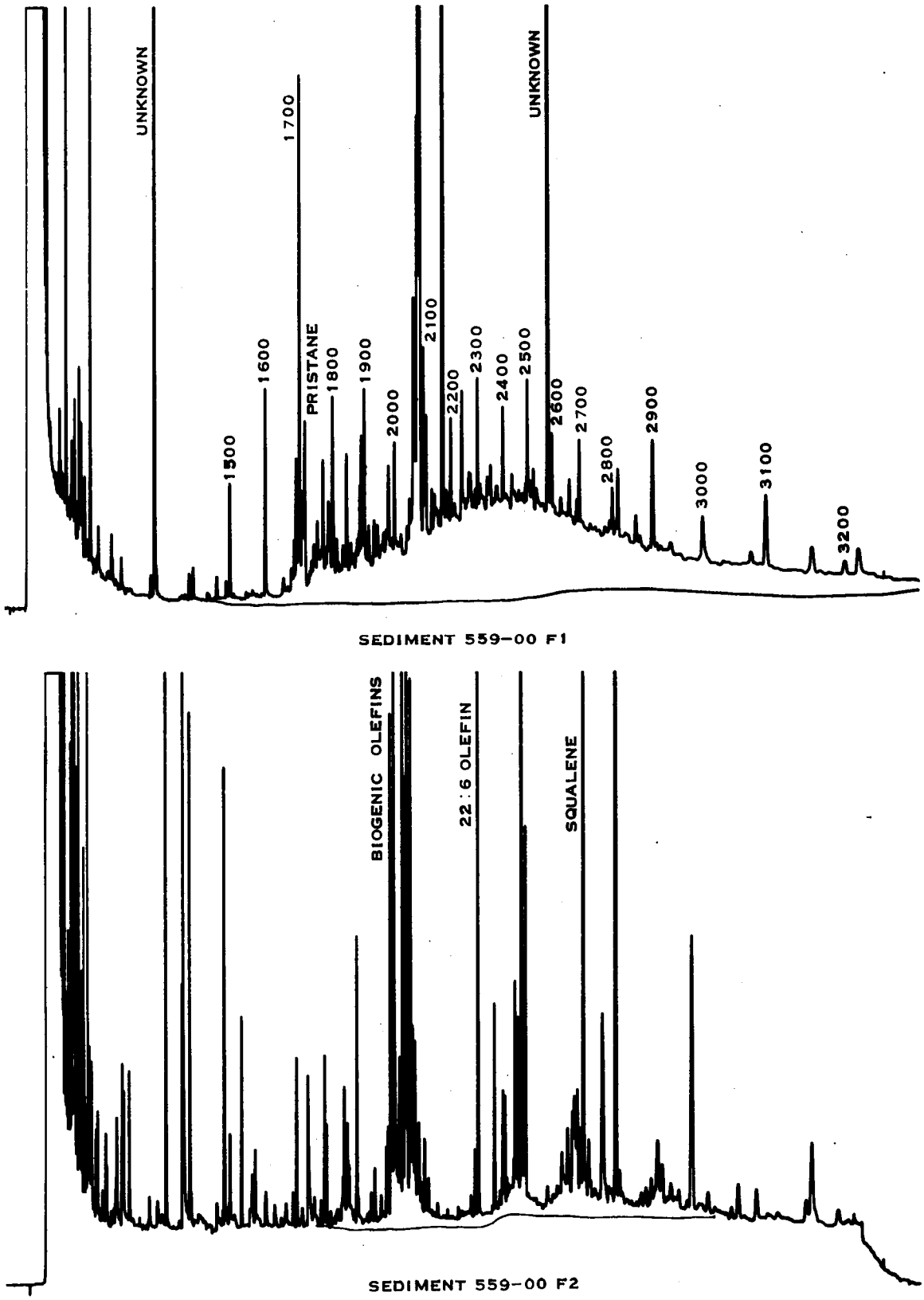


Figure 3.3-8. Gas Chromatograms of Sediment Sample 559, Fractions 1 (Top) and 2 (Bottom), Station 7D, Spring 1977

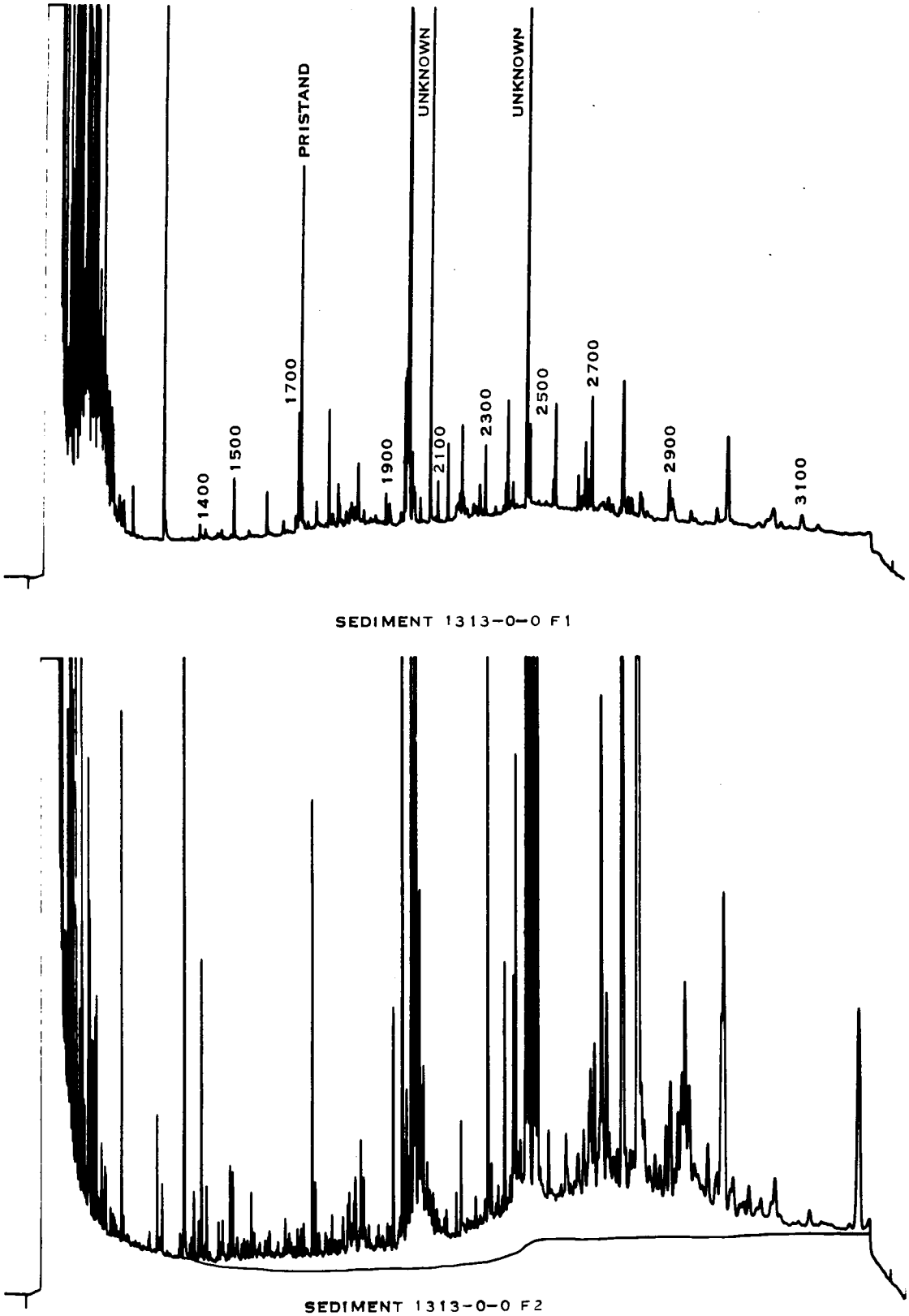
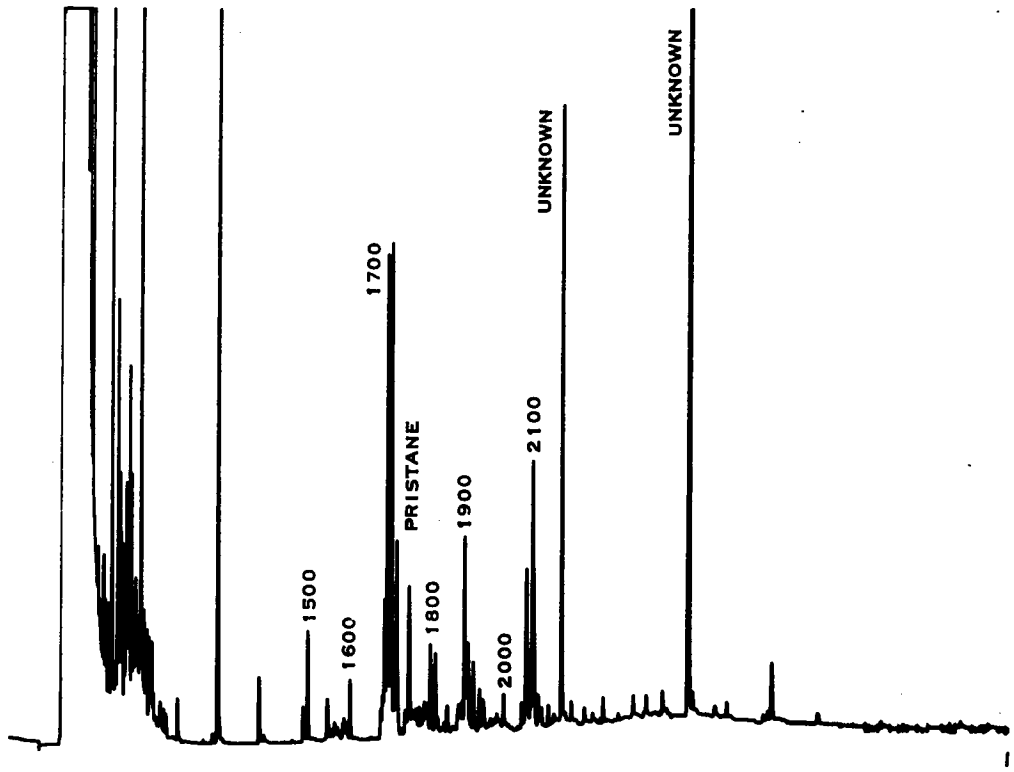
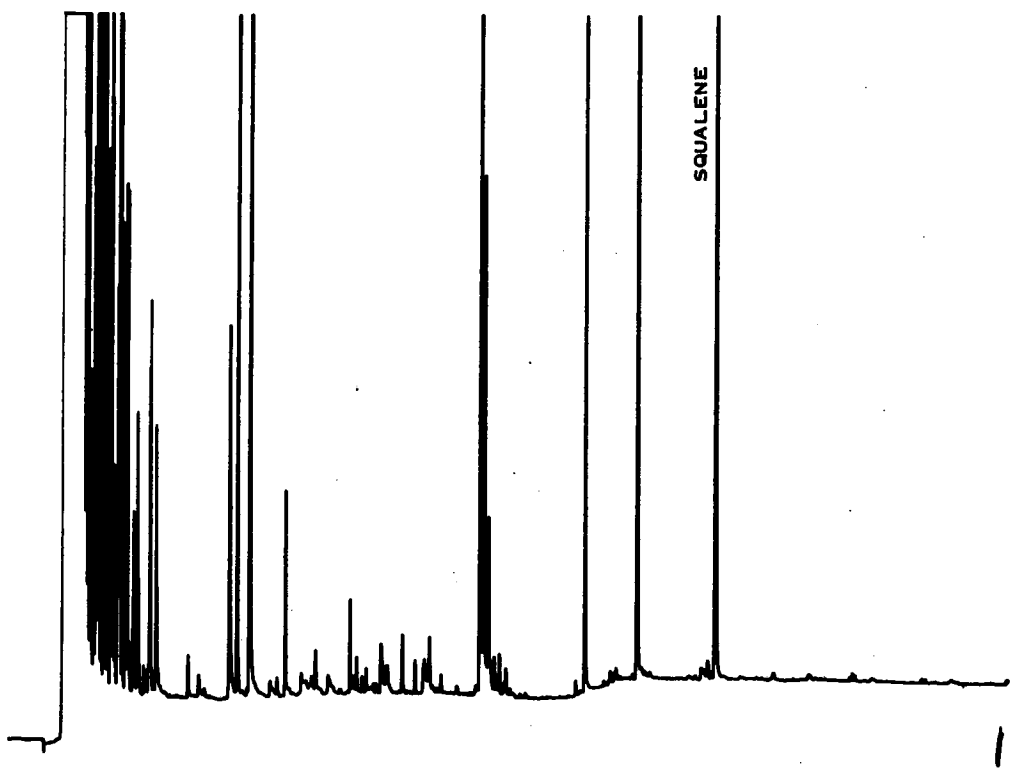


Figure 3.3-9. Gas Chromatograms of Sediment Sample 1313, Fractions 1 (Top) and 2 (Bottom), Station 7E, Summer 1977

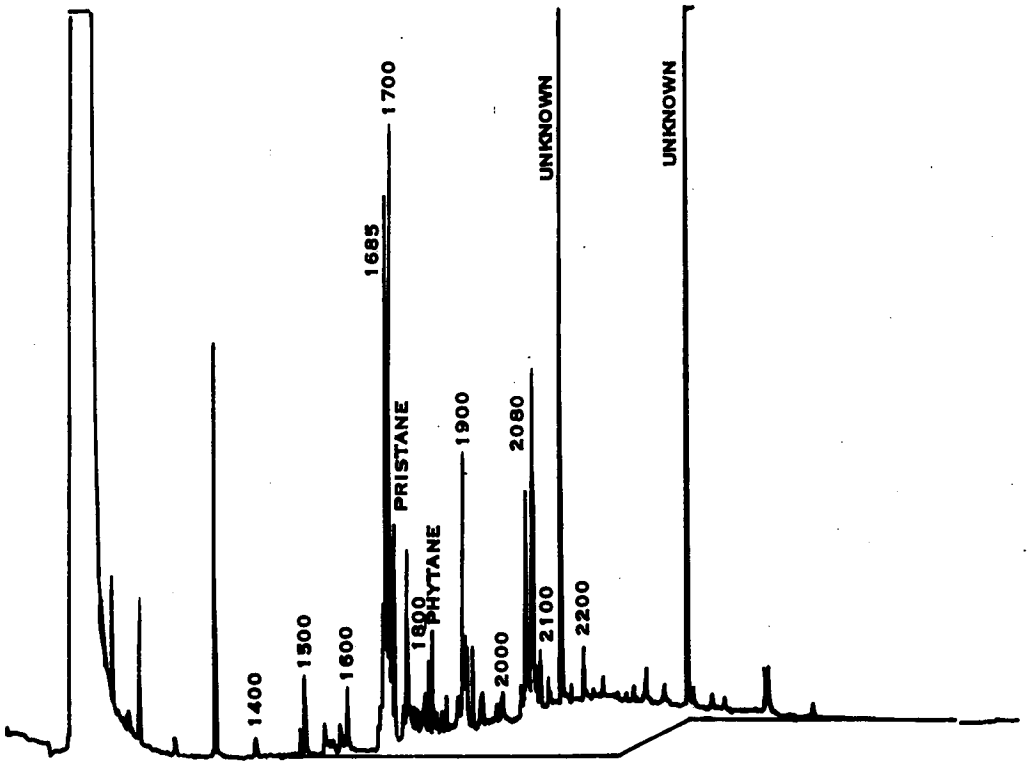


SEDIMENT 1270 F1

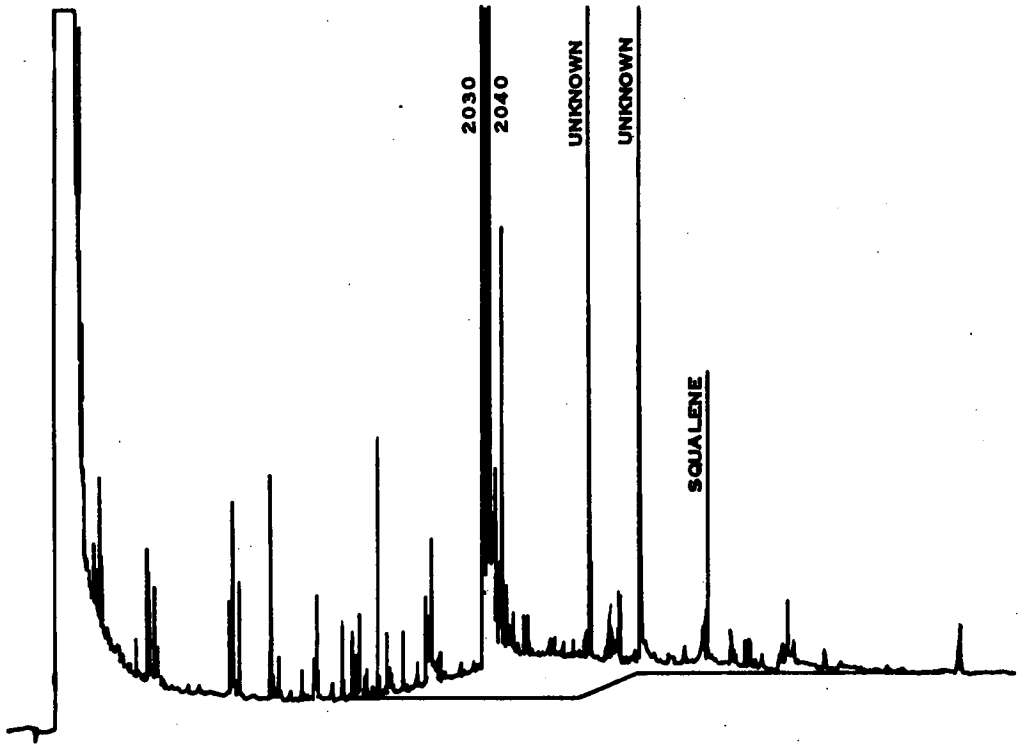


SEDIMENT 1270 F2

Figure 3.3-10. Gas Chromatograms of Sediment Sample 1270, Fractions 1 (Top) and 2 (Bottom), Station 5D, Summer 1977



SEDIMENT 831-0-3 F1



SEDIMENT 831-0-3 F2

Figure 3.3-11. Gas Chromatograms of Sediment Sample 831, Fractions 1 (Top) and 2 (Bottom), Station 5D, Summer 1977

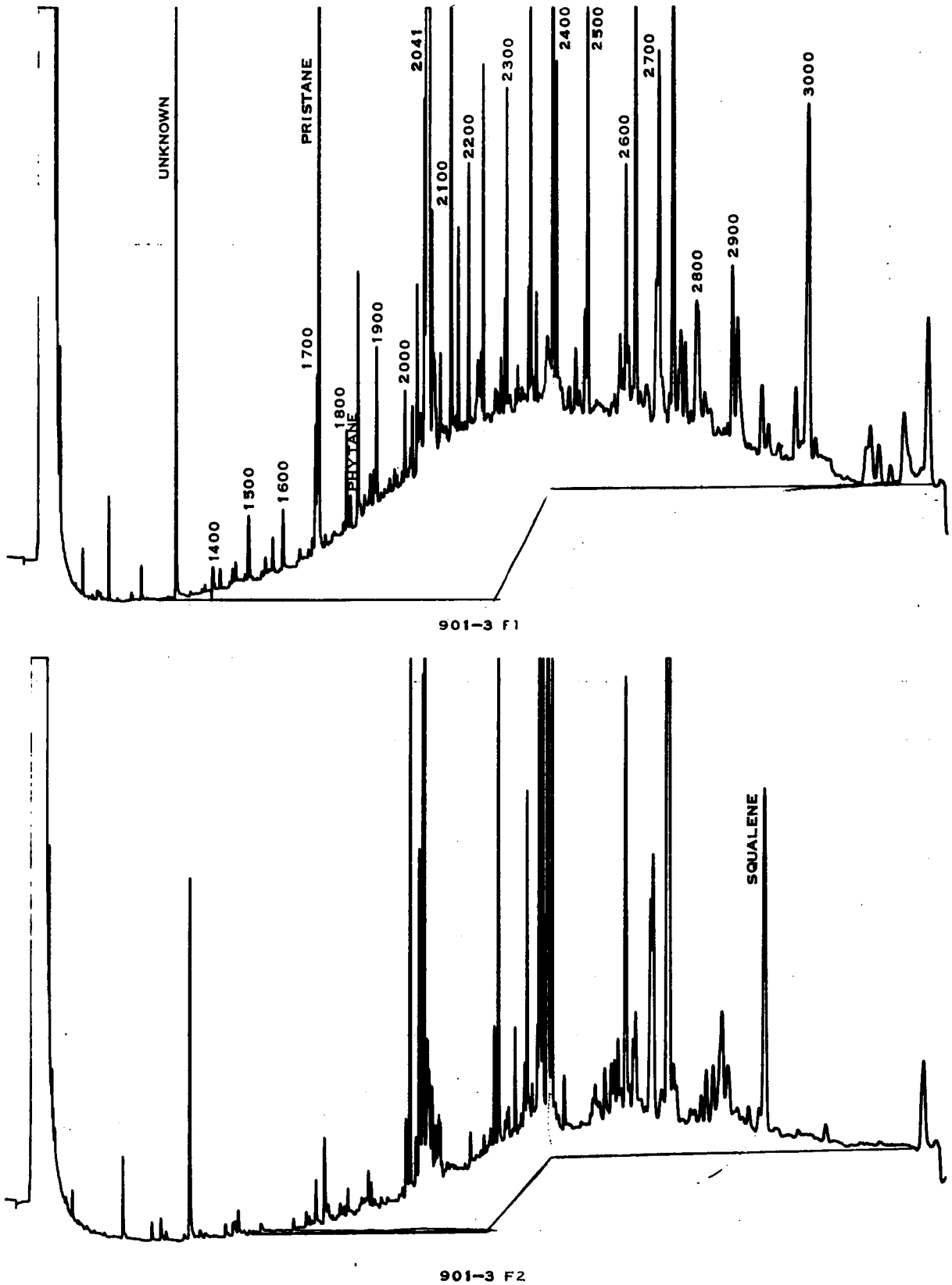
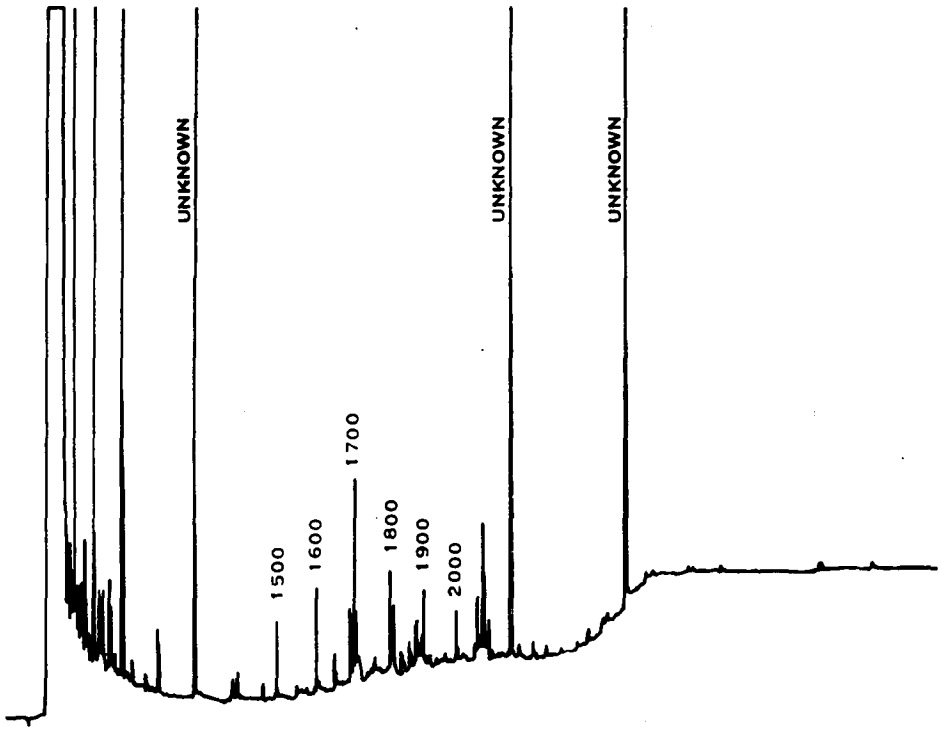
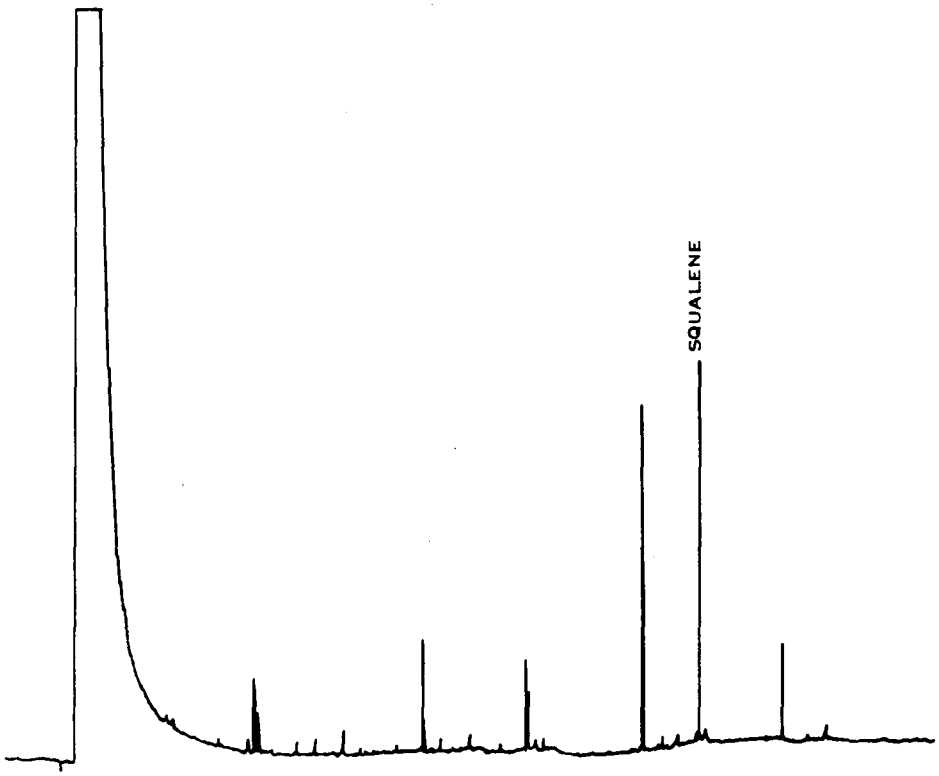


Figure 3.3-12. Gas Chromatograms of Sediment Sample 901, Fractions 1 (Top) and 2 (Bottom), Station 5D, Summer 1977

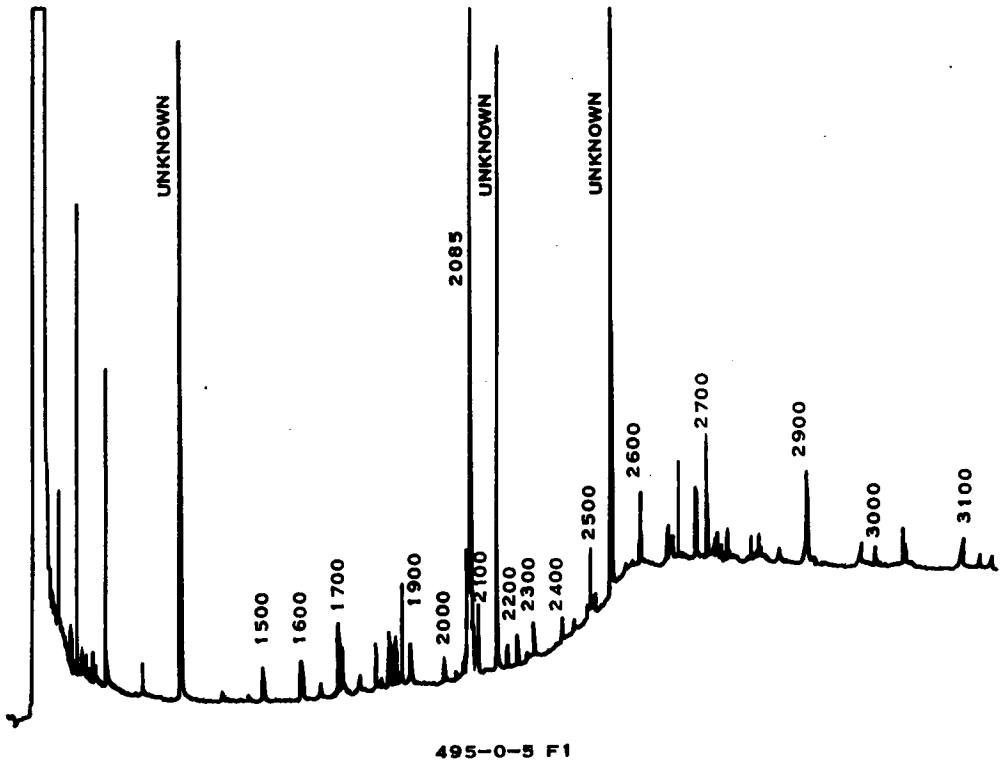


533 F1



533 F2

Figure 3.3-13. Gas Chromatograms of Sediment Sample 533, Fractions 1 (Top) and 2 (Bottom), Station 5G, Spring 1977



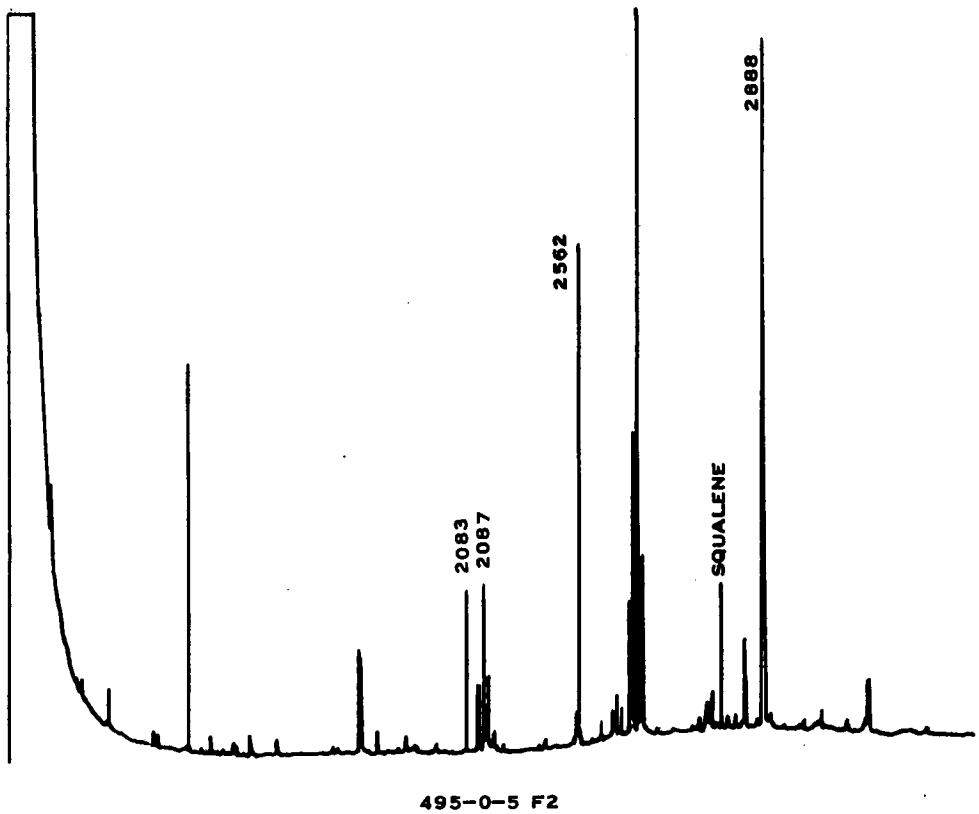


Figure 3.3-14. Gas Chromatograms of Sediment Sample 495, Fractions (1) Top and (2) Bottom, Station 2G, Spring 1977

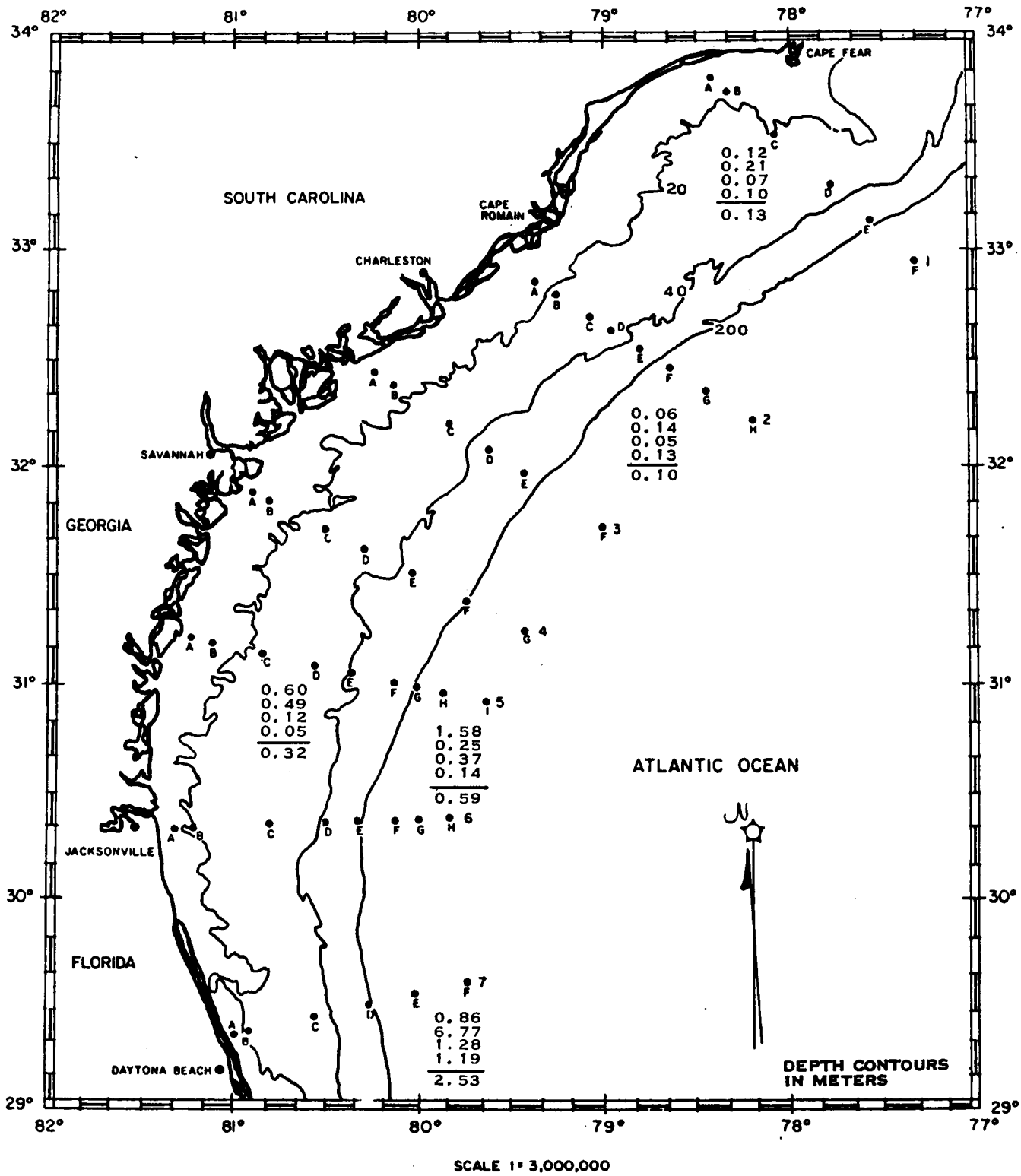


Figure 3.3-15. Unsaturated/Aromatic Hydrocarbons (μg/g) of Sediment Collected During Four Seasons at Stations 1C, 2F, 5D, 5H, and 7E (Order of Values: Winter, Spring, Summer, Fall, Average)

Table 3.3-13. Replicate Variability of Sediment Samples

Sample Set Number	n	F1 Resolved Components (μg/g)[b]		F2 Resolved Components (μg/g)[b]		PR/C_{16}		C_{15}/C_{16}		C_{29}/C_{30}	
451	6	0.57	(35)	0.23	(35)	1.6	(50)	Note c		2.0	(25)
455	6	0.23	(13)	0.21	(48)	Note c		1.2	(49)	Note c	
459	6	0.33	(38)	0.21	(50)	1.2	(37)	Note c		Note c	
464	6	0.17	(66)	0.11	(50)	1.6	(56)	0.9	(72)	1.7	(8)
468	6	0.57	(91)	0.26	(69)	1.1	(29)	0.6	(53)	Note c	
477	6	0.30	(49)	0.20	(39)	1.2	(39)	0.7	(44)	Note c	
481	6	0.24	(50)	0.21	(22)	1.3	(36)	1.0	(42)	Note c	
486	6	0.47	(35)	0.30	(58)	1.3	(28)	Note c		Note c	
491	6	0.39	(50)	0.14	(43)	1.5	(35)	Note c		Note c	
495	6	0.45	(34)	0.80	(45)	1.6	(33)	1.0	(28)	4.2	(5)
739	6	0.39	(127)[d]	0.12	(53)	2.3	(45)	2.4	(55)	2.4	(28)
822	6	0.18	(50)	0.11	(17)	2.8	(34)	1.1	(39)	1.6	(31)
826	6	0.23	(50)	0.14	(61)	2.4	(32)	1.3	(24)	1.7	(13)
831	6	0.15	(40)	0.11	(36)	2.9	(22)	1.3	(16)	1.7	(27)
836	6	0.10	(13)	0.25	(137)[e]	1.7	(42)	1.3	(31)	1.7	(27)
840	5[a]	0.12	(46)	0.13	(32)	1.1	(35)	1.7	(28)	1.7	(42)
844	6	0.13	(31)	0.07	(28)	1.5	(58)	0.9	(36)	1.8	(29)
849	6	0.23	(53)	0.17	(17)	2.0	(33)	1.5	(37)	1.4	(34)
853	6	0.46	(174)[d]	0.29	(107)	Note c		0.7	(32)	2.9	(33)
888	6	0.20	(39)	0.19	(28)	1.4	(60)	2.0	(27)	2.6	(28)
892	6	0.22	(61)	0.25	(43)	3.4	(21)	1.7	(11)	1.5	(29)
897	6	0.30	(62)	0.19	(38)	1.8	(55)	1.4	(22)	1.8	(36)
901	6	1.48	(38)	1.13	(17)	21.4	(32)	1.2	(46)	2.4	(34)
1318	6	0.15	(64)	0.25	(91)	1.5	(56)	0.8	(57)	1.5	(22)
Average		0.34	(54)[f] (84)[g]	0.25	(49)[f] (94)[g]	2.7	(39)[f] (159)[g]	1.2	(37)[f] (37)[g]	2.0	(27)[f] (34)[g]

[a]One sample lost during processing.

[b]Numbers in parentheses are relative standard deviations (%).

[c]Insufficient data.

[d]One sample in set was heavily contaminated with paraffin wax, probably from a tar ball.

[e]One sample in set was heavily contaminated with silicone oil.

[f]Mean of relative standard deviations (%).

[g]Relative standard deviation of means (%).

Table 3.3-14. Correlations of Sediment Hydrocarbons With Sediment Characteristics, Total Organic Carbon, and Near-Bottom Particulate Hydrocarbons

Significant Correlation	Probability[a]
Sediment total hydrocarbon versus mean quartile grain size	0.001
F1 sediment hydrocarbon versus mean quartile grain size	0.003
Sediment pristane versus mean quartile grain size	0.001
Sediment phytane versus mean quartile grain size	0.04
Median grain size versus total sediment hydrocarbon	0.003
F1 sediment hydrocarbon versus median grain size	0.01
Sediment pristane versus median grain size	0.0004
Sediment pristane versus ϕ quartile deviation	0.01
Sediment pristane versus skewness	0.01
Total sediment hydrocarbon versus pan fraction	0.0001
F1 sediment hydrocarbon versus pan fraction	0.0001
Sediment pristane versus pan fraction	0.0001
Total sediment hydrocarbon versus sediment total organic carbon	0.0001
F1 sediment hydrocarbon versus sediment total organic carbon	0.0001
Sediment pristane versus sediment total organic carbon	0.0001
Sediment pristane versus near-bottom total particulate hydrocarbon	0.003
Sediment pristane versus near-bottom F1 particulate hydrocarbon	0.05
Sediment pristane versus near-bottom particulate pristane	0.03

[a] Let R denote the sample correlation coefficient, and r denote the calculated value of the sample correlation coefficient. Then,

$$\Pr\ |R|>|r| = p$$

can be thought of as a measure of the degree of agreement between the data collected and the hypothesis of no correlation. This measure can take values between zero and one, with small values of p (generally less than 0.10, 0.15, or 0.01) indicating poor agreement and higher values indicating better agreement. More technically,

$$\Pr\ |R|>|r| = p$$

is the probability before collection of data, if obtaining a value of the statistic R without a sign greater than the observed value of r without a sign, given that the assumption of no correlation represents the true state of nature.

Highest hydrocarbon concentrations were noted in *Synodus poeyi* (offshore lizard fish), averaging 43 μg/g saturated and 32 μg/g fraction 2. The principal saturated hydrocarbons were pristane, n–C_{17}, and n–C_{15}, which averaged 4, 3, and 18 μg/g, respectively. The principal component of F2 hydrocarbons was squalene, which averaged 15 μg/g. Table 3.3-17 presents replicate variability data for fish of this species; the mean values for F1 (saturated) hydrocarbons in fish analyzed individually had standard deviations of ±40 to 50% of the mean. F2 (aromatic) hydrocarbons had standard deviations that were 60 to 120% of the mean. These data provide adequate demonstration that pooling of five individuals of this species and analyzing the pooled sample would yield data representative of hydrocarbon concentrations with individual variability eliminated. There were no significant differences in the hydrocarbon concentrations in the same species among the four seasons. Total sediment hydrocarbon correlation with the hydrocarbon content of *Synodus poeyi* appears in Table 3.3-18. The near-bottom particulate pristane correlated with total hydrocarbon concentration of *Diplectrum formosum*. A few lizard fish samples had fatty livers (Chapter 10 and Volume 6), but this abnormality could not be related to differences in hydrocarbon concentrations.

Table 3.3-15. Fish Hydrocarbons

Season	Scientific Name	Common Name	Station	Concentration (μg/g) F1	F2	Pristane	C_{17}	C_{15}
Winter	*Paralichthys dentatus*	Summer flounder	1C	7	10	1.0	0.3	0.4
	Urophycis regius	Spotted hake	2D	2	28	1.4	0.4	0.1
			4C	2	17	1.0	0.1	0.3
			4D	4	21	0.1	0.1	0.3
			4E	35	23	11.0	0.5	1.0
			5A	6	82	2.0	0.4	0.3
			5C	3	19	0.1	0.1	0.1
			5D	9	16	6.0	0.3	1.0
			7E	1	214	–	–	1.5
	Synodus foetens	Inshore lizard fish	1D	8	4	0.1	1.3	3.1
	Synodus poeyi	Offshore lizard fish	4F	40 ± 19	28 ±17	12.6 ±9.0	3.6 ±1.2	14.3 ±5.6
	Stenotomus chrysops	Scup	2E	4	31	–	4.0	0.2
	Trachurus lathami	Rough scad	2F	15	33	6.0	0.4	0.3
	Phycis chesteri	–	5I	4	11	0.1	0.4	0.3
	Haemulon aurolineatum	–	6C	20	25	0.3	0.4	–/2
	Diplectrum formosum	Sand perch	7C	1	4	0.4	0.3	0.1
Spring	*Trachinocephalus myops*	–	1F	3	4	0.3	0.4	2.6
			2F	4	5	0.2	0.4	1.9
	Diplectrum formosum	Sand perch	1D	2	8	0.2	–	0.2
			2E	1	4	0.3	0.02	0.1
			4D	18	60	4.8	0.3	1.1
			5C	1	5	0.03	0.01	0.02
			5G	1	6	0.1	0.01	0.04
			6E	1	7	0.04	0.01	0.03
	Decapterus punctatus	Round scad	2B	12	22	5.2	0.4	1.8
			5C	26	138	13.9	1.4	4.0
			6B	13	61	9.1	0.6	2.1
			7C	8 ±2	27 ±13	3.2	0.4	2.7
	Synodus poeyi	Offshore lizard fish	3E	76	13	2.5	1.3	10.0
			4F	65 ±22	65 ±60	1.0 ± 0.5	7.1 ±2.3	37 ±15
			5G	44 ±26	20 ±8	2.7 ±2.1	5.2 ± 3.3	20 ±9
	Synodus foetens	Inshore lizard fish	2B	4	6	0.1	0.8	2.3
			6B	3	6	0.2	2.2	5.9

Table 3.3-15. Fish Hydrocarbons (Continued)

Season	Scientific Name	Common Name	Station	Concentration (μg/g) F1	F2	Pristane	C_{17}	C_{18}
Spring (cont)	*Stenotomus chrysops*	Scup	2B	1	11	0.03	0.03	0.02
	Etrumeus teres	–	1D	189	142	18.7	16.5	139.0
	Pagrus sedecim	Porgy	7C	1	20	0.8	–	0.5
	Urophycis regius	Hake	4F	6	18	0.4	0.1	0.1
	Prionotus roseus	Bluespotted searobin	4F	0.2	12	0.2	–	–
	Pedrilus triacanthus	–	7E	7	55	1.6	0.2	2.0
	Bothus ocellatus	–	5G	2	13	0.4	0.05	–
Summer	*Synodus foetens*	Inshore lizard fish	1C	4	7	0.1	1.3	2.4
			2E	6	15	0.3	2.0	2.3
			3E	7	6	0.1	1.6	4.0
			5D	7	13	0.3	1.5	2.7
			6C	10	10	–	3.2	4.8
	Synodus intermedius	Sand diver	2E	12	10	0.1	1.8	7.8
			3E	13	12	0.3	3.1	6.9
			4F	29	8	0.5	4.6	16.5
			7C	0.2	10	0.1	–	–
	Prionotus scitulus	Leopard searobin	1C	3	11	0.3	0.1	0.1
			1D	2	6	0.7	0.07	0.03
			2F	40	11	0.1	0.1	0.03
			4F	49	20	0.2	–	0.02
	Monocanthus	–	1C	2	13	0.2	0.2	0.9
			1D	3	31	0.5	0.2	0.2
			2B	4	22	0.5	0.3	0.6
			2D	2	14	0.1	0.2	0.1
	Sparidae	Porgies	1C	89	7	0.1	0.1	0.1
			1D	5	24	0.1	0.04	0.1
			2B	3	36	0.1	0.1	0.1
			2D	2	14	0.1	0.2	0.1
	Ophidion holbrooki	–	1D	7	7	0.1	0.08	0.05
	Hemipteronotus navacula	–	2B	2	15	1.0	–	–
	Decapterus punctatus	Round scad	2B	7	65	3.3	0.9	1.2
			4C	14	51	1.4	0.6	1.8
			4D	31	36	10.9	2.5	8.8
			4D	1	3	0.1	–	–
			4E	4	6	0.1	0.1	0.1
	Haemulon aurolineatum		2D	2	55	0.2	0.2	0.2
	Haemulon siurus		7C	8	30	1.1	0.3	0.3

Table 3.3-15. Fish Hydrocarbons (Continued)

Season	Scientific Name	Common Name	Station	Concentration (μg/g) F1	F2	Pristane	C_{17}	C_{15}
Summer (cont)	*Diplectrum formosum*	Sand perch	2E	1	7	–	0.1	0.1
			3D	3	6	0.2	0.1	0.7
			4C	7	34	2.3	1.4	–
			5C	6	9	0.2	0.2	0.3
			5D	1	12	0.1	0.04	0.1
			6C	2	6	0.2	0.1	0.1
			6E	3	8	0.1	0.1	0.2
	Urophycis regius	Spotted hake	7E	5	19	–	–	–
	Urophycis tentuis	Hake	7F	2	25	0.1	–	–
	Centropristis ocyurus	–	2E	4	7	0.3	0.1	0.2
			4F	9	6	0.3	0.1	0.1
	Clupeidae	Herring	3B	36	19	1.6	9.8	14.6
			5D	139	100	52.1	5.9	64.3
	Mullus auratus	–	3E	7	24	0.5	0.6	1.7
	Syacium	–	4F	11	16	0.2	0.4	0.9
	Anchoa hepsetus	–	5A	118	41	33.9	4.0	31.6
	Larimus fasciatus	–	5A	2	8	0.6	0.1	–
	Menticirrhus americanus	–	5A	1	18	0.03	0.1	–
	Bothus ocellatus	–	5G	2	9	0.3	0.1	0.1
			6E	5	12	0.3	0.04	–
	Leiostomus xanthurus	–	6B	4	2	0.02	0.2	0.03
	Paralichthys algigutta	Flounder	7E	2	5	0.2	–	–
Fall	*Synodus poeyi*	Offshore lizard fish	2E	6	2	0.3	1.2	4.2
			4D	23	11	2.4	5.0	10.2
			4F	48	12	6.3	0.6	28.5
	Synodus intermedius	Sand diver	4F	6	7	0.1	1.4	3.3
			6B	8	5	3.2	0.2	3.2
	Urophycis regius	Hake	4F	6	10	0.1	0.1	0.1
			7E	5	10	4.0	0.1	0.1
	Diplectrum formosum	Sand perch	2D	1	4	0.4	0.1	0.6
			2E	1	3	0.3	0.1	0.3
			3E	0.3	4	0.1	0.02	0.1
			4C	2	75	0.6	0.2	0.4
			4D	2	5	0.7	0.5	0.1
			7C	2	5	0.3	0.1	0.2

Table 3.3-15. Fish Hydrocarbons (Continued)

Season	Scientific Name	Common Name	Station	Concentration (μg/g) F1	F2	Pristane	C_{17}	C_{18}
Fall (cont)	*Stenotomus chrysops*	Scup	2B	2	29	0.2	0.1	0.1
	Decapterus punctatus	Round scad	2D	12	44	6.1	0.7	3.3
			4C	5	11	3.0	0.3	0.5
			7C	26	17	19.0	1.4	2.8
	Haemulon eurolineatum	–	1D	1	10	0.2	0.1	0.1
	Prionotus carolinus	–	1D	10	6	0.5	0.1	0.1
	Lagodon rhomboides	–	2B	2	62	0.3	0.2	0.2
	Centropristis philadelphica	–	2D	2	2	0.3	0.1	0.1
	Leiostomus xanthurus	–	6B	43	49	0.2	0.1	0.1
	Trachurus lathami	–	5C	20	37	14.0	0.7	3.4
	Trachinocephalus myops	–	5G	9	4	0.1	1.5	5.9
	Pomatomus saltatrix	–	6B	31	21	10.0	–	10.8
	Syacium papillosum	–	4F	1	5	0.2	0.1	0.1

Table 3.3-16. Benthic Invertebrate Hydrocarbons

Season	Scientific Name	Common Name	Station	Concentration (μg/g) F1	F2	Pristane	C_{17}	C_{18}
Winter	*Loligo pealei*	Squid	1C	15	3	12.0	0.2	0.1
			2D	12	1	6.7	0.2	–
			2E	8	1	5.3	0.2	0.1
			2F	10	5	5.0	0.4	0.1
			3D	21	9	18.0	0.4	1.0
			4D	9	3	6.4	0.2	0.4
			4F	3 ±3	1 ±1	1.2	0.3	0.1
			7C	3 ±1	2 ±1	2.5	0.2	0.1
	Octopus vulgaris	–	7F	4	2	0.3	–	–
	Sicyonia brevirostris	Shrimp	2D	4	31	0.4	0.4	–
	Hepatopancreas		3D	55	513	1.0	1.9	0.1
			3E	6	27	1.0	–	–
			6C	17	4	0.1	0.1	0.2
	Caridea	Hepatopancreas	2F	34	36	1.0	1.0	0.1
	Brachyura	–	1C	36	49	0.6	1.0	0.6
	Holothuria imperator-arenico	Sea cucumber	4C	7	8	0.1	0.1	0.3
			5D	19	38	0.1	0.1	–
	Bivalvia	–	4E	24	65	1.0	1.5	6.0
	Polychaeta	–	5A	5	12	0.1	0.1	0.1
Spring (cont)	*Loligo pealei*	Squid	2B	8 ±6	3 ±2	3.2 ±1.5	0.4 ±0.2	1.1 ±0.4
			6B	2	4	0.7	0.3	0.1
			7C	4 ±3	3 ±2	1.0 ±0.2	0.2 ±0.1	0.4 ±0.2
	Sicyonia brevirostris	Rock shrimp	2B	4	6	0.1	0.1	–
			2E	3	20	0.1	0.1	0.04
			6E	17	12	0.3	0.3	0.7
	Penaeus setifer	Shrimp	4F	2	3	0.3	0.03	–
	Portunus spinicarpus	Crab	4F	1	3	0.1	0.01	0.02
	Ovalipes stephensoni	Lady crab	2B	15 ±8	18 ±12	2.5 ±0.7	0.4	–
			6E	5	13	0.4	0.1	0.1
	Argopecten gibbus	Scallop	6E	8	10	0.1	0.1	0.1
	Pecten	–	6E	1	12	0.1	0.04	0.03
	Holothuria imperator-arenico	Sea cucumber	4C	24	69	0.1	0.3	0.1
			5C	25	6	0.001	0.003	0.01
Summer	*Loligo pealei*	Squid	2E	12	11	3.4	0.8	2.0
			3D	8	3	2.5	0.7	1.8
			4D	17	3	3.2	0.7	1.5

Table 3.3-16. Benthic Invertebrate Hydrocarbons (Continued)

Season	Scientific Name	Common Name	Station	F1	F2	Pristane	C_{17}	C_{15}
				Concentration (μg/g)				
Summer (cont)	*Loligo pealei (cont)*	Squid (cont)	4E	26	8	9.2	1.7	3.6
			5C	18	11	7.2	2.1	3.9
			5D	13	4	5.8	1.3	3.9
			5G	7	4	1.8	0.4	3.2
			6C	12	7	4.3	1.4	4.0
			7C	38	2	13.2	2.9	5.8
	Octopus vulgaris	–	7C	15	1	10.5	0.5	0.8
	Sicyonia brevirostris	Rock shrimp	1C	5	3	0.1	0.1	0.1
			3D	26	13	0.2	0.1	0.1
			4D	45	10	0.2	0.4	0.1
			4F	95	193	0.1	0.2	0.02
			5G	65	4	0.3	0.3	0.2
	Penaeus setiferus	Shrimp	5A	8	11	0.3	0.2	–
	Portunus gibbessi	Crab	1C	25	47	0.7	0.2	0.2
	Scyllarus chacei	–	2D	1	3	0.1	0.1	0.2
	Loliguncula brevis	–	5A	6	6	2.4	0.6	0.5
	Holothuria imperator-arenico	Sea cucumber	4C	33	77	0.3	0.7	0.2
			5C	95	198	0.4	0.7	0.4
			5D	54	91	2.2	2.1	0.6
			6C	2	4	–	0.2	0.2
Fall	*Loligo pealei*	Squid	4C	41	8	4.6	0.6	1.4
			4D	2	5	1.2	0.1	0.2
			4E	7	7	2.6	0.3	0.9
			5C	6	3	2.8	0.5	0.8
			5D	5	4	2.3	0.4	0.7
			5G	4	21	1.9	0.3	0.6
			7C	302	2	46.8	0.2	1.9
	Sicyonia brevirostris	Rock shrimp	4D	8	4	0.1	0.04	0.02
			4F	53	7	0.7	0.1	0.1
			5G	18	5	0.2	0.1	0.03
			6E	11	5	0.1	0.01	0.02
	Holothuria imperator-arenico	Sea cucumber	5C	3	5	0.1	0.1	0.03

Table 3.3-17. Replicate Variability of Macrofauna Samples

Amount of Component in Sample (μg/g)

Fraction	Retention Index	Individuals of Species A[a] 1	2	3	4	5	Average[c]	Individuals of Species B[b] 1	2	3	4	5	6	Average[c]
1	1500	27.5	15.0	9.5	8.6	25.8	17.3 ±8.9	1.7	1.7	1.1	0.9	0.3	0.7	1.1 ±0.6
	1600	1.3	0.8	1.1	0.4	1.1	1.0 ±0.4	<0.1	<0.1	<0.1	<0.1	0.2	<0.1	<0.1
	1688	2.8	1.0	1.0	0.7	2.4	1.6 ±0.9	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	1700	6.7	3.4	3.1	1.8	5.9	4.2 ±2.0	0.5	0.6	0.5	0.3	0.5	0.4	0.5 ±0.1
	1706[d]	22.8	14.1	10.9	3.1	27.2	15.6 ±9.6	9.2	9.5	6.2	5.0	6.1	5.2	6.9 ±2.0
	1800	1.2	0.8	1.4	0.5	1.0	1.0 ±0.4	0.3	0.2	0.2	0.1	0.5	0.2	0.3 ±0.1
	1872	2.6	1.2	0.7	1.6	2.6	1.7 ±0.8	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	1890	1.9	0.8	0.6	0.9	1.8	1.2 ±0.6	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	1900	4.8	2.9	2.2	0.5	4.9	3.1 ±1.7	0.1	<0.1	<0.1	0.1	0.2	0.3	0.1 ±0.1
	2000	0.9	0.5	0.4	0.2	0.7	0.5 ±0.3	<0.1	<0.1	<0.1	<0.1	0.1	0.2	<0.1
	2100	0.7	0.4	0.2	0.1	0.4	0.4 ±0.2	<0.1	<0.1	<0.1	<0.1	0.1	0.2	<0.1
2	1874	1.5	0.4	0.4	0.3	1.4	0.8 ±0.6	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	1890	2.4	1.3	0.7	0.3	4.5	1.8 ±1.7	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	2056	1.2	1.1	0.6	0.2	2.2	1.1 ±0.8	0.9	0.9	<0.1	0.4	<0.1	<0.1	0.4 ±0.4
	2075	4.4	1.1	0.3	0.2	1.2	1.4 ±1.7	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	2156	0.9	0.8	0.1	0.1	0.7	0.5 ±0.4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	2162	1.3	0.9	0.2	0.1	0.9	0.7 ±0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	2339	12.3	3.2	2.0	3.4	6.1	5.4 ±4.1	1.2	0.8	<0.1	0.4	<0.1	<0.1	0.4 ±0.5
	2360	13.3	2.9	2.1	2.4	6.1	5.4 ±4.7	0.6	0.6	<0.1	0.2	<0.1	<0.1	0.3 ±0.3
	2808[e]	33.9	7.2	5.1	4.7	26.3	15.4 ±13.7	4.9	5.8	3.4	4.3	2.1	1.5	2.9 ±1.9
	2879	1.0	4.5	3.6	1.1	2.2	2.5 ±1.5	0.3	0.9	<0.1	<0.1	<0.1	<0.1	0.1 ±0.2

[a]Offshore lizard fish, sample 203, replicates 1–5

[b]Squid, sample 286, replicates 1–6

[c]Reported as mean value ±1 standard deviation ($\bar{x} \pm 1\sigma$)

[d]Pristane

[e]Squalene

Table 3.3-18. Macrofauna Hydrocarbons Correlated With Sediment Hydrocarbons and Near-Bottom Particulate Hydrocarbons

Species	Particulate Hydrocarbons	Probability[a]
Loligo pealei	Total sediment hydrocarbon versus squid F1 hydrocarbon	0.02
	F1 sediment hydrocarbon versus squid total hydrocarbon	0.003
	F1 sediment hydrocarbon versus squid F1 hydrocarbon	0.0006
	F1 sediment hydrocarbon versus squid total hydrocarbon	0.0007
	Sediment pristane versus squid F1 hydrocarbon	0.0001
	Sediment pristane versus squid total hydrocarbon	0.0001
Diplectrum formosum	Near-bottom particulate pristane versus sand perch F1 hydrocarbon	0.0001
	Near-bottom particulate pristane versus sand perch total hydrocarbon	0.0001
Synodus poeyi	Total sediment hydrocarbon versus lizard fish F1 hydrocarbon	0.004
	Total sediment hydrocarbon versus lizard fish total hydrocarbon	0.007

a Let R denote the sample correlation coefficient, and r denote the calculated value of the sample correlation coefficient. Then,

$$\Pr\ |R|>|r| = p$$

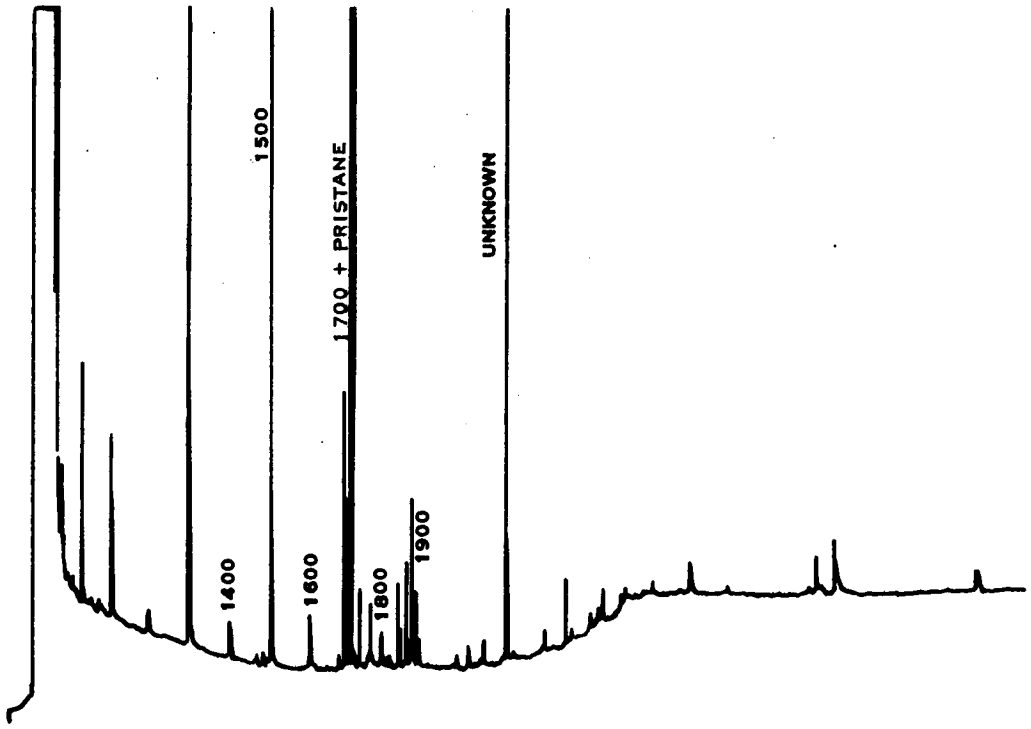
can be thought of as a measure of the degree of agreement between the data collected and the hypothesis of no correlation. This measure can take values between zero and one, with small values of p (generally less than 0.10, 0.15, or 0.01) indicating poor agreement and higher values indicating better agreement. More technically,

$$\Pr\ |R|>|r| = p$$

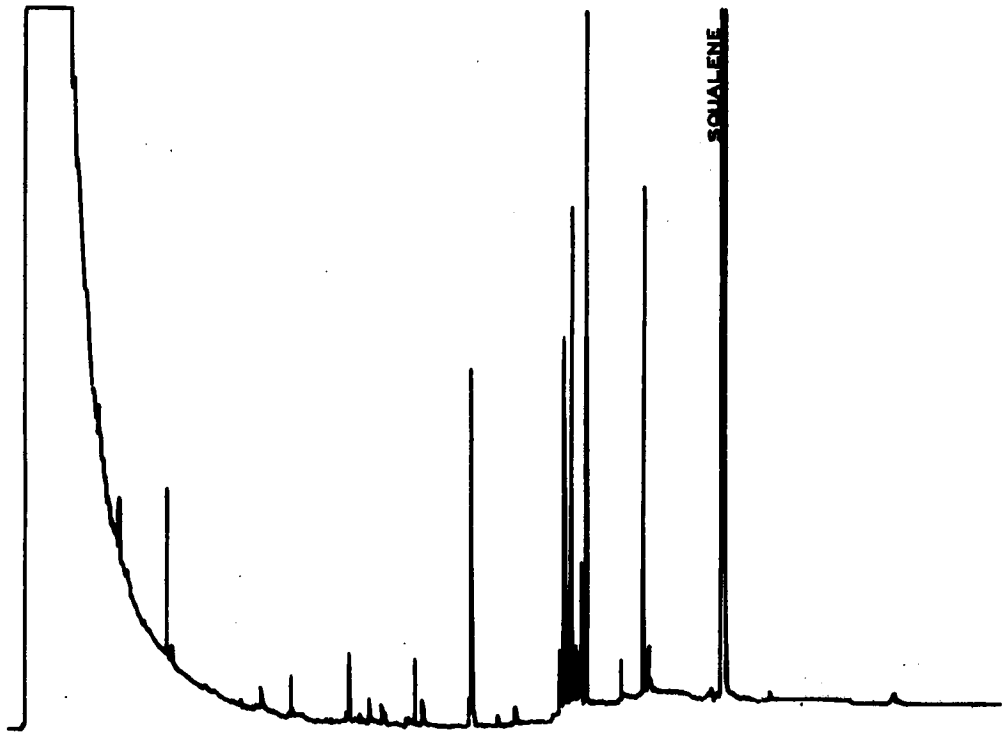
is the probability before collection of data, if obtaining a value of the statistic R without a sign greater than the observed value of r without a sign, given that the assumption of no correlation represents the true state of nature.

Synodus foetens, the inshore lizard fish, had much lower hydrocarbon concentration than did *Synodus poeyi*: the saturated hydrocarbon concentration averaged 6 μg/g and the F2 hydrocarbons averaged 8 μg/g. The sand perch *Diplectrum formosum,* was widely collected and had a low hydrocarbon concentration, averaging 3 μg/g saturated hydrocarbon concentration. Figures 3.3-16 and 3.3-18 are gas-liquid chromatograms of hydrocarbons from *Decapterus punctatus, Sicyonia brevirostris* and *Loligo pealei.*

An occasional high or low value was observed for hydrocarbon concentrations in samples from one station, e.g., for sand perch at certain stations along transect 4 (Table 3.3-15). Further study with more samples over a longer time would show if animals from certain stations had consistently high or low hydrocarbon concentrations.

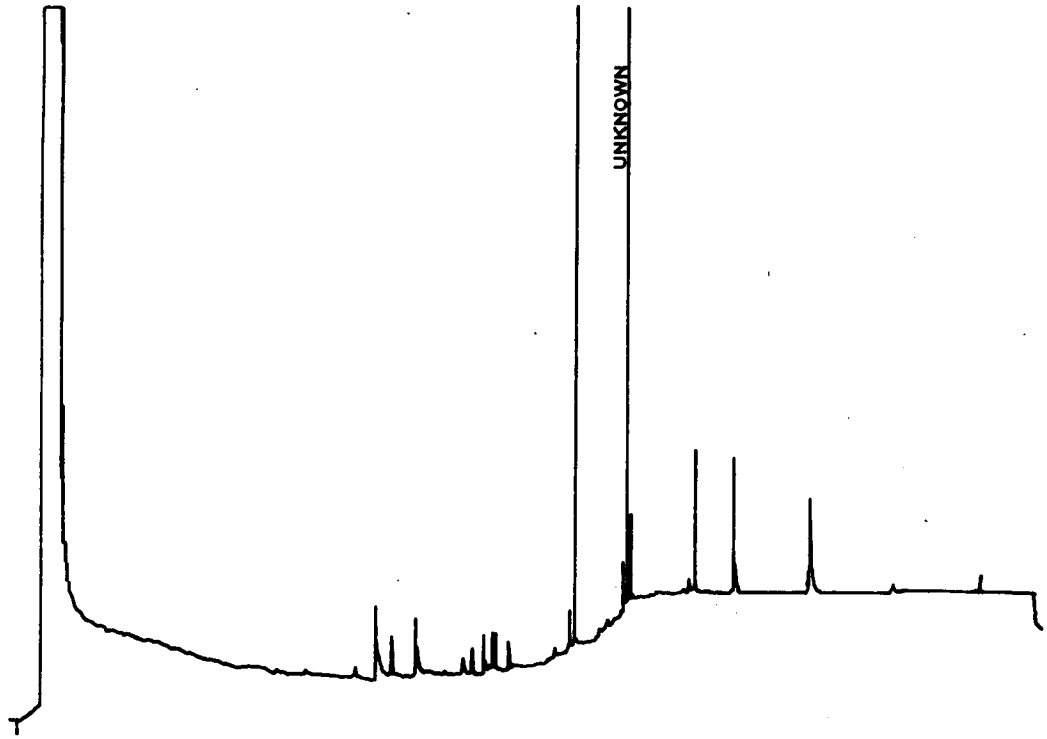


MACROFAUNA 518-3-0 F1

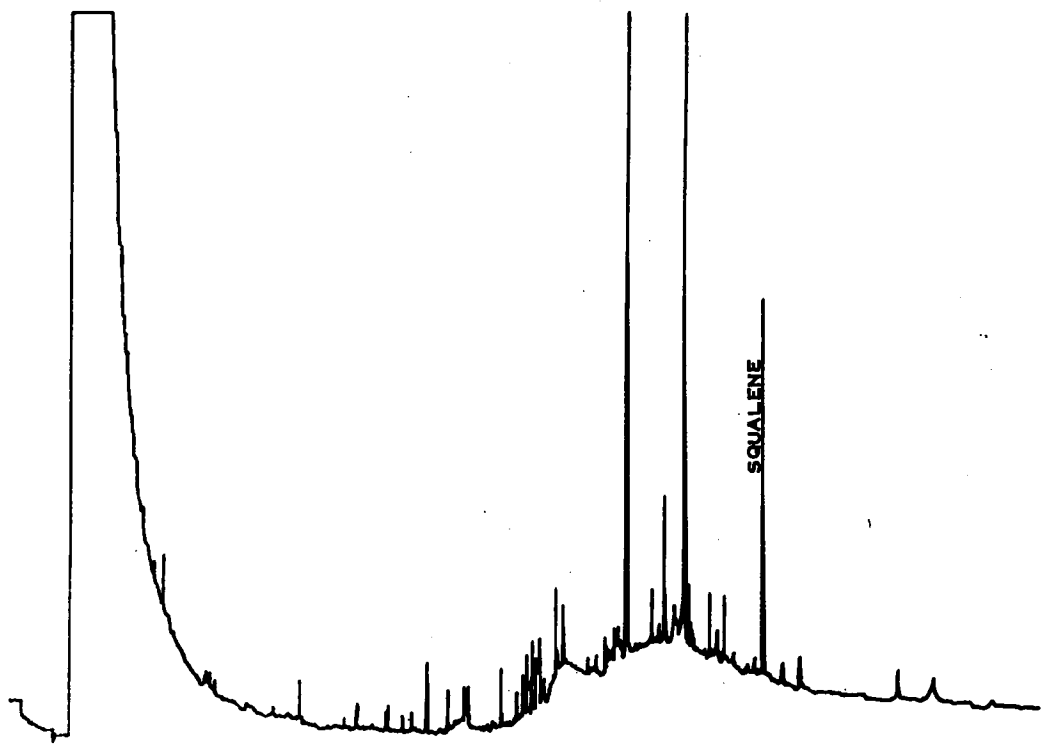


MACROFAUNA 518-3-0 F2

Figure 3.3-16. Gas Chromatograms of *Decapterus punctatus* Sample 518-3, Fractions 1 (Top) and 2 (Bottom), Station 5C, Spring 1977

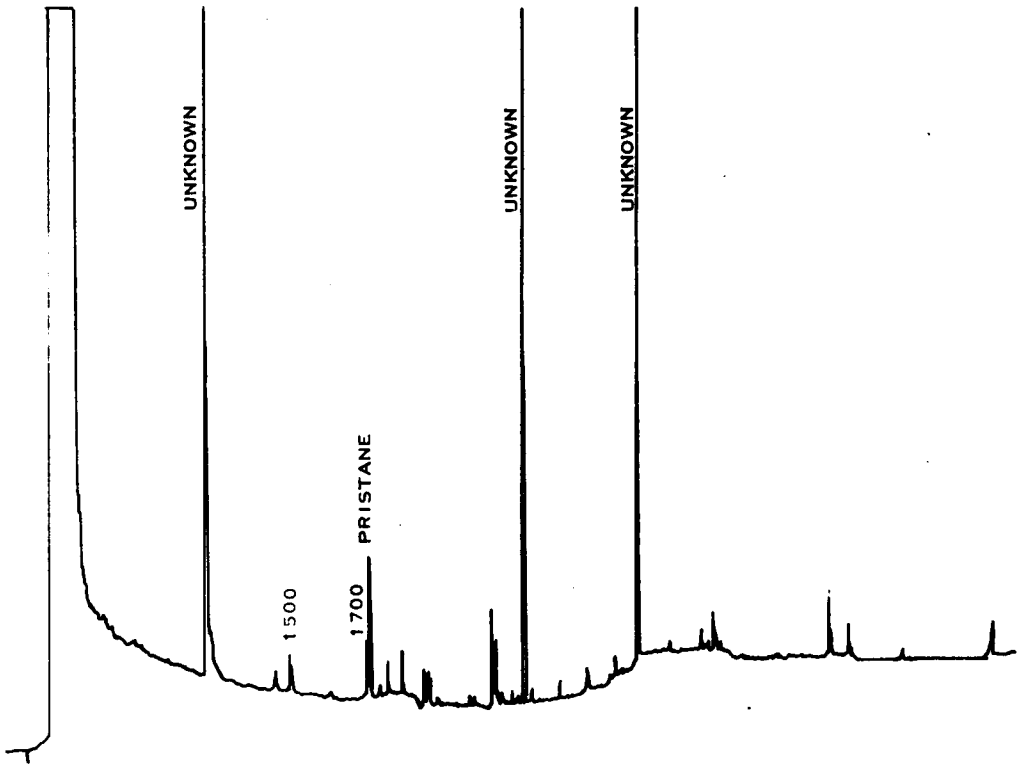


MACROFAUNA 548-4-0 F1

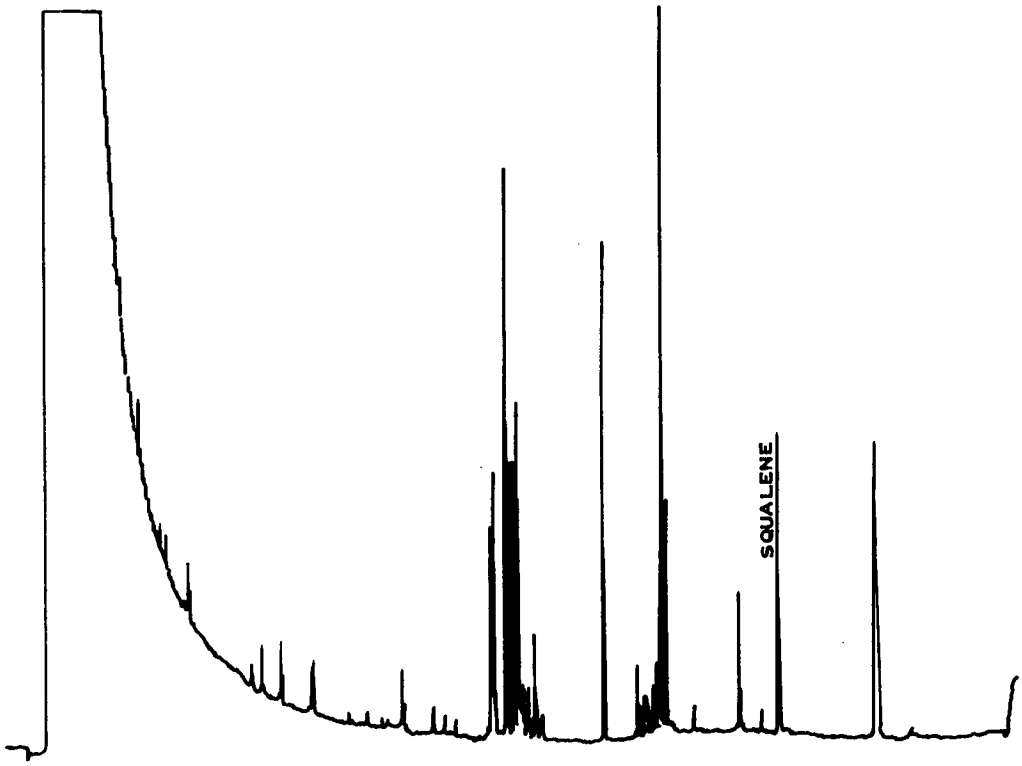


MACROFAUNA 548-4-0 F2

Figure 3.3-17. Gas Chromatograms of *Sicyonia brevirostris* Sample 548-4, Fractions 1 (Top) and 2 (Bottom), Station 6E, Spring 1977



MACROFAUNA 548-1-0 F1



MACROFAUNA 548-1-0 F2

Figure 3.3-18. Gas Chromatograms of *Loligo pealei* Sample 548-1, Fractions 1 (Top) and 2 (Bottom), Station 6H, Spring 1977

For most of the benthic invertebrates, the range of saturated hydrocarbon concentrations was from 5 to 30 μg/g; most fish fell in the range of 2 to 40 μg/g. The sea cucumber *Holothuria imperator-arenico* was the invertebrate with the highest hydrocarbon concentrations (total averaging 84 μg/g) with a range of 6 to 293 μg/g—probably because this deposit feeder derives some hydrocarbons from the sediment.

Among the invertebrates, squid were consistently collected during all seasons and at most stations: total hydrocarbon content averaged 17 μg/g, except for samples from station 7C. Pristane, n–C_{17}, and n–C_{15} accounted for most of the saturated hydrocarbon fraction in squid. Squid from station 7C in the fall had an F1 hydrocarbon concentration of 302 μg/g. Replicate variability of individuals of this invertebrate appears in Table 3.3-17. The major hydrocarbon components of fraction 2 were squalene and several polyunsaturated olefins (Table 3.3-17). Total sediment hydrocarbon, F1 hydrocarbon, and sediment pristane correlated with squid hydrocarbon concentrations (Table 3.3-18).

The hydrocarbon concentrations of *Urophycis regius, Decapterus punctatus, Synodus foetens, Sicyonia brevirostris,* and *Ovalipes stephensoni* showed no significant correlations with hydrocarbon concentrations of sediments and near-bottom particulates (Appendix 3.3D in Volume 6). Whether *Loligo pealei* and *Synodus poeyi* can be used to monitor hydrocarbons in sediment or near-bottom particulates remains to be determined in future investigation.

Although gas-liquid chromatography/mass spectrometry was used to analyze 35 F2 hydrocarbons in macrofauna samples, aromatic hydrocarbons were detected in only a few samples by a selected ion scan of the data. (The amounts present were too low to show up in the gas chromatograms or in the normalized total ion chromatograms.) The primary aromatic hydrocarbons in these macrofauna samples were naphthalene and phenanthrene (Table 3.3-6).

G. SUMMARY OF RESULTS

The major saturated hydrocarbons were: C_{19}, surface film; C_{15}, dissolved in water; C_{17}, particulates in water; pristane, zooplankton; pristane, benthic macrofauna; and C_{17}, sediment. These are assumed to have been biogenic in origin. In addition, C_{14} and C_{28} were important alkanes in some samples. Hydrocarbons in F2 included squalene and the polyunsaturated olefin 21:6, as well as other polyunsaturated hydrocarbons. Some samples showed small amounts of aromatic hydrocarbons.

The components found in F1 by gas-liquid chromatography/mass spectrometry were n-alkanes, branched alkanes, cycloalkanes, and monolefins. Table 3.3-19 lists the compounds by retention index, characteristic ions, and types of samples in which they were found. The mass spectrum of each compound appears in Volume 6, Appendix 3.3I. In the absence of an extensive set of known reference compounds or additional chemical and spectrometric data, the identity of the F1 components cannot be established conclusively. The mass spectra typically show a high degree of fragmentation and, although they are similar in many respects, there usually are distinctive features in terms of certain fragment ion ratios that allow class distinctions to be made.

The components found in F2 by GC-MS analysis were primarily biogenic olefins, but there were also small amounts of aromatic hydrocarbons, silicones, and plasticizers. Table 3.3-20 lists the nonaromatic hydrocarbon and biogenic olefins found in F2 and the types of samples in

Table 3.3-19. Hydrocarbons Found in Fraction 1 by GC-MS Analysis

Retention Index	Major Characteristic Ions, m/e (Relative Intensity)	Class[b]	Occurrence in Sample Type[a] Macro-fauna[c]	Zoo-plankton	Sediment	Surface Film	Water	Particulate
1388	43(100), 41(83), 55(78), 57(60)	U	0	0	+	0	0	0
1400	57(100), 43(96), 71(50), 41(44)	S	+	+	+	0	+	0
1462	57(100), 43(81), 71(77), 40(50)	S	+	+	+	0	0	0
1473	55(100), 69(93), 41(86), 210(8)	U	+	0	0	0	0	0
1490	55(100), 43(98), 41(91), 57(73)	U	+	0	+	0	0	0
1500	43(100), 57(99), 41(72), 71(50)	S	++	++	+	0	+	+
1550	40(100), 43(76), 57(68), 71(64)	U	0	0	+	0	0	0
1560	43(100), 57(63), 41(58), 71(42)	S	+	0	0	0	0	0
1590	43(100), 57(90), 55(78), 41(76)	U	+	0	0	0	0	0
1600	55(100), 71(90), 85(73), 43(55)	S	+	+	+	+	+	+
1650	57(100), 71(70), 85(49), 43(48)	S	+	+	+	0	0	0
1670	41(100), 55(85), 43(73), 83(53)	U	+	+	+	0	0	0
1688	41(100), 55(94), 69(86), 238(10)	U	+	+	++	0	0	0
1700	57(100), 71(88), 85(75), 43(61)	S	++	+	++	+	+	+
1706	57(100), 71(95), 43(52), 85(45)	S	++	++	++	+	+	+
1711	55(100), 41(91), 97(72), 238(8)	U	0	0	++	0	0	0
1715	69(100), 55(96), 57(76), 56(67)	U	0	0	+	0	0	0
1729	69(100), 56(90), 70(88), 57(77)	U	+	0	0	0	0	0
1734	57(100), 55(76), 43(73), 69(68)	U	0	0	+	0	0	0
1738	69(100), 41(69), 70(62), 57(56)	U	+	0	0	0	0	0
1743	57(100), 43(93), 71(74), 41(59)	S	+	+	+	+	0	0
1750	57(100), 41(92), 55(86), 69(85)	U	+	0	0	0	0	0
1752	43(100), 85(74), 57(42), 56(47)	U	0	+	+	0	0	0
1758	57(100), 43(83), 71(55), 85(36)	S	+	0	+	+	0	0
1770	57(100), 43(68), 41(67), 56(49)	S	0	0	+	+	0	0
1777	43(100), 55(95), 41(82), 69(75)	U	+	0	0	0	0	0
1788	55(100), 41(99), 43(93), 69(81)	U	+	0	++	0	0	0
1800	57(100), 43(87), 71(61), 41(52)	S	++	+	++	+	+	+
1810	71(100), 57(97), 85(62), 43(46)	S	+	0	++	+	+	+
1815	55(100), 41(94), 69(93), 57(86)	U	0	0	+	0	0	0
1831	43(100), 68(97), 82(50), 95(47)	U	+	+	+	0	0	+
1840	57(100), 70(70), 55(68), 71(55)	U	+	0	+	+	0	0
1859	43(100), 81(99), 82(93), 68(90)	U	+	+	+	0	0	+
1872	43(100), 41(87), 81(93), 82(77)	U	+	+	+	0	0	+
1880	57(100), 71(55), 43(55), 85(37)	S	+	0	0	+	0	0
1883	55(100), 97(88), 43(60), 41(55)	U	0	0	+	0	0	0
1890	41(100), 43(98), 55(82), 57(72)	U	+	+	+	0	0	0
1900	57(100), 43(98), 71(57), 41(56)	S	+	+	+	0	+	+
1913	43(100), 41(97), 55(95), 97(54)	U	+	0	+	0	0	0
1931	41(100), 43(100), 57(92), 55(91)	U	0	0	+	0	0	0
1964	57(100), 43(82), 83(70), 82(60)	U	0	0	0	+	0	0
1975	57(100), 69(98), 55(80), 111(68)	U	+	0	0	0	0	0
1987	57(100), 71(75), 43(67), 85(56)	S	0	0	0	+	0	0
2000	57(100), 43(92), 71(61), 41(53)	S	+	+	+	+	+	+
2052	67(100), 82(95), 81(94), 96(86)	U	+	+	0	0	0	0
2063	41(100), 55(86), 82(80), 67(79)	U	+	+	++	0	0	0
2075	43(100), 69(88), 55(86), 41(72)	U	+	0	++	0	0	0
2082	43(100), 55(68), 41(63), 69(58)	U	+	+	++	0	0	+
2088	43(100), 41(90), 55(89), 57(83)	U	+	0	0	0	0	0
2100	57(100), 43(85), 71(60), 41(47)	S	+	+	+	+	+	+
2110	43(100), 57(66), 41(65), 69(60)	U	+	0	+	0	0	0

Table 3.3-19. Hydrocarbons Found in Fraction 1 by GC-MS Analysis (Continued)

Retention Index	Major Characteristic Ions, m/e (Relative Intensity)	Class[b]	Occurrence in Sample Type[a] Macro-fauna[c]	Zoo-plankton	Sediment	Surface Film	Water	Particulate
2135	57(100), 43(75), 55(72), 69(71)	U	+	0	0	0	0	0
2140	71(100), 57(99), 85(73), 43(55)	S	0	+	0	0	0	0
2151	55(100), 69(98), 57(60), 83(58)	U	+	0	0	0	0	0
2161	57(100), 43(80), 69(71), 55(68)	U	+	0	0	0	0	0
2200	57(100), 43(90), 71(58), 85(48)	S	+	+	+	+	+	+
2240	57(100), 71(70), 43(52), 85(34)	S	+	+	+	0	0	0
2293	97(100), 83(94), 57(89), 55(87)	U	+	0	0	0	0	0
2300	57(100), 43(96), 71(68), 85(53)	S	+	+	+	+	+	+
2400	43(100), 57(99), 71(74), 85(53)	S	+	+	+	+	+	+
2500	57(100), 43(85), 71(65), 85(51)	S	+	+	+	+	+	+
2600	57(100), 43(89), 71(70), 85(50)	S	+	+	+	0	0	0
2670	57(100), 71(76), 43(53), 85(45)	S	+	0	0	0	0	0
2680	57(100), 43(79), 69(77), 55(66)	U	+	0	0	0	0	0
2697	57(100), 69(89), 83(87), 55(78)	U	+	0	0	0	0	0
2700	57(100), 43(86), 71(69), 85(56)	S	+	+	+	0	0	0
2800	57(100), 43(76), 71(66), 85(38)	S	0	+	+	0	0	0
2900	57(100), 43(82), 71(68), 85(63)	S	+	+	+	0	0	0
3000	57(100), 71(65), 43(60), 85(53)	S	0	+	+	0	0	0
3100	57(100), 43(65), 71(61), 85(36)	S	0	+	+	0	0	0
3200	57(100), 43(90), 71(73), 85(60)	S	0	+	+	0	0	0

[a]0 = not found; + = low levels; ++ = relatively high levels.

[b]S = straight-chain or branched-chain saturated hydrocarbon; U = unsaturated or cyclic hydrocarbon.

[c]Macrofauna species are listed in Appendixes 3.3V, 3.3W, 3.3X, and 3.3Y.

which they were found. The mass spectrum of each of these compounds appears in Volume 6, Appendix 3.3I. A variety of biogenic olefins was found in every F2 extract studied; however, they were generally more plentiful in the extracts from zooplankton, macrofauna, and sediment samples. The majority of the biogenic olefins found in zooplankton and benthic macrofauna were also found in sediments. The aromatic hydrocarbons and miscellaneous chemicals found in F2 and the types of samples in which they were detected are listed in Table 3.3-6; their mass spectra, in conjunction with retention index data, permitted them to be identified conclusively in most cases. Most of the components were found in only a small number of samples and in most cases may represent contamination during the sampling and processing steps.

H. SUMMARY OF INDEPENDENT QA/QC LABORATORY ANALYSES

As a contract requirement, TI collected separate sediment, macrofauna, and zooplankton samples for QA/QC verification by an independent laboratory designated by BLM. Laseter and Overton (1978) reported results of GC and GC-MS analyses on 23 sediment, 4 macrofauna, and 4 zooplankton samples collected during the four seasonal cruises for QA/QC verification.

Sediment samples were reported to contain normal hydrocarbons (detected for C_{15} to C_{19}), the C_{19} and C_{20} isoprenoid hydrocarbons, several isomers of phytadiene, unknown olefins, and other compounds in the n-hexane (F1) fractions. The F2 (40% benzene in n-hexane) fractions were reported to suggest two general distributions. One distribution showed little

Table 3.3-20. Nonaromatic Hydrocarbons Found in Fraction 2 by GC-MS Analysis

Retention Index	Major Characteristic Ions, m/e (Relative Intensity)	Occurrence in Sample Type[a] Macro-fauna[b]	Zoo-plankton	Sedi-ment	Water	Particulate
1369	67(100), 81(83), 55(70), 82(65)	0	0	+	0	0
1476	79(100), 55(63), 93(62), 67(55)	0	0	+	0	0
1557	41(100), 57(67), 67(41), 55(41)	0	0	+	0	0
1566	41(100), 55(50), 67(42), 54(36)	+	0	+	0	0
1570	91(100), 79(75), 81(55), 121(49)	+	0	0	0	0
1664	41(100), 55(95), 67(72), 81(60)	+	0	+	0	0
1673	41(100), 55(83), 67(48), 81(40)	+	0	+	0	0
1792	85(100), 57(96), 71(92), 141(38)	+	0	0	0	0
1831	43(100), 41(46), 68(73), 123(38)	0	0	+	0	0
1845	55(100), 41(77), 67(60), 69(42)	+	0	0	0	0
1859	43(100), 81(50), 82(50), 123(22)	+	0	+	0	0
1865	55(100), 82(70), 81(66), 69(61)	+	0	0	0	0
1872	81(100), 43(96), 82(75), 123(50)	+	++	+	0	0
1880	81(100), 82(86), 95(80), 123(45)	+	0	0	0	0
1898	97(100), 83(66), 55(48), 153(14)	+	0	+	0	0
1904	97(100), 83(66), 55(46), 153(15)	0	0	+	0	0
1972	109(100), 55(78), 107(65), 121(50)	0	0	+	0	0
2030	79(100), 80(64), 91(57), 67(54)	+	++	++	0	++
2040	67(100), 79(78), 55(75), 41(64)	+	++	++	0	0
2043	83(100), 165(30), 179(24), 233(16)	+	0	++	0	0
2056	79(100), 80(99), 67(71), 93(52)	+	0	++	0	0
2062	55(100), 83(91), 43(65), 69(64)	0	0	++	0	0
2075	69(100), 163(22), 177(15), 233(10)	+	++	++	0	+
2080	83(100), 55(61), 165(10), 179(10)	+	0	++	0	0
2089	83(100), 165(28), 179(20), 233(10)	+	0	++	0	0
2094	55(100), 41(69), 48(49), 231(10)	+	0	++	0	0
2105	69(100), 81(90), 95(84), 151(14)	+	+	++	0	+
2110	109(100), 43(28), 69(22), 205(5)	0	0	++	0	+
2115	69(100), 41(92), 55(43), 81(25)	+	+	+	0	+
2121	69(100), 95(60), 81(52), 109(46)	+	+	+	0	+
2136	69(100), 81(37), 95(30), 41(28)	+	0	+	0	0
2162	69(100), 41(95), 55(50), 81(25)	+	0	+	0	0
2184	69(100), 41(77), 55(45), 81(26)	+	0	0	0	0
2290	69(100), 41(51), 55(48), 109(30)	+	0	0	0	0
2307	69(100), 41(73), 55(53), 109(28)	+	0	0	0	0
2316	69(100), 41(50), 81(28), 55(18)	+	++	0	0	0
2325	69(100), 41(70), 81(27), 55(18)	+	0	0	0	0
2339	69(100), 41(62), 109(46), 55(42)	+	++	+	+	+
2355	191(100), 67(38), 81(34), 192(32)	0	+	+	0	0
2360	69(100), 81(43), 41(23), 68(20)	+	0	+	0	0
2461	43(100), 107(67), 205(22), 231(18)	0	0	+	0	0
2490	55(100), 41(83), 147(20), 161(16)	0	0	+	0	0
2530	69(100), 41(38), 55(34), 81(30)	+	0	+	0	0
2553	55(100), 95(86), 69(82), 231(12)	+	0	+	0	0
2560	69(100), 55(75), 83(74), 217(8)	+	0	+	0	0
2567	55(100), 69(86), 83(48), 41(44)	+	+	+	0	0
2573	55(100), 83(71), 41(62), 69(52)	0	0	+	0	0
2601	69(100), 109(35), 149(24), 191(18)	+	+	+	0	0
2604	79(100), 41(88), 67(84), 43(77)	+	0	0	0	0
2610	55(100), 69(83), 83(56), 43(55)	+	0	0	0	0
2640	69(100), 81(58), 55(50), 41(48)	+	0	0	0	0
2676	69(100), 41(52), 81(41), 55(33)	+	0	0	0	0

Table 3.3-20. Nonaromatic Hydrocarbons Found in Fraction 2 by GC-MS Analysis (Continued)

Retention Index	Major Characteristic Ions, m/e (Relative Intensity)	Occurrence in Sample Type[a] Macro-fauna[b]	Zoo-plankton	Sedi-ment	Water	Particulate
2702	69(100), 55(51), 109(39), 41(38)	+	0	0	0	0
2729	83(100), 69(96), 55(74), 57(48)	+	0	0	0	0
2760	69(100), 41(52), 55(31), 81(23)	+	0	+	0	0
2773	69(100), 41(49), 81(39), 55(19)	+	0	+	0	0
2789	81(100), 69(78), 95(75), 109(60)	0	0	+	0	0
2859	43(100), 41(59), 145(96), 147(28)	+	0	+	0	0
2879	69(100), 81(50), 41(47), 191(8)	+	0	0	0	0
2899	69(100), 191(70), 192(21), 231(13)	+	0	+	0	0
2906	55(100), 43(75), 145(28), 159(23)	+	0	+	0	0
2992	91(100), 79(94), 93(55), 67(54)	0	0	+	0	0
3042	69(100), 81(47), 41(33), 55(28)	+	0	0	0	0
3098	55(100), 69(77), 82(73), 96(62)	+	0	0	0	0

[a]0 = not found; + = low levels; ++ = relatively high levels.

[b]Macrofauna species are listed in Appendixes 3.3V, 3.3W, 3.3X, and 3.3Y.

contamination by polynuclear aromatic (PNA) compounds. The second distribution observed showed that the sediment contained several PNAs and their alkylated homologs. Most of these compounds were present at concentrations of <1 ppb (1 ng/g) and could not be quantified by GC. Their presence was detected qualitatively, however, by GC-MS by comparison of sample mass spectra with mass spectra of known compounds. It was concluded that, because of the extremely low concentrations present, petroleum contamination of the sediment could not be demonstrated from these data.

Concentrations of saturated hydrocarbons ranged from 0.048 μg/g to 2.56 μg/g, with most values in the 0.1- to 1.0-μg/g range. The major saturated component was the C_{17} alkane. Other important F1 components were C_{18}, pristane, and phytane. The average pristane-to-phytane ratio was 2. Several phytadiene isomers were identified and were the highest individual unsaturated contributors to the total concentration of F1 hydrocarbons. The major aromatic sediment hydrocarbons identified were biphenyl, phenanthrene, naphthalene isomers, and pyrene. Generally, individual aromatic compounds were 3 to 30 ng/g with total F2 concentrations ranging from 0.1 to 0.6 μg/g. Texas Instruments results and those of the independent QA/QC laboratory were in almost complete agreement for qualitative and quantitative sediment hydrocarbon data.

Analysis of the epifauna (*Pomatomus saltatrix, Leiostomus xarthurus,* and two *Sicyonia brevirostris*) samples contained normal hydrocarbons, the C_{19} and C_{20} isoprenoid hydrocarbons, and phytadiene isomers in the hexane fraction (F1). There were no odd-carbon preferences and most samples were reported to contain small unresolved complex mixtures. These characteristics generally are considered an indication of the presence of petroleum contamination. The F2 (40% benzene in n-hexane) fractions were reported to contain naphthalene and its alkylated homologs, fluorine, phenanthrene, and several unknown compounds. The presence of petroleum contamination could not be demonstrated unequivocally by these data. Agreement between these analyses and the analyses performed by Texas Instruments appears to be excellent. Qualitative and quantitative data correspond quite closely between the two laboratories.

The F1 (n-hexane) fractions of zooplankton QA/QC samples were reported to contain normal paraffins (C_{15} through C_{30}), the C_{19} and C_{20} isoprenoid hydrocarbons, branched and/or cyclic hydrocarbons, and unknown olefins. The major saturated hydrocarbon was C_{15}, with a mean value of 0.19 μg/g and a standard deviation of 0.14 μg/g. The pristane:phytane ratio averaged 56. The size of the pristane peak obscured the n–C_{17} peak; therefore, these two hydrocarbons were quantified and reported together. However, pristane was by far the major saturated hydrocarbon in the zooplankton samples analyzed. Total F1 concentrations were 1.9 to 5.95 μg/g.

No pronounced odd-carbon preferences were shown, and most samples contained complex unresolved mixtures, which, again, suggests petroleum contamination. However, the predominant class of hydrocarbons in this complex mixture may be composed of biogenic material rather than the result of petroleum contamination.

The F2 (40% benzene in n-hexane) fractions contained naphthalene and biphenyl, several biogenic olefins, unknown compounds, and several long-chain fatty-acid esters (wax esters). No evidence of petroleum contamination of these samples could be shown.

The major hydrocarbon in the F2 fraction was squalene with values of 0.5 to 2.7 μg/g of this hydrocarbon alone. Total F2 hydrocarbon concentrations were 6.2 to 15.2 μg/g. These data agree with the SABP hydrocarbon analyses.

The QA/QC analyses done for sediment, macrofauna, and zooplankton confirm the analytical results reported by Texas Instruments. Both laboratories reported the predominance of biogenic hydrocarbons in macrofauna and zooplankton. The presence of this material in the F2 fractions made analysis for polynuclear aromatic compounds extremely difficult, necessitating the use of GC-MS analyses and, because of the low levels involved, the use of selected ion scans to identify any aromatic compounds present. The use of uniform methodology (through participation in the BLM Hydrocarbon Methodology Review Group) was a direct cause of the close agreement between the two laboratories.

SECTION 4
DISCUSSION

A predominance of odd-chain alkanes is generally found in living organisms, while the ratio of odd:even-chain alkanes in petroleum is close to unity. Thus, some measure of the extent of petroleum contaminations in a sample is given by the odd:even ratio of n-alkanes. However, some organisms (e.g., certain bacteria) show no odd-chain predominance (Davis, 1968). Therefore, an n-alkane odd:even ratio of unity is not sufficient by itself to indicate petroleum in a sample. Most of the zooplankton from the South Atlantic OCS area have an odd:even ratio greater than unity; many water and sediment samples have an odd:even ratio close to unity.

A. SURFACE-FILM HYDROCARBONS

The major hydrocarbon of surface film collected in the South Atlantic was the C_{19} normal alkane. In the North Atlantic OCS benchmark study (Boehm, 1977), the hydrocarbons of the surface film showed a maximum at C_{29}; also, a significant unresolved complex mixture that Boehm suggested was caused by small tar particles was observed in the hydrocarbons of the surface film from this area. The hydrocarbon data from the South Atlantic surface films suggest that this area has less petroleum in surface films than does the North Atlantic OCS area.

Ledet and Laseter (1974) collected surface samples off Florida and Louisiana and found an n-heptane eluate to average 0.36 mg/m^2. Resolved alkanes were only 35 $\mu g/m^2$. Most of the alkanes were branched and cyclic paraffins, but water below the surface was mainly normal paraffins. In the summer, saturated hydrocarbons from surface films in the South Atlantic averaged 0.27 mg/m^2 and n-paraffins were the predominant components.

B. WATER HYDROCARBONS

The averages and range of hydrocarbon concentrations in waters of the South Atlantic OCS area are similar to those of the South Texas OCS area (Parker et al., 1975) and for the Eastern Gulf of Mexico OCS area (Calder, 1977). In the South Texas and South Atlantic OCS areas, the highest hydrocarbon concentrations have been noted in the spring and similar normal alkane series have been observed in both waters, although the maximum in South Texas OCS waters was the C_{21} alkane in spring and the C_{31} alkane in summer, whereas C_{17} and C_{28} were the major alkanes in South Atlantic water. In the Florida Straits, the average water hydrocarbon concentrations were 0.4 $\mu g/l$ and 0.3 $\mu g/l$ for dissolved and particulate hydrocarbons, respectively, compared with averages of 0.5 and 0.4 $\mu g/l$, respectively, in the South Atlantic area. Squalene was the major component in F2 for dissolved hydrocarbon from bottom waters of both the Florida Straits and the South Atlantic. Calder (1977) reported that the major F1 particulate hydrocarbon was the C_{15} alkane, which averaged 0.044 $\mu g/l$ and that the major F2 particulate hydrocarbon was squalene. South Atlantic OCS waters generally had C_{17} as the major alkane in the particulates and C_{15} the major alkane in the dissolved phase. In waters off Nova Scotia, Gordon et al. (1978) found the C_{17} normal alkane to be the most abundant saturated hydrocarbon in the water.

The concentration of both dissolved and particulate hydrocarbons was higher in the New England OCS area [30 $\mu g/l$ and 0.9 $\mu g/l$, respectively, for dissolved and particulate hydrocarbons

(Boehm, 1977)] than in the South Atlantic OCS area. Concentrations were higher in winter (30 μg/l) than in spring (12 μg/l), and particulate hydrocarbon concentrations were always higher than dissolved hydrocarbon concentrations. A cursory view of the data suggests that, with respect to hydrocarbons, waters of the South Atlantic OCS area resemble waters of the Gulf of Mexico rather than waters of the North Atlantic OCS area.

Although a correlation between hydrocarbon concentrations and chlorophyll has been found in waters of west Africa (Zsolnay, 1973), chlorophyll in the South Atlantic OCS correlated with water hydrocarbons only during some seasons, suggesting that particulate and dissolved hydrocarbons in this area are not completely derived from phytoplankton.

C. ZOOPLANKTON HYDROCARBONS

Pristane, an isoprenoid hydrocarbon with 19 carbons, and the C_{17} normal alkane were the predominant hydrocarbons in South Atlantic OCS zooplankton. Pristane was the major zooplankton hydrocarbon in the Eastern Gulf of Mexico, South Texas, and North Atlantic OCS area (Boehm, 1977; Calder, 1977; Parker et al., 1975). Phytane, a 20-carbon isoprenoid hydrocarbon, is always a minor component unless petroleum is present (e.g., small tar lumps caught in the net). In the absence of petroleum, pristane:phytane ratios are often 50. Phytol, a long-chain alcohol found in chlorophyll, is converted to pristane; since pristane is generally absent from algae, the compound is a good zooplankton indicator.

D. SEDIMENT HYDROCARBONS

It is difficult to determine the absolute amount of petroleum hydrocarbons in the South Atlantic area where biogenic hydrocarbons have much higher concentrations than petroleum. Petroleum hydrocarbons can be distinguished from biogenic hydrocarbons by the presence of a more complex mixture, a homologous series with an odd:even ratio near unity, and more kinds of cycloalkanes and aromatic hydrocarbons. South Atlantic OCS sediments show little or no unresolved complex mixture, an odd:even ratio generally exceeding unity, and only traces of aromatic hydrocarbons.

Overton and Laseter (1978), reporting on the distribution of polycyclic aromatic hydrocarbons in sediments from North Atlantic, South Texas, Mid-Atlantic, and Southern California OCS areas, found aromatic hydrocarbons in all sediment samples taken from these areas; the aromatic hydrocarbons included naphthalene, biphenyl, alkylated naphthalenes, fluorine, phenanthrene, alkylated phenanthrenes, and pyrene. The concentration of these compounds in the North and Middle Atlantic was mostly in the 1- to 100-ng/g range. The major aromatic hydrocarbons detected in the sediments of the South Atlantic OCS were naphthalene, biphenyl, phenanthrene, and pyrene. Overton and Laseter (1978) found that sediments from the Southern California OCS area had higher polycyclic aromatic hydrocarbon concentrations than did those from other regions and speculated that the high concentrations in this region may have been caused by natural oil seeps.

Most of the hydrocarbon concentrations in the sediments of the South Atlantic OCS area were low and uniform except at stations 7D and 7E off Daytona Beach, Florida. Nitrate concentrations in the bottom waters of station 7D averaged 20 μg-at/l, whereas other stations along the other transects had a range of 0 to 2 μg-at/l. During the SABP winter cruise, heavy

phytoplankton growth was noted in zooplankton tows along transect 7 (Lee, 1977b). Barber (1977), in a quarterly report for the SABP, referred to the more or less permanent upwelling on the shelf between Cape Canaveral and Jacksonville, and Green (1944) noted upwelling off the northeastern coast of Florida in the vicinity of Daytona Beach.

Table 3.3-21 summarizes transect 7 sediment data. Station 7E sediment was characterized by high silt/clay (average 30%), high total organic carbon (average 7,000 μg/g), and high hydrocarbon content (average 4 μg/g). In the report by Barun Sen Gupta (Chapter 10 of this volume), it is noted that 7E's foraminifera mean density was much higher than at the other stations and that the population was different from that at other stations. Another interesting observation is of the commercial scallop beds off Cape Canaveral, which is in the same general area. The 7E data suggest that the nature of this area's unique sediment needs further investigation.

E. MACROFAUNA HYDROCARBONS

All marine organisms that have been examined to date contain hydrocarbons, which generally account for ≤1% of their body lipids; these are the so-called biogenic or "natural" hydrocarbons that are biosynthesized by plants and animals. The major components are generally a series of normal and branched-chain alkanes. In all the fish collected from the South Atlantic OCS during the SABP, the major branched-chain hydrocarbons were pristane and squalene, which are also the major isoprenoid hydrocarbons in fish from other marine areas (Ackman, 1971; Blumer, 1967; Kayama et al., 1969; Lambersten and Holman, 1963). Phytane is either absent or present only in trace quantities. In the normal alkane series, the odd-numbered alkanes are dominant.

When petroleum hydrocarbons are taken up by an animal, they are superimposed over the biogenic hydrocarbon pattern. An unresolved envelope is generally noted in petroleum-contaminated animals. An interesting study conducted by Rossi et al. (1978) compared the hydrocarbons of sand crabs from a natural oil-seep area with those from cleaner offshore waters: the oil-seep area crabs had a hydrocarbon concentration of 46 μg/g, an unresolved complex mixture of 18 μg/g, and alkanes with an odd:even ratio close to unity; the offshore crabs had hydrocarbon concentrations of 4 μg/g, an unresolved complex mixture of 0.3 μg/g, and a strong odd-numbered-chain-length preference. Most of the animals collected from the South Atlantic OCS during the SABP showed little or no unresolved complex mixture and an odd:even ratio greater than 1.5.

The concentrations and types of hydrocarbons for macrofauna of the South Atlantic OCS were similar to those of the South Texas OCS area (Giam, 1975)–and many of the same species (e.g., squid and inshore lizard fish) were analyzed. The South Texas OCS saturated hydrocarbon fraction had a series of normal alkanes in which the major components included C_{15}, C_{17}, C_{29}, and C_{31}. The major alkanes in North Atlantic OCS herring were C_{19}, C_{25}, C_{27}, and C_{29} (Lambersten and Holman, 1963), whereas C_{15} and C_{17} were the major alkanes in herring collected during the South Atlantic OCS study. Squalene and polyolefins appear to be the major components of F2 hydrocarbons in marine invertebrates from the various OCS areas (Rossi et al., 1978; Giam, 1975).

Table 3.3-21. Summary of Sediment Data for Transect 7

Season	Station	Concentration (μg/g) F1	F2	Total Organic Carbon	Pan[a] (%)	Depth (m)
Winter	7C	–	–	–	–	21
	7D	0.44	0.27	–	0.6	43
	7E	0.90	0.86	2,027	51	226
	7F	0.42	0.20	9,500	28	536
Spring	7C	0.19	0.24	162	–	21
	7D	7.16	0.32	557	–	44
	7E	1.44	6.77	115	24	256
	7F	0.42	0.18	4,300	14	485
Summer	7C	0.43	0.45	105	0.3	22
	7D	0.43	0.19	960	2	45
	7E	3.11	1.28	6,100	27	180
	7F	–	–	8,500	16	467
Fall	7C	0.33	0.26	420	0.1	23
	7D	0.88	0.66	610	2	44
	7E	2.51	1.19	8,100	27	225
	7F	0.58	0.86	5,200	23	545

[a]Sediment particle size smaller than 40 (<31.3 μm).

SECTION 5
CONCLUSIONS

- Surface-film hydrocarbons were a mixture of ship contaminants with some terrestrial input of C_{23} to C_{29} n-alkanes.
- Particulate hydrocarbons in water were higher in the winter and spring (0.5 and 0.7 μg/l) than in the summer and fall (0.2 and 0.1 μg/l).
- Particulate hydrocarbon concentrations were significantly correlated with zooplankton hydrocarbons, suggesting that some of the particulate hydrocarbons are derived from zooplankton, possibly through the zooplankton feces.
- Total dissolved hydrocarbon concentrations during winter, spring, summer, and fall averaged 0.4, 0.4, 0.4, and 0.3 μg/l, respectively, indicating no seasonal influence for dissolved hydrocarbons. A series of n-alkanes from C_{14} to C_{30} was observed in the saturated hydrocarbon fraction, with C_{14} and C_{15} as the principal components. There were few or no unresolved complex mixtures and the odd-chain-length: even-chain-length ratio was generally near unity.
- In some seasonal samples, total dissolved hydrocarbons, F1 hydrocarbons, and dissolved pristane correlated with particulate organic carbon, dissolved organic carbon, and chlorophyll. Also, in some samples, total dissolved hydrocarbons, F1 dissolved hydrocarbons, and dissolved pristane correlated with total zooplankton hydrocarbons, F1 zooplankton hydrocarbons, and zooplankton pristane. This can be explained as conversion of phytol to pristane during metabolism of chlorophyll by zooplankton.
- Zooplankton hydrocarbons showed a reversed relationship over season to that shown for particulate hydrocarbons, with an order of magnitude lower average values in the winter and spring compared with those in the summer and fall (Table 3.3-10). The concentration of total zooplankton hydrocarbons, F1 hydrocarbons, and pristane during winter and summer correlated with the abundance of the copepods *Paracalanus* and *Clausocalanus*. The abundance of the decapods and copepods *Centropages* and *Eucalanus* correlated with the concentration of zooplankton pristane.
- Sediment hydrocarbon concentrations were very low in all sediment samples except those taken at stations 7D and 7E. The average concentration for all stations for four seasons was 0.6 μg/g. The range was 0.04 to 2.2 μg/g, with most samples in the 0.1- to 1.0-μg/g range.
- The major saturated sediment hydrocarbon was generally the n–C_{17} alkane. Other important saturated components were n–C_{18}, pristane, and phytane. The average ratio of odd-numbered alkanes to even-numbered alkanes was 2; the average ratio of pristane to phytane was 1.5, with many sediment samples having ratios of unity or less. There was little or no unresolvable complex mixture in most sediment samples.
- Generally, the unsaturated (F2) sediment hydrocarbons were biogenic olefinic hydrocarbons such as squalene or the polyunsaturated 21:6 hydrocarbon. Low levels of aromatic hydrocarbons could be detected in some samples by GC-MS, but not by GC alone because of their low concentrations and interference from biogenic olefinic hydrocarbons.

- The major aromatic hydrocarbons detected were biphenyl, phenanthrene, naphthalene, and pyrene; there were trace amounts of perylene, chrysene, dimethylphenanthrene, methylphenanthrene, trimethylbiphenyl, methylfluorene, tetramethylnaphthalene, diphenylethane, trimethylnaphthalene, and methylbiphenyl in some samples. Silicones and plasticizers were also detected in some samples.
- Concentrations of sediment hydrocarbons were significantly correlated with several sediment characteristics (size parameters, total organic carbon) and with near-bottom particulate hydrocarbons.
- Highest macrofauna and demersal fish hydrocarbon concentrations were found for *Synodus poeyi* (offshore lizard fish), averaging 43 μg/g in saturated (F1) and 32 μg/g in aromatic (F2) fractions. The principal saturated hydrocarbons were pristane, n–C_{17}, and n–C_{15}, which averaged 4.3 and 18 μg/g, respectively. The principal component of F2 hydrocarbons was squalene, which averaged 15 μg/g. There were no significant differences in the hydrocarbon concentrations in the same species among the four seasons.
- *Synodus foetens,* the inshore lizard fish, had much lower hydrocarbon concentration than did *Synodus poeyi:* the saturated hydrocarbon concentration averaged 6 μg/g and the F2 hydrocarbons averaged 8 μg/g.
- The sand perch *Diplectrum formosum,* was widely collected and had a low hydrocarbon concentration, averaging 3 μg/g saturated hydrocarbon concentration. An occasional high or low value was observed for hydrocarbon concentrations in samples from one station, e.g., for sand perch at certain stations along transect 4. Further study with more samples over a longer time would show if animals from certain stations had consistently high or low hydrocarbon concentrations.
- For most of the benthic invertebrates, the range of saturated hydrocarbon concentrations was from 5 to 30 μg/g; by comparison, most fish fell in the range of 2 to 40 μg/g. The sea cucumber *Holothuria imperator-arenico* was the invertebrate with the highest hydrocarbon concentrations (total averaging 84 μg/g) with a range of 6 to 293 μg/g–probably because this deposit feeder derives some hydrocarbons from the sediment.
- Among the invertebrates, squid were consistently collected during all seasons and at most stations: total hydrocarbon content averaged 17 μg/g, except for samples from station 7C. Pristane, n–C_{17}, and n–C_{15} accounted for most of the saturated hydrocarbon fraction in squid. Squid from station 7C in the fall had an F1 hydrocarbon concentration of 302 μg/g. The major hydrocarbon components of fraction 2 were squalene and several polyunsaturated olefins. Total sediment hydrocarbon, F1 hydrocarbon, and sediment pristane correlated with squid hydrocarbon concentrations.
- The hydrocarbon concentrations of *Urophycis regius, Decapterus punctatus, Synodus foetens, Sicyonia brevirostris,* and *Ovalipes stephensoni* showed no significant correlations with hydrocarbon concentrations of sediments and near-bottom particulates. Whether *Loligo pealei* and *Synodus poeyi* can be used to monitor hydrocarbons in sediment or near-bottom particulates remains to be determined through future investigation.

- Although gas-liquid chromatography/mass spectrometry was used to analyze 35 F2 hydrocarbons in macrofauna samples, aromatic hydrocarbons were detected in only a few samples by a selected ion scan of the data. (The amounts present were too low to show up in the gas chromatograms or in the normalized total ion chromatograms.) The primary aromatic hydrocarbons in these macrofauna samples were naphthalene and phenanthrene.
- In all samples analyzed for this task of the program, little evidence for the presence of petroleum contamination was found.

SECTION 6
RECOMMENDATIONS FOR ADDITIONAL STUDIES

Dispersion or modification of oil in the ocean depends on various biological, chemical, and physical processes (e.g., winds, waves, and currents). In the South Atlantic OCS, nearshore hydrographic conditions are characterized by a boundary, or turbid zone, located approximately 15 km offshore; currents inside this zone are regulated largely by tidal forces. The existence of this zone suggests several questions:

(1) If oil is released outside the boundary and is transported shoreward, what exchanges of water (and, hence, oil) occur between the two areas?

(2) If the oil is released in the turbid zone, will the fine sediments and associated oil be transported shoreward to the coastal estuaries?

Specific research problems that can be formulated in response to the above questions include the following:

(1) Exchange and diffusion rates of water between near and offshore zones

(2) Character and gradient of suspended particles in these zones

(3) Ability of suspended particles in these waters to adsorb petroleum components.

Other studies should be carried out to evaluate the importance of biodegradation, volatilization, photochemical degradation, and sedimentation as they affect the fate of oil in both the waters and sediments of the South Atlantic OCS.

No faults such as those occurring on the western coast of the United States extend into the Atlantic outer continental shelf, so no natural oil seeps have been discovered in this area (Travers and Luney, 1976). Subsurface processes are highly improbable along the Atlantic continental shelf because of its geological history. Travers and Luney (1976) have suggested that this is the safest region in U.S. "domestic and offshore waters for the development and production of petroleum resources." During the drilling and recovery of petroleum, hydrocarbons in the formation water (brine) are released into the environment, but input of petroleum hydrocarbons into the South Atlantic OCS area from such activity should be detectable since present levels of petroleum in the water, sediment, and biota of this area are extremely low. In summary, it is believed that this 1-year study of hydrocarbons in this OCS area will provide preliminary hydrocarbon data that will be useful in future studies of the area.

SECTION 7
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CHAPTER 4

TRACE METAL CHEMISTRY OF SOUTH ATLANTIC/GEORGIA BIGHT

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ABSTRACT

Results of analyses of trace metals in water, suspended sediments, zooplankton, bottom sediments, macroinvertebrates, and demersal fishes on the outer continental shelf of the southeastern U.S. as part of BLM's South Atlantic Benchmark Program (SABP) are discussed in relation to previous studies and the data are interpreted in relation to seasonal and geographical variations.

Generally, analyses of water-column components, particularly total water samples and suspended sediment samples, suffer from sampling and analytical problems that are typical of the state of the art. Results of zooplankton analyses, however, appear to be consistent with previous results and show little seasonal variation. Trace metal concentrations in shelf benthic sediments appear to be more homogeneous and lower than concentrations in slope sediments; most of the trace metals appear to be associated with weak acid-soluble phases of the sediment. Concentrations of trace metals in macroinvertebrates and demersal fishes vary over a wide range. Concentrations appear to follow both normal and log-normal distribution patterns.

SECTION 1
INTRODUCTION

The basic purposes of analyzing trace metals in water, sediment, and biological samples collected during the South Atlantic Benchmark Program were to determine ranges and trends and to determine how useful the results are for comparison with later data.

The components of the South Atlantic OCS system that were sampled and analyzed for trace metals during this study were the total water column, suspended sediments and zooplankton, benthic sediments and macroinvertebrates, and demersal fishes. All reduced data pertinent to the discussion appear in the 3.4 appendixes in Volume 6.

A. STATE OF KNOWLEDGE

1. Water Column

Considerable trace metal research has been conducted over the past several years in the South Atlantic OCS region, but much of this has pertained to concentrations in the water column and input processes that affect these concentrations. Most of this work has been conducted by Windom and coworkers at the Skidaway Institute of Oceanography, Savannah, Georgia.

Since Windom and Smith (1972) determined concentrations of Cd, Co, Ni, and Zn in continental shelf waters of the study area, and these results indicated that excursions of the Gulf Stream may affect metal levels in shelf waters, additional studies of offshore areas have addressed input mechanisms to shelf waters and regional variations in trace metal concentrations. Windom et al. (1975) investigated seasonal variations in surface-water mercury concentrations in the Georgia Bight; mean values for different seasons varied significantly, and these authors suggested that atmospheric input was responsible. More recently, Windom and Taylor (1978) reevaluated this possibility but could not unequivocally confirm this conclusion. They did point out, however, that atmospheric input of mercury is probably as inportant as river input. They suggested that Gulf Stream intrusion was the major mechanism that controlled Hg concentrations in continental-shelf water.

The concentration of the major forms of arsenic in waters of the continental shelf, Sargasso Sea, and Gulf Stream was determined by Waslenchuk (1977), who found that As(V) was the predominant form of arsenic and that its concentration varied around 1 μg/l. Dimethylarsenic was detected in most samples but represented a small percentage of the total arsenic. The second must abundant species was As(III), which varied with respect to As(V) in a way that suggested biological mediation since surface productive waters had the highest reduced arsenic concentrations.

Windom and Smith (1978a) found that concentrations of copper in surface waters vary regionally. Windom and Smith (1978b) also determined concentrations of Cu, Ni, and Zn in shelf waters, estimating the relative importance of various transfer pathways (i.e., rivers, atmosphere, and Gulf Stream intrusions) and concluding that the most important input mechanisms for these metals is intrusions.

It is clear from past studies that Gulf Stream intrusion exerts the major influence on levels of trace metals in shelf waters. Since shelf waters have a residence time of about 2.7 months (Atkinson et al., 1978), it is unlikely that total metal concentrations in the water column will reflect local inputs unless they are quite large.

2. Suspended Sediment and Zooplankton

Before the SABP study, there were no data on concentrations of trace metals in suspended sediments in the study area. Some data existed on concentrations of Cd, Cu, Pb, and Zn in zooplankton collected from the region (Windom, 1972), but it was of questionable quality since some samples had been contaminated with paint chips. However, results of mercury analysis of zooplankton samples by Windom et al. (1973), which indicate increased levels near shore, appear to be reliable.

Although there is little current information on trace metal concentrations in suspended sediments and zooplankton from the study area, research in other regions has clearly indicated the importance of these components in the transport of trace elements in the marine environment. Zooplankton, for example, had been shown to transport trace elements through vertical migrations across mixing barriers (Pearcy and Osterberg, 1967), moulting of exoskeletons (Fowler and Small, 1967), sinking of skeletal structures after death (Arrhenius, 1963), incorporation of elements into fast-sinking fecal pellets (Osterberg et al., 1963), and passage of elements to a higher trophic level (Osterberg et al., 1964). Trace metal concentrations in suspended matter, both biogenic and terrigenous, may be elevated because of chemical processes such as chelation, adsorption, precipitation, and flocculation; and small marine zooplankton often adsorb or ingest this material, concentrating the metal ions and transporting them to benthos or higher in the food chain.

The concentration of trace metals in zooplankton may vary because of the amount of the element available (Goldberg, 1957), the temperature and salinity of surrounding waters (Duke et al., 1969), population turnover rates (Martin, 1970), or the physiological state of the organisms (Haywood, 1970). Zooplankton populations will show further differences in elemental composition since each population can consist of up to 12 phyla with differing morphologies and trophic levels. Moreover, each species may exhibit vastly different chemical contents (Nicholls et al., 1959).

3. Bottom Sediments

Bottom sediments on the South Atlantic OCS are predominantly composed of coarse-grained calcareous and silicate sands (Pilkey et al., 1969; Field and Pilkey, 1969). Recent sedimentation on the shelf is restricted to the nearshore area out to a depth of approximately 10 m along the Georgia coast (Pilkey and Frankenberg, 1964).

As Volume 5 of this report indicates, Holocene sediments cap all other sediments out to at least the shelf edge. Below that depth, Miocene and Paleocene sediments predominate. These continental slope sediments are mostly composed of finer grained materials.

Since, on the whole, the shelf is relatively undisturbed and represents relict deposits, very little work has been conducted on their trace metal levels. Recently, however, trace metal studies by the USGS were conducted on 115 cores from this general area (M. Bothner, personal communication). These data are contained in Volume 5 of this report.

4. Macroinvertebrates and Demersal Fishes

The few studies of the concentrations and distributions of trace metals in macroinvertebrates of the study area have focused on inshore species although studies such as those of Windom (1972), Wolfe et al. (1976), and Kendall (1978) did consider species such as penaeid shrimp and other nektonic invertebrates that are also present in offshore waters. Because of the migratory nature of these species, however, results are questionable in terms of establishing a characteristic trace metal concentration for the biota of this region.

There has also been limited research on concentrations and distributions of trace metals in fin fish but with little emphasis on demersal species, although studies by Windom et al. (1973) and Cross et al. (1973) contained some results of trace metal analyses on fin fish such as *Centropristes striatus, Decapterus punctatus,* and *Lagodon rhomboides,* all common offshore demersal species.

SECTION 2
MATERIALS AND METHODS

Trace metal analyses of zooplankton, suspended matter, sediments, and benthic organisms were carried out by atomic absorption spectrophotometry and neutron activation using the methodologies cited in Volume 2 of this report.

SECTION 3
RESULTS

A. WATER COLUMN (TOTAL TRACE METAL CONCENTRATIONS)

During the SABP study, water samples were collected from the surface at six stations (1D, 3D, 5B, 5E, 5G, and 7D) on each of four seasonal cruises in 1977 and analyzed for cadmium, chromium, copper, iron, lead, nickel, and zinc by atomic absorption spectrophotometry. The results of these analyses are presented in Appendix 3.4B of Volume 6.

In most cases, cadmium, chromium, and nickel were below detection limits (approximately 0.038, 0.063, and 0.2 μg/l, respectively). Copper, iron, lead, and zinc were generally higher than expected. Copper concentrations, for example, ranged from 0.60 to 12.5 μg/l, whereas the mean value reported by Windom and Smith (1978b) for waters in the Georgia Bight was 0.17 ±0.06 μg/l; likewise, the SABP's reported range for zinc concentration was 3.78 to 33.3 μg/l, which was higher than the mean value of 1.40 ±0.2 μg/l reported by Windom and Smith (1978b).

These results make it clear that water samples for total trace metal analysis were contaminated for copper, iron, lead, and zinc. The data are, therefore, of little use for future comparisons.

B. ZOOPLANKTON TRACE METAL COMPOSITION

Zooplankton, important members of marine food webs, are predominantly filter feeders that use suspended particulates for energy. They have been found to indiscriminantly use particles ranging in size from 1 to 50 μm and to effectively sweep water volumes ranging from 72 to >2000 ml/24 hr/mg dry weight (Jorgenson, 1966). Manheim et al. (1972) emphasized the importance of filter-feeding zooplankton for the extraction of biogenic and terrigenous particles from the upper layers of the ocean to form larger, rapidly settling fecal aggregates. Other authors have also noted the potential importance that zooplankton fecal pellets and other metabolic products might have in transporting trace elements (Fowler, 1977), radioactive nuclides (Higgo et al., 1977), and other particulates both in and through the deep ocean to the sediment/water interface (Smayda, 1971; Schrader, 1971; Honjo, 1977). This evidence would indicate that zooplankton could be instrumental in effecting the distribution of suspended matter and, therefore, trace elements in the hydrosphere. Little work has been done, however, to evaluate whether changes in the composition of suspended matter affect the trace metal composition of zooplankton.

To evaluate seasonal changes in their chemical composition, zooplankton were collected in the winter, spring, summer, and fall of 1977 in the southeastern Atlantic Bight. On each cruise, a single sample was taken in 202-μm and 505-μm nets (method detailed in Volume 2) at station D on transects 1, 6, and 7 and at station E on transects 2, 4, and 5 of the continental shelf (Figure 3.4-1). Also, to evaluate the variability in the zooplankton trace metal composition and to establish some limits for changes in composition from one location to the next, which might be considered statistically significant, four time-series stations were sampled. The multiple-net tows were made at stations E and I on transect 5 and at stations D and H on transect 6 (Figure 3.4-1); at each of the latter two stations, seven samples were taken.

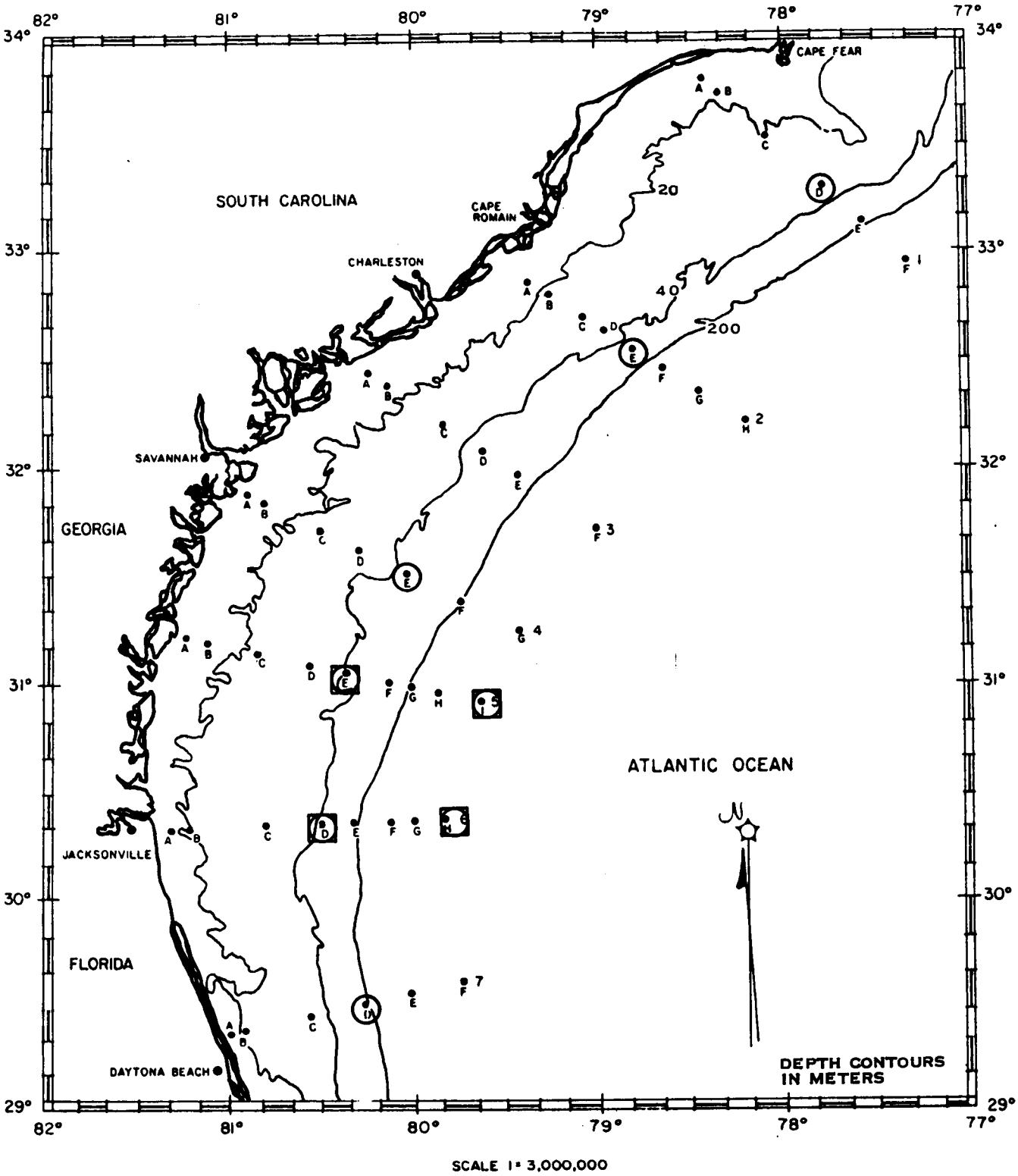

Figure 3.4-1. Station Locations for Zooplankton Sampling Seasonally (○) and in Summer Time Series (□)

From concentrations of cadmium, chromium, copper, iron, lead, nickel, and zinc in zooplankton from the southeastern Atlantic Bight (Volume 6), it was apparent that there were large variations in trace metal composition for materials collected on transects 1, 2, 4, 5, 6, and 7 during winter, spring, summer, and fall and during the summer time-series cruises on transects 5 and 6. Variation in the elemental composition of zooplankton was not expected since different zooplankton species can have very different elemental contents (Nicholls et al, 1959) and may have different means with which to concentrate a particular element. The rates of uptake via these pathways, in turn, depend on the amount of a given element available for uptake (Goldberg, 1957), various physical factors such as temperature and salinity (Duke et al, 1969), population turnover rates (Martin, 1970), and the physiological state of the organisms [e.g., the difference between senescent and growing diatoms (Gross and Zuethen, 1948; Hayward, 1970)].

The mean elemental composition of zooplankton from the southeastern Atlantic Bight is presented in Table 3.4-1 and compares most favorably with results reported by Martin and Knauer (1973) for the open Pacific and by Betzer et al. (1976, 1978) for the eastern Gulf of Mexico, although there are some obvious discrepancies. The mean concentrations of lead and zinc in zooplankton were less than half those reported by all other investigators. In addition, the mean concentrations of cadmium, chromium, copper, iron, and nickel were the lowest that have been reported. Normally, this would be an indication that the other investigators contaminated their samples and that SABP sampling had been done more carefully; unfortunately, however, the recoveries of cadmium, chromium, copper, lead and nickel from National Bureau of Standards bovine liver and orchard leaves were either so variable or so low that no such claim can be made (Volume 2). Given this situation, there is no basis for further discussion of the data for these five elements. The only elements for which there were consistently good recoveries from NBS standards were iron and zinc. Thus, these are the ones that it is reasonable to compare with previously published works that present analytically sound data.

Table 3.4-1. Comparison of 1977 SABP Zooplankton Metal Concentration With Other Studies

	Averages (ppm dry weight)[a]						
Study	Cd	Cr	Cu	Fe	Ni	Pb	Zn
SABP (TI, 1977)	2.8	0.8	7.2	92	2.6	0.94	37
Eastern Pacific (Martin and Knauer, 1973)	2.3	<1	11.5	100	8.4	2.1	180
South Texas OCS (Horowitz and Presley, 1977)	2.9	5.6	13.4	725	4.6	8.0	103
Eastern Gulf of Mexico OCS (Betzer and Peacock, 1976)	7.1	0.8	18.0	222	2.8	2.2	–
Clyde Sea (Topping, 1972)	1.0	–	16.2	–	–	15.0	228
Eastern Gulf of Mexico OCS (Betzer et al., 1978)	2.2	0.8	–	146	3.2	3.9	76

[a]Averages for material collected in 202-μm nets.

Table 3.4-2. Mean Metal Concentrations and Single Standard Deviations for Zooplankton Collected in 202-μm Nets During Time Series, Summer 1977

	Concentration (μg/l)						
Station	Cd	Cr	Cu	Fe	Ni	Pb	Zn
5E	0.40 ± 0.36 (0.75)	1.2 ± 2.5 (0.52)	10.0 ± 4.6 (1.1)	74 ± 59 (141)	4.2 ± 2.7 (4.0)	0.44 ± 0.32 (0.41)	42 ± 14 (38)
5I	0.16 ± 0.13	0.44 ± 0.15	11.3 ± 5.3	96 ± 56	5.7 ± 2.4	0.87 ± 0.99	40 ± 19
6D	0.32 ± 0.30 (0.41)	0.46 ± 0.28 (0.13)	7.9 ± 1.1 (2.9)	49 ± 11 (103)	3.4 ± 0.3 (1.4)	1.3 ± 1.5 (0.44)	30 ± 18 (21)
6H	0.26 ± 0.15	0.86 ± 0.20	14.1 ± 3.8	84 ± 51	6.6 ± 2.8	0.72 ± 0.64	41 ± 7

[a]Values in parentheses are those gathered from a single sample during the regular summer sampling.

It is obvious from Table 3.4-1 that the mean iron and zinc levels for zooplankton from the southeastern Atlantic Bight were the lowest ever reported. The iron and zinc data were examined for seasonal and geographic trends but none were evident; in fact, no statistically significant seasonal or regional trends were found when the data were examined quantitatively. We are unaware of any reports of seasonal trends in zooplankton zinc concentrations, but Betzer and Peacock (1976) reported large increases in zooplankton iron concentrations during the winter in the Gulf of Mexico, ascribing the increased iron levels to increased levels of iron-rich suspended matter that had been stirred up during winter storms. Given the large amounts of fine-grained, iron-rich suspended matter that was present over the southeastern continental shelf during the winter of 1977, it is surprising that no increases in zooplankton iron were noted.

The trace metal data from the zooplankton time series during summer 1977 are presented in Table 3.4-2. Cadmium, chromium, copper, lead, and nickel are not discussed because of their poor and variable recoveries. Iron and zinc single standard deviations about the mean averaged 58 and 38%, respectively. It is significant that the iron values for the single samples collected at stations 5E and 6D during the summer were higher than a single standard deviation above the mean concentration in the time series. In contrast, there was good agreement between the mean metal concentrations established during the time series and the concentrations noted during a single sampling at the same location during the summer.

The trace metal data for cadmium, chromium, copper, iron, lead, nickel, and zinc from zooplankton gathered in 202- and 505-μm nets were compared. No statistically significant compositional difference was evident. Thus, the herbivores and carnivores caught in the two nets had essentially the same trace metal concentrations (Table 3.4-3).

C. SUSPENDED SEDIMENTS

1. Suspended Particle Loads

Suspended particle loads can be valuable indicators of the various processes affecting their horizontal, vertical, and seasonal distribution. The mean and single standard deviations for surface and bottom suspended loads in inshore and offshore locations (Figure 3.4-2) on the southeastern Atlantic continental shelf during winter, spring, summer, and fall 1977 are

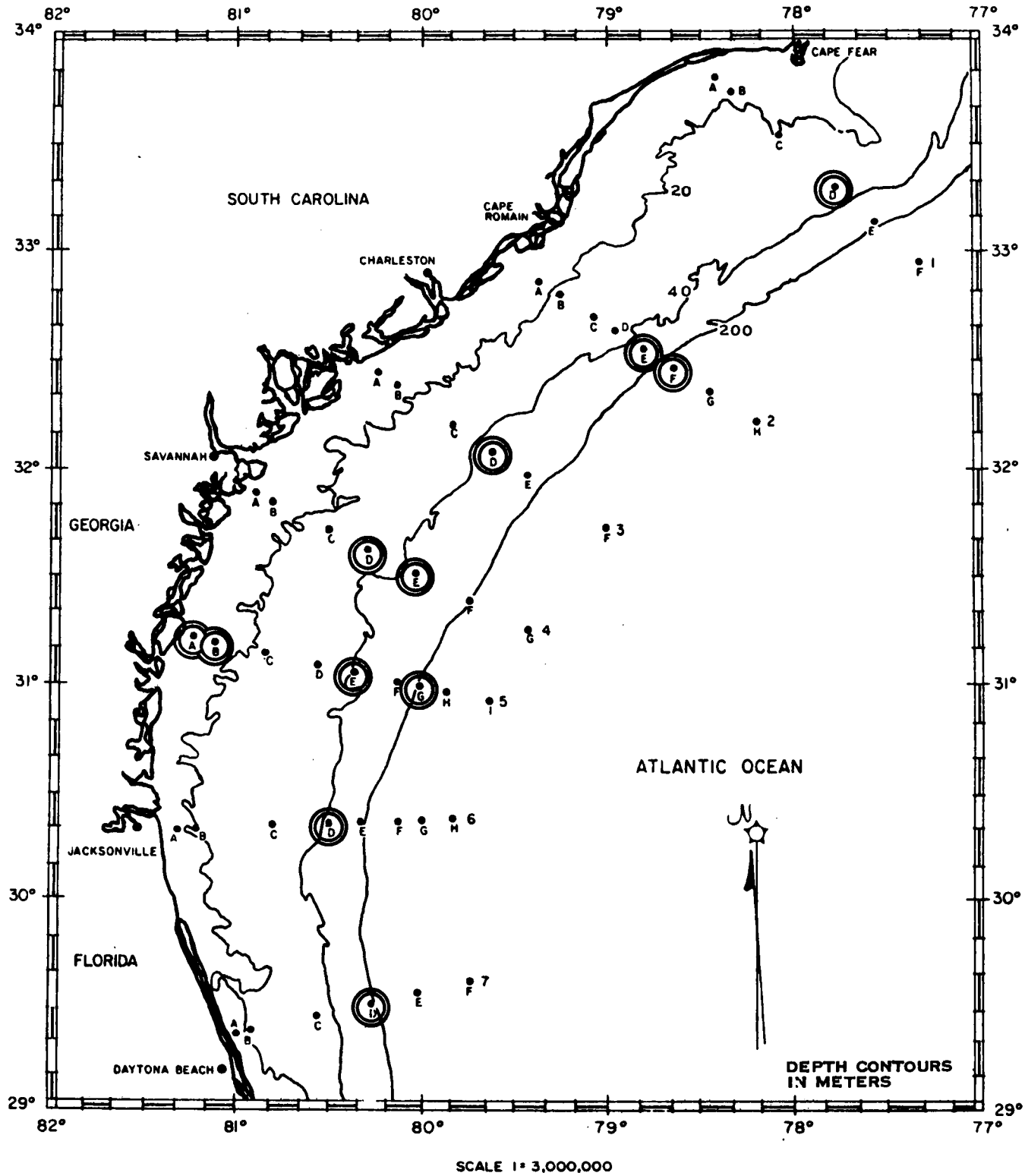

Figure 3.4-2. Station Locations for Seasonal Collections of Suspended Matter, 1977

Table 3.4-3. Seasonal Zooplankton Trace Metal Mean Concentration

Net Mesh (μm)	Season	Concentration (μg/g) Cd	Cr	Cu	Fe	Ni	Pb	Zn
202	1	0	1.55 ±0.65	5.4 ±1.65	112 ±100	0	0.69 ±0.55	31.4 ±16.5
505	1	0	1.18 ±0.55	4.90 ±2.05	49.7 ±56.7	0	0.64 ±0.46	34.2 ±18.4
202	2	2.17 ±0.72	0.17 ±0.07	16.2 ±13.3	98.8 ±23.4	1.79 ±1.53	2.10 ±2.50	40.7 ±12.0
505	2	6.05 ±5.24	0.16 ±0.07	16.5 ±16.4	102 ±37.2	1.35 ±1.08	2.20 ±3.80	45.5 ±18.1
202	3	0.51 ±0.20	0.32 ±0.19	1.86 ±0.95	94.5 ±36.4	3.72 ±2.19	0.35 ±0.18	32.7 ±18.3
505	3	0.57 ±0.22	0.94 ±1.20	1.66 ±0.79	123 ±88.2	2.64 ±1.37	0.29 ±0.28	30.2 ±10.3
202	4	5.67 ±7.20	1.04 ±1.51	5.42 ±2.57	74.5 ±65.9	2.41 ±1.83	0.62 ±0.31	44.8 ±20.8
505	4	4.97 ±1.55	1.62 ±1.72	4.20 ±1.99	94.6 ±16.4	1.68 ±2.13	0.19 ±0.04	50.6 ±17.7

presented in Table 3.4-4. Seasonal and regional trends were evident. Generally, the elevated suspended loads in offshore locations during winter and spring appeared to be related to storms and/or the impingement of the Gulf Stream on the outer shelf, which result in substantial sediment/water interactions and subsequent resuspension of fine-grained bottom materials. While storms can influence the concentrations of suspended matter in inshore areas (stations 5A and 5B), it was apparent from the bottom-water nutrient data that the Gulf Stream never moved very close to shore on transect 5 and appeared to focus its energy on the outer shelf. Thus, the suspended particle loads in both surface and bottom waters were significantly higher (at the 95% confidence level) during winter and spring than during the other seasons. In addition, there were marked regional differences in suspended particle loads; for the most part, they reflected nearness to shore. Thus, the inshore stations on transect 5 (A and B) always had much higher suspended loads than did offshore stations. There are other inputs that are important determinants of the concentration of suspended particles, however, including biological productivity, river input, sediment/water interactions, and water masses—but these require chemical data for resolution. They are discussed later.

During the winter and spring of 1977, there was evidence of increased suspended loads over the entire outer shelf (Table 3.4-4). Suspended loads for winter and spring were shown to be more than twice those found on the outer shelf during summer and fall. The difference between the winter-spring and summer-fall means was significant at the 95% confidence level. In addition, the suspended loads found on the inner shelf (stations 5A and 5B) were consistently higher than those for the offshore stations (Table 3.4-4); this was true for all seasons, but especially so during spring when inshore salinities were low, indicating that the abundant suspended material in surface waters was derived from terrigenous input.

The nitrate data from the water-column cruises provided evidence that the Gulf Stream had moved over the outer shelf on at least one transect in all except fall sampling. It is important to point out, however, that the Gulf Stream may have moved over the shelf in the fall but simply was not present during the water-column sampling. The Gulf Stream's presence was associated

Table 3.4-4. Seasonal Averages of Suspended Particle Loads Over Southeastern Atlantic Continental Shelf

	Averages (μg/l)[a, f]			
	Inshore[b]		Offshore[c]	
Season	Surface[d]	Bottom[e]	Surface	Bottom
Winter	2,730 ± 1,708	3,116 ± 977	969 ± 380	1,040 ± 564
Spring	12,273 ± 13,473	9,023 ± 3,376	652 ± 497	994 ± 870
Summer	1,154 ± 727	1,373 ± 455	267 ± 110	351 ± 112
Fall	1,099 ± 111	3,858 ± 3,963	234 ± 171	280 ± 138

[a]Numbers following averages are single standard deviations about mean.

[b]Stations 5A and 5B.

[c]Stations 1D, 2E, 2F, 3D, 4D, 4E, 5E, 5G, 6D, and 7D.

[d]Surface samples gathered at 3m.

[e]Bottom samples collected from 5m above bottom.

[f]Values accurate to ±1 μg/l

with extremely high near-bottom suspended loads: for example, during winter and spring samplings at station 7D when the Gulf Stream was present, near-bottom suspended loads were 2,525 and 3,158 μg/l, respectively; during summer and fall when the Gulf Stream was offshore, near-bottom suspended loads dropped to 255 and 362 μg/l, respectively. The nine- to tenfold changes in suspended loads imply that the Gulf Stream is an active erosional force that moves substantial amounts of material seaward during its onshore-offshore cycles over the shelf. Then, too, there is some supporting evidence for this interpretation from the seasonal sediment grain-size analysis at station 7D; there, the weight percent of material in the 3ϕ and 4ϕ fractions dropped significantly between the winter and summer samplings. This trend toward decreasing fine fractions in surface sediments between winter and summer was observed also in the 3ϕ and 4ϕ fractions of surface sediment at stations 1D and 2E; these too were locations where the Gulf Stream impinged on the shelf in either winter or spring.

In marked contrast to the substantial seasonal changes in the fine fractions on the outer shelf, no change was indicated on the inner shelf (station 5B): there was no perceptible change in the 3ϕ or 4ϕ fraction between summer and winter. This is consistent with our hypothesis about the Gulf Stream as a causative agent, as it never reached this location during any of its shoreward incursions. Thus, surface sediments on the outer portions of the southeastern Atlantic continental shelf that are impacted by the Gulf Stream display seasonal changes not evident on the inner portions of this shelf that are outside its direct influence. It is important to note that some of the seasonal grain-size variability for outer-shelf locations could be because the sediments, sampled at somewhat different locations, displayed significant variations in the 3ϕ and 4ϕ fractions. While this may have contributed to the changes noted, it would be remarkable if these random changes corresponded with known physical events.

Seasonal changes in suspended particulate matter were noted also at stations such as 1D and 6D where there was never any evidence of Gulf Stream intrusions; however, the average increase in suspended matter at stations 1D and 6D was approximately twofold instead of the nine- to

tenfold differences in suspended matter in near-bottom waters at station 7D between winter-spring and summer-fall samplings. This emphasizes that sediment/water interactions characteristic of the winter-spring period were accentuated by Gulf Stream intrusions.

In summary, seasonal and regional differences were found in suspended loads on the South Atlantic OCS in 1977. The three major sources of suspended material in this area are: sediment/water interactions (including storms and Gulf Stream intrusions), river inputs, and biological productivity. As noted previously, the large suspended loads found over this extensive continental shelf during winter and spring were probably the result of intense sediment/water interactions during storms and Gulf Stream incursions. However, gravimetric data can be used only to infer a probable source of any suite of particles. Chemical analysis is needed to discriminate the most important sources of particle suites.

2. Suspended Sediment Composition

The data for suspended matter composition (Volume 6) show some major changes between winter-spring and summer-fall samplings. These seasonal differences and trends are evident also in the compositional data for suspended material over the southeastern continental shelf. As in the case of the zooplankton trace metal analyses, the suspended particulate matter analyses must be viewed in the context of elemental recoveries from standard materials. After an exhaustive examination of the available data on standards and samples (Volume 2), the most conservative position was to use particulate aluminum only as representing the environment in question; the other data were suspect because of problems with our analytical precision and accuracy or simply because the concentrations were below the detection limit for the method employed (Volume 6). In addition, as has been discussed in Volume 2, the lack of agreement between atomic absorption and neutron activation analyses of the same sample (zinc is the only exception) rendered other neutron activation data on suspended particulate material unusable. This indicates that the suspended particulate trace metal data must be viewed with serious suspicion. These data must be subjected to the test of future work to determine their accuracy.

Tables 3.4-5 and 3.4-6 present data for particulate aluminum and particulate organic carbon, respectively. Regionally, concentrations of particulate aluminum were always higher in suspended material from the inner shelf than in samples from the outer shelf; in contrast, particulate organic carbon tended to be higher on the outer shelf than on the inner shelf. This is consistent with the work of Manheim et al. (1970) in surface waters of this same area. Simply, the organic-rich matter on the outer shelf was not diluted by the terrigenous input that dominated inner-shelf waters. The smallest contrast in particulate organic carbon was noted during the winter when physical processes (storms and intrusions) were the primary controls over the distribution and composition of suspended matter. During the period of highest freshwater input to the shelf (spring), there was a large difference (16 fold) between inner and outer shelf waters because the inner shelf was dominated by aluminosilicates; POC near shore averaged 2.5%, versus 17% on the outer shelf.

Particulate organic carbon also showed seasonal trends: both inner and outer shelf samples had low POC percentages in the winter-spring period and highs during summer-fall. This was a reflection of decreasing sediment/water interaction and freshwater input, as well as the increasing importance of biological activity to suspended matter over the shelf during summer-fall.

Table 3.4-5. Seasonal Averages of Particulate Aluminum Concentrations in Inner- and Outer-Shelf Locations Over South Atlantic Continental Shelf

	Averages (μg/l)[a]			
	Inner Shelf[b]		Outer Shelf[c]	
Season	Surface	Near Bottom	Surface	Near Bottom
Winter	974 ± 433	929 ± 185	153 ± 100	163 ± 95
Spring	2,692 ± 2,939	2,160 ± 2,135	164 ± 50	135 ± 84
Summer	14 ± 12	18 ± 11	2.6 ± 1.6	1.9 ± 1.5
Fall	33 ± 17	18 ± 11	3.4 ± 1.4	2.5 ± 1.3

[a]Data presented as mean plus or minus a single standard deviation.
[b]Stations 5A and 5B.
[c]Stations 1D, 2E, 2F, 3D, 4D, 4E, 5E, 5G, 6D, and 7D.

Table 3.4-6. Seasonal Averages of Particulate Organic Carbon at Inner- and Outer-Shelf Locations Over South Atlantic Continental Shelf

	Averages (%)[a]			
	Inner Shelf[b]		Outer Shelf[c]	
Season	Surface	Near Bottom	Surface	Near Bottom
Winter	5.2 ± 3.5	3.7 ± 0.7	8.0 ± 4.7	8.2 ± 4.9
Spring	2.9 ± 2.4	2.2 ± 0.2	19.7 ± 11.1	14.8 ± 12.7
Summer	15.9 ± 6.9	17.1 ± 0.6	34 ± 12	40.5 ± 21.8
Fall	34.4 ± 7.5	15 ± 11	77 ± 42	55 ± 20

[a]Data as percent of total suspended load plus or minus a single standard deviation.
[b]Stations 5A and 5B.
[c]Stations 1D, 2E, 2F, 3D, 4D, 4E, 5E, 5G, 6D, and 7D.

Unfortunately, since neither weak acid-soluble calcium (an indicator of coccolithophores) nor amorphous silica (an indicator of diatoms) was measured, it is not possible to determine phytoplankton contribution to suspended particle composition in the Georgia Bight.

The Gulf Stream intrusions during winter and spring at station 7D had a major effect on the suspended load as well as on the suspended particle composition. The particulate aluminum data for the near-bottom samples represented 8.9 and 8.6%, respectively, of the total suspended load, showing that substantial amounts of bottom sediment were stirred up during the winter and spring. The corresponding values of particulate aluminum in near-bottom waters during summer and fall were 0.15 and 0.30%, respectively. Thus, approximately 30 times more clay was in suspension while the Gulf Stream was present. As expected, near-bottom POC values dropped at station 7D during the winter and spring intrusions (<1% and 2.5%, respectively), whereas summer and fall values were 29% and 36%, respectively. Although the seasonal data set is incomplete, station 3D showed the same relationship between Al_p, POC, and Gulf Stream intrusions.

Inshore regions (stations 5A and 5B) of the southeastern Atlantic shelf were not influenced by the Gulf Stream; intrusions seemed to be restricted to the outer shelf. There were some interesting seasonal changes in suspend matter composition, however, and there was good evidence that the concentrations and composition of suspended matter during winter-spring were quite different from summer-fall (Tables 3.4-5 and 3.4-6). On the average, concentrations of particulate aluminum were 50 to 100 times greater during winter-spring than during summer-fall. This is consistent with what is known of the atmospheric and hydrologic character of this continental shelf, which changes markedly from winter-spring to summer-fall. First, storms are prevalent during winter and spring, causing major sediment-water interactions; this has been noted in the seasonal distributions for the outer portions of this continental shelf. In addition, the hydrologic cycle, that brings large volumes of fresh water to the shelf during the winter-spring period (see salinity data in Volume 6), also accentuates the contrast between winter-spring and summer-fall samples. It is well known that surface seawater is depauperate in particulate aluminum and that fresh water carries large concentrations of aluminum-rich terrigenous material. Salinity distributions during the four seasonal samplings clearly showed that the maximum freshwater input to the southeastern shelf occurred in the winter-spring period. It is not surprising, therefore, that the concentrations of particulate aluminum were extremely high during winter and spring and low during summer and fall.

The impact of winter storms and freshwater inputs on the inner shelf was evident also in the particulate organic carbon data (Table 3.4-6): when freshwater input was high and there was a pronounced atmospheric interaction with the ocean, inorganic-rich material dominated suspended particle suites; when these inputs and interactions decreased (i.e., summer-fall), the inner-shelf system was dominated by organic materials reported by Manheim et al. (1970) to dominate suspended particle loads in these waters.

D. BOTTOM SEDIMENTS

Bottom sediments were collected at 25 stations on transects 1, 2, 5, and 7 (Figure 3.4-3) during each of the four seasons in 1977. Six box cores were taken at each station, and subcores from each were pooled for trace metal analyses. Once during the study, subcores from all six box cores collected at a given station were analyzed separately. All samples were analyzed for trace metals in the weak acid-soluble fraction of the sediment; only 25% of the samples were analyzed for total metal content. All data for trace metal concentrations in sediments are presented in Appendix 3.4D of Volume 6.

The results (Table 3.4-7) suggest that metal levels generally are relatively similar at all shelf stations but that slope stations have higher concentrations of cadmium, chromium, iron, and nickel. The results for vanadium show an order-of-magnitude decrease in concentration between spring samples and summer samples, suggesting an analytical artifact. Aluminum results show a relatively wide variability as well, possibly also because of analytical procedures, since both of these elements were determined by neutron activation analysis (NAA). Barium in all samples was below detection by NAA (<50 $\mu g/g$). Calcium, which was determined only in fall samples, ranged from 0.4 to 26%, exhibiting highest concentrations on the more southerly transects.

Most of the trace metals showed a strong correlation with grain size or percent clay and silt (pan fraction), which are related (Appendix 3.4D). Metals also correlated with bottom depth, to which grain size is related. For example, a plot (Figure 3.4-4) of the average percent clay and silt in sediments by station for the four sampling transects indicates that slope stations generally had

Table 3.4-7. Acid-Soluble Trace Metals in Bottom Sediments

Mean and Standard Deviation (Dry-Weight Basis)

Transect	Station[a]	Cruise	Aluminum[c] (μg/g)	Cadmium[b] (μg/g)	Chromium[b] (μg/g)	Copper[b] (μg/g)	Iron[b] (μg/g)	Lead[b] (μg/g)	Nickel[b] (μg/g)	Vanadium[c] (μg/g)	Zinc[b] (μg/g)
1	B	2	3.5 ± 0.5	0.022 ± 0.011	4.2 ± 0.6	0.70 ± 0.64	0.72 ± 0.35	0.81 ± 0.15	0.34 ± 0.04	13 ± 3	3.4 ± 0.8
	C	2	2.2 ± 0.2	0.024 ± 0.007	3.5 ± 0.2	0.41 ± 0.07	0.85 ± 0.55	0.71 ± 0.07	0.20 ± 0.08	12 ± 2	2.1 ± 0.1
	D	2	0.9 ± 0.8	0.021 ± 0.009	2.5 ± 2.5	0.17 ± 0.19	0.35 ± 0.42	0.26 ± 0.33	0.21 ± 0.09	10 ± 8	0.8 ± 0.7
	E	2	2.5 ± 0.5	0.031 ± 0.005	5.3 ± 0.8	0.41 ± 0.15	0.60 ± 0.55	0.85 ± 0.46	0.38 ± 0.11	14 ± 5	1.8 ± 0.6
	F	2	0.2 ± 0.6	0.048 ± 0.016	8.9	0.60 ± 0.40	0.29 ± 0.30	0.45 ± 0.57	0.23 ± 0.38	1.9 ± 13	0.7 ± 1.4
2	B	3	0.3 ± 0.3	0.032 ± 0.020	1.1 ± 0.3	0.16 ± 0.05	1.00 ± 0.11	0.81 ± 0.17	0.81 ± 0.17	1.4 ± 2.5	1.7 ± 0.4
	C	2	1.6 ± 0.7	0.010 ± 0.004	2.3 ± 1.1	0.22 ± 0.14	0.54 ± 0.30	0.96 ± 0.59	0.24 ± 0.26	17 ± 3	1.5 ± 0.5
	D	2	3.6 ± 0.6	0.011 ± 0.004	3.5 ± 1.7	0.23 ± 0.14	0.91 ± 0.16	1.68 ± 0.17	0.84 ± 0.13	29 ± 2	2.4 ± 0.3
	E	2	1.2 ± 0.7	0.022 ± 0.010	3.9 ± 2.4	0.20 ± 0.10	0.16 ± 0.15	0.89 ± 0.53	0.37 ± 0.04	14 ± 3	1.0 ± 0.3
	F	2	1.1 ± 0.1	0.021 ± 0.008	6.1 ± 1.6	0.14 ± 0.10	0.37 ± 0.47	0.83 ± 0.32	0.27 ± 0.09	14 ± 3	1.7 ± 2.5
	G	2	13.8 ± 9.0	0.039 ± 0.019	5.3 ± 2.1	0.19 ± 0.18	0.38 ± 0.38	0.68 ± 0.88	1.94 ± 0.61	92 ± 67	7.2 ± 4.3
	H	2	0.8	0.074	13.1	0.09	0.51	0.35	3.10	---	4.6
5	B	3	0.08 ± 0.04	0.027 ± 0.015	0.5 ± 0.2	0.20 ± 0.18	0.26 ± 0.04	0.56 ± 0.13	0.56 ± 0.14	0.9 ± 0.4	1.3 ± 0.4
	C	3	0.08 ± 0.03	0.050 ± 0.014	1.5 ± 0.2	0.28 ± 0.13	0.19 ± 0.01	0.67 ± 0.32	0.67 ± 0.32	1.3 ± 0.2	1.4 ± 1.0
	D	3	0.10 ± 0.04	0.040 ± 0.018	3.7 ± 1.1	0.15 ± 0.12	0.98 ± 0.66	0.85 ± 0.16	0.86 ± 0.17	1.8 ± 0.5	1.9 ± 0.6
	E	3	0.14 ± 0.07	0.039 ± 0.011	4.0 ± 1.5	0.13 ± 0.09	1.07 ± 0.78	0.60 ± 0.17	0.33 ± 0.11	2.1 ± 0.8	1.9 ± 0.7
	F	3	0.10 ± 0.01	0.023 ± 0.009	3.7 ± 0.3	0.07 ± 0.01	0.34 ± 0.05	0.58 ± 0.14	0.25 ± 0.01	1.5 ± 0.1	1.3 ± 0.1
	G	3	0.11 ± 0.04	0.025 ± 0.013	6.0 ± 0.8	0.11 ± 0.02	0.82 ± 0.03	0.50 ± 0.22	0.38 ± 0.04	2.2 ± 0.8	1.8 ± 0.2
	H	3	0.18 ± 0.05	0.023 ± 0.018	11.2 ± 1.1	0.33 ± 0.12	0.93 ± 0.08	0.92 ± 0.56	0.34 ± 0.40	3.0 ± 1.2	2.9 ± 0.4
	I	3	1.1 ± 0.5	0.145 ± 0.088	20.1 ± 16.6	0.50 ± 0.40	2.89 ± 2.63	0.44 ± 0.43	0.78 ± 0.38	7.3 ± 1.8	7.1 ± 5.3
7	B	3	0.18 ± 0.04	0.038 ± 0.013	3.7 ± 1.5	0.05 ± 0.06	1.03 ± 0.49	0.76 ± 0.34	0.28 ± 0.25	2.2 ± 0.3	1.6 ± 0.6
	C	3	0.10 ± 0.06	0.023 ± 0.016	3.3 ± 3.4	0.0058 ± 0.002	0.54 ± 0.39	0.10 ± 0.08	0.11 ± 0.07	2.0 ± 0.9	1.4 ± 0.5
	D	3	0.09 ± 0.15	0.015 ± 0.003	2.4 ± 2.9	0.08 ± 0.11	0.20 ± 0.38	0.54 ± 0.65	0.09 ± 0.02	2.1 ± 2.1	0.8 ± 1.0
	E	3	0.04 ± 0.10	0.023 ± 0.007	1.6 ± 2.1	0.16 ± 0.23	0.13 ± 0.32	0.20 ± 0.40	0.05 ± 0.08	0.2 ± 0.2	0.9 ± 1.2
	F	4	0.82 ± 0.17	0.184 ± 0.081	11.0 ± 2.0	0.49 ± 0.24	3.75 ± 0.60	0.30 ± 0.10	2.5 ± 0.7	8.1 ± 2.0	7.7 ± 1.1

[a]Six subcores each station.

[b]Analyzed by atomic absorption spectrophotometry.

[c]Analyzed by neutron activation analysis.

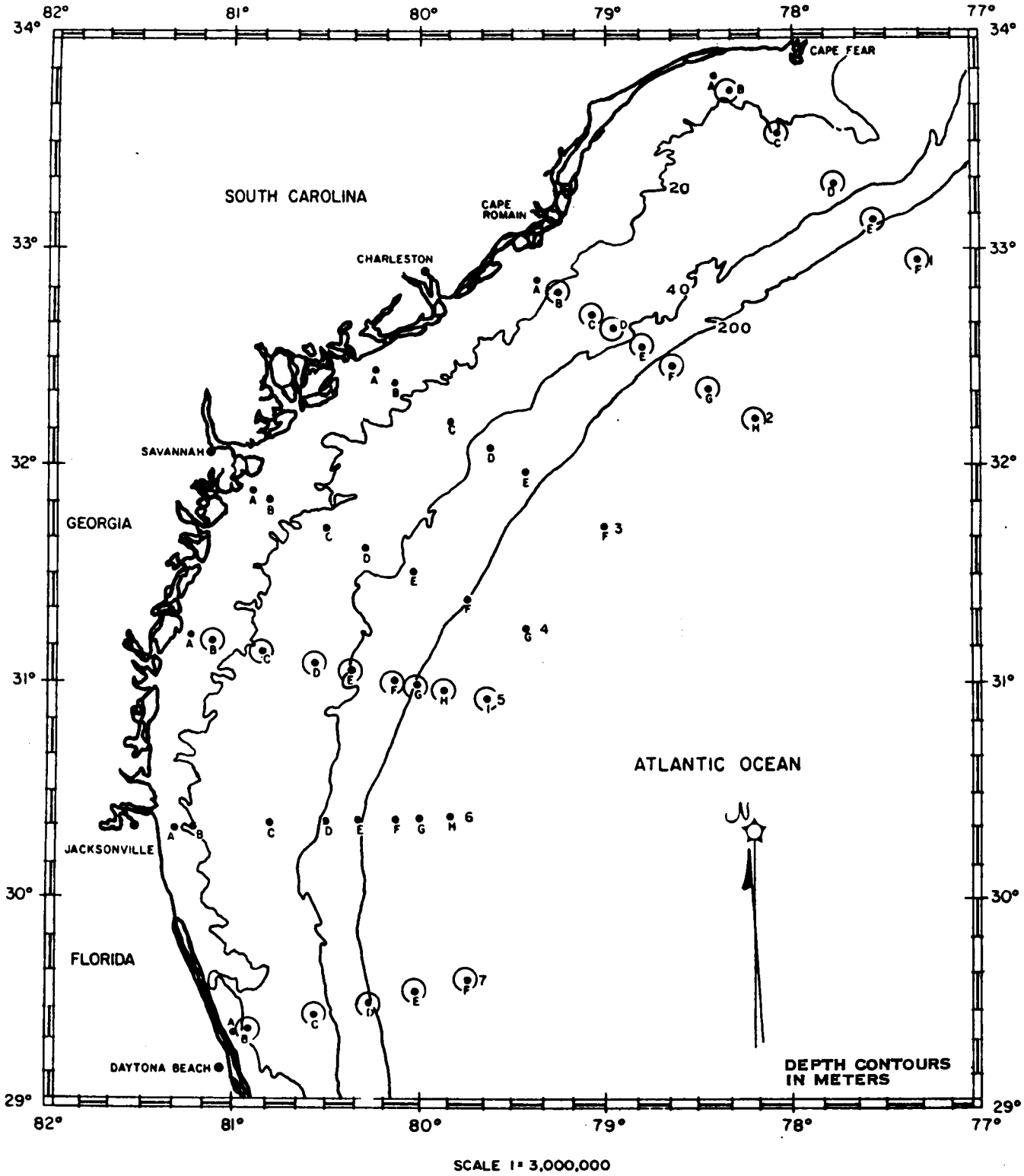

Figure 3.4-3. Bottom Sediment Sampling Stations

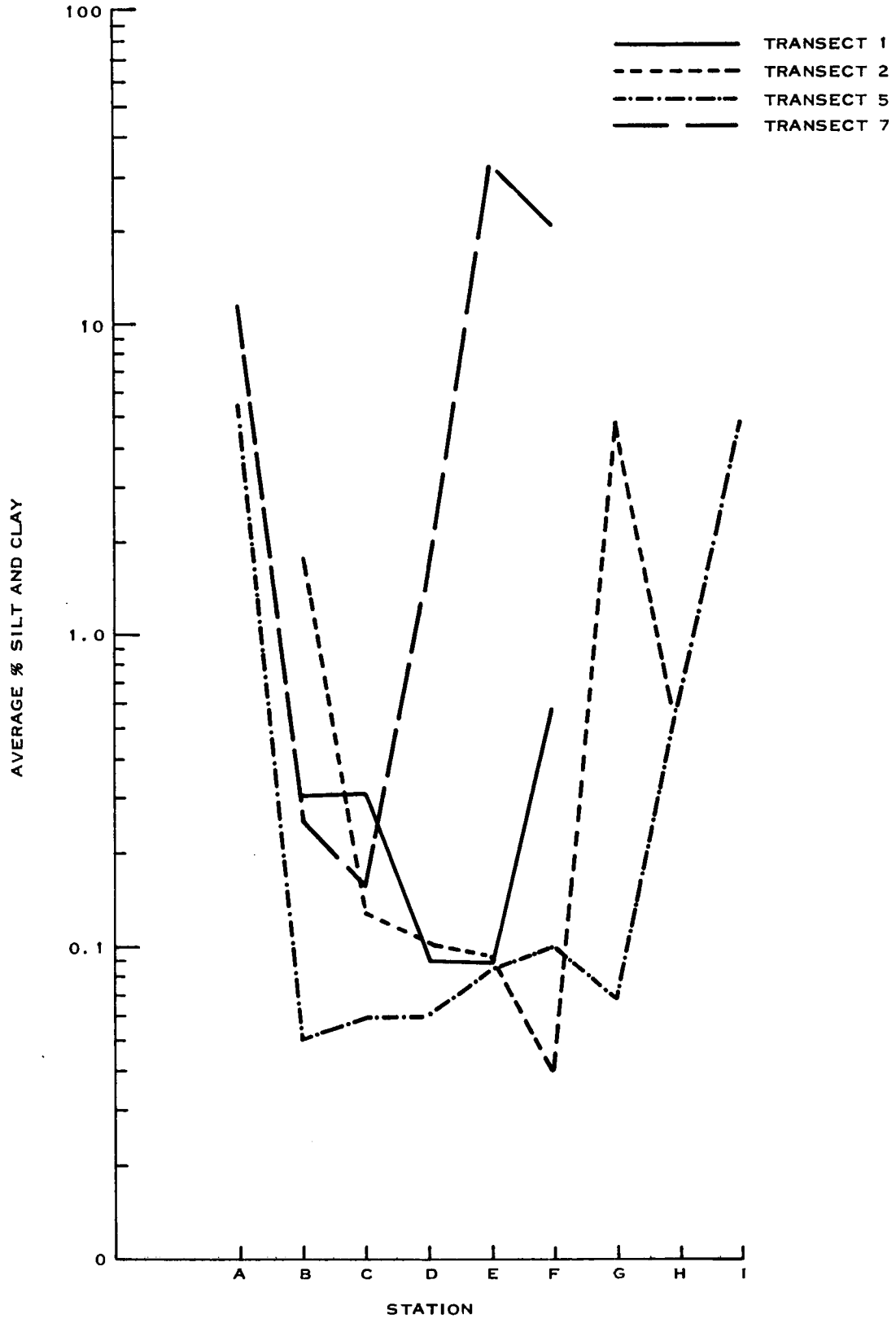

Figure 3.4-4. Average Percent of Clay and Silt in Bottom Sediments

the highest levels and that shelf-station levels were lower and relatively constant around 0.1 to 0.2%. Metals followed a similar trend, indicating that two sedimentary provinces are represented by these data.

The chemical homogeneity of the sediment can be evaluated by comparing the mean concentrations of the weak acid-soluble trace metals determined from the individual analysis of the subcores from the six box cores taken at a station during one season with the means determined from the analysis of pooled samples from the other three seasons. Sediment chemistry is not expected to vary seasonally, but the location of seasonal samples from a given station will vary because of uncertainties in ship positioning. If sediments are inhomogeneous, this should be reflected in the trace metal chemistry.

This approach was taken using the data from the four inner-shelf stations (1B, 2B, 5B, and 7B), the four middle-shelf stations (1D, 2D, 5D, and 7D), and the four slope stations (1F, 2G, 5I, and 7F). A mean concentration for each trace metal was calculated from the pooled sediment data at each station for three seasons and plotted as the ordinate value in the graphs in Figures 3.4-5 and 3.4-6. Similarly, a mean concentration for each trace metal was calculated from individual sediment data for the fourth season and plotted as the abscissa. Closely grouped stations may be considered as an indication that sediment trace metal concentrations are homogeneous. Results for chromium, iron, nickel, and zinc indicated that shelf sediments (inner and middle) were homogeneous with respect to these metals, since the variations between the means were small (Figure 3.4-5). Slope sediments, however, appeared to be inhomogeneous with respect to these metals since the seasonal mean concentrations deviated considerably from the subcore means.

Cadmium may be distributed in sediments similar to zinc, showing homogeneity on the shelf and inhomogeneity on the slope. Generally, however, the seasonal mean concentrations of this metal deviate from the mean concentrations of the subcores in both shelf and slope sediments (Figure 3.4-6). Some of the deviation is probably analytical, however. In the case of copper and lead, the inner- and middle-shelf sediments appeared to be as inhomogeneous as the slope sediments. Again, some of the variability may have been analytical, but the results suggest that slope sediments are not significantly different from shelf sediments with respect to concentrations of these metals.

Samples collected along transect 5 during the summer were analyzed for both total and weak acid-soluble trace metals. Results indicated that most of the chromium, iron, nickel, and zinc was generally in the weak acid-soluble fraction and that their percentages in this fraction were greatest in outer-shelf and slope sediments (Table 3.4-8). This, taken with the other results, suggests that these four metals may be associated with a hydrated ferromanganese phase.

Copper and lead appear to be more associated with refractory phases of the sediments, possibly silicates. Results for cadmium, on the other hand, indicate that this metal is totally contained in the weak acid-soluble fraction. However, the high coefficient of variation in the analyses precludes drawing any conclusions as to cadmium's partitioning in sediments.

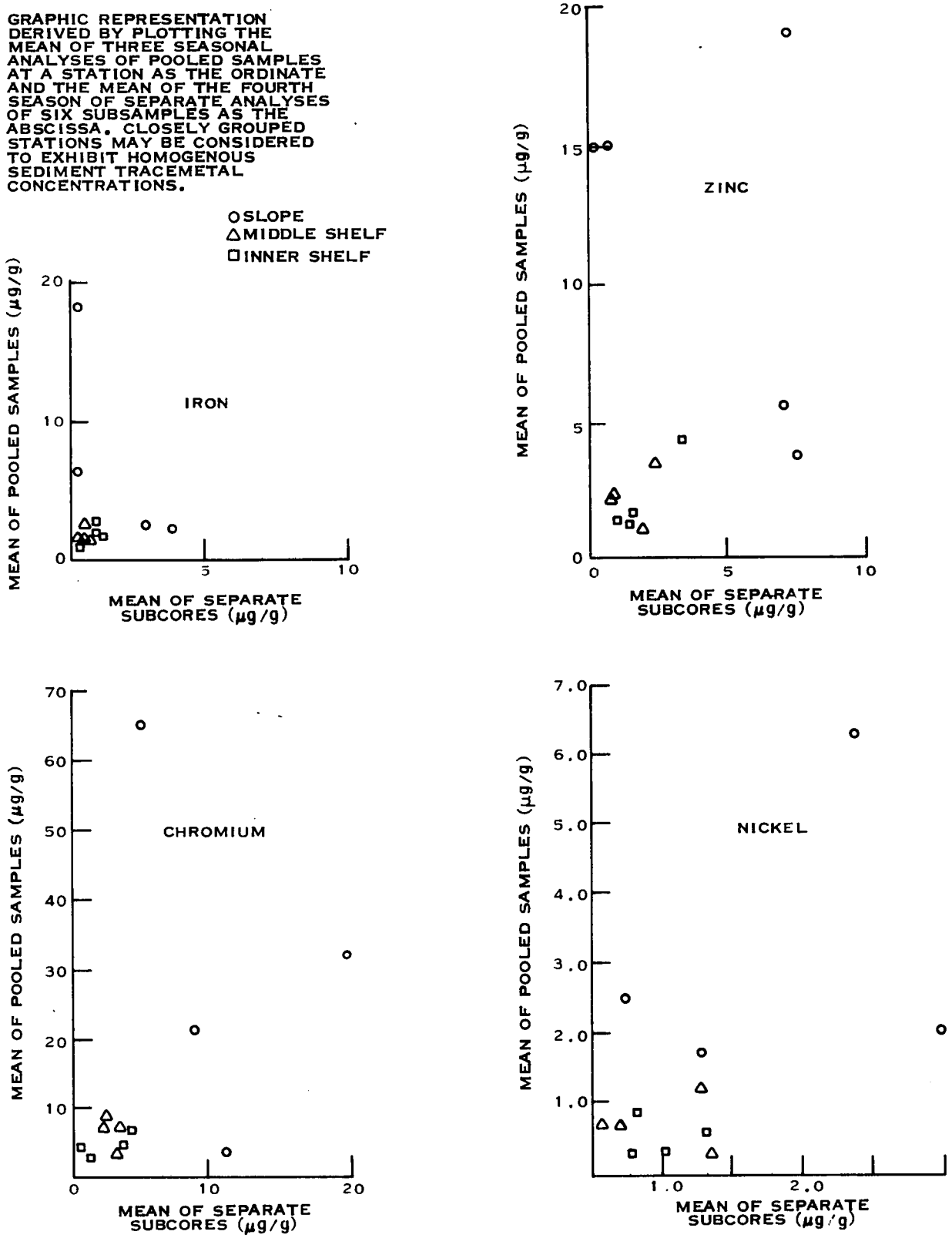

Figure 3.4-5. Relationship of Mean Concentrations of Chromium, Iron, Nickel, and Zinc at Stations on the Continental Shelf and Slope

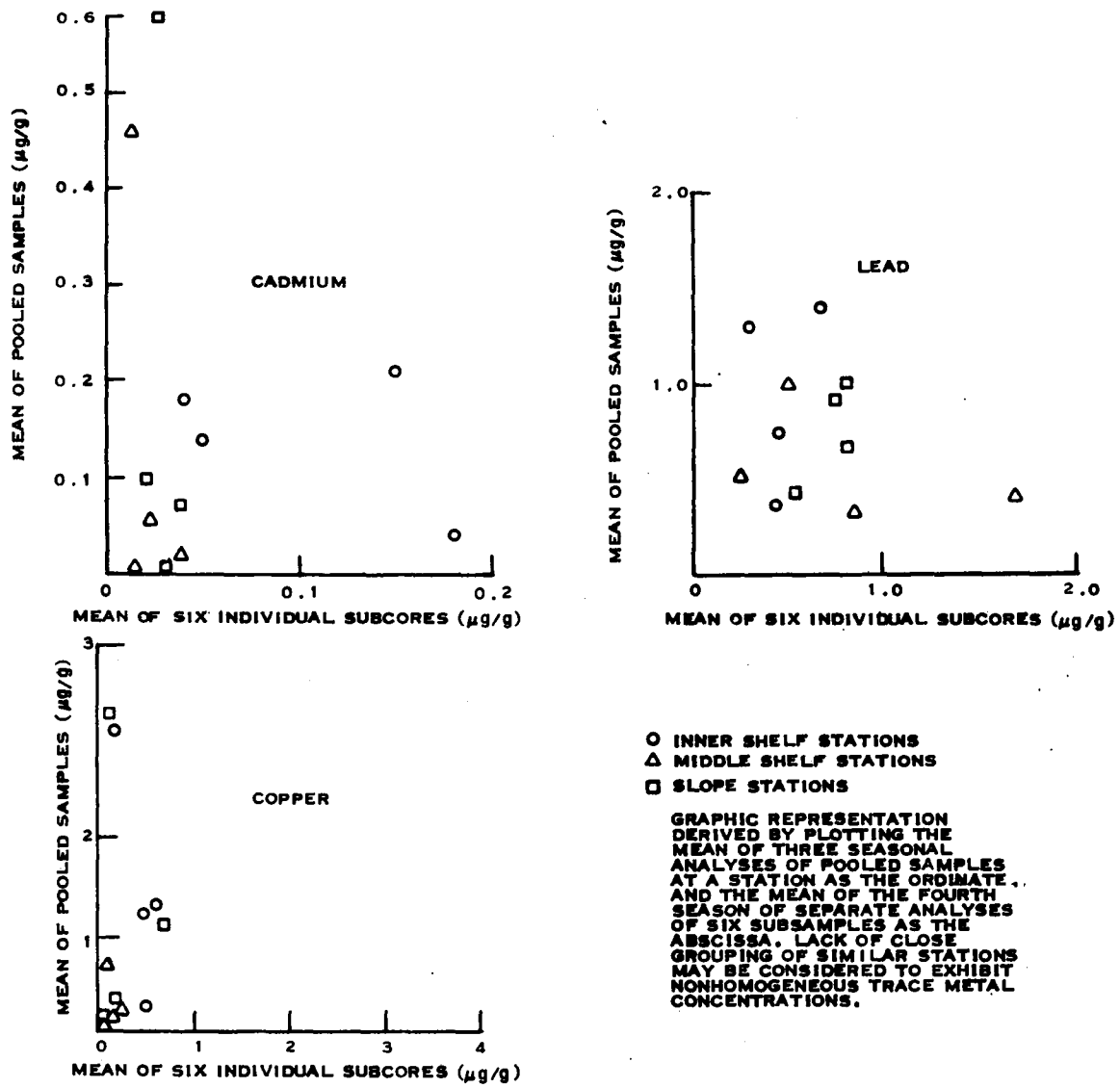

Figure 3.4-6. Comparison of Mean Concentrations of Cadmium, Copper, and Lead in Six Subcores With Mean of Pooled Samples

Table 3.4-8. Percent ($\bar{x} \pm 1\sigma$) of Trace Metals in Weak Acid-Soluble Fraction of Bottom Sediments, Summer 1977

	Trace Metal (%)[b]						
Station[a]	Cd	Cr	Cu	Fe	Ni	Pb	Zn
B	100 ±80	19 ±8	36 ±33	30 ±5	38 ±3	18 ±5	62 ±20
C	100 ±43	48 ±6	54 ±23	49 ±4	60 ±13	21 ±10	82 ±61
D	100 ±100	63 ±20	31 ±25	100 ±87	45 ±10	25 ±5	79 ±28
E	100 ±88	60 ±22	35 ±23	69 ±50	41 ±14	18 ±5	65 ±23
F	100 ±56	37 ±3	18 ±2	29 ±4	29 ±2	18 ±4	63 ±4
G	100 ±100	100 ±15	23 ±5	100 ±6	59 ±6	24 ±11	100 ±15
H	100 ±77	100 ±13	42 ±16	100 ±16	71 ±50	46 ±28	100 ±16
I	100 ±100	100 ±19	23 ±18	100 ±59	35 ±17	26 ±25	20 ±14

[a]Transect 5
[b]Six samples analyzed for weak-acid analysis.
One pooled sample analyzed for total trace metals.

E. MACROINVERTEBRATES AND DEMERSAL FISHES

Macrobenthos sampling was accomplished using a 13.6-m (45-ft) otter trawl for demersal fishes and other macroinvertebrates. Samples were collected at 25 stations during winter and summer cruises and at 15 stations during fall and spring cruises (Figure 3.4-7). Based on collections made during the first seasonal (winter) cruise, nine species were identified as being nearly ubiquitous in the study area. Thus, emphasis was placed on trace metal analyses of these species during the study since they represented the most likely candidates as index organisms; however, results of sample collections during subsequent cruises indicated that several of the initial choices were poor for this purpose. Nonetheless, the majority of the trace metal data is for these nine species and the discussion in this section is limited to them.

This group of organisms included five demersal fish species and four macroinvertebrates representing three phyla: Mollusca, Arthropoda, and Echinodermata. The results, therefore, should give a reasonably general view of trace metals in the macrofauna.

Results of individual trace metal analyses of the nine selected species appear in Appendix 3.4C, and mean concentrations and standard deviations are summarized in Table 3.4-9. Mean metal concentrations of demersal fishes are generally lower than those of the macroinvertebrates. The exception is the starfish *Asterias forbesii*; the bulk of this species is in its carbonate skeletal material, so trace metal concentrations are limited by their ability to substitute into this mineral lattice. For this reason alone, this and similar species would probably be poor selections as index organisms.

Judging by the high coefficient of variation (Table 3.4-9), the variability in trace metal concentrations is large within individual species. This is probably natural, however. In fact, most of the metals appeared to follow a log-normal distribution within a given species. For example, the frequency distributions of copper in *Loligo pealei* and *Diplectrum formosum* (Figure 3.4-8)

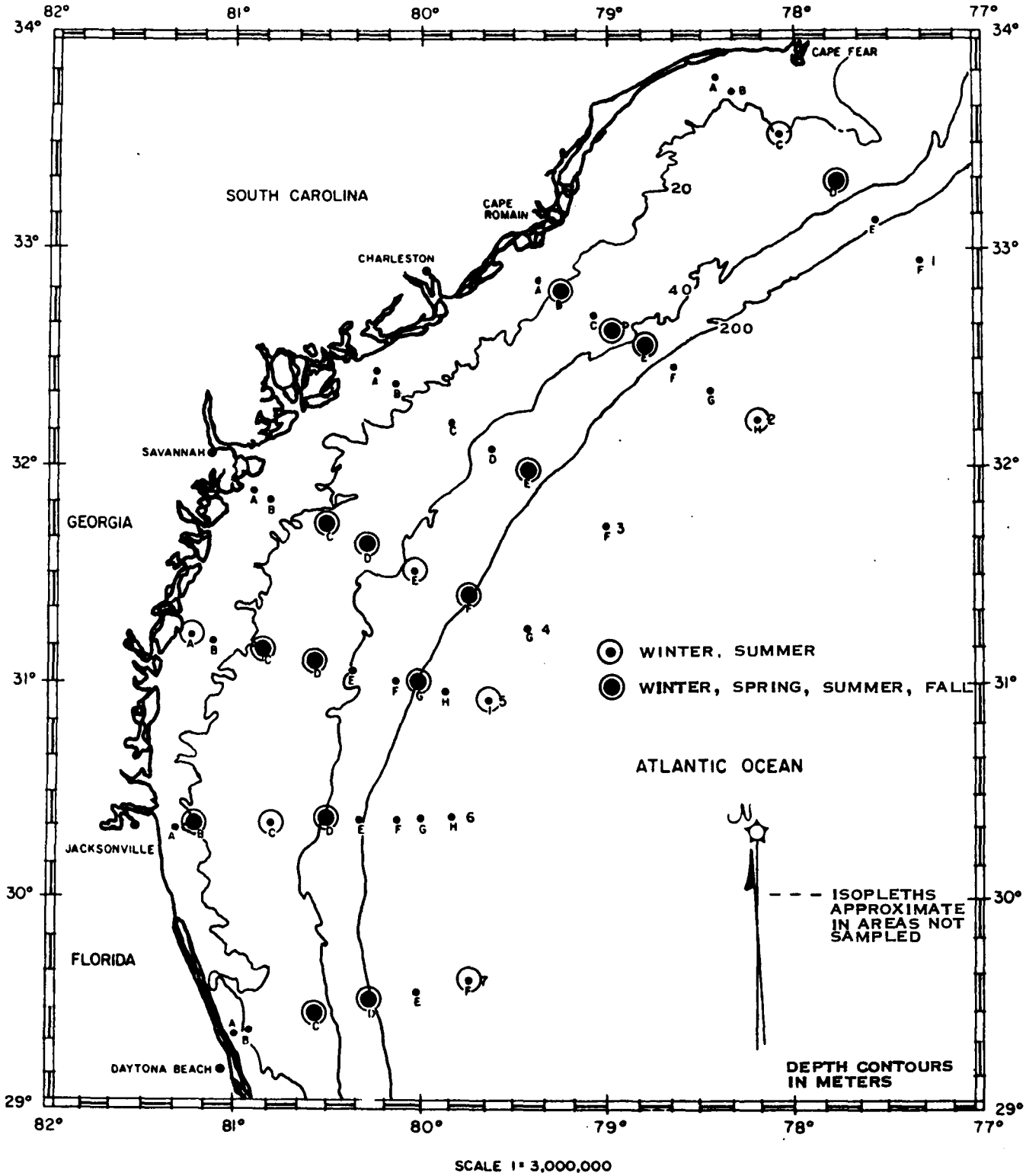

Figure 3.4-7. Sampling Stations for Macrobenthos for Trace Metals Analysis

Table 3.4-9. Trace Metal Concentrations in Nine Dominant Species of Macroinvertebrates and Demersal Fishes

Mean and Standard Deviation (Dry-Weight Basis)

	Al (mg/g)	Ca (mg/g)	Cd (μg/g)	Cr (μg/g)	Cu (μg/g)	Fe (μg/g)	Ni (μg/g)	Pb (μg/g)	V (μg/g)	Zn (μg/g)
Diplectrum formosum (sand perch)	5.5 (26) ±22.	5.8 (2) ±2.6	1.35 (24) ±3.16	1.50 (25) ±2.13	7.37 (25) ±9.41	34.0 (25) ±51.7	1.15 (19) ±1.68	1.49 (24) ±4.71	23 (14) ±34	30.0 (25) ±51.7
Synodus poeyi (blue striped lizard fish)	2.9 (9) ±4.5	241. (1) ---	1.66 (7) 2.17	0.70 (9) 0.68	4.77 (10) 3.06	29.8 (10) 29.2	0.69 (6) ±0.59	0.52 (10) ±0.45	21 (5) ±27	30.6 (10) 15.3
Decapterus punctatus (round scad)	3.6 (11) ±7.6	1.3 (3) ±0.9	0.58 (12) ±0.69	1.24 (12) ±2.40	10.2 (12) ±7.4	84. (12) ±130.	1.56 (10) ±2.35	2.68 (11) ±6.12	31 (8) ±34	56.4 (11) ±55.8
Synodus foetens (inshore lizard fish)	1.2 (10) ±2.3	180. (2) ±254.	0.93 (10) ±1.61	1.81 (9) ±1.80	12.0 (9) ±22.1	32.3 (10) ±31.9	0.73 (8) ±0.82	0.39 (10) ±0.50	39 (7) ±80	40.6 (10) ±57.6
Urophycis regius (spotted hake)	12.5 (13) ±18.0	654 (7) ±505.	2.15 (8) ±2.55	1.80 (15) ±1.30	16.4 (15) ±25.1	84. (15) ±181.	1.88 (12) ±2.11	0.42 (15) ±0.33	90 (10) ±84	86.6 (14) ±99.7
Sicyonia brevirostris (rock shrimp)	1.4 (27) ±2.2	178. (11) ±221.	1.93 (22) ±1.58	1.30 (28) ±2.06	64.7 (28) ±75.7	71. (28) ±109.	1.30 (26) ±0.96	0.74 (28) ±1.27	51 (22) ±62	103. (28) ±61.
Loligo pealei (squid)	7.4 (28) ±23.	118. (9) ±142.	6.27 (23) ±8.44	1.31 (30) ±1.58	31.3 (30) ±21.2	45. (30) ±99.	0.61 (26) ±0.51	0.23 (29) ±0.16	29 (20) ±45	65. (30) ±17.7
Asterias forbesii (starfish)	1.6 (11) ±2.0	442 (2) ±243	0.30 (9) ±0.35	1.39 (11) ±1.29	1.95 (11) ±1.98	77. (11) ±73.	0.35 (9) ±0.19	0.27 (10) ±0.17	24 (9) ±41	15.9 (11) ±13.0
Ovalipes stephensoni (crab)	5.3 (6) ±2.8	228 (3) ±221	25. (5) ±42.	16. (6) ±32.	25. (6) ±5.9	401. (6) ±682.	4.2 (4) ±3.1	5.0 (6) ±7.3	218. (6) ±322.	143. (6) ±119.

appeared to best fit a log-normal pattern. Results of individual analyses also suggest that cadmium, chromium, iron, lead, and vanadium follow log-normal distributions.

Nickel and zinc appeared to be the only metals to follow normal distribution. Results of zinc concentrations in *Loligo pealei* and *Diplectrum formosum* (Figure 3.4-9) clearly indicate this type of distribution in the former and suggest this for the latter as well, with the higher concentrations probably resulting from sample contamination or analytical error.

Metal levels in demersal fishes and macroinvertebrates showed no relationship to concentrations in sediments. Correlation coefficients given in Appendix 3.4C (Volume 6) showed no significant relationship to metal levels in bottom sediments or to near-bottom particulate trace metals.

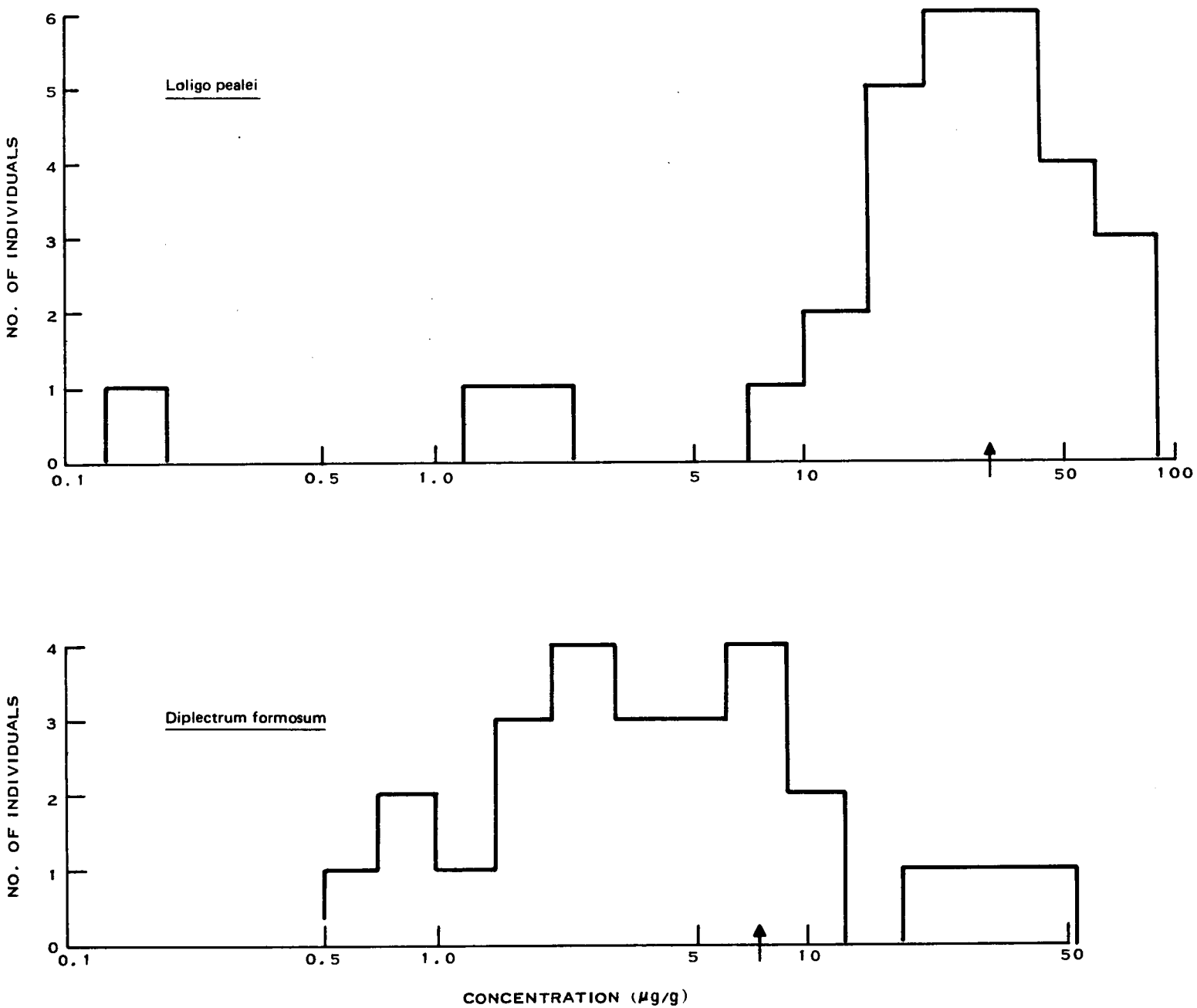

Figure 3.4-8. Frequency Distribution of Copper Concentrations in *Loligo pealei* and *Diplectrum formosum* (Arrows indicate mean concentrations)

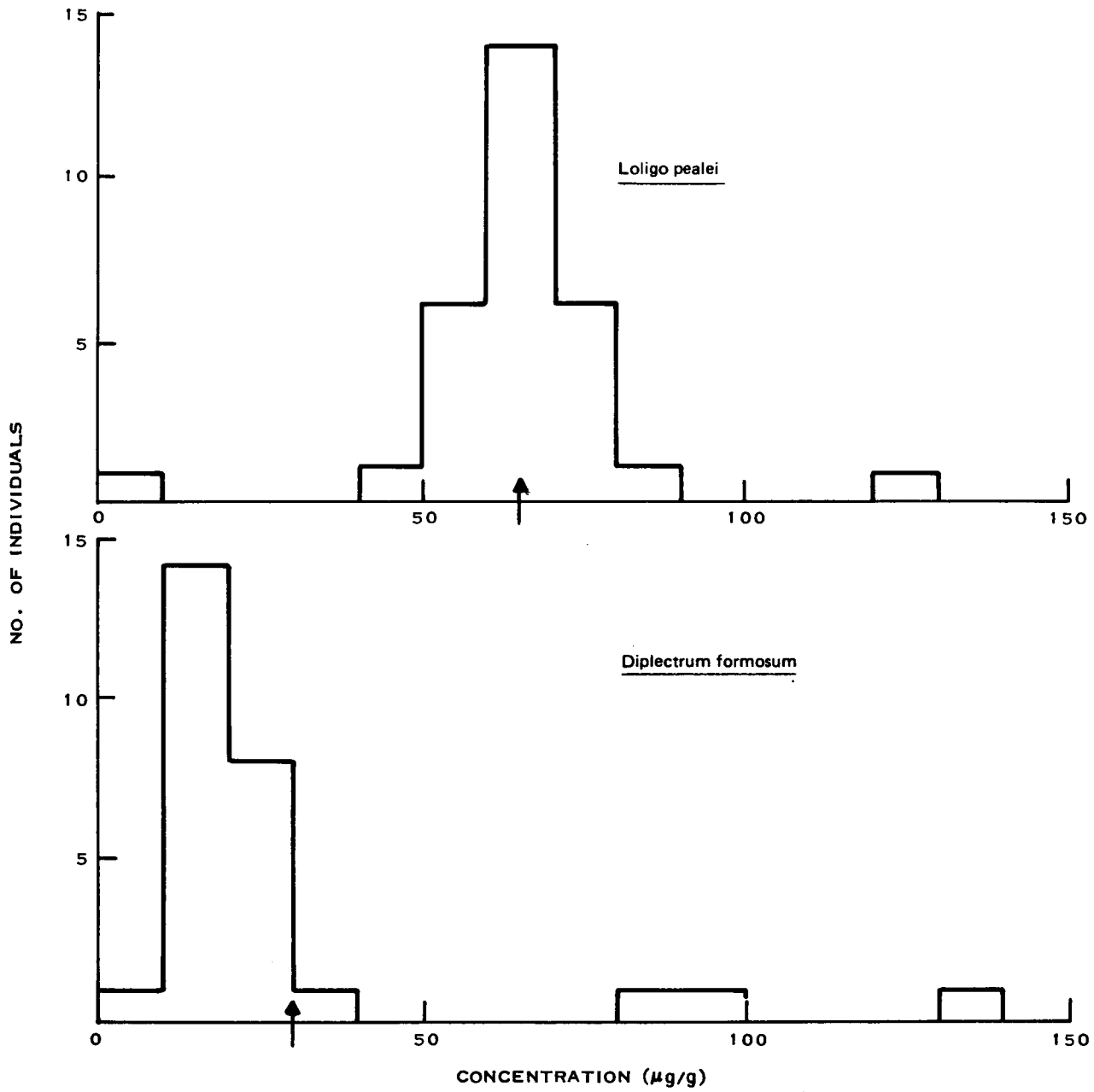

Figure 3.4-9. Frequency Distribution of Zinc in *Loligo pealei* and *Diplectrum formosum*
(Arrows indicate mean concentrations)

SECTION 4
DISCUSSION

Results of all trace metal studies related to the water column appeared to suffer from analytical difficulties, both in terms of apparent accuracy (judging from comparison with other studies) and of replicate precision, a possible exception being the zooplankton analyses, which agreed well with other studies. This was not surprising since the state of the art has not developed to the point where uncontaminated sampling and analysis are routine. However, in relation to developing a trace metal benchmark with which to assess long-term environmental impacts of petroleum exploration and exploitation, studies of the water column are probably of little use anyway since this is the most dynamic part of the continental shelf system of the Georgia Bight. For evaluation of short-term impacts, however, studies of this part of the system are important. For example, since suspended loads are very low over most of the Georgia Bight and, more important, are depauperate in trace metals, it would seem that even small inputs (on the order of 1 μg/l) of oil, brine, or drilling mud would be easily detected. Thus, the composition of suspended solids in the Georgia Bight would be an integral and important part of any assessment of production effects. The gap in the data base is an important problem, however, and could be critical in interpreting whether there were detectable inputs of trace metals to waters of the Georgia Bight after explorator drilling or production were initiated. This argues for additional studies of these reactive phases in the Georgia Bight.

Bottom sediments over most of the continental shelf were homogeneous with respect to trace metals. Concentrations were low compared with typical inshore muddy sediments. This was not surprising, considering that southeastern estuaries effectively trap continental detritus presently carried by rivers (Meade, 1969; Windom et al., 1971).

Because of their characteristics, bottom-sediment trace metal data provide a good benchmark for future potential changes resulting from petroleum exploration and exploitation.

Trace metal concentrations in demersal fishes and macroinvertebrates varied over a wide range. This variability followed a discernible pattern, however, potentially allowing use of the data as a trace metal benchmark for the marine biota. Individual values appear in Volume 6, Appendix 3.4.

There are four species whose distribution is sufficiently ubiquitous to allow their potential use as indicator organisms (Table 3.4-10). These are *D. formosum* (sand pearch), *S. Foetens* (inshore lizard fish), *L. pealei* (squid), and *O. stephensoni* (crab). Their winter and summer distributions, according to catches, are shown in Figures 3.4-10 through 3.4-13. Before these species can be truly judged to be candidates as indicator organisms, however, considerably more life-history information must be obtained.

Additional studies related to trace metals indicated by the results of this work are:

- Affinity/mobility studies of various petroleum-related materials in Georgia Bight shelf waters: Oil, gas, brines, and drilling muds can be released to a certain extent during resource exploitation. One of the major unanswered and critical questions concerning the release of these materials into the environment is how they will distribute themselves and their associated trace metals between soluble and particulate phases.

Table 3.4-10. Winter/Summer Distribution of Possible Indicator Organisms

Station	Station Code	*Diplectrum formosum*		*Synodus foetens*		*Loligo paelei*		*Ovalipes stephensoni*	
1C	23	No	X	No	X	X	X	X	X
1D	24	X	X	X	X	X	X	No	No
2B	12	No	X	No	X	X	X	X	No
2D	24	X	X	X	X	X	X	X	X
2E	25	X	X	X	X	X	No	No	No
2F	26	No	No	X	X	X	X	X	No
2H	38	No	No	No	No	No	No	No	No
3B	12	No	X	X	X	X	X	X	No
3D	24	X	X	X	X	X	X	X	No
3E	25	No	No	X	X	X	X	X	X
4C	23	No	X	X	X	X	X	X	X
4D	24	X	X	X	X	X	X	X	X
4E	25	X	X	X	X	X	X	X	No
4F	26	No	No	No	X	X	X	X	X
5A	11	No	No	No	X	X	No	X	No
5C	23	No	X	X	X	X	X	X	X
5D	24	No	X	X	X	X	X	X	X
5G	27	X	X	No	X	X	X	No	X
5I	39	No	No	No	No	No	No	No	No
6B	12	No	X	X	X	X	X	X	X
6C	23	X	X	X	X	X	X	X	No
6E	25	X	X	X	X	X	X	No	X
7C	23	X	X	X	X	X	X	X	No
7E	35	No	No	No	No	No	X	No	No
7F	36	No	No	No	No	No	No	No	No

Their distribution will, in large part, affect their residence time and their availability to organisms. Laboratory mixing experiments using these materials and freshwater shelf samples could provide an important data base with which to predict their behavior, residence time, and fate.

- Large-particle flux studies: Some detailed studies of the flux of large particles of bottom sediments should be initiated to characterize the interaction of the water column with bottom sediments.
- Trace metal variations in resident Georgia Bight organisms in relation to their life history: To establish a true trace metal index for indicator organisms, variations in concentration must be well-known and related to the specific characteristics of the given organism. For example, studies should evaluate metal variations related to the organism's dietary intake, environmental levels, sex, and age; sources of food and migratory habits are also important to know.

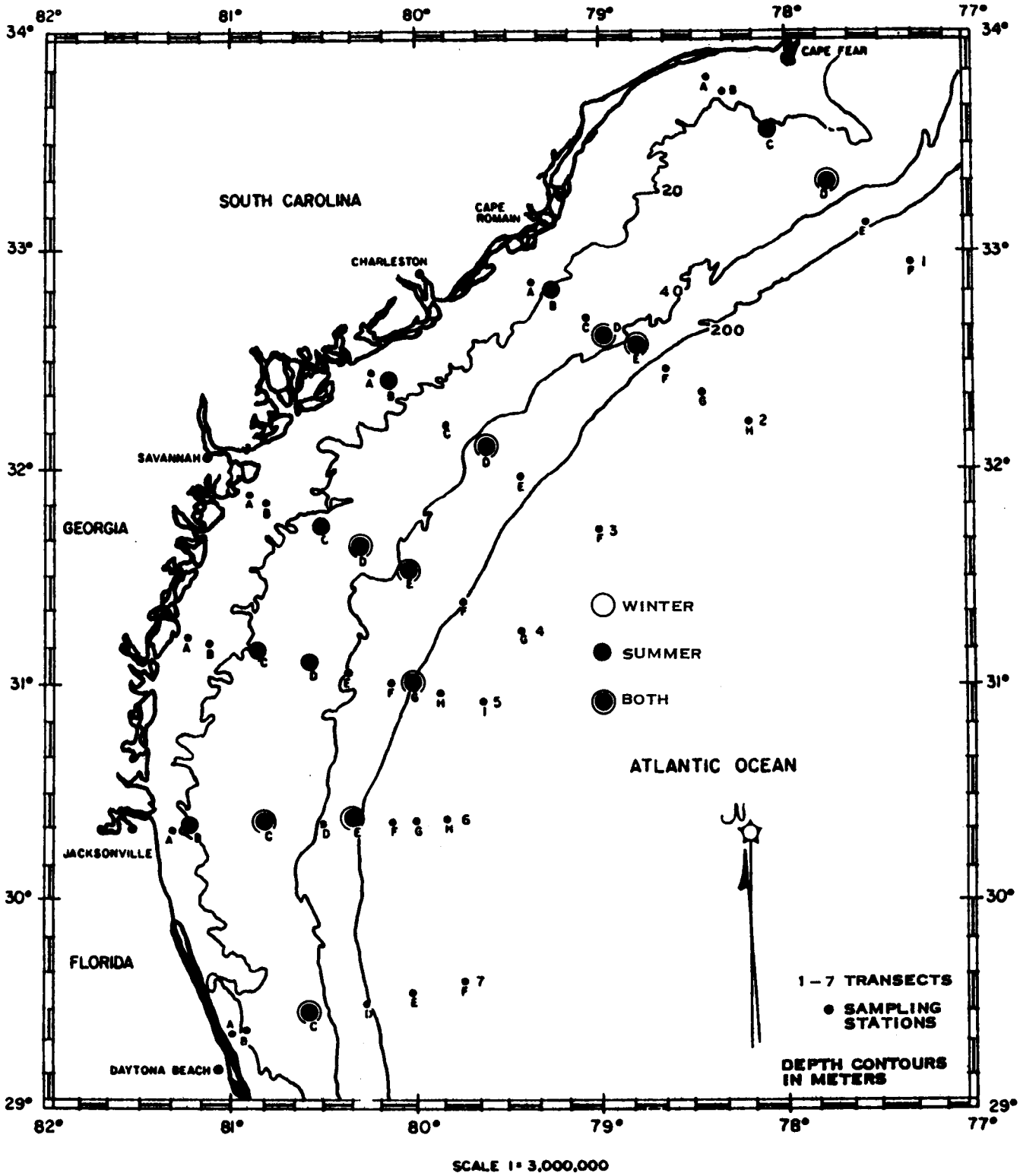

Figure 3.4-10. Winter and Summer Distributions of *Diplectrum formosum* Established by SABP Study

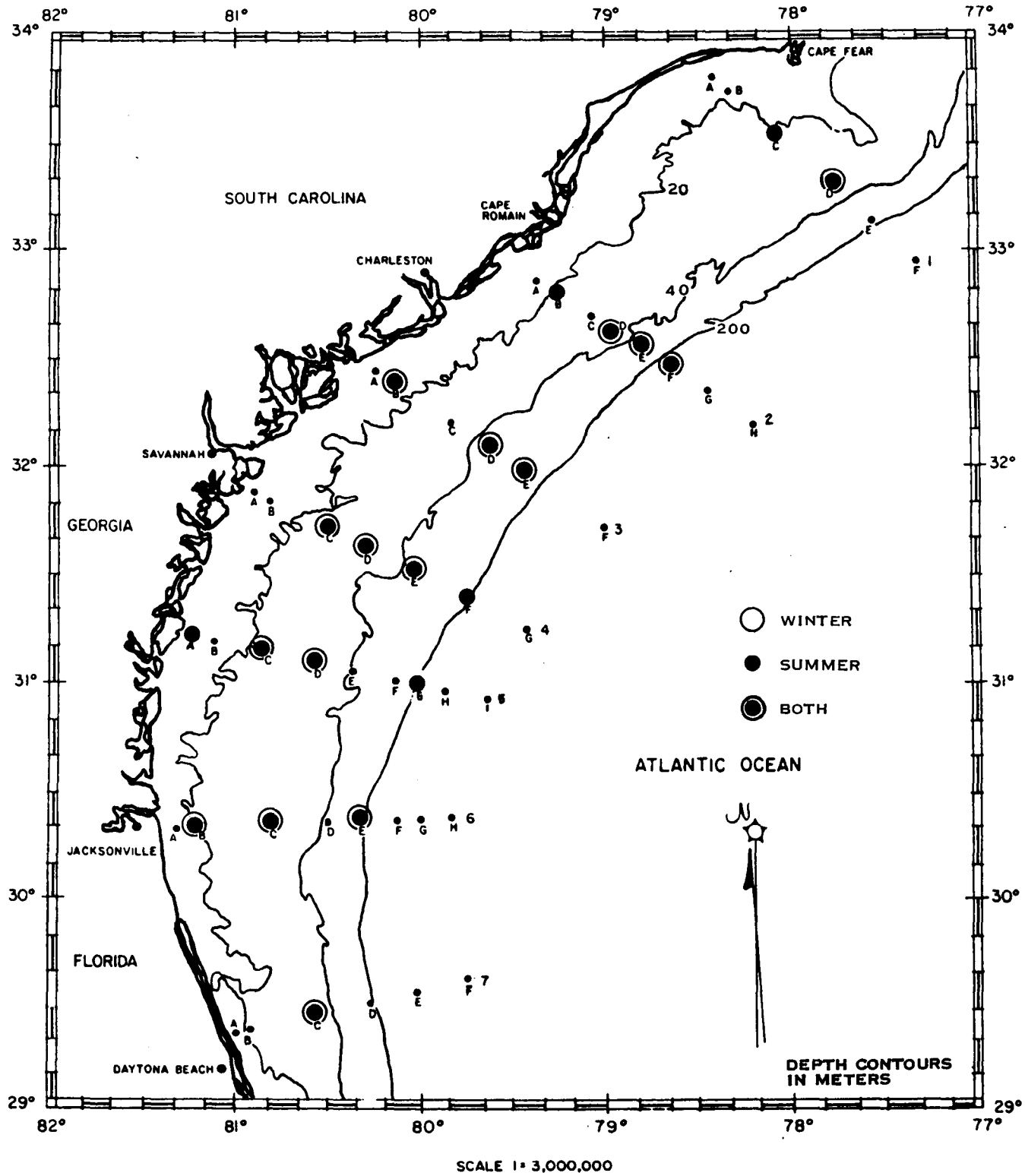

Figure 3.4-11. Winter and Summer Distributions of *Synodus foetens* Established by SABP Study

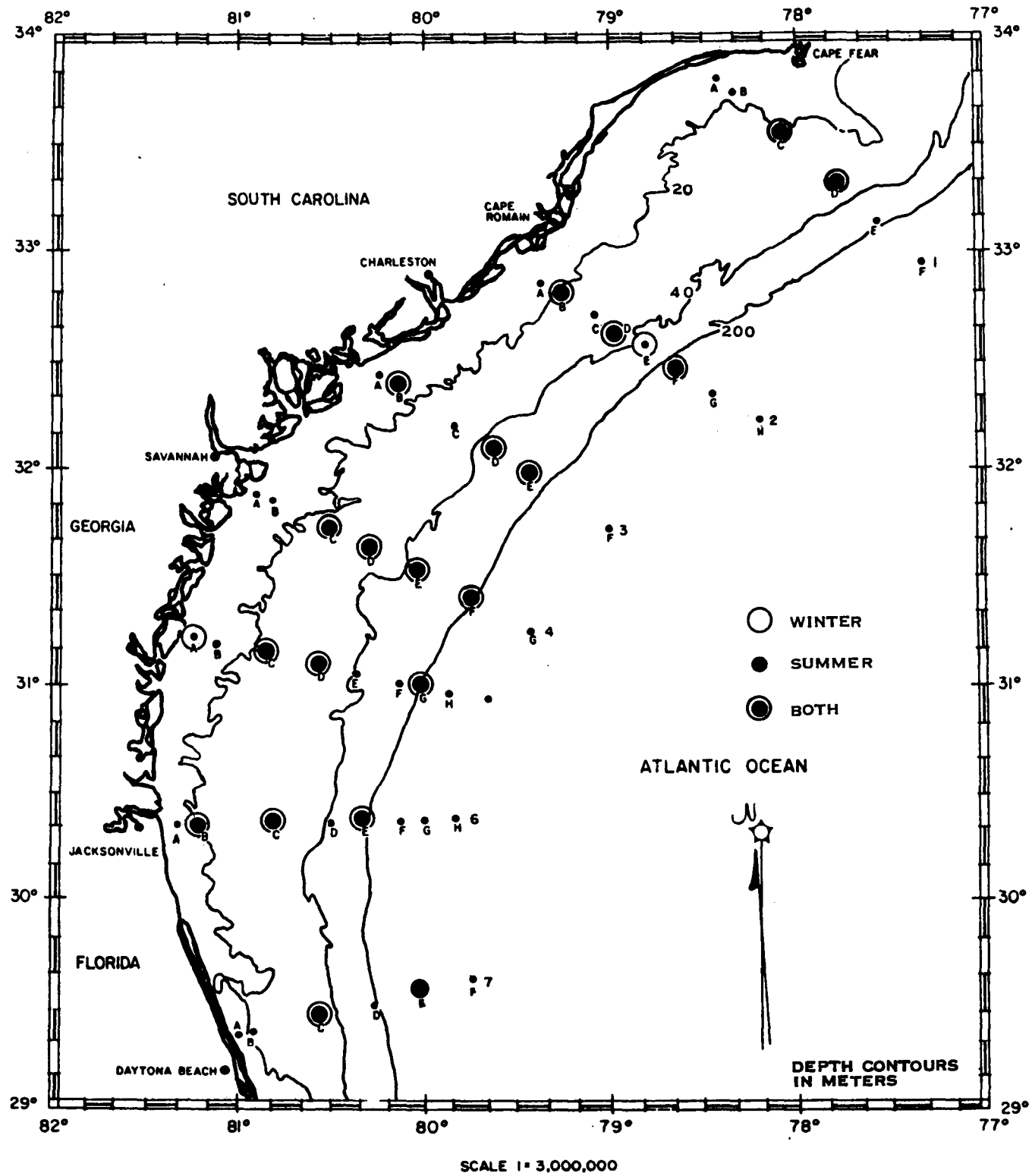

Figure 3.4-12. Winter and Summer Distributions of *Loligo pealei* Established by SABP Study

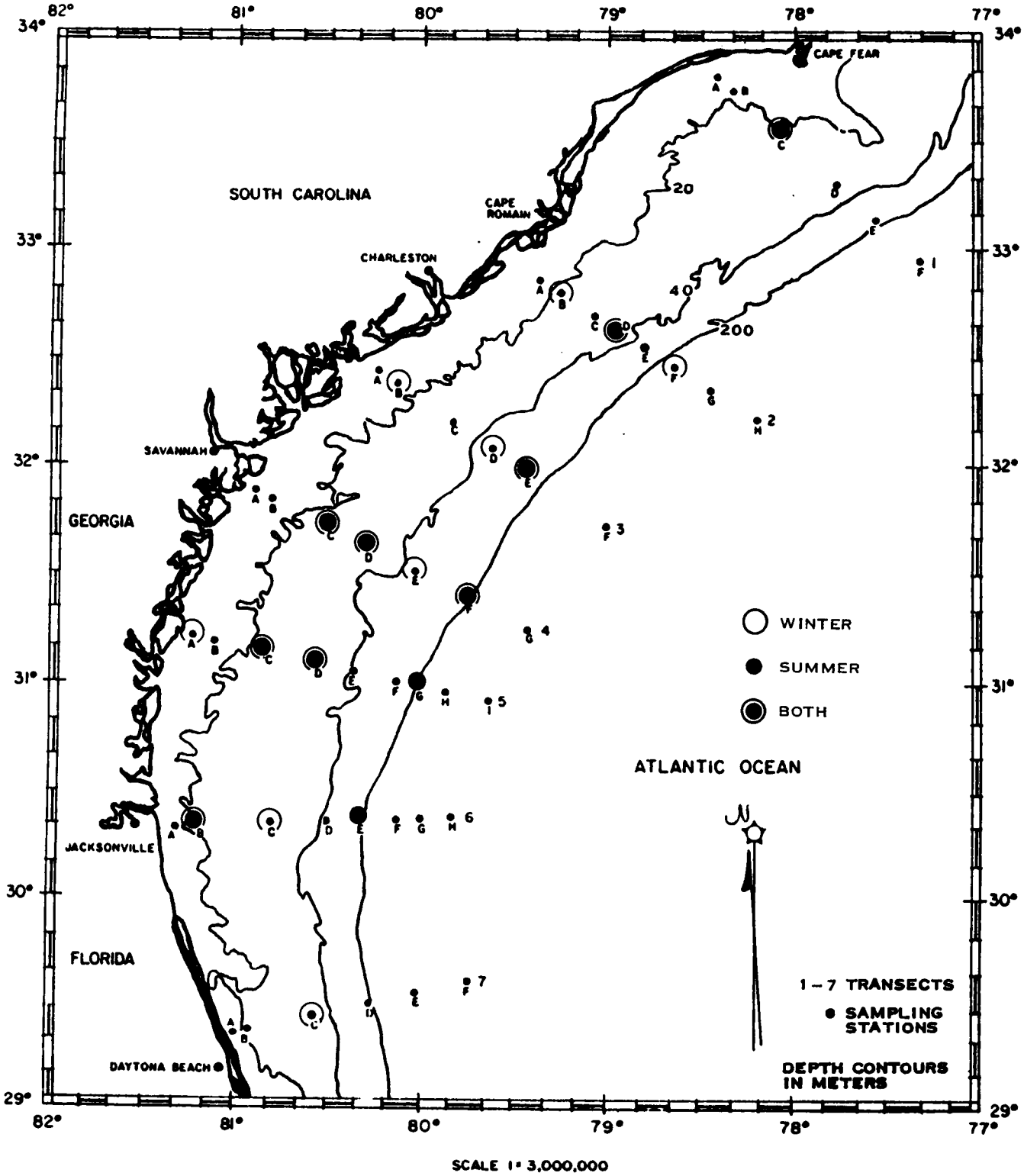

Figure 3.4-13. Winter and Summer Distributions of *Ovalipes stephensoni* Established by SABP Study

SECTION 5
CONCLUSIONS

- There are no apparent seasonal or regional trends in the trace metal concentrations of zooplankton populations from the Georgia Bight.
- Zooplankton caught in 202-μm and 505-μm nets had essentially the same trace metal concentrations.
- Physical processes such as atmospheric forcing and Gulf Stream intrusions seem to have major impacts on the concentration and composition of suspended particles in the Georgia Bight.
- River input to the inner shelf produces large increases in particulate aluminum and concomitant decreases in particulate organic carbon during the winter-spring period.
- Bottom sediments of the Georgia Bight continental shelf are homogeneous in trace metal chemistry.
- Concentrations of trace metals in slope sediments are higher than in shelf sediments and are less homogeneous.
- Most of the trace metals in bottom sediments (except copper and lead) appear to be associated with weak acid-soluble phases.
- The shelf sediment probably receives little input presently from continental runoff.
- Trace metal concentrations in macroinvertebrates and demersal fishes vary widely, following normal (Ni and Zn) and log-normal (Cd, Cr, Cu, Fe, Pb, and V) distribution patterns.
- Several macroinvertebrate and demersal fish species are potential candidates as indicator species, but additional information on life histories is required.

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CHAPTER 5

ZOOPLANKTON OF SOUTH ATLANTIC/GEORGIA BIGHT

by
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ABSTRACT

Texas Instruments sampled zooplankton over a series of six shelf stations in the southeastern Atlantic Ocean off the United States over four different seasons during the course of its 1977 outer continental shelf (OCS) environmental studies for the Bureau of Land Management. Shannon-Weaver indices show that the study area is one of great diversity.

Mean density of samples collected with 505-μm bongo nets was 212 organisms/m^3, while finer mesh (202 μm) collected 563 organisms/m^3. Copepods dominated both net tows (34% for the 505-μm net and 58% for the 202-μm net), but chaetognaths, ostracods, gastropods, and urochordates also contributed significantly at different periods. Summer collections yielded the maximum numbers.

Calanoid copepod associations may be used to determine whether shelf or a mixture of shelf and oceanic water is present.

SECTION 1
INTRODUCTION

A. PURPOSE OF STUDY

The western Atlantic Ocean from Virginia to the Gulf of Maine is an area in which zooplankton has been studied extensively. Generally speaking, zooplankton populations reach maximum levels in the neritic area and decrease as one passes out onto the continental shelf over the slope into the Sargasso Sea. Few investigations have considered the overall zooplankton populations in the southeastern area of the Atlantic Ocean from shallow water to the edge of the continental shelf, although various components of the zooplankton have been studied. Therefore, the following objectives were established for the 1977 South Atlantic Benchmark Program (SABP) conducted by Texas Instruments for the Bureau of Land Management:

(1) Acquire a general seasonal overview of south Atlantic zooplankton populations from the present investigation and a review of the literature

(2) Document major trends in distribution, abundance, and variation during an annual cycle

(3) Relate physiochemical and biological parameters to the qualitative and quantitative nature of the zooplankton.

(4) Distinguish (if possible) latitudinal differences in zooplankton assemblages.

B. STATE OF KNOWLEDGE

The study area (Figure 3.5-1) is one in which the hydrography is dynamic and complex because of the influence of the Gulf Stream. This, coupled with the tendency for zooplankton populations to change radically within short periods, necessitates a rather extensive review of the literature so study results may be best understood and maximum information obtained. The literature survey included studies conducted in the southeastern area inshore and the southeastern area offshore, studies of adjacent areas that overlap with the study area, and investigations that encompass the study area.

1. Inshore Studies

Inshore plankton studies of the area have been conducted from Beaufort, North Carolina, to Biscayne Bay, Florida. Sutcliffe (1950), describing zooplankton of the Beaufort area from a single-station location, reported that *Acartia tonsa* dominated the samples. Williams et al. (1968), in a survey of the zooplankton in the estuaries near Beaufort conducted over a complete year, found a dearth of zooplankton in the system: average dry weight was 4.4 to 24.2 mg/m^3 (calculated from volume), and maximum densities occurred from November through February, with a decline noted in March and April. The authors concluded that zooplankton is relatively unimportant in the food chains of the shallow-water area studies, although it may be more important in some years than others. Copepods dominated throughout the year, but the study reveals no information regarding the key genera.

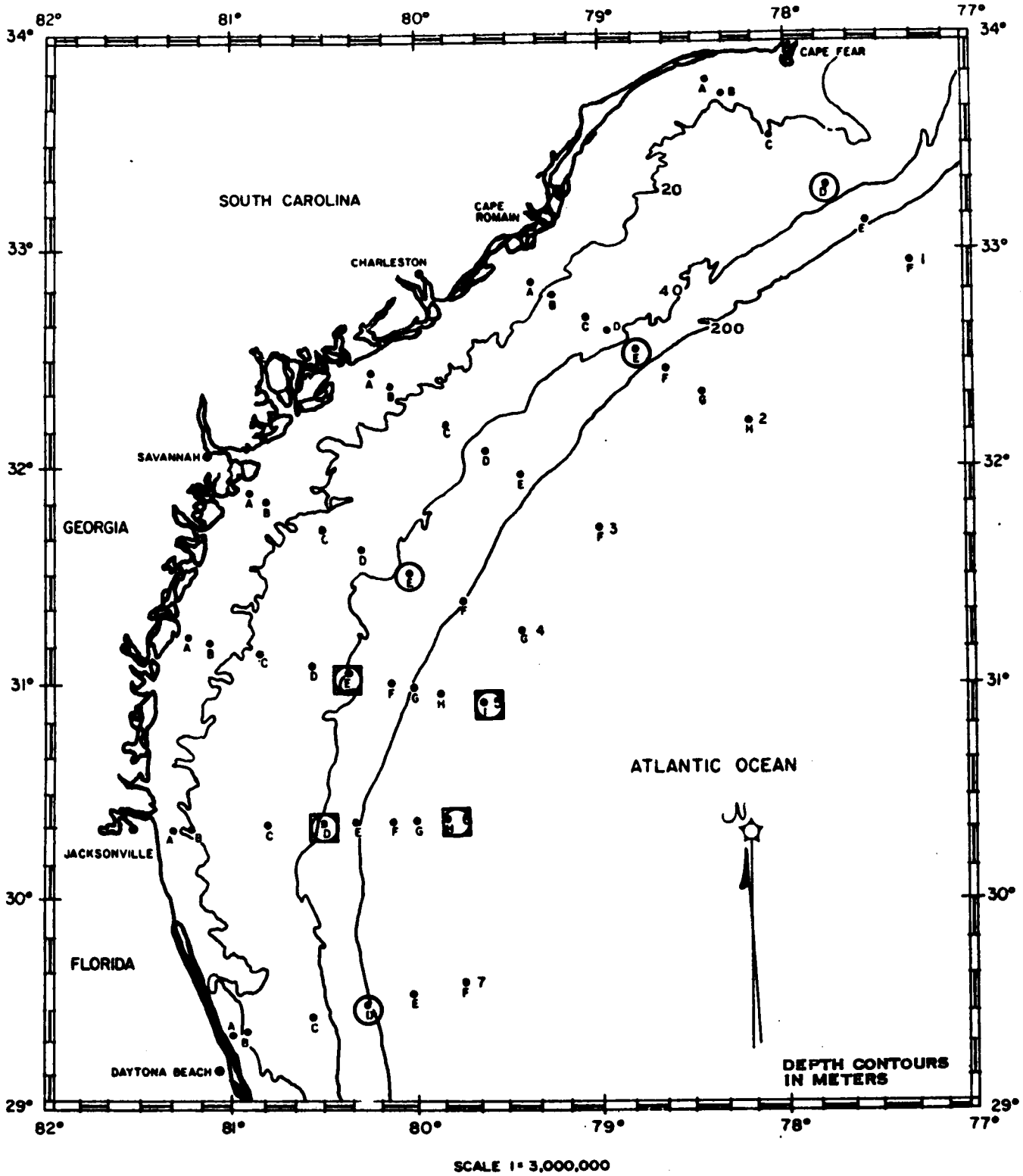

Figure 3.5-1. Sampling Sites for Zooplankton

Thayer et al. (1974), sampled a series of stations in the Newport River estuary over a period of 2 years and also concluded that there was a dearth of zooplankton in the system. Peaks occurred between March and June and again between October and December. Copepods comprised 81% of the zooplankton, with *Acartia tonsa, Oithona, Corycaeus,* and *Centropages* being the most abundant.

Lonsdale and Coull (1977) provided information on zooplankton sampled over a 20-month period at North Inlet near Georgetown, South Carolina. They found that density had major peaks between April and July; copepods comprised 64 to 69% of total zooplankton; *Parvocalanus, Acartia tonsa, Oithona,* and *Euterpina* were the most abundant copepods; and biomass values ranged between 0.6 and 140 mg dry weight/m^3. The authors concluded that the zooplankton of this area is most closely allied to that of Florida waters.

Some information on zooplankton of Georgia estuaries is available from the study by Stickney and Knowles (1975) near Skidaway Institute. Although the purpose of the study was to determine how much use was made of the zooplankton by fish, the authors determined that the copepods *Acartia tonsa* and *Pseudodiaptomus coronatus* were the most abundant forms.

Woodmansee (1958) and Reeve (1964) studied the shallow-water zooplankton of Florida. Woodmansee found that zooplankton in the Chicken Key region peaked in October and December and that the dominant organism was *Acartia tonsa.* Reeve (1964) describes four major peaks for Biscayne Bay zooplankton (January, April/May, July, and October), with copepods dominating samples and *Acartia bermudensis* and *Acartia spinata* being the most abundant copepod forms.

In a study conducted in two shallow-water stations in Bermuda, Herman and Beers (1969) described zooplankton populations that were dominated by copepods (*Calanopia* and *Paracalanus*) and that had peaks similar to those that occurred in the Chicken Key and Biscayne Bay (Florida) studies of Woodmansee (1958) and Reeve (1964).

2. Offshore Studies

Zooplankton in deeper waters off the southeastern coast of the U.S. has been studied by Moore (1949), Fish (1954), Bsharah (1957), Menzel and Ryther (1961), Deevey (1971), and Deevey and Brooks (1971).

Moore (1949), in his studies of zooplankton offshore from Bermuda, found maximum zooplankton densities from May to June and a minimum in October. Fish (1954), studying zooplankton in the Sargasso Sea, found maximum numbers from April to June, low numbers from June to December, and an annual mean of 239 organisms/m^3, with copepods making up 62% of the zooplankton. In Bsharah's investigation of the zooplankton of the Florida current 64 km east of Miami (1957), abundance peaked between March and June and dry weights averaged 0.45 mg/m^3. Menzel and Ryther (1961) reported a spring maximum of zooplankton 24 km southeast of Bermuda; they determined that an average of 63% of the zooplankton dry weight between 0 and 2,000 m occurred below 500 m. At the same station used by Menzel and Ryther, Deevey (1971) conducted a more comprehensive study on the zooplankton samples collected in the upper 500 m and obtained highest dry weights (mean of 2.61 mg/m^3) in March and April. Copepods dominated the samples (61 to 79%), and *Oithona, Clausocalanus,* and *Oncaea* were the

most abundant, although ostracods, tunicates, and chaetognaths were also numerous. Deevey and Brook (1971) reported on the zooplankton at the same station down to 2,000 m, recording different maxima for the various levels: numbers of organisms decreased greatly from the upper waters to 1,000 m. Crustacea increased in importance and diversity below 500 m; copepods comprised 70% of the plankton in the upper 500 m and 85% in the deepest waters sampled. Ostracoda were the next most abundant group present.

Egan and Conrad (1975) examined the zooplankton of the Gulf Stream as it moved northward during the summer period; calanoid copepods dominated their tows, but they were unable to detect a buildup or depletion of the population with the progress of the flow north in the Gulf Stream. They indicated that the dry organic matter was more than an order of magnitude below that which is theoretically possible.

3. Studies in Adjacent Areas (Inshore and Offshore)

Leavitt (1938), working on the vertical distribution of macroplankton in the Atlantic Ocean basin, located two of his stations in deep water east of Cape Hatteras. Leavitt mentioned the paucity of catches of zooplankton in the Sargasso Sea and the Gulf Stream compared with those in slope water.

Bigelow and Sears (1939), studying zooplankton from Martha's Vineyard to near latitude 36°, with one cruise south of Cape Hatteras, divided their entire sampling area into a northern sector (Atlantic City north to Martha's Vineyard), a southern sector (to latitude 36°), an inshore belt (30 mi out from the coast), and an offshore belt (to the 200-m contour). Cruises (winter, spring, and summer) spanned a 3-year period. During the winter, plankton was at its minimum and largest numbers were on the inner half of the shelf and to the south. In May, the offshore belt supported a larger volume of plankton than the inshore belt; there was little difference between plankton volumes of the northern and southern sectors. During summer, the center of abundance shifted from east of New York to south of New York. In summary, Bigelow and Sears detected little latitudinal difference in the richness of plankton from Chesapeake Bay to the Gulf of Maine in late winter and early spring when zooplankton was at its minimum; from May to July, the catches south of Cape Cod were most abundant, and, during the period of maximum abundance, the sector between Cape Cod and Delaware Bay carried the largest populations and the Bay of Fundy and the Gulf of St. Lawrence had the smallest. In winter, copepods *(Centropages typicus, Calanus finmarchicus)*, chaetognaths, and pteropods accounted for more than 85% of the zooplankton; in spring and summer, a similar dominance was noted, as well as a large increase in *Calanus.*

Clarke (1940) surveyed the zooplankton between Montauk Point, New York, and Bermuda over a period of 1½ years but, unfortunately, collected samples only between May and October. He detected no apparent seasonal change in the Sargasso Sea area but significant changes in coastal and slope areas, with the warm part of the year carrying larger zooplankton populations; on the average, plankton volumes were four times higher in the coastal area than in the slope area, and those in the latter were about four times higher than those in the Sargasso Sea area. The copepods *Calanus finmarchicus* and *Centropages typicus* fluctuated widely but dominated the plankton tows.

Grice and Hart (1962), compiling information on zooplankton during a series of seasonal cruises from New York to Bermuda over a period exceeding 1 year, found largest standing crops at the shelf edge and innermost slope area. The amount of plankton down the slope was markedly reduced. As in almost all other studies, Grice and Hart determined that the shelf plankton was richer than the slope plankton, which was richer than either the Gulf Stream or Sargasso Sea fauna. Average numbers of organisms per cubic meter were: neritic, 1,540; slope, 310; Gulf Stream, 134; and Sargasso Sea, 71. Largest seasonal differences occurred in shelf and slope waters, and there was almost no seasonal variation in the Gulf Stream and Sargasso Sea. Copepods were the most abundant organisms (0 to 96%, with a mean of 51%), and *Centropages, Oithona,* and *Pseudocalanus* were the most abundant copepods. Chaetognaths were the second most abundant group encountered, with highest values occurring on the shelf.

4. Studies Within the SABP Study Area

St. John (1958) reported on several series of samples taken in May/June and January off the coast of North Carolina. He offers little information on the qualitative nature of the zooplankton, but discusses the volume of plankton found in relation to the various hydrographic features.

The Florida Current flows northeastward off the North Carolina coast and parallels the 200-m depth contour south of Cape Hatteras. The salinity of the shallower layers off North Carolina is approximately 36.0 o/oo or higher during the winter or spring, with surface temperatures between 20° and 25°C. The Florida Current south of Cape Hatteras may change its direction of flow so that its waters penetrate over the adjacent continental shelf. The water over the coastal area from Cape Cod to Cape Hatteras is referred to as Virginia coastal water; surface water temperatures in the winter range from 2° to 10°C and, by May and June, have increased to a range of 12° to 20°C. Salinities range from 30 to 36 o/oo. The higher salinity is a result of the influence of the Florida Current. Carolinian coastal water occurs south of Cape Hatteras. Surface water temperatures range from 10° to 20°C in winter, with salinities of 32 to 36 o/oo, and, during the spring months, increase to 25°C south of Cape Hatteras, with salinity near 35 o/oo. Carolinian coastal water rarely exhibits the lower temperature and salinity values characteristic of Virginia coastal water because of the lack of freshwater runoff and the influence of the Florida Current.

St. John reported that maximum zooplankton volumes for the shelf waters occurred at stations over the outer half of the shelf near the 40-m depth contour. Relatively constant zooplankton volumes in samples collected between midwinter and late spring were a result of local hydrographic conditions. This finding is quite different from findings in other coastal areas of the north Atlantic that indicate a wide difference in volumes between the two seasons. Oftentimes, water of the Florida Current penetrates the shelf area; this may be detected through the identification of the fauna.

Bowman (1971) has provided an excellent paper on the distribution of calanoid copepods off the southeastern United States from Cape Hatteras to Daytona Beach. He examined specimens collected in a series of nine cruises between January 1953 and December 1954. As expected, the number of copepod species increased from the coastal area out toward the open ocean. He found that a calanoid association was a reliable indicator of the presence of coastal, shelf, and oceanic water at a given locality. The calanoid associations comprised 13 commonly occurring copepods.

Paracalanus parvus, Centropages furcatus, Eucalanus pileatus, and *Temora turbinata* comprise the shelf association in Carolinian coastal waters south of Cape Hatteras. The species composition of this group remains rather constant throughout the year south of Cape Hatteras and may be found north of the Cape during the warmer months. As one goes farther north, the species composition begins to change at first during the colder months and later year-round. *Pseudocalanus minutus* and *Centropages typicus* become the dominant forms. Essentially, the same species make up the oceanic association on both sides of Cape Hatteras. The association moves farther offshore to the north, and a region of slope water may also be present, mixing slope and oceanic calanoid species. This does not occur south of Cape Hatteras. *Calanus minor, Undinula vulgaris, Euchaeta marina, Clausocalanus furcatus,* and several others are the key organisms. *Acartia tonsa* and *Labidocera aestiva*, widely distributed estuarine species that tolerate changes in the environment, make up the coastal association. Farther north, *Acartia tonsa* becomes increasingly limited to the warmer months and is gradually replaced by *Acartia clausii. Labidocera* occurs from early summer to early winter north of Cape Hatteras.

Bowman's explanation for the various assemblages is related to the hydrography of the area and the tolerance limits of the various copepods. Temperature and salinity conditions north and south of Cape Hatteras are fairly similar for the oceanic species, regardless of whether they are found in the Florida Current, the Gulf Stream, or the Sargasso Sea—and these oceanic assemblages enjoy stable conditions. Coastal species must tolerate wide fluctuations in temperature and salinity and thus are able to do well over a great latitudinal range. The shelf species have neither a constant environment nor tolerance to environmental changes; they are unable to survive north of Cape Hatteras in the colder parts of the year and are replaced by other species.

5. Relation of Zooplankton Community to South Atlantic Water–Column Constituents and Hydrography

The complex hydrography of the southeast Atlantic and its subsequent effect on zooplankton have been mentioned while discussing individual investigations. The area in question is dynamic, and incursions of the Gulf Stream often complicate the picture. Identification of zooplankton groups (especially the calanoid copepods) permits identification of various water masses.

Increases in phytoplankton populations are frequently followed by increased numbers of zooplankton. The general picture obtained from the literature regarding shelf zooplankton populations in the southeastern area of the U.S. does not show much seasonal variation during the year. Temperature and salinity changes in this shelf area covered with Carolinian water are not substantial and tend to have little effect on existing populations. This is in contrast to rather abrupt changes that occur farther north above the Cape.

6. Holoplankton and Meroplankton Importance

All the studies conducted in the area from Florida to Cape Hatteras and adjacent areas have shown that meroplanktonic forms are important in the shelf zooplankton and become less important farther offshore. Meroplankton is more abundant in neritic areas because of the dependence of many forms on the bottom during some later stage in their life history. Thus, many of the benthic forms spend a part of their lives as members of the plankton. Likewise, many fish spend the early part of their lives as members of the meroplankton.

During most periods of the year, holoplanktonic forms tend to dominate shelf zooplankton samples. The most abundant forms are calanoid copepods which, at times, may contribute 95% of the total plankton. Chaetognaths, ostracods, and other groups may be significant at various times of the year.

C. DEFICIENCIES IN EXISTING DATA

Many of the zooplankton studies in the southeastern region have been conducted farther inshore in the Gulf Stream or Sargasso Sea regions; few have been performed on the shelf proper, particularly in the midshelf area where zooplankton is supposed to be most abundant. There is also very little information on whether seasonal or latitudinal variations occur on the shelf from Florida to Cape Hatteras.

SECTION 2
MATERIALS AND METHODS

A. FIELD PROGRAM

Zooplankton was collected at approximately the midpoint stations of each transect once during each of the four seasons. The sites (Figure 3.4-7) were:

Transect	Station
1	D
2	E
4	E
5	E
6	D
7	D

An attempt was made to collect samples at the same time of day during comparable tides. In addition to collecting plankton samples, standard meteorological determinations were made and standard environmental parameters measured. Oblique tows were made with 202-μm and 505-μm Nitex nets (60-cm mouth) mounted in aluminum bongo frames. Details of the sampling and shipboard processing appear in Volume 2 of this report. Splitting and treating of samples collected for chemical analysis are also detailed in Volume 2.

Samples for taxonomic and biomass studies were split into two parts and treated in the following manner:

(1) Taxonomy (identification) and enumeration. One hundred subsamples were fixed in 4% buffered formaldehyde, preserved in 4.5% propylene glycol, and stored in 500-ml screw-cap jars precleaned with potassium permanganate (Steedman, 1974).

(2) Biomass. Samples were oven-dried at 60°C until constant weight was attained, then stored in desiccators and frozen until analyzed (Lovegrove, 1966).

B. LABORATORY PROGRAM

1. Zooplankton Identification and Enumeration

Preserved specimens were washed through sieves with a smaller mesh size than the collecting net (usually 63 μm) and diluted to 1,000 ml. Samples were stirred thoroughly and an aliquot of 7 to 10 ml (dependent upon plankton density) removed and placed in a Bogorov counting chamber. Specimens were examined under a dissecting microscope. A minimum of 450 individuals was counted for each sample. Copepods were identified to species where possible, while many of the other plankters were identified to the lowest possible level. The major taxa were subjected to a two-way analysis of variance (ANOV) to determine whether season or station had an effect on the particular group.

2. Zooplankton Biomass

Frozen samples were defrosted in a tap-water bath, drained on 63-μm mesh sieves, and transferred into preweighed crucibles in which they were dried at 62°C to a constant weight. The total weight of samples was determined on a Mettler balance. Ash-free dry weight was determined after ashing in a muffle furnace at 500°C. Organisms larger than 2.5 cm were excluded from the biomass measurement.

Multiple regression analyses were made for ash-free dry weight and organic carbon water-column constituents. See Volume 2 and Appendixes 3.5A and 3.5B in Volume 6 for further information on statistical techniques. Correlation coefficients between ash-free dry weight and nutrients and water quality were determined. Net biomasses for 202-μm and 505-μm nets were compared through ANOV.

SECTION 3
RESULTS

A. TOTAL ZOOPLANKTON

1. Density

The mean numbers of zooplankters per cubic meter of water for each station over each season for both nets (505 μm and 202 μm) are shown in Figure 3.5-2. The mean in the 505-μm net ranged from a low of 28 organisms/m^3 at station 6D to a higher of 830 organisms/m^3 at station 2E. All of the stations except 2E had similar values. For the 202-μm net, the mean ranged from 203 organisms/m^3 at station 6D to 904 organisms/m^3 at station 2E. In general, the mean density of organisms decreased from station 1D to station 7D. Large collections usually were in the 505-μm net at station 2E (3,200 organisms/m^3) and station 7D (869 organisms/m^3) during the fall. The density of zooplankton was high in summer collections at station 2E (2,475 organisms/m^3).

The densities of organisms for all cruises for both nets appear in Table 3.5-1. Figure 3.5-3 indicates mean numbers of zooplankters collected during each season. In the 505-μm net, the mean increased from winter samples to a maximum of 719 organisms/m^3 in the fall. In the 202-μm net, the mean was 810 organisms/m^3 during the summer cruise and the minimum was 126 organisms/m^3 in winter. In almost all cases, the smaller-meshed net collected more organisms.

2. Biomass

All biomass values were determined on a Mettler H-51 Analytical Balance with accuracy of ±0.01 mg. Figure 3.5-4 indicates the dry weight and ash-free dry weight of plankton in the 505-μm and 202-μm nets. Mean dry weight for the coarse mesh ranged from a low of 1.388 mg/m^3 at station 6D to a maximum of 56.003 mg/m^3 at station 2E. Ash-free dry weights showed a similar trend, the mean minimum being 0.642 mg/m^3 at station 6D and the maximum being 17.955 mg/m^3 at station 2E. Dry weight for the 202-μm net reached a new maximum of 11.185 mg/m^3 at station 2E and a mean minimum of 2.084 mg/m^3 at station 6D. Ash-free dry weight showed similar patterns: a mean maximum of 5.553 mg/m^3 at station 2E and a mean minimum of 1.229 mg/m^3 at station 6D. Mean biomass dry weight for the 505-μm net increased from a mean minimum of 1.271 mg/m^3 in winter to a mean maximum of 45.364 mg/m^3 in the fall. Ash-free dry weight showed a similar trend: values ranged from 0.913 mg/m^3 in winter to a fall high of 11.551 mg/m^3. Mean biomass dry-weight values for the 202-μm net ranged from a minimum of 1.847 mg/m^3 in winter to a maximum of 13.069 mg/m^3 in summer. Again, ash-free dry weights followed the pattern of low numbers in winter (1.421 mg/m^3) and high values in summer (6.903 mg/m^3).

A complete listing of biomass dry weight and ash-free dry weight appears in Tables 3.5-2 and 3.5-3.

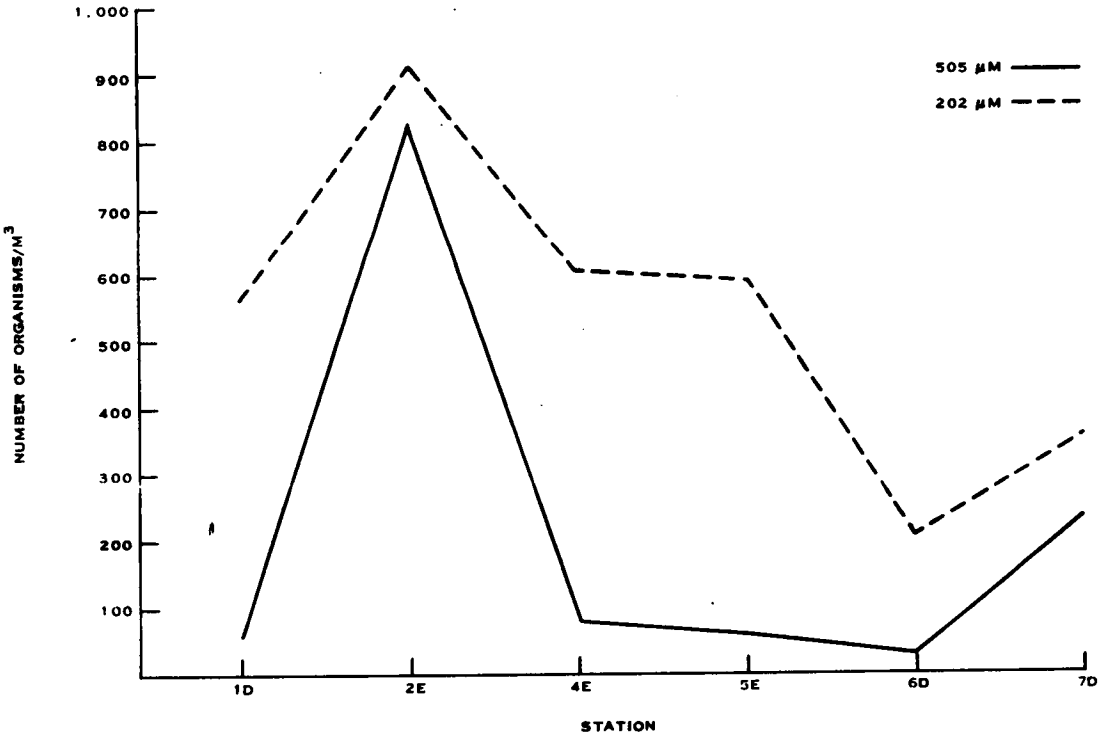

Figure 3.5-2. Mean Numbers of Zooplankton Organisms at All Sampling Stations

Table 3.5-1. Density (No./m³) of Zooplankton Organisms for Each Station

Net	Season	1D	2E	4E	5E	6D	7D	$\bar{X}$
505 μm	Winter	15.68	24.53	9.04	59.56	14.75	23.51	24.51
	Spring	62.01	43.68	52.19	44.96	3.55	6.88	35.55
	Summer	59.08	53.39	204.79	62.43	22.77	17.23	69.95
	Fall	76.38	3,200.69	44.79	54.68	71.83	869.12	719.57
	$\bar{X}$	53.28	830.58	77.70	55.41	28.23	204.18	
202 μm	Winter	57.97	4.04	211.92	182.5	80.74	218.30	125.91
	Spring	923.57	551.92	874.54	1,157.05	177.88	720.44	734.23
	Summer	376.48	2,475.91	931.51	854.20	178.05	45.73	810.31
	Fall	886.97	584.32	388.29	158.48	377.22	436.75	472.01
	$\bar{X}$	561.25	903.95	60.157	588.06	203.47	355.31	–

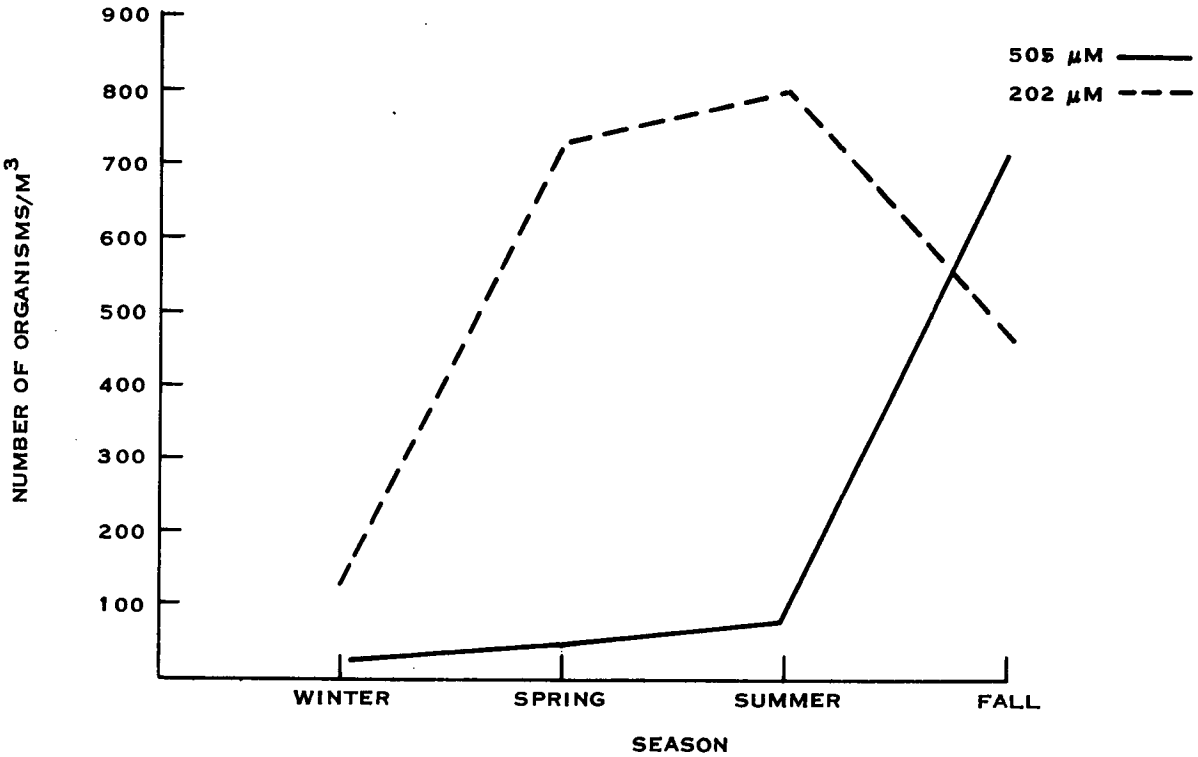

Figure 3.5-3. Mean Numbers of Zooplankton Organisms for All Sampling Seasons

3. Composition

Table 3.5-4 lists the dominant groups (by percentage) from all samples collected in the survey in both the coarse-mesh and fine-mesh nets. Although the same major groups dominated both nets, the rank was somewhat different. Copepods dominated both nets, comprising 58.75% of the 202-µm-net samples and 35.12% of the 505-µm-net samples. Except when chaetognaths dominated the 505-µm-net tows, copepods dominated every collection during every season. Dominant taxa by station are listed in Table 3.5-5.

a. Copepods

Figure 3.5-5 represents the percentage of copepods in both nets each season. For the 505-µm net, the lowest percentage was 20.5 in the spring and the maximum was 58.0 in the summer. The percentage of copepods in the 202-µm net was higher and much more consistent: lowest percentages were in the summer, highest in the spring.

Table 3.5-6 represents the percentage of calanoid copepods, other copepods, and total copepods during each season in both nets. Calanoid copepods dominated each season, and "other" copepods contributed significant percentages to the 202-µm net.

The mean numbers of copepods for each mesh size by station are plotted in Figure 3.5-6. Mean copepod abundance reached a maximum at station 2E and a minimum at station 6D for the 505-µm net. The stations appeared to be essentially equal except for station 2E. The mean in the 202-µm net was maximum at station 1D and minimum at station 6D. The mean generally decreased from station 1D to station 7D.

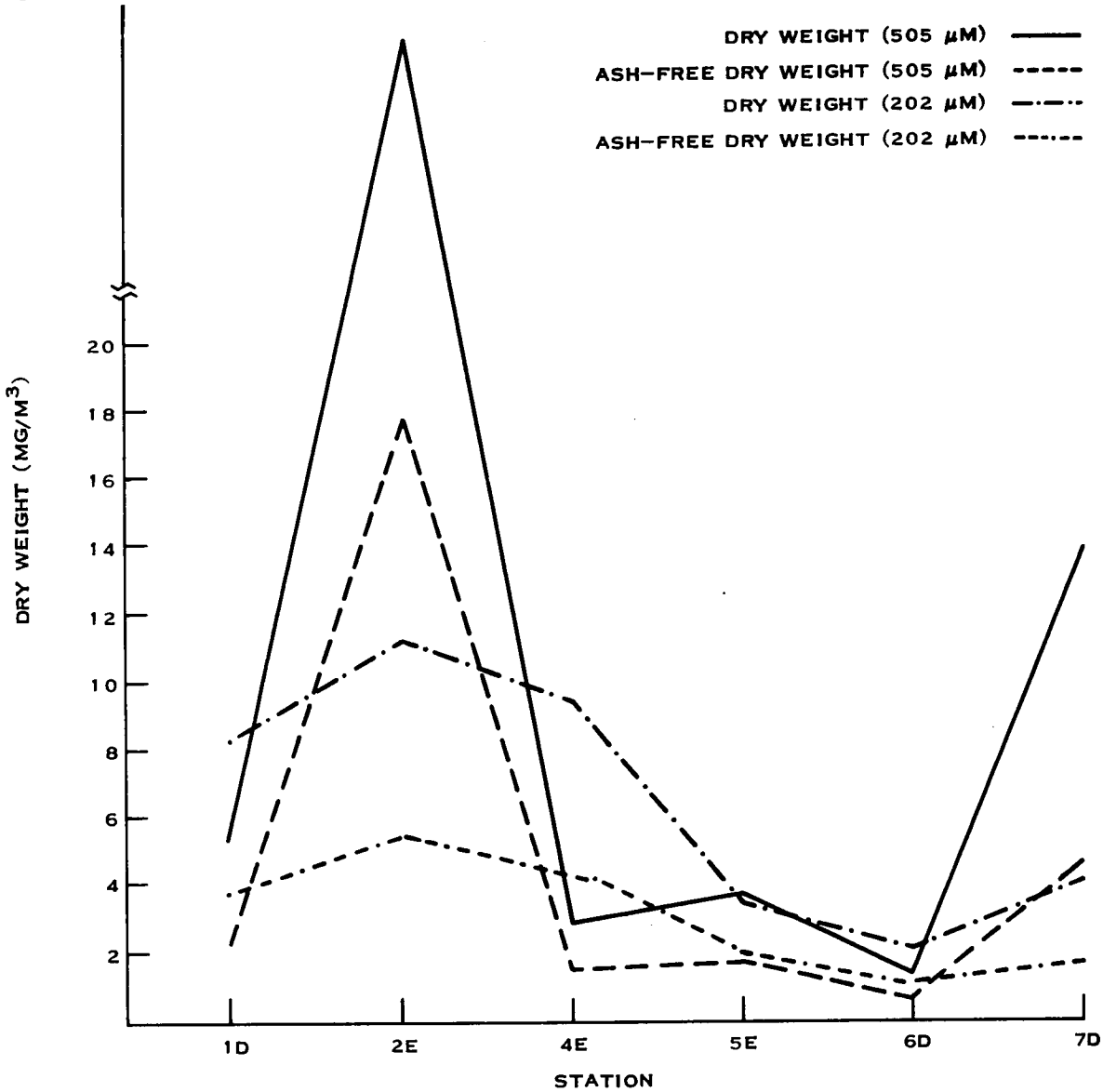

Figure 3.5-4. Mean Dry Weight of Zooplankton at All Sampling Stations

Table 3.5-2. Dry-Weight Zooplankton (mg/m³)

Net	Season	1D	2E	4E	5E	6D	7D	$\bar{X}$
505 μm	Winter	1.085	1.281	1.250	2.259	0.963	0.807	1.271
	Spring	8,050	7.632	4.192	4.897	0.404	0.556	4.288
	Summer	8.897	3.914	5.605	6.349	1.839	2.059	4.777
	Fall	2.713	211.374	0.767	1.561	2.346	53.425	45.364
202 μm	Winter	3.689	0.089	2.037	2.404	0.876	1.987	1.847
	Spring	12.163	8.631	7.179	5.834	2.692	10.206	7.793
	Summer	12.197	33.502	24.967	4.891	2.856	0.638	13.069
	Fall	4.670	2.517	4.087	1.350	2.701	3.976	3.217

Table 3.5-3. Ash-Free Dry-Weight Zooplankton (mg/m³)

Net	Season	1D	2E	4E	5E	6D	7D	$\bar{X}$
505 μm	Winter	0.880	0.912	0.934	1.444	0.746	0.563	0.913
	Spring	2.867	2.449	1.588	1.861	0.115	0.256	1.523
	Summer	4.039	1.629	4.252	3.369	0.983	0.791	2.511
	Fall	0.989	66.83	0.241	0.520	0.723	15.901	11.551
202 μm	Winter	2.887	0.054	1.531	1.978	0.585	1.488	1.421
	Spring	4.099	3.243	2.536	1.861	0.905	4.576	2.870
	Summer	6.352	18.098	11.699	2.964	1.908	0.394	6.903
	Fall	1.884	0.815	1.736	0.503	0.799	1.170	1.151

Table 3.5-4. Dominant Groups at All Stations

505-μm Mesh Net		202-μm Mesh Net	
Group	(%)	Group	(%)
Copepoda	35.12	Copepoda	58.75
Gastropoda	17.72	Ostracoda	22.61
Decapoda	16.45	Urochordata	6.01
Chaetognatha	12.40	Gastropoda	4.71
Ostracoda	12.18	Decapoda	2.83
Amphipoda	3.90	Chaetognatha	2.63
Urochordata	3.32	Cirripedia	0.95
Mysidacea	2.18	Amphipoda	Trace
Cnidaria	2.09	Polychaeta	Trace
Cirripedia	Trace	Cnidaria	Trace
Euphausiacea	Trace	Mysidacea	Trace
Polychaeta	Trace	Euphausiacea	Trace

The dominant genera of copepods at all stations are given by percentages in Table 3.5-7. *Undinula, Centropages,* and *Temora* dominated the 505-μm net collections. *Parvocalanus, Temora,* and *Oncaea* were most abundant in the finer-mesh net. The various copepods collected during the survey and the season in which each was collected are detailed for the 505-μm net and the 202-μm net in Tables 3.5-8 and 3.5-9, respectively, and are discussed in the following paragraphs.

(1) 505-μm Net

The most abundant copepod collected with the coarse mesh was *Undinula,* which had a mean of 228.0 organisms/m³ and accounted for 51% of the total copepods. *Undinula vulgaris* comprised 66.1% of the genus, with the remainder being classified as *Undinula* unidentified. *Undinula* was present in small numbers in the winter and spring, increased in the summer, and reached a maximum in the fall. The overall maximum occurred at station 2E.

Table 3.5-5. Dominant Taxa for Each Station, All Cruises Listed in Descending Order of Total Abundance

Station	202-μm Net	505-μm Net	Station	202-μm Net	505-μm Net
1D	Copepoda	Copepoda	5E	Copepoda	Copepoda
	Parvocalanus	*Sagitta*		*Parvocalanus*	*Sagitta*
	Oncaea	*Undinula*		Ostracoda	Decapoda
	Ostracoda	Decapoda		*Coryceus*	*Undinula*
	Temora	*Temora*		Decapoda	*Euchaeta*
	Larvacea	Ostracoda		Larvacea	Ostracoda
	Clausocalanus	Gastropoda		*Sagitta*	*Centropages*
	Gastropoda	*Eucalanus*		Gastropoda	*Nannocalanus*
	Corycaeus	Amphipoda		*Temora*	Amphipoda
	Decapoda	Larvacea		*Oncaea*	Siphonophora
2E	Ostracoda	Copepoda	6D	Copepoda	Copepoda
	Copepoda	Decapoda		*Parvocalanus*	*Sagitta*
	Parvocalanus	*Undinula*		*Oncaea*	Ostracoda
	Oncaea	Ostracoda		Larvacea	*Undinula*
	Temora	Gastropoda		Ostracoda	Decapoda
	Corycaeus	*Sagitta*		*Corycaeus*	*Eucalanus*
	Oithona	Amphipoda		*Oithona*	Larvacea
	Gastropoda	Mysidacea		Decapoda	Gastropoda
	Clausocalanus	*Temora*		*Temora*	Cirripedia
	Sagitta	Siphonophora		Gastropoda	Siphonophora
4E	Copepoda	Copepoda	7D	Copepoda	Copepoda
	Parvocalanus	*Centropages*		*Parvocalanus*	*Sagitta*
	Ostracoda	*Sagitta*		*Temora*	*Undinula*
	Corycaeus	*Eucalanus*		Larvacea	*Centropages*
	Temora	Amphipoda		Thaliacea	Decapoda
	Centropages	Decapoda		Doliolidae	Larvacea
	Larvacea	Ostracoda		Ostracoda	*Eucalanus*
	Oncaea	*Undinula*		*Clausocalanus*	Siphonophora
	Sagitta	Gastropoda		*Oncaea*	Gastropoda
	Gastropoda	*Temora*		Decapoda	Ostracoda

Table 3.5-6. Seasonal Distribution of Copepods

Net	Season	Distribution (%) Calanoid	Others	Total
505 μm	Winter	31.0	1.1	33.8
	Spring	19.4	1.1	20.5
	Summer	55.2	2.8	58.0
	Fall	31.0	2.6	33.6
202 μm	Winter	29.9	22.2	52.1
	Spring	51.5	15.0	66.5
	Summer	34.6	15.3	49.9
	Fall	45.2	18.4	63.6

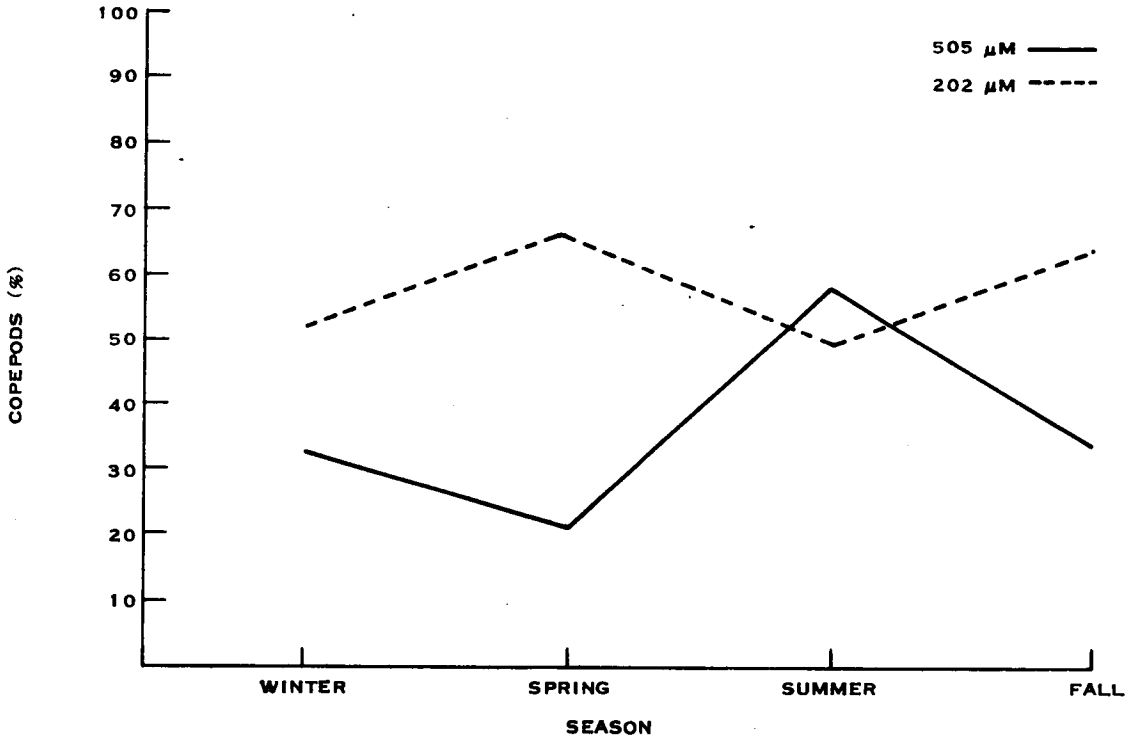

Figure 3.5-5. Copepod Percentages by Season

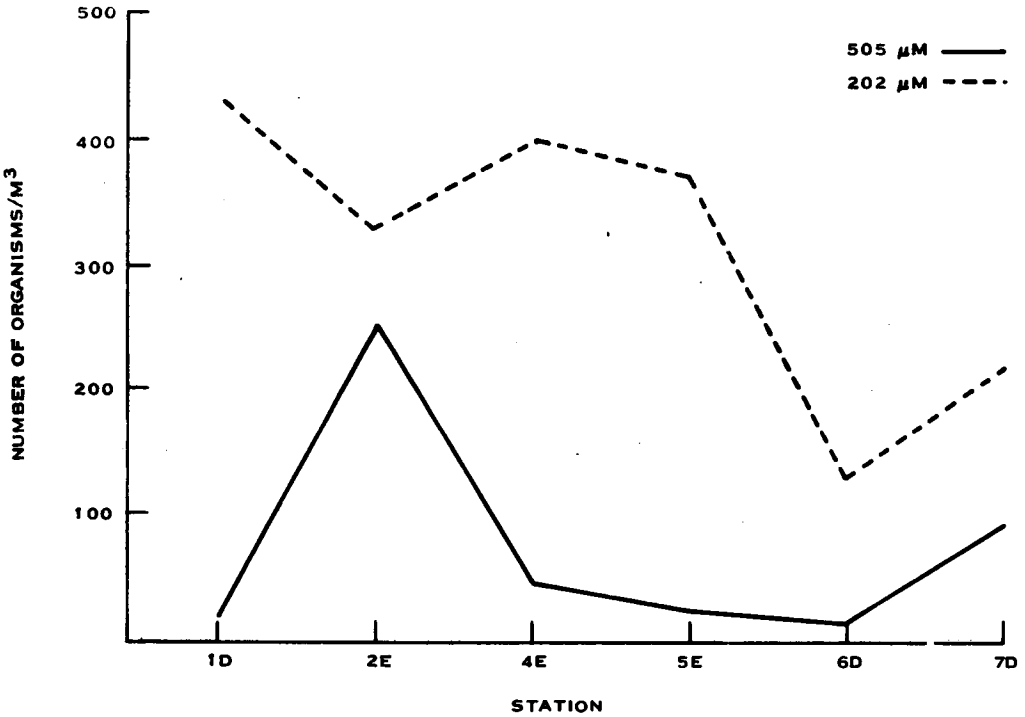

Figure 3.5-6. Station Means of Copepod Abundances

Table 3.5-7. Dominant Copepod Genera

Net	Genera	% $\bar{X}$ All Stations
505 μm	*Undinula*	51.02
	Centropages	11.42
	Eucalanus	8.45
	Temora	7.26
	Euchaeta	3.60
	Copilia	3.50
	Corycaeus	2.95
	Scolecithrix	2.52
	Nannocalanus	1.32
	Candacia	1.07
202 μm	*Parvocalanus*	32.89
	Temora	9.49
	Oncaea	9.36
	Corycaeus	8.88
	Oithona	3.94
	Centropages	3.92
	Clausocalanus	3.87
	Eucalanus	1.97
	Undinula	1.94
	Acartia	1.60

The second most abundant copepod, with a mean of 50 organisms/m^3, was *Centropages.* More were collected at station 4E than at any other station. This copepod appeared in trace amounts in the winter, in small numbers at most stations in the spring, increased in the summer, and reached maximum density in the fall. *C. furcatus* accounted for 87% of the genus, and *C. violaceus* for 4.6%; the remainder was unidentified *Centropages. Eucalanus* had a mean density of 38 organisms/m^3. Overall, the most were at station 7D. Three species were positively identified: *E. monachus*, 69%; *E. attenuatus*, 9%; and *E. elongatus*, trace amounts. Unidentified *Eucalanus* accounted for 22%. Maximum numbers were collected during the fall cruise. ANOV (Appendix 3.5B in Volume 6) revealed a slight seasonal effect on the distribution of this group.

The mean abundance for *Temora* at all stations was 32 organisms/m^3. This copepod was present in low numbers at all stations in the winter, increased slightly in abundance in the spring, increased again during the summer, and reached a maximum in the fall. *Temora stylifera* accounted for 93% of the genus, followed by *T. turbinata* (5.8%) and unidentified *Temora* (1.2%). Overall, this copepod was most abundant at station 4E.

Euchaeta reached maximum abundance overall at station 7D. Mean abundance at all stations was 16 organisms/m^3. *Euchaeta marina* accounted for 34% of the members of the genus collected; 65% were categorized as unidentified *Euchaeta.* Maximum numbers were recorded in summer and fall and traces in winter and spring. Calculations of the two-way ANOV (Appendix 3.5B in Volume 6) indicated (PR > F = 0.0792) that there is some seasonal effect on this genus. ANOV calculates the probability (likelihood) that the conditions observed would occur if there was no difference between seasons. The resulting probability values fall between 0.0 and 1.0.

Table 3.5-8. Copepods Collected in 505-μm Mesh Nets

Species	Season			
	Winter	Spring	Summer	Fall
Acartia danae		X		
Labidocera aestiva	X	X	X	
Parvocalanus (Paracalanus) spp.	X	X	X	X
Temora turbinata	X	X	X	X
Temora stylifera	X	X	X	X
Temora spp.		X		
Centropages furcatus	X	X	X	X
Centropages violaceus		X	X	X
Centropages spp.		X	X	X
Nannocalanus minor	X	X	X	X
Nannocalanus spp.		X		
Undinula vulgaris	X	X	X	X
Undinula spp.	X	X	X	X
Eucalanus attenuatus	X	X	X	X
Eucalanus elongatus		X	X	
Eucalanus mucronatus			X	
Eucalanus monachus		X	X	X
Eucalanus spp.	X	X	X	X
Rhincalanus coronutus	X	X	X	X
Rhincalanus spp.	X	X	X	X
Clausocalanus arcuicornis		X		X
Calocalanus spp.			X	X
Calocalanus pavo			X	
Euaetideus gresbrechti			X	
Euchaeta marina		X	X	X
Euchaeta spp.	X		X	X
Scolecithrix danae	X	X	X	X
Scolecithrix spp.			X	
Lucicutia spp.			X	
Haloptilus longicornis		X	X	X
Haloptilus spiniceps			X	
Candacia bipinnate				
Candacia pachydactyla	X	X	X	X
Candacia spp.	X	X		X
Calanopea americana		X		X
Pontellina plumate			X	X
Aetidius spp.		X		
Aetidopsis multisirata		X		
Aetidopsis spp.		X	X	
Neocalanus robustior		X		
Calanus tenucornis			X	X
Oithona spp.		X	X	X
Corycaeus spp.	X	X	X	X
Copila vitrea	X	X	X	X
Copila quadrata			X	
Sapphirina nigromaculata	X	X	X	X
Sapphirina opalina			X	
Oncaea	X	X	X	X
Pachos punctatum			X	
Cyclopoids (unidentified)			X	
Peltidium sp.			X	

Table 3.5-9. Copepods Collected in 202-μm Mesh Nets

Species	Season Winter	Spring	Summer	Fall
Acartia danae		X	X	
Acartia spp.		X		
Parvocalanus (Paracalanus) spp.	X	X	X	X
Temora turbinata	X	X	X	X
Temora stylifera	X	X	X	X
Temora spp.	X	X	X	X
Centropages furcatus	X	X	X	X
Centropages violaceus			X	
Centropages spp.		X		X
Neannocalanus minor	X		X	X
Neannocalanus spp.				X
Undinula vulgaris	X	X	X	X
Undinula spp.				X
Epischura spp.		X		
Eucalanus attenuatus	X	X	X	
Eucalanus elongatus			X	
Eucalanus spp.	X	X		X
Rhincalanus coronutus	X	X	X	X
Rhincalanus spp.	X		X	
Clausocalanus arcuicornis	X	X		X
Clausocalanus furcatus	X	X		X
Clausocalanus spp.	X	X	X	X
Ctenocalanus spp.		X		
Calocalanus pavo			X	X
Calocalanus styliremis				X
Calocalanus spp.	X	X	X	X
Euchaeta marina			X	X
Euchaeta spp.	X	X		X
Phaenna spinifera			X	
Scolecithrix danae	X	X	X	X
Scolecithrix spp.				X
Lucicutia flavicornis			X	X
Lucicutia spp.		X	X	X
Haloptilus longicornis			X	
Haloptilus spp.			X	
Candacia spp.		X		X
Candacia pachydactyla		X	X	
Calanopia americana		X		X
Calanopia spp.				X
Neocalanus gracilis			X	
Calanus tenuicornis			X	
Pontellidae	X			
Calanus spp.				X
Mecynocera clausi				X
Oithona spp.	X	X	X	X
Corycaeus spp.	X	X	X	X
Farranula spp.			X	X
Copila vitrea			X	X

Table 3.5-9. Copepods Collected in 202-μm Mesh Nets (Continued)

Species	Season			
	Winter	Spring	Summer	Fall
Copilia spp.				X
Sapphirina nigromaculata		X	X	
Sapphirina spp.				X
Oncaea spp.	X	X	X	X
Lubbockia spp.		X		
Ratania spp.				
Cyclopodia (unidentified)	X		X	X
Longipedia helgolandica	X	X		X
Euterpina acutifrons	X	X	X	X
Clytemnestra rostrata	X	X	X	X
Clytemnestra spp.				X
Macrosetella gracilis	X	X	X	X
Peltidium spp.			X	
Oculosetella spp.			X	
Tisbidae			X	
Harpacticoid (unidentified)	X	X		

Probabilities near 1.0 indicate that the values observed do not significantly differ from what might be expected if there was no difference between seasons. Probability values near 0.0 (0.10, 0.05, 0.01) indicate that the observed data are unlikely to occur if there is, in fact, no difference between seasons.

Copilia vitrea comprised most of the *Copilia* captured, but several specimens of *C. quadrata* also were identified. Mean density was 16 organisms/m^3, with the maximum occurring in the fall. Overall, station 2E yielded the greatest numbers of this copepod.

Mean density for *Corycaeus* was 13.20 organisms/m^3, with maximum numbers occurring during the fall cruise. Station 2E was the area of greatest abundance.

Scolecithrix increased in abundance during summer and fall, and 99% of the identified specimens were *Scolecithrix danae.* Station 2E was the area of greatest abundance.

Nannocalanus minor and *Candacia* spp. appeared sporadically, with *Candacia* reaching maximum numbers at station 2E and *Nannocalanus* peaking at station 5E. Analysis of variance of the *Candacia* data suggested that the distribution of this species might be affected by season (PR = 0.113).

Other copepods appeared periodically and sporadically, but none were sufficiently abundant to be considered important.

(2) 202-μm Net

Parvocalanus (Paracalanus) dominated zooplankton tows with the 202-μm net, accounting for approximately 33% of the total copepods. Mean density for this group was 104

organisms/m^3, maximum numbers were collected during the spring series, and station 5E was the richest area. ANOV (Appendix 3.5B in Volume 6) showed a definite seasonal effect. Although it is likely that several different species were present, all specimens have been included in the one category.

The second most abundant copepod in the 202-μm net was *Temora,* which had a mean density of 179 organisms/m^3. Numbers collected were maximum during summer and generally higher at station 4E. *Temora stylifera* comprised 16% of the genus and *T. turbinata* 49%; the remainder were unidentified *Temora.* Calculated values from ANOV showed PR > F = 0.0992, which indicates a seasonal effect.

Based on mean densities, three cyclopoid copepod genera made up the three next most abundant groups. Ranking third was *Oncaea* with a mean density of 177 organisms/m^3. There was no attempt to break down *Oncaea* into component species. Station 1D was the area of greatest abundance and had large numbers throughout the study. ANOV values showed both a seasonal and station effect on this copepod group. *Corycaeus* species, with a mean density of 168 organisms/m^3, was omnipresent; abundance peaked at stations 4E and 5E during most of the year, and numbers were maximum in summer samples. The two-way ANOV showed both a seasonal and a station effect. *Oithona* species had a mean density of 74 organisms/m^3; station 2E had the summer and fall maxima, although this copepod was found everywhere. As with the other cyclopoids, the ANOV showed a seasonal effect but no station effect.

Centropages and *Clausocalanus* had mean densities of 73 organisms/m^3. *Centropages* was most abundant overall at station 4E and demonstrated maxima during spring. *Centropages furcatus* made up approximately 50% of the genus; there were trace amounts of *C. violaceus*, and 50% were unidentified *Centropages. Clausocalanus* reached maximum numbers during fall sampling and was most abundant at station 1D. *Clausocalanus arcuicornis* comprised 19% of the group and *C. furcatus* 28%; 53% were unidentified *Clausocalanus*. ANOV showed a definite seasonal effect.

Eucalanus had a mean density of 37 organisms/m^3 and comprised 1.97% of the total copepods. Numbers were maximum in the fall, and station 4E yielded the largest amounts. *Eucalanus monachus* made up 40% of the group and *E. attenuatus* 21%; there were trace amounts of *C. elongatus*, while 38% were unidentified *Eucalanus*. ANOV (Appendix 3.5B in Volume 6) indicated a station effect for this group.

Undinula, with a mean density of 37 organisms/m^3, reached maximum numbers at station 1D; a fall maximum prevailed, with minimum numbers occurring in the winter. *Undinula vulgaris* accounted for 54% of the group, and 46% were unidentified. ANOV demonstrated a seasonal effect but no station effect.

Acartia reached maximum density in the spring, and station 1D had the peak abundance. Approximately 50% of the population was identified as *Acartia danae*, while 50% remained unidentified. A seasonal effect was determined with ANOV.

As in the larger-mesh net, there were smaller numbers of numerous other copepods (Table 3.5-9).

b. Gastropoda

Mean density of gastropods in the 505-μm net was 118 organisms/m^3. Fall sampling yielded the most, and station 2E had the maximum. Pteropods comprised 91% of the gastropods; further identification was not made.

Gastropods were slightly less abundant in the 202-μm net (86 organisms/m^3). Mean density peaked in the spring. Station 1D yielded the greatest abundance. Pteropods made up 76% of the gastropod identification. ANOV values indicated a seasonal effect on both pteropods and gastropods.

c. Decapoda

Decapods ranked third in abundance in the 505-μm net and fifth in the 202-μm net. Mean density in the coarse net was 209 organisms/m^3, with brachyura larvae accounting for 23%, *Lucifer* 33%, *Coridea* 19%, and unidentified decapods 10%. Fall samples yielded maximum numbers, with station 2E samples possessing the largest numbers of all categories. Decapods in the 202-μm net had a mean density of 91 organisms/m^3; abundance peaked in spring sampling, and stations 3E and 5E yielded the most. *Lucifer* (45%), brachyura (18%), and unidentified decapods (37%) were dominant. ANOV demonstrated a seasonal effect for decapods captured in the fine-mesh net.

d. Chaetognatha

All chaetognaths have been identified to the genus *Sagitta*, which ranked fourth in the 505-μm net and sixth in the 202-μm net. The mean in the coarse-meshed net was 158 organisms/m^3, with more organisms being collected at station 2E. The period of maximum abundance was spring. The fine-meshed net had a lower mean density (84 organisms/m^3 but a similar spring maximum, and station 4E was the locale of greatest abundance. ANOV for distribution showed a seasonal effect in both series, but the coarser net had slightly lower limits.

e. Ostracoda

This group ranked second in the fine-meshed net and fifth in the coarse-meshed net: mean density was 727 organisms/m^3 and 151 organisms/m^3, respectively. The former was primarily caused by a large influx of ostracods at station 2E during the summer. The largest numbers in the coarse-meshed net occurred in the fall.

f. Amphipoda

Hyperids dominated the makeup of the amphipods in both types of net: 71% in the 505-μm net and 77% in the 202-μm net. Mean densities were 49 organisms/m^3 and 21 organisms/m^3, respectively. Station 2E had the coarse-net maximum in the fall, and station 4E had the fine-net maximum in the summer.

g. Urochordata

Larvacea dominated the pelagic tunicates, making up 83% of the fine-mesh net catches (164 organisms/m^3) and 67% of the coarse-mesh net catches (30 organisms/m^3). Larvacea comprised two genera, *Oikopleura* and *Fritillaria*, while Thaliacea comprised both salps and doliolids.

h. Other Groups

At various times mysids, echinoderm larvae, bivalve larvae, cladocerans (*Penilia*), cnidarians, barnacle larvae, and polychaetes contributed to the zooplankton (Table 3.5-4). (A complete list of taxa is given in Appendix B of Volume 2.)

B. ANOV OF DENSITY OF KEY GROUPS

The two-way ANOV between density of key groups and season and station (Appendix 3.5B in Volume 6) yielded mixed results. The only groups common to both net sizes were chaetognaths and the copepods *Euchaeta* and *Eucalanus*. The 202-μm net showed significant correlation for many more copepods than did the 505-μm net (Table 3.5-10).

Table 3.5-10. ANOV Density of Key Groups With Seasons and Stations[a]

Net	Group	Season	Station
505 μm	Chaetognatha	X	
	Larvacea	X	
	Salpa	X	
	Siphonophora	X	
	Hydromedusa	X	
	Cirripedia	X	
	Euchaeta	X	
	Eucalanus	X	
	Candacia	X	
202 μm	Chaetognatha	X	X
	Pteropoda	X	
	Gastropoda	X	
	Polychaeta	X	X
	Decapoda	X	
	Copepoda	X	
	Centropages		X
	Eucalanus		X
	Clausocalanus	X	
	Undinula	X	
	Temora	X	
	Euchaeta	X	
	Corycaeus	X	X
	Oncaea	X	X
	Oithona	X	

[a]Denotes significance.

C. ASH-FREE BIOMASS AND ORGANIC CARBON IN WATER

Multiple regression analyses (Appendix 3.5A in Volume 6) were conducted on ash-free dry-weight samples from both the fine-mesh and coarse-mesh nets and on organic carbon in both the bottom and the water column. Organic carbon included particulate organic carbon, dissolved organic carbon, and chlorophyll *a*. There were no significant correlations, with the possible exception of a slight seasonal effect between 202-μm biomass and POC, DOC, and chlorophyll *a*.

D. CORRELATION OF ASH-FREE BIOMASS WITH NUTRIENTS AND WATER QUALITY

Results of the correlation of biomass from both nets with nutrients and water quality (Appendix 3.5A, Volume 6) showed few significant relationships, although a slight correlation could be seen between 202-μm biomass and chlorophyll *a*, dissolved oxygen, and water temperature. Significant correlation for 505-μm biomass could be seen only with SiO_2 in the water column.

E. COMPARISON OF NET BIOMASSES

The analysis of variance for a comparison of biomass using all data from all stations occupied during the SABP (Appendix 3.5A) indicated that any difference between the two nets was random. The calculated probability (PR = 0.5725) indicates that data were within the range of natural variability in collections if the nets were equivalent in sampling ability.

F. DIVERSITY

The number of taxa from cruise to cruise varied from 21 during the winter cruise at station 2E to 52 at station 7D during the fall. Shannon-Weaver diversity test results are presented in Table 3.5-11. Shannon-Weaver diversity values (H) vary between 0.0 and the $\log_2$ of the number of species collected. In general, the higher the value of H, the more heterogeneous the community (many species, few individuals); and the lower the value of H, the more homogeneous the community (few species, many individuals). Most of the diversity (H) values are high and tend to increase toward summer. The statistic J provides a measure of the closeness of a community of x taxa to one in which each of x taxa occurs with equal frequency. Evenness as denoted by J takes on values between 0.0 and 1.0. Small values are generally associated with community dominance by a few taxa while high values indicate similar occurrence of all taxa in the community. J values for the SABP zooplankton studies were generally high and like the H values, tended to increase during summer. A very low H value was recorded for the 202-μm net during summer at station 2E because of the dominance of ostracods in the sample.

Table 3.5-11. Shannon-Weaver Test Results

Season	Net	Indices[a]	Estimates of Taxa Diversity and Evenness 1D	2E	4E	5E	6D	7D
Spring	505 μm	H	3.65	2.02	3.44	29.5	3.34	3.38
		J	0.65	0.41	0.69	0.64	0.69	0.64
Spring	202 μm	H	3.38	3.68	3.49	2.66	3.51	3.89
		J	0.68	0.72	0.70	0.51	0.68	0.72
Winter	505 μm	H	2.59	3.39	3.32	4.15	4.14	4.07
		J	0.55	0.77	0.72	0.81	0.81	0.79
Winter	202 μm	H	3.06	3.65	3.80	4.16	3.66	3.76
		J	0.61	0.77	0.77	0.79	0.82	0.77
Summer	505 μm	H	4.35	4.16	?	4.23	4.28	4.09
		J	0.79	0.75		0.79	0.82	0.76
Summer	202 μm	H	3.83	1.86	3.60	3.77	3.30	4.18
		J	0.73	0.38	0.73	0.71	0.63	0.74
Fall	505 μm	H	4.06	3.85	3.94	4.31	4.25	4.18
		J	0.78	0.78	0.79	0.83	0.80	0.80
Fall	202 μm	H	4.21	3.85	4.01	4.35	4.29	4.23
		J	0.80	0.73	0.77	0.84	0.77	0.74

[a]H = diversity; High values indicative of many species, few individuals; low values indicate few species, many individuals.

J = evenness;

SECTION 4
DISCUSSION

Numerous studies have shown the inadequacy of collecting zooplankton in any one net; typically, a particular mesh size is selected in order to capture a specific group. Since the SABP already was dedicated to gaining as much information as possible on south Atlantic zooplankton population, the use of two different mesh-size nets, a coarser mesh (505 μm) and a finer mesh (202 μm), was an important aspect of the program design. ANOV of biomass values from both nets indicated that there was no significant difference between net biomass catches; any differences were attributable to randomness.

The mean number of organisms collected by the 505-μm net during the entire survey was 212 organisms/m^3; 37% of the total zooplankton population collected could be attributed to copepods and 34% to calanoids. The 202-μm net yielded a mean of 536 organisms/m^3; approximately 58% of the total zooplankton population was copepods, with calanoids accounting for 43%. Thus, it becomes clear that a large portion of the copepods being collected by the 202-μm net represented "other" copepods, primarily smaller cyclopoids of the genera *Oncaea, Corycaeus,* and *Oithona,* that were not being collected in any quantity in the larger-meshed net.

Table 3.5-1 in Section 3 shows the dominant groups collected by each net; the same groups are represented, although ranked differently. Again, the smaller organisms (e.g., larvacea and doliolids) were collected in higher numbers by the smaller mesh, while some of the larger forms (e.g., decapods and chaetognaths) were collected more efficiently by the larger-meshed net. One further point which should be made here is that the mesh size of the smallest net was still too large to retain many of the developmental stages of crustacea, especially copepods; as a result, few nauplii of copepods were collected.

According to St. John (1958), maximum numbers of zooplankton off North Carolina occur on the outer half of the continental shelf near the 40-m depth contour. All the stations used for the SABP zooplankton survey were in this area, which presumably represented the richest zooplankton areas along the shelf. Also, the mean abundances (numbers of organisms per cubic meter) of zooplankton collected by Grice and Hart (1962) in their survey from New York to Bermuda using a 230-μm net were: neritic, 1,540; slope, 310; Gulf Stream, 134; and Sargasso Sea, 71. The SABP study's means of 212 organisms/m^3 and 563 organisms/m^3 (both nets) place it between the neritic and slope areas of Grice and Hart. The higher number associated with the 202-μm net is probably the more legitimate number to use, since this net is essentially the same as that used by Grice and Hart. The abundance of zooplankton in the study area is somewhat higher than the mean of 234 organisms/m^3 described by Fish (1954) for the Sargasso Sea but substantially below that described by Lonsdale and Coull (1977) in a shallow-water estuary in South Carolina.

A similar trend may be seen from the biomass dry-weight mean values of 6.48 mg/m^3 and 13.93 mg/m^3, for the 202-μm and 505-μm nets, respectively. Bsharah (1957) found an average dry weight of 0.45 mg/m^3 in the Florida Current off Miami; Menzel and Ryther (1961) recorded an average of 2.61 mg/m^3 off Bermuda; and the study of Lonsdale and Coull (1977) at North Inlet near Georgetown, South Carolina, described a biomass dry weight of 162 mg/m^3. The SABP study area would seem to be intermediate between higher neritic values and lower Gulf Stream-Sargasso Sea numbers.

An attempt was made to correlate biomass (ash-free dry weight) with organic carbon in the water and with nutrients and water quality (Appendix 3.5A in Volume 6). Few correlations were significant. A significant correlation was found between the season and POC, DOC, and chlorophyll *a* for the 202-μm net; and significant correlations were seen for 202-μm biomass and chlorophyll *a*, dissolved oxygen, and temperature. Significant correlations for the 505-μm biomass existed for SiO_2 in the water column. The lack of significant correlations in some cases was unusual; for example, one would expect to find a correlation of 505-μm biomass with chlorophyll *a* as well as with 202-μm biomass, etc.

The mean abundance of zooplankton in the 505-μm net was low in the winter, gradually increased in spring and summer, and was much larger in fall. The highest mean in the fall was the result of unusually large samples collected at stations 2E (3,200 organisms/m^3) and 7D (869 organisms/m^3). The increase at station 2E was not the result of an influx of any one major group of organisms or of water mass since water quality remained essentially similar to that at the prior station; rather, it represented a large increase in many different groups. A possible explanation comes from the sample at station 4E, which could have represented the time-of-dawn rise of zooplankton before their descent from the surface areas; this would result in a very rich zooplankton haul. No such explanation is available for the sample collected at station 7D at 1345. If the two unusual tows are not calculated in the mean, then the fall mean is slightly less than that of the summer. Zooplankton in the 202-μm net was minimal in the winter and maximum in the summer. Values from both nets agreed with summer peaks of abundance in other studies in adjacent offshore waters.

Station 2E appeared to be the area of highest mean density and station 6E the area of lowest mean density for both the coarse-mesh and fine-mesh nets. The maximum at station 2E with the 505-μm net was primarily a result of fall zooplankton, but no hydrographic or physical phenomenon seems to explain the 202-μm maximum at station 2E or either net's minima at station 6D.

As in most of the previous studies in adjacent areas, copepods dominated SABP zooplankton tows. Fish (1954) recorded 62%, Menzel and Ryther (1962) 61 to 79%, Grice and Hart (1962) 51%, and Deevey (1971) 70%. Copepods were most abundant at station 1D in the 202-μm net and at station 7D in the 505-μm net.

According to Bowman (1971), calanoid copepods may be used as associations to determine the type of water that is present. He lists *Paracalanus parvus, Centropages furcatus, Eucalanus pileatus,* and *Temora turbinata* as members of the shelf association; *Calanus minor, Undinula vulgaris, Euchaeta marina,* and *Clausocalanus furcatus* as oceanic association members; and *Acartia tonsa* and *Labidocera aestiva* as comprising a coastal association. Based on this scheme of classification, all stations are a combination of shelf or shelf-oceanic associations. SABP station 1D was essentially a shelf association with the occasional presence of oceanic-association copepods; 2E seemed to be a mixture of both shelf- and oceanic-association copepods; 4E, like 1D, had dominant shelf-association copepods and occasional oceanic copepods; and 5E had a mixture of shelf- and oceanic-association copepods; station 6D seemed to represent the best example of shelf association, having only a rare appearance of oceanic copepods, and 7D was a good mixture of both shelf and oceanic species. The coastal association is undoubtedly inshore away from these shelf stations, since few *Labidocera* or *Acartia* copepods were found. Thus, based on calanoid copepods, the SABP zooplankton samples were collected primarily in shelf

water with varying degrees of influence from offshore water. One might have expected stations 2E and 7D to have contained a higher percentage of offshore forms because of their offshore proximity.

Investigators studying nearby waters have mentioned the abundance of various groups and their importance in zooplankton tows: Bumpus and Pierce (1958) and Pierce and Wass (1962) discussed the significance of chaetognaths of south Atlantic areas; Chen and Hillman (1970) described the pteropods off Cape Hatteras and their use as indicators of water masses; and Deevey (1971) mentioned the great abundance of ostracods in her samples. Each of these groups was a significant part of the zooplankton collected during the SABP study. Several other groups also were prominent in zooplankton samples from both net sizes, e.g., decapods and urochordates. The latter were represented by oikopleurans and doliolids, which indicate a more oceanic type of water; these were most abundant at stations 2E, 5E, and 7D. Other groups appeared sporadically. Euphausids were conspicuous by their absence in many of the samples.

Holoplanktonic forms tend to dominate zooplankton samples—and this survey was no exception. Because most of the samples were away from the coastal area, holoplanktonic numbers were quite high: collections were approximately 95% holoplankton in the 202-μm net and 85% in the 505-μm net.

As mentioned earlier, a two-way ANOV was run using each of the 43 main taxa (Table 3.5-10). There was little agreement between the analyses run on both mesh sizes; the 505-μm net showed significance with nine groups, while the 202-μm net showed significance with 15 groups. Mesh clogging and selective sampling by the 202-μm net was probably responsible for the inconsistency, and there is some question about the validity of these findings.

Results of the Shannon-Weaver test (Table 3.5-11) showed both sets of values (H and J) to be very high, with several exceptions as explained in Section 3. From the data, it is possible to conclude that the entire zooplankton sampling area is one of very high diversity. There is a slight tendency for an increase in diversity toward the summer period. These diversity values may be important in the future, since any perturbation that is harmful to the system may be detected with this type of analysis.

It is exceedingly difficult to understand zooplankton populations based on samplings conducted every 3 months. Earlier comments in this chapter refer to the dynamic nature of zooplankton and the rapid changes that may take place. When possible, samples should be collected weekly; however, in this sort of project, such an undertaking would be impossible. It would have been helpful, however, to have had at least one or two areas that could have been sampled on a monthly basis; this would have given some idea as to the reliability of data from other stations. More information would have been provided, also, if one or two coastal stations or at least one transect from west to east had been included with several additional stations; this may have provided information on coastal associations.

When few plankton samples are collected in a survey, it is better to collect the samples at approximately the same time to minimize sampling bias. If one of a series of six samples is collected during the dawn rise of a vertical migration, this sample will contain greater numbers than will a sample collected during midday in clear water when many of the plankters are near the bottom. On the basis of this, some bias may be encountered in some of the tows.

There is evidence to support the concept that the outer half of the shelf area in the southeastern Atlantic Ocean is rarely invaded by coastal water and its constituent fauna and that shelf water predominates with periodic inshore movement of oceanic water. The most immediate marker of this activity is the calanoid copepod association described by Bowman (1971).

The major pollution problems that are likely to occur in this study area are related to offshore drilling for oil and concomitant release of drilling fluids, turbidity, and oil. Plankton populations may be temporarily disrupted, but they probably will return to a normal state if the pollutants are not longlasting. Jeffries and Johnson (1976) assessed the effects of petroleum on zooplankton of the shelf area, finding that there might be some short-term difficulties for copepods at point discharges but that lasting damage does not seem likely. Low-level petroleum pollution seemed to have little effect on copepod populations. Jeffries and Johnson noted, however, that various members of the meroplankton may be harmed to a greater extent. These investigators also generalized that the direct effect of energy-related activities on copepods is not a concern in open coastal areas in the mid-Atlantic Bight.

Further sampling would permit an increase in the confidence limits of the diversity index. This may well be the best measure of perturbation on the zooplankton community.

In spite of the problems encountered and the deficiencies noted, this plankton survey represents a definite first step toward an understanding of the zooplankton in the southeastern Atlantic Ocean area of the United States.

SECTION 5
CONCLUSIONS

- Numbers of zooplankton collected during the SABP survey (212 organisms/m^3 and 563 organisms/m^3 by the 505-μm and 202-μm nets, respectively) were intermediate between those in the neritic and slope areas reported by other investigators.
- Zooplankton peaked in abundance during the summer, with SABP station 2E appearing to be the richest zooplankton area and station 6D the most impoverished.
- Ash-free, dry-weight biomass showed little correlation with various constituents in the water column.
- Copepods dominated plankton samples in both the 505-μm and 202-μm nets: *Parvocalanus* dominated the fine-meshed net; *Undinula* dominated the coarse-meshed net.
- Important constituents of the plankton were chaetognaths, ostracods, decapods, gastropods, and urochordates.
- Calanoid copepod associations may be used to determine whether shelf water or a combination of shelf and oceanic water is present; stations 2E, 5E, and 7D were categorized as having a mixture of shelf and oceanic forms.
- The Shannon-Weaver diversity index showed the sampling area to be one of high diversity, tending slightly toward an increase in the summer. With adequate background information, it may be possible to use the diversity index to measure the effect of perturbations on the environment.

SECTION 6
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CHAPTER 6

EPIFAUNA: BENTHIC INVERTEBRATE AND DEMERSAL FISH POPULATIONS OF SOUTH ATLANTIC/GEORGIA BIGHT

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ABSTRACT

The results of otter trawl sampling of benthic epifaunal invertebrates and demersal fishes at 24 stations located on seven transects across the continental shelf in the south Atlantic Bight are summarized. Replicate samples were taken during all four seasons of the 1977 South Atlantic Benchmark Program. A previously unknown live-bottom area was identified off South Carolina.

Statistical treatment of data to determine similarity between stations indicated the presence of four distinct longitudinal faunal zones. The boundaries of these shelf faunal assemblages showed seasonal fluctuations that may have been induced by Gulf Stream eddies and consequent changes in shelf hydrography. Cluster analyses revealed that the deep assemblage of fishes and invertebrates was faunistically disjunct from the shelf zones.

While the shelf environment in the Georgia Bight is largely composed of sand-bottom areas of low epifaunal biomass, patchy reef outcrops support a rich assemblage of epifauna and reef fishes. Epifaunal distribution patterns and ichthyofaunal diversity indicate a healthy environment.

SECTION 1
INTRODUCTION

The epifaunal benthic communities over the inner and outer continental shelf environments off the southeastern United States are typical temperate-tropical faunal assemblages (Menzies et al., 1973). The epifauna distribution is evidently influenced by the Gulf Stream and the topography of the shelf, which is relatively narrow off the Florida coast and broadens northward to 80 to 85 km off the Carolina coast. The shelf in the Georgia Bight is devoid of canyons that characterize the mid-Atlantic shelf; and the seafloor is relatively smooth, with a somewhat homogeneous terrain composed of a foraminiferan sand-mud matrix occasionally containing shell-hash and gravel. Macintyre and Milliman (1970) described the physiography of this shelf. The exceptional physiographic feature is the patchy occurrence of ledges, rock outcrops, and reefs of different configurations that support rich epifaunal growths and associated fish fauna.

In the nearshore environment, particularly within 5 km off the North Carolina coast, "coquina" or "blackrock" formations occur at depths of 5 to 15 m (Pearse and Williams, 1951). Except for the ahermatypic solitary coral *Oculina*, reef-building corals are generally absent in such formations. In this hard-substrate area is the fossil pelecypod *Venus gardeneri* and a faunal assemblage that includes primarily boring and sessile clams, the sessile snail *Vermicularia spirata*, and tubiculous polychaetes. However, reef-forming coral species occur in the outcrops in the midshelf areas in Onslow Bay (Macintyre, 1970). The dominant reef-forming tropical coral species on the south Atlantic shelf are *Solenastrea hyades* and *Sidestrea siderea*. The rich epifaunal community associated with these outcrops constitutes the "live-bottom area," which is dominated by a variety of sessile invertebrates, including sponges, bryozoans, seapens, hydrozoans, and corals. The areas also apparently support a variety of commercially and recreationally important fin-fish fishes that include the porgy *Pagrus*, grouper *Epinephelus*, snapper *Lutjanus*, and grunts *Haemulon* (Huntsman, 1976). Live-bottom areas are also known to exist off Georgia (Hunt, 1974) and off the Florida coast (Moe, 1963), but knowledge is meager with reference to the precise size, extent, bottom relief, and epifaunal community structure of these coral patches.

Along the shelf break approximately 76 km from the North Carolina coast at a depth of 80 to 110 m, lithothamnion reefs have been reported (Menzies et al., 1966), with sessile species that include gorgonians, hydroids, bryozoans, and echinoids. The epifauna in the reef areas exhibit a tropical affinity because of the impact of the northward-flowing warm Florida Current, which is by and large responsible for introducing southern species into the OCS environment of the Carolinas and Georgia. In a recent dredging and submersible study off Fort Pierce, Florida, rich aggregations of motile invertebrate epifauna and fish populations were found in association with exposed limestone bedrocks, with flourishing scleractinian coral colonies of *Oculina vericosa* at the shelf-slope break (Avent et al., 1977).

Clearly, from the information cited above, various types of live-bottom areas show a patchy distribution both in the nearshore and offshore shelf in the Georgia Bight regions. In the 24 trawl stations established in seven selected transects within the shelf from Cape Fear to Cape Canaveral in the 1977 SABP study, only one live-bottom station (2D) off the South Carolina coast was encountered. Undoubtedly, the reef formations are localized.

The most conspicuous bottom type in this continental shelf environment is evidently the sand-mud matrix: stretching from Cape Hatteras to Cape Canaveral, it occupies far more than 90% of the shelf's surface area. From a zoogeographic point of view, it is characterized as the Carolinian province. The northern inner shelf is very much in confluence with the Virginia faunal province, and the southern part merges with the tropical Caribbean faunal province; therefore, the shelf contains a transitional fauna that is primarily a mixture of northern and southern species with some endemic species. The zoogeographic generalization is thus far determined on the basis of nearshore epifauna (Johnson, 1934; Hedgpeth, 1953). The present study engulfs a broader mesoscale approach to epifaunal distribution and deals with the entire Carolinian province, including stations (Figure 3.6-1) originating at shallow nearshore areas and stations beyond the shelf break along seven different transects off the coasts of North Carolina (33° to 34°N), South Carolina (32°N), Georgia (31° to 32°N), and Florida (29° to 31°N). This SABP report, therefore, provides information pertaining to broad qualitative patterns of latitudinal and longitudinal epifaunal distribution over the Georgia Bight shelf region.

The epifauna, including large invertebrates and demersal fishes in this shelf province, has been adequately studied from a taxonomic point of view ever since early explorations by such research vessels as the *Blake* (Agassiz, 1888) and the *Albatross* (Townsend, 1900). Because of this, most species collected during this project, both fishes and invertebrates, were found to be identified species. Also, monographic studies, such as the extensive work by Williams (1965) on the decapod crustaceans that constitute a prominent component of the epibenthos, contributed substantially to an understanding of this shelf's epifaunal species composition. The epifaunal community, however, has not been examined previously from a quantitative standpoint with emphasis on seasonal variations in distribution.

A 1966 study (Ceramé-Vivas and Gray, 1966) of the epifaunal invertebrates of the North Carolina continental shelf from near shore to shelf break established the distinct latitudinal variation between a nearshore epifaunal community that is influenced by the cold Virginia Current and an offshore epifaunal community that is influenced largely by the warm Gulf Stream. There is also a considerable body of literature covering the systematics and, secondarily, various aspects of the ecology and life histories of Carolinian fishes (see Dahlberg, 1975, and contained references). Many of these references were useful for identification purposes, but the ecological information was of little use; much of it pertained to estuarine and nearshore species or to Gulf of Mexico components of the Carolinian fauna. Biological information is sparse, even for commercially important species. Beaumariage and Bullock (1976) could cite only three comprehensive life-history studies on red grouper and red snapper. Basic resource assessment information, on the other hand, has been accumulating for quite some time. The fisheries resources of the continental shelf from Cape Hatteras to Cape Canaveral have been the subject of considerable research for many years. The U.S. Bureau of Fisheries conducted a study of the coastal shrimp grounds between Cape Romain, South Carolina, and Cape Canaveral from 1931 to 1935; fishes caught incidental to the shrimp were discussed by Anderson (1968). Also, from 1953 to 1954, the Bureau of Commercial Fisheries conducted nine cruises between Cape Hatteras and Jupiter Inlet, Florida (see Moore and Gorsline, 1960, and contained references); these cruises collected plankton, hydrographic data, and sediment samples. From 1959 to 1964, the Bureau of Commercial Fisheries conducted a comprehensive exploratory fishing survey in the same area; results from the more than 900 stations were analyzed and discussed by Struhsaker (1969). However, because all this research, as well as some subsequent National Marine Fisheries Service research (Wilk and Silverman, 1976) was directed toward fisheries, none of it approaches the comprehensive nature of the Bureau of Land Management South Atlantic Benchmark Program.

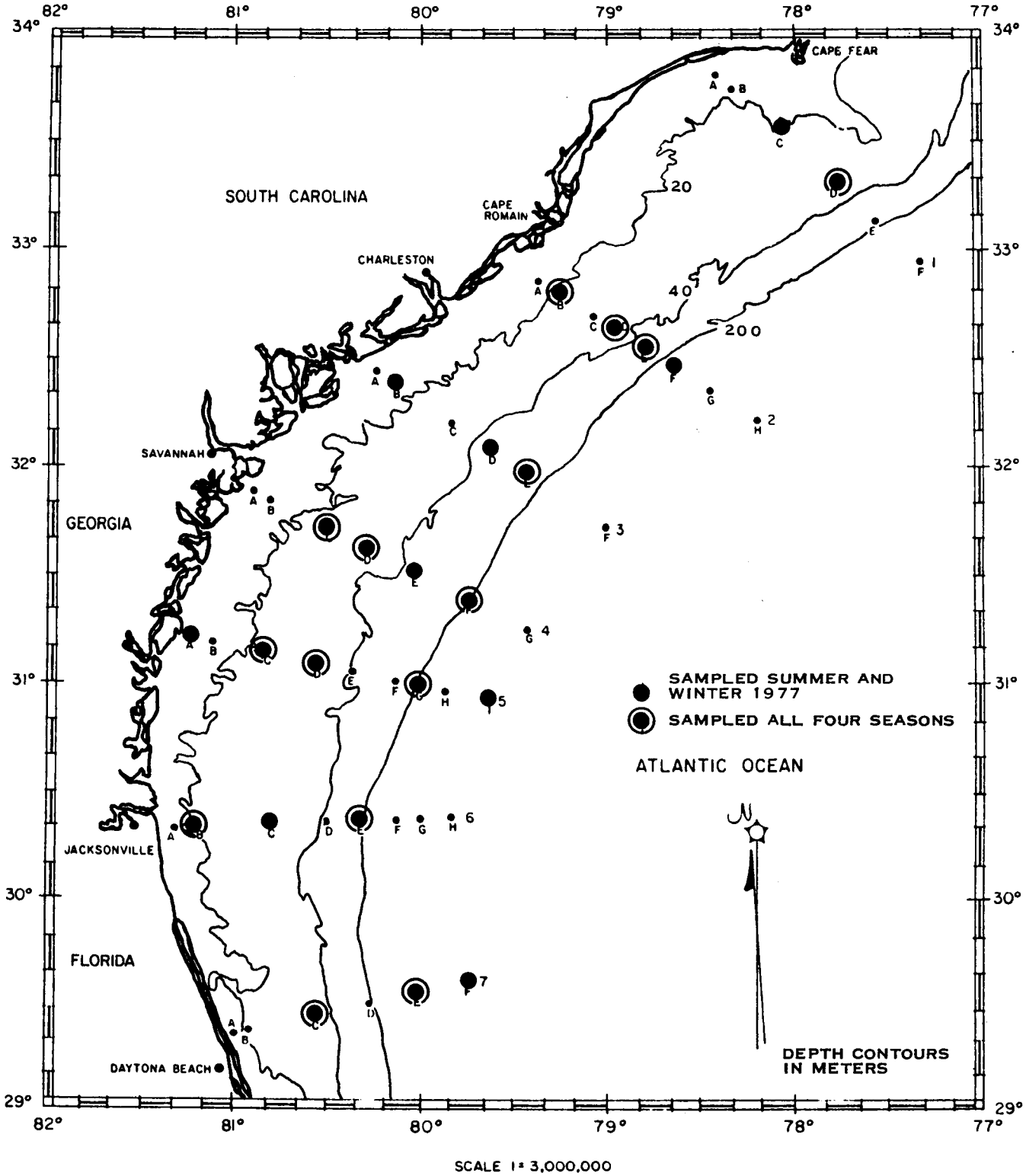


Figure 3.6-1. Otter-Trawl Stations in Shelf Transects

The epifaunal data obtained during the extensive SABP sampling survey deal with demersal fishes and invertebrates commonly captured in otter trawls. The program employed a 45-ft otter trawl and, therefore, collected only large epifaunal organisms such as fishes, crabs, and echinoderms; characterization of molluscan fauna would have required appropriate sampling with a "tumbler" or scallop dredge. The otter trawl samples were obtained from 24 stations (Figure 3.6-1) during summer and winter of 1977; during spring and fall, only 15 of the 24 stations were reoccupied. This portion of the SABP study was conceived to characterize the epifaunal communities of the shelf in conjunction with the establishment of a baseline biological data base for future evaluations of the environmental impact of oil resource developments. This report on epifauna focuses primarily on the following major objectives:

- Evaluation of species similarity between stations to determine faunal alliance on the basis of cluster analysis using results of the Jaccard similarity index and the Morisita index for both demersal fishes and invertebrates during the four seasons of the year
- Examination of apparent patterns of demersal fish and invertebrate distribution in relation to distance from shore in the inner-shelf, midshelf, and offshore stations in the vicinity of the shelf break
- Assessment of significant within-station temporal epifaunal changes during the four sampling periods
- Characterization of the epifaunal community in the hard substrate or live-bottom stations and its affinity with other shelf stations
- Estimation of the relative abundances and biomasses of dominant, commercially important fish and crustacean species.

SECTION 2
MATERIALS AND METHODS

This study is based on epifauna samples obtained with an otter trawl at stations on seven transects (Figure 3.6-1) during the four seasons of 1977.

The wet-weight biomass of individual species of invertebrates and fishes was evaluated, and the species were enumerated to document their relative abundance. Voucher specimens were used for species identification. The relative abundance of individual taxa was determined in terms of percentage representation in the total biomass of the stations sampled.

The relative abundance, exact number captured in 30-min trawls, and biomass were used for data analysis leading to determination of similarity or dissimilarity between pairs of stations. The statistical procedures included the Canberra metric analysis, Jaccard index for similarity matrix development, and Morisita similarity index. (A detailed discussion of these three statistical methods appears in Volume 2). The Canberra metric analysis was used in this study only on the demersal fishes; the method has utility when distribution of the subject organisms is patchy (Musick, 1975). The Jaccard and Morisita similarity indices were used for both invertebrates and fishes. It should be pointed out that the Jaccard index measures similarity on the basis of the presence of species common to both stations being compared; the Morisita index reveals a similarity between stations not only on the basis of mere presence or absence of species, but also on the basis of the relative abundance of those species commonly encountered.

A similarity matrix tree involving all the stations sampled in the four different seasons was generated. On the basis of a cluster analysis (see Volume 2 for detailed description), the results were carefully analyzed to draw dendrograms to distinguish the formation of different clusters of stations within the area under study. From these dendrograms, a map was prepared to show the precise location of the clusters containing member stations of statistically significant faunal affinity for each season.

An extensive literature survey of earlier studies formed the basis for generalizations pertaining to latitudinal epifaunal distribution patterns of zoogeographic significance and zonation patterns over the shelf from the nearshore environment to the shelf break in the Georgia Bight shelf region.

SECTION 3
RESULTS

A. BENTHIC INVERTEBRATES

The dendrograms derived from the cluster analysis using both the Jaccard and Morisita indices of similarity revealed apparent faunal zones within this shelf environment from North Carolina to Florida. Such a zonation within the shelf indicates the presence of four distinct faunal assemblages: nearshore, midshelf, outershelf, and upper slope (deep). Although the four different assemblages can be demarcated by the cluster analysis in all four seasons of the year, the boundaries of the cluster have a tendency to vary from one season to another, suggesting seasonal shifts in species distribution and population dynamics at all 24 stations.

The stations within the four faunal assemblages invariably showed a relatively higher affinity in terms of the Morisita index than the level of similarity by the Jaccard index. The range of Jaccard similarity between members of the cluster varied between 28 and 54, while the Morisita level of similarity between stations in the cluster varied between 0.50 and 0.99. However, both methods generated dendrograms of comparable station alliance with four different clusters in all four seasons. Within the shelf region in the south Atlantic Bight, obvious seasonal variations in the geographic distribution of the cluster were apparent. It is, therefore, pertinent to examine the cluster distribution by season.

1. Clusters

a. Winter 1977

Four station clusters were recognized from the winter epifaunal invertebrate data (Figure 3.6-2). It is of interest to note that all sampling stations inshore of the 20-m isobath (1C, 2B, 3B, 4C, 5A, and 6B) belonged to the nearshore cluster. The midshelf cluster included stations from all seven transects, although most members were off the Georgia and South Carolina shelf at depths of 20 to 180 m (1D, 2E, 2D, 3D, 4D, 4E, 4F, 5C, 5D, 5G, 6C, 6E, and 7C). This region is under the intermittent influence of the Gulf Stream intrusions onto the shelf. The outer-shelf cluster contained only two member stations, 2F and 3E, both located at the shelf break in the northern area. The upper-slope (deep) cluster was distinct and included 7E and 5I. These two deep (226-m) stations, located beyond the shelf break, generally included members of the archibenthal fauna typically found on the upper continental slope and fewer epifaunal invertebrate species.

b. Spring

During the spring (Figure 3.6-3), four clusters of stations were identified on the basis of epifaunal distribution. Near shore, the cluster included 2B and 4C as in the winter, but did not contain the southern nearshore stations 5A and 6B. This situation may be attributed to the warming trends and, therefore, the gradual depletion of northern faunal elements in the southern nearshelf zones. Other stations embraced in this spring cluster were 2D and 2E off South Carolina. The spring midshelf cluster included the northernmost station 1D and the three

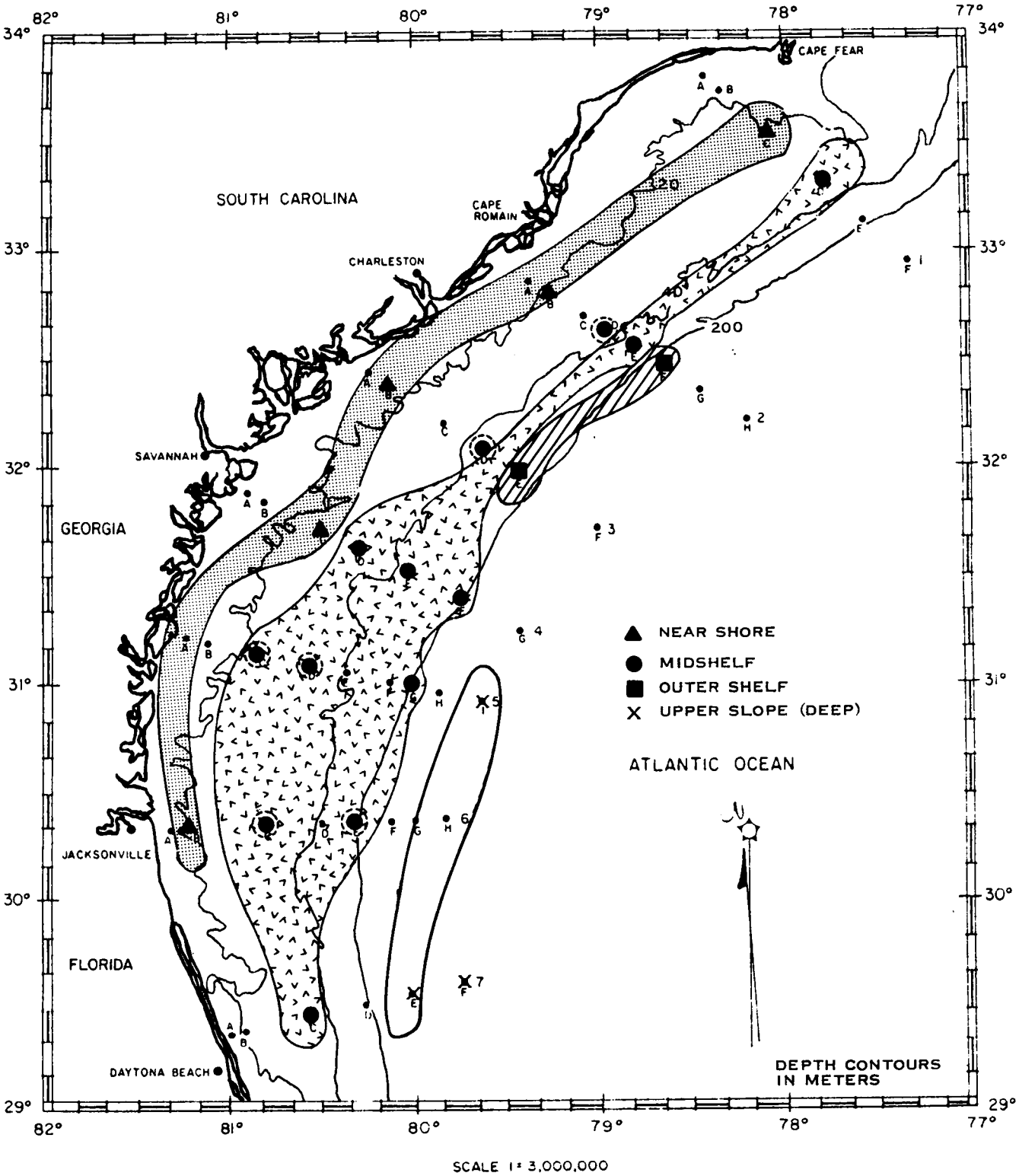


Figure 3.6-2. Winter Epifaunal Invertebrate Assemblages Based on Cluster Analysis Using Morisita Index of Similarity

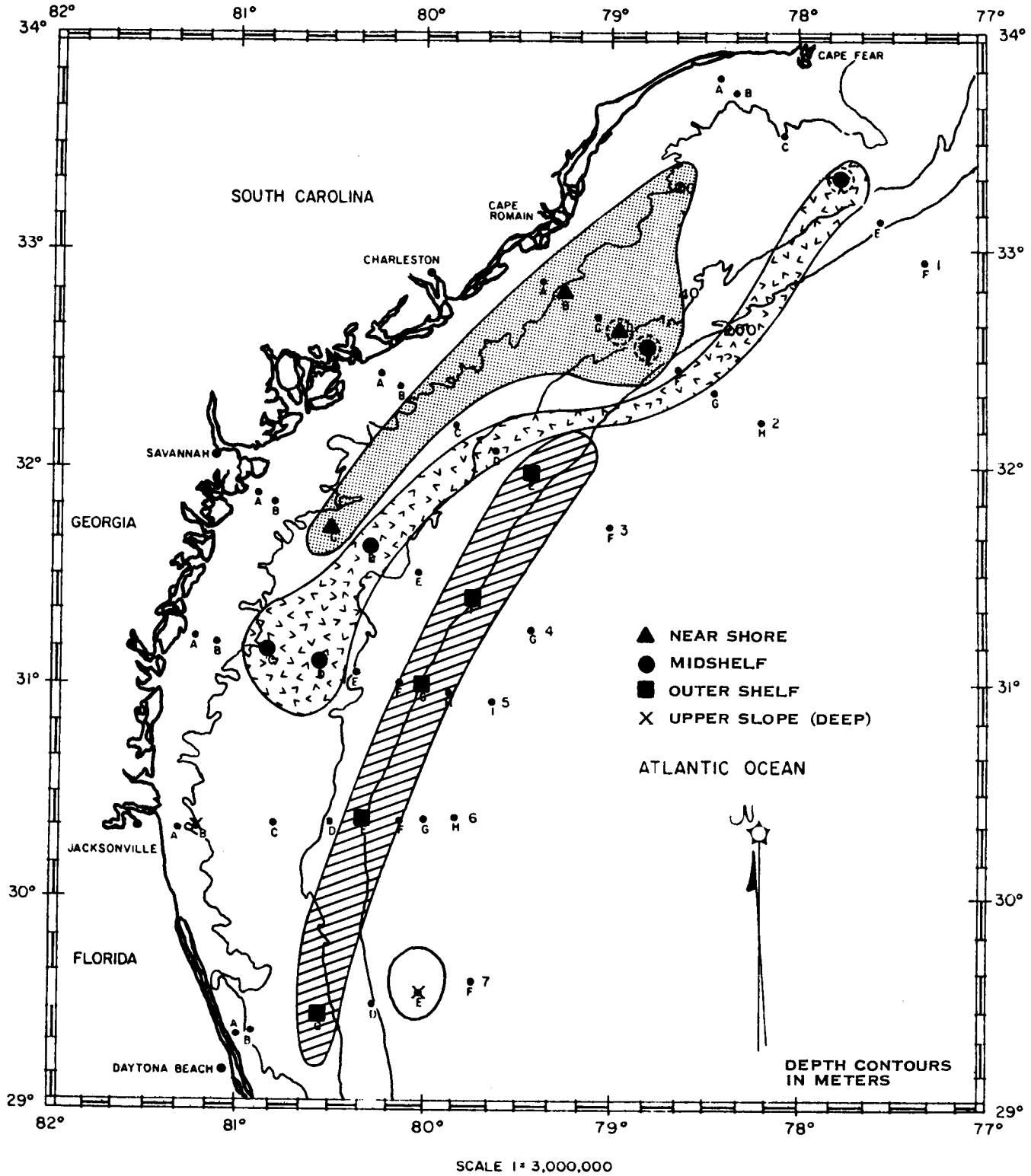


Figure 3.6-3. Spring Epifaunal Invertebrate Assemblages Based on Cluster Analysis Using Morisita Index of Similarity

midshelf stations 4E, 5C, and 5D off Georgia. Stations located in the vicinity of the shelf edge (3E, 4F, 5G, 6E, and 7C) comprised the outer-shelf cluster. On the upper slope (deep), there was a single station, 7E, that appeared to be faunistically isolated from all the others.

c. Summer

The epifaunal invertebrate clusters for the summer (Figure 3.6-4) also showed clearly the four faunal assemblages, but there was a remarkable variation in the geographic boundary of the summer clusters compared with those of the preceding seasons, the most conspicuous being the considerable extension of the outer-shelf faunal assemblage toward the north into the Carolinas and a concurrent reduction of the nearshore faunal assemblages, particularly off South Carolina. The summer cluster contained stations 1C, 2B, 4B and 5C; the absence of the southern nearshore stations, 5A and 6B, is noteworthy. The midshelf cluster embraced 3D, 4D, 4E, 5D, 5G, 6B, 6C, and 7C off Georgia and Florida; this cluster appears to be dominant in the southern half of the shelf in the South Atlantic Bight in summer. The cluster apparently gained significant representation in the shelf regions off the Carolinas. The two live-bottom stations 2D and 2E, which in the winter belonged to the midshelf faunal assemblage and in the spring belonged to the nearshelf faunal assemblage, became a part of the outer-shelf faunal assemblage during the summer. Other members of this cluster were 1D, 3E, 4F, and 5E. The upper slope (deep) cluster was somewhat stable in its geographic location over the different seasons, and station 7E was always the chief member of this cluster. The fauna, here, as pointed out earlier, is a mixture of outer-shelf and predominantly archibenthal (Menzies et al., 1973) species.

d. Fall

The fall station clusters (Figure 3.6-5) were a striking change from the summer clusters: there was an obvious shrinkage of the outer-shelf faunal assemblage. The two live-bottom stations 2D and 2E, as well as an adjacent nearshore station 2B, constituted the outer-shelf faunal assemblage. The most dominant feature of the nearshore cluster was its close affinity to topographic midshelf stations off Georgia. These stations (4C, 4D, 4G, 5C, 5D, and 5G), which belonged to the midshelf faunal assemblage during the winter and summer, joined to form the fall nearshore faunal cluster. The northernmost stations 1D and 6B off Florida also belonged to this fall cluster. The cluster contained stations 3E and 6E, both located at the edge of the shelf. Consistently, offshore station 7E, with a characteristic deep-water fauna dominating throughout the year, remained the major member of the upper-slope (deep) cluster.

It is clear from a careful examination of the seasonal oscillations of the three major shelf assemblages (Figures 3.6-2, 3.6-3, 3.6-4, and 3.6-5) that epifaunal invertebrate species tend to migrate both latitudinally and over the shelf during different seasons of the year. Beyond the shelf break, a link between the archibenthal fauna and that of the upper abyssal zone is postulated. This hypothesis is based on the distribution of epifaunal invertebrates, primarily large echinoderms and decapod crustaceans.

Shifts in faunal boundaries are linked to the life-history strategies of the member species. Epifaunal distribution is also governed by patterns of shelf circulation and water-mass distribution during the different seasons; even short-term events such as Gulf Stream intrusion can cause significant changes in the boundaries of the shelf faunal assemblages. The influence of such a temporal phenomenon is not yet completely understood. Furthermore, present results generally

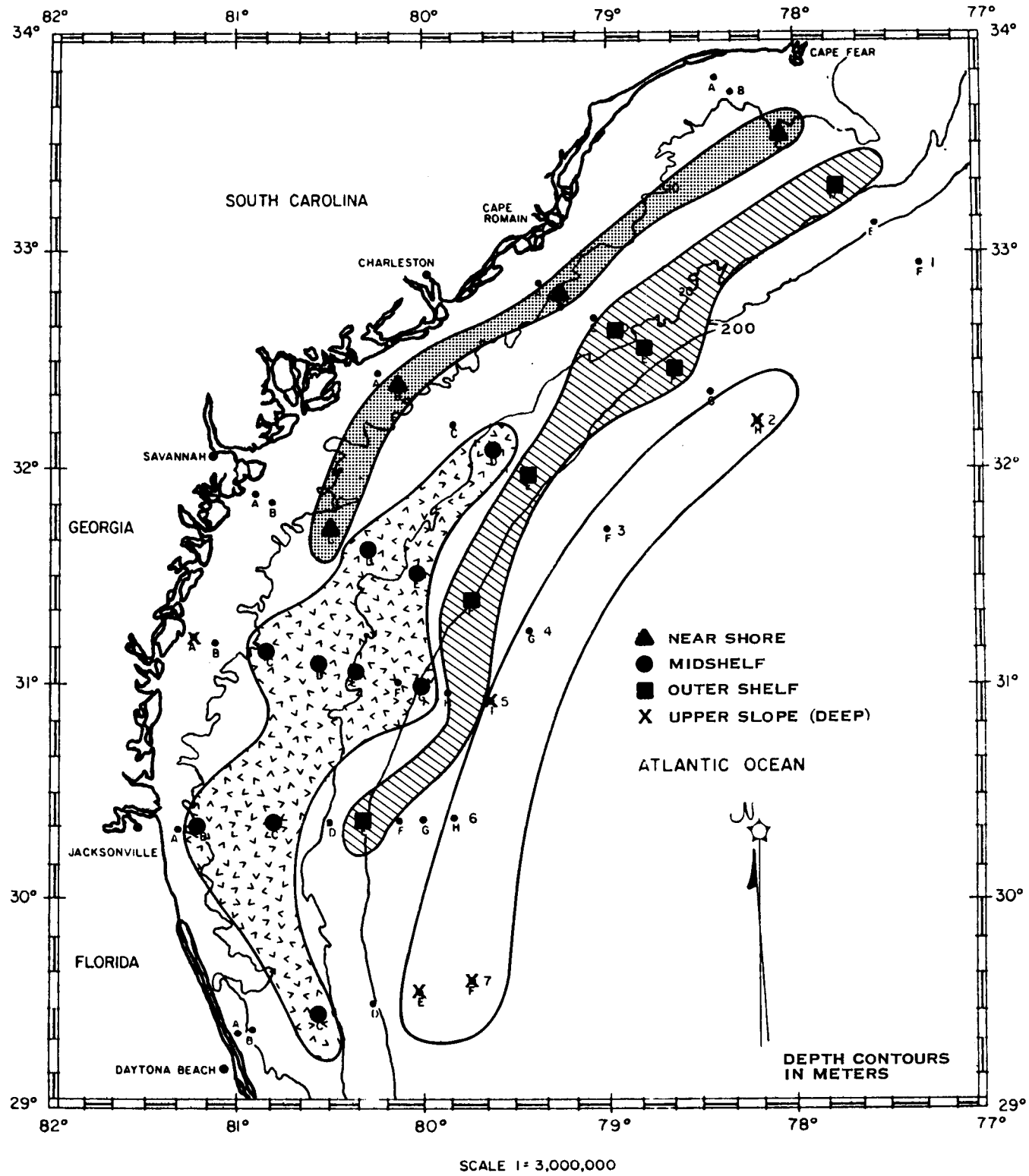


Figure 3.6-4. Summer Epifaunal Invertebrate Assemblages Based on Cluster Analysis Using Morisita Index of Similarity (Stations 2H and 5A do not belong to any cluster)

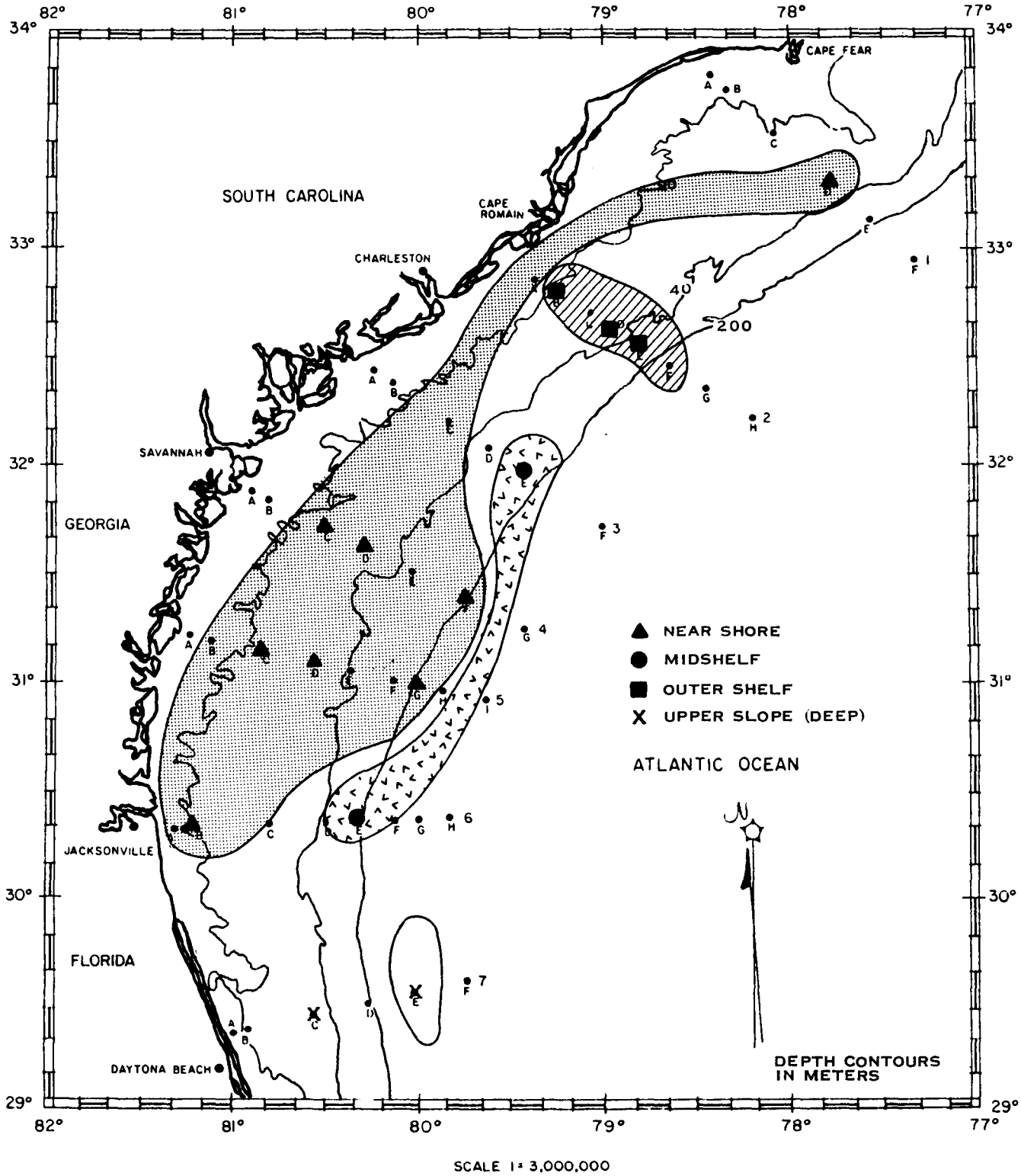


Figure 3.6-5. Fall Epifaunal Invertebrate Assemblages Based on Cluster Analysis Using Morisita Index of Similarity

delimit mesoscale patterns of shelf zonation in the south Atlantic Bight. As seen in the following section, this general pattern holds for large epifauna such as crabs and star fishes that represent the bulk of the otter trawl samples.

Regression and correlation coefficient analyses of the numerical abundance and biomass of epifaunal invertebrates were also made in this study to examine possible correlations of epifaunal distribution with total organic carbon of the bottom sediment, bottom depth, sediment grain size, and latitude. No statistically significant correlations were delineated. The correlation with latitude showed a significant level of confidence (0.075), which reinforces the interpretation of north-south changes in the faunal clusters.

2. Within-Station Epifaunal Changes

Figure 3.6-6, a comparison of epifaunal invertebrates at three selected stations representing nearshore, midshelf, and offshore shelf environments, points out the considerable faunal changes from one season to another. This speaks for the marked changes in population dynamics and species composition in the temperate-tropical shelf. Most species have a short life cycle and annual reproductive peaks. Dissimilarity between otter-trawl samples from different seasons is therefore conceivable and explains the low Jaccard value. On the basis of the Morisita index, there appears to be a great deal of similarity between winter and spring, as well as between summer and fall, at nearshore station 2B. At midshelf station 7C, the similarity between seasons was striking; on the contrary, at offshore station 7E, the Morisita index showed high dissimilarity between seasons. This possibly reflected changes in population dynamics rather than in species composition.

3. Biomass and Numerical Abundance of Epifaunal Invertebrates

The number of invertebrate species encountered in the entire shelf from Florida to North Carolina varied from 111 in the spring to 241 in the summer (Table 3.6-1). Total catch per cruise ranged from 111 kg in the fall to 321 kg in the spring. Large epifaunal species approximated 250, but were as few as 10 and as many as 106 in the seasonal samples from the seven transects (Table 3.6-2). The spring sampling, despite the fewer stations, yielded the most specimens; generally, high biomass was caused by the presence of a few large species such as the holothurian *Holothuria imperator*, the starfishes *Luidia clathrata* and *Luidia alternata,* and the cephalopod *Loligo pealeii.* Peak biomass coincided with the dominant occurrence of certain species. *Aplysia wilcoxi,* for example, constituted 68 kg in the summer otter-trawl samples from transect 7. Similarly, the sea cucumber *Holothuria imperator* was abundant off the coast of Georgia in transects 4 and 5. At station 4D, 112 specimens weighing a total of 28.4 kg were encountered during the spring sampling period. This number represented 58% of the total specimens captured in 4D and 79% of the station biomass. This holothurian is poorly distributed in the northern transects off the Carolinas and the southern transects off Florida. Perhaps the sediment regime off Georgia is more conducive for the relative abundance of this deposit-feeding organism.

The starfishes *Luidia clathrata,* and *L. alternata* occurred on all seven transects, but the latter was far more abundant on the northern transects. Ecologically, these species are extremely significant because of their predation and consequent role in regulating species diversity.

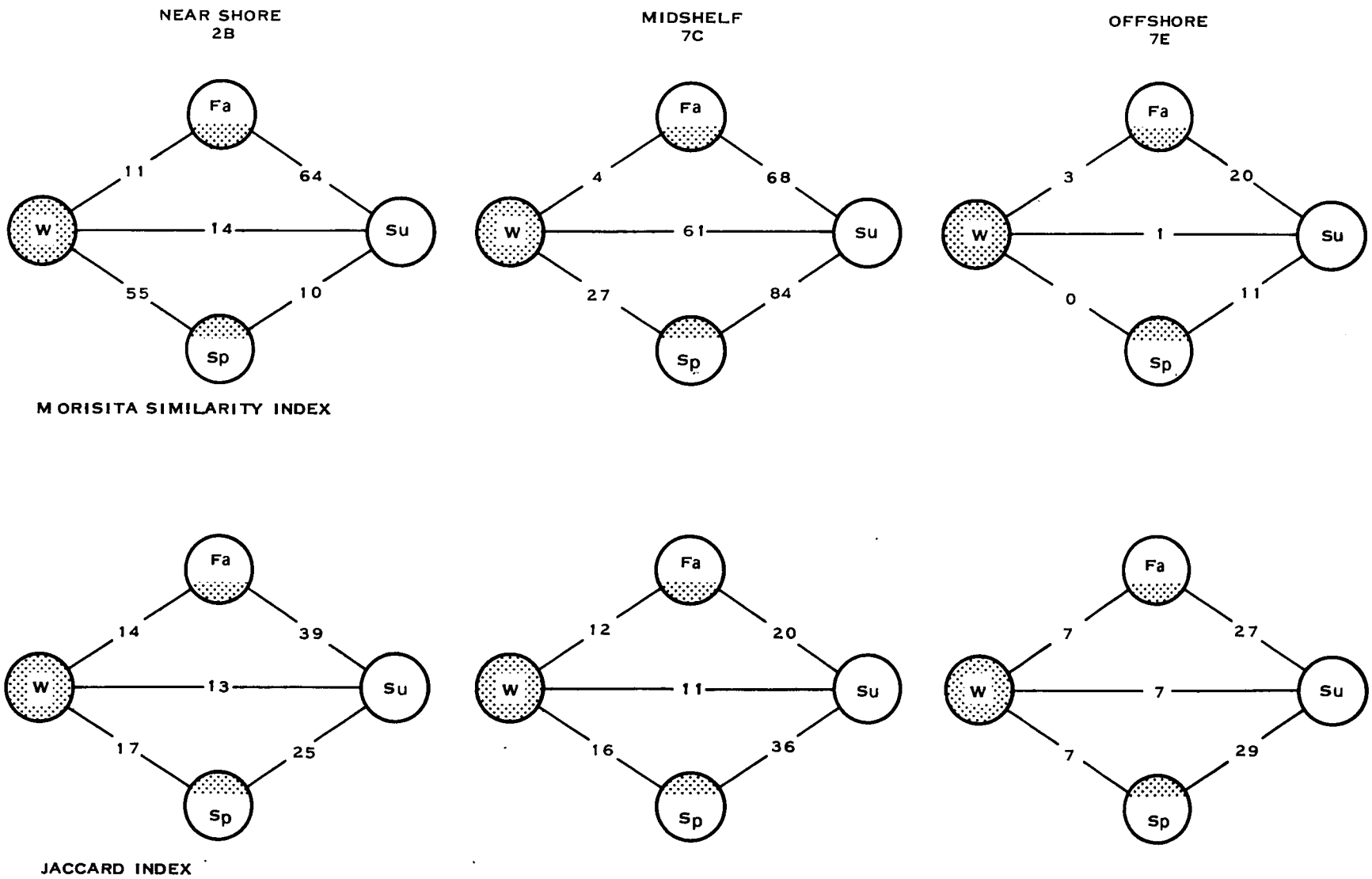


Figure 3.6-6. Comparison of Three Selected Stations (One Each From Nearshore Shelf, Midshelf, and Offshore) on Basis of Seasonal Faunal Alliance Using Jaccard and Morisita Similarity Indices

Table 3.6-1. Number of Epifaunal Species, Total Wet-Weight Biomass, and Total Number of Epifaunal Specimens Captured During Four Sampling Seasons in 1977

Season	No. of Stations	No. of Species	Biomass (kg)	No.of Specimens
Winter	24	174	146	8,154
Spring	15	111	321	20,915
Summer	24	241	193	11,409
Fall	15	113	111	4,168

Table 3.6-2. Number of Epifaunal Species Encountered in Seven Selected Transects During Four Different Seasons of 1977

Transect	Location	No. of Stations	No. of Epifaunal Species			
			Winter	Spring	Summer	Fall
1	Off North Carolina	2	16	27	48	10
2	Off South Carolina	4	61	42	106	53
3	Off South Carolina	3	41	24	34	15
4	Off Georgia	4	56	31	65	43
5	Off Georgia	5	57	27	67	25
6	Off Florida	3	55	44	56	44
7	Off Florida	3	41	34	85	28

The most conspicuous and dominant group of epifaunal invertebrates was the decapod crustaceans, and the most common of these were the four species of the crab genus *Portunus, (P. gibbesii, P. ordwayi, P. sayi,* and *P. spinicarpus); Galathea rostrata; Ovalipes stephensoni; O. ocellatus* (a southern species); *Parthenope serrata; Bathyplax typhla; Pilumnus sayi; Rochinia crassa;* and *Stenorhynchus seticornis.* Several commercially important crustacean species were patchily distributed all along the shelf: the penaeid shrimp *Penaeus aztecus* and *P. setiferus* and the crab *Callinectes sapidus* occurred primarily in the nearshore faunal assemblages; the midshelf contained the crab *Calappa flamea* and the relatively unexploited but potentially important commercial species of rock shrimp *Sicyonia brevirostris* (Table 3.6-3). Another commercially important deep-sea red crab *Geryon quinquidens* occurred at station 5I but was somewhat rare in this region compared with the mid-Atlantic shelf slope area off Virginia. The biomass and numerical abundance of the two species of the common deep-water crab in this area, *Cancer borealis* and *C. irroratus,* are tabulated in Table 3.6-4. These two species were found primarily in the outer-shelf and deep faunal assemblages in the vicinity of and beyond the shelf break.

4. Live-Bottom Community

SABP sampling revealed a hard-bottom area only at station 2D, although the presence of sessile epifauna and reef fishes was evidence of a reef-type bottom at stations 2E and 6C. Tunicate colonies, soft corals, sessile sponges, and the scleractinian coral *Oculina* were in the otter-trawl sample from 2D, which is also near a scallop bed; spring sampling captured 306 individuals of the scallop *Astropecten gibbus.* The otter-trawl sample contained 9,850 specimens

Table 3.6-3. Biomass (Wet Weight) and Abundance (Number) of Rock Shrimp *Sicyonia brevirostris* in Otter-Trawl Samples From Seven Transects During Four Seasons in 1977

Transect	Location	No. of Stations	Winter Biomass (g)	Winter Abundance (N)	Spring Biomass (g)	Spring Abundance (N)	Summer Biomass (g)	Summer Abundance (N)	Fall Biomass (g)	Fall Abundance (N)
1	Off North Carolina	2	40	4	0	0	752	70	252	10
2	Off South Carolina	4	1,257	156	191	33	14,284[a]	925	33	2
3	Off South Carolina	3	1,348	96	13,458[a]	1,364	1,126	63	20	1
4	Off Georgia	4	1,624	145	9,450	1,015	5,211	289	2,148	118
5	Off Georgia	5	249	24	3,997	1,040	817	43	797	41
6	Off Florida	3	282	49	12,264[a]	1,453	890	56	2,008	51
7	Off Florida	3	0	0	842	111	0	0	0	0

[a]>25% of total biomass.

Table 3.6-4. Biomass and Relative Abundance of Brachyuran Crabs *Cancer borealis* and *Cancer irroratus* at Station 7E During Four Sampling Periods

	Sampling Period: Winter	Spring	Summer	Fall
C. borealis				
No. of specimens	8	8	24	162
Biomass (g)	1,000	888	2,841	19,318
Relative abundance (% of sample biomass)	14.8	17.6	45	41
C. irroratus				
No. of specimens	19	7	24[a]	31
Biomass	3,000	1,136	354[a]	2,301
Relative abundance (% of sample biomass)	44.3	23.8	5.6	4.9
Total station biomass	6,765	5,367	6,320	47,136
Total no. of species	16	12	14	14

[a]Juvenile specimens

of the tunicate *Styela plicata* weighing 49 kg. The soft corals flourishing in this live-bottom area are *Titanideum frauendeldii* and *Telesto fruiticulosa.*

B. DEMERSAL FISHES

Demersal fish species collected and seasonal mean catch per 30 minute tow are presented in Table 3.6-6.

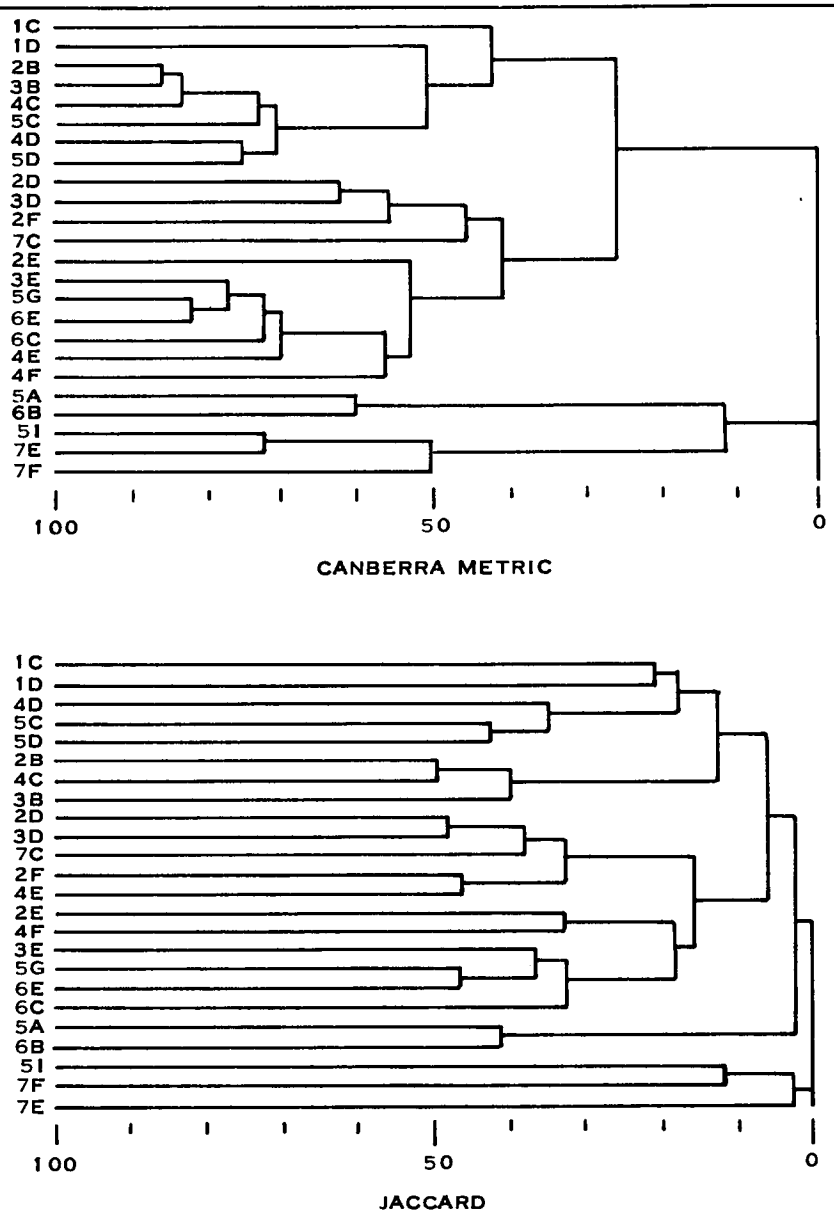


Figure 3.6-7. Comparison of Canberra Metric and Jaccard Cluster Dendrograms for Summer Data

Dendrograms were drafted for each of the three clustering techniques for each seasonal sampling period and for the combined data for the year. The clusters generated by the Jaccard and Canberra metric indices were similar, the primary difference being that the Jaccard clusters were formed at much lower levels of similarity than were the Canberra metric clusters (Figure 3.6-7).

To ensure that all samples were of adequate size to represent the sampled population, a graph was plotted for number of species versus number of individuals (Hessler and Sanders, 1967). The resultant curve indicated that individual abundance and number of species at stations yielding fewer than approximately 30 individuals did not exhibit a linear relationship. Application of this criterion to the clusters eliminated four winter stations (2H, 3B, 5G, 7F), two spring stations (4C and 5D), and one fall station (5D).

The geographic distributions of the clusters were plotted on charts of the South Atlantic Bight. Examination of the charts demonstrated three to five major groupings. Their distributions are described by season.

1. **Winter**

Four station groups (Figure 3.6-8) were apparent from the winter sampling data. The inshore group (1C, 2B, 5A, and 6B) was distributed inshore of the 20-m isobath, while the midshelf group (1D, 4C, 5C, and 5D) was between the 20-m and 30-m isobaths from transect 1 to transect 5. The group on the outer shelf (2D, 2E, 2F, 3C, 3D, 4D, 4E, 4F, 5G, 6C, 6E, and 7C) was widely distributed between 26 m and the shelf break from transect 2 to transect 7. The deep cluster (stations 5I and 7E) was on the continental slope at a depth of >200 m.

2. **Spring**

Three groups (Figure 3.6-9) evolved from the spring sampling data. The inshore-midshelf group (2B, 4D, 5C, and 6B) occurred along the 20-m isobath. The group on the outer shelf (1D, 2D, 2E, 3E, 4F, 5G, 6E, and 7C) extended the length of the study area from a depth of 30 m to the shelf break. The only deep station in the spring was 7E (226 m).

3. **Summer**

Summer sampling yielded four station groups (Figure 3.6-10), but they were not the same as those seen in the winter sampling. The group inshore-south (5A and 6B) was inside the 20-m isobath off southern Georgia. An inshore-north/midshelf group (1C, 1D, 2B, 3B, 4C, 4D, 5C, and 5D) occurred at depths of 13 to 30 m from offshore of the inshore-south group to the northern limit of the study area, and a midshelf-south/outer shelf group (2D, 2E, 2F, 3D, 3E, 4E, 4F, 5G, 6C, 6E and 7C) was primarily between 30 m and the shelf break although one station (7C) was at a depth of only 20 m. The deep group (5I, 7E, and 7F) was between 200 and 550 m on the continental slope.

4. **Fall**

Clustering the fall sampling data (Figure 3.6-11) yielded five station groups: two are large, while three have only one station each:

- Inshore-North–2B; depth = 16 m.
- Inshore-South–6B; depth = 19 m.
- Midshelf–1D, 4C, 4D, 5C, 5G, and 7C; depth between 20 and 40 m along the entire length of the study area.
- Outer Shelf–2D, 2E, 3E, 4F, and 6E; along the edge of the shelf from about 35 m to the shelf break.
- Deep–7E; depth = 225 m.

In addition to being clustered for each season separately, the data were combined and the three clustering techniques applied to the year's data. However, the results are not useful; they indicate that the affinities of some stations vary seasonally and that others do not, but this is much more easily seen by examining the cluster distribution plots (Figures 3.6-2, 3.6-3, 3.6-4 and 3.6-5).

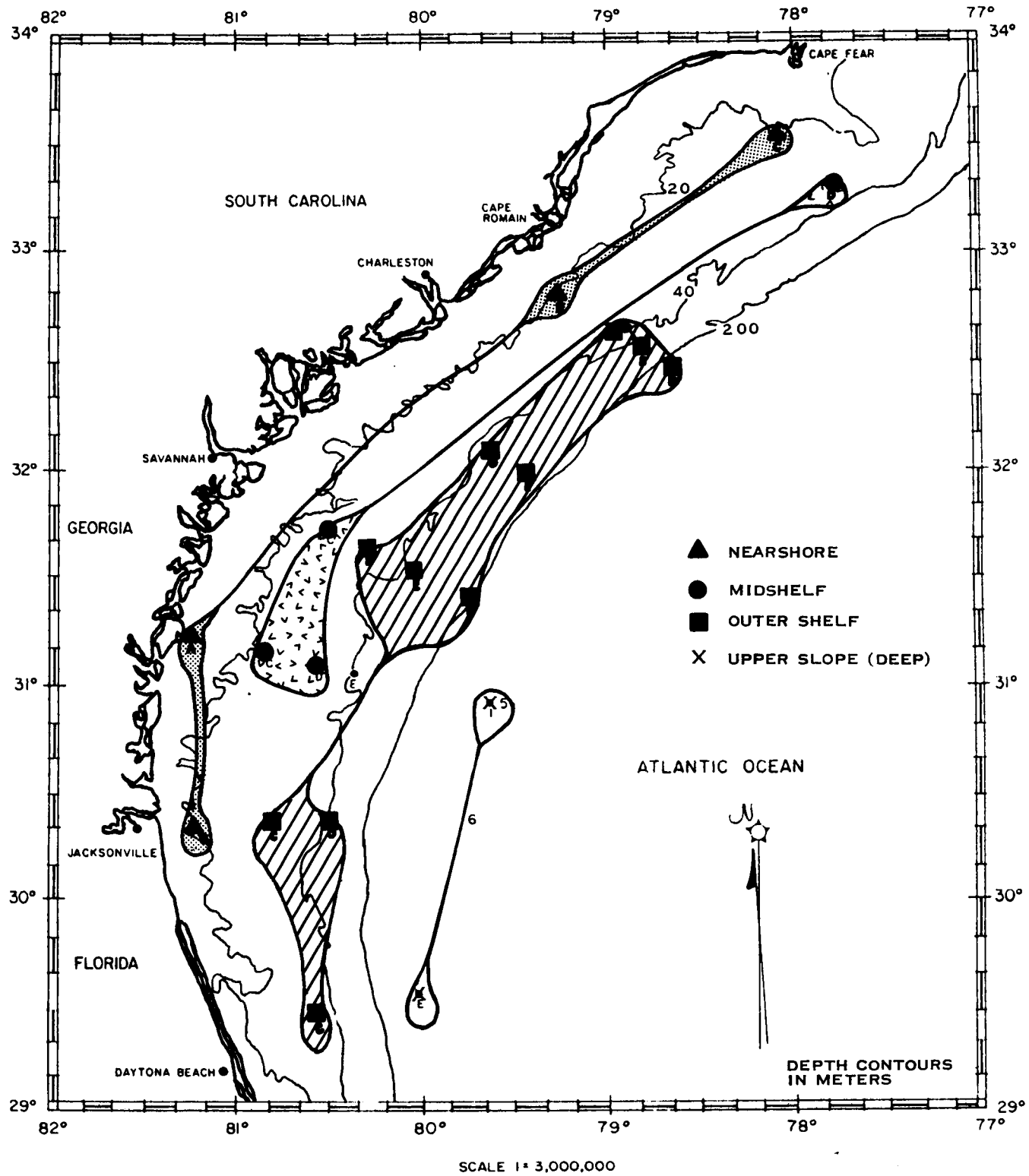


Figure 3.6-8. Winter Demersal Fish Assemblages

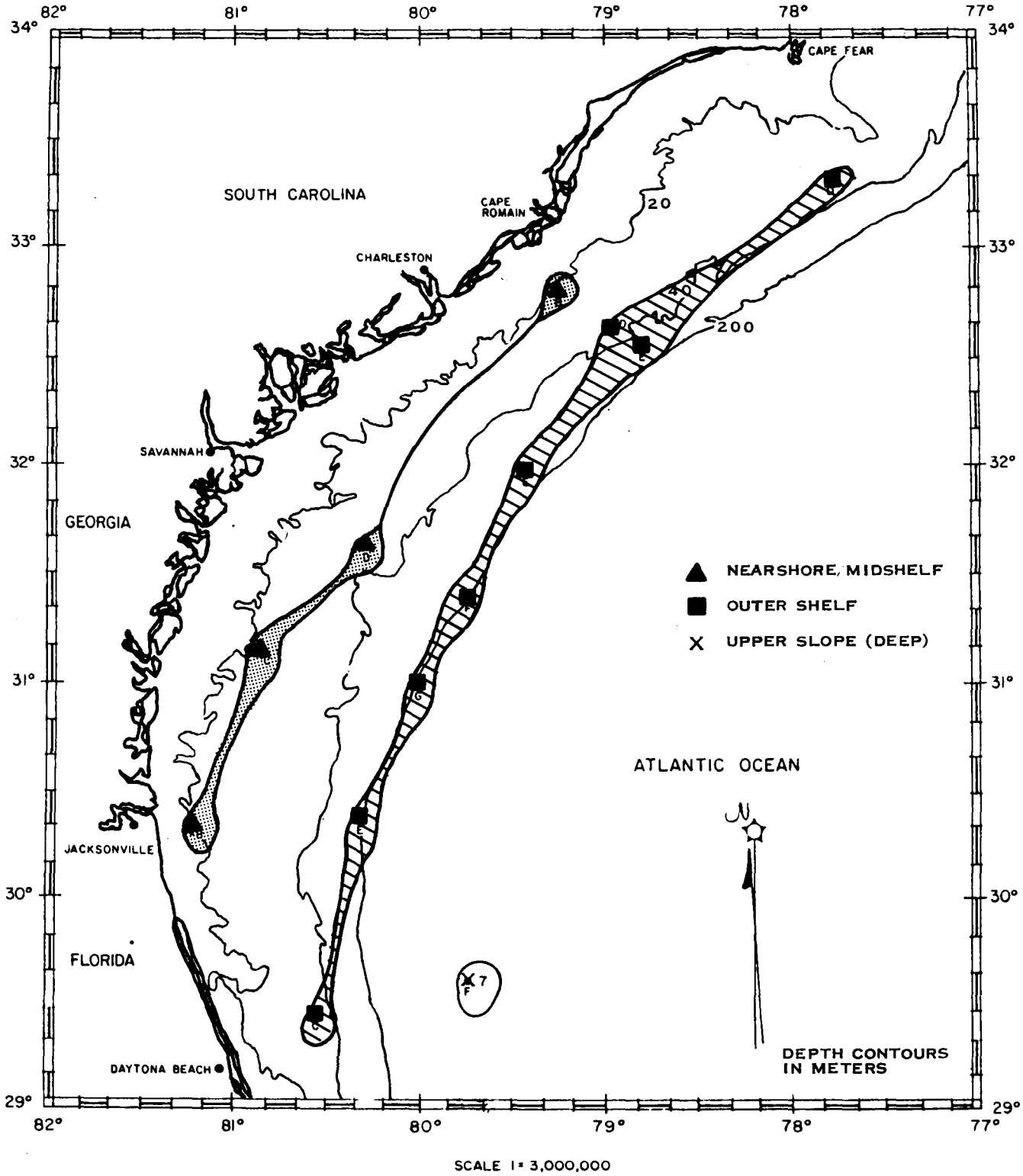


Figure 3.6-9. Spring Demersal Fish Assemblages

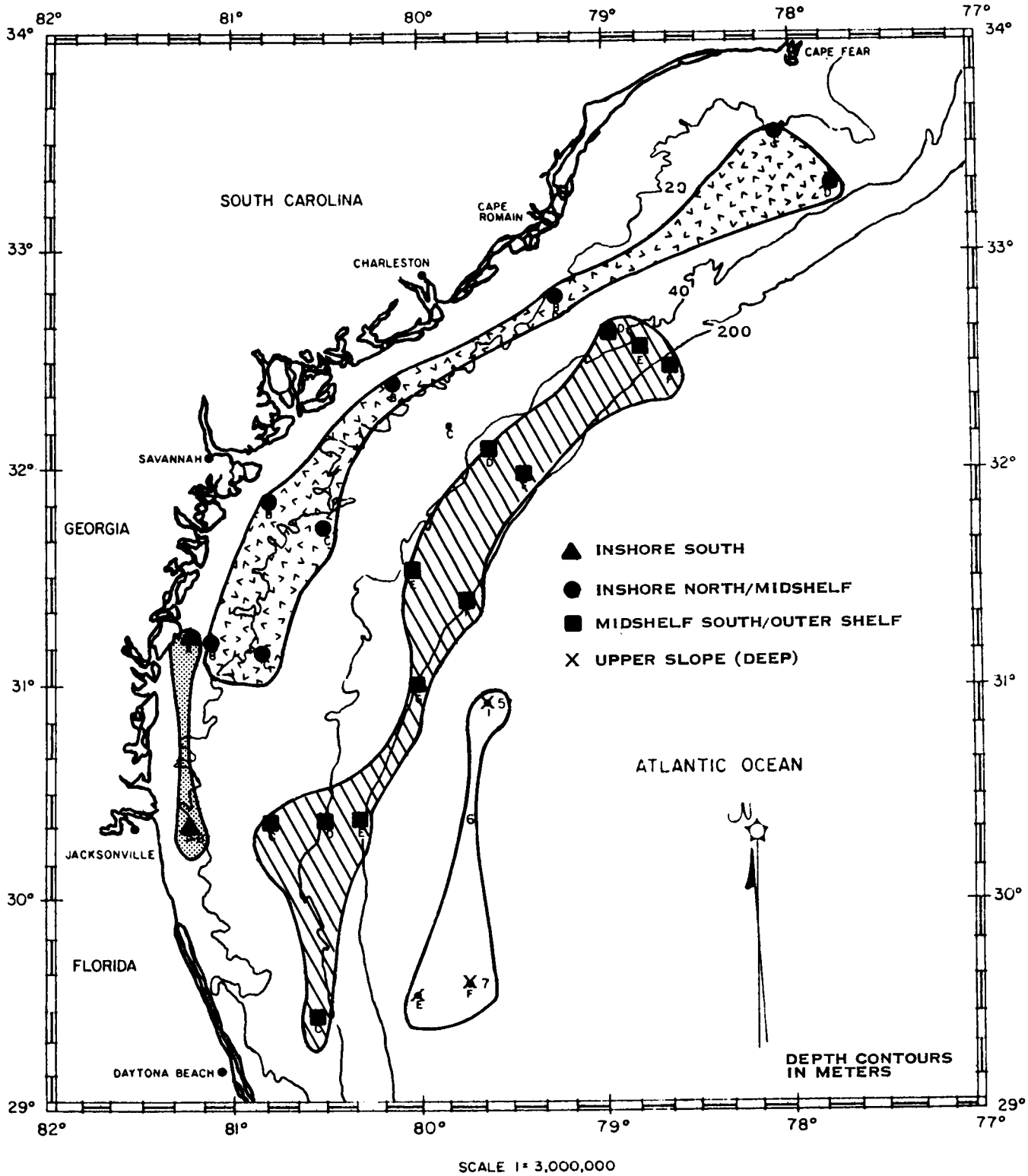


Figure 3.6-10. Summer Demersal Fish Assemblages

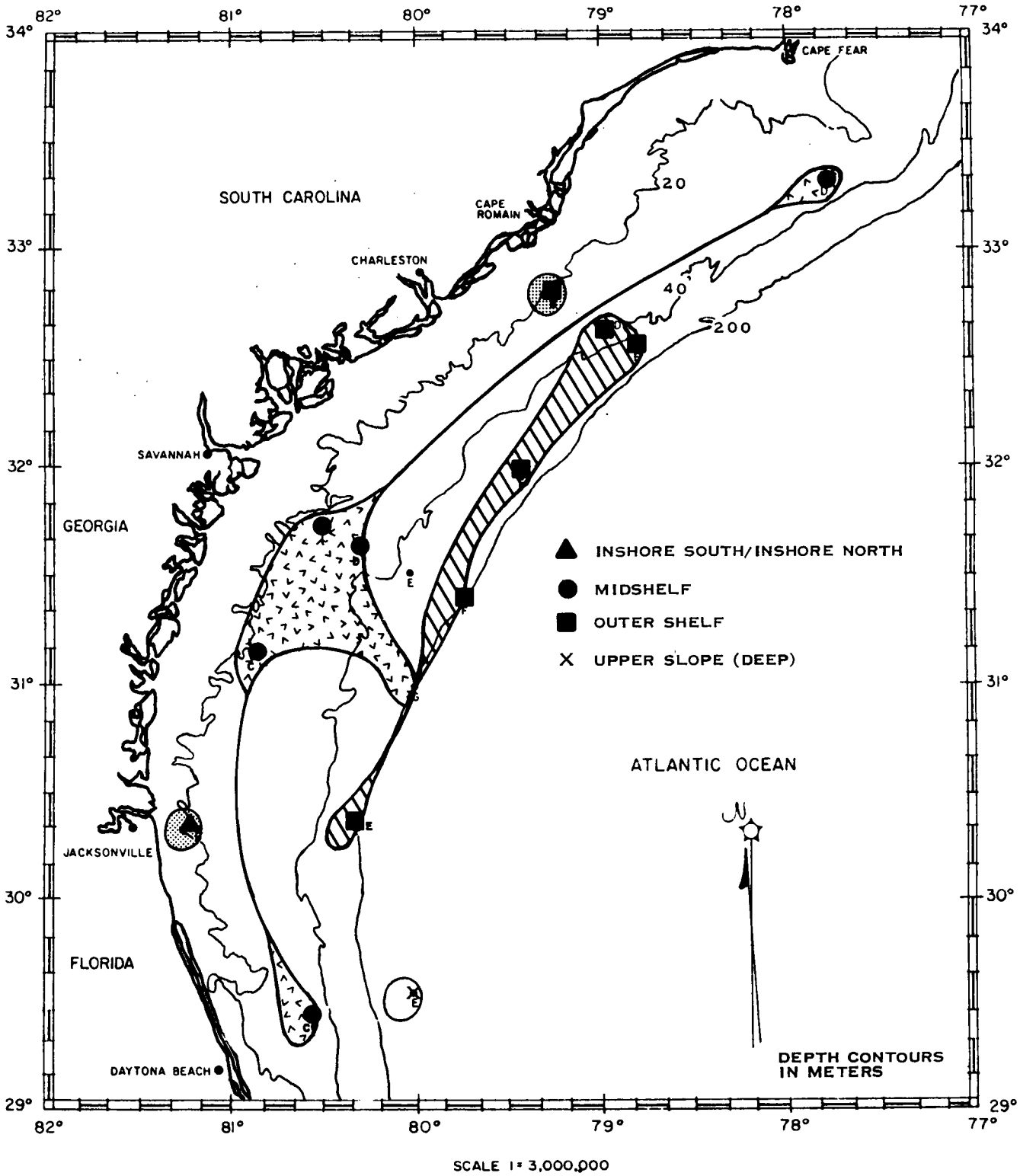


Figure 3.6-11. Fall Demersal Fish Assemblages

C. REGRESSION ANALYSES

Correlation and regression analyses were run on the numerical abundance and biomass data for fishes in an attempt to correlate variation with various sediment characteristics, depth, and latitude. No statistically significant associations were found. Reasons for this are discussed later.

D. NUMERICAL ABUNDANCE AND BIOMASS

The ranges of variation in numerical abundance and biomass of fishes were quite large: station means ranged from 3 to 4,657 individuals/30-min tow, biomass was 12 to 72,761 g wet weight/30-min tow, and absolute values showed even greater variation. As mentioned previously, variation in abundance and biomass did not correlate with any of the parameters measured, including depth and latitude.

The relative abundance and biomass data do indicate the dominant species associated with the assemblages derived from the cluster analyses. Numerical abundance and biomass information for the most dominant species in each assemblage by season is summarized in Tables 3.6-5 through 3.6-8.

1. Inshore Assemblage

During the winter, this assemblage (Table 3.6-5) was dominated by juvenile spotted hake *Urophycis regius* and pinfish *Lagodon rhomboides.* By spring, *U. regius* had moved offshore and been replaced by sand perch *Diplectrum formosum* and other sand-bottom species. The summer assemblage reflected increased sampling inside the 20-m isobath. This coastal habitat with its generally smooth sandy-mud bottom is populated by many sciaenids (*Leiostomus, Larimus, Menticirrhus, Cynoscion,* and *Micropogon*), and these genera dominated the inshore assemblage. *Anchoa,* a pelagic forage species, entered the data base because of the capture of occasional large schools. Fortuitous captures of large rays (*Dasyatis sayi* and *Myliobatis freminvillei*) abnormally elevated biomass values in the same way that the captures of large schools of anchovies and herrings elevated abundance values.

The fall inshore-north station was dominated by the scup *Stenotomus chrysops* but this density is not surprising, since *S. chrysops* is a ubiquitous schooling species on the shelf. The fall inshore-south station was dominated by species of the coastal sandy-mud habitat, *Leiostomus* and *Micropogon.* The bluefish, *Pomatomus saltatrix* in this assemblage is a migratory species of considerable economic value that ranges seasonally from New York to Florida.

2. Midshelf Assemblage

The midshelf assemblage (Table 3.6-6) was dominated in the winter by juvenile spotted hake, as was the inshore assemblage. The rest of the dominants are characteristic sand-bottom species. No distinct midshelf assemblage was evident from the spring data. Dominating the summer assemblage were species associated with sand-bottom (*Diplectrum formosum* and *Stenotomus chrysops*) and the pelagic schooling species *Monacanthus hispidus* (planehead filefish) and *Decapterus punctatus* (round scad). The fall assemblage was essentially like the summer assemblage, although the orange filefish *Aluterus schoepfi,* a large species, dominated biomass.

Table 3.6-5. Dominant Species in Inshore Assemblage Ranked by Abundance and Biomass for Each Season

Season	Number	Mean Percent	Weight (g)	Mean Percent
Winter	*Urophycis regius*	36.5	*D. sayi*	24.0
	Lagodon rhomboides	24.0	*L. rhomboides*	23.9
	Anchoa hepsetus	12.1	*Raja eglanteria*	22.6
	Citharichthys macrops	10.8	*U. regius*	19.3
	Dasyatis sayi	2.4	*C. macrops*	1.8
Spring	*Diplectrum formosum*	28.3	*D. formosum*	47.5
	Decapterus punctatus	19.6	*D. punctatus*	14.9
	Trachurus lathami	13.8	*S. foetens*	14.0
	Synodus foetens	12.8	*S. chrysops*	11.4
	Stenotomus chrysops	11.3	*T. lathami*	4.2
Summer	*Anchoa mitchilli*	40.0	*L. xanthurus*	20.6
	Chloroscombrus chrysurus	23.9	*C. chrysurus*	12.7
	Leiostomus xanthurus	10.7	*Menticirrhus americanus*	10.3
	Larimus fasciatus	11.1	*Cynoscion nothus*	7.4
	Anchoa hepsetus	4.6	*Micropogon undulatus*	5.8
Fall				
North assemblage	*Stenotomus chrysops*	92.1	*S. chrysops*	98.7
	Lagodon rhomboides	7.4	*L. rhomboides*	1.1
	Synodus poeyi	0.1		
	Scorpaena brasiliensis	0.1		
	Citharichthys macrops	0.1		
South assemblage	*Anchoa mitchilli*	34.7	*M. undulatus*	42.3
	Micropogon undulatus	23.7	*L. xanthurus*	24.0
	Leiostomus xanthurus	13.7	*Pomatomus saltatrix*	13.1
	Anchoa nasuta	7.2	*Myliobatis freminvillei*	6.4
	Sardinella anchovia	5.7	*Synodus foetens*	4.2

3. Midshelf/Outer-Shelf Assemblage

In winter this assemblage (Table 3.6-7) was similar to the warmer-season assemblages found at shallower depths. As in the previous two assemblages, juvenile *Urophycis regius* were again numerically dominant. The spring assemblage was a typical sand-bottom association, but biomass was dominated by the bothid flatfishes *Bothus ocellatus* and *Syacium papillosum.* The summer assemblage resembled the spring assemblage with the addition of the bank cusk-eel *Ophidion holbrooki* and the sand diver *Synodus intermedius.* The sand perch *Diplectrum formosum* and the offshore lizard fish *Synodus poeyi* dominated the fall assemblage, and the rock sea-bass *Centropristis philadelphica* was present because it is a common component of the live-bottom, reef-type habitat sampled on transects 2, 4, and 6.

4. Deep Assemblage

This assemblage (Table 3.6-8) was characteristic of the ichthyofauna of the upper and middle continental slope (archibenthic zone of transition, Menzies et al., 1973). The same species occur at similar depths in the Straits of Florida (Staiger, 1970); George and Staiger have sampled species of this assemblage along the edge of the Blake Plateau.

Table 3.6-6. Dominant Species in Midshelf Assemblage Ranked by Abundance and Biomass for Each Season

Season	Number	Mean Percent	Weight (g)	Mean Percent
Winter	*Urophycis regius*	61.8	*U. regius*	22.7
	Synodus foetens	18.2	*S. foetens*	19.7
	Decapterus macarellus	5.8	*P. dentatus*	6.2
	Diplectrum formosum	2.9	*Prionotus scitulus*	5.2
	Paralichthys dentatus	1.2	*Myliobatis freminvillei*	2.7
Spring	Assemblage absent	–	–	–
Summer	*Monacanthus hispidus*	29.3	*D. formosum*	21.5
	Diplectrum formosum	21.9	Clupeidae	16.5
	Clupeidae	18.9	*M. hispidus*	15.8
	Decapterus punctatus	11.4	*S. chrysops*	12.8
	Stenotomus chrysops	5.0	*Aluterus schoepfi*	7.8
Fall	*Decapterus punctatus*	25.8	*Aluterus schoepfi*	26.4
	Monacanthus hispidus	12.9	*D. formosum*	17.3
	Diplectrum formosum	10.9	*D. punctatus*	10.8
	Stenotomus chrysops	7.5	*S. chrysops*	10.3
	Bothus ocellatus	5.0	*M. hispidus*	5.1

Table 3.6-7. Dominant Species in Midshelf/Outer-Shelf Assemblage Ranked by Abundance and Biomass for Each Season

Season	Number	Mean Percent	Weight (g)	Mean Percent
Winter	*Urophycis regius*	23.3	*Dasyatis sayi*	14.8
	Synodus poeyi	17.7	*D. formosum*	9.4
	Trachurus lathami	9.5	*S. foetens*	8.8
	Synodus foetens	7.2	*Raja eglanteria*	5.6
	Diplectrum formosum	6.5	*Syacium papillosum*	4.5
Spring	*Bothus ocellatus*	11.5	*B. ocellatus*	10.7
	Synodus poeyi	10.2	*Diplectrum formosum*	10.7
	Stenotomus chrysops	10.0	*Syacium papillosum*	8.6
	Pagrus sedecim	7.8	*S. chrysops*	7.9
	Etrumeus teres	6.9	*P. sedecim*	6.7
Summer	*Synodus intermedius*	16.2	*D. formosum*	17.5
	Diplectrum formosum	15.3	*Synodus foetens*	8.9
	Bothus ocellatus	10.2	*Syacium papillosum*	7.9
	Stenotomus chrysops	5.4	*B. ocellatus*	7.1
	Ophidion holbrooki	5.0	*O. holbrooki*	6.1
Fall	*Synodus poeyi*	21.2	*D. formosum*	25.3
	Decapterus punctatus	19.6	*S. poeyi*	9.9
	Diplectrum formosum	13.0	*Synodus intermedius*	9.6
	Centropristis philadelphica	6.0	*D. punctatus*	9.0
	Hemipteronotus novacula	4.2	*Syacium papillosum*	7.0

Table 3.6-8. Dominant Species in Deep Assemblage Ranked by Abundance and Biomass for Each Season

Season	Number	Mean Percent	Weight (g)	Mean Percent
Winter	*Breviraja plutonia*	27.9	*Urophycis regius*	21.8
	Chlorophthalmus agassizi	20.6	*B. plutonia*	21.0
	Bregmaceros atlanticus	14.8	*Phycis chesteri*	12.7
	Laemonema barbatulum	11.2	*Urophycis tenuis*	10.1
	Citharichthys arctifrons	7.0	*Merluccius albidus*	6.7
Spring	*Urophycis regius*	92.4	*U. regius*	92.6
	Citharichthys arctifrons	5.3	*P. triacanthus*	4.2
	Peprilus triacanthus	2.0	*C. arctifrons*	2.7
	Paralichthys oblongus	0.1	*P. oblongus*	0.4
	Gadidae	0.1		
Summer	*Citharichthys arctifrons*	25.5	*C. arctifrons*	18.4
	Breviraja plutonia	24.0	*B. plutonia*	16.8
	Laemonema barbatulum	19.5	*L. barbatulum*	14.9
	Nezumia bairdii	7.9	*U. regius*	12.4
	Urophycis regius	6.0	*N. bairdii*	9.4
Fall	*Urophycis regius*	79.0	*U. regius*	87.0
	Lepophidium cervinum	8.8	*L. cervinum*	3.1
	Enchelyopus cimbrius	3.3	*E. cimbrius*	3.1
	Paralichthys oblongus	2.5	*P. oblongus*	3.0
	Citharichthys arctifrons	2.5	*Urophycis floridanus*	2.2

The deep assemblage showed little seasonal variation except for the addition of young *Uroophycis regius* as they grow and move offshore during spring and summer.

E. BOTTOM PHOTOGRAPHS

Bottom photography can be an efficient tool with which to study the natural distribution of large epifaunal animals on the seafloor. It may be to identify major sedimentary features indicating bottom currents (ripple marks), deposition (sediment accumulation), bioturbation (animal activities), and abundance of coarse material such as shell-hash and gravel. Figures 3.6-12 through 3.6-14 are representative photographs taken during the SABP on the shelf of the south Atlantic Bight. In Figure 3.6-12, the abundance of demersal fishes at station 2G is noteworthy; this station was in the vicinity of the live-bottom station on transect 2.

Ripple marks caused by the influence of the northward-flowing Gulf Stream were commonly seen in the outer/midshelf zone. From trawl samples and bottom photographs, the biomass and abundance of epifauna in this zone appeared to be rather low. The most common starfishes on this shelf, *Astropecten articulatus, Luidia clathrata,* and *L. Alternata,* were seen in bottom photographs but usually occurred as solitary individuals (Figure 3.6-13). Upper-slope station 7E showed sedimentary features that are characteristic of a seafloor environment with higher silt and clay fractions. The bottom photographs taken at 7E revealed the brachyuran crab Cancer borealis, shelf fishes, and signs of bioturbation (animal burrows and tracks as shown in

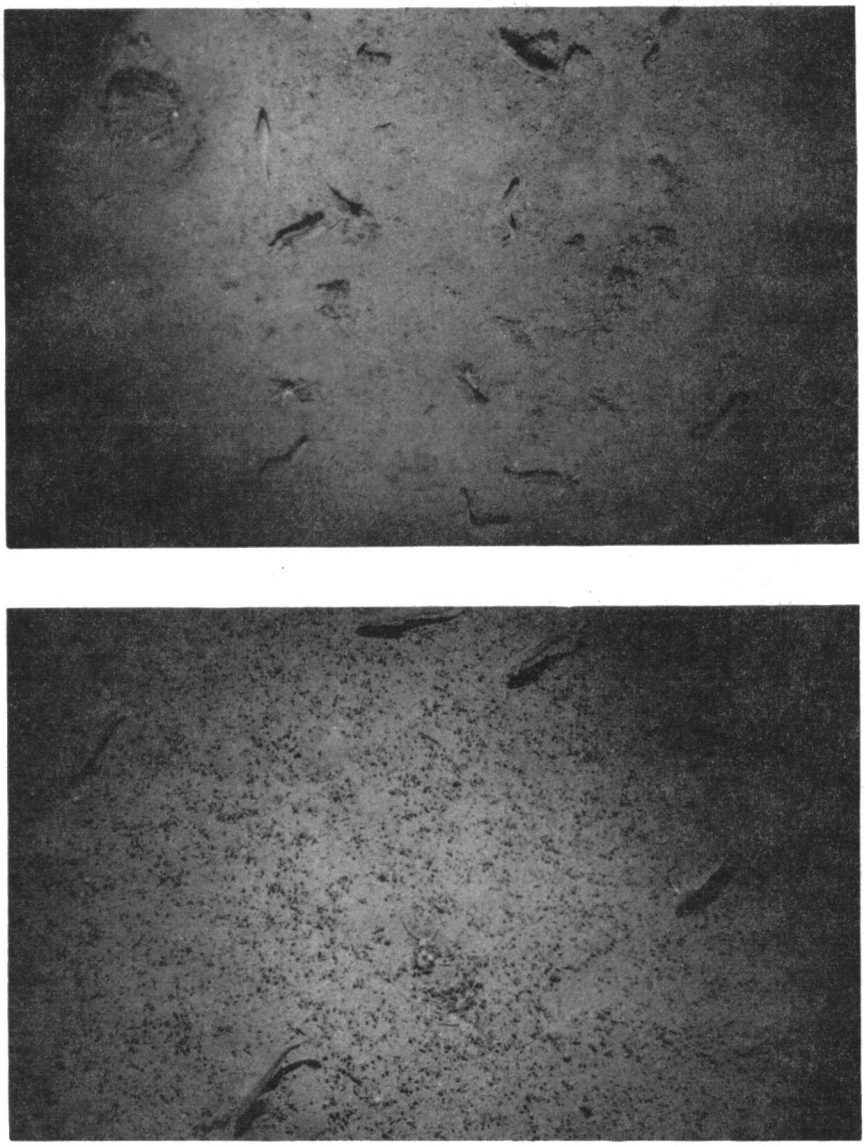
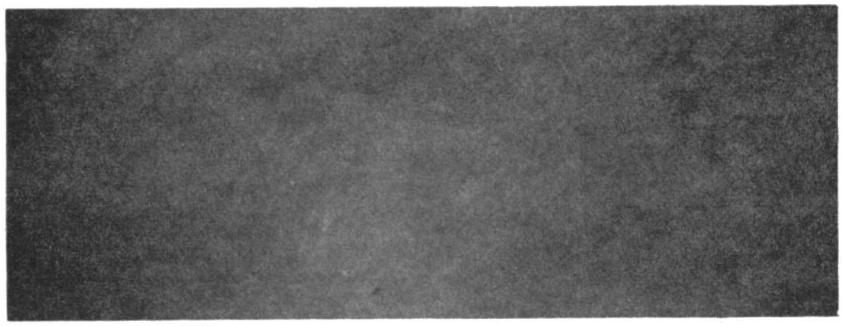
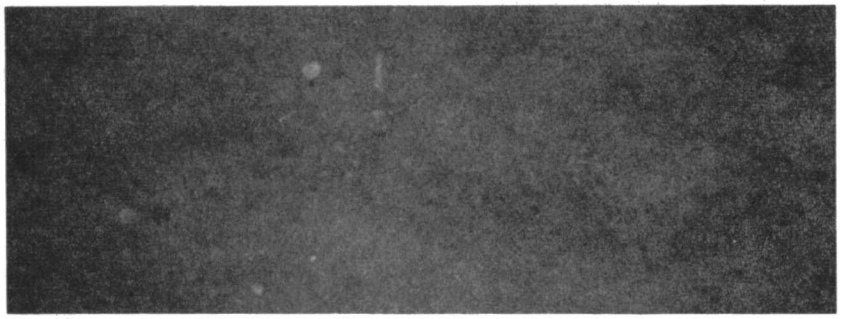


Figure 3.6-12. Bottom Photographs Showing Occurrence of Epifauna and Fishes at Station 2G During Cruise 4

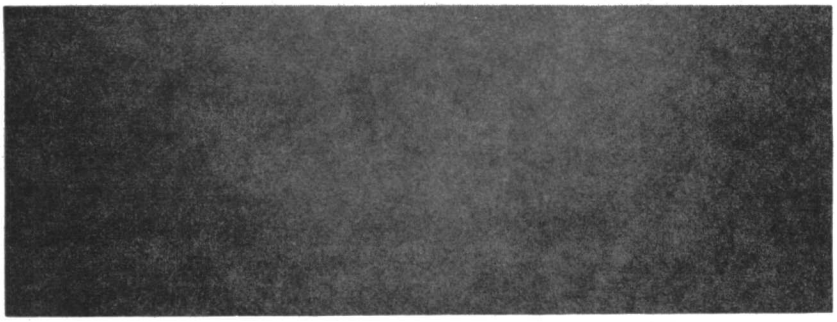
Figure 3.6-14). In general, however, bottom photographs from the South Atlantic/Georgia Bight showed few organisms and confirmed the uniformity of the substrate. While some useful data were derived from the bottom photography task, the results do not seem to justify the inclusion of these activities in future studies of soft/sand bottom studies in the South Atlantic OCS region.



Astropecten articulatus—STATION 1C



Luidia alternata—STATION 7C



Luidia clathrata—STATION 7C

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Figure 3.6-13. Bottom Photographs Showing Three Most Common Star Fishes at Stations 1C and 7C During Cruise 4

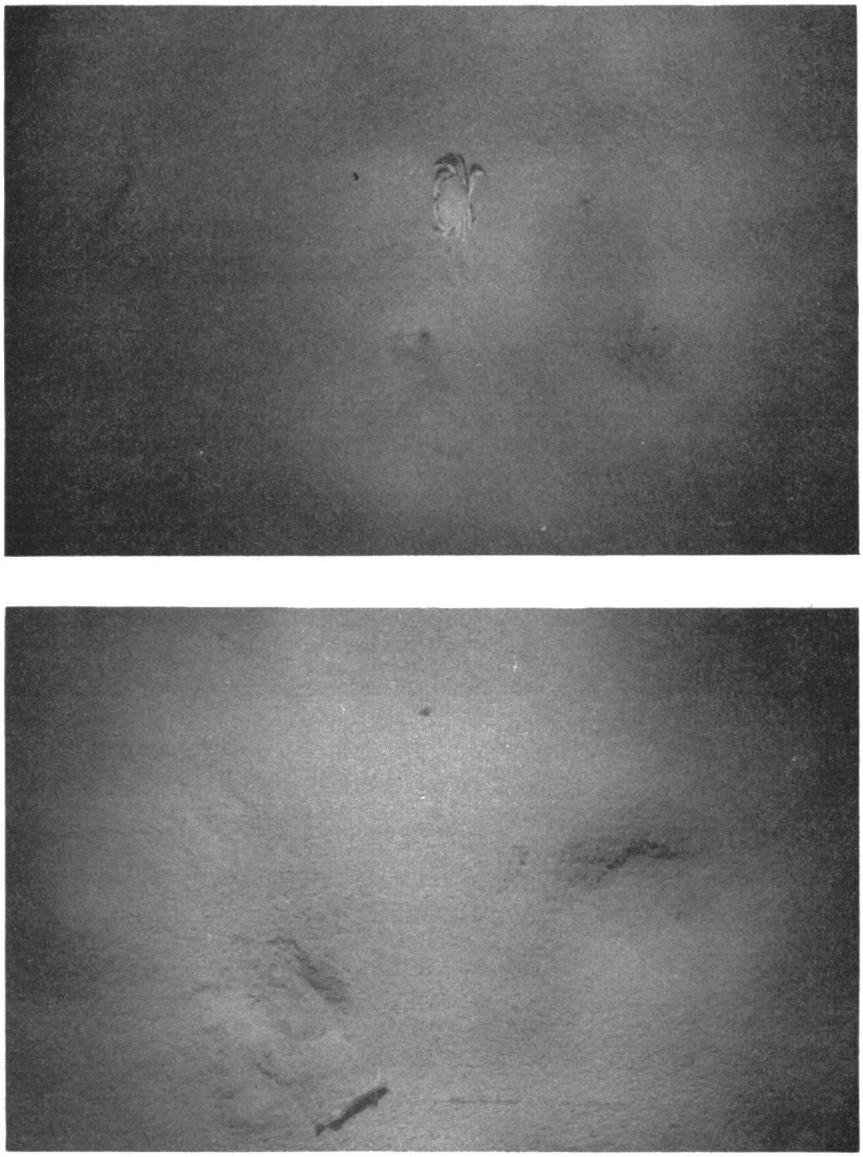

Figure 3.6-14. Bottom Photographs Showing *Cancer borealis* at Station 7E During Cruise 4 (Note burrows indicating bioturbation activities)

SECTION 4
DISCUSSION

A. LIVE-BOTTOM COMMUNITY

It has become clear from this study that the live-bottom areas in the south Atlantic Bight are patchy. Only at stations 2D and 2E were sessile epifauna and associated reef fishes obtained. Of the other 22 stations, 6C contained reef fishes but showed no evidence of sessile epifauna such as corals or sponges. There are two possible explanations: station 6C may be located in the vicinity of a reef structure or the reef fishes may have come from an adjacent wreck or an artificial reef. Unless these reefs are mapped more definitively with side-scan sonar and extensive photography, it will not be possible to describe the precise extent and distribution patterns of these reefs within the Georgia Bight.

From the published literature and the SABP study, it is evident that these reef structures are far more common off the North Carolina coast within Onslow Bay (Macintyre and Pilkey, 1969) and off the Florida coast (Moe, 1963). Gray's reef in the inner-shelf zone off Georgia (Hunt, 1974) appears to be strikingly different from the midshelf and outer-shelf reef formation. The midshelf reefs are dominated by the corals *Solenastrea hyades* and *Siderastrea siderea,* which tend to tolerate exposure to low temperature during winter (Macintyre and Pilkey, 1969). The outer-shelf lithothamnion reef structures located at the shelf break do not encounter low temperatures during the winter, so their faunal assemblage is more typical of the tropical-Caribbean fish and invertebrate fauna (Menzies et al., 1966). Because of the lack of knowledge on the distribution of these reefs, much work remains to be done before an unequivocal interpretation of the reef community in terms of the potential fishery resources is obtained. Obviously, these patchy live-bottom areas are excellent for recreational and commercial fishing and should be considered to be fragile ecosystems containing a high-biomass marine habitat. The epifaunal biomass of sponges, tunicates, and soft corals was extremely high at station 2E, for example; this midshelf reef formation off South Carolina, hitherto unreported in the literature, is inhabited by at least 60 large epifaunal invertebrate species and more than 40 demersal fish species.

Assemblages of live-bottom fishes were encountered at stations 2D, 2E, and 6C. Live-bottom associates such as the tomtate *Haemulon aurolineatum* and the bank sea bass *Centropristis philadelphica,* were among the dominants, but there were also dominants from among tropical sand-bottom associates: sand perch *Diplectrum formosum,* inshore lizard fish *Synodus foetens,* and sand diver *Trachinocephelus myops.* Sessile, live-bottom-associated invertebrates were not sampled at 6C.

Many of the species that were dominant over the entire midshelf area (e.g., scup *Stenotomus chrysops,* pinfish *Lagodon rhomboides,* bank cusk-eel *Ophidion holbrooki,* eyed flounder *Bothus ocellatus,* and dusky flounder *Syacium papillosum*) occur in both open-shelf and live-bottom areas (Struhsaker, 1969). Undoubtedly, their presence in some samples resulted from trawling across or near small live-bottom habitats, but the existence of live-bottom areas at the stations sampled cannot be ascertained from the occurrence of these species in the samples. A number of these species shelter diurnally in dense schools over reefal areas and forage nocturnally in a wide area over the adjacent open-shelf (Starck and Davis, 1966; Hobson, 1968); thus, time of capture also affects assessment of the live-bottom community.

B. SHELF SAND-BOTTOM FAUNAL ASSEMBLAGES

1. Invertebrate Community Associations

The most comprehensive evaluation of distributional patterns of benthic invertebrates is by Ceramé-Vivas and Gray (1966) for the continental shelf off North Carolina. Their study was based on dredge collections composed entirely of epifaunal invertebrates. They divided the shelf into three distinct faunal provinces: an inner-shelf Virginian province with a mixture of inshore and northern species; a midshelf Carolinian province with typical temperate epifaunal species; and an offshore tropical province dominated by southern species. The SABP study, which embraced a vast area containing the shelf environments off the Carolinas, Georgia, and northern Florida, also revealed three major faunal provinces–inner, midshelf, and outer shelf–that are strongly influenced by seasonal shifts in boundaries. There appeared to be a homogeneity in species composition, but epifaunal populations tended to occupy various shelf provinces as seasons progressed. Evidently, the most conspicuous pattern of epifaunal distribution in the shelf environment of the south Atlantic Bight was indeed the dynamic shifts of populations through the seasons.

The inner-shelf epifauna includes certain species such as *Penaeus setiferus* and *P. aztecus* that occur only in nearshore sediment regimes that are nutritionally enriched by continental runoff from river inflows and by detritus input from adjacent salt marshes. The blue crab *Callinectes* is more a coastal species that occasionally occupies the inner-shelf zone.

The midshelf epifaunal province is inhabited by at least nine different species of starfish; of these, *Luidia clathrata, L. alternata,* and *Astropecten articulatus* are ubiquitous species for all seven transects. Two other dominant invertebrate species in the midshelf and in the outer-shelf provinces are the cephalopod *Loligo pealii* and the decapod *Sicyonia brevirostris* (rock shrimp).

The epifaunal species inhabiting the inner-shelf province experience a wide thermal variation–from 8°C in the winter to 28°C in the summer. The species there are eurythermal, and their population structure shows significant seasonal changes. Conversely, the outer-shelf epifauna comprises warm stenothermal species that experience relatively little seasonal thermal changes; these warm-water species experience winter mortality, as was observed in the extreme winter of 1977.

Except for the peak abundance of the deposit-feeding sea cucumber *Holothuria imperator,* biomass in the midshelf and outer-shelf provinces off Georgia is low. The topography and high sediment input from the piedmont rivers in this region may contribute toward this prevailing ecological condition of low epifaunal species diversity in the outer-shelf province off Georgia.

The south Atlantic Bight is devoid of the swale environments that characterize the mid-Atlantic shelf (Boesch et al., 1978). Furthermore, the seasonal and temporal impact of the Gulf Stream eddies (Bumpus, 1955) in the south Atlantic Bight is dominant in inducing population shifts and larval dispersal leading to new recruitments.

2. Fish Community Associations

The most recent comprehensive study concerning the demersal fishes of the Georgia Bight (Struhsaker, 1969) divided the area into five habitat types–coastal, open shelf, live bottom, shelf edge, and lower shelf–and correlated the distributions of fishes with these habitats. The present study only minimally sampled the coastal habitat. The innermost trawl stations on each transect were within the depth zone (shallower than 18 m), but the sciaenid-dominated coastal fauna was sampled only a few times.

Demersal fishes of the Georgia Bight have been reported to five habitat zones–coastal, open shelf, live bottom, shelf edge, and lower shelf (Struksaker, 1969). The 1977 SABP study of this area was concentrated in areas offshore from the coastal habitat, only minimally sampling the outer extremes of the shallower than 18 m area defined by Struhsaker (Winter/Summer–4 stations; Spring/Fall–2 stations). The scaenid-ariid dominated coastal zone fauna was indicated but not clearly defined by SABP sampling.

The Georgia Bight continental shelf from the outer extreme of the coastal habitat to the shelf break is a shallow, relatively smooth sand-bottom region. Jaccarel and Canberro metric cluster analysis of SABP demersal fish catches identified two assemblages in this broad region. Both assemblages are composed primarily of species characteristic of the Carolinean province. The midshelf assemblage which occurs immediately offshore of the coastal zone from Cape Fear southward to Georgia or northern Florida, depending on the season, contained species characteristic of areas somewhat north of the Georgia Bight (e.g., *Prionostus carolinus* and *P. tribulus*) and essentially represents the southern extreme of their range.

The mid/outer shelf assemblage parallels the midshelf at somewhat greater depth. In this region, the predominantly Carolinean fauna is supplemented by tropical forms such as *Chaetodon ocellatus, Holocanthus bermudensis, Equetus lanceotatus, Fistularia tabacaria* and *Apogon pseudomaculatus* on and near live bottom areas. This region underlies the Florida current and the Gulf Stream. As evidenced by winter bottom water temperatures, it is subjected to less temperature variation than shoreward regions. Periodic incursions of warm nutrient-laden Gulf Stream waters undoubtedly contribute significantly to the presence of the tropical components of this assemblage.

The SABP study did not sample the shelf-break fish assemblage described by Struhsaker (1969). The shelf break, the area where the continental shelf ends, often has rock outcrops and rough topography. The topographic highs support large populations of snappers and groupers. The commercial and recreational fishery for these species has been reviewed by Huntsman (1976).

C. UPPER-SLOPE DEEP COMMUNITY

Most often the shelf province is identified with the topographic shelf that extends to 180 m in the geographic region. The region adjacent to the shelf break is the Hatteras-Florida slope that bridges the Blake Plateau with the continental shelf. The present study of epifauna included very few stations in the upper slope, so it gives only a marginal impression of the slope's epifaunal community. The samples from stations 7E and 5I demonstrated a distinct fauna that appears to be composed of elements belonging to the archibenthal zone (Menzies et al., 1973). The characteristic invertebrates include *Geryon quinquidens, Cancer borealis, C. irroratus,* and two species of the genus *Munida.* Several fish species seen–*Laemonema barbatulum, Citharichthys*

arctifrons, Breviraja plutonia, and *Merluccius albidus*—are dominant components of the demersal fish fauna of the Straits of Florida (Staiger, 1970). Since the sampling effort in this depth zone was so low (one to three stations), the data reflect a very small portion of this large and diverse transitional fauna.

D. CORRELATIONS OF EPIFAUNA DISTRIBUTION WITH INFAUNA, ZOOPLANKTON, AND HYDROGRAPHY

The homogeneous nature of the shelf provinces in terms of species composition was evident not only in the case of epifauna but also in the case of macroinfauna (see Chapter 7). The seasonal shifts in the boundaries of the inner-, mid-, and outer-shelf provinces were recognizable also from the distribution of both the large epifauna and the macroinfauna. The factors responsible for governing this mesoscale pattern of distribution may be associated with the impinging influence of the Gulf Stream and major changes in the shelf's hydrography.

It is of interest that population densities of zooplankton (Chapter 5) peaked (the maxima ranged between 830 and 2,500/m^3) over station 2E where a live-bottom area was identified in the benthic sampling survey. Perhaps the benthic productivity of the live-bottom areas influenced peak zooplankton abundance at this shelf station.

Temperature and salinity data during the four seasons of 1977 (Chapter 2) indicated pronounced seasonal changes. An onshore-offshore gradient in temperature and salinity prevailed throughout the winter. The water masses showed three distinct longitudinal strata: inner-shelf water was 8°C, midshelf water was 10°C, and outer-shelf water was 18°C. Inner-shelf water was diluted to 31 $^{o}/oo$. In the spring, the temperature gradient across the shelf became less pronounced; but in the summer, the inner shelf warmed to 28°C while the outer shelf remained constant at 18° to 19°C because of the Gulf Stream influence. In the fall, the hydrography of the shelf was more homogeneous. This hydrographic condition was possibly a major factor in inducing the seasonal population shifts observed in this study across the shelf.

E. POTENTIAL RESPONSES OF EPIFAUNAL COMMUNITY TO OIL DRILLING AND PRODUCTION

The potential effects of oil drilling and production on marine biota have been discussed in detail in a recent paper (George, 1975). Deposit-feeding benthic organisms derive all nutrients from the bottom sediment, so the heavy metals in such organisms may reflect the baseline levels in the sediment. Filter-feeding benthic animals such as clams are known to accumulate and release petroleum hydrocarbons.

Despite the importance of establishing baseline conditions for heavy metals and hydrocarbons in benthic organisms, it is essential that the very first step be dedicated to characterizing the benthic community. The rationale behind this study of epifauna revolved around the establishment of generalities of epifaunal distribution in this shelf environment. Therefore, concerns about the potential effects of petroleum exploration and development center around two interrelated factors: the potential for damaging the economically important fishery resources and the potential for damaging the unique live-bottom communities. Struhsaker (1969), whose primary purpose was to locate commercially exploitable stocks of demersal fishes, concluded that the open-shelf area was relatively unproductive; the productive areas were the live-bottom and

shelf-edge habitats, the former amenable to a trawl fishery but the latter too rough for trawling. The shelf edge and the adjacent live-bottom areas are the grounds fished by the head-boat fishery reported on by Huntsman (1976).

Research on the effects of hydrocarbon and trace metal pollution on marine organisms has been mainly in estuarine, lagoon, and nearshore environments; exceptions to this are recent studies on the effects of sewage sludge on deep-sea fishes (Grieg and Wenzloff, 1977) and the GURC study on the effects of offshore oil drilling and production on the general ecology of Louisiana coastal waters (Morgan et al., 1974). Grieg and Wenzloff concluded that sewage-sludge dumping had not significantly affected the trace metal content of demersal fishes sampled in the vicinity of the dump site. Morgan et al. (1974) concluded that oil drilling and production had no adverse effect on the environment.

The live-bottom areas are havens for most of the economically important fishes on the OCS. Many of these species (especially snappers) that are nocturnal foragers would presumably be able to seek diurnal shelter elsewhere if their usual habitats were disturbed. The reef-associated invertebrates and fishes that forage on the reef itself would be eliminated if the habitats were destroyed. It is important, then, that exploratory and production platforms not be sited on or adjacent to live-bottom habitats. It is assumed that permanent production platforms in the open-shelf area would act as artificial reefs and thus contribute to the fishery potential of the area. Of 37 distinct fishing grounds on the Florida continental shelf north of Cape Canaveral (Moe, 1963), eight are either wrecks or artificial reefs, with some supporting intensive fishing efforts. It is believed that production structures would function in a similar manner, as they have in the Gulf of Mexico.

The Georgia Bight OCS has been little affected by humans. Known offshore dumping has been restricted to the dredge spoils in the coastal zone. Dumping of sewage sludge and industrial wastes, a considerable concern in the mid-Atlantic Bight, has not occurred in the study area (Council on Environmental Quality, 1970).

Fish diversity has often been used as a measure of environmental quality (Livingston, 1975; Haedrich, 1975; Bechtel and Copeland, 1970), but the study by Struhsaker (1969) is the only comprehensive one upon which conclusions on the current health of the study area can be based. However, Struhsaker's data do not, themselves, lead to detailed species-diversity calculations. His results, summarizing the data taken from 956 stations between 1959 and 1964, give an absolute diversity of about 300 species from a depth of 11 m in the coastal zone to a depth of 180 m on the continental slope. Approximately one-third of those species are from depths not sampled in the present study. However, the SABP summer cruise alone sampled 152 species of fish from only 24 stations. The species that dominated Struhsaker's data also dominated SABP catches. It is apparent from these observations that the diversity of demersal fishes is stable (or perhaps even increasing). The overall condition of the outer continental shelf is believed healthy.

The unusually cold winter of 1977 may have resulted in abnormal conditions in the nearshore area; catch data for station 3B (winter cruise) are indicative of a cold-kill: 11 individuals were caught—one *Synodus foetens,* two *Citharichythys macrops,* one *Monacanthus hispidus,* and seven *Hemipteronotus novacula.* All eight specimens of the latter two species were decomposing, while the three individuals of the former two species were alive but not healthy. The bottom temperature was 7.7°C. Such a natural mortality may be an annual occurrence. It is essential that adequate data on natural mortalities and on the life-history strategies of key species in this shelf ecosystem be obtained.

SECTION 5
CONCLUSIONS

- Both the epifaunal invertebrates and demersal fishes can be naturally divided into three basic shelf zones and a slope zone beyond the shelf break. Identified through cluster analyses, they are the inner-shelf, midshelf, outer-shelf, and deep-slope zones. Although their boundaries are not rigidly defined, the shelf zones are longitudinally parallel to the shore and shelf break.
- There are definite seasonal shifts in the boundaries of the three major shelf zones since the species composition of the shelf faunal assemblages greatly overlaps. The most striking distributional trend is evidently at the population level of common epifaunal invertebrates and fishes. The winter faunal assemblage is generally dominant in the inner shelf, which is characterized by wide thermal and salinity variations.
- The inner-shelf fauna contains some coastal and mud-associated components. In spring and summer, the mixing of midshelf and outer-shelf fishes leads to the development of an assemblage that is distributed beneath the Gulf Stream. The mid- and outer-shelf epifaunal invertebrates show marked seasonal variations. Assemblages at specific stations reveal qualitative dissimilarity from season to season.
- The slope assemblage bears little resemblance to the shelf assemblages and is obviously associated with the archibenthal zone of transition that forms a bridge separating the shelf from the Blake Plateau.
- The sampling strategy in this investigation did not provide adequate data on molluscan fauna, which must be collected by dredging.
- The continental shelf in the Georgia Bight is devoid of ridge or swale topography as on the mid-Atlantic shelf. The characteristic feature of this shelf is the patchy occurrence of reefs that support high-diversity, high-biomass sessile fauna and reef fishes. A live-bottom area has been identified on transect 2 off South Carolina.
- The epifaunal distribution appears to be governed largely by the hydrography and the Gulf Stream eddies. Correlation between biology and physical oceanographic parameters is essential in arriving at generalities. Life-history strategies, larval dispersal, and new recruitments, as abetted by currents, should receive careful analysis.
- This shelf is not influenced by anoxic or hypoxic conditions as on the mid-Atlantic shelf, but winter cooling such as that experienced in the extreme winter of 1977 leads to some natural mortalities.
- Ichythofaunal diversity and historical comparisons indicate a healthy environment. The commercially important species are generally restricted to the live-bottom areas in the mid- and outer-shelf zones.

The long-range objectives of the South Atlantic Benchmark Program as they relate to epifauna were only partially attained. The sampling program established for demersal fishes and epifaunal invertebrates was adequate for a qualitative assessment of species composition but was inadequate for a quantitative treatment designed to elaborate such variables as seasonal changes in abundance, biomass, and diversity at individual stations. Valid conclusions concerning the cluster-derived species assemblages were reached by analyzing combined data.

Future sampling should be designed to include more shorter-duration otter-trawl tows instead of two 30-min tows; five to seven 10-min tows are suggested. Roessler (1965) discussed the reasons for this type of sampling strategy. To sample buried epifauna, an anchor or tumbler dredge should be used; the otter trawl used to sample demersal fishes and epifaunal invertebrates functions well but does not adequately sample the known molluscan fauna–and, since molluscs are especially important as accumulators of suspended compounds, their absence from the present samples has left an important gap in the data base. In addition, scavenger-type benthopelagic animals should be captured by means of traps in order to gather data on this important trophic level within the shelf food chain.

To continue sampling only three trawl stations beyond the shelf break (5I, 7E, 7F) that are associated with transitional fauna distinctly separate from the fauna of the continental shelf is of questionable utility. Characterization of these fauna and their variation requires considerable additional sampling, which should extend down onto the Blake Plateau.

Apparently because of the lack of accurate locality data for the larger live-bottom areas and the patchiness of their distribution, the hard-bottom habitat was not adequately studied during the 1977 SABP. Since such habitats are highly productive and presumably most vulnerable to disturbance, a comprehensive study of their ecology is recommended. Such a study should be approached as a separate program involving a combination of side-scan sonar surveying, scuba diving, submersible observations, underwater TV monitoring, and time-lapse photography to document biological events.

SECTION 6

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CHAPTER 7
MACROINFAUNAL BENTHOS OF SOUTH ATLANTIC/GEORGIA BIGHT

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ABSTRACT

During the South Atlantic Benchmark Program (SABP) conducted in 1977, macroinfauna were studied in box-core samples obtained at 25 stations occupied during all four seasons and at another 25 stations occupied during winter and summer. The goals were to determine density and biomass and determine whether density distribution of the total and individual major taxa correlate with hydrographic and sedimentary parameters. The Jaccard similarity index was used to delimit spatial and temporal clustering of stations.

Polychaetes generally dominated, accounting for more than 50% of total density and biomass in most samples, but there was not clearcut dominance of one or several species. Innermost stations on all transects clustered throughout the year and middle-shelf stations showed some degree of subclustering, but the outer, deeper stations did not cluster, even with each other. Biomass averages were low at the outer stations, relatively high in the large middle region of the shelf, and fluctuated greatly at the inner stations, falling to a low after the extremely cold winter and regaining in summer to maximum levels. Depth, not latitude, seemed to be the main factor in community delimitation.

The macroinfauna of the Georgia Bight can be characterized as an oligotrophic system having high species diversity but low standing biomass because of low nutrient input and a relatively unfavorable sedimentary regime.

SECTION 1
INTRODUCTION

Although there is good published information available on deep-sea and nearshore benthos (Rowe and Menzies, 1969; Rowe, 1971; Smith, 1971; Frankenberg, 1965, 1968, 1971; Frankenberg and Leiper, 1977; Dorges, 1977), there are few studies of the macroinfaunal benthos of the continental shelf proper off the southeastern coast of the United States. Ceramé-Vivas and Gray (1966) and Day et al. (1971) studied distributional patterns of macrobenthos of the continental shelf off North Carolina and McNulty et al. (1962) studied benthic community structure off southern Florida, but these study areas lay outside the shelf region of the Georgia Bight proper. Most interest has centered around the geology of the so-called "hard bottoms" that are characteristic of this shelf region. Tenore et al. (1978) studiedbenthic processes over a wide area of the Georgia continental shelf but only reported macrofaunal standing crop and no spatial or seasonal delimitations. Dorges (1977) reported densities of major taxonomic groups of infaunal benthos in 100 stations off Sapelo Island, Georgia, but only mentioned the names of dominant species and did not identify the seasons in which samples were taken. Thus, there have been no comprehensive studies of the macroinfauna of the offshore continental shelf of the Georgia Bight proper (i.e., the geographic area from Cape Lookout to Cape Canaveral), nor has there been a sampling design encompassing seasonal patterns of distribution. Such site-specific information is needed if any effects of offshore oil exploitation in this unique benthic environment are to be determined.

Little information is available on subtropical shallow-water communities, especially those tied to large estuarine complexes. In the past, river discharge and tidal outwelling of marshes were generally assumed to be the major nutrient inputs of this area. On the contrary, estuaries and their associated marshes are not an important source of particulate organic matter or inorganic nutrients (nitrogen) to the outer coastal system; the organic carbon found in shelf regions is of autochthonous origin (Haines and Dunstan, 1975, Brokaw and Oertel, 1976). Along the coast, about 20 km offshore, is a turbidity front that causes most suspended materials originating inland to remain inshore. Thus, in the Georgia Bight, coastal runoff probably supplies very few, if any, nutrients to the outer shelf ecosystem—except possibly during storms (Atkinson et al, in press). A major nutrient input to the outer shelf is from nitrogen-rich Gulf Stream intrusions (Blanton, 1971; Stefansson et al., 1971; Dunstan and Atkinson, 1976; Atkinson et al., in press). Large phytoplankton blooms in areas of otherwise low primary production have frequently been observed in areas of intrusions (Dunstan and Atkinson, 1976). Such unique characteristics of this particular shelf region are important because of the overlying primary production [or detrital system and major factor affecting benthic production (Rowe 1971)].

Another characteristic of much of the Georgia Bight is the broad, shallow continental shelf. The shallowness causes the benthic environment to be more greatly influenced by wind and tidal scour and sediment resuspension.

Because of these differences from contiguous shelf regions and the possibility of future disturbances associated with oil exploitation, there was a need for a comprehensive study of spatial and temporal patterns of the macroinfauna to:

- Delimit areas of similar community composition and their stability throughout the year
- Determine patterns of standing biomass
- Characterize stability of species composition
- Relate these distributional patterns with hydrography and sedimentary composition.

SECTION 2
MATERIALS AND METHODS

Sampling design and procedures were reported in detail in Volume 2 and will be only briefly summarized here.

In general, of 50 sampling stations, 25 were occupied during all four sampling periods (winter, spring, summer, fall) and the other 25 only in winter and summer. At each station, six box cores (0.06 m^2) were taken for macroinfauna. Aboard ship, the samples were sieved through a 0.5-mm screen and preserved in buffered formalin; later, in the laboratory, they were sorted, enumerated, and identified. Preserved wet weight of major taxa (total, polychaetes, arthropods, echinoderms, molluscs, miscellaneous) were determined and ash-free dry weight (AFDW) estimated from wet weight-AFDW conversion factors calculated for each group (Appendix 3.7C in Volume 6).

Subcores were taken from each box core also for analysis of sediment composition (mean and median particle size, silt-clay fraction, sorting coefficient, skewness, and total organic carbon).

Stepwise multiple-regression techniques were used to correlate density distribution of the total and individual major taxa with hydrographic and sedimentary parameters (Appendix 3.7B in Volume 6). The Jaccard similarity index was used to delimit spatial and temporal clustering of stations (Appendix 3.7A in Volume 6).

SECTION 3
RESULTS

Sampling of the benthic macroinfauna of the South Atlantic/Georgia Bight on four seasonal cruises during 1977 provided extensive data relative to the study area. Seasonal station mean density and ash-free dry-weight biomass (mean of six replicate 0.06 m^2 box-core samples at a station), total number of species collected, and Shannon-Weaver diversity (H′) at each station during the four seasons are summarized in Table 3.7-1. Taxonomic data, including identification and enumeration of specimens collected by replicate sample; station, transect, and cruise summaries; additional diversity and data analyses; and supplementary chemical and physical data appear in Volume 6, Appendix 3.7.

Low mean density and biomass and high species diversity (H′) were characteristic of the macroinfaunal community throughout the study area. The outer stations of each transect, those located on the Continental Slope, were especially depauperate and generally less diverse than those on the shelf proper. Seasonally, mean density, biomass, and total numbers of species were highest during the spring sampling period and lowest during the summer (Table 3.7-2). There was no pronounced pattern for these factors among transects, although transects 1 and 3 in the northern portion of the study area were generally lower for all factors than the more southern stations. Transect 2, which also lies in the northern area, had the highest mean total number of species per station and the second highest annual mean density. High values in these categories may be attributable to the influence of scattered hard-bottom reef communities discovered in the mid- and outer-shelf regions of transect 2 during trawl operations.

The Shannon-Weaver diversity index (H′) assesses the relationship between the species that make up a community and their relative abundances. Generally, small values of H′ (0.0 to 1.0) would be indicative of communities with few species or strong dominance, while high values ($\geqslant$3.0) would suggest diversity. H′ values in excess of 3.0 were determined for 89% (133) of the season/station data sets, and over 22% (33) of the data sets exceeded 5.0 (Table 3.7-3). On the shelf proper, less than 1% (one station during one season) of the data sets fell below 3.0. Transect 1 showed the least variation in diversity between stations, with all calculated values falling between 2.06 and 4.95. The single observation during 1977 of diversity below 2.0 was at station 2H during the summer. In all other respects, however, transect 2 closely approximated percentages for pooled study area data as did transects 3, 5, and 6. Transects 4 and 7 showed higher percentages of H′ in the 2.0 to 2.99 range as a result of low values at deep water stations on the continental slope. Seasonally, there was little variation in the percentage distribution of H′ other than during the summer period when samples from the Continental Slope were generally lower in numbers of species and, as a consequence, in diversity.

Polychaetes generally dominated the macroinfauna, accounting for more than 50% of total density and biomass for most samples. The relatively few low values of polychaete contribution to total biomass resulted from the presence of large megabenthos in those samples. There was no clearcut dominance of one or several species, either throughout or in geographic portions of the shelf (Table 3.7-4). For example, *Spiophanes bombyx* and *Unciola* B were the only species composing more than 5% relative abundance of the fauna: *S. bombyx* in winter and spring and *Unciola* sp. in spring. Even the contribution of these species was reduced in the other seasons. These percentages are low, in part, because they represent averages for all stations.

Table 3.7-1. Summary of Seasonal Benthic Macroinfauna Data for 1977 Studies of South Atlantic/Georgia Bight

Transect and Station	Winter				Spring				Summer				Fall			
	Mean[a] Density per 0.06 m²	Mean[a] Biomass per 0.06 m²	Total[b] Taxa	Diversity (H')	Mean[a] Density per 0.06 m²	Mean[a] Biomass per 0.06 m²	Total[b] Taxa	Diversity (H')	Mean[a] Density per 0.06 m²	Mean[a] Biomass per 0.06 m²	Total[b] Taxa	Diversity (H')	Mean[a] Density per 0.06 m²	Mean[a] Biomass per 0.06 m²	Total[b] Taxa	Diversity (H')
1A	317	1,042	121	3.81					50	851	86	4.21				
1B	239	408	98	3.64	98	1,042	87	3.91	129	962	110	4.06	224	729	98	4.16
1C	232	734	96	4.21	332	598	126	3.85	258	642	126	4.14	336	3,208	182	4.84
1D	107	1,008	108	4.16	257	483	178	4.68	206	1,401	206	4.95	431	456	142	3.48
1E	222	2,279	186	3.88	502	1,109	207	3.25	262	482	186	3.86	140	887	143	4.95
1F	116	151	75	2.06	50	140	74	3.54	28	168	47	2.50	61	150	84	3.74
2A	325	1,878	136	3.56					40	797	50	2.54				
2B	479	9,603	210	4.64	924	13,115	249	4.84	317	5,459	232	4.82	1,035	3,767	221	4.43
2C	554	1,304	256	5.18	436	1,838	225	5.04	283	1,205	213	5.02	518	1,002	192	4.84
2D	393	1,384	258	5.36	412	2,012	220	4.65	314	1,844	238	5.26	669	2,951	226	4.69
2E	104	657	141	4.77	902	3,241	325	4.96	117	828	119	4.11	147	1,166	189	5.38
2F	366	714	259	5.08	824	2,091	249	3.61	352	2,136	203	4.46	413	1,247	148	3.93
2G	94	534	110	3.98	171	714	134	4.01	75	349	83	3.39	182	597	97	3.27
2H	28	371	44	3.52	40	834	68	3.24	11	470	30	1.74				
3A	346	1,631	138	4.52					134	1,135	95	4.15				
3B	251	1,027	179	4.71					122	1,825	160	5.02				
3C	212	556	171	4.89					204	609	207	5.17				
3D	448	1,431	217	4.86					250	794	182	5.08				
3E	143	864	168	5.16					91	781	88	3.75				
3F	54	639	100	3.60					22	578	37	2.36				
4A	580	1,036	120	3.16					101	1,466	108	3.91				
4B	230	1,322	146	4.16					1,275	1,477	116	2.35				
4C	1,002	13,583	180	3.99					1,416	7,370	233	4.28				
4D	456	760	150	3.75					247	790	187	4.80				
4E	413	2,500	203	4.80					295	1,672	245	5.63				
4F	180	1,788	134	3.87					36	137	72	4.01				
4G	42	474	48	3.29					42	517	25	2.26				
5A	525	3,601	129	3.29					66	1,070	92	4.17				
5B	535	1,501	206	4.62	571	2,389	177	4.56	128	669	123	3.89	555	6,250	159	4.47
5C	450	4,782	147	4.62	298	8,171	148	4.02	459	3,873	161	4.26	615	6,584	165	4.26
5D	331	876	159	4.07	353	1,113	136	4.04	260	2,744	162	4.40	213	1,415	133	4.23
5E	273	3,237	210	5.19	455	3,778	234	5.24	218	1,098	202	5.28	569	2,141	224	5.00
5F	382	8,686	182	4.20	633	5,236	279	4.86	352	3,330	202	3.86	555	5,590	183	3.43
5G	336	5,839	216	4.74	436	2,970	137	3.70	382	3,246	166	4.12	564	4,200	140	3.27
5H	279	2,865	202	4.07	256	2,391	218	5.11	84	798	155	4.90	121	1,426	157	5.06
5I	6	18	14	2.09	91	535	131	4.41	18	112	29	2.14	131	221	108	3.62
6A	200	2,308	106	4.01					82	334	116	4.27				
6B	494	3,813	204	4.99					628	2,903	300	4.74				
6C	379	1,038	230	5.00					170	674	191	4.88				
6D	346	1,432	238	4.92					220	1,831	223	5.06				
6E	448	5,773	248	5.20					155	4,698	183	4.61				
6F	377	3,503	225	5.15					154	1,664	191	5.13				
6G	128	1,717	129	4.66					139	821	117	4.19				
6H	22	66	52	3.10					18	58	50	2.39				
7A	314	10,975	146	4.05					365	20,801	129	4.09				
7B	151	4,825	175	5.09	234	3,316	199	5.09	546	2,015	297	5.31	133	4,142	166	4.98
7C	318	1,267	228	5.12	350	2,468	242	5.37	783	3,335	262	5.76	197	6,084	197	5.23
7D	158	1,776	210	5.64	272	2,804	260	5.22	200	2,082	208	5.09	263	1,990	217	5.28
7E	145	943	75	2.35	106	727	72	2.71	128	288	70	3.48	23	582	48	2.91
7F	60	91	84	3.62	21	182	63	2.90	9	84	11	2.46	16	138	41	2.97

[a]Mean of six replicate 0.06 m² box cores.

[b]Total number of taxa from six replicate 0.06 m² box cores.

Table 3.7-2. Seasonal and Annual Mean Densities, Ash-Free Dry-Weight Biomass, and Total Numbers of Species

	Mean Density per 0.06 m²					Mean Biomass per 0.06 m²					Mean Total number of Species				
Transect	Winter	Spring	Summer	Fall	Annual[a]	Winter	Spring	Summer	Fall	Annual[a]	Winter	Spring	Summer	Fall	Annual[a]
1	205.5	247.8	155.5	238.4	209.0	937.0	674.4	751.0	1,086.0	860.5	114.0	134.4	126.3	129.8	125.6
2	292.9	529.9	188.6	494.0	362.9	2,055.6	3,406.4	1,636.0	1,788.3	2,210.6	176.8	210.0	146.0	178.8	176.7
3	242.3		137.2		189.8	1,024.7		953.7		989.2	162.2		128.2		145.2
4	414.7		487.4		451.1	3,066.1		1,918.4		2,492.3	140.1		140.9		140.5
5	346.3	386.6	218.6	415.4	338.2	3,489.4	3,322.9	1,882.2	3,478.4	3,022.2	162.8	182.5	143.6	158.6	161.4
6	299.3		195.8		247.5	2,456.3		1,622.9		2,039.6	179.0		171.4		175.2
7	191.0	196.6	338.5	126.4	217.8	3,312.8	1,899.4	4,767.5	2,587.2	3,223.4	153.0	167.2	162.8	133.8	154.5
Combined[a]	291.8	361.0	244.8	338.0		2,412.2	2,531.9	1,905.5	2,371.8		157.4	177.5	146.4	152.5	

[a]Annual and combined means were calculated directly from station values to avoid biases caused by unequal station numbers. They *cannot* be reproduced from the summation of seasonal or transect means.

Table 3.7-3. Distribution of Shannon-Weaver H' Values by Transect and by Season

Transect	<2.00	2.00–2.99	3.00–3.99	4.00–4.99	>5.00
	Percentage of Total Stations With Shannon-Weaver H' Value				
1		9.1	45.5	45.5	
2	3.4	3.4	27.6	41.4	24.1
3		8.3	16.7	41.7	33.3
4		14.3	42.9	35.7	7.1
5		5.9	20.6	55.9	17.6
6		6.3	6.3	56.3	31.3
7		27.3	9.1	13.6	50.0
Combined	0.7	10.1	24.2	42.3	22.8
Season					
Winter		6.0	30.0	42.0	22.0
Spring		8.0	28.0	40.0	24.0
Summer	2.0	16.0	14.0	44.0	24.0
Fall		8.3	29.2	41.7	20.8

Table 3.7-4. Seasonal Changes in Percent Relative Abundance of Macroinfaunal Species Constituting >0.2% for All Stations in at Least One Season

Species	Winter	Spring	Summer	Fall
Spiophanes bombyx	5.3	7.3	1.5	0.3
Parapionosyllis longiciratta	3.3	0.9	1.6	1.9
Spio pettiboneae	2.0	1.4	2.4	0.2
Exogone lourei	2.0	0.4	0.4	1.2
Oxyurostylis smithi	1.4	*	*	*
Prionospio cristata	1.3	0.4	2.0	0.2
Synelmis albini	1.3	0.9	1.3	1.1
Protodorvillea kefersteini	1.2	0.9	0.6	1.0
Unciola B	*	6.0	1.5	*
Ericthonius brasiliensis	0.5	1.6	*	*
Leptochela serratorbita	*	1.6	*	*
Paleanotus A	0.8	1.4	0.4	0.5
Prionospio cirrifera	0.6	0.3	1.0	*
Typosyllis regulata arolinae	0.5	0.8	0.7	1.2
Pseudovermilia occidentallis	*	*	0.4	1.2
Haploops A	0.2	0.5	0.2	1.2
Goniadides carolinae	0.7	0.5	0.6	1.0
Sphaerosyllis bulbosa	0.7	0.3	0.4	1.0

*Less than 0.2% relative abundance.

Sporadically at a few stations, there were high densities of particular species (e.g., in spring sampling, *Spiophanes bombyx* constituted up to 22% of the fauna at five stations), but there was no geographical pattern to this patchy distribution. Most of the species could be considered rare. Only 18 species constituted more than 0.2% of mean total density in at least one seasonal sampling. Numerous remaining species each made up less than 0.2% of mean total density.

Clustering of stations using the Jaccard similarity index (Appendix 3.7A), based on absence or presence, indicated a clustering of innermost stations (A) on all transects that persisted through the year and a major clustering of middle-shelf stations (to 200 m) that showed some degree of subclustering (Figure 3.7-1). The outer, deeper stations did not cluster, even with each other. Figures 3.7-2 through 3.7-6 illustrate seasonal and pooled annual clustering relative to the geographical station locations. Figure 3.7-7 separates the primary subclusters of the mid-shelf region that were defined through analysis of pooled annual catch data.

Depth, not latitude, seemed to be the main factor in community delimitation. Stepwise multiple regression (Table 3.7-5) supported this observation, showing depth and sediment particle size to be the major correlations with macroinfaunal biomass. Similar results were obtained with epifaunal density (Chapter 6).

Seasonal and annual mean density and biomass of the shelf/slope strata defined by cluster analysis clearly show that samples from the outer stations were consistently much lower in both total numbers of individuals and ash-free dry-weight biomass than were the stations of the shelf proper (Table 3.7-6). The broad mid-shelf region was highest of the strata in numbers of individuals and mean total biomass per 0.06 m^2. The ratio of biomass to density, actually a calculation of mean weight (g) per individual, indicates that individuals in the near-shore region, while fewer in number, are larger than those in the mid-shelf and slope regions, particularly during the summer and fall seasons. Mean organism weight was approximately equal in the mid-shelf and slope regions.

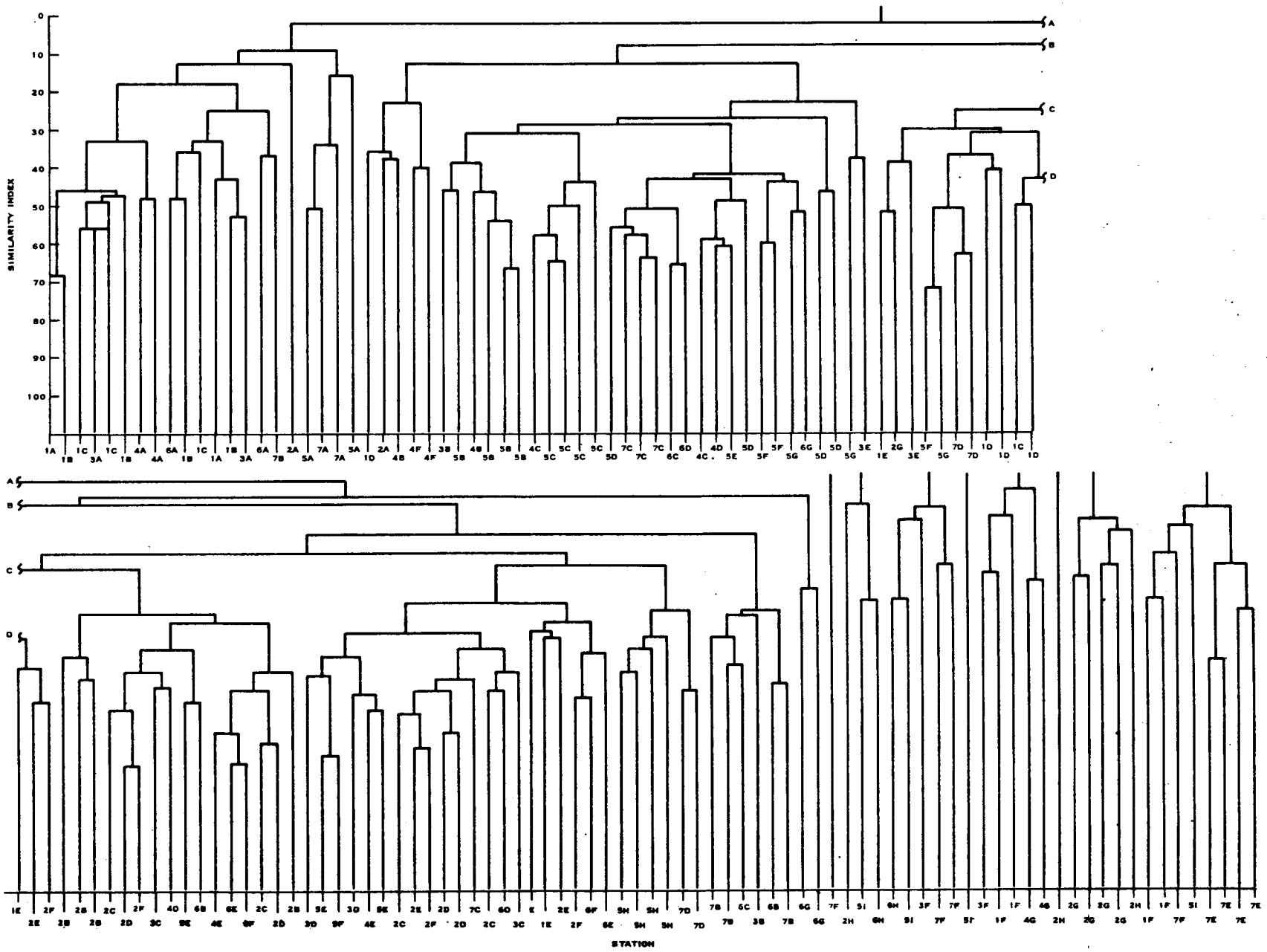

Figure 3.7-1. Station Clustering Using Total 1977 SABP Data

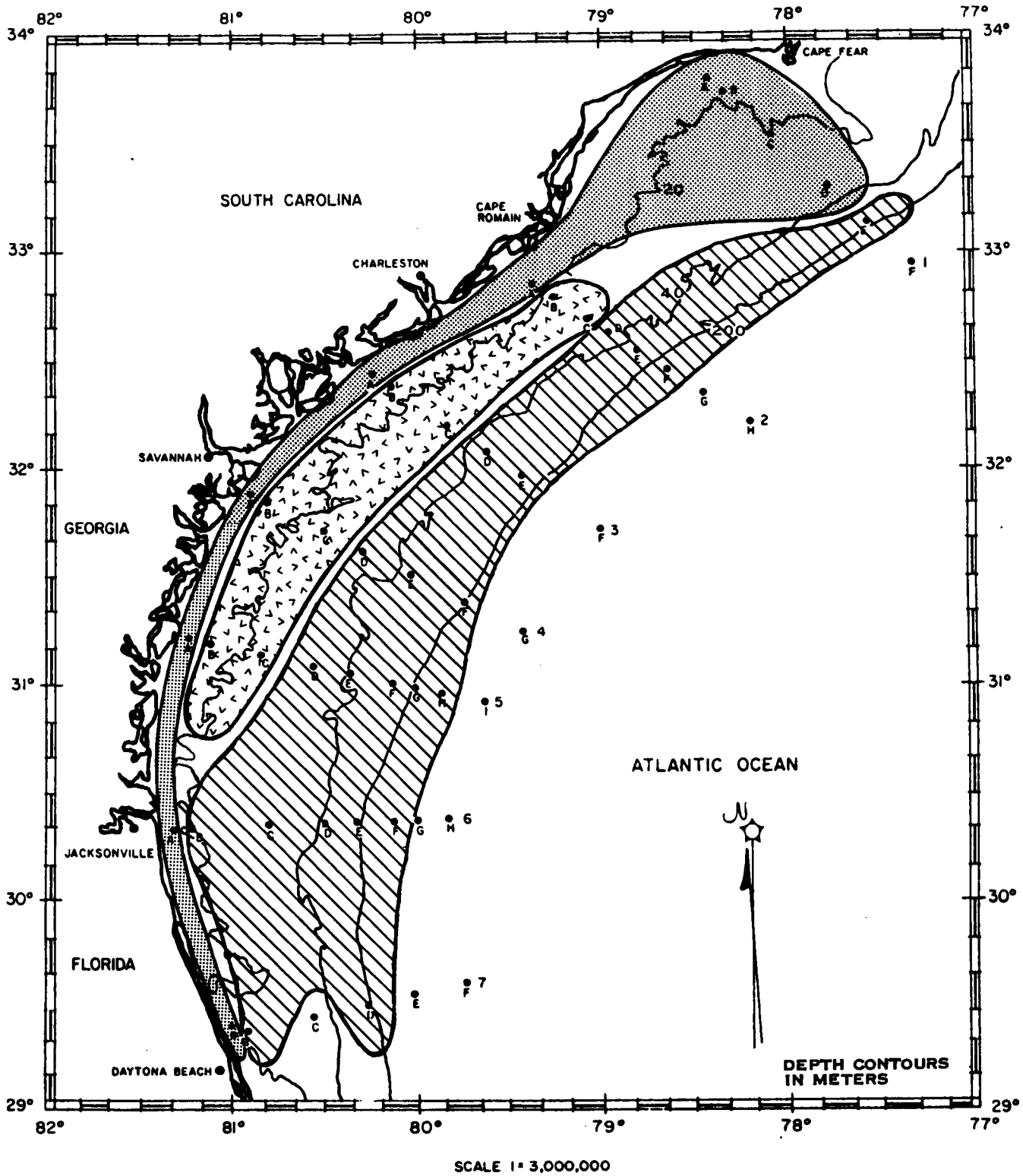

Figure 3.7-2. Graphic Display of Clusters for Winter Macroinfaunal Data

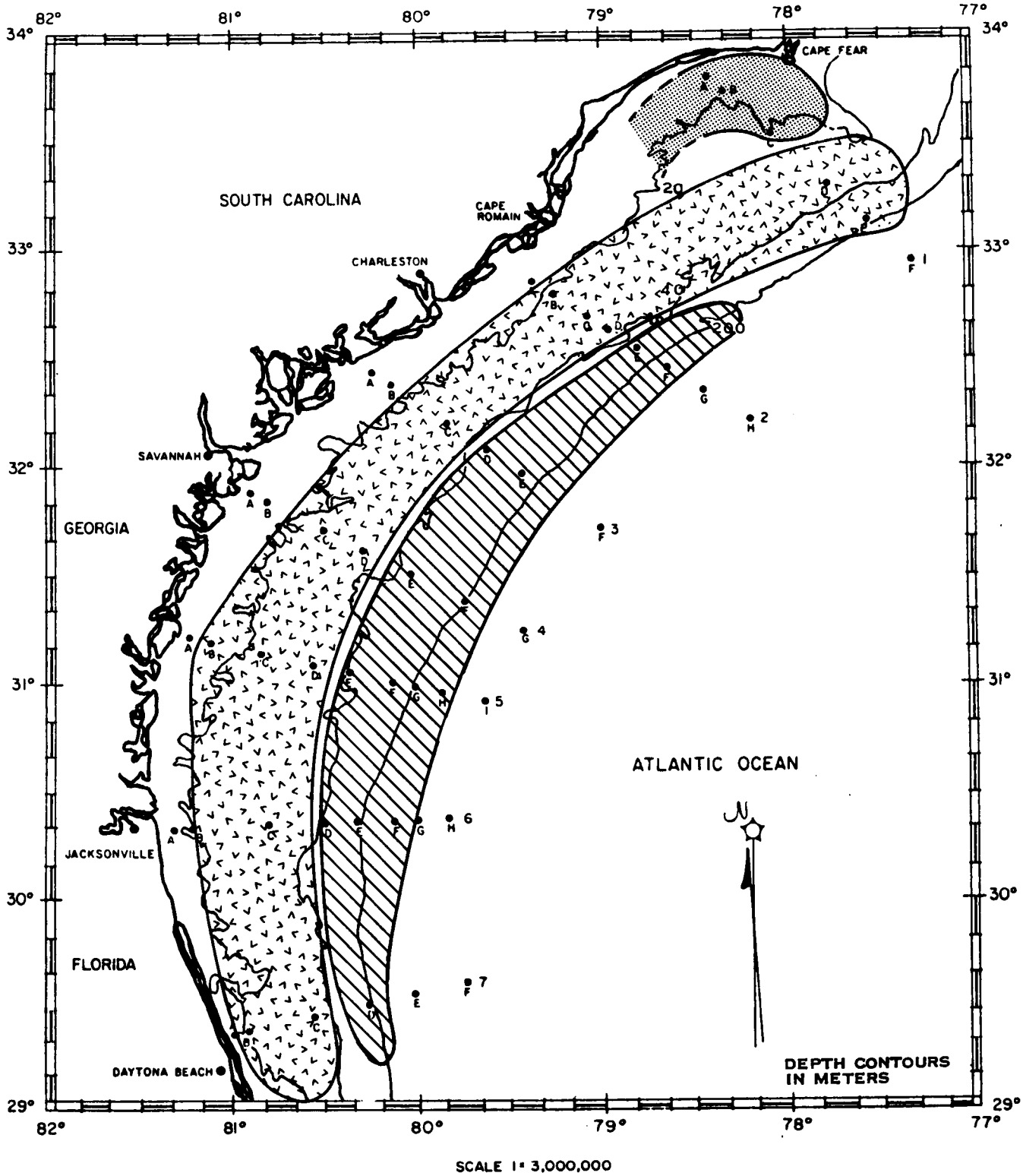

Figure 3.7-3. Graphic Display of Clusters for Spring Macroinfaunal Data

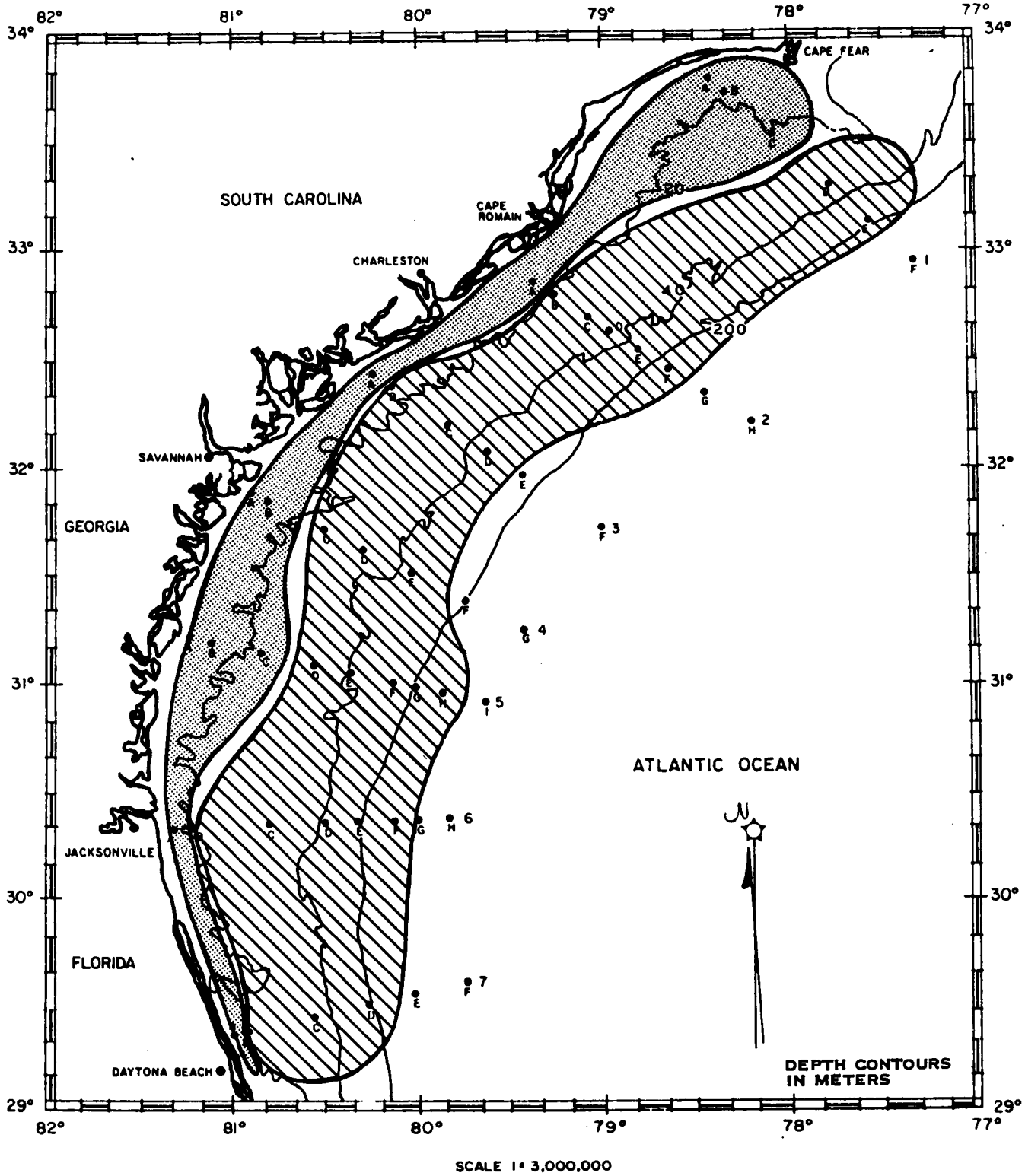

Figure 3.7-4. Graphic Display of Clusters for Summer Macroinfaunal Data

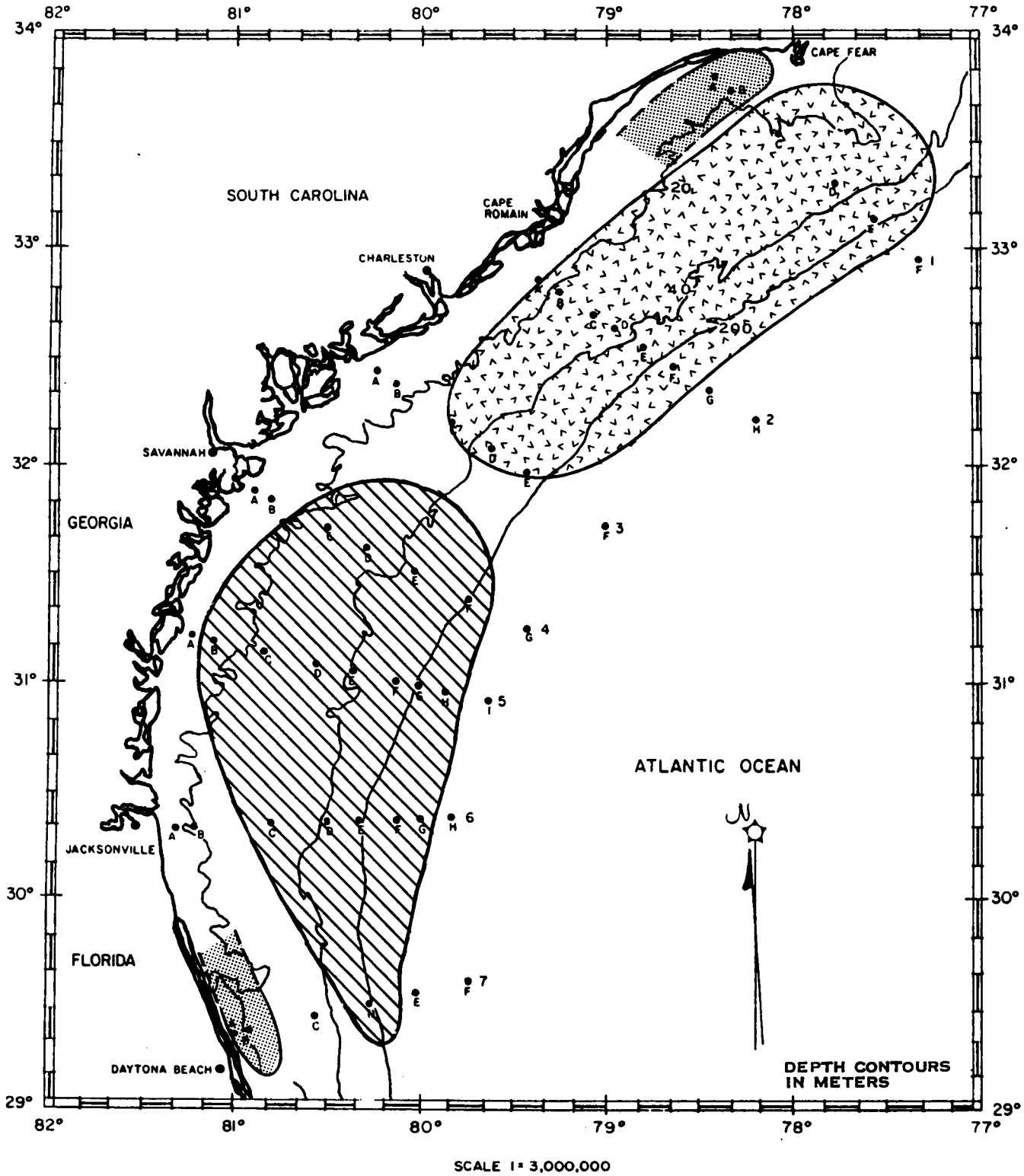

Figure 3.7-5. Graphic Display of Clusters for Fall Macroinfaunal Data

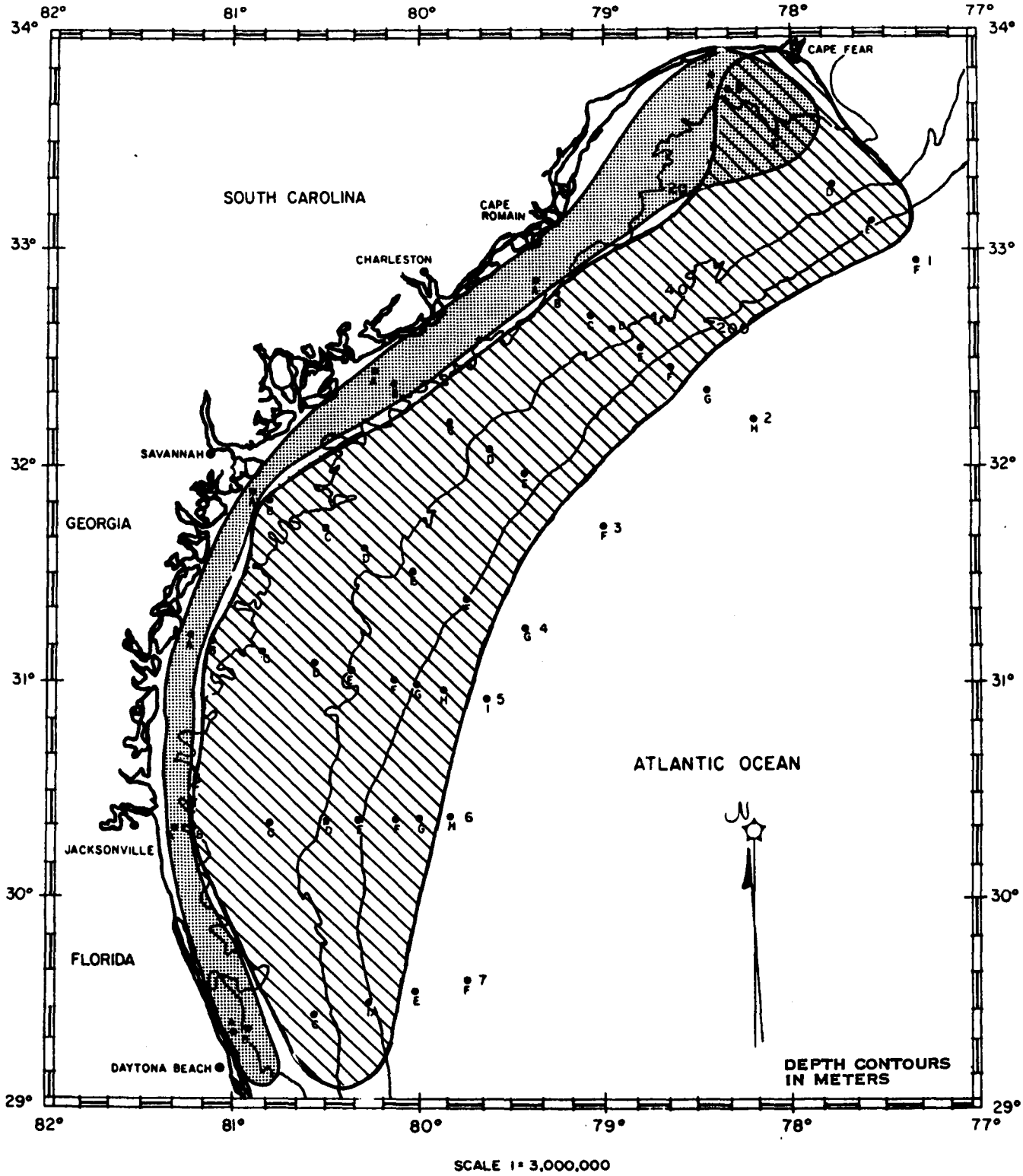

Figure 3.7-6. Graphic Display of Clusters for Total Annual Macroinfaunal Data

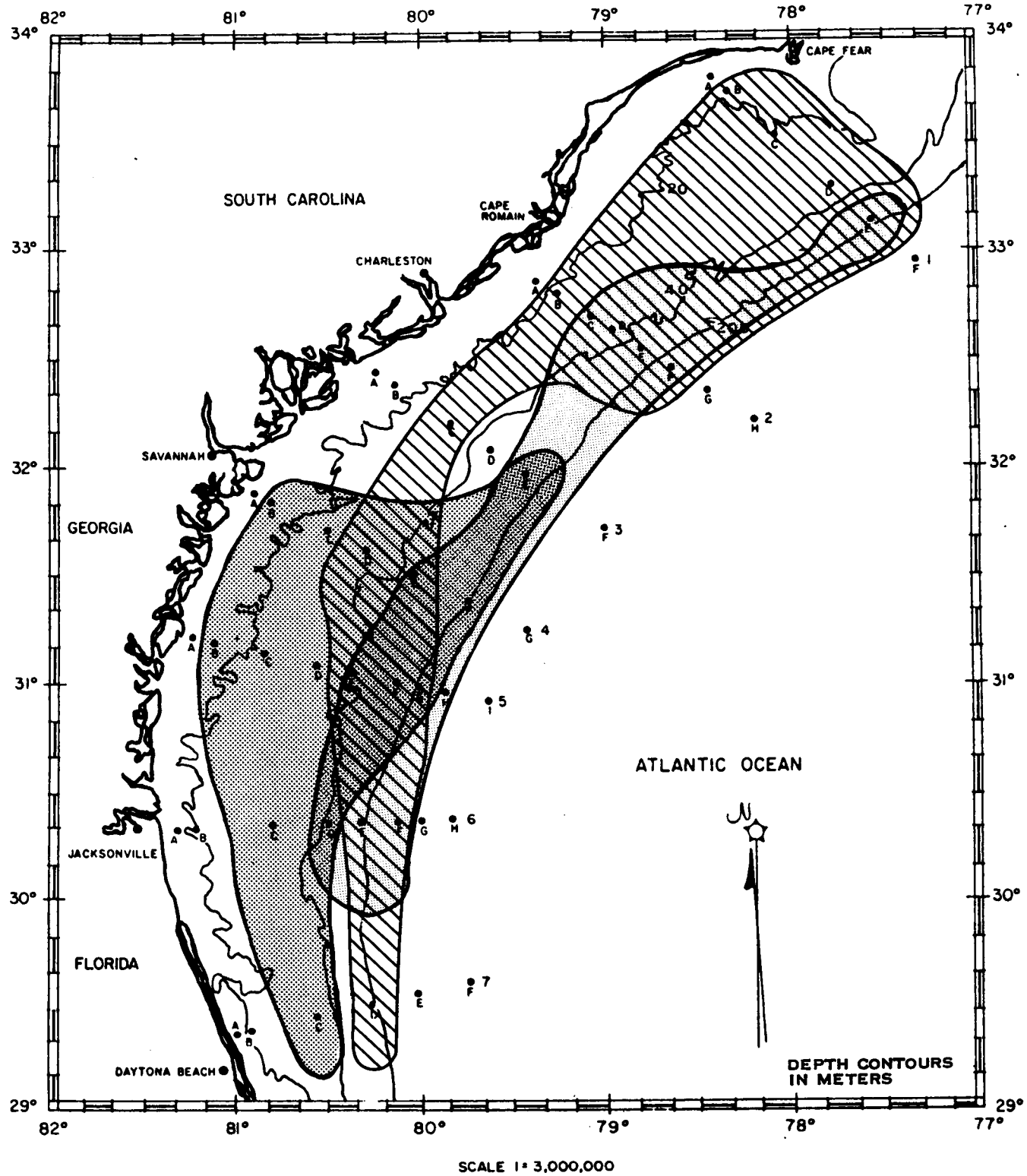

Figure 3.7-7. Subclustering Within Broad Annual Macroinfaunal Clustering From Jaccard Similarity Matrix

Table 3.7-5. Results of Stepwise Multiple Regressions of Macrofaunal Density (Total and Individual Components) to Sedimentary and Hydrographic Parameters[a]

	Macroinfaunal Group									
Season	Total		Echinoderm		Arthropod		Mollusc		Polychaete	
Winter										
r^2 [b] = 0.45	D	0.32	ME	0.18	C	0.17	D	0.13	D	0.24
	T	0.34	MD	0.24	D	0.34	T	0.19	ME	0.28
Spring										
r^2 = 0.76	D	0.38	ME	0.18	NS[c]		D	0.29	D	0.32
	ME	0.47	MD	0.24	NS		L	0.39	ME	0.45
Summer										
r^2 = 0.28	D	0.13	NS		NS		NS		D	0.14
	ME	0.23	NS		NS		NS		ME	0.21
Fall										
r^2 = 0.57	D	0.32	SK	0.23	NS		D	0.27	D	0.36
	MD	0.42	L	0.34	NS		C	0.28	MD	0.40

[a]D = water depth
ME = sediment mean
MD = median particle size
C = silt/clay fraction
SK = skewness
C = total organic carbon
L = latitude
T = bottom water temperature

[b]The correlation coefficient r^2 is given for the complete regression for the total macroinfaunal biomass for each season. The first and second significant (p = 0.05) contributors, if any, to the stepwise regression are given with the cumulative correlation coefficient.

[c]NS = no significant regression.

Table 3.7-6. Seasonal and Annual Mean Density and Ash-Free Dry-Weight Biomass Per 0.06 m^2 at Three Depth Strata Defined by Jaccard Similarity Index With Biomass-to-Density Ratio

	Density Number per 0.06 m^2				Biomass g per 0.06 m^2				Biomass: Density			
	Inner	Middle	Outer	Combined[a]	Inner	Middle	Outer	Combined[a]	Inner	Middle	Outer	Combined[a]
Winter	316.4	344.2	63.0	291.8	2.68	2.78	0.37	2.41	0.008	0.008	0.006	0.008
Spring	221.3	461.7	79.8	361.0	1.65	2.72	0.52	2.53	0.007	0.006	0.007	0.007
Summer	172.1	324.5	39.0	244.8	2.77	2.25	0.23	1.91	0.016	0.007	0.006	0.008
Fall	231.0	420.3	82.6	338.0	2.69	3.04	0.34	2.37	0.012	0.007	0.004	0.007
Annual[a]	240.4	372.7	62.4	295.1	2.59	2.65	0.35	2.26	0.011	0.007	0.006	0.007

[a]Combined and annual means were calculated directly from station data to avoid biases caused by unequal station numbers in the various strata and transects. The value presented *cannot* be calculated directly from the summation of stratum and/or transect means.

SECTION 4
DISCUSSION

Benthic macroinfauna of the South Atlantic/Georgia Bight during 1977 were characterized by low density (numbers of individuals) and ash-free dry-weight biomass relative to other continental shelf areas and high species diversity. While some species (i.e., *Spiophanes bombyx*) were present in sufficient numbers to approach dominance at a single station or small group of stations (not necessarily geographically contiguous), community relative abundance was generally quite even, with few species present in disproportionately high numbers in even a single set of replicate samples. Only 18 species (13 polychaetes, 3 amphipods, a cumacean and a caridean shrimp) were present in numbers equal to or greater than 0.2% of the total catch in one or more seasons.

Numbers of individuals and biomass in a particular community may be used as indicators of the general productivity of an ecosystem. It would then seem that the low values determined for the macroinfauna are indicative of low primary productivity and/or of some limitation to the flow of energy through the system. A density front located approximately 20 km offshore in the study area restricts terrigenous organic and inorganic nutrient outflow to the continental shelf region. Gulf Stream intrusions onto the outer regions of the shelf introduce some inorganic nitrogen to the system, but, in general, primary productivity, and, as a consequence, contribution of organic material from the water column to the benthic community are low.

High species diversity and species evenness are frequently indicative of a stable, mature environment that has a large number of ecological niches. Benthic communities associated with such habitats are usually productive. While it is true that a great number of microhabitats are available in an area as broad as the South Atlantic Continental Shelf, the stringent sedimentary regime of the area, low density and biomass, and pronounced seasonal variations in species composition and relative abundance suggest that this area does not represent such a system. It seems more likely that the patchy station-to-station distribution and even replicate sample variability reflect density peaks associated with uneven settling of the meroplanktonic larvae that are characteristic of subtropical benthos (Thorson, 1966). The fauna is composed of species that have a characteristically short generation time [another characteristic of subtropical fauna (Thorson, 1966; Mileikovsky, 1971)] and forms adapted to the sedimentary regime.

The approach used in most benthic ecology studies is to delimit a community by characterizing the species that are dominant and a constant significant component of the faunal assemblage. This concept, which was developed in benthic ecology by Peterson (1918), Thorson (1957), and Sanders (1960), was succinctly summarized by Fager (1963), who defined community as having a structure of recurrent groups of species, forming a part of each other's environment and inhabiting a similar environment. However, Frankenberg and Leiper (1977) pointed out the "open-endedness" of such communities in shallow-water benthic systems of subtropical environments, suggesting that benthos of such systems are more "population dominated" rather than being a community composed of relatively stable densities of dominant species; i.e., population parameters of settlement, recruitment, growth, and mortality are more pronounced and important components of community structure. This premise was represented in the seasonality or temporal variability seen in the composition of the benthic fauna of the South Atlantic Continental Shelf. Thus, seasonal water movement patterns, recruitment, and resulting

emigration/immigration patterns of meroplanktonic larvae produce a faunal assemblage that, while seasonally variable and extremely diverse on the small scale, is discernible as a cohesive assemblage on the broad spatial and temporal scales.

SECTION 5
CONCLUSIONS

A strong demarcation of community assemblages is discernible from the SABP data. Based on depth contour, the inner stations throughout the shelf zone showed marked compositional similarity, and the middle zone throughout the sampling area showed a large measure of similarity, with more minor seasonal subgrouping, probably reflecting settling patterns. The outermost stations did not cluster, even among themselves. This points out the extreme heterogeneity at these stations because of depth, bottom-water temperatures, and sediment composition. There was little latitudinal influence on the benthic faunal assemblage of the Georgia Bight. These results agree with those reported for the meiofauna and foraminifera (Chapters 8 and 9).

The macroinfauna of the Georgia Bight can be characterized as an oligotrophic system having high species diversity but low standing biomass. The probable reason for the benthic biomass impoverishment of this shelf environment are low nutrient input and a relatively unfavorable sedimentary regime. The shelf receives low nutrient input from coastal runoff, because of the existence of a salinity front approximately 20 km offshore. Most suspended materials originating inland from the vast marsh ecosystem remain nearshore within this boundary. Similarly, few inorganic nutrients outwell from the land, so there is low pelagic primary production. Because of these factors, there is little regular local input of food resource into the benthic system. The relatively higher biomass of macrobenthos in the mid-shelf stations might result from intrusion-related biological production. The periodic intrusions of oceanic water along the shelf result in higher primary production in the overlying water column and in benthic microalgae.

Another probable reason for the low macroinfaunal biomass was the unfavorable sedimentary regime, which is typical for most of the mid-shelf region. The shallow depth of the shelf results in pronounced wind-induced and tidal scouring of the sediments; the shelf sediments are generally coarse and well-sorted (Howard et al., 1973), characteristic of unstable, reworked sediment. Most of the macrobenthos found in the study were small, relatively mobile surface forms that can survive in such an environment.

The data base resulting from this program indicates a pristine environment showing no evidence of man-induced alteration. Solid understanding of the natural variability represented by the effect in time of population parameters is therefore of particular interest should future studies wish to detect changes due to offshore effects of oil exploitation.

SECTION 6

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CHAPTER 8

MEIOFAUNA OF SOUTH ATLANTIC/GEORGIA BIGHT

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ABSTRACT

Meiofauna, it has been suggested, is an extremely sensitive indicator of environmental perturbation and thus ideal for monitoring an area subject to potential alteration. In a multidisciplinary study of the outer continental shelf of the South Atlantic (Figure 3.1-3) conducted by Texas Instruments Incorporated, meiofaunal assemblages were described and related to the sediments, depth, and latitude.

Meiofauna density in the study was found to be higher than has been reported for other shelf regions of the world. Marine free-living nematodes comprised 51% of all the meiofaunas, copepods 19.1%, and gastrotrichs 6.7%. Density was highest in midshelf regions and decreased to lowest values at depths greater than 100 m. An inshore density depression was evident south of Charleston where large river inputs apparently reduced meiofauna density. The five dominant families of nematodes and copepods were typical inhabitants of sandy sediment, and no differences were found in "familial" community structure on the shelf. Mystacocarida were regular inhabitants of three sampling stations and thus cannot continue to be classified as typical sandy-beach organisms. Familial identifications limited correlation of faunal density with sediment granulometric parameters and delineation of meiofaunal assemblages. They also limited the value of meiofauna as an indicator of environmental perturbation.

SECTION 1
INTRODUCTION

Although research on meiofauna was ongoing in the early 1900s (Remane, 1933), the term "meiobenthos" (meiofauna) was first coined by Mare (1942) to describe benthic metazoans of intermediate size. They are smaller than animals traditionally called "macrobenthos" but larger than the "microbenthos" (i.e., algae, bacteria, and protozoa).

There is a wide diversity in the habitats of meiofauna. Some are interstitial (moving between the sediment particles), others are burrowing (moving through or displacing sediment particles), while still others have an epibenthic and phytal existence. The meiofauna may be broken down further into: temporary meiobenthos, those which spend only their larval stages as part of the meiobenthos (usually larvae of the macrofauna); permanent meiobenthos, including Rotifera, Gastrotricha, Nematoda, Archiannelida, Tardigrada, Copepoda, Ostracoda, Mystacocarida, Turbellaria, Acarina, Gnathastomulida; and some specialized members of the Hydrozoa, Nemertina, Bryozoa, Gastropoda, Aplacophora, Holothuroidea, Tunicata, Priapulida, Polychaeta, Oligochaeta, and Sipuncula. Despite the broad definition, it is generally accepted that the term meiofauna refers to those metazoans that pass through a 0.5-mm sieve and are retained on a sieve with mesh widths smaller than 0.1 mm.

In recent years, aroused interest in meiofauna has produced an ever-increasing volume of literature. Examination of this literature, however, reveals little data on the quantitative significance of meiofauna in continental-shelf ecosystems. Most benthic research has been centered on macrofauna, probably because of its commercial importance. In fact, Carriker, in his review of benthic ecology (1967), devotes but one subtitle to meiofauna and states that the lack of data is even more "thwarting" now that benthic ecologists recognize more clearly the profound ecological significance of smaller benthic organisms. Even though most benthic research has neglected meiofauna, it has been suggested (Gerlach, 1971, 1978) that it may be responsible for five times the benthic energetics of the macrofauna at any given spot.

On the average, one can expect to find $10^6/m^2$ meiofaunal organisms and a standing-crop dry-weight biomass of between 1 and 2 g/m^2. Obviously, these numbers will vary according to season, latitude, water depth, etc., but they are reasonable approximations of worldwide meiofauna density and biomass (Gerlach, 1978). Numbers and biomass decrease with increasing depth (Thiel, 1975), and the highest values ($2.6 \times 10^7/m^2$) are known to be from intertidal mudflats (R.M. Warwick, personal communication). Values tend to be highest in detritally derived sediments and lowest in clean sands. Nematodes and harpacticoid copepods are usually the two most abundant taxa in all sediments, although another taxon occasionally assumes first or second place (Hogue, 1978).

Certain taxa are restricted to particular sediment types. Burrowing meiofauna tend to dominate sediments where the median particle diameter is less than 125 μm (2.3 ϕ). Interstitial groups, (e.g., Gastrotricha—except one genus, *Musellifer*—and Tardigrada) are excluded from muddy substrates where the interstitial lacunae are closed. Obviously, the converse is true in that a burrowing taxon (e.g., Kinorhyncha, with one exception, *Cateria*) is excluded from the interstitial habitat. For taxa having both interstitial and burrowing representatives (e.g., Nematoda, Copepoda, and Turbellaria), there is a difference in the morphology of mud and sand

dwellers. The sand fauna tends to be slender since it must maneuver through the narrow interstitial openings; the mud fauna, on the other hand, is not restricted to a particular morphology but is generally larger.

Vertically, meiofauna is concentrated in the upper levels of the sediments, decreasing to near zero in the redox potential discontinuity (RPD), although some taxa may remain in the RPD in sandy sediments as true anaerobes (Fenchel and Riedl, 1970). In muddy detrital sediments, 90 to 95% of all the fauna is located in the upper 1 cm of sediment. On sandy beaches, the marine fauna is known to be distributed up to 90 cm or to the depth of the groundwater (McIntyre, 1969). Subtidally, most of the studies indicate that >95% of the fauna is in the upper 7 cm and 60 to 70% in the upper 2 cm (e.g., Wieser, 1960; McIntyre, 1964; Muus, 1967; Tietjen, 1969; Coull, 1970; de Bovee and Soyer, 1974). However, McLachlan et al. (1977) report significant numbers of meiofauna as deep as 30 cm in cores from 27-m water depth and correlate this distribution with oxygen availability in the sediment. They never reached the RPD and, therefore, continued to encounter fauna.

Horizontally, meiofauna exhibits a patchy distribution (Vitiello, 1968; Gray and Rieger, 1971; Hogue, 1978) in sediments that appear to be homogeneous. Small-scale physical variations may be present, and what appears as a homogeneous habitat to the investigator may not be to the meiofauna. The causes of meiofauna patchiness are not known, but several ideas have been put forth. Bush (1966) and Gerlach (1977) suggested that the random placement of a macrofaunal carcass (dead fish, dead crab, etc.) and its subsequent leaking of organic matter may attract meiofauna and thus the patches may be the result of attraction to an organic point source. Others (Gray and Johnson, 1970; Giere, 1975; Lee et al., 1977) suggested that the food of meiofauna (bacteria, microflora) is patchily distributed and that certain "attractive" food sources being so localized then determine the horizontal distribution of meiofauna.

On the southeastern United States continental shelf and slope, five studies (Tietjen, 1971, 1976; Coull, 1972; Coull et al., 1977; Tenor et al., in press) deal with the quantitative ecology of meiofauna and several papers (e.g., Schöpfer-Sterrer, 1969, 1974; Ruppert, 1970; Coull, 1971, 1973a-d; Rieger, 1971, 1976; Ott, 1972; Steerer and Rieger, 1974; Tyler and Rieger, 1975; Bartsch, 1977) deal with taxonomy/systematics of the meiofauna occurring in this region, but there has yet to be a study in the Georgia Embayment as comprehensive, in either time or space, as the one being reported here. It is indeed unfortunate that the previous work on the shelf/slope region of the southeastern United States coast has been scattered over wide regions and time scales, making interinvestigation calibration most impractical, if not impossible.

Of the quantititative studies, Coull (1972) and Tietjen (1971, 1976) reported distinct zonation patterns of meiofauna traversing the shelf, slope, and abyssal plain off the Carolinas. For harpacticoid copepods (Coull, 1972) and nematodes (Tietjen, 1971, 1976), both authors reported a distinct shelf assemblage (<100 m), a slope assemblage (100 to 1,000 m) and an abyssal assemblage (>1,000 m). Neither Coull nor Tietjen could delineate species group assemblages on the shelf, and both concluded that the sandy shelf sediments harbored a homogeneous fauna, at least over the areas that they studied. From their data then, it appeared *a priori* that, in similar sediments at similar depths (their shelf samples were between 21 and 100 m), the Carolina sandy-shelf meiofauna was homogeneous and had no distinct faunal dissimilarity.

Meiofauna, because of small size, rapid generation, etc., has been suggested as an extremely sensitive indicator of environmental perturbation (Coull, 1972; Marcotte and Coull, 1974; Pequegnat, 1975) and, thus, ideal for monitoring an area subject to potential alteration. By first establishing inherent variability, both temporally and spatially, one should be able to adequately detect a perturbational response; and theoretically, the meiofauna provides an excellent assemblage to test such responses. However, if taxonomic identification becomes overwhelming (as it so often does with meiofauna), one is left with only generalities and can describe only major taxonomic trends and associations–which may or may not truly reflect the ongoing community dynamics.

The meiofaunal assemblages (to the level identified) on the continental shelf of the southeastern United States are described as they occurred in the SABP, relating the major trends to available physical correlates. When the lowest identified taxonomic unit is the family (nematodes, copepods) or phylum (gastrotrichs, polychaetes, etc.), the data and thus the subsequent interpretation will be necessarily limited. Obviously, an increased effort to identify at least the major taxa to species is requisite to truly delineating the community dynamics. Even so, this study, although preliminary, provides a much needed descriptive major taxon base for continental-shelf meiofauna.

SECTION 2
METHODS AND MATERIALS

A. FIELD

Sampling for meiofauna was conducted at all 50 stations on the winter and summer cruises and at 25 stations on the spring and summer cruises (Figure 3.8-1). One box core from each site was identified for micro/meiofaunal analyses, and all the meiofaunal box cores coincided in time and location with the replicates for the macroinfaunal community studies.

Three 15-cm cores were taken from a box core from each station and split immediately into three 5-cm subfractions (0 to 5 cm, 5 to 10 cm, and 10 to 15 cm). Each 5-cm length of sediment was placed in a separate sampling jar to which rose bengal (a vital stain that aids in distinguishing meiofauna from sediment in subsequent sorting) in 10% buffered formalin had been added and appropriately labeled. The preserved samples were shipped to TI's aquatic processing laboratory in Dallas for sorting, identification, and enumeration.

B. LABORATORY

In the laboratory, the meiofauna in each fraction of each core was extracted using the shaking-supernatant (elutriation) technique of Wieser (1960). The supernatant was poured through sieves with mesh widths of 0.5 mm and 0.062 mm to concentrate the meiofauna. Elutriation was done three times per sample to ensure adequate extraction (Tietjen, 1969; Coull, 1970) and the residue remaining on the two sieves then washed into finger bowls. The residue on the 0.5-mm sieve was examined under a dissecting microscope, and any meiofauna organisms that remained were picked out and identified. Since meiofauna was operationally defined as benthic metazoans passing through a 0.5-mm sieve, those remaining on this larger sieve were not numerous and were primarily those that had become entangled.

The fauna from the 0.063-mm fraction was taken from the finger bowls in aliquots and placed in counting dishes. Using as many aliquots as necessary, all the sediment/organism mixture from the finger bowl was examined. Each organism was enumerated, picked out, and identified to major taxon (e.g., Nematoda, Copepoda, Polychaeta). Subsequently, subsamples of at least 100 nematodes (Dr. J.H. Tietjen directed these identifications) and at least 100 harpacticoid copepods from each station were identified to family (Dr. B.C. Coull directed these identifications). This subsampling permitted the statistically valid characterization of the dominant components of the meiofaunal community while reducing the total number of analyses to a manageable level.

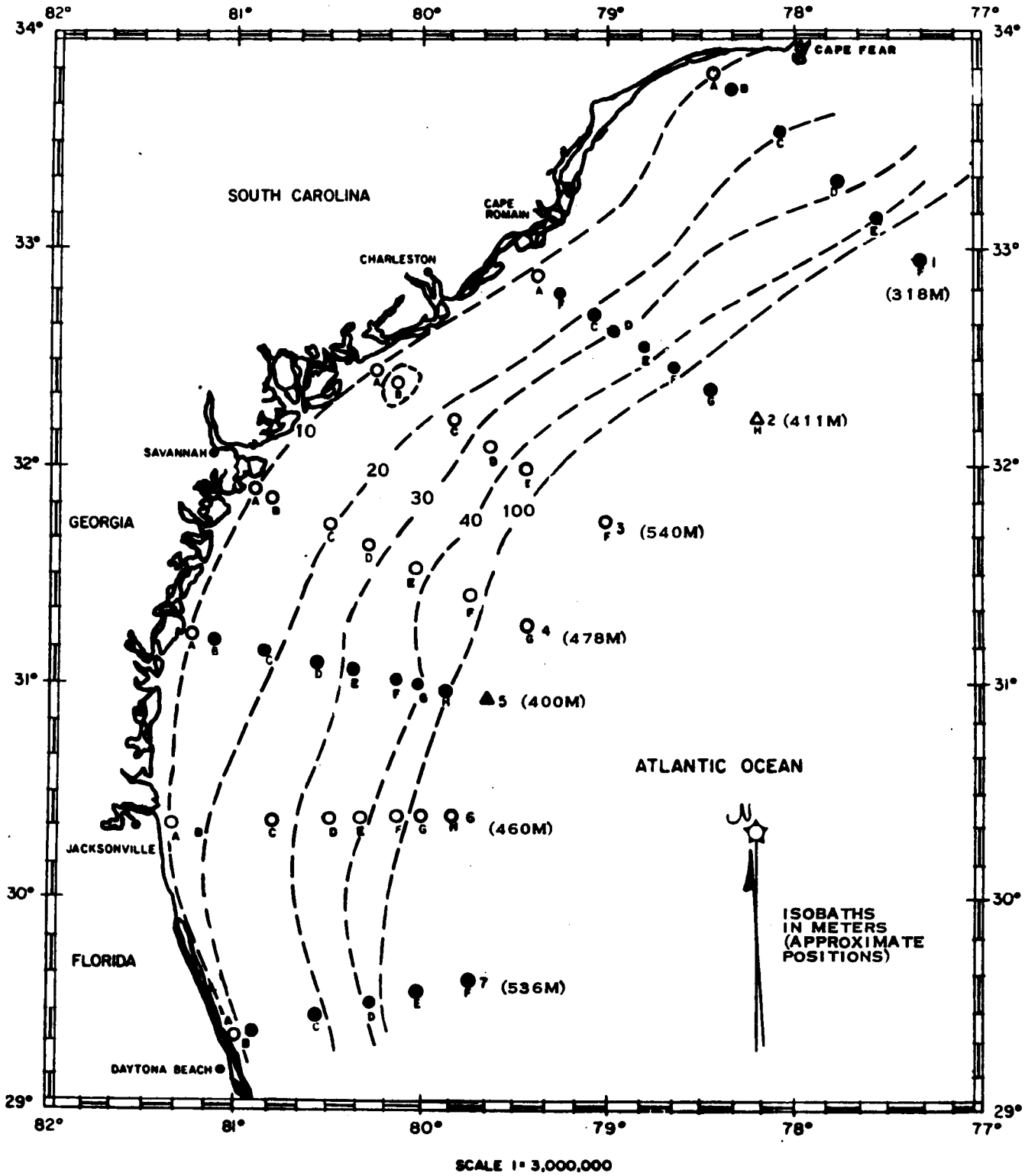
C. DATA ANALYSIS

All values reported have been converted to the standard meiofauna unit of number per 10 cm^2 (Hulings and Gray, 1971). The 44 dominant families of the two most abundant taxa (nematodes, 30 families; copepods, 14 families) were clustered (Appendix 3.8A in Volume 6) using the Morisita clustering technique (described in Volume 2) for similarity at each season as an exploratory technique to discern any potential meiofauna zonation patterns. Using these same 44 families and total meiofauna, Kendall's tau correlation coefficients and multiple correlations (Appendix 3.8B in Volume 6) were calculated against five physical variables: sediment median

diameter, sediment sorting, total sediment organic carbon, depth, and latitude. Green's index (Elliott, 1971) of spatial dispersion:

$$\left(\frac{S^2/\bar{x} - 1}{\Sigma x - 1}\right)$$

where S^2 = variance, $\bar{x}$ = mean number of animals of the three replicate samples, and x = number of animals in each replicate, was calculated for the 44 dominant families and total meiofauna at each station occupied. Green's index values of 0, >1, and <1 indicate a random distribution, clumped (patchy) distribution, and uniform distribution, respectively.



● STATIONS SAMPLED, ALL FOUR SEASONS

○ STATIONS SAMPLED, WINTER AND SUMMER

Figure 3.8-1. Stations Sampled for Meiofauna

SECTION 3
RESULTS

Marine free-living Nematoda was the dominant taxon encountered (Figures 3.8-2 through 3.8-5). Overall, nematodes comprised 51.0% of the total meiofauna (all stations, all seasons). Copepod (>90% harpacticoids) was the second most abundant taxon, comprising 19.1% of the total meiofauna; they were more abundant than nematodes on only eight occasions–stations 2B and 5C during the spring (Figure 3.8-3) and stations 2B, 2C, 3C, 4C, 5C, and 6B during the summer (Figure 3.8-4). Gastrotricha, the third most abundant taxon, was responsible for 6.7% of the total meiofauna density. Representatives of all the meiobenthic groups listed in Section 1 of this chapter were encountered, but only once in 145 sets of samples did a taxon other than Nematoda, Copepoda, or Gastrotricha dominate; that taxon was Oligochaeta at station 7F in the summer.

While analysis of sample fractions by depth below the sediment surface indicated that the meiofauna in areas of deep, medium- and coarse-grained sands inhabited deeper strata than had been previously reported, the increased depth of specimens in sediments was slight and only Nematoda were found below the upper 5 cm of sediments. It is assumed that presence of nematodes below 5 cm in sediments was a function of the subsampling procedure which allowed residual water in the large box cores to drain through the sand after the majority of surface water retained in the box was removed with a suction bulb. This drainage might have washed the worms into deeper strata or they might have actively sought areas of greater moisture as the water drained away from them, thus appearing in strata below their normal area of habitation. The combined data of the depth strata have been used for further analyses to assure the inclusion of all specimens in the assessment.

Total meiofauna density (all taxa–$\bar{x}$ of three replicate cores) ranged from seven (station 7F, fall) to 2,645/10 cm^2 over the study stations and time period, with a mean shelf (<100 m) value of 957/10 cm^2 and a mean of 364/10 cm^2 in depths >100 m. Total meiofauna densities, of course, reflected the density fluctuations of the major taxa and, overall, indicated highest densities in midshelf regions and on the more northern transects, decreasing to lowest values at the >100-m stations. In all seasons, meiofaunal densities peaked at stations deeper than >20 m (except transect 1, Figure 3.8-4, and transect 1, Figure 3.8-5). Figure 3.8-6 schematically illustrates the meiofaunal density trends combining all seasons at a particular station. The overall trends reflect the seasonal data (Figures 3.8-2 through 3.8-5), illustrating both an offshore and latitudinal decrease in meiofaunal density, with peak densities primarily on the midshelf south of Charleston. Seasonally, total meiofauna density on the transects occupied each season was lowest in the spring (Figure 3.8-7). All transects appeared to have fluctuations of about the same order of magnitude.

Although trends appear evident from the schematics, multiple regression of total meiofauna density (all seasons, all stations combined) and five physical variables (sediment median grain size, sediment sorting, total organic carbon, depth, and latitude) provides an r^2 value of only 0.015, indicating that very little of the observed variation is explained by these five parameters. Of all the variables, depth explains the most variation (PR > T = 0.27). Using Kendall's tau by season, there is always a significant ($p \geqslant 0.001$) negative correlation between total meiofauna density and depth. There is no significant or consistent pattern with the other variables.

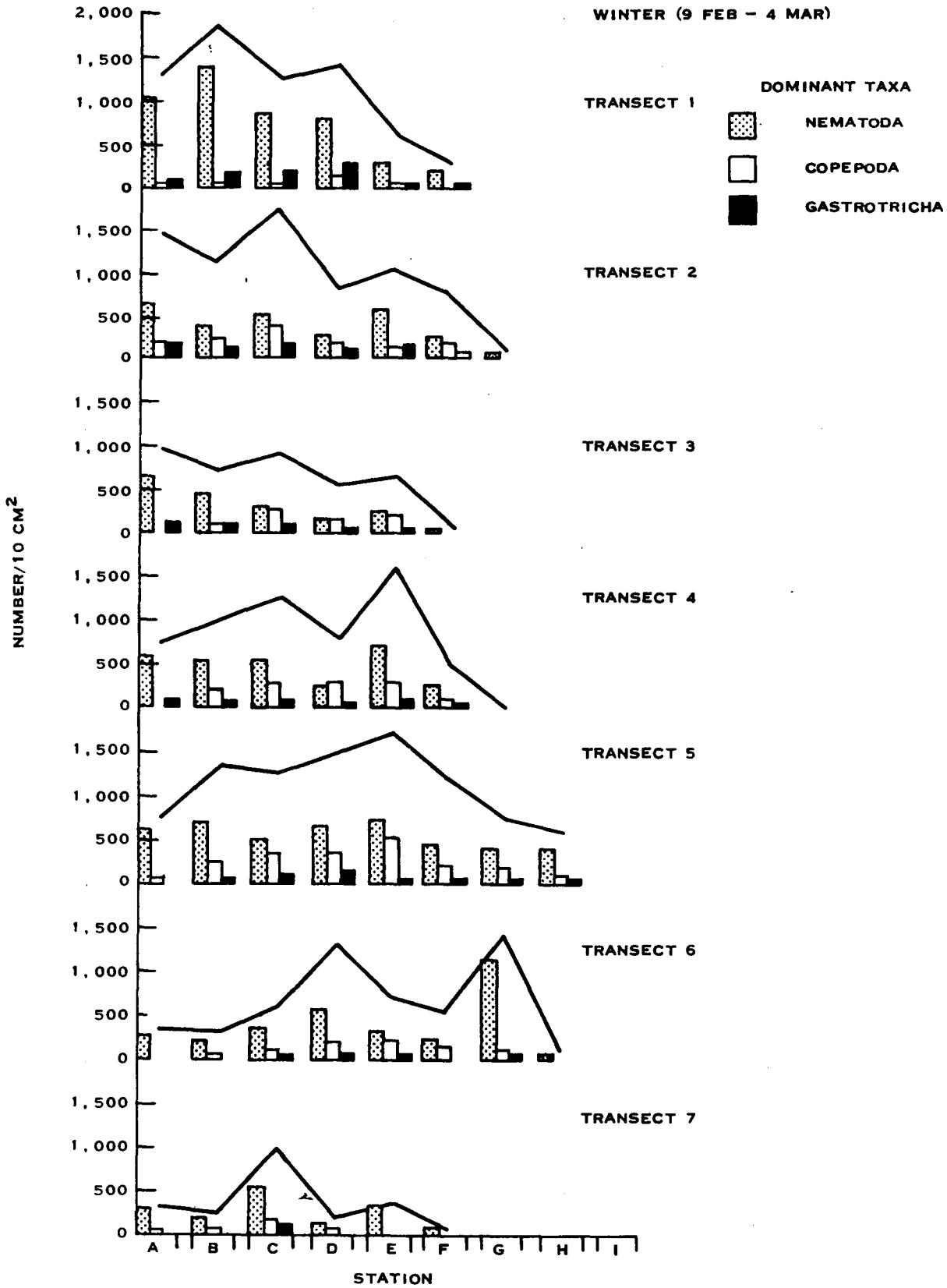


Figure 3.8-2. Mean Total Numbers of Meiofauna (Solid Line) and Dominant Taxa (Histograms), Winter 1977

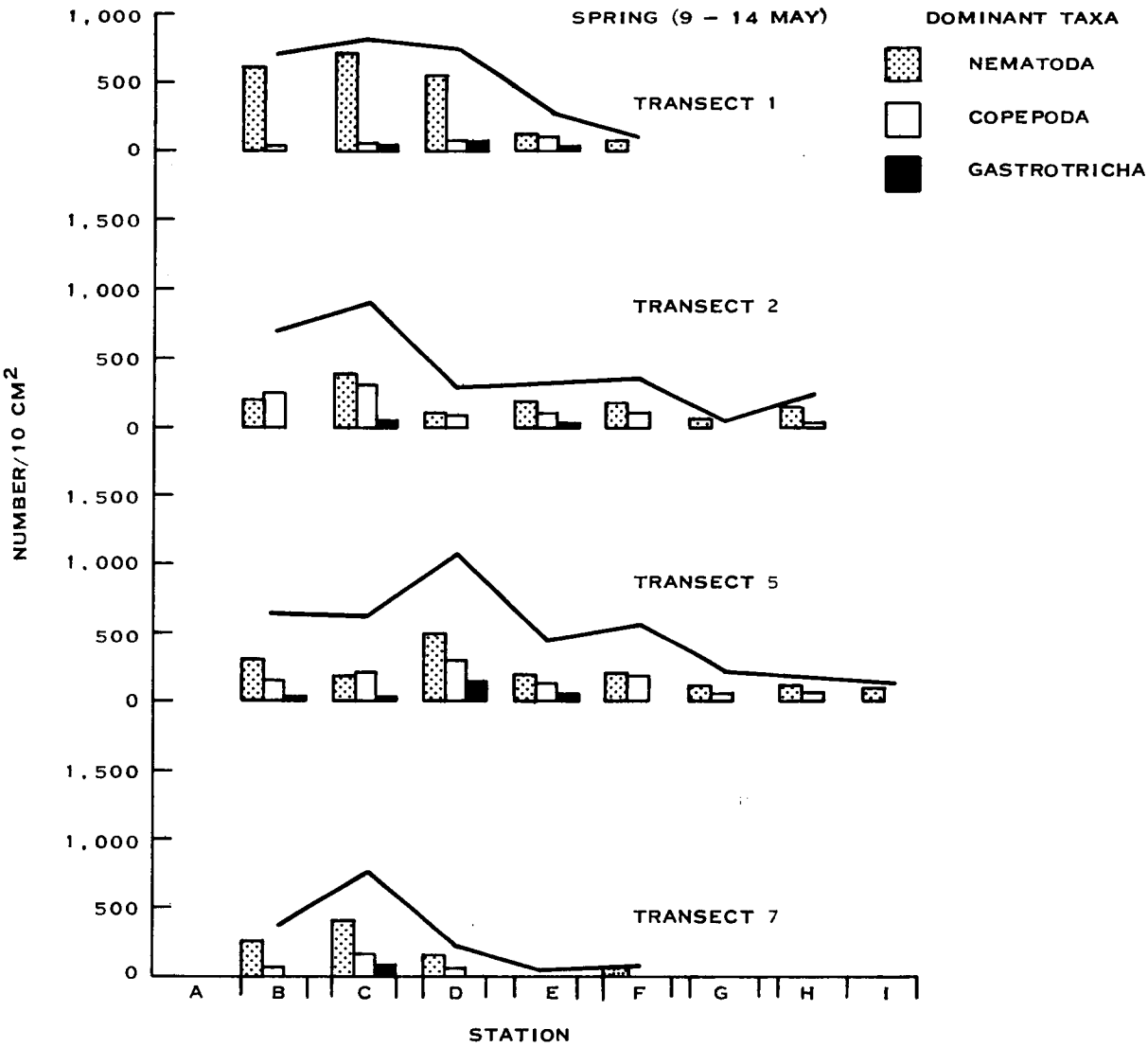


Figure 3.8-3. Mean Total Numbers of Meiofauna (Solid Line) and Dominant Taxa (Histograms), Spring 1977

As expected within stations (i.e., between replicates), total meiofauna density was always patchy. Of the 145 sets of Green's index values, only four indicated a uniform distribution and none a random distribution.

The study encountered 34 families of marine free-living nematodes; five families (Desmodoridae, Monohysteridae, Chromadoridae, Cyatholaimidae, Ceramonematidae, listed in order of overall abundance) accounted for 38% of all the nematodes. These five families are listed, along with their densities (mean of three replicate samples) at each station occupied quarterly, in Table 3.8-1. Again using the multiple correlation, there is a consistent negative correlation ($p \geqslant 0.05$) of the five nematode families with depth, and four of the five (excluding Chromadoridae) are negatively correlated with latitude. Kendall's tau also indicates the same trends but no consistent negative or positive correlations with any other parameters. Table 3.8-1

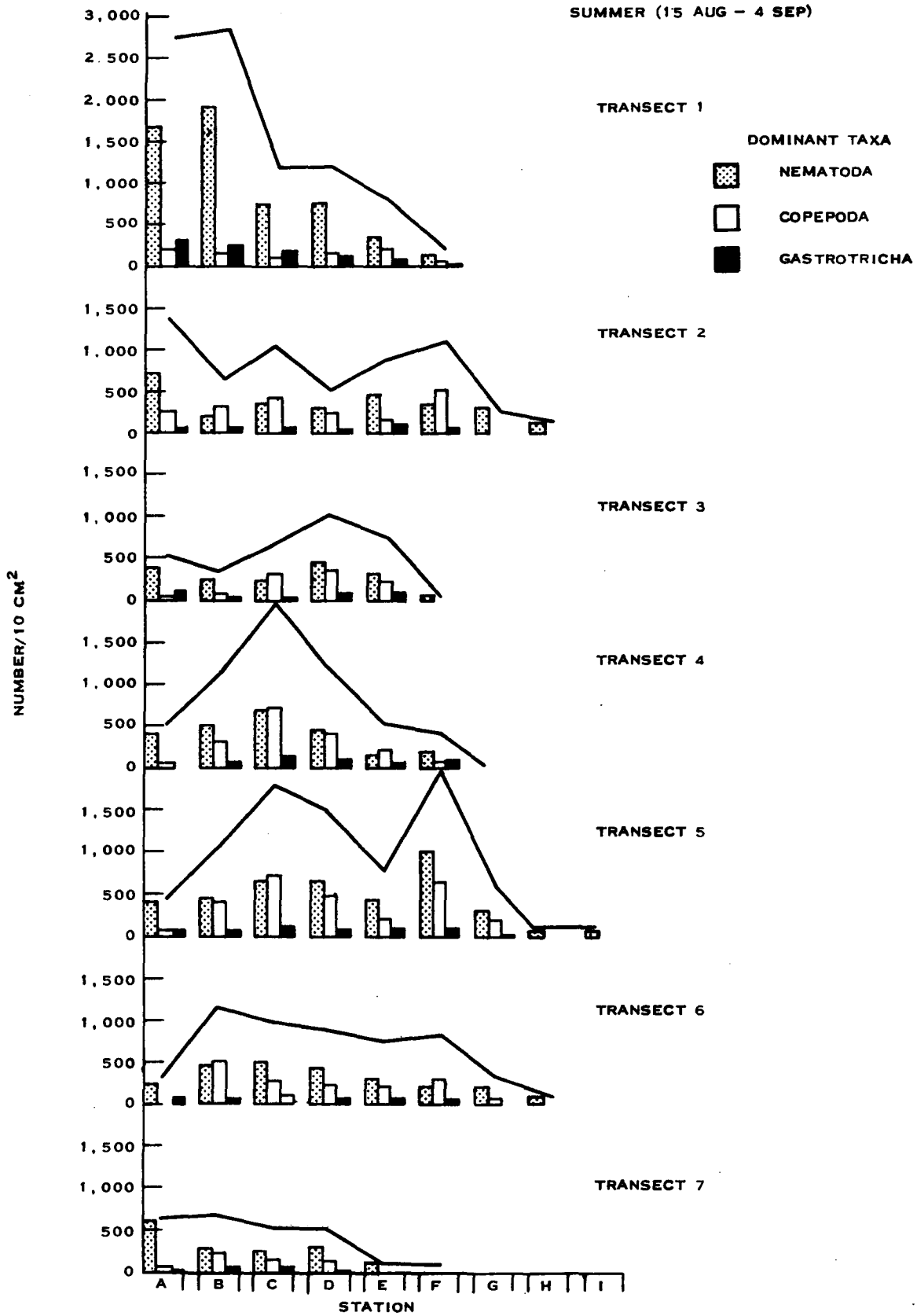


Figure 3.8-4. Mean Total Numbers of Meiofauna (Solid Line) and Dominant Taxa (Histograms), Summer 1977

Table 3.8-1. Mean Numbers/10 cm² (of Three Replicate Cores) of Five Dominant Nematode Families on Four Transects (1, 2, 5, 7) Occupied Quarterly

	Desmodoridae				Monhysteridae				Chromadoridae				Cyatholaimidae				Ceramonematidae			
Station	W[a]	Sp	Su	F	W	Sp	Su	F	W	Sp	Su	F	W	Sp	Su	F	W	Sp	S	F
1A	139		410		259		293		101		46		117		172		44		147	
1B	119	74	355	188	304	100	232	177	166	53	249	96	187	76	282	61	118	48	216	80
1C	139	85	167	217	139	113	131	182	82	58	73	160	63	65	81	78	94	97	61	122
1D	160	98	185	55	117	39	118	25	57	73	67	33	118	69	73	24	63	30	58	24
1E	99	30	45	54	62	17	67	52	28	15	32	35	37	13	47	16	16	8	25	23
1F	65	11	27	25	29	9	24	22	12	5	8	7	10	1	8	3	4	1	7	3
$\bar{X}$	120	60	200	108	151	55	144	92	74	41	79	68	88	42	110	37	57	37	86	51
2A	148		137		112		157		75		89		48		29		12		19	
2B	67	14	20	44	37	30	27	12	62	39	56	43	12	6	8	6	4	2	1	2
2C	88	64	60	141	96	47	69	94	48	35	53	60	58	22	13	31	26	30	19	16
2D	45	17	40	44	43	12	37	40	46	26	165	72	24	4	18	26	16	1	9	8
2E	132	32	110	72	62	19	73	50	67	24	45	40	44	14	26	44	22	9	18	23
2F	22	34	35	41	45	26	79	21	54	22	59	22	12	9	14	7	10	3	5	5
2G	5	3	35	3	14	2	43	8	3	0	24	6	1	2	10	0	0	2	6	0
2H		21	18			17	18			6	0			9	10			3	0	
$\bar{X}$	74	26	57	58	58	22	63	38	52	22	49	40	28	10	16	19	13	7	10	9
5A	33		19		295		115		33		59		10		10		3		10	
5B	175	39	108	107	105	36	90	46	77	25	50	83	41	17	24	63	30	7	14	20
5C	82	29	59	87	60	16	96	73	87	29	95	102	15	10	24	24	12	2	10	20
5D	156	76	117	111	126	192	130	180	86	18	92	141	33	10	30	95	39	31	33	47
5E	106	34	77	83	213	31	81	104	117	23	74	87	58	16	22	30	29	9	18	29
5F	133	37	195	233	99	46	156	92	75	35	175	77	18	13	63	44	12	3	14	16
5G	116	18	89	267	61	15	53	121	69	9	48	85	19	7	10	54	15	8	10	24
5H	78	14	3	39	65	18	5	27	53	10	8	16	3	5	4	10	19	5	3	5
5I		12	10	2		11	8	4		8	8	1		3	1	1		2	1	0
$\bar{X}$	110	32	75	116	128	45	82	81	75	20	68	74	24	10	21	40	20	8	3	20
7A	7		12		52		206		33		60		2		10		0		0	
7B	41	62	63	118	32	47	41	113	43	23	33	42	14	20	16	24	5	20	14	12
7C	122	88	33	109	90	61	24	121	107	51	56	53	53	28	23	41	20	20	8	17
7D	20	26	54	27	16	9	26	33	16	8	50	54	9	7	1	14	5	5	14	5
7E	45	2	7	33	50	5	27	32	20	1	3	7	20	0	0	8	1	0	0	1
7F	9	2	0	0	3	10	0	2	1	1	0	0	6	0	0	1	1	1	0	0
$\bar{X}$	41	36	28	58	40	26	54	60	37	9	34	31	17	11	10	18	5	9	6	7

[a]W = winter; Sp = spring; Su = summer; F = fall.

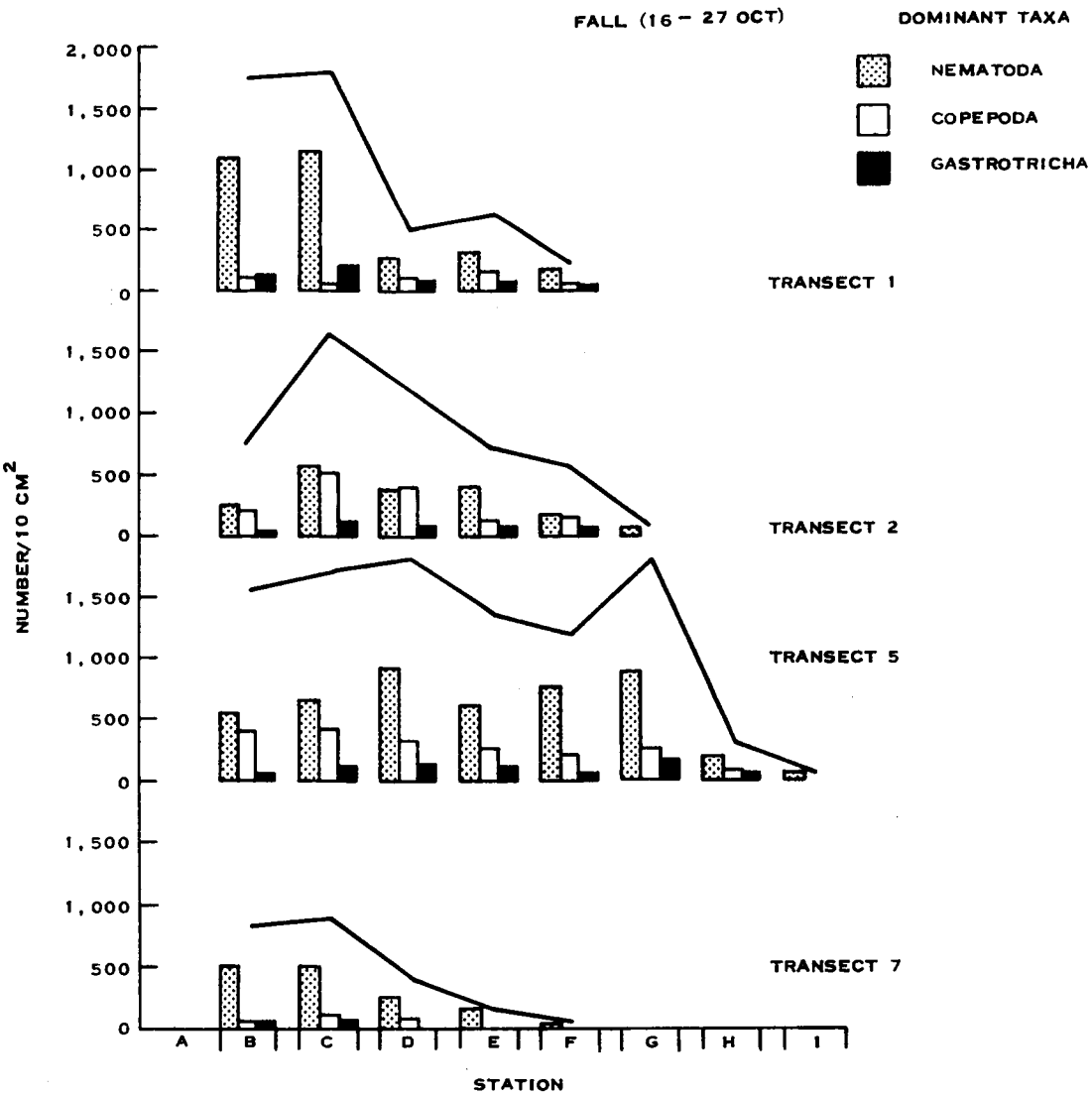


Figure 3.8-5. Mean Total Numbers of Meiofauna (Solid Line) and Dominant Taxa (Histograms), Fall 1977

also indicates the decrease in numbers of these five dominant families with depth and latitude. Tietjen (1976) reported that the sandy-shelf sediments off the Carolinas between 50 and 250 m were dominated by Desmodoridae, Chromadoridae, Ceramonematidae, and Enopolidae–and indeed three of these families (Desmodoridae, Chromadoridae, Ceramonematidae) are dominant in the SABP study. Tietjen's other dominant family (Enopolidae) is sixth in the SABP, and Tietjen's fifth and sixth (1976, Figure 1) are second and fourth in the SABP.

The five dominant harpacticoid copepod families (Diosaccidae, Paramesochridae, Cylindropsyllidae, Ameiridae, Ectinosomitidae) and their mean densities are presented in Table 3.8-2. Again, there is a consistent decrease with depth and latitude and both Kendall's tau ($p \geqslant 0.05$) and multiple regression point to these as the consistent factors in density changes. In 15 of the 20 cases (five families, four seasons), total organic carbon is also negatively correlated with

Table 3.8-2. Mean Numbers/10 cm² (of Three Replicate Cores) of Five Dominant Harpacticoid Copepod Families on Four Transects (1, 2, 5, 7) Occupied Quarterly

	Diosaccidae				Paramesochridae				Cylindropsyllidae				Ameiridae				Ectinosomidae			
Station	W	Sp	Su	F	W	Sp	Su	F	W	Sp	Su	F	W	Sp	Su	F	W	Sp	Su	F
1A	0		47		36		20		4		37		1		8		0		7	
1B	1	0	25	12	23	6	12	6	20	7	22	14	1	0	4	2	5	2	9	7
1C	2	1	9	7	11	9	5	3	11	5	8	6	0	1	4	1	5	1	3	3
1D	34	10	50	16	19	8	24	5	37	12	24	30	10	1	5	5	3	0	0	1
1E	16	15	83	31	10	8	15	10	10	2	5	7	1	8	10	10	1	1	5	5
1F	4	1	6	3	1	2	3	3	1	0	1	0	0	0	1	2	1	0	0	0
$\bar{X}$	10	5	37	14	17	6	13	6	14	5	16	11	2	2	5	4	3	1	4	3
2A	58		31		22		26		62		120		11		19		10		16	
2B	58	19	37	31	24	16	33	20	34	17	26	12	34	77	43	19	20	11	18	17
2C	76	51	110	166	45	53	37	50	51	89	35	56	36	23	42	24	34	15	14	5
2D	38	20	58	34	18	11	20	28	10	3	8	13	21	7	17	29	15	6	14	20
2E	36	12	27	31	20	10	41	16	12	8	14	12	8	6	6	10	3	4	5	4
2F	46	12	76	40	22	6	59	18	10	3	73	7	18	11	59	14	7	2	17	8
2G	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	1
2H		2	0			1	0			0	0			5	0			2	0	
$\bar{X}$	43	17	42	67	22	14	26	21	26	17	34	17	18	19	23	16	13	6	11	9
5A	0		6		0		0		0		0		0		0		21		14	
5B	64	24	57	100	31	25	59	44	40	15	89	35	20	15	60	24	20	8	22	33
5C	63	24	174	99	59	22	39	24	54	19	90	44	20	21	103	62	16	8	29	7
5D	29	11	151	33	48	127	24	65	58	60	58	41	48	12	35	34	12	5	17	18
5E	99	18	55	41	31	10	13	32	118	19	27	18	46	17	17	35	38	5	8	12
5F	55	43	229	35	21	9	22	26	12	11	41	23	12	24	22	22	21	13	33	6
5G	33	9	71	79	8	2	5	3	14	4	12	14	16	6	22	22	20	4	12	18
5H	9	5	0	11	10	4	0	4	5	2	0	2	7	6	0	1	13	3	1	4
5I		0	1	1		0	0	0		0	0	0		0	1	0		0	1	1
$\bar{X}$	44	17	83	50	26	25	18	25	37	16	35	22	21	13	29	25	20	6	15	12
7A	1		13		0		0		0		1		6		7		6		8	
7B	4	6	50	11	10	5	2	3	2	9	3	3	2	4	3	1	6	8	22	5
7C	19	21	63	32	23	10	7	10	22	20	3	12	16	26	16	8	12	9	5	4
7D	13	7	32	14	5	0	7	1	0	0	1	0	4	3	3	2	8	3	15	5
7E	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0
7F	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$\bar{X}$	6	7	26	11	7	3	3	3	4	6	1	3	5	7	5	2	6	4	8	3

[a]W = winter; Sp = spring; Su = summer; F = fall.

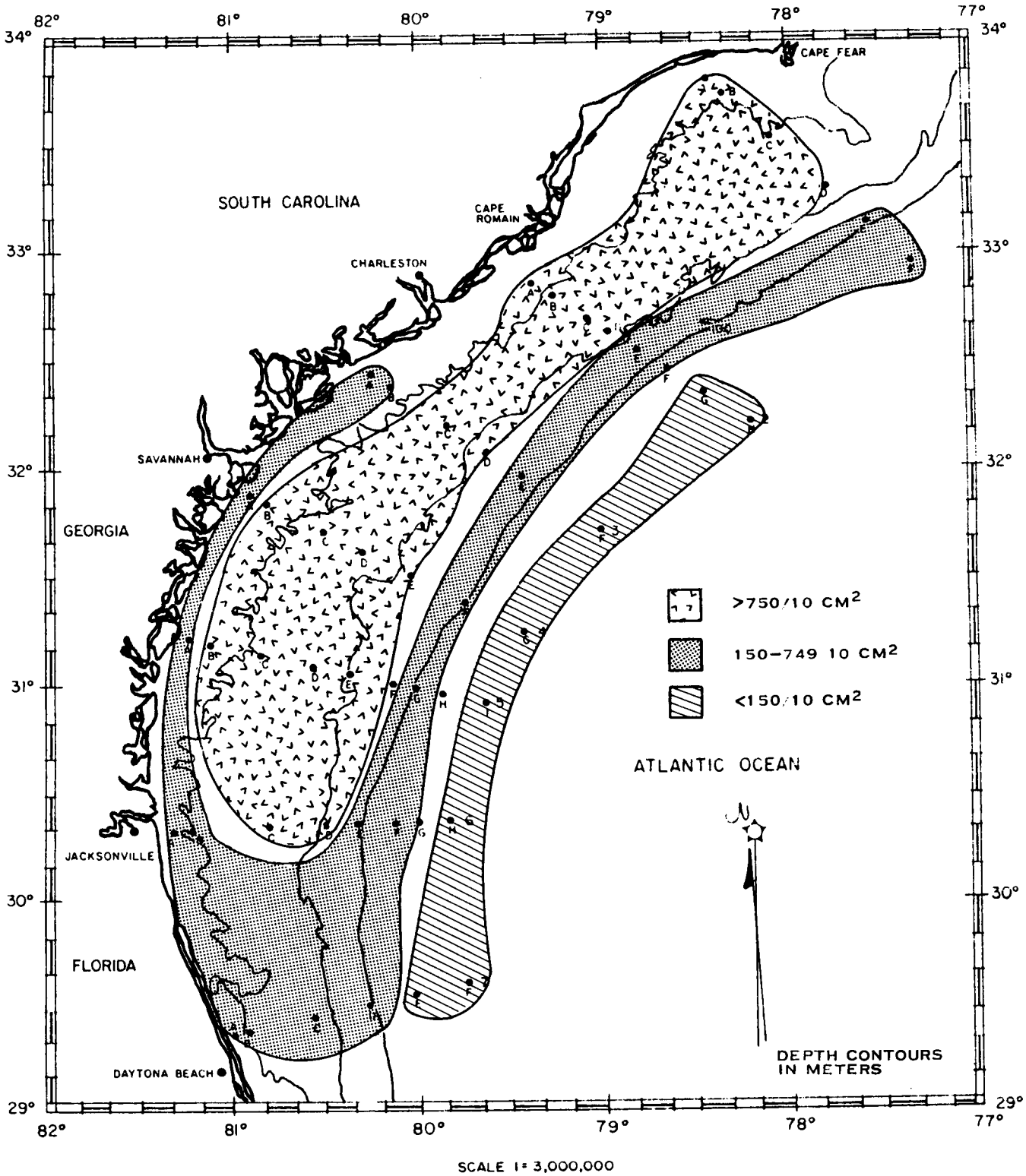


Figure 3.8-6. Distribution of Mean Total Meiofauna Destiny, All Seasons Combined

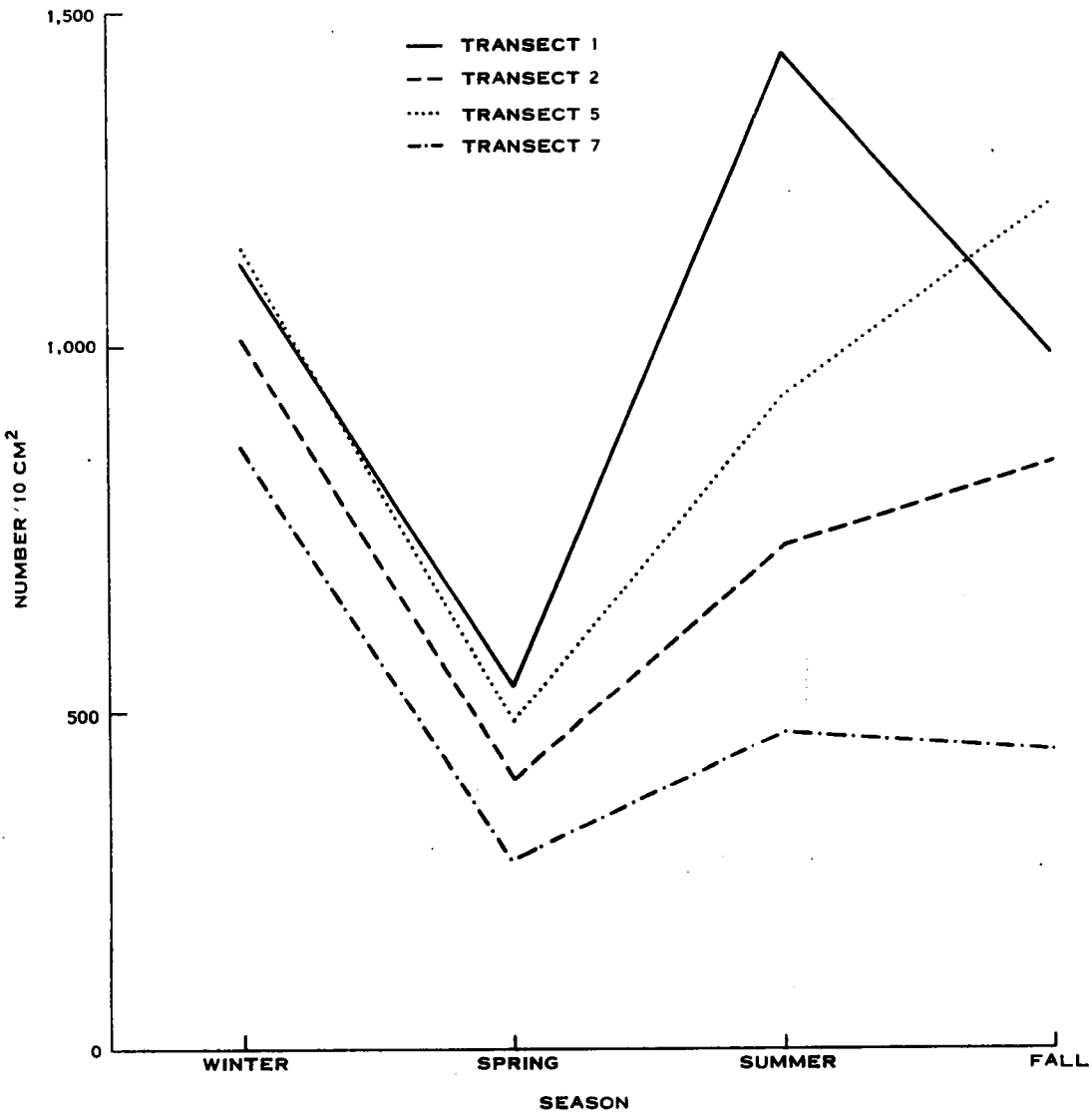


Figure 3.8-7. Mean Total Meiofauna Densities for Four Transects Sampled Each Season (Values represent means over an entire transect for a particular season)

copepod density. Coull (1971) also found these five families to dominate the sandy-shelf area off the Carolinas.

Only depth gave a reasonable number of significant correlations when the most abundant 44 families of nematodes and copepods in each season were used. There was never a significant positive correlation with depth; and of 44 potential correlations with each season, depth, and family, density was significantly correlated with 13 families in winter, 16 in spring, 23 in summer, and 16 in the fall. There were no more than six significant correlations with any other variable during any season.

Using the same 44 families of nematodes and copepods as in the multiple regressions and Kendall's tau analysis, stations were clustered at >60% similarity for each season. Figures 3.8-8 and 3.8-9 illustrate the resultant station groups using 50 stations from the summer cruise (Figure 3.8-8) and using 25 stations from the fall cruise (Figure 3.8-9).

A surprise in the SABP meiofauna sampling was the irregular occurrence of members of the crustacean subclass Mystacocarida, which traditionally inhabits sandy, intertidal beaches. Table 3.8-3 lists the number and location of mystacocarid captures during the study. Only recently have mystacocarids been reported subtidally (Renaud-Mornant and Deboutteville, 1976; Rieger and Ruppert, 1978) so their abundance on the southeastern U.S. outer continental shelf was unexpected.

Table 3.8-3. Density of Crustacean Subclass Mystacocarida on Southeastern Continental Shelf

		Density (Number/10 cm²)			
Station	Sediment (ϕ, median diameter)	Winter	Spring	Summer	Fall
2F	0.7–1.0	1		1	
3E	1.1–1.2	1		1	
4C	1.0–1.1	15		16	
5C	1.0–1.2	10	5	6	
5D	1.3–1.4	9	4	8	
5H	1.4				1
7D	0.9			2	

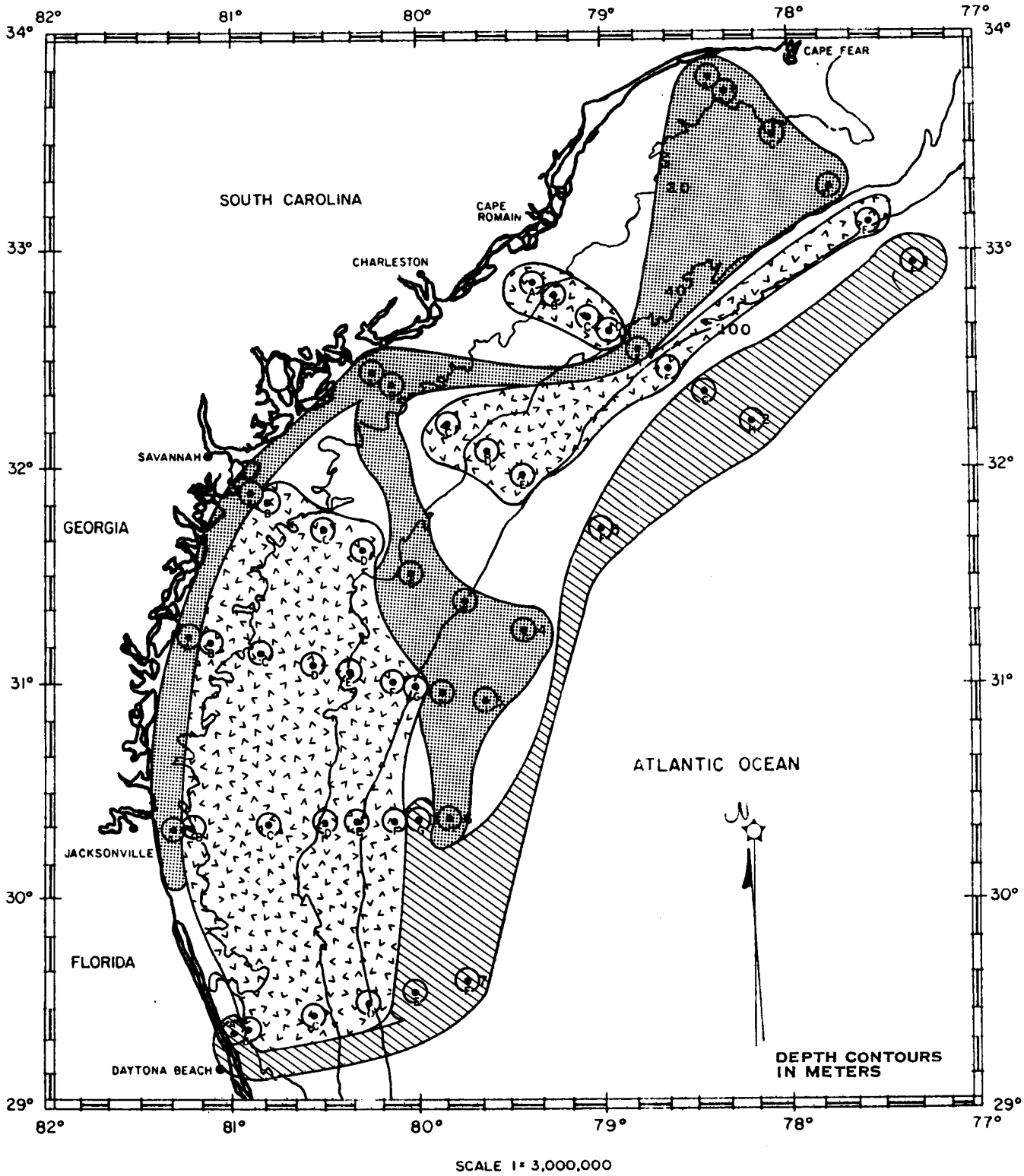


Figure 3.8-8. Similarity, Summer (15 August–4 September) 1977, Based on Morisita Clustering at >60%. (Clustering based on 44 dominant families: 30 nematode families, 14 copepod families. Clusters are connected for visual ease and do not imply that areas between stations are identical)

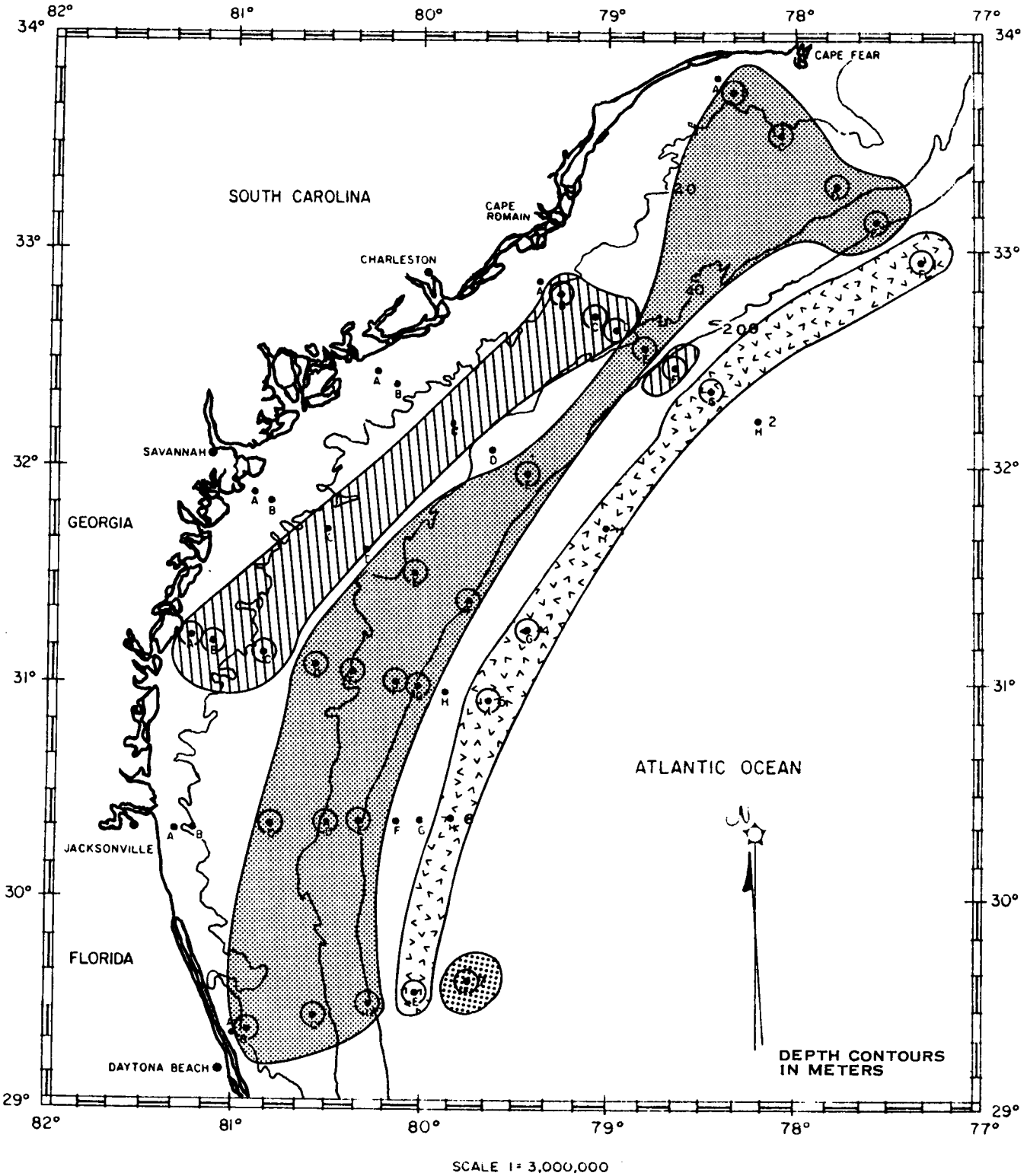


Figure 3.8-9. Similarity, Fall (16–27 October) 1977, Based on Morisita Clustering at >60%. (Clustering based on 44 dominant families: 30 nematode families, 14 copepod families. Clusters are connected for visual ease and do not imply that areas between stations are identical.)

SECTION 4
DISCUSSION

The total meiofaunal density values shown in Figures 3.8-2 through 3.8-6 were slightly higher than values for other continental-shelf ecosystems. Tietjen (1971) found 352 to 849/10 cm^2 off the Carolinas; Wigley and McIntyre (1964) found 127 to 988/10 cm^2 on the shelf off southern New England; and the Baltimore Canyon OCS study reported 59 to 704/10 cm^2 (D.J. Hartzband, personal communication). The SABP mean value of 957/10 cm^2 for the shelf represented increased values on the midshelf region (Figure 3.8-6) and, most likely, the more comprehensive sampling over so much of the shelf. The decrease in numbers off the shelf was consistent with other slope studies, and the mean value of 364/10 cm^2 in waters deeper than 100 m agreed with the Wigley and McIntyre (1964) values of 117 to 537 off New England, Tietjen (1971) values of 40 to 1,174 off the Carolinas, and Coull et al. (1977) values of 217 to 1,138/10 cm^2 on the slope off the Carolinas at 400 and 800 m.

Within the SABP sampling scheme, the general decrease with depth was as predicted and known from other meiofaunal studies (Thiel, 1975). Intriguing, however, were the low densities inshore with the density maxima on the midshelf (Figures 3.8-2 through 3.8-5). From the overall data, the trend is particularly evident south of Charleston (Figure 3.8-6) where river runoff is significant. Thus, coastal influence (runoff, silts, etc.) appears to be responsible for lower meiofaunal densities. The increased suspended sediment load of coastal waters may well reduce benthic algal production to the point where meiofaunal densities are also decreased. The large inputs from the Cooper, Savannah, Altamaha, and St. Johns Rivers make this trend particularly evident south of Charleston. Offshore (midshelf) regions are beyond the influence of these sediment sources and thus have the higher meiofaunal densities.

The general latitudinal decrease in density (Figure 3.8-6) is most likely a function of decreased food reserves (caused by the higher metabolic rate with increased temperature) and the strong correlation of respiration (maintenance) and temperature. In areas of increased temperature, much more of the energy consumed by the fauna must go to maintenance; thus, total densities are lower. Coull (1970) in Bermuda and Renaud (1955) in the Bahamas both reported low meiofaunal densities attributable to low food availability. The data from the present survey are in agreement with these previous studies in that the meiofauna at the lower latitudes was also reduced.

Since meiofaunal densities were lowest in the spring on each transect occupied quarterly (Figure 3.8-7), it appears that summer through late fall is the period of maximum reproductive activity for the SABP meiofauna. Since recruitment from other regions is unlikely (meiofauna larvae are not pelagic), the low spring densities most likely reflect the remains of the overwintering assemblage, and the winter peak reflects the resultant populations of the fall reproductive activity. Even in shallow estuarine waters of South Carolina (Coull, unpublished), reproductive activity is greatest from late spring through fall (reaching maximum abundance in fall-winter), and the shelf assemblages appear to follow the same general reproductive patterns.

Most meiofaunal studies have been able to correlate meiofaunal density and sediment granulometric parameters. The absence of such correlations on the SABP is indicative of the rather homogeneous distribution of meiofauna and sediments on the southeastern Atlantic shelf.

There is no doubt that the faunal assemblages (based on the dominant nematode and copepod families, Tables 3.8-1 and 3.8-2) are typical of medium- to coarse-grained sand habitats. It is not coincidental that the dominant nematode and copepod families that were collected were the same as those reported by Tietjen (1976) and Coull (1971) from Carolina sandy shelf sediments. They are regular interstitial inhabitants of sandy habitats; in fact, of the harpacticoid families (Table 3.8-2), the Paramesochridae (second-ranked) and Cylindropsyllidae (third-ranked) are restricted to the interstitial habitat, the Ameiridae (fourth-ranked) are predominantly interstitial, and the Diosaccidae (first) and Ectinosomitidae (fifth) have representatives in all soft-bottom habitats (i.e., at the family level—"jacks of all sediments"). The requirements of an interstitial existence are obviously the reason that these copepod families negatively correlated with total organic carbon in 15 of 20 cases. TOC tends to be highest in fine sediments where truly interstitial residents do not occur (the fine material blocks the interstices)—thus, the expected finding of dominance by interstitial and not burrowing families.

The low number of significant correlations between density and community composition and sediment granulometric parameters is believed to be a function of taxonomic identification level and similarity of sediment types. There may well have been species correlations but they could not be delineated at the familial level.

The clustering of the nematode and copepod families to elucidate zonation patterns was also limited by the level of taxonomic identifications. The one season with few stations (Figure 3.8-9) shows distinct faunal zones; yet, when more data (stations) are available (Figure 3.8-8), the pattern becomes more muddled. Clustering at the familial level is deceiving. While the family patterns may provide us with broad generalizations (e.g., the five dominant nematode and copepod families are sandy-sediment inhabitants), they do not allow more detailed interpretation of the community patterns.

The occurrence of the traditionally intertidal crustacean subclass Mystacocarida on the shelf appears to be a persistent phenomenon at stations 4C, 5C, and 5D (Table 3.8-3). Rieger and Ruppert (1978) reported a population of *Derocheilocaris* sp. at 22 m near SABP station 1E, and now the repeated findings in the SABP certainly indicate the ability of these animals to live and flourish subtidally. Rieger and Ruppert (1978) reported that their population inhabited coarse-shell gravel; although the SABP animals are in relatively coarse sand (Table 3.8-1), it is not shell gravel.

This first analysis of southeastern OCS meiofauna has provided a general overview of faunal densities, taxon and family dominance, and seasonality, but further studies of community structure on the species level are necessary if the role of meiofauna in the South Atlantic OCS is to be clearly defined.

SECTION 5
CONCLUSIONS

- Marine free-living nematodes were the dominant taxon, harpacticoid copepods were second, and gastrotrichs were third.
- Meiofaunal density was greatest in midshelf regions and lowest at depths of >100 m. Mean total meiofauna density on the shelf was 957/10 cm^2 and 364/10 cm^2 at depths > 100 m. These density values are higher than those previously reported.
- The depression in density near shore, particularly south of Charleston, was most likely caused by the large volume of river runoff in the southern portions of the study area and the suspected low benthic diatom production.
- Density decreased with latitude.
- Mystacocarids, typically intertidal sandy-beach crustaceans, were regular inhabitants of three stations; thus, the order cannot continue to be classified as strictly intertidal.
- Only depth and latitude correlated (both negatively) with total meiofaunal density. The 44 dominant families of nematodes (30 families) and copepods (14 families) also correlated negatively with depth and latitude.
- Correlations of total meiofauna, nematode, and copepod families with sediment parameters were rarely significant, and the traditionally correlated sediment granulometric parameters indicated no trends. The use of familial identifications to discern zonation patterns or organism/environmental correlations was inadequate to determine the factors controlling the community dynamics of meiofauna.
- Species identifications are requisite to determining organism/environmental interactions since different species in the same family react differently to the environment. Familial identifications masked the true species interactions.

SECTION 6

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CHAPTER 9

FORAMINIFERA OF SOUTH ATLANTIC/GEORGIA BIGHT

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ABSTRACT

Living populations of 184 foraminiferal species were recognized in benthic samples collected in 1977 from the Georgia Bight; 52 of these occurred with a 5% or greater frequency in one or more samples. In addition, 143 species were found only as dead populations. The numerical density of the assemblage was high in the southern sector of the study area. In the inshore waters and on the slope, the Shannon-Wiener function of diversity was depressed.

Bolivina lowmani, the typical dominant species of the slope area, also had the highest mean population density among all benthic foraminiferal species in the embayment. *Planulina exorna* was the most nearly ubiquitous species on the shelf and the most dominant form on the middle and outer parts of the shelf. *Elphidium excavatum* forma *clavatum* was clearly the principal dominant species on the inner shelf. *Ammonia beccarii,* another species abundant in inshore waters, exhibited increased density and greater relative abundance in the southern part of the zone. Analysis of variance confirmed seasonal contrasts in the relative abundance of *Ammonia beccarii* and *Bolivina lowmani,* as well as the depth preferences of several species. Depth and substrate preferences of some species were also demonstrated by regression analysis.

Two techniques of clustering using the Jaccard coefficient and a distance function (preceded by a principal components analysis) revealed a strong faunal similarity among inshore stations and a low-level similarity among slope stations. Major biotope boundaries were recognized at depths of 15 to 20 m and 40 to 50 m, but the location of the outer boundary of the shelf-edge/upper-slope biotopes was not ascertained.

A special faunal assemblage, a significant proportion of which was *Bolivina subaenariensis* var. *mexicana,* existed at station 7E. Samples from this station were characterized also by unusually high values of overall foraminiferal density (mean, 3132/3 cm^3), hydrocarbon content, and total organic carbon. *Bolivina lowmani* and several other species common in fine-grained substrates will probably be useful in monitoring the state of the benthic environment.

SECTION 1
INTRODUCTION

A. OBJECTIVE

Benthic foraminifera are now recognized as sensitive indicator organisms of the marine environment. On an open-shelf/upper-slope habitat such as the Georgia Bight, their high diversity and intra-assemblage variations make them particularly useful markers in charting biotope boundaries and in understanding the effects of gross environmental changes. Repeated seasonal sampling from a designated set of stations is expected to lead to a data base on foraminiferal species that will help identify significant distribution patterns. It is hoped that later changes in these patterns, if any, from natural or manmade causes will be identified by similar studies.

B. PREVIOUS STUDIES

There are no published reports on the occurrence or distribution of living populations of benthic foraminifera in the Georgia Bight, but there have been several studies on the distribution patterns of total (living and dead) foraminiferal assemblages in the area.

Wilcoxon (1964), on the basis of the relative abundance of species, recognized four depth-related foraminiferal assemblages in the region between Cape Hatteras and the Florida Straits: beach fauna (0 to 1 m), inner-shelf fauna (1 to 15 m), middle-shelf fauna (15 to 61 m), and outer-shelf/upper-slope fauna (61 to 183 m). Wilcoxon noticed the increase in the number of species from shallower to deeper zones and a particular abundance of the agglutinated species in the middle-shelf zone. Hyaline species were found to constitute the major group on the shelf; the relative abundance of the porcelaneous group was observed to be highest in nearshore waters. No preference by a species for a particular substrate was noticed. Wilcoxon suggested that most species were restricted to the continental shelf and upper slope because of the location of the Gulf Stream; the tests found in deeper waters were thought to be possibly displaced. Reports on foraminifera from the western north Atlantic south of Cape Hatteras, published before Wilcoxon's study (e.g., Cushman 1918–31, 1947), emphasized descriptions and illustrations of species and occasionally listed provenances of specimens but presented no descriptions of regional distribution patterns.

The study by Schnitker (1971) of foraminifera from the North Carolina continental shelf, an area in which assemblages show many similarities with those found in the SABP study area, confirmed the presence of a significant faunal boundary at Cape Hatteras; such a boundary had been suggested by earlier workers, including Cushman (1918–31). Regarding depth zones, Schnitker separated a "central shelf" thanatotope from a "shelf edge" one, with the boundary at about 60 m. He recognized a relict Pleistocene fauna in the surface sediments near the shelf edge. Sen Gupta (1972), summarizing foraminiferal faunas of five biogeographic provinces commonly recognized on the western north Atlantic continental shelf, stressed the similarity between the Carolinian (which includes the SABP area) and the Caribbean provinces. He noted that the chief difference between the foraminifera of the two provinces is in the restriction of a number of reef genera and species, especially soritids and rotaliids, in the latter.

Kilbourne (1970), on the basis of relative abundance of foraminiferal species in 15 samples, recognized three faunal areas on the Georgia continental shelf: the nearshore (1 to 15 m) *Ammonia-Elphidium* zone, the middle-shelf (15 to 35 m) *Asterigerina-Planorbulina* zone, and the outer-shelf (35 to 100 m) *Placopsilina-Textularia* zone. The study was expanded by Sen Gupta and Kilbourne (1971, 1973, 1974, 1976) to cover the entire Georgia continental shelf; 78 box cores were obtained from stations chosen on a stratified, random sampling plan. Sen Gupta and Kilbourne (1974) observed that two indices of species diversity, the species number S and the Shannon-Wiener information function $\bar{H}$, showed a rise in nearshore waters at depths of shallower than 12 to 15 m. In deeper waters, down to the shelf edge and beyond, the values remained steady, with S almost 50 and H almost 3. They explained the diversity pattern by the fact that, in terms of variations in water temperature, salinity, and substrate conditions, the nearshore habitat on the Georgia shelf is much more unstable or unpredictable than is the offshore habitat. They did not detect any north-south diversity gradient within the area. Sen Gupta and Kilbourne (1976) noted that among the species that are abundant on some or all parts of the Georgia shelf, *Elphidium excavatum* forma *clavatum* and *Ammonia beccarii* attain their maximum frequencies in water shallower than 20 m, *Asterigerina carinata* and *Planorbulina mediterranensis* in depths of 15 to 30 m, and *Planulina exorna, Islandiella subglobosa, Textularia conica,* and *Bigenerina irregularis* in depths exceeding 40 m.

A multivariate Q-mode cluster analysis of the relative frequencies of the 80 most widespread species, preceded by an R-mode principal components analysis (Sen Gupta and Kilbourne, 1976), revealed the limits of three foraminiferal thanatotopes on the Georgia shelf, each characterized by the preferred location of a major cluster. Thanatotope 1, with its outer boundary at an approximate depth of 25 m, includes the inner shelf and part of the middle shelf; thanatotope 2 is limited to the middle shelf, with the outer boundary at about 40 m; thanatotope 3 comprises the area around the shelf edge. The faunal characters of the thanatotopes were summarized as follows:

Thanatotope 1: an increase in percentages of the agglutinated and porcelaneous groups from the shallowest to the deepest part; an increase in the values of species diversity, ending at a depth of 12 to 15 m; *Ammonia becarii* abundant mainly in the inshore part; *Planulina exorna, Planorbulina mediterranensis,* and *Elphidium excavatum* forma *clavatum* abundant; *Quinqueloculina lamarckiana* common; *Asterigerina carinata* and *Placopsilina bradyi* (later recognized as *P. confusa*) common in the deeper part.

Thanatotope 2: *Planulina exorna, Planorbulina mediterranensis,* and *Asterigerina carinata* abundant; *Quinqueloculina lamarckiana* common to abundant; *Rosalina floridana* and *Elphidium excavatum* forma *clavatum* common.

Thanatotope 3: maximum abundance of *Planulina exorna; Islandiella subglobosa, Textularia conica,* and *Bigenerina irregularis* abundant; *Hanzawaia concentrica* common.

High seasonal variation of the bottom-water temperature in the nearshore and shelf-edge regions, compared with the relative stability of the central part of the shelf, was cited by Sen Gupta and Kilbourne (1976) as the major factor influencing the trends of faunal distribution.

Applying the technique of recurrent group analysis to the occurrence data of the 187 species identified by Sen Gupta and Kilbourne (1976), Sen Gupta and Hayes (1977) discriminated 13 species-groups. The largest group consisted of 33 members, including such ubiquitous species of the Georgia shelf as *Hanzawaia concentrica, Planorbulina mediterranensis, Planulina*

exorna, Reussella atlantica, and *Quinqueloculina lamarckiana;* the highest occurrence values of this group (>90% of the constituent species present) were at stations within the depth range of 19 to 30 m. The second group, consisting of five species, occurred at only a single station on the upper slope. The third group, which consisted of *Cibicides floridanus* (later recognized as *C. pseudoungerianus*), *Saccammina atlantica, Nodobaculariella cassis* (later recognized as *N. atlantica*), and *Gaudryina aequa,* had its highest occurrence value (all species present) at stations near the shelf edge, generally in depths between 37 and 77 m. Each of the other 10 groups contained only two or three species. The majority of the species in the total assemblage did not belong to any recurrent group.

Distribution trends of modern and relict benthic foraminifera present in the surface sediments of two areas of the Georgia-South Carolina continental slope were reported by Arnold (1977) and Arnold and Sen Gupta (1978). Three thanatotopic boundaries were recognized. High frequencies of *Textularia conica* and *Islandiella subglobosa* were observed near the shelf edge; *Islandiella subglobosa* and *Bolivina lowmani* were found dominant between the 50- and 100-m isobaths; and a distinctive assemblage of accessory species such as *Amphistegina lessonii, Textulariella barretti,* and *Nodobaculariella atlantica,* believed to be related to a lower stand of sea level, was reported for the 100- to 165-m interval. The dominance of *Islandiella subglobosa, Bolivina lowmani* and *Cibicides pseudoungerianus* was typical of greater depths. The most conspicuous trend observed in diversity values was a sharp decrease in equitability and the Shannon-Wiener information function at a depth of approximately 100 m.

SECTION 2
MATERIAL AND METHODS

Details of shipboard and laboratory procedures appear in Volume 2. The following paragraphs summarize the operation and discuss the justification for the staining method that was used.

A. SAMPLING

Two 3-cm subcores were obtained from a box core at each sampling station except 2G (winter) where only one subcore was obtained. The subcores were preserved in a seawater solution of formalin (5%) and calcium chloride (0.2%) buffered to a pH of 8.3. A third subcore was preserved for archiving.

The number of stations sampled (Figure 3.9-1) for benthic foraminifera was as follows: winter, 48; spring, 25; summer, 49; and fall, 24.

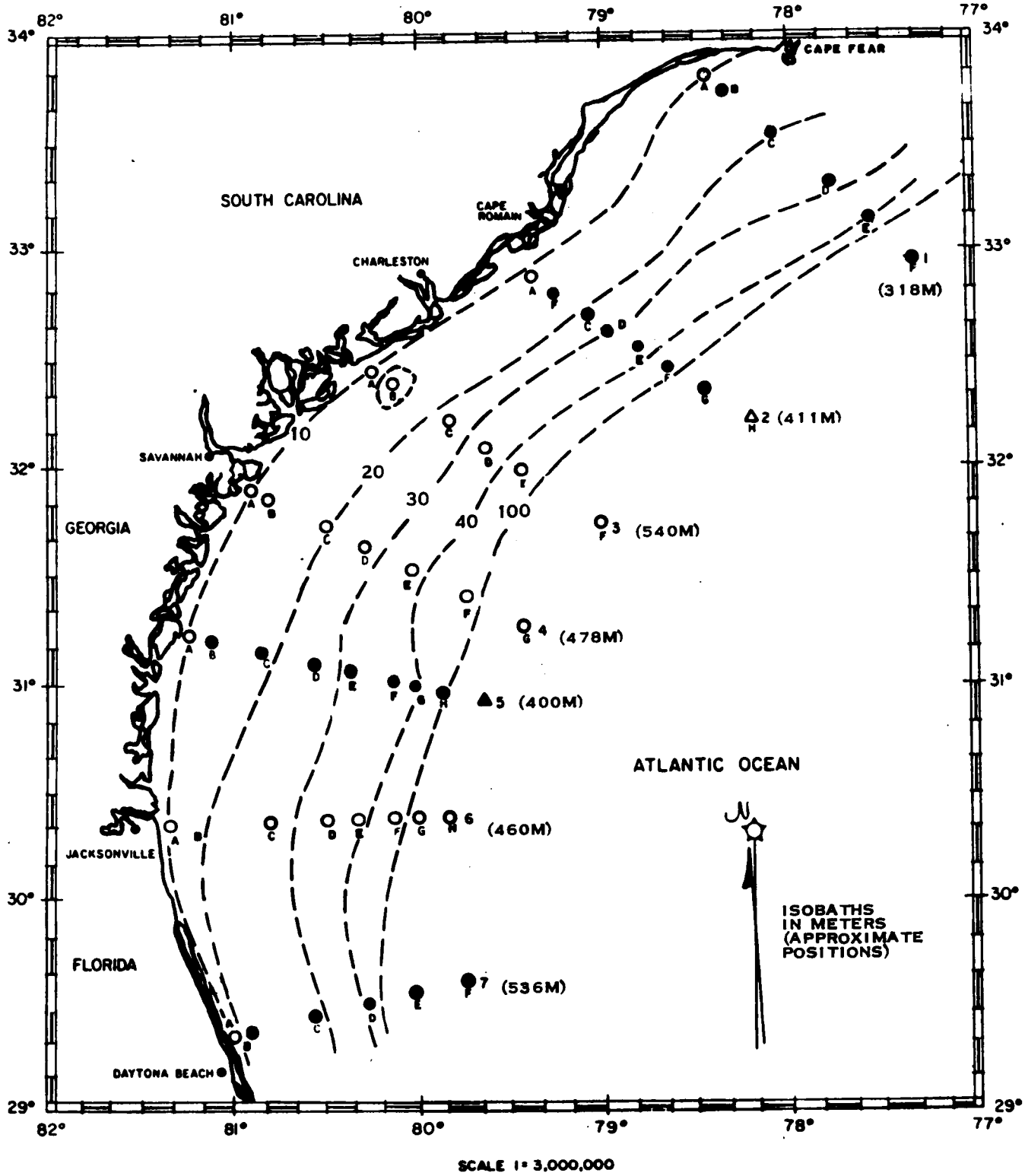
B. RATIONALE FOR STAINING WITH SUDAN BLACK B

Numerous workers have demonstrated that the commonly used technique using rose bengal to stain for foraminiferal tests is erratic and unreliable. Martin and Steinker (1973) reported that the stain does not often penetrate the protoplasm within the test; when penetration does occur, different shades of pink appear on the tests. Furthermore, empty tests may show stains as intense as those containing protoplasm. Walker et al. (1974) cited a long list of workers who have encountered serious difficulties in using this stain for foraminiferal tests. The difficulties are of two main kinds: living individuals may or may not get stained, and tests with adhering algae and bacteria often catch the stain. In one laboratory experiment (Scott, in Atkinson, 1969), individuals of the well-known calcareous perforate species *Elphidium crispum* were not stained, even when they showed pseudopodial activity. In another experiment with culture specimens (Walker et al., 1974), only about 70% of a population of *Rosalina floridana* accepted the stain.

Foraminiferologists had long been aware of the problems of the rose bengal method (Murray, 1973) but had continued to use it because no other staining method had been demonstrated to be superior, until a definitive work by Walker et al. (1974) using Sudan Black B was successful on 95% of the experimental specimens containing protoplasm. The stain did not color empty tests, and all groups, including agglutinated and porcelaneous kinds, were well-stained; no difficulties were encountered when sediment samples (with foraminifera) were used instead of isolated specimens (D.A. Walker, personal communication). To overcome these problems, samples for the SABP were stained with Sudan Black B.

C. LABORATORY PROCEDURE

A saturated solution of the stain was prepared by dissolving approximately 10 g of Sudan Black B in 1 l of 70% ethanol. The subcore sample, which was fixed aboard ship, was washed with water. The Sudan Black B solution was heated to 40°C and added to the washed sample. The sample remained in a water bath at 40°C for 30 min, then the excess stain was decanted. The stained sample was sieved through a 63-μm sieve to separate the sand-gravel and silt-clay fractions. After being washed with 70% ethanol, these fractions were dried and weighed. The



● STATIONS SAMPLED, ALL FOUR SEASONS

○ STATIONS SAMPLED, WINTER AND SUMMER

▲ STATION SAMPLED, SPRING, SUMMER AND FALL

△ STATION SAMPLED, SPRING ONLY

Figure 3.9-1. Stations Sampled for Foraminifera

coarser fractions of the two subcores from the same station were then mixed together and floated in a 10:4 mixture of bromoform and acetone, after the particles coarser than 1 mm, if any, were sieved out. The "float" and the 1-mm+ residue were examined for foraminifera. All portions of the original sample were properly labeled and stored.

The "living-total" ratio was obtained by counting 300 or more specimens of benthic foraminifera (stained and unstained) present in a suitable fraction of the composite foraminiferal sample; the frequencies of living individuals of different species were determined by identifying and counting 300 or more stained specimens from a larger fraction. These fractions were obtained by using a modified Otto microsplitter. If the sample contained fewer than 300 living specimens, all specimens were counted. Species were identified by consulting extensive taxonomic literature, including the American Museum of Natural History Catalog of Foraminifera, and by comparison with specimens in the author's collection; a few species were identified by comparison with primary types loaned by the U.S. National Museum. All living (stained) specimens examined, as well as many representative dead specimens, were mounted on standard micropaleontological slides. The information entered on laboratory data sheets included sand-silt weights, living-dead numbers, fraction examined for species frequencies, and frequencies of all living species.

D. TREATMENT OF NUMERICAL DATA

The following statistics were obtained from the frequency data on the foraminiferal species: living-total ratio, number of individual species and higher taxa/cm^2 of the subcore cross section (i.e., per 3 cm^3), relative abundances of species and higher taxa as percentages of the assemblage, number of species in the composite sample; and Shannon-Weaver (H') and Shannon-Wiener ($\overline{H}$) functions of diversity. Data from two slope samples (3F in winter and 4G in summer) were rejected because of the unreliable nature of the samples: the foraminiferal residue in each included numerous fragmented, stained, and mineralized specimens; the samples were apparently turbiditic. The 3F winter sample contained a single living foraminifer; there were three living specimens in the 4G summer sample.

Several techniques of data analysis were used. The details of statistical strategy are described in Volumes 2 and 6 of this report, but a brief outline is given below.

1. Analysis of Variance

The standard ANOV procedure (Appendix 3.9D in Volume 6) was applied on the mean relative abundances of selected taxa so station and season effects could be determined. Significant differences among stations and seasons were checked by Duncan's multiple-range test.

2. Regression Analysis

A multiple-regression analysis tested the relationship between abundance variations of selected taxa and seven environmental parameters (Appendix 3.9C). A supplementary procedure of stepwise improvement of R^2 was used to identify the parameters that explained a large part of the variation.

3. Cluster Analysis

The Jaccard coefficient of similarity (Appendix 3.9A) is given by

$$S_j = \frac{c}{a + b + c} 100$$

where a is the number of species present only in sample a, b is the number of species present only in sample b, and c is the number of species common to both samples. The Q-mode cluster analysis was performed by computing the Jaccard coefficient for all sample pairs and obtaining a dendrogram by the complete-linkage (i.e., farthest-neighbor) method.

Cluster analysis in conjunction with principal components (Appendix 3.9B) was performed using the following steps:

Extraction of principal components that would account for at least 70% of the variance in the species frequency data

Computation of principal-factor scores

Computation of a Q-mode similarity matrix using a standardized Euclidean metric (distance function) given by the equation

$$D_{1,2} = \sum_{i=1}^{M} (X_{i1} - X_{i2})^2 / M$$

where M is the number of variables and X is the normalized value of variables

Q-mode clustering by the complete-linkage method.

SECTION 3
RESULTS

A. GENERAL CHARACTERISTICS

1. Composition of Assemblage

The benthic foraminiferal assemblage of the Georgia Bight consists of 327 species and varieties; 184 of these taxa were identified as living specimens in the seasonal samples of 1977. Appendix 3.9E in Volume 6 is a list of the species that were found living. Species present only as dead populations in each sample are listed in Appendix 3.9F.

All the results discussed in this report, except for the living-total ratio, are based on the living population data.

2. Living-Total Ratio

The living-total ratio recorded for all stations is presented in Table 3.9-1. The majority of the values were <10. The seasonal values at most stations had a high coefficient of variation.

Table 3.9-1. Living-Total Ratio (%)

		Station								
Transect	Season	A	B	C	D	E	F	G	H	I
1	Winter	4.3	12.6	3.0	1.5	3.2	3.8	–	–	–
	Spring	–	5.2	2.8	5.7	2.3	9.5	–	–	–
	Summer	3.6	2.2	8.4	4.3	4.8	4.3	–	–	–
	Fall	–	13.3	2.9	5.3	2.3	3.2	–	–	–
2	Winter	30.4	1.9	7.5	3.1	6.5	5.6	5.7	–	–
	Spring	–	2.8	5.0	10.3	9.8	10.1	29.3	13.3	–
	Summer	29.9	10.6	8.5	7.6	8.9	9.2	8.0	–	–
	Fall	–	10.9	8.3	7.2	3.3	7.1	9.1	–	–
3	Winter	4.3	13.2	4.7	2.1	4.9	–	–	–	–
	Summer	5.4	12.5	9.2	8.3	3.1	2.2	–	–	–
4	Winter	10.0	7.8	7.1	1.6	5.1	10.2	1.3	–	–
	Summer	20.4	4.1	5.7	4.5	7.6	4.7	–	–	–
5	Winter	21.2	8.9	3.8	4.1	6.8	3.1	7.3	8.3	–
	Spring	–	7.8	7.4	8.8	5.2	8.7	4.9	10.1	18.4
	Summer	9.2	11.3	10.2	3.7	8.4	10.2	5.0	10.3	14.9
	Fall	–	5.0	9.6	5.3	6.4	7.6	2.3	7.5	4.5
6	Winter	9.4	2.7	12.5	3.8	4.0	4.9	7.2	2.9	–
	Summer	15.5	16.6	11.4	9.5	6.8	2.9	5.1	1.3	–
7	Winter	14.9	4.2	7.0	3.5	5.4	5.6	–	–	–
	Spring	–	2.4	6.0	20.5	7.7	13.3	–	–	–
	Summer	17.6	3.8	12.0	5.9	5.1	5.1	–	–	–
	Fall	–	3.0	5.0	5.1	9.1	5.0	–	–	–

3. Numerical Density of Assemblage

Table 3.9-2 summarizes the seasonal values of the numerical density of the living foraminiferal assemblage (No./cm^2 for sediment thickness of 3 cm). The mean and coefficient of variation at each station appear in Table 3.9-3.

In general, the coefficient of variation was high. However, a distribution map of the mean density (Figure 3.9-2) shows a concentration of high values in inshore waters (depths of <20 m) and on the slope. Both the inner-shelf and slope areas, compared with the middle part of the shelf, are characterized by a substrate of finer grain size. Figure 3.9-3 plots the foraminiferal density in the seasonal samples from each station against the percentage of the silt-clay fraction in the sediment (bulk sample from box core); a correlation is indicated despite the scatter. The mean foraminiferal density at most stations on the middle shelf was low (<15).

The mean numerical density of foraminifera also exhibited a somewhat erratic latitudinal increase from north to south. Values on transect 1 were consistently higher than those at comparable stations on transect 7. The highest mean foraminiferal density value in inshore waters was attained at station 7A (approximately 353, with 13% coefficient of variation). The highest value on the slope was station 7E (approximately 3,132 with 85% coefficient of variation); the high coefficient of variation was caused partly by one unusually low seasonal value.

B. RELATIVE ABUNDANCE AND DISTRIBUTION OF SUBORDERS

Agglutinated, porcelaneous, and hyaline groups constitute the three principal suborders of foraminifera. The hyaline group (Rotaliina) is clearly the dominant group at all the Georgia Bight stations. The group includes >80% of the living individuals of foraminifera that were present in 84% of the seasonal samples.

The relative abundance of the agglutinated group (Textulariina) and the porcelaneous group (Miliolina) appear in Tables 3.9-4 and 3.9-5, respectively. Generally, the agglutinated group had the least relative abundance in the assemblage; with one exception (1D in winter), it constituted <20% of the assemblage in the samples. In more than 75% of the samples, the group constituted <5% of the assemblage. A plot of the relative abundance of the agglutinated foraminifera against station depths (Figure 3.9-4) indicated that all values higher than 2% were confined to depths less than 45 m. Apparently, the relative abundance of the group decreases sharply near the shelf edge.

A depth plot of the relative abundance of the porcelaneous group (Figure 3.9-5) shows a similar but less drastic decrease near a depth of 45 m; virtually all values in deeper water were <5%. Even on the shelf, there is an apparent trend toward decreasing percentages from shallower to deeper stations. The high values are <45%, with one exception—in the summer sample from station 1B, the group constituted 100% of the assemblage.

C. SPECIES DIVERSITY

The number of species (S) and the Shannon-Weaver function (H′) were obtained for every sample. To compare values obtained in the SABP study with those available in recent

Table 3.9-2. Approximate Seasonal Numercial Density (No./cm² in 3-cm core) of Living Foraminifera

Transect	Season	Station A	B	C	D	E	F	G	H	I
1	Winter	8	5	9	7	8	50	–	–	–
	Spring	–	7	10	14	8	14	–	–	–
	Summer	2	1	17	15	20	10	–	–	–
	Fall	–	9	5	15	10	10	–	–	–
2	Winter	14	3	24	5	11	4	65	–	–
	Spring	–	2	7	13	23	9	32	39	–
	Summer	17	5	9	16	20	12	548	–	–
	Fall	–	4	5	6	7	4	80	–	–
3	Winter	24	17	3	5	11	–	–	–	–
	Summer	37	19	4	22	14	16	–	–	–
4	Winter	37	2	2	1	4	55	1	–	–
	Summer	98	1	2	5	16	58	–	–	–
5	Winter	269	5	2	3	4	4	6	19	–
	Spring	–	3	6	12	12	12	8	21	31
	Summer	100	2	3	5	18	7	10	275	396
	Fall	–	5	4	6	13	8	3	17	47
6	Winter	15	5	26	6	7	16	35	3	–
	Summer	2	43	84	24	22	21	1343	3	–
7	Winter	319	6	6	4	2680	88	–	–	–
	Spring	–	5	16	31	32	44	–	–	–
	Summer	386	14	30	108	3274	129	–	–	–
	Fall	–	9	5	207	6542	271	–	–	–

Table 3.9-3. Numerical Density (No./cm³) of Living Foraminifera and Coefficient of Variation (%)

Transect	Statistic	Station A	B	C	D	E	F	G	H	I
1	Mean	5.0	2.8	10.3	12.8	11.5	21.0	–	–	–
	c.v.[a]	85.0	62.0	49.0	30.0	50.0	93.0	–	–	–
2	Mean	15.5	3.5	11.3	10.0	15.3	7.3	181.3	39.0	–
	c.v.	14.0	37.0	77.0	54.0	49.0	54.0	135.0	*[b]	
3	Mean	30.5	18.0	3.5	13.5	12.5	16.0	–	–	–
	c.v.	30.0	8.0	20.0	89.0	17.0	*	–	–	–
4	Mean	67.5	1.5	2.0	3.0	10.0	56.5	1.0	–	–
	c.v.	64.0	47.0	0.0	94.0	85.0	4.0	*	–	–
5	Mean	184.5	3.8	3.8	6.5	11.8	7.8	6.8	83.0	158.0
	c.v.	65.0	40.0	46.0	60.0	49.0	43.0	44.0	154.0	131.0
6	Mean	8.5	24.0	55.0	15.0	14.5	18.5	689.0	3.0	–
	c.v.	108.0	120.0	75.0	85.0	73.0	19.0	134.0	0.0	–
7	Mean	352.5	8.5	14.3	87.5	3132.0	133.0	–	–	–
	c.v.	13.0	48.0	82.0	104.0	85.0	74.0	–	–	–

[a]Coefficient of variation (standard deviation as percentage of mean).
[b]Asterisk indicates single value.

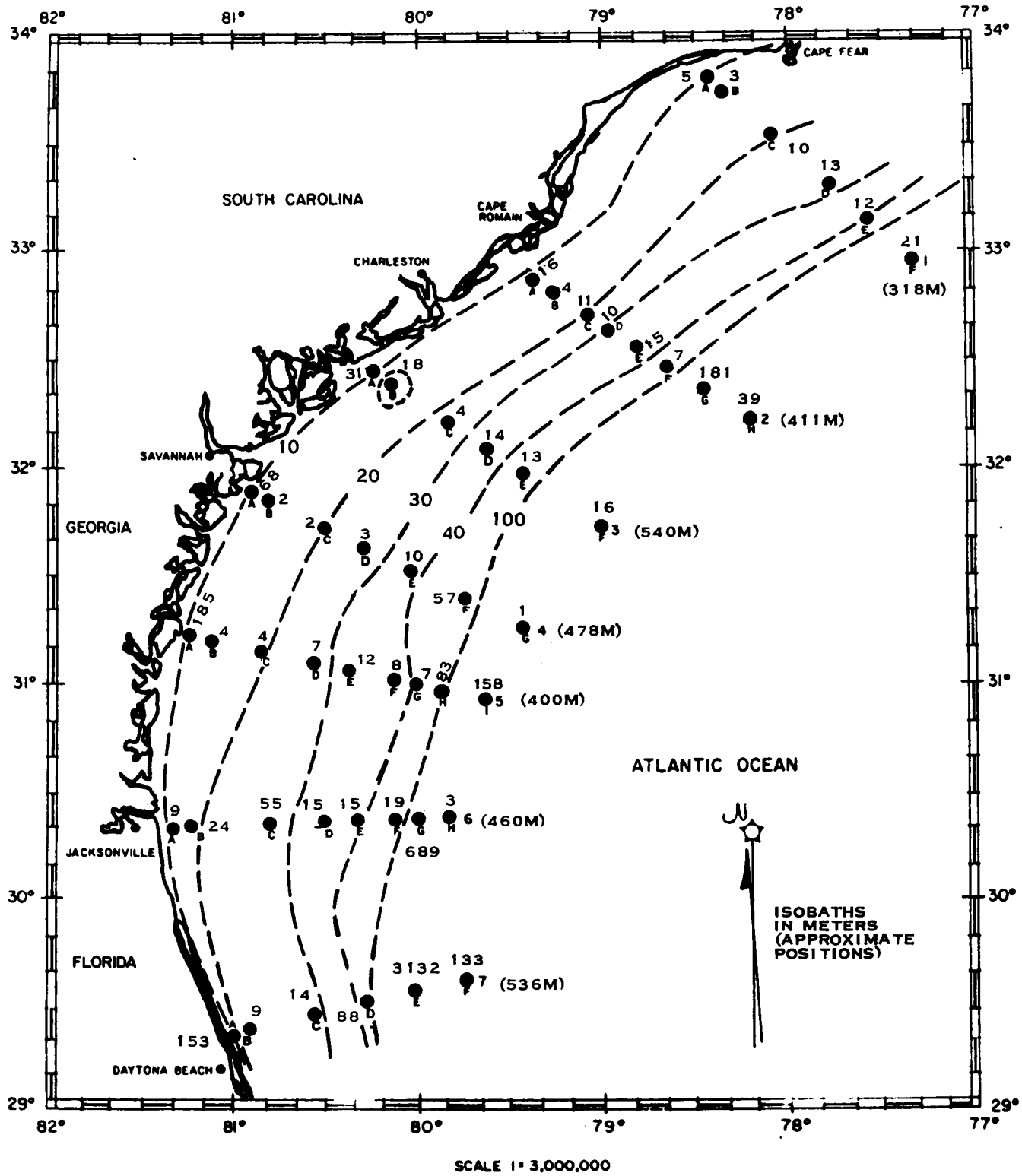


Figure 3.9-2. Distribution of Mean (Approximate) Numerical Density (No./cm³)

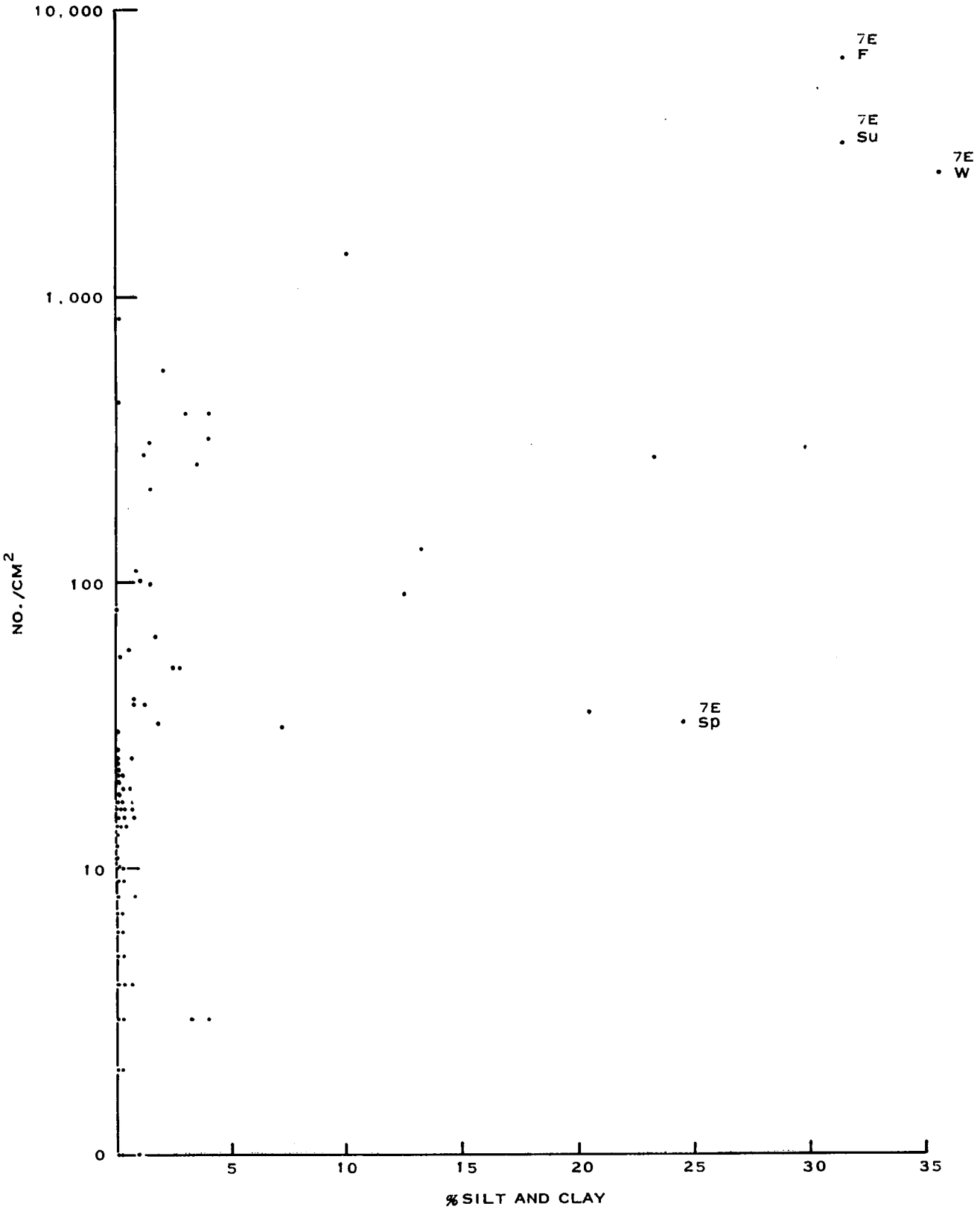


Figure 3.9-3. Foraminiferal Density and Grain Size (Plots for seasonal samples from station 7E labeled)

Table 3.9-4. Relative Abundance (%) of Agglutinated Foraminifera

Transect	Season	Station A	B	C	D	E	F	G	H	I
1	Winter	11.5	27.7	0.0	11.8	1.3	1.6	–	–	–
	Spring	–	15.6	3.1	6.5	1.3	1.4	–	–	–
	Summer	0.0	0.0	1.2	1.3	1.0	1.0	–	–	–
	Fall	–	1.1	3.8	2.0	0.0	0.0	–	–	–
2	Winter	1.4	9.4	15.2	3.9	0.0	2.4	0.0	–	–
	Spring	–	0.0	6.3	8.1	2.2	4.5	0.3	0.0	–
	Summer	0.0	1.9	3.5	7.7	2.5	1.7	0.0	–	–
	Fall	–	0.0	0.0	3.2	0.0	5.3	0.3	–	–
3	Winter	4.4	4.2	8.8	5.8	2.9	–	–	–	–
	Summer	0.0	1.1	2.5	8.2	8.1	0.0	–	–	–
4	Winter	0.3	5.0	0.0	0.0	0.0	1.5	0.0	–	–
	Summer	0.0	0.0	0.0	1.9	0.6	3.0	–	–	–
5	Winter	1.2	2.2	0.0	0.0	5.7	2.7	3.4	1.6	–
	Spring	–	0.0	3.6	9.2	13.1	9.6	2.6	1.5	0.0
	Summer	0.0	6.3	0.0	11.8	3.4	15.2	17.5	3.6	0.0
	Fall	–	2.2	0.0	4.8	7.1	8.0	14.7	1.2	0.3
6	Winter	0.0	0.0	7.1	3.6	8.6	11.4	0.6	0.0	–
	Summer	0.0	1.9	2.6	3.4	3.8	4.8	0.3	0.0	–
7	Winter	0.3	1.7	6.8	0.0	0.0	2.0	–	–	–
	Spring	–	0.0	3.2	0.7	0.0	0.2	–	–	–
	Summer	0.0	0.0	0.0	2.1	0.3	0.3	–	–	–
	Fall	–	2.2	1.9	0.6	0.0	1.0	–	–	–

foraminiferal literature, the Shannon-Weaver diversity number for each sample was converted to the Shannon-Wiener function ($\overline{H}$) by changing the base of the logarithm from 2 to e,

$$\overline{H} = -\Sigma \, Pi \, \ell n \, Pi$$

where Pi is the proportion of the *ith* species in the sample. The values of $\overline{H}$ for all seasonal samples appear in Table 3.9-6. The mean values (with coefficients of variation) of S and $\overline{H}$ are in Tables 3.9-7 and 3.9-8, respectively.

The highest value of S in a seasonal sample was 43 (1E, summer); the highest mean value at a station was 31 (4F). The coefficient of variation was generally high, and no clear bathymetric or latitudinal trend was observed in mean S.

The seasonal values of $\overline{H}$ were <3 except 3.02 in one summer sample (6E). Values lower than 1.5, however, were found almost exclusively in the inner-shelf and slope assemblages. At most stations, the coefficient of variation of $\overline{H}$ was much less than that of S. The distribution map of mean $\overline{H}$ (Figure 3.9-6) reveals that the value along most transects increased on the inner shelf (i.e., in waters shallower than 15 m), attained a plateau on the middle and outer shelves, and decreased near the 200-m isobath. Among the four transects on which most stations were sampled in all four seasons, transect 5 showed the least coefficients of variation in the mean values of $\overline{H}$; along this transect, the mean value of $\overline{H}$ was <2 only at the two terminal stations, A (11 m) and I (400 m).

Table 3.9-5. Relative Abundance (%) of Porcelaneous Foraminifera

Transect	Season	Station A	B	C	D	E	F	G	H	I
1	Winter	44.9	17.0	38.1	2.9	5.3	0.4	–	–	–
	Spring	–	17.2	33.7	15.8	1.3	1.4	–	–	–
	Summer	29.4	100.0	19.6	17.5	15.1	0.0	–	–	–
	Fall	–	15.4	9.6	36.2	4.0	1.0	–	–	–
2	Winter	1.4	25.0	5.5	7.8	1.8	14.3	0.6	–	–
	Spring	–	13.3	10.9	12.2	2.2	5.6	0.3	0.0	–
	Summer	1.8	11.5	11.6	7.0	10.6	15.4	0.0	–	–
	Fall	–	20.5	0.0	4.8	4.2	2.6	0.5	–	–
3	Winter	10.7	16.2	35.3	0.0	1.0	–	–	–	–
	Summer	13.8	31.0	12.5	5.9	9.6	1.9	–	–	–
4	Winter	1.4	5.0	10.0	0.0	0.0	3.0	0.0	–	–
	Summer	0.6	12.5	0.0	1.9	13.9	11.9	–	–	–
5	Winter	0.5	17.8	0.0	14.7	14.3	5.4	3.4	8.9	–
	Spring	–	3.4	7.3	6.7	6.6	11.4	2.6	4.5	0.3
	Summer	1.0	12.5	11.8	2.0	6.8	13.6	7.8	5.6	1.3
	Fall	–	10.9	21.6	11.3	16.5	5.0	2.9	1.8	0.7
6	Winter	0.7	28.3	16.2	10.9	12.9	12.0	1.6	3.7	–
	Summer	0.0	21.8	14.2	16.5	29.7	17.1	1.6	6.7	–
7	Winter	0.0	13.3	15.3	8.6	1.0	3.9	–	–	–
	Spring	–	5.9	7.0	2.6	1.3	0.7	–	–	–
	Summer	0.0	17.2	19.3	13.3	0.3	0.0	–	–	–
	Fall	–	8.7	9.6	3.5	0.6	2.6	–	–	–

D. DOMINANT SPECIES

Fifty-two species and varieties occurred with a 5% or higher frequency in at least one sample. These taxa are listed in Table 3.9-9, the numerical code is then used in the companion Table 3.9-10 to show the ranking of species (with frequencies equal to or greater than 5%) in the assemblage of each seasonal sample. At 40% of the stations that were sampled in two or more seasons, the principal dominant species (the one with the greatest number of individuals) did not change from season to season. A simple procedure was followed to identify the typical dominant species (on an annual basis) at other stations. A species was designated as dominant if it retained its lead in more seasons than any other species. If the lead of any one species was not clearly the most persistent, the mean relative abundance for all sampling seasons was the criterion. The distribution of these characteristic dominant species of the Georgia Bight is shown in Figure 3.9-7; six of the species are illustrated in Figure 3.9-8.

Most of the stations in waters shallower than 20 m are dominated by *Elphidium excavatum* forma *clavatum*. *Ammonia beccarii*, *Planorbulina mediterranensis*, and *Rotorbinella lomaensis* are the dominant forms at a few stations in this depth zone. *Planulina exorna* is clearly the most widespread dominant species on the middle and outer parts of the shelf. *Hanzawaia concentrica* and *Islandiella subglobosa* dominate a few stations on the middle shelf and the shelf-edge zone, respectively. All but one of the slope stations deeper than 200 m are dominated by *Bolivina lowmani;* the one exception (4G) is dominated by *Anomalina semipunctata*. *Bolivina lowmani* is also the dominant species at several shelf stations.

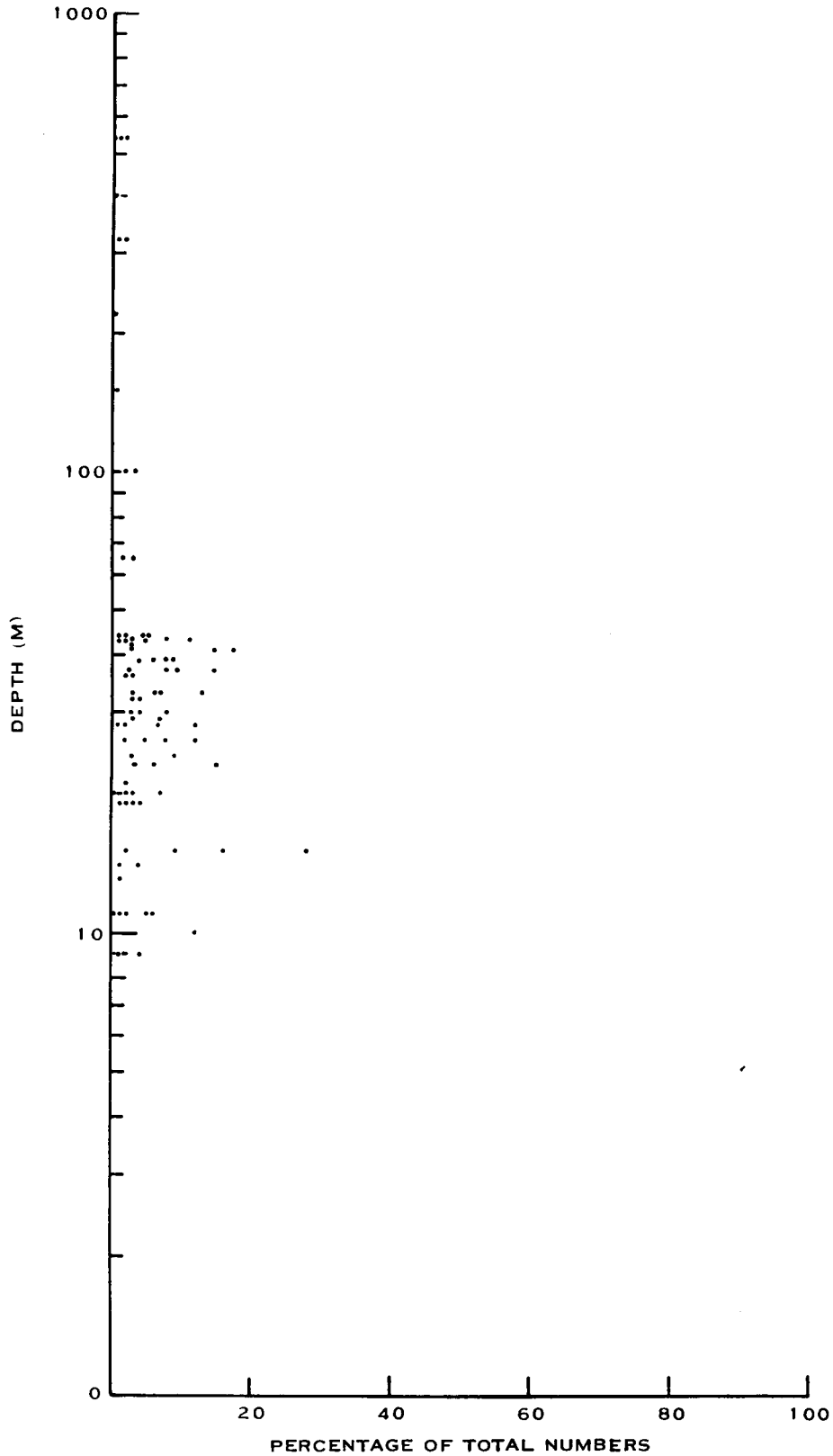


Figure 3.9-4. Relative Abundance of Agglutinated Forminifera

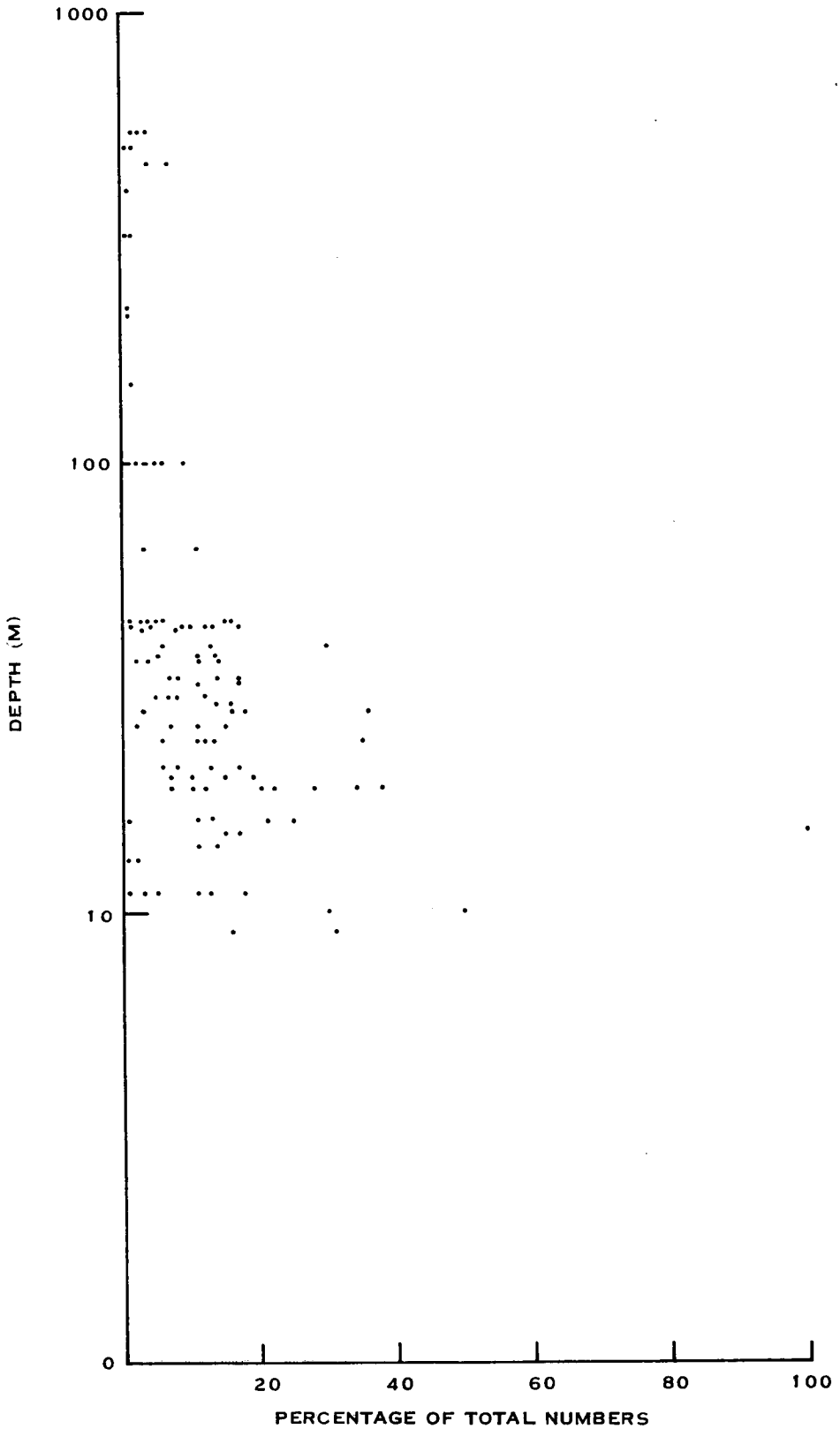


Figure 3.9-5. Relative Abundance of Porcelaneous Foraminifera

Table 3.9-6. Values of Shannon-Wiener Function of Diversity ($\bar{H}$) in Seasonal Samples

Transect	Season	Station A	B	C	D	E	F	G	H	I
1	Winter	2.49	2.40	2.63	2.23	2.22	2.17	–	–	–
	Spring	–	1.93	2.74	2.58	2.05	1.66	–	–	–
	Summer	1.39	0.80	2.78	2.67	2.73	1.60	–	–	–
	Fall	–	2.34	2.39	2.61	2.25	1.95	–	–	–
2	Winter	1.53	2.44	2.60	2.06	2.19	2.43	1.49	–	–
	Spring	–	2.06	2.38	2.78	2.22	2.05	1.39	1.55	–
	Summer	0.73	2.27	2.90	2.39	2.35	2.29	1.01	–	–
	Fall	–	2.50	1.25	2.40	1.95	1.75	1.32	–	–
3	Winter	2.28	2.51	2.52	1.56	1.80	–	–	–	–
	Summer	2.43	2.86	2.53	2.33	2.41	1.38	–	–	–
4	Winter	1.62	2.34	2.29	0.94	2.20	2.20	1.30	–	–
	Summer	1.17	1.67	1.34	2.21	2.52	2.52	–	–	–
5	Winter	1.80	2.61	1.65	2.52	2.15	2.22	2.36	2.18	–
	Spring	–	1.94	2.64	2.59	2.27	2.65	1.88	2.21	1.28
	Summer	1.91	2.08	2.52	2.18	2.42	2.72	2.62	2.27	1.52
	Fall	–	2.53	2.21	2.81	2.93	2.37	1.97	1.46	1.51
6	Winter	0.89	2.74	2.89	2.18	2.11	2.54	1.88	1.41	–
	Summer	0.58	2.73	2.70	2.87	3.02	2.86	1.84	1.64	–
7	Winter	1.48	1.98	2.55	2.25	1.92	2.43	–	–	–
	Spring	–	1.81	2.90	2.11	1.88	1.75	–	–	–
	Summer	1.71	2.79	2.98	2.54	1.34	0.36	–	–	–
	Fall	–	2.70	2.24	1.92	1.90	1.24	–	–	–

Table 3.9-7. Approximate Mean Value of Simple Species Diversity (No. of Species S) and Coefficient of Variation (%)

Transect	Statistic	Station A	B	C	D	E	F	G	H	I
1	Mean	13.5	13.5	25.3	24.3	26.0	28.0	–	–	–
	c.v.[a]	79.0	56.0	27.0	23.0	48.0	60.0	–	–	–
2	Mean	11.0	13.8	22.8	20.8	25.3	17.3	22.0	24.0	–
	c.v.	52.0	23.0	57.0	34.0	34.0	31.0	19.0	*[b]	–
3	Mean	27.0	29.0	18.0	18.0	25.0	19.0	–	–	–
	c.v.	21.0	20.0	8.0	71.0	34.0	*	–	–	–
4	Mean	17.5	9.0	9.0	9.0	19.0	31.0	5.0	–	–
	c.v.	12.0	47.0	47.0	79.0	37.0	9.0	*	–	–
5	Mean	22.0	13.3	14.0	20.3	22.3	19.0	17.3	24.0	23.0
	c.v.	6.0	38.0	32.0	28.0	30.0	17.0	34.0	20.0	9.0
6	Mean	4.5	26.5	34.5	26.0	27.0	31.0	26.5	10.0	–
	c.v.	78.0	35.0	2.0	65.0	52.0	0.0	13.0	14.0	–
7	Mean	16.0	20.5	25.8	27.0	25.8	25.5	–	–	–
	c.v.	9.0	31.0	38.0	41.0	20.0	47.0	–	–	–

[a]Coefficient of variation (standard deviation as percentage of mean).
[b]Asterisk indicates that S represents a single seasonal value.

Table 3.9-8. Approximate Mean Value of Shannon-Wiener Diversity Function ($\bar{H}$) and Coefficient of Variation (%)

Transect	Statistic	Station A	B	C	D	E	F	G	H	I
1	Mean	1.99	1.86	2.64	2.52	2.31	1.85	–	–	–
	c.v.[a]	36.0	40.0	7.0	8.0	13.0	15.0	–	–	–
2	Mean	1.13	2.32	2.28	2.41	2.19	2.13	1.30	1.55	–
	c.v.	50.0	9.0	31.0	12.0	8.0	14.0	16.0	*[b]	–
3	Mean	2.36	2.69	2.53	1.95	2.11	1.38	–	–	–
	c.v.	5.0	9.0	0.4	28.0	20.0	*	–	–	–
4	Mean	1.40	2.01	1.82	1.58	2.36	2.36	1.30	–	–
	c.v.	23.0	23.0	37.0	57.0	10.0	10.0	*	–	–
5	Mean	1.86	2.29	2.26	2.53	2.44	2.49	2.21	2.03	1.44
	c.v.	4.0	14.0	19.0	10.0	14.0	10.0	16.0	19.0	10.0
6	Mean	0.74	2.74	2.80	2.53	2.57	2.70	1.86	1.53	–
	c.v.	30.0	0.4	5.0	19.0	25.0	9.0	2.0	10.0	–
7	Mean	1.60	2.32	2.67	2.21	1.76	1.45	–	–	–
	c.v.	10.0	22.0	13.0	12.0	16.0	60.0	–	–	–

[a]Coefficient of variation (standard deviation as percentage of mean).
[b]Asterisk indicates that $\bar{H}$ represents a single seasonal value.

E. ABUNDANCE VARIATIONS OF PRINCIPAL DOMINANT SPECIES

The principal dominant species showed patterns of distribution that were clearly related to the depth gradient of the Georgia Bight.

All stations where *Ammonia beccarii* occurred in moderate or high numbers were in the inshore waters. Only the A stations of transects 4, 5, and 7 had a population density >10/3 cm^3; station 7A had the highest mean density (152 with a c.v. of 4%). The only living individuals found in the slope samples were at 7E in the winter and at 7F in the spring: a single specimen of the species was counted in the split examined for each of these two samples. The maximum scatter in the values of relative abundance (percentage of the assemblage) was within the 10- and 20-m isobaths (Figure 3.9-9); several of the samples for this zone contained a significant proportion (⩾20%) of the species, the highest relative abundance being 46% (7A, winter).

The frequency variation of *Elphidium excavatum* forma *clavatum* was comparable to that of *Ammonia beccarii*, except for slightly higher densities at a few midshelf stations and at the inshore stations of transects 2 and 3; 7A had the highest mean density (105 with a c.v. of 12%). There is virtually no record of living populations beyond the shelf edge. In the plot of relative abundance versus depth (Figure 3.9-10), the scatter was high between 10 and 20 m; however, most sample values in this depth range were >10% with a maximum of 76% (2A, summer). For stations deeper than 20 m, the values were invariably <10%, approaching zero near the shelf edge.

Planulina exorna, the most nearly ubiquitous species on the shelf region of the Georgia Bight, had population densities of >10/3 cm^3 at stations deeper than 20 m; the highest density

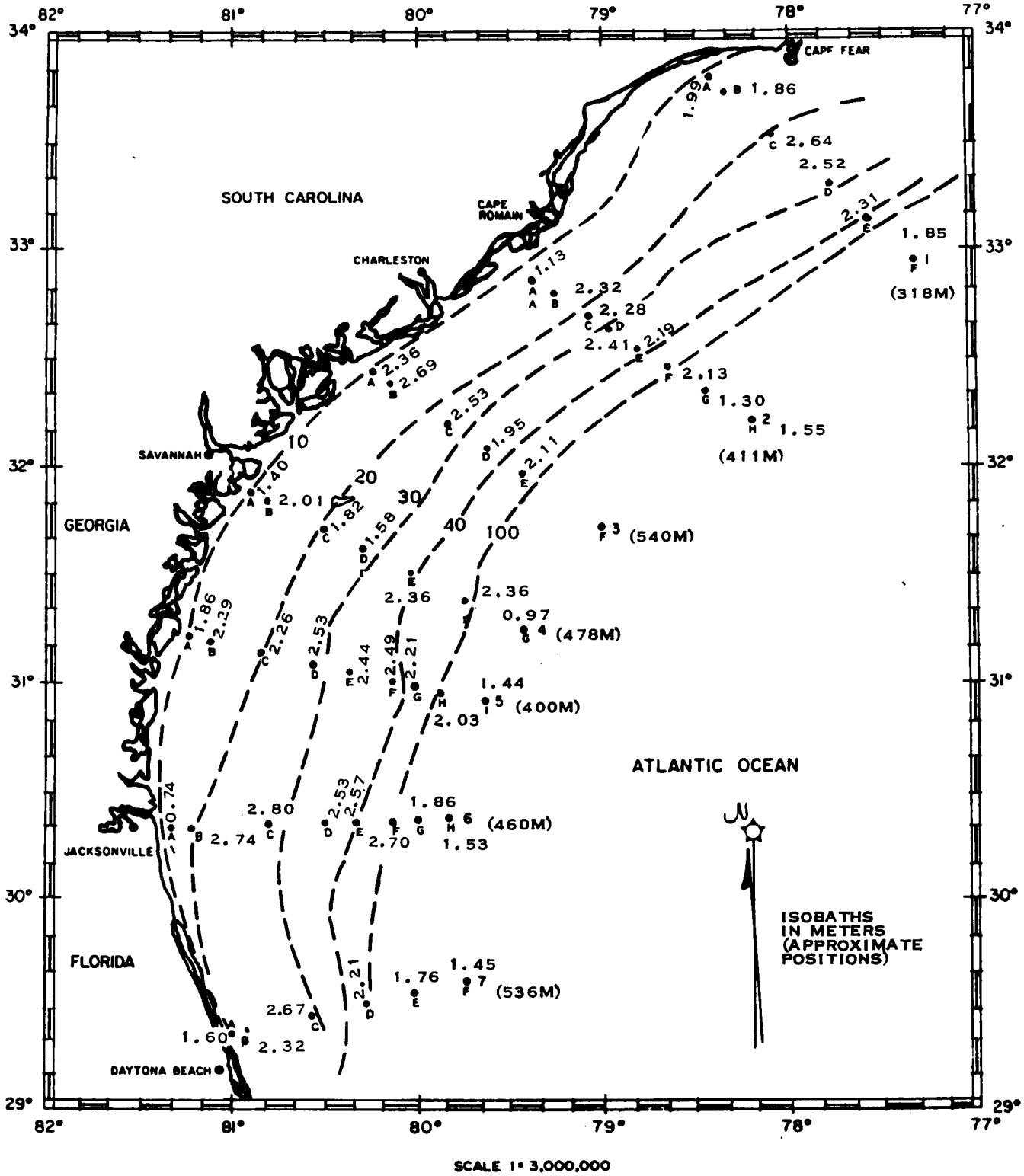


Figure 3.9-6. Species Diversity at Stations: Plot of Shannon-Wiener Values ($\bar{H}$)

Table 3.9-9. Dominant Species[a]

Numerical Code	Species	Numerical Code	Species
1	*Ammonia beccarii*	27	*Miliolinella oblonga*
2	*Anomalina semipunctata*	28	*Mississippina concentrica*
3	*Anomalina* sp. A	29	*Neoconorbina terquemi*
4	*Articulina mucronata*	30	*Nonionella atlantica*
5	*Asterigerina carinata*	31	*Peneroplis proteus*
6	*Bolivina lowmani*	32	*Planorbulina mediterranensis*
7	*Brizalina spathulata*	33	*Planulina exorna*
8	*Brizalina subaenariensis* var. *mexicana*	34	*Poroeponides lateralis*
9	*Buccella hannai*	35	*Quinqueloculina jugosa*
10	*Bulimina aculeata*	36	*Quinqueloculina lamarckiana*
11	*Buliminella elegantissima*	37	*Rectobolivina advena*
12	*Cassidulina laevigata*	38	*Reussella atlantica*
13	*Cibicides pseudoungerianus*	39	*Robertinoides charlottensis*
14	*Ehrenbergina trigona*	40	*Rosalina floridana*
15	*Elphidium advenum*	41	*Rosalina floridensis*
16	*Elphidium discoidale*	42	*Rotorbinella lomaensis*
17	*Elphidium excavatum* forma *clavatum*	43	*Sagrina pulchella*
18	*Elphidium poeyanum*	44	*Sigmoilina sigmoidea*
19	*Elphidium* sp. A	45	*Spirillina decorata*
20	*Eponides antillarum*	46	*Textularia agglutinans*
21	*Guttulina australis*	47	*Textularia conica*
22	*Guttulina* sp. cf. *Guttulina yabei*	48	*Trifarina angulosa*
23	*Hanzawaia concentrica*	49	*Trifarina bradyi*
24	*Hoeglundina elegans*	50	*Triloculina trigonula*
25	*Islandiella subglobosa*	51	*Trochammina lobata*
26	*Miliolinella circularis*	52	*Trochammina squamata*

[a]Occurring with a relative abundance of at least 5% at one or more stations.

(122) was observed in a slope sample (6G, summer). In the scatter plot of relative abundance (Figure 3.9-11), all values higher than 30% were in the 25- to 45-m depth range. The highest relative abundance was 69% (4D, winter).

The population density of *Hanzawaia concentrica* was <10 except in samples from two slope stations (7E and 6G), the latter having the highest value, 61/3 cm^3, in the summer. The scatter plot of the relative abundance (Figure 3.9-12), however, reveals that the best values were between depth limits of 20 and 45 m. All values higher than 20% were in this range, the highest being 53% at 7B in the spring.

Islandiella subglobosa was generally either absent or present in small numbers at the inner- or middle-shelf stations. Densities above 15/3 cm^3 were seen near the shelf edge and on the slope. The highest value in a seasonal sample was 813 (7E, fall); 7E in winter, 2G in summer, and 6G in summer had values near 200. The scatter of the relative abundance (Figure 3.9-13) was very high beyond the 40-m isobath, but all values above 25% occurred in shelf edge or slope samples; the highest value of the relative abundance was 58% (2G, winter).

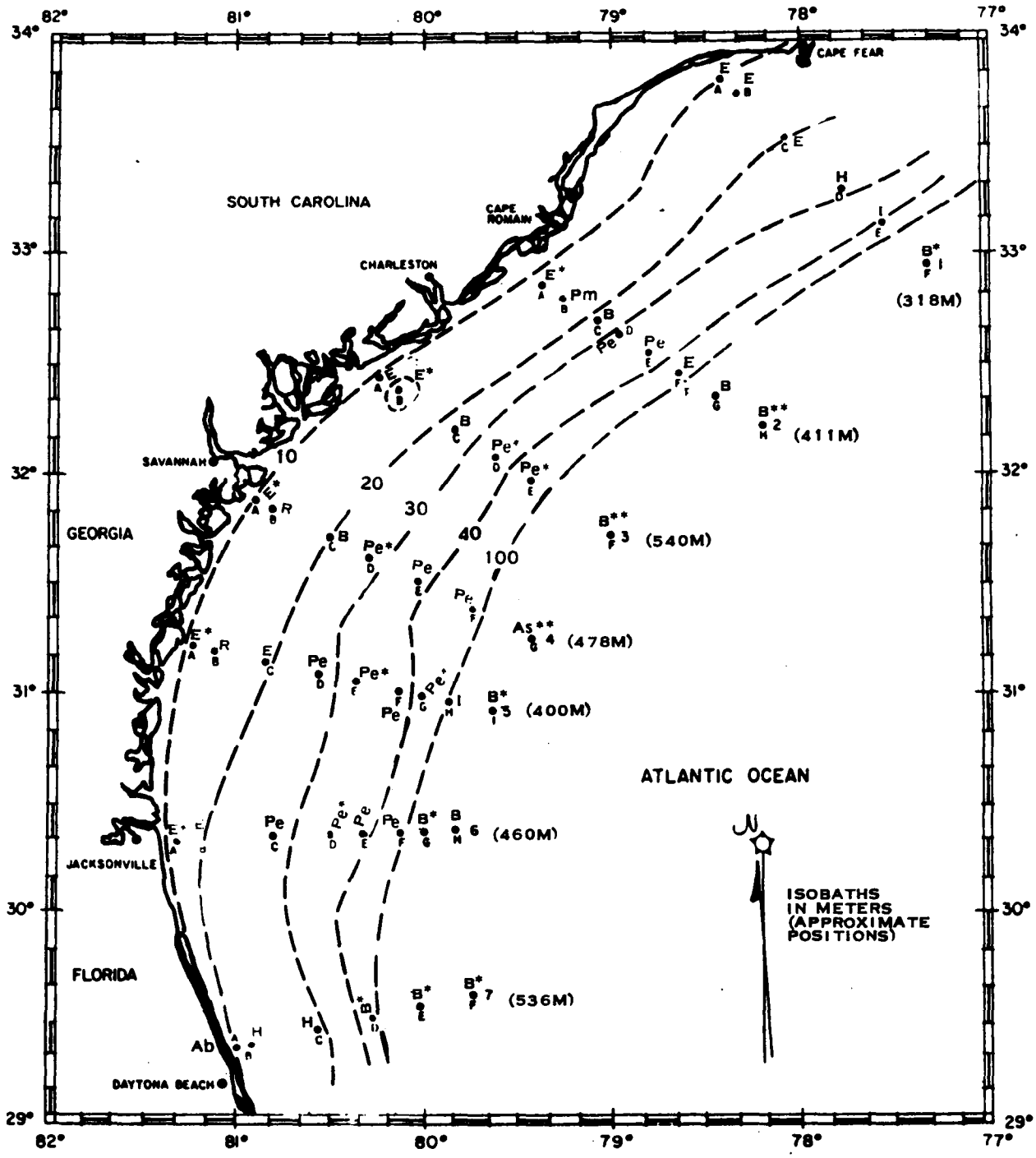
Table 3.9-10. Dominant Species (Rank-Ordered) by Station[a]

Transect	Season	Station A	B	C	D	E	F	G	H	I
1	Winter	36, 17, 35, 1, 51, 27, 42	17, 51, 46, 36, 23, 9	17, 36, 23	23, 33, 46, 17	23, 33, 25, 20, 16	6, 12, 49			
	Spring		17, 1, 6, 36	17, 23, 36, 30, 26	23, 5, 33, 32, 17, 4	25, 23, 33, 6, 18	6, 25			
	Summer	17, 35, 1, 27, 36, 41	36, 35, 50	17, 23, 36, 40, 33, 1	25, 33, 5, 17, 36, 32	25, 33, 6, 23, 26	6, 25, 12			
	Fall		17, 1, 42, 36	1, 23, 17, 36, 43	31, 5, 33, 23, 36, 17	25, 6, 23, 33, 32	6, 25, 12			
2	Winter	17, 1, 42	33, 17, 36, 6, 23, 50	6, 23, 47, 33, 48	33, 32, 23, 5, 30	23, 33	25, 33, 26, 12, 13, 34	25, 6		
	Spring		32, 36, 1, 17, 40, 42, 5, 15, 23	6, 32, 33, 17, 23	33, 32, 47, 49, 25	33, 23, 25, 32, 22	25, 33, 6, 49, 47, 26	6, 25	6, 25, 13	
	Summer	17, 1	6, 25, 33, 36, 42, 17	33, 6, 42, 23	6, 33, 17, 47, 25	33, 25, 6, 32, 23	25, 6, 26, 33, 49, 32	6, 25		
	Fall		17, 5, 33, 23, 32, 1, 27, 36, 50, 42	6, 33	33, 38, 23, 6, 32, 40, 5	33, 25, 32, 23	25, 6, 33, 48	6, 25		
3	Winter	17, 1, 32, 48	17, 23, 1, 32, 36	36, 32, 33, 46, 6, 5, 1	33, 23, 32, 47	33, 23, 25, 22, 32				
	Summer	17, 33, 1 32, 23	17, 33, 36, 32, 1	6, 5, 33, 36, 48, 42, 23	33, 25, 6, 48	33, 25, 46, 32	6, 25			
4	Winter	17, 1, 48	17, 1, 6, 38, 48, 47, 36, 7, 37, 42, 9, 16	33, 1, 6, 17, 36, 31, 37, 25, 42, 5, 32, 23	33, 23, 5, 32	33, 23, 30, 22, 6, 48, 12	33, 25, 23, 30	2, 24, 6, 10, 3		

Table 3.9-10. Dominant Species (Rank-Ordered) by Station[a] (Continued)

Transect	Season	Station A	B	C	D	E	F	G	H	I
4 (cont)	Summer	17, 1, 33	42, 27, 6, 33, 32, 17	6, 33, 28, 25, 38, 48	33, 6, 25, 5, 48, 17	6, 25, 33, 26, 48	25, 6, 33, 26, 40, 16			
5	Winter	17, 1, 48	32, 6, 33, 17, 36	17, 33, 1	33, 23, 5, 21, 22, 25, 32	33, 26, 22, 47, 25, 32, 30, 23	33, 23, 48, 30	33, 25, 6, 48, 30, 23	25, 33, 6, 26	
	Spring		6, 33, 42, 25, 40, 32	33, 6, 1, 32, 17, 48, 25, 23	5, 33, 32, 23, 17	33, 47, 23, 32	33, 25, 32, 23, 47, 48, 40	33, 6, 25, 23	6, 25, 33, 23	6, 25
	Summer	17, 1, 6, 33	42, 26, 6, 48, 17, 52, 25, 29, 33	25, 33, 38, 17, 6, 19	33, 6, 5, 47, 25	33, 25, 42, 17, 6	33, 25, 38, 42, 23, 46, 47, 26, 36	33, 25, 47, 6, 40	6, 17, 25, 33, 40	6, 25
	Fall		23, 6, 25, 48, 33, 42, 17	17, 33, 26, 36, 6, 40	33, 25, 6, 29, 32, 42	33, 6, 26, 25, 32	6, 25, 42, 33, 47, 40, 32	33, 25, 47, 6, 38, 40	25, 6	33, 25, 14
6	Winter	17, 1	17, 48, 36, 40, 6	32, 33, 23, 6, 17, 26, 38	33, 23, 32, 30, 25, 26,	33, 23, 47, 26, 48	33, 32, 23, 26, 47	6, 25, 33, 30	6, 7, 49	
	Summer	17, 1	17, 33, 6, 42, 26, 36	33, 32, 17, 36, 23	33, 6, 17, 23, 32	26, 33, 6, 25, 48, 16	6, 25, 33, 26	6, 25, 33, 23, 48	6, 14, 44	
7	Winter	1, 17, 6, 48	23, 36, 40, 33, 17, 48	23, 15, 17, 36, 6, 26, 38	6, 25, 33, 23, 26, 48	6, 8, 25, 12, 40	6, 13, 25, 39			
	Spring		23, 17	23, 6, 32, 33	6, 33, 25	6, 8, 13, 12, 30	6, 49			
	Summer	1, 17, 6	17, 23, 26, 40, 6, 1, 26, 33	33, 23, 17, 26, 6, 25	6, 25, 26, 48	6, 25, 8	6			
	Fall		23, 17, 1, 33, 42, 6	33, 23, 17, 40, 41	6, 25, 16, 33	6, 25, 8, 11	6, 25			

[a]Occurring with relative abundances of 5% or more at stations for which they are listed. For numerical species code, see Table 3.9-9.



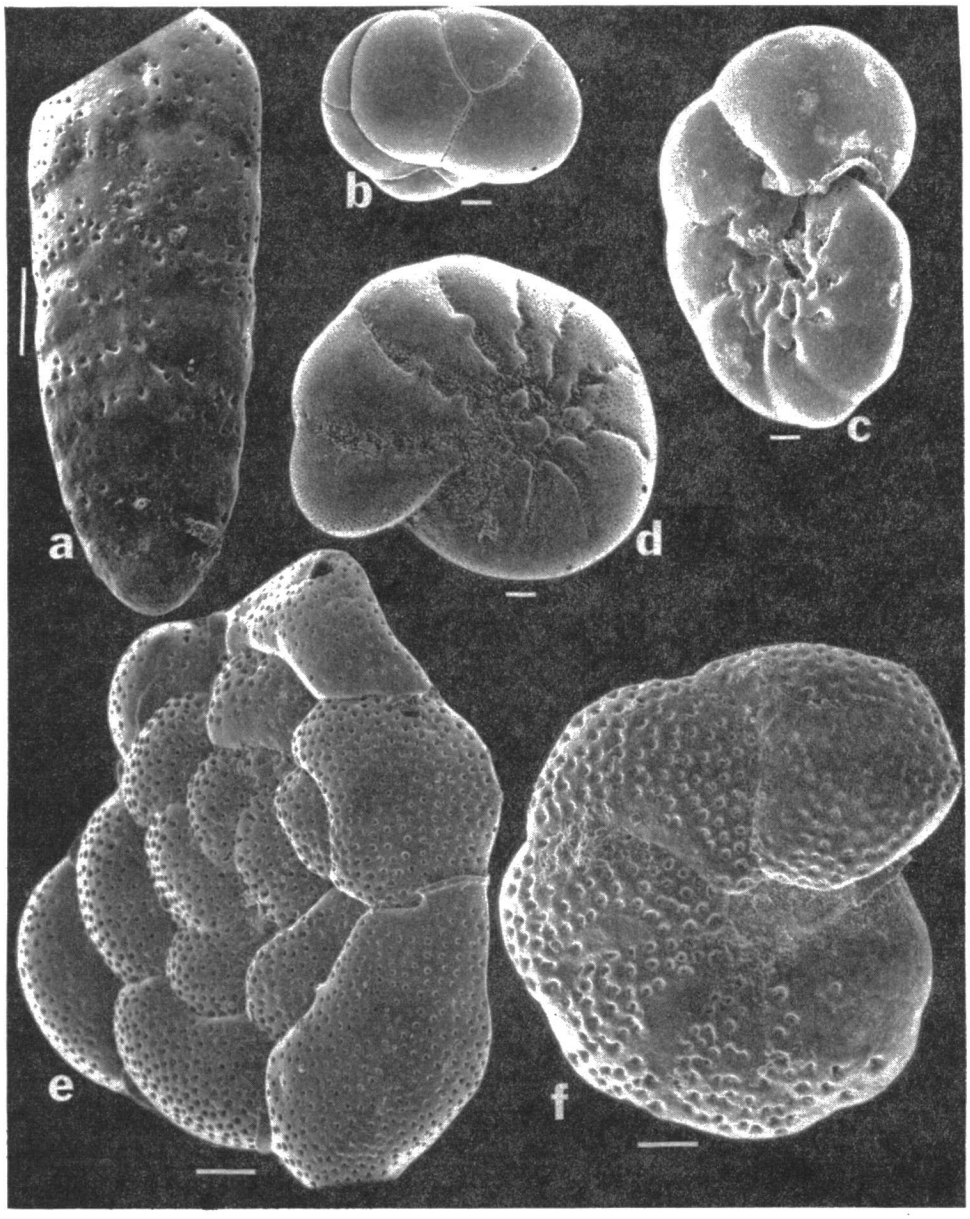
SPECIES CODES:

Ab = Ammonia beccarii
As = Anomalina semipunctata
B = Bolivina lowmani
E = Elphidium excavatum forma clavatum
H = Hanzawaia concentrica
I = Islandiella subglobosa
Pe = Planulina exorna
Pm = Planorbulina mediterranensis
R = Rotorbinella lomaensis

SCALE 1 = 3,000,000

*SAME SPECIES DOMINANT, ALL SEASONS
**OBSERVATION LIMITED TO ONE SEASON

Figure 3.9-7. Distribution of Characteristic Dominant Species (Only most dominant species shown for each station. When different species dominated a station in different seasons, the one that retained its dominance in most seasons was chosen; when the lead of any one species was not clearly the most persistent, the mean relative abundance for all sampling seasons was the criterion.)



a. Bolivina lowmani
b. Islandiella subglobosa
c. Hanzawaia concentrica
d. Elphidium excavatum forma clavatum
e. Planorbulina mediterranensis
f. Planulina exorna
—— = 0.05 mm

Figure 3.9-8. Representative Dominant Species of Benthic Foraminifera, Georgia Bight (Scanning electron photomicrographs by R.T. Kilbourne)

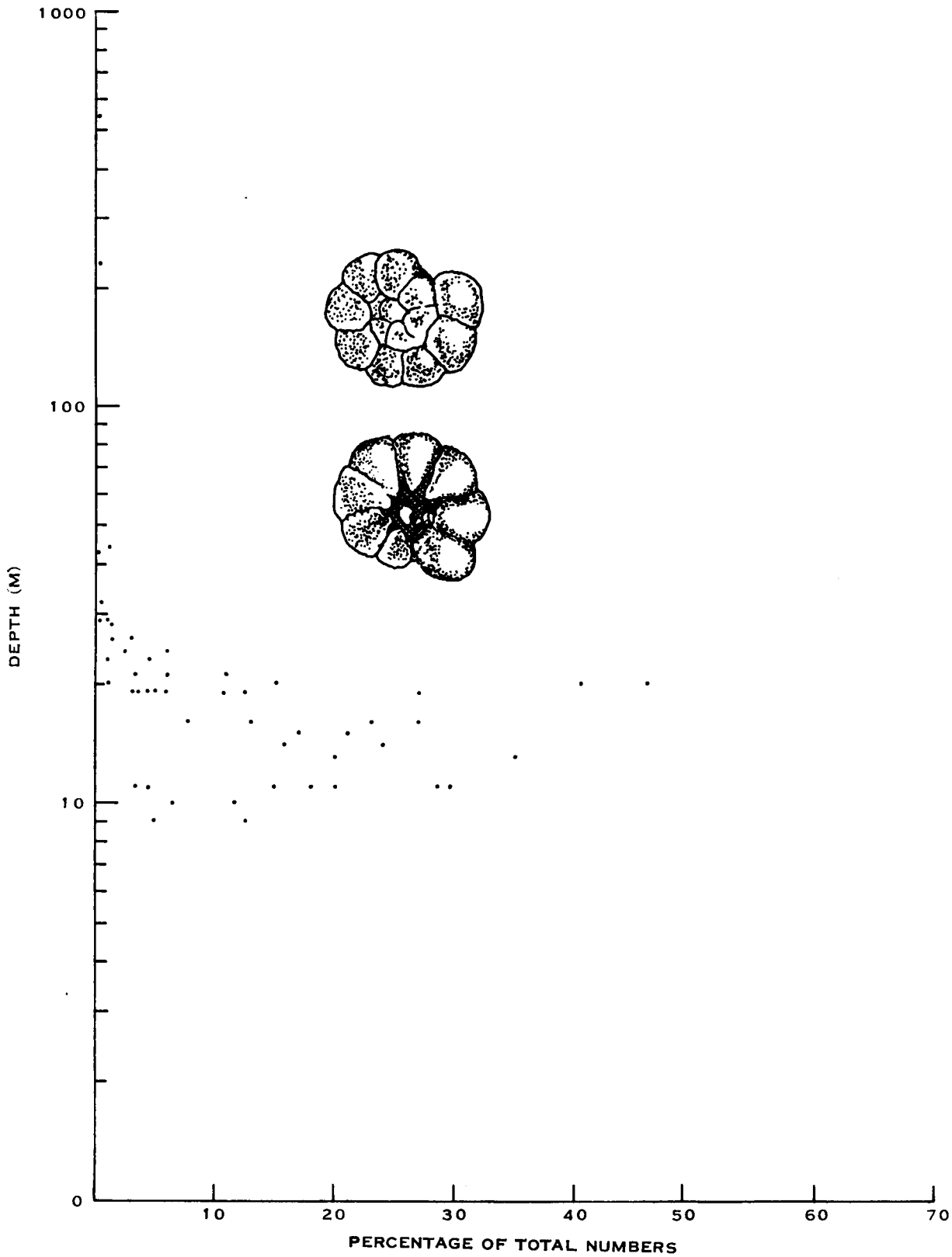


Figure 3.9-9. Relative Abundance of *Ammonia beccarii*

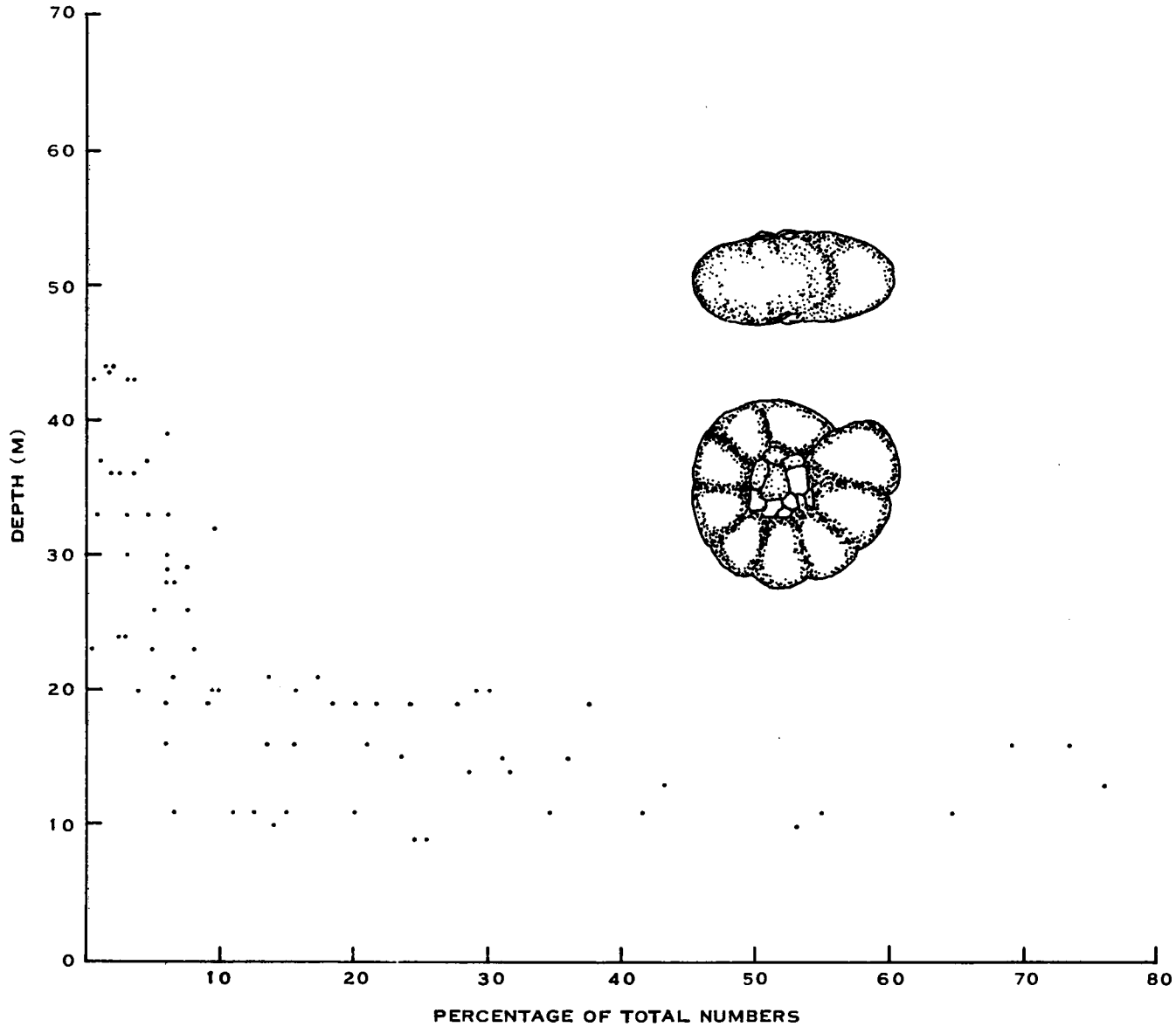


Figure 3.9-10. Relative Abundance of *Elphidium excavatum* forma *clavatum*

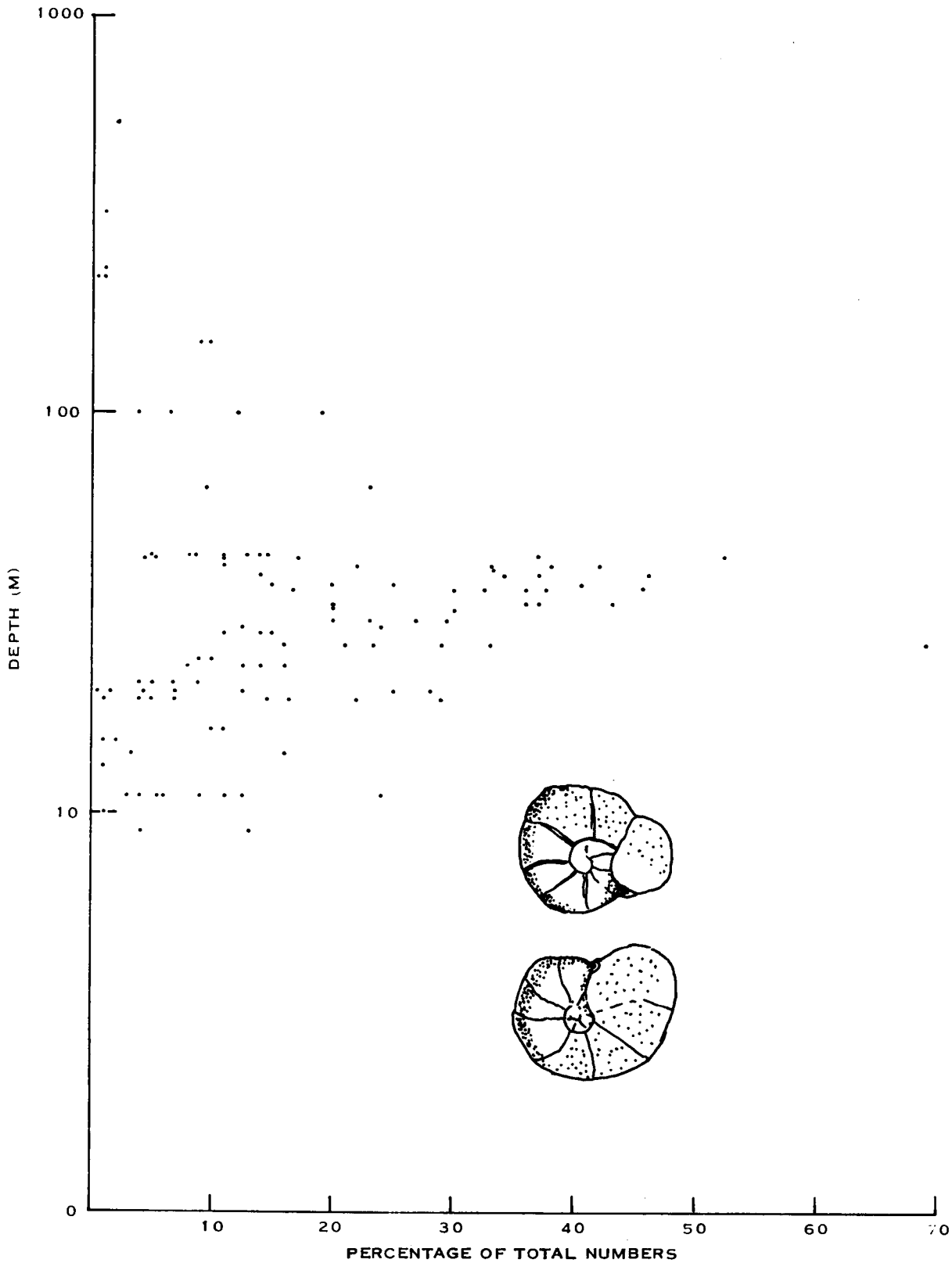


Figure 3.9-11. Relative Abundance of *Planulina exorna*

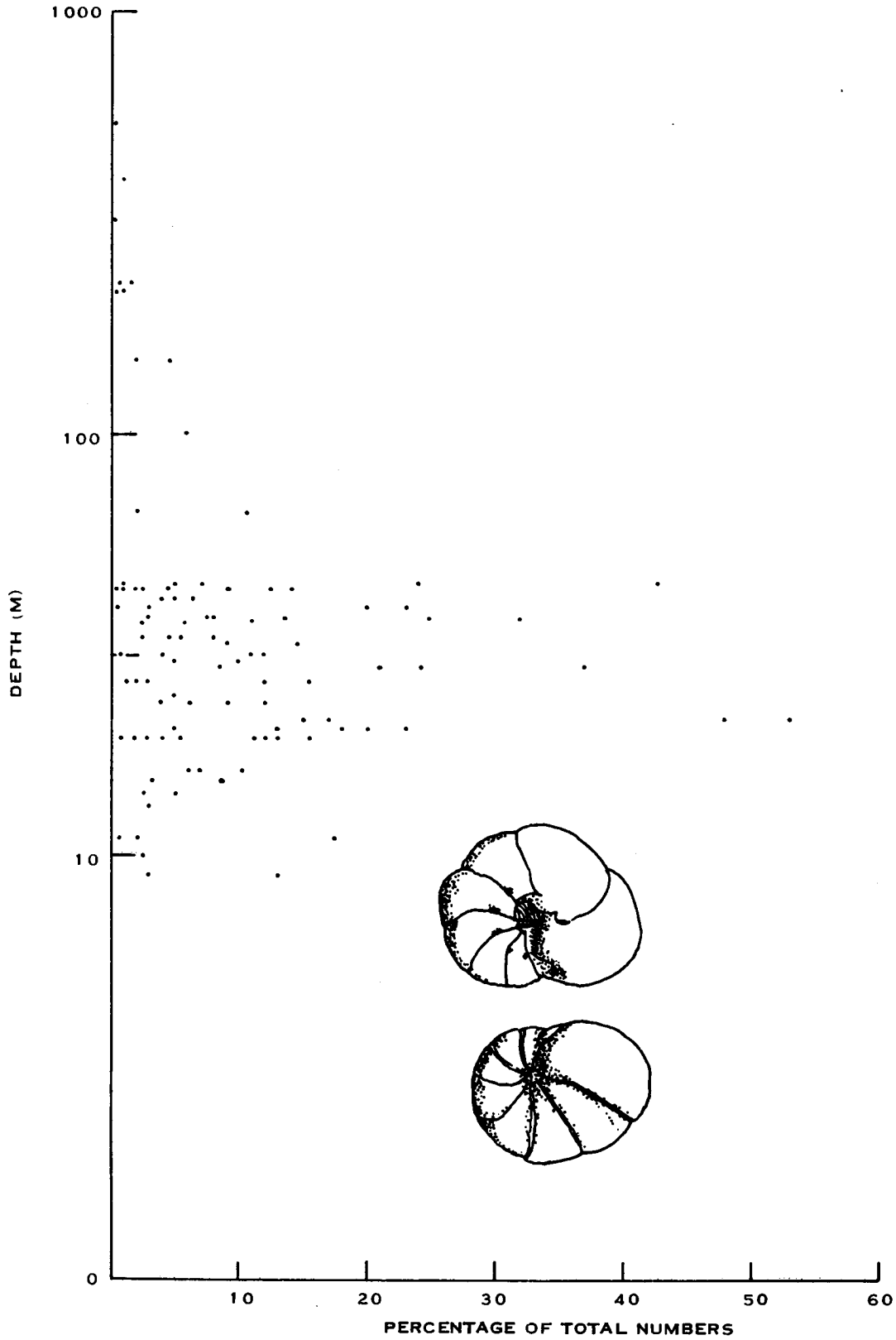


Figure 3.9-12. Relative Abundance of *Hanzawaia concentrica*

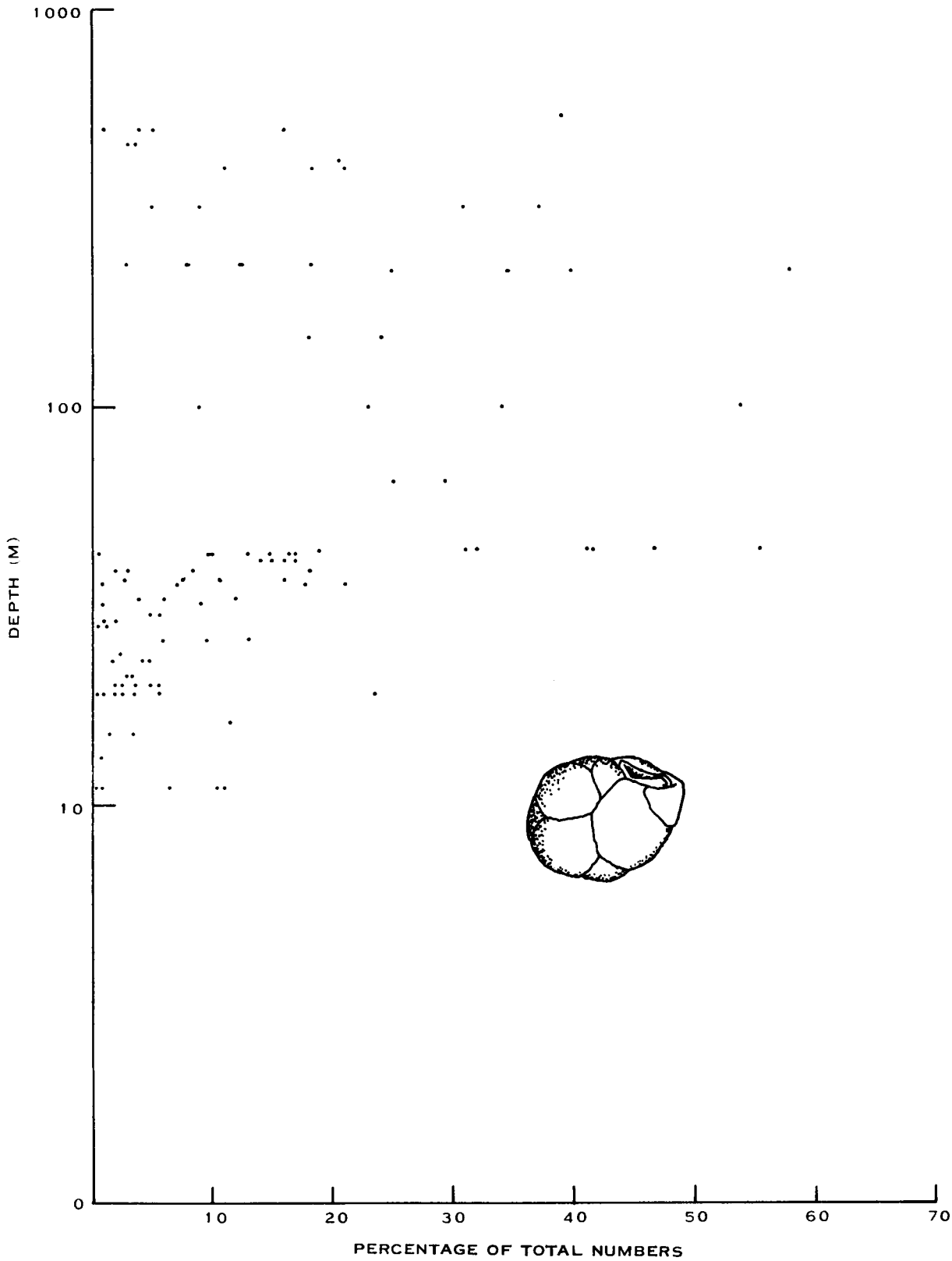


Figure 3.9-13. Relative Abundance of *Islandiella subglobosa*

Considering all the seasonal samples of the present study, *Bolivina lowmani* had the highest mean density among all foraminiferal species found in this study of the Georgia Bight. This was primarily because the populations were very large (>100/3 cm^3) in nine slope samples; the maximum was 3,479 at 7E in the fall. In a majority of the shelf samples, density was generally low (<1/3 cm^3). The only inshore station where *Bolivina lowmani* attained a moderate density was 7A; the mean value for two seasons was 36 (c.v. of 12%). The plot of the relative abundance against depth (Figure 3.9-14) shows a high scatter in virtually all depth ranges. With one exception, however, all values above 60% represent samples from stations deeper than 100 m.

F. ANALYSIS OF VARIANCE

The analysis of variance (ANOV) was performed on the mean relative abundance of the three major suborders (Textulariina, Miliolina, and Rotaliina) and a number of species within these suborders (Appendix 3.9D). The variance was considered significant if the probability was ≤0.05 in the test of the F statistic (for season or station effect) on the ANOV table. The following inferences were made with the help of Duncan's multiple-range test.

Station differences are apparently significant for the suborders, but the groupings do not show any obvious geographic patterns. The same inference can be made regarding the interstation variances of *Textularia conica* and *Quinqueloculina lamarckiana*.

Both seasonal and station differences are significant for *Bolivina lowmani*. The winter mean is significantly lower than the means for the other three seasons. The stations include two mutually exclusive sets (Figure 3.9-15). The means for stations in set 1 (○) are significantly higher than those in set 2 (Δ); within each set, the differences in means are not significant. Set 1 consists of eight slope stations; set 2 consists of 13 shelf and shelf-edge stations.

For *Islandiella subglobosa*, the means at a number of shelf-edge and slope stations (1E, 1F, 2F, 2G, 4F, 5H, 6G) are significantly higher than the means at all other stations except 2H and 5I.

For *Planulina exorna*, two sets of stations can be recognized with significantly different means between the sets (but not within them). The set with higher means (set 1, ○ in Figure 3.9-16) consists of 13 shelf and shelf-edge stations; the one with lower means (set 2, Δ in Figure 3.9-16) consists of six slope and two inner-shelf stations.

The means of relative abundances of *Ammonia beccarii* are significantly higher in the winter samples than in the other seasonal samples. Station differences in the mean clearly identify the preferred habitat of this species. The stations on the nearshore ends of the transects (except 1A) show significantly higher means than all other stations. A similar preference for the nearshore habitat is exhibited by *Elphidium excavatum* forma *clavatum*. The means of the relative abundance of the taxon are significantly higher at the A stations on all transects than at the remainder of the stations.

G. REGRESSION ANALYSIS

Dominant taxa selected for multiple-regression analysis (by general linear models) included three suborders, 17 families, and 47 species and varieties (Appendix 3.9C). The parameters examined were the median grain size of the sediment, ϕ quartile deviation, proportion of silt and

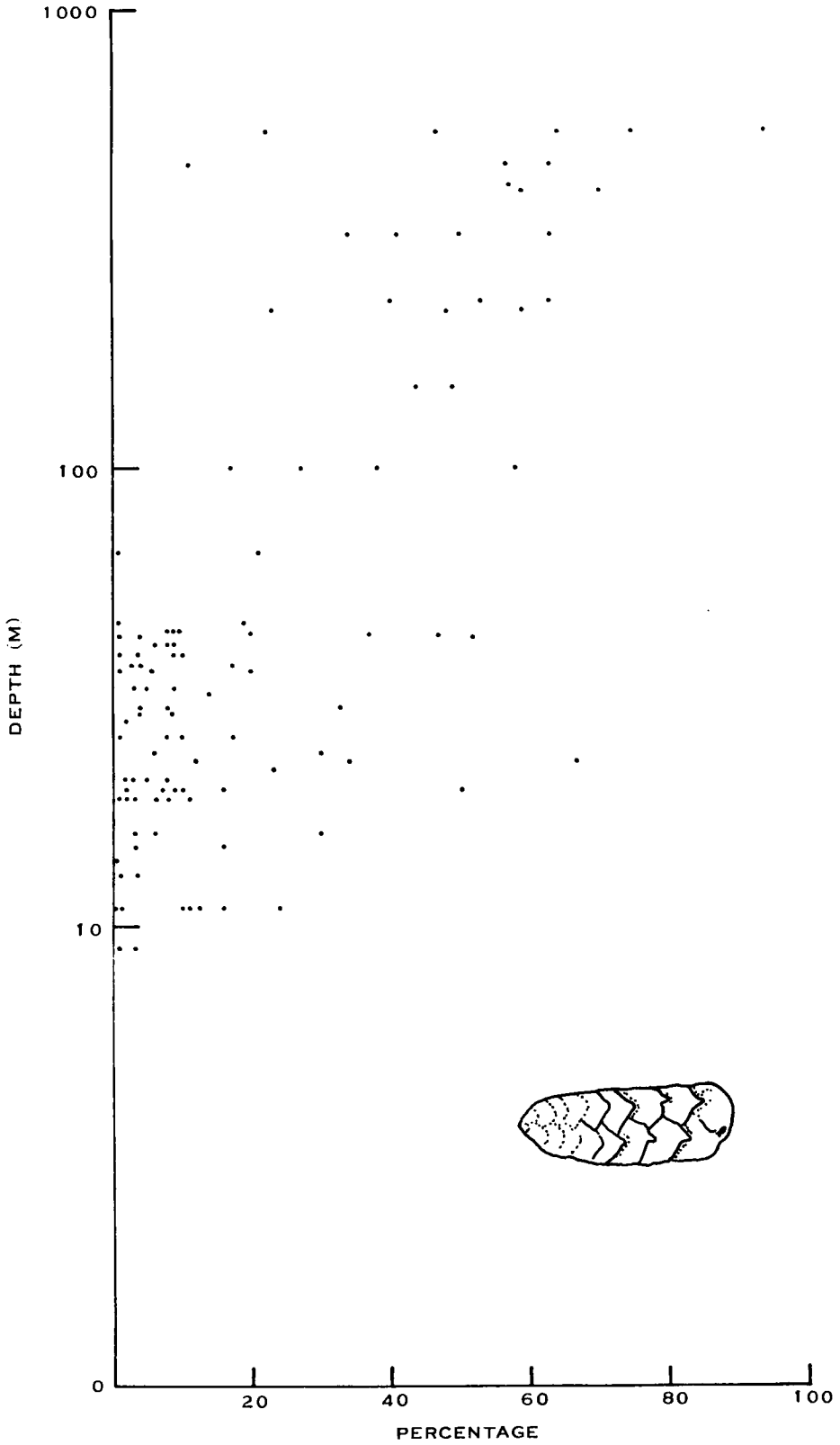


Figure 3.9-14. Relative Abundance of *Bolivina lowmani*

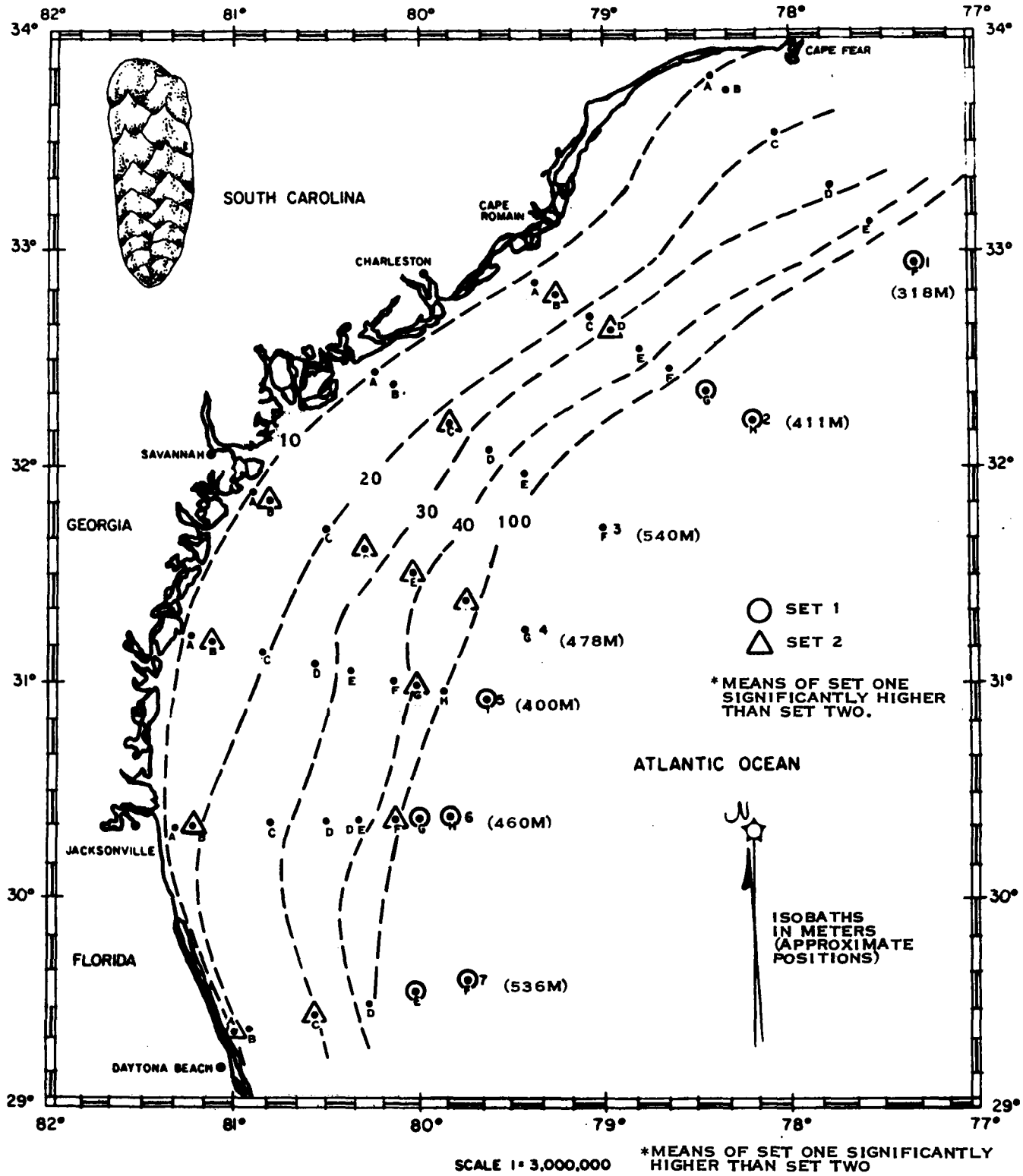


Figure 3.9-15. Station Differences Shown by Analysis of Variance of *Bolivina lowmani*

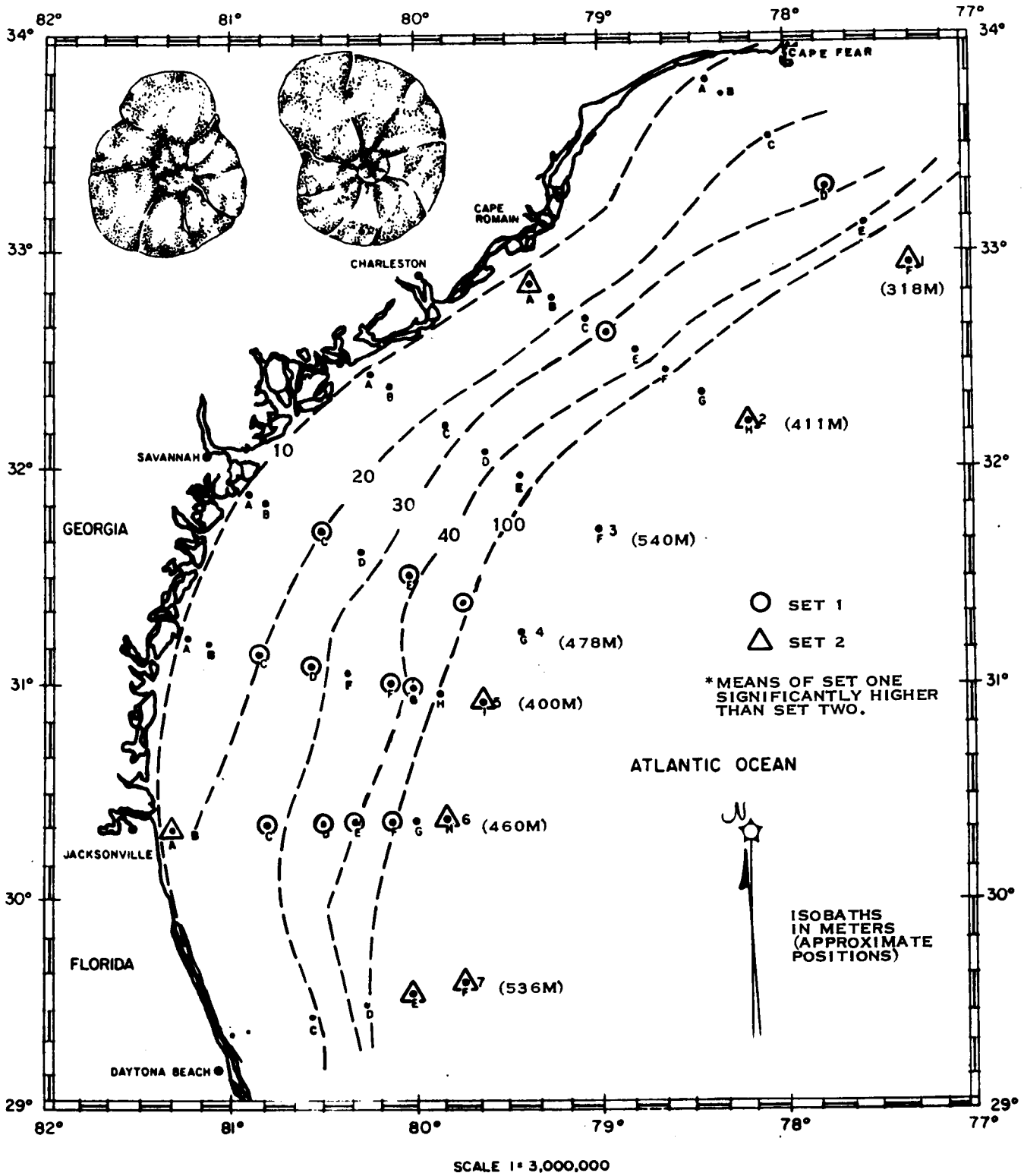


Figure 3.9-16. Station Differences Shown by Analysis of Variance of *Planulina exorna*

clay in the sediment, total organic carbon (TOC), depth, latitude, and effect of seasons. The relationship with bottom-water temperature could not be examined because of missing data at several stations. When the seven parameters, combined, accounted for ⩾50% of the variance ($R^2 \geqslant 0.5$ in the ANOV table), the results of the second multiple-regression analysis (by stepwise improvement of R^2) were examined to assess the relative effects of the measured parameters on the abundance variation of the taxa. The few significant results obtained from the regression analyses may be summarized as follows.

The relative abundance of the family Bolivinitidae has a significant positive correlation with depth. The second most effective variable is the proportion of silt and clay in the substrate. Similar correlations with the two parameters are shown by *Bolivina lowmani*, the most abundant species in the family.

The proportion of silt and clay in the sediment is the one variable that has a strong positive effect on the abundance of *Brizalina subaenariensis* var. *mexicana* and *Bulimina marginata*. The coefficients of determination (R^2) are 0.45 and 0.50, respectively, for the two species when the analysis is performed with this variable alone. The other variable with a significant positive effect on the relative abundance of the two species is the seasonality in spring.

H. CLUSTER ANALYSIS

1. Introduction

As explained earlier, two procedures of Q-mode cluster analyses were followed: the Jaccard similarity coefficient, based only on presence/absence of species, led to one set of cluster diagrams; a principal-components analysis (PCA), followed by clustering with the use of Euclidean distances on several principal components, led to a second set of dendrograms. The two types are referred to simply as the Jaccard clusters and the PCA clusters. The winter sample from station 3F and the summer sample from 4G, even though present in some dendrograms, were not used for interpretation of the clusters because of the unreliability of the species frequency data from these samples.

2. Jaccard Clusters

The Jaccard clusters proved to be less useful in the present study than the PCA clusters. The dendrograms are in Appendix 3.9A.

In the Jaccard dendrogram for the winter samples, no major clusters are seen at a high level of similarity. At the phenon line of 0.5 (on a 0 to 1 scale), all clusters consist of three or fewer stations. At the low similarity level of 0.14, there are three major clusters, each with >12 stations, but no special patterns are discernible, except that all but one of the slope stations belong to a single cluster. At the same or a slightly higher level (0.2) of similarity, the spring stations cluster into three groups; all the slope stations (for this partial sampling season) now join to form one cluster. The clustering of the summer stations reveals no conspicuous distribution patterns.

The Jaccard dendrogram for fall is comparable to that for spring. Again, one of the clusters consists of slope or shelf-edge stations; the separation between the slope and the shelf stations, however, is not as distinct as in the spring dendrogram. The composite Jaccard cluster diagram

with all the seasonal samples is not particularly illuminating with regard to bathymetric or geographic grouping of stations or the similarity of seasonal samples from the same area.

3. PCA Clusters

The data matrix of the relative abundance of species was reduced to facilitate the principal-components analysis (Appendix 3.9B). For the seasonal samples, the species and varieties with ≥0.1% mean relative abundance (calculated on the basis of the mean numerical density at stations) were taken into account; for the comprehensive PCA for all stations and all seasons, the critical mean abundance was taken to be 0.002%. Thus, 46 taxa were considered for the winter samples, 24 for spring, 43 for summer, 23 for fall, and 97 for the total pool. A large number of factors (principal components) had to be extracted to account for 70% or more of the variations: 13 (73%), winter; 7 (73%), spring; 12 (72%), summer; 7 (70%), fall; and 29 (70%), all seasons combined.

Both the winter and summer dendrograms (Figures 3.9-17 and 3.9-18, respectively) reveal sizable clusters at low Euclidean distance levels (i.e., high similarity levels). In the winter dendrogram, 18 clusters are present at the phenon line, representing a distance level of 1.61, and only three of the clusters contain more than three stations; an identical number of clusters (also including three major clusters) can be recognized at the 1.28 phenon line in the summer dendrogram. The areal distribution of the stations belonging to the major clusters in each of these two seasons is shown in Figures 3.9-19 and 3.9-20. In terms of geographic contiguity, the most conspicuous cluster on the winter map (Figure 3.9-19) is C (□), which contains a majority of stations in waters shallower than 20 m. A comparable cluster (X) in the summer dendrogram and distribution map (Figure 3.9-20) is restricted to an even narrower depth range: it consists solely of the most inshore stations (all within a depth limit of 16 m) on all seven transects. For each of the two seasons, one major cluster (B in Figures 3.9-17 and 3.9-19; Y in Figures 3.9-18 and 3.9-20) mainly contains scattered stations between the 20- and 100-m isobaths. The stations within the smallest of the three clusters (A in Figures 3.9-17 and 3.9-19; Z in Figures 3.9-18 and 3.9-20) are erratically distributed on the shelf.

In the spring and fall dendrograms, no major clusters with apparent bathymetric or latitudinal significance can be recognized at low distance levels. The total-pool dendrogram (Figure 3.9-21), however, reveals the strong similarity among many inshore stations; of the 52 clusters present at the 1.19 phenon line, a majority consist of a single seasonal sample, and only three clusters (labeled 1, 2, and 3 in Figure 3.9-21) contain more than seven samples. In this context, it is remarkable that cluster 1 includes 12 of the 14 seasonal samples taken from the stations closest to the shoreline.

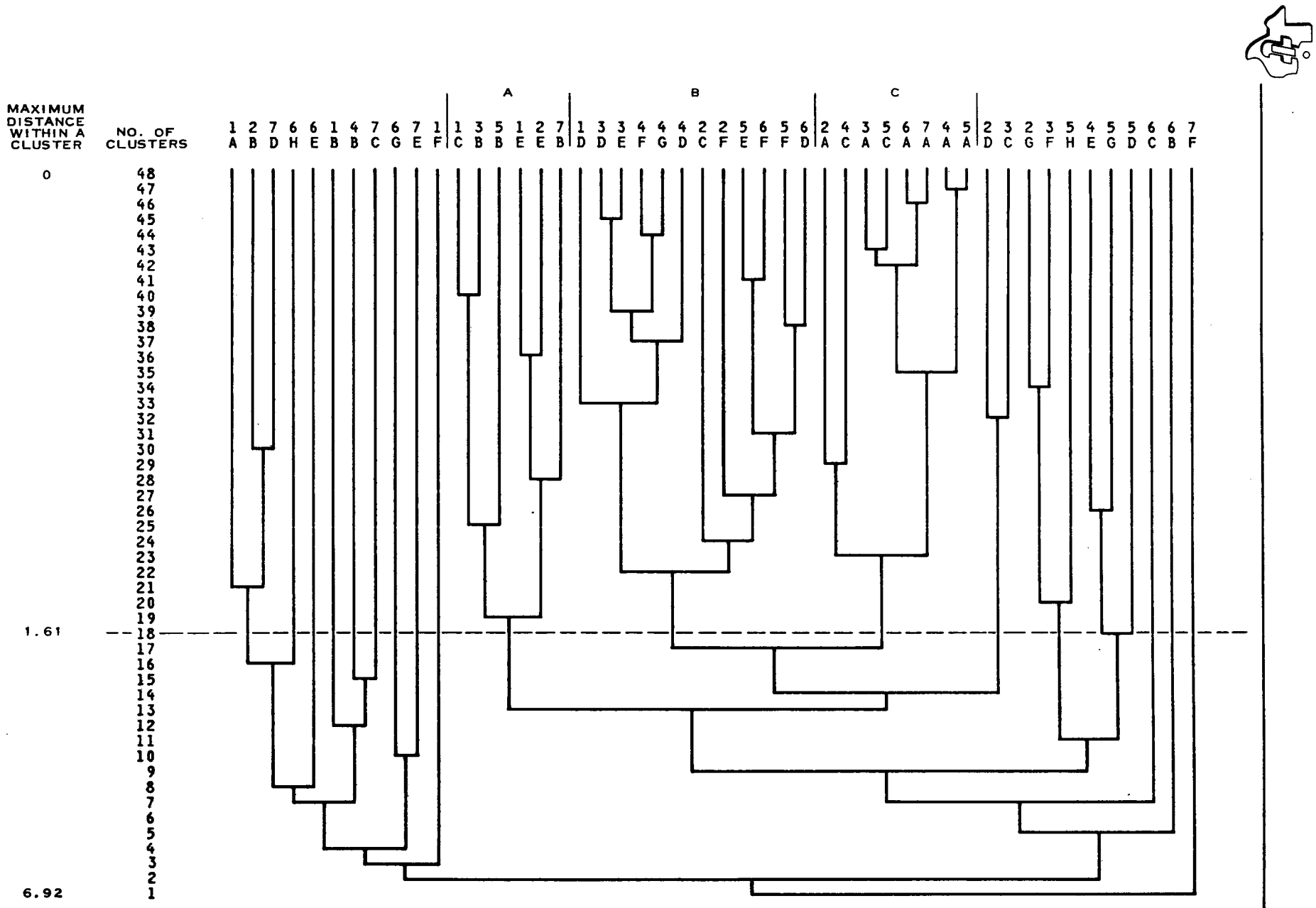


Figure 3.9-17. PCA Clusters for Winter Samples

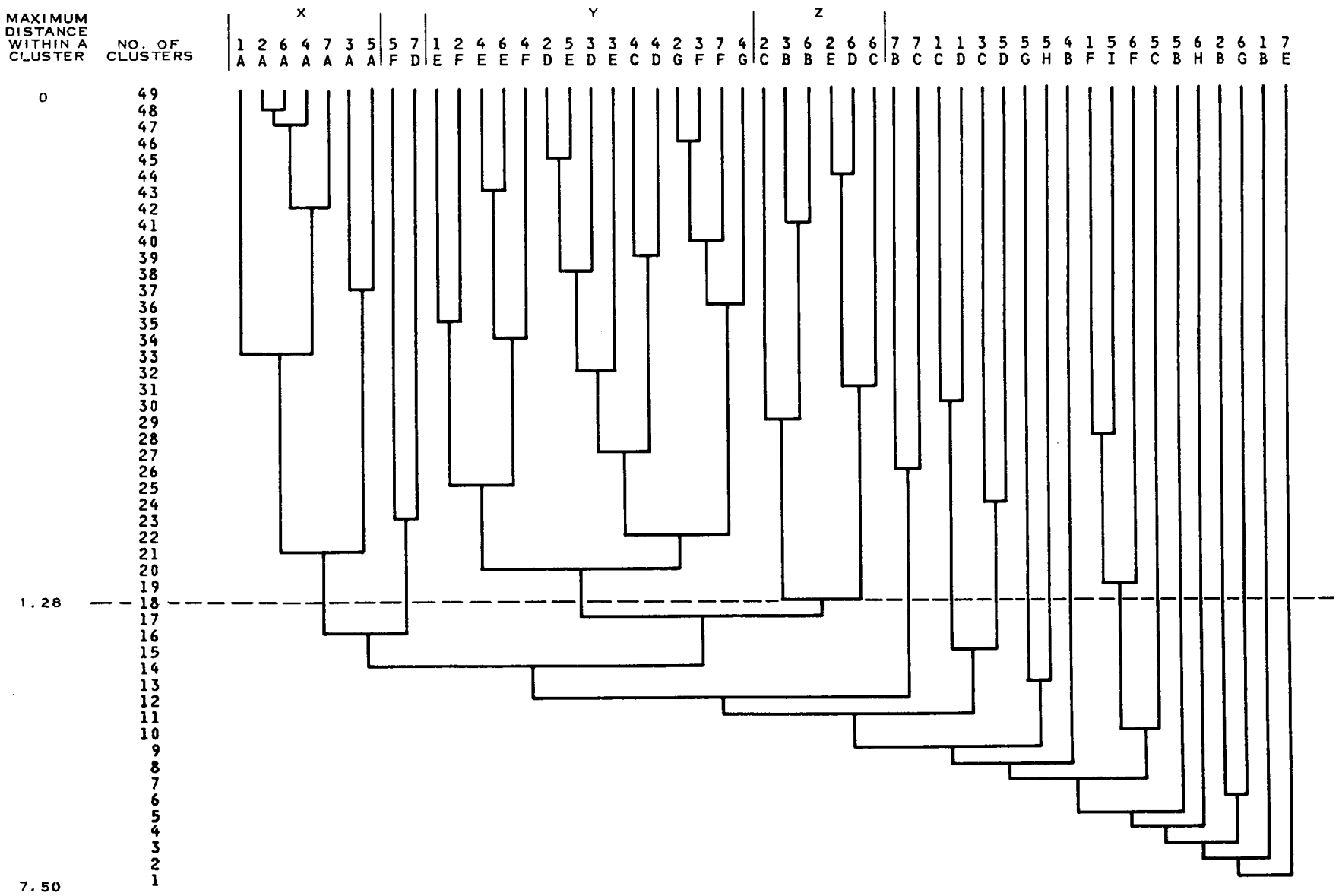


Figure 3.9-18. PCA Clusters for Summer Samples

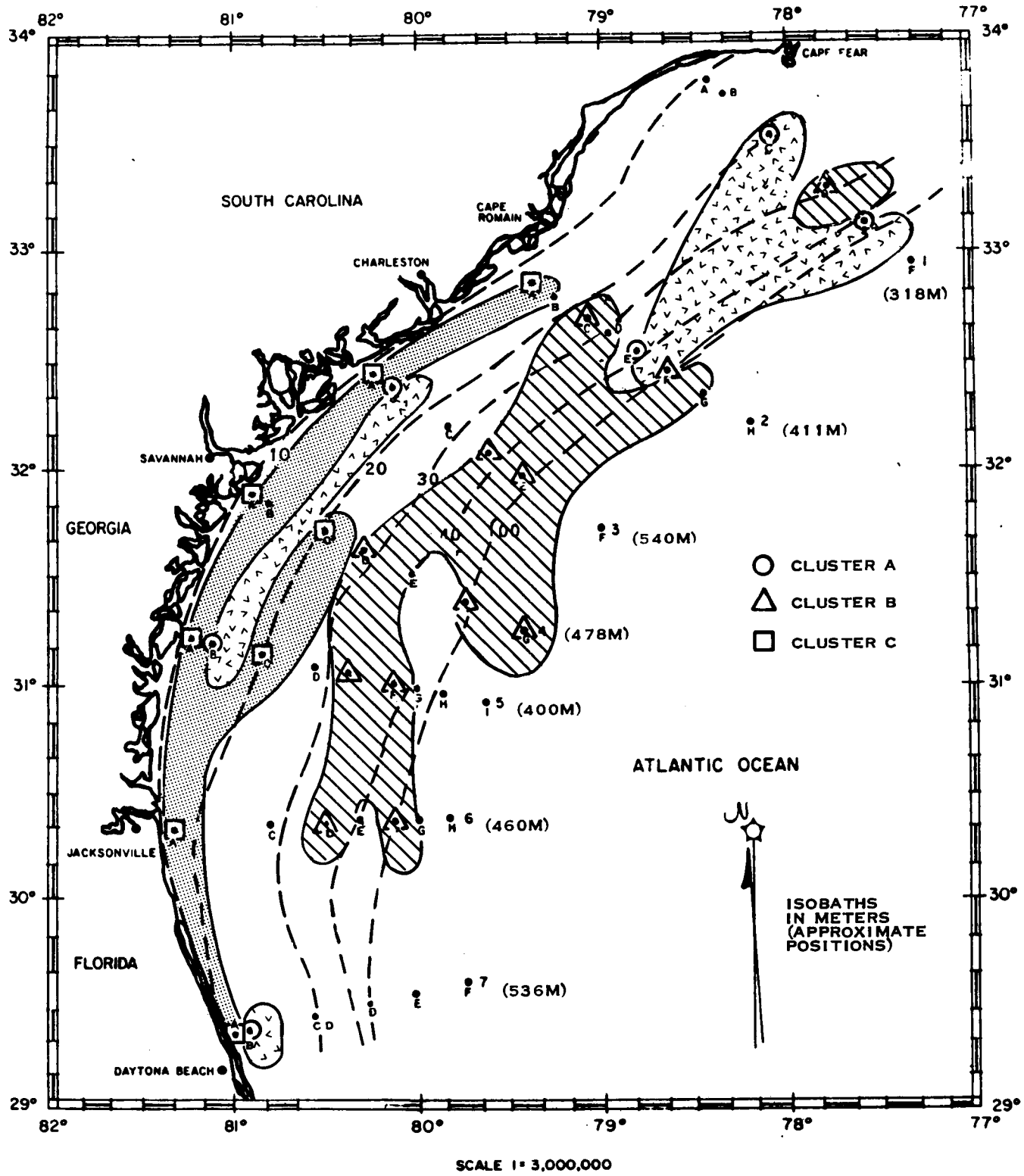


Figure 3.9-19. Distribution of Major PCA Clusters for Winter

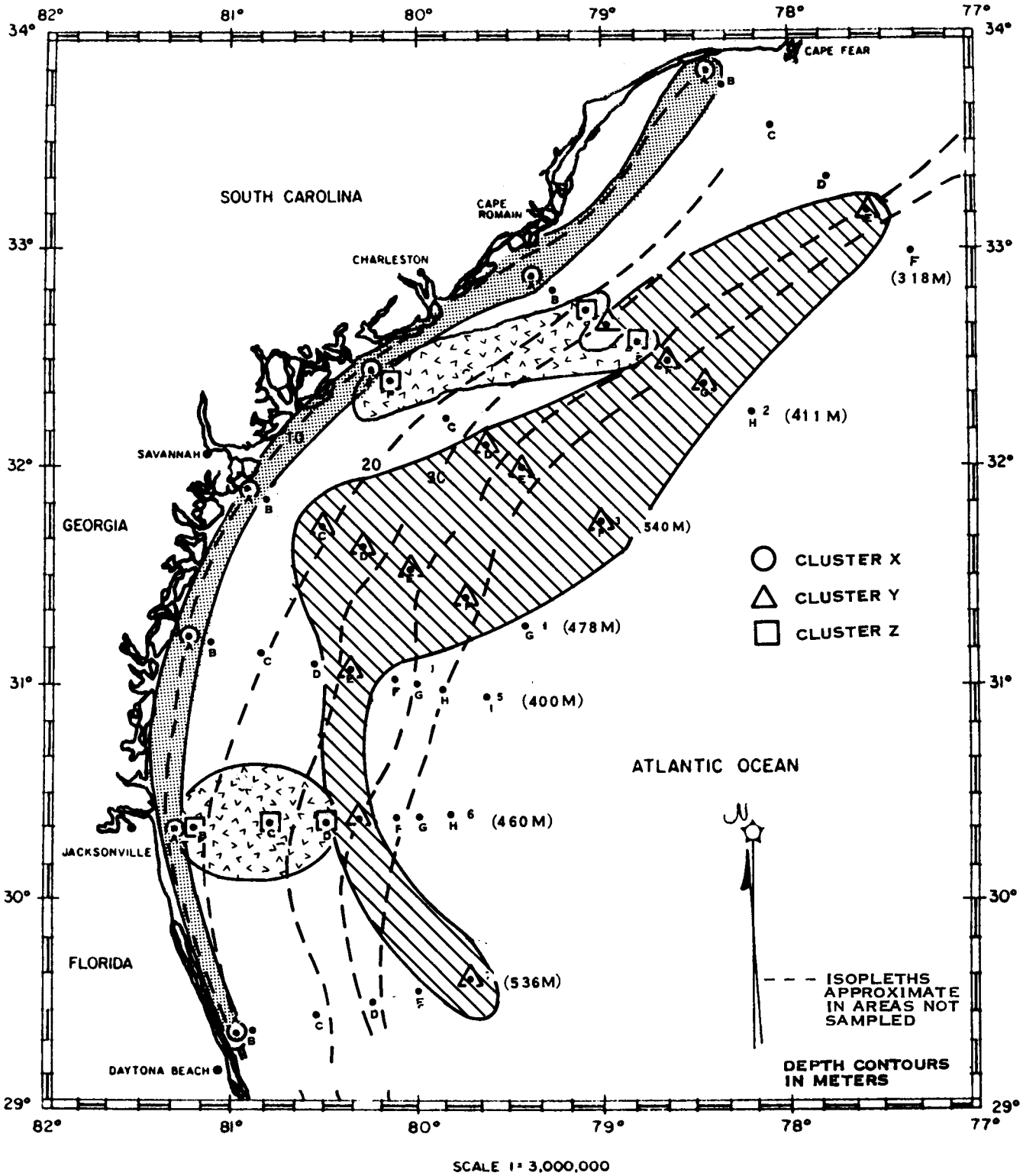


Figure 3.9-20. Distribution of Major PCA Clusters for Summer

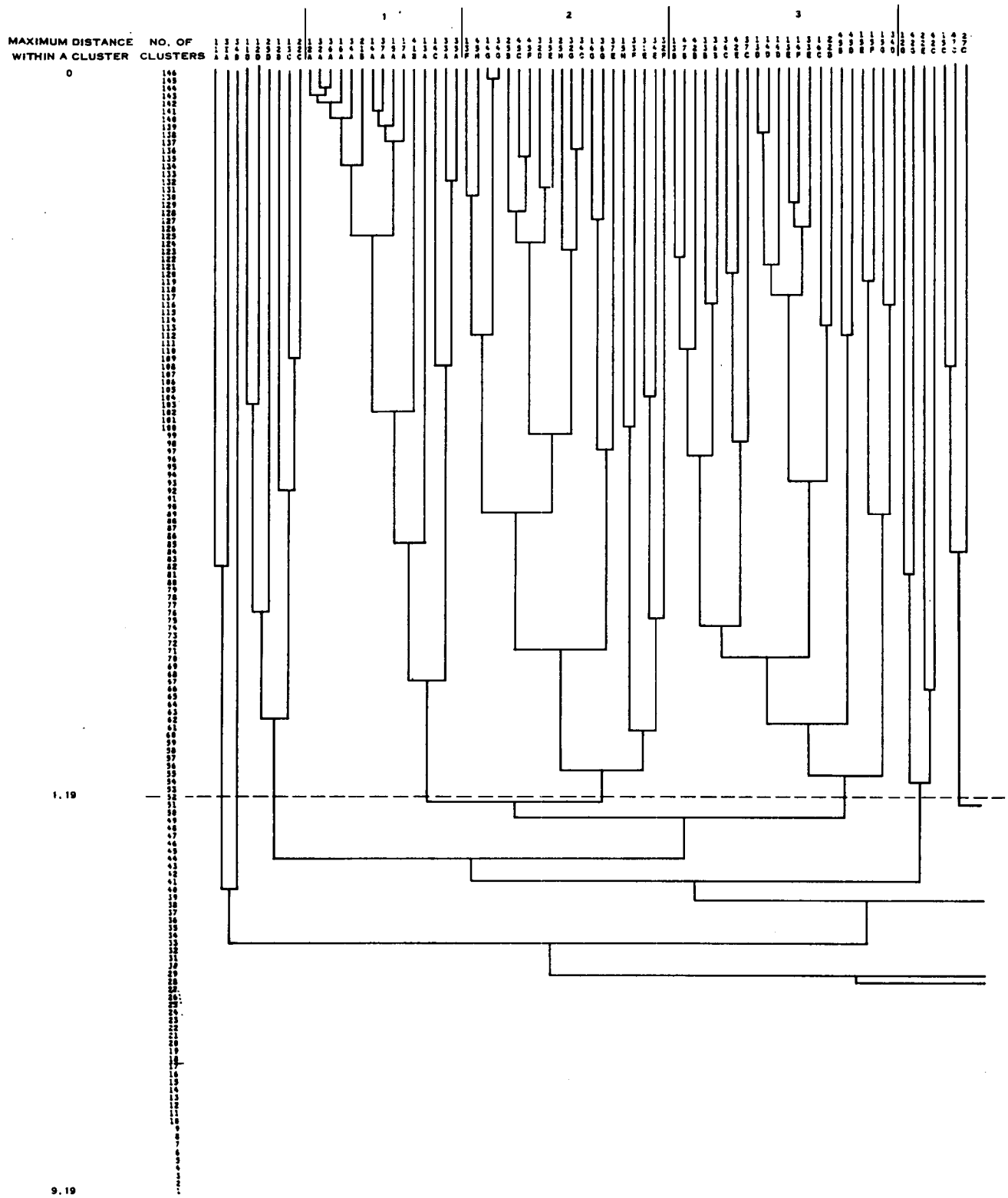


Figure 3.9-21. PCA Clusters (right side of dendrogram is not reproduced) for Samples From Four Seasons

SECTION 4
DISCUSSION

A. LIVING-TOTAL RATIO

The living-total ratio for benthic foraminifera has been used as an indicator of the rate of sedimentation (Phleger, 1960), but the model is dependable only in areas of minor transport of sedimentary particles after their initial deposition. In areas such as the middle and outer parts of the Georgia Bight continental shelf, the distribution of the values of the living-total ratio is expected to be erratic; the bulk of the finer particles deposited there has been winnowed out, leaving a relatively coarse, palimpsest substrate. The means of the seasonal values of the living-total ratio show high standard deviations. Means higher than 10 were seen at several inshore stations; the assemblages at stations on the nearshore ends of all transects except 1 and 3 had mean living-total ratios higher than 12; this rise was apparently related to the influx of terrestrial sediments carried by coastal rivers. Comparable values of the living-total ratio at a few slope stations (2G, 2H, 5I) may be related to high pelagic sedimentation.

The difficulty of explaining the living-total ratio by the rate of sedimentation is illustrated by the data from the MAFLA study area (Bock, 1976). The ratio was found to range between 6% and 60%. (The values are not directly comparable with those obtained in the SABP study because of Bock's use of a nonstaining technique for the recognition of living individuals.) Bock noted that the percentages were relatively high, even though the known rate of sedimentation in the region was low; he concluded that the observed living-total ratios were related to a bloom in many foraminiferal species during the sampling.

B. NUMERICAL DENSITY

The numerical density of the benthic foraminiferal assemblage ranged between 1 and 6,542/cm^2 surface area in the seasonal subcore samples (i.e., for a 3-cm^3 volume of the wet sediment). The average for all samples was 36. For the Georgia Bight as a unit, both the range and the average density are higher than in the BLM mid-Atlantic (New Jersey-Delaware-Maryland-Virginia) study area; for the latter area, Ellison (1977) reported a range of 0 to 1,000 and an average density of 110/20 cm^3. (Ellison used the rose bengal stain to recognize the living individuals.)

Intrastation and interstation variations in foraminiferal density were high within the Georgia Bight. General trends revealed were: highest values on the slope, moderately high values at stations shallower than 20 m, mostly low values on the middle and outer parts of the shelf, an irregular rise in the density from the northern to the southern transects, and an increase in density in substrates with a substantial proportion of fine particles, a spectacular increase being observed in samples (all from the same station) with >30% silt and clay. The high values of density in inshore and slope waters were seemingly related to the clay-silt factor; the substrate is finer than medium sand only in these waters.

The bathymetric trend of the increase in density was pronounced. All values higher than 500 were confined to the slope samples; values exceeding 300 were in the inner-shelf samples; and, between the 20-m and 40-m isobaths, the values did not reach 100. A latitudinal increase

becomes apparent when the mean densities along the extreme northern transect (range 5 to 21) are compared with those along the extreme southern transect (range 9 to 3,132). Winter, summer, and fall samples from station 7E had very high densities. This was the only station from which some seasonal samples showed population densities of certain species (*Bolivina lowmani, Brizalina subaenariensis* var. *mexicana, Islandiella subglobosa*) exceeding 500/3 cm^3.

The latitudinal variations of density seemed erratic in the outer part of the Bight where depth exceeded 400 m. A more thorough sampling of the area may reveal an overall homogeneity of the density. Off the North Carolina coast, densities of meiofauna (including foraminifera) were reported to be homogeneous within large areas at depths of 400, 800, and 4,000 m; patchiness seemed to be a "small-scale phenomenon" (Coull et al., 1977).

C. TRENDS OF DIVERSITY

Sen Gupta and Kilbourne (1974), from a study of a large number of Georgia shelf stations chosen by a stratified random sampling plan, demonstrated a rise in diversity values (S and $\bar{H}$) from the shoreline to water depths of about 15 m. On the middle and outer parts of the shelf, the values remained steady or showed slight increase. Actual diversity values were generally higher than those found in the SABP study, because the species assemblages for total (living and dead) populations were much larger than those for living populations. The values of the Shannon-Wiener functions of diversity ($\bar{H}$) in the present study, however, show the same general trend of increase on the inner shelf.

There was apparently a reduction in the mean value of $\bar{H}$ at stations deeper than 200 m. The high variability of the bottom water temperature in the inshore and slope areas may have caused the depressed diversity in these areas. In contrast, the middle and outer parts of the continental shelf provide relatively stable environments (in terms of factors such as water temperature, salinity, and substrate) and show no pronounced diversity gradient (Sen Gupta and Kilbourne, 1974). No latitudinal trends were recognized in any depth zone.

D. RELATIVE ABUNDANCE OF TAXA

The absolute abundance of all common taxa had more erratic geographic distribution than did relative abundance. Part of the discrepancy can be explained by the large populations of many species in a few samples of fine grain size.

The scatter plots of the proportions of the relatively less abundant suborders, namely the Textulariina (the agglutinated group) and the Miliolina (the porcelaneous group), show an inverse relationship with depth, especially near the shelf edge. The regression analysis indicates such a relationship—but at a low coefficient of determination.

The analysis of variance clearly shows that *Elphidium excavatum* forma *clavatum* and *Ammonia beccarii* have a distinct preference for the inshore part of the Bight. The ANOV test also shows that *Ammonia beccarii* constitutes significantly larger proportions of the assemblage in winter than in any other season. The data on both absolute and relative abundances of this species indicate a possible trend of a north-south increase within the inshore area.

The most widespread species of the shelf, *Planulina exorna*, shows a preference for the middle and outer parts of the shelf; the analysis of variance indicates a significant relationship. The highest proportions of the species are found near the shelf edge.

Bolivina lowmani has the largest population among all foraminiferal species of the Georgia Bight. A previous study of the total foraminiferal populations of the Georgia shelf (Sen Gupta and Kilbourne, 1976) did not reveal the importance of *Bolivina lowmani* in the living fauna because the small, fragile, dead tests of the species are easily destroyed in regimes of significant sediment movement such as those of the inner shelf and slope. The analysis of variance indicates lower percentages in the winter and a preference for the slope habitat. The species, however, tolerates a considerable depth range. Its proportions in shelf assemblages are high in samples of finer grain size. The regression analysis demonstrates that both water depth and percentage of silt and clay in the substrate have significant positive effects on the relative abundance of *Bolivina lowmani*. The ANOV test shows that *Islandiella subglobosa* is another common species with distinct preference for the shelf-edge and slope habitats.

A study of the patterns of species dominance establishes *Elphidium excavatum* forma *clavatum*, *Planulina exorna*, and *Bolivina lowmani* as the leading species of the inner shelf, the middle and outer shelves, and the slope, respectively. *Elphidium excavatum* forma *clavatum* also dominated many of the inner-shelf stations of the BLM mid-Atlantic study area (Ellison, 1977). The dominance pattern of foraminiferal species in the middle and outer shelves off Delaware and New Jersey (part of the mid-Atlantic study area), however, showed one marked contrast with that of the Georgia Bight: Ellison (1977) reported high proportions of *Reophax atlantica* in the assemblage; in the SABP study area, this species (called *Saccammina atlantica* in the taxonomic list, Appendix B in Volume 2) was rare.

E. DELINEATION OF FORAMINIFERAL BIOTOPES

The biotope boundaries that were established by the study are clearly depth-related. The most conspicuous PCA cluster for samples from one season or all seasons consists mainly of the stations nearest to the shoreline. The Jaccard dendrograms indicate a low-level similarity among the slope stations. The preferences of some dominant species for the inner shelf, the middle and outer shelves, or the continental slope are also demonstrated by the analysis of variance and the regression analysis. The offshore boundaries of the shelf biotopes are at depths of 15 to 20 m and 40 to 50 m. The deep-water boundary of the biotope covering the shelf edge and part of the continental slope cannot be determined from the present information. The 15- to 20-m boundary agrees well with the diversity gradient and with the results of a recurrent group analysis performed on the total frequencies of foraminiferal species of the Georgia shelf (Sen Gupta and Hayes, 1977); the outer boundary of the Georgia-shelf nearshore thanatotope, identified by Sen Gupta and Kilbourne (1976) on the basis of a cluster analysis of total foraminiferal data, was reported to be somewhat deeper.

In terms of special features of the foraminiferal assemblage, a station that requires particular mention is 7E. In all four seasonal samples, three taxa, *Bolivina lowmani*, *Brizalina subaenariensis* var. *mexicana*, and *Islandiella subglobosa*, represented 70% or more of the assemblage. *Bolivina lowmani* was the persistent dominant species (mean relative abundance, 52%), but the most unusual feature of the assemblage was the significant proportion of *Brizalina subaenariensis* var. *mexicana* (mean, 14%). This species (or variety) occurred at nine other stations (including 7C,

7D and 7F) on the shelf and slope, the density at each being <1/3 cm^3. At 7E, the densities of the species in winter, spring, summer, and fall were 307, 9, 261, and 521, respectively. The regression analysis establishes a significant positive correlation between the relative abundance of the species and the clay-silt content of the sediment. Among all the samples, the sediment at 7E had the highest clay-silt and hydrocarbon content (Chapters 3 and 4 in this volume and Appendix 3.9C in Volume 6) and very high total organic carbon (Appendix 3.9C); it yielded the highest seasonal and mean densities of the foraminiferal assemblage (Figure 3.9-3). In the PCA cluster diagrams for the four seasons, 7E did not join any cluster except at or near the last phenon line, which represents the maximum Euclidean distance or the lowest level of similarity among the stations. The distinction between 7E and adjacent stations was less sharp in the Jaccard dendrograms since the variation in the abundances of species is not taken into account in the calculation of the Jaccard coefficient.

F. STATE OF ENVIRONMENT

A comparison of living foraminiferal abundance and species diversity of the Georgia Bight with those of other open-shelf areas of the north Atlantic (Grand Banks, Cape Cod, the shelf and slope from New Jersey to Virginia, Cape Hatteras) indicates that the SABP study area supports a normal diverse assemblage typical of the Carolinian faunal province. In general, the physicochemical parameters of the marine environment that are known to have correlations with major features of benthic foraminiferal distribution include depth (a secondary factor reflecting the combined effects of several primary factors), bottom-water temperature, salinity, proportion of organic carbon in the sediment, and grain size of the substrate. Water depth and clay-silt content of the substrate are two environmental factors identified by regression analysis as significant in their effects on the distribution of some species of the Georgia Bight foraminifera. However, in a shallow marine area affected by engineering activity (Buckley et al, 1974, causeway construction across Canso Strait, Nova Scotia), factor analysis indicated that interspecific relations were more important in accounting for the distribution of foraminiferal populations than the measured physical and chemical variables. Trophic relations between the foraminifera and other organisms (Lipps and Valentine, 1970) are poorly known and may not help explain the obvious features of distribution. Pyritization in living foraminifera, an indicator of environmental stress (Seiglie, 1973), was not observed in the species, including *Ammonia beccarii* (Seiglie's indicator species from Puerto Rico). In terms of characterization of the area, seasonal changes in foraminiferal distribution were not significant.

G. FUTURE ASSESSMENT OF PETROLEUM PRODUCTION EFFECTS

Features of normal oil and gas production, i.e., structure emplacement, drilling, and the disposal of muds and cuttings (U.S. Department of the Interior, BLM, 1977), are not expected to cause any noticeable shifts of foraminiferal biotope boundaries. Sessile species (e.g., *Acervulina inhaerens, Calcituba decorata,* and *Placopsilina confusa*) whose preferred habitat is the coarse-grained substrate of the middle and outer shelf (particularly, the live-bottom areas) will probably show an even greater clumping than they do now because of the availability of drilling platforms as substrate. The significance of foraminiferal clumping because of man-made substrates has not been reported in the literature, but the new BLM program on the monitoring of Gulf of Mexico drilling platforms may yield interesting findings. The routine effects of oil and gas production are expected to be negligible with regard to the broad features of foraminiferal distribution, including seasonal and annual population densities.

Extensive pollution of the ocean floor by petroleum, however, will cause measurable changes in foraminiferal abundances and species distribution patterns. Using analogs of man-made effluents that increase the organic content of the substrate (Bandy et al., 1964; Seiglie, 1968; Schafer and Sen Gupta, 1969; Schafer and Cole, 1974), the main effects will be a sharp reduction in species diversity, changes in the locations of significant biotope boundaries, and a possible temporary increase in the relative abundances of a few species. Based on a published report on the relationship between abundances of foraminiferal populations and availability of organic carbon in the substrate (Seiglie, 1968), species of *Bulimina, Buliminella, Fursenkoina,* and *Nonionella* may adjust to a somewhat polluted environment better than the more abundant rotaliids. Also, the relative abundance of the leading species of the Georgia Bight, *Bolivina lowmani*, particularly numerous in fine sediments of the continental shelf and slope, may show a rise should there be a moderate hydrocarbon spill, even though the numerical density may decline. An extensive and sustained petroleum pollution, of course, is most likely to result in a substrate barren of all foraminifera.

A chronic or sustained oil spill is likely to remain in a fine-grained substrate for a protracted period. The species particularly abundant in such a substrate, in diverse depths of the Georgia Bight, include *Bolivina lowmani, Brizalina subaenariensis* var. *mexicana, Islandiella subglobosa, Elphidium excavatum* forma *clavatum,* and *Ammonia beccarii.* These and several other species may serve as indicators of the extent of the environmental deterioration.

H. PLANS FOR ADDITIONAL STUDY

The characterization of a large marine area such as the Georgia Bight on the basis of 1 year's foraminiferal samples from 50 stations necessarily leaves room for substantial improvement. Three approaches are suggested here for additional study in the future, depending on available resources:

(1) Repetition of the sampling program for at least another year to cover the entire area. The foraminiferal investigation formed only a part of the overall benchmark study, and the sampling design will have to meet the requirements of diverse specialists. If a new design is preferred, a stratified random sampling plan would best serve the needs of the foraminiferal study. The stratification should be based on depth intervals—10 m from the shore to the shelf edge and 100 m on the slope.

(2) 1- to 2-year sampling of the area between the 50-m and 500-m isobaths, using closely spaced stations chosen under a random sampling plan. The present conclusions regarding the foraminiferal biotas of this area are the most tentative.

(3) 1- to 2-year sampling around transects 1 and 7, with stations being selected on a random sampling plan. Such a study would clarify the latitudinal variations within the major foraminiferal biotopes. The limits of distribution of the special biota of station 7E would be established by following this scheme or (2).

SECTION 5
CONCLUSIONS

The living foraminifera of the Georgia Bight constitute one of the most diverse assemblages known from the continental shelf and slope of the eastern United States. In the seasonal samples of 1977, 184 species were present as living populations; 52 of these occurred with ⩾5% frequency in at least one sample. The living-total ratio was generally <10%, except in the nearshore area and at a few slope stations.

The numerical density of foraminifera is extremely variable. The highest values are associated with a high clay-silt content of the substrate and are confined to parts of the slope and the inner shelf. The mean densities in the southernmost part of the area (transect 7) are greater than those in the northernmost part (transect 1). The Shannon-Wiener function of species diversity does not show any pronounced trend on the middle and outer parts of the shelf but shows low values in depths <15 m and >200 m.

The most numerous species of the Georgia Bight is *Bolivina lowmani*, dominating mainly the slope biota. *Islandiella subglobosa* dominates several shelf-edge stations. *Planulina exorna* dominates the middle- and outer-shelf assemblages. *Elphidium excavatum* forma *clavatum* and *Ammonia beccarii* are the principal dominant species of the inner shelf. Significant seasonal variations in relative abundance were observed for *Bolivina lowmani* (winter low) and *Ammonia beccarii* (winter high). The mean abundance of *Ammonia beccarii* increases in the southern part of the inner shelf. Water depth and composition of the substrate have pronounced effects on the abundance of several species.

The variation in faunal similarities among stations demonstrated a bathymetric control on the boundaries of the major foraminiferal biotopes. On the continental shelf, these boundaries are at depths of 15 to 20 m and 40 to 50 m. The outer boundary of the deep-water biotope (shelf edge and part of slope) has not been determined. The most distinct cluster was formed by the inner-shelf stations. The station showing the least similarity with the rest of the stations was 7E. The high foraminiferal density and the unusual composition of the assemblage at this station may be related to the high hydrocarbon and total organic carbon content of the sediment.

The species considered particularly suitable for monitoring the state of the benthic environment include *Bolivina lowmani, Brizalina subaenariensis* var. *mexicana, Islandiella subglobosa, Elphidium excavatum* forma *clavatum,* and *Ammonia beccarii.* A major change in the environment will cause biotopes to shift and both the absolute and relative sizes of populations of foraminiferal species to change.

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CHAPTER 10

HISTOPATHOLOGY OF BENTHIC MACROINVERTEBRATES AND DEMERSAL FISHES

by

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ABSTRACT

Benthic invertebrates and demersal fishes were collected by otter trawl at a series of stations on the outer continental shelf of the Georgia Bight (Figure 3.1-3) in February, May, August, and November 1977 for use in normal histology and histopathology studies as part of the South Atlantic Benchmark Program (SABP) performed by Texas Instruments Incorporated for the Bureau of Land Management. Such data will permit the interpretation of changes in cells and tissues of animals in the same area after development for oil and gas production.

A total of 38 species was examined; 10 species (two bivalve and one cephalopod mollusc, three crustaceans, and four demersal fishes) were examined intensively for histopathology.

Normal tissues were examined by light and electron microscopy; abnormal tissues were studied primarily by light microscopy, but electron microscopy was used on some. The results are illustrated in a separate atlas, Volume 4, of this SABP final report.

Respiratory, digestive, and reproductive tissues were subjected to the most intensive examinations. No tumors were found, nor was there evidence of chemical damage.

Animal parasites, particularly helminths, were plentiful in both invertebrates and fishes. The incidence of infection is often high (i.e., 80 to 100%), but the pathology induced is usually not extensive; in some individual animals, however, more extensive damage and disease is evident. Bacterial infections were detected as well as numerous lesions of unknown etiology. There are suggestions that some infections vary with season but probably not with location.

Overall, the histopathology of the animals examined is consistent with the concept of a normal, unstressed population of benthic invertebrates and fishes.

SECTION 1
INTRODUCTION

The purpose of this project was to describe the normal histology and any histopathology of key species of invertebrates and fishes in the study area (Figure 3.1-3). In addition, the electron microscope was used to describe normal subcellular structure as baseline information for interpretation of tumors, particularly if viral structures are seen in tumors.

The study was designed to provide correlations between histopathological data and chemical (hydrocarbon and trace metal) data. To accomplish this, tissues from animals collected at certain stations were analyzed for histopathology and for concentrations of selected chemicals in the tissues. By using specimens collected during winter, spring, summer, and fall, it was hoped that seasonal changes in tissue structure could be identified as well.

The indicator species studied are listed in Table 3.10-1.

Table 3.10-1. Indicator Species of Invertebrates and Fishes Used for Normal Histology and Histopathologic Data

Phylum	Class	Species
Mollusca	Bivalvia	*Pecten dislocatus*
		Aequipecten gibbus
	Cephalopoda	*Loligo pealei*
Arthropoda	Crustacea	*Sicyonia brevirostris*
		Penaeus aztecus
		Portunus spp.
Chordata	Osteichthyes	*Bothus ocellatus*
		Decapterus punctatus
		Synodus foetens
		S. intermedius
		S. poeyi
		Urophycis regius

It was reasoned that the respiratory, digestive, and reproductive tissues would be the ones most likely to be damaged by chemical stressors. These were examined most intensely, and other tissues were examined when available.

Animal parasites were found frequently but could not be identified to species in tissue sections; they were recorded by major group (cestodes, trematodes, nematodes, or protozoa). Bacteria and parasitic arthropods were scored separately. Pathological conditions were scored in broad categories such as inflammation, necrosis, fatty degeneration, etc.

This report summarizes the incidences of tissue abnormalities in target species and discusses their significance. A separate atlas (Volume 4) contains photographs of normal tissues as seen by light microscopy and electron microscopy, examples of parasites, and the damage done to host tissues. Additional appendixes (3.10I, 3.10J, and 3.10K in Volume 6) contain tabular data on specimens examined and the proportion of animals with tissue abnormalities by species and by station. Because no pathologies were found that could be attributed reasonably to chemical stress, there is no discussion of hydrocarbon or trace metal correlates.

The literature concerning invertebrate fish histology and histopathology is scattered, spotty, and often old. However, several monographs are useful for general reference in this type of work, either present or future. The best single source of histological information for invertebrates and fish is *Comparative Histology* by Leake (1975). Additional information for some invertebrates can be found in the volumes by Hyman (1940–67). *Selected Invertebrate Types* by Brown (1950) is useful for general anatomical orientation. Certain general aspects of microanatomy are summarized in such specialized monographs as *Molluscs* by Morton (1967) and *Aspects of the Physiology of Crustacea* by Lockwood (1967). Diseases of invertebrates are described by Sparks (1972) in *Invertebrate Pathology, Noncommunicable Diseases* (communicable diseases will be included in a second volume in preparation), by Snieszko (1970) in *A Symposium on Diseases of Fishes and Shellfishes,* and by Sindermann (1970) in *Principal Diseases of Marine Fish and Shellfish.* Useful information on anatomy and function at the gross and microscopic levels is summarized in the 6-volume work *Fish Physiology* by Hoar and Randall (1970). *The Pathology of Fishes* by Ribelin and Migaki (1975) summarizes the most recent findings in this field. Much useful information on helminth parasites, particularly those of fish, is found in the multivolume work of Yamaguti (1963). Other general information on parasites appears in *General Parasitology* by Cheng (1973).

SECTION 2
MATERIALS AND METHODS

Specimens were collected primarily by otter trawl and were rough-sorted by species. Either individual animals were preserved intact, or selected tissues were placed in appropriate fixative. Bouin's fixative was used for fishes and molluscs; Helly's solution was used for crustaceans. After 24 hr, the fixative was replaced with 70% ethanol in which the specimens were returned to the histology laboratory in Dallas.

In the Dallas laboratory, the tissues were removed, trimmed, and washed in running water for 12 to 24 hr, then dehydrated in S-Z9 series, cleared in UC-670 series, embedded in Paraplast, and sectioned at 8 μm. Crustaceans were rinsed and decalcified in Cal-Ex, after which they were trimmed, washed, dehydrated, cleared, embedded, and sectioned as above.

Harris hematoxylin and eosin were used as the routine stain. Microscopic examination was made with a Bal-Plan compound microscope under 40X, 400X, and 1,000X magnification.

Significant findings were recorded on 35-mm black-and-white film. Table 3.10-2 summarizes the processing and analysis.

Table 3.10-2. Summary of Histopathology Effort

	Number of Samples				
Task	**W[a]**	**Sp**	**Su**	**F**	**Total**
Animals collected[b]	152	1,140	1,719	732	3,743
Animals, histopathology[b]	152	758	562	423	1,895
Slides prepared (stained, unstained)	277	2,465	1,650	870	5,262
Slides examined	152	1,222	573	435	2,382
Species sampled					74
Species examined					38

[a]Cruises: W = winter; Sp = spring; Su = summer; F = fall.

[b]To ensure that a sufficient number of organisms were preserved for the histopathology task, any species present in the catch in sufficient numbers for analysis was saved. Specimens for histopathological analysis were then chosen from the total collection on the basis of general distribution in the study area and desired trophic attributes.

SECTION 3
RESULTS

A. NORMAL HISTOLOGY

Normalities have been defined operationally by examining numerous apparently healthy individuals of appropriate species. The architecture of various tissues was examined for any irregularity, and individual cells were characterized and classified where appropriate.

The results have been summarized and illustrated in a separate atlas (Volume 4 of this final report).

B. HISTOPATHOLOGY

1. Nonspecific Pathology

There was remarkably little evidence of tissue damage caused by chemical or physical stress. Apparent fatty degeneration of liver in several *Synodus poeyi* was the only suggestive data – and even this must be interpreted carefully since livers were collected opportunistically and not over all seasons. Histologically, the picture is comparable to the vacuolation of parenchymal cells of spot *(Leiostomus xanthurus)* exposed to Aroclor 1254 (5 ppb) for 2 weeks (Couch, 1975). However, it cannot be ascertained whether these cells were normal and glycogen-rich but depleted during the embedding process.

A number of unidentified abnormalities, generally of an inflammatory nature, were recorded. In most cases, these were probably the stigmata of past parasitization; in other cases, parasites were disintegrating and were unrecognizable. No consistent pattern of distribution was evident in any species.

2. Generalizations About Pathological Conditions Caused by Parasitization

Infection of invertebrates and fishes by animal parasites was common. Bacterial infestations of external surfaces were detected in several species, and there was a possible case of an infection by a parasitic dinoflagellate. The overall incidence of infection of indicator species by parasite taxon, where data are available from comparable stations on two or more cruises, is summarized in Table 3.10-3. The incidence of parasitization of indicator species is summarized by tissue and parasite for specimens obtained during the second, third, and fourth cruises in Appendix 3.10K. Comparable data have been presented in previous quarterly reports.

Table 3.10-3. Incidence of Infection of Invertebrate and Fish Hosts by Location and Season

Phylum	Host Species	Station[a]	Parasite	Cruise: Winter	Spring	Summer	Fall
Mollusca	*Loligo pealei*	2-1	Cestodes		25	0	–
			Protozoa		0	5	
		2-2	Cestodes		17	0	–
			Trematodes		0	30	
		3-2	Cestodes		5	16	–
			Trematodes			16	
			Nematodes			5	
			Protozoa			16	
			Arthropods			5	
		4-2	Cestodes		5	0	5
			Trematodes		0	2	33
			Protozoa		0	2	8
		5-2	Cestodes		0	14	7
			Trematodes		0	2	37
			Nematodes		0	2	2
			Protozoa		0	5	–
		6-1	Cestodes		25	10	–
			Trematodes		5	0	
			Protozoa		0	20	
			Bacteria		0	10	
		6-2	Cestodes		15	0	–
			Nematodes		8	0	
Arthropoda	*Sicyonia brevirostris*	2-2	Cestodes	90	38	80	–
			Trematodes	20	0	0	
			Nematodes	70	25	55	
			Protozoa	40	100	25	
		3-2	Cestodes	100	55	90	–
			Trematodes	10	0	0	
			Nematodes	95	35	70	
			Protozoa	35	65	70	
			Arthropods	5	5	0	
		4-2	Cestodes	–	–	100	100
			Nematodes			60	80
			Protozoa			40	65
		5-2	Cestodes	–	75	100	94
			Nematodes		5	90	18
			Protozoa		90	60	18
		6-2	Cestodes	–	85	90	–
			Trematodes		0	10	
			Nematodes		5	45	
			Protozoa		40	70	
	Penaeus setiferus	5-1	Cestodes	–	–	20	–
			Trematodes			30	
			Nematodes			10	
	Penaeus aztecus	5-1	Trematodes	–	–	20	–
			Nematodes			10	
Chordata	*Decapterus punctatus*	2-1	Cestodes	–	74	10	–
			Trematodes		16	10	
			Nematodes		100	100	
		4-2	Cestodes	–	–	45	75
			Trematodes			10	35
			Nematodes			85	80

Table 3.10-3. Incidence of Infection of Invertebrate and Fish Hosts by Location and Season (Continued)

Phylum	Host Species	Station[a]	Parasite	Cruise Winter	Spring	Summer	Fall
		5-2	Cestodes	–	87	–	63
			Trematodes		90		5
			Nematodes		27		84
			Bacteria		20		0
		7-2	Cestodes	–	65	–	65
			Trematodes		0		40
			Nematodes		90		70
	Urophycis regius	4-2	Cestodes	–	100	–	100
			Trematodes		20		40
			Nematodes		75		100
		7-3	Cestodes	100	85	65	70
			Trematodes	20	5	20	40
			Nematodes	60	60	60	45
			Arthropods	20	0	0	0
	Synodus poeyi or *S. intermedius*	3-2	Cestodes	–	45	40	25
			Trematodes		100	50	80
			Nematodes		50	60	85
			Protozoa		10	0	15
		4-2	Cestodes	–	28	50	33
			Trematodes		56	40	33
			Nematodes		22	80	28
			Protozoa		6	0	5
	Bothus ocellatus	5-2	Cestodes	–	50	100	40
			Trematodes		10	10	7
			Nematodes		50	90	80
			Protozoa		0	10	0
		6-2	Cestodes	–	20	80	–
			Trematodes		10	10	
			Nematodes		30	70	
			Protozoa		0	10	
			Acanthocephalans		0	10	

[a]Stations are grouped by inshore, midshore, and offshore locations. First number is transect and second number is station: 1, inshore; 2, midshore; 3, offshore.

3. Pathologies of Indicator Species

a. Mollusca

(1) *Loligo pealei*

Since squid are carnivores and feed on a variety of invertebrates, including crabs, they can serve as intermediate hosts for several parasitic species. They especially harbor pleurocercoid stages of cestodes and, in turn, are eaten by fish or sharks that serve as hosts for adult cestodes. Volume 4 shows examples of typical parasitic forms that were found in various squid tissues.

In the samples examined, incidence of infection with cestodes varied with season and location. In general, the incidence of infection of the population was fairly low, although individuals often were heavily infected.

Damage to tissue was minimal when parasites were found either in the intestinal lumen or in extraintestinal sites. Structural and functional changes in host tissues were minimal in the intestine. In other sites, there was a marked response around worms. Overall, the cestode-squid relationship seemed to be a stable one. Both adult and larval flukes were found in squid. There was a tendency for a greater incidence of infection in the summer and fall than in the winter. This could have been caused by the accumulation of parasites with continued feeding or change in diet with season. Trematodes were commonly found in extraintestinal sites; there was usually a cellular response by the host. Damage to host tissues was minimal, however, and heavy infections were not common. Roundworms were found only occasionally in squid. Infections tended to be light and tissue damage minimal. Nematodes did not seem to stress the squid host greatly. Protozoans were found in squid gills. However, the local damage and the host's attempts to repair it were not extensive, so the overall effect was minimal. Several types of protozoa, some which are probably sporozoa, were present in different animals. The most interesting infection resembled a parasitic dinoflagellate previously reported in several crustaceans (Newton and Johnson, 1975; MacLean and Ruddell, 1978) but not in molluscs. In one squid sample, bacterial mats were attached to the gill surfaces. There seems to have been little damage or important stress to the species. In a summer squid sample, parasitic copepods were attached to the gills. Local tissue damage was pronounced, but the respiratory function was probably not seriously impeded.

(2) *Pecten dislocatus; Aequipecten gibbus*

Scallops host larval stages of tapeworms. In *A. gibbus,* an apparently everted cysticercus was observed in the lumen of the intestine and uneverted cysticerci were seen in the blood vessel adjacent to the gonad. In neither case was any host reaction evident. Cysticerci were seen in *P. dislocatus* beneath the intestine and among digestive diverticula. In these cases, only minimal host response was seen. Trematode metacercariae were seen in the gills. Nematodes observed in scallops seemed to be abnormal but only infrequent infection was noted. Only one example of a presumed protozoan was seen in the gills, and it was apparently encysted.

b. Arthropoda

(1) *Sicyonia brevirostris*

Arthropods serve as intermediate hosts for many cestodes and usually become infected by ingesting eggs. Larval cestodes (cysticercoids) were found in many tissues. These infections were extremely common in the rock shrimps examined and, in several cases, were almost universal (Table 3.10-3). This picture did not change appreciably with station or season.

Members of the order Trypanorhyncha were found in rock shrimp. The adults of this group parasitize the intestine or spiral valve of sharks and are distinguished by four eversible proboscides on the scolex, which may or may not be "armed" (have hooks).

Other larval tapeworms were seen also (see Volume 4 for examples). These immature forms were often in large numbers, and there may have been pronounced host cellular response to their presence. A particularly dramatic infection was seen with numerous cestodes along the nerve tract associated with the cerebral ganglion. Despite these heavy infections, damage to host tissue was not great. Whether function (including nervous function) was impaired was questionable.

Sicyonia serves as second intermediate host for at least one species of trematode. Cercariae penetrate the cuticle, and metacercariae are found in underlying tissues. There is relatively little reaction, and tissue damage is minimal. The incidence of infection was low (Table 3.10-3), and there was no apparent pattern of infection associated with season or location.

Roundworms were found frequently and often in large numbers in rock shrimp, but the number of species was not known. These are motile parasites that occur in essentially all tissues. They may or may not elicit a host response, and there seems to be surprisingly little tissue damage other than physical displacement caused by the worms' presence. Sensitive tissue such as nerve or eye may suffer some impairment of function, but actual tissue damage is minimal. The incidence of infection seemed to decrease in spring samples and increase again in summer samples from two areas (Table 3.10-3). A similar increase was noted in samples from transect 4, but the reverse was found in transect 5 samples. In any case, *S. brevirostris* is commonly infected by nematodes but apparently is little damaged by them.

Ciliates of unknown species were found on the gills of many rock shrimp; usually, they are associated with the surface and no apparent damage is done, but they may be found also in the lamella, distending the tissue (see Volume 4 examples). The incidence of infection was usually high, regardless of season or location (Table 3.10-3).

Parasitic arthropods (presumably copepods) were found attached to the gills of two individual rock shrimp collected at station 3-2 (one from the winter cruise and one from the spring cruise). There was local damage to gill filaments and an inflammatory response at the point of attachment.

(2) *Penaeus setiferus* and *P. aztecus*

Two species of penaeid shrimp were collected at station 5-1 during the summer cruise: *P. setiferus* contained some cestode larvae, trematodes, metacercariae, and larval nematodes; *P. aztecus* had no cestodes but had some trematodes and nematodes (Table 3.10-3). Since these were single collections, no comparative data were available. In neither case was there evidence of significant disease, an observation of interest because of the commercial importance of these two species.

c. Chordata

(1) *Decapterus punctatus*

Larval tapeworms were found frequently and often in high density in the intestine of *D. punctatus*. There was clear damage to the gut wall, particularly desquamization of the mucosa (Volume 4). Both trypanorhynch and tetrophyllidean cystacerci were seen, presumably obtained by ingestion of the first intermediate host. Adult worms attached to and damaged the gut wall

of *D. punctatus,* serving as definitive hosts. There was some apparent variation in incidence of infection with season, but location did not seem to be an important factor (Table 3.10-3).

Adult flukes were found in the intestine, as well as in a number of extraintestinal sites, but caused little damage to adjacent tissue and elicited little host response. The incidence of infection seemed to vary with both season and area (Table 3.10-3), presumably reflecting variation in diet.

Roundworms are the most constant parasite of this fish (Table 3.10-3). They occur very frequently, often in large numbers, and may be found in most tissues. In spite of this, there is little to suggest that they cause significant tissue damage or impairment of function (Margolis, 1970). Some of these worms were of the genus *Contracecum,* identified by dissecting them from a piece of fixed liver.

At least two types of protozoa were seen in gills of *D. punctatus* (Volume 4). They damaged individual fish but seemed to have limited distribution within the species. Bacterial infections of the gills may be seen in some populations of this fish, causing inflammation and sloughing of gill tissue. However, these infections are not widely distributed.

(2) *Urophycis regius*

Tapeworms were found in *U. regius* in both locations where the fish was captured. The incidence of infection was high, regardless of season (Table 3.10-3). Cysticerci were commonly associated with the intestinal wall. Larvae burrow through the intestine and may cause serious local tissue damage. Later stages were seen around the intestine and in adjacent tissue (Volume 4). It was not possible to determine how many species were present but at least one member each of the Trypanorhyncha and Tetraphylidea were seen. Adult cestodes were not found.

Adult flukes often were present in the alimentary canal (5 to 40%) but usually not in large numbers. The powerful suckers damaged the intestinal mucosa locally (Volume 4), but it is unlikely that this was seriously or permanently debilitating. Metacercariae may be found in superficial tissues (e.g., the gill) but, if present in moderate numbers, cause minimal tissue damage. (Refer to Volume 4.)

Roundworms were frequently found in many tissues of *U. regius.* There was often a pronounced host response, and it was not unusual to observe dead and disintegrating worms. Because of large numbers and motility, there was often considerable damage to host tissue; but whether there are functional consequences of this was unclear. Only larval stages were seen, suggesting that this fish serves only as an intermediate host. The consistently high incidences of infection did not vary significantly with season or location (Table 3.10-3).

(3) *Synodus* sp. (*S. poeyi* and *S. intermedius*)

Cestode infections of these fish were relatively constant (25 to 50%), regardless of area or season. Extremely heavy infections of adult worms were noted in the intestine (Volume 4), with severe erosion of the mucosa. That amount of tissue destruction probably has some effect on the function of the intestine.

Adult trematodes were seen in large numbers in the stomach, and the incidence of infection did not seem to vary greatly with season or location (Table 3.10-3). The dense aggregations of flukes were truly dramatic; indeed, they were so closely packed that they seemed to be attached to each other rather than to the host tissue (Volume 4). Larval trematodes are seen in a variety of tissues of fish acting as second intermediate hosts, but they do not appear to be very pathogenic.

Acanthocephala were found only in one lot of *Synodus* (Table 3.10-3) and primarily in the tissues immediately beneath the intestine. There was no detectable host reaction (Volume 4). Since adult worms are normally attached to the mucosa by the proboscis, this was presumably an immature form for which *Synodus* serves as a paratenic host.

Larval nematodes were found in the muscularis of the intestine (Volume 4) in many *Synodus* examined. Infection rates varied from 22 to 85% with season, but there was no appreciable variation with location. There was some minor inflammatory response to the presence of roundworms but only limited damage to tissue.

Muscle bundles of the body wall were infected with Myxosporidia (Volume 4) and presumably were nonfunctional. Ciliates on the gills may have evoked a moderate leukocytic response but probably did not damage the gills greatly. On the other hand, an unknown protozoan invaded individual gill lamellae and distended them greatly, causing significant local damage. These were not seen frequently, however, and overall respiratory function was probably unimpaired.

(4) *Bothus ocellatus*

Tapeworms were common in *B. ocellatus*. There may be an increase in incidence of infection during the summer, but the sharp decrease in the fall at station 5-2 (Table 3.10-3) suggests that sampling bias may explain the variation. Adult tetraphyllidean tapeworms were attached to the intestinal mucosa by suckers, which caused appreciable local damage (Volume 4). Larval trypanorhynchs were seen in extraintestinal sites where they may or may not have been encapsulated by host tissue. Other cestode larvae in the intestinal wall usually were encapsulated.

Trematodes were infrequent in *B. ocellatus* and did not seem to be an important parasite. Metacercaria were present but did little damage. Adults were seen infrequently in the intestine. There was little seasonal or areal variation.

Immature acanthocephalans occurred in the area around the intestine. Host response was minimal, and there was little evidence of direct damage to host tissue. These parasites were found only during the summer and in only 10% of the fish at two locations, so it is presumed that they are not a significant burden.

Nematode infections were quite common (30 to 90%, Table 3.10-3). Larval stages were frequently found in extraintestinal sites and were often encapsulated and sometimes degenerating. Damage to host tissue was minimal. There may be a tendency for increasing incidence of infection with season, but there is no variation with location.

(5) Other Fish Species

In addition to the fish just cited, numerous other species were collected—some were examined for histopathology. Several isolated examples of striking pathologies were discovered and are illustrated in the atlas, Volume 4. Because only small numbers of fish were obtained on an occasional basis, no generalization can be made; however, they have been included because of similarities to the indicator species collected in the area.

SECTION 4
DISCUSSION

Tissues from several species of invertebrates (two bivalves, squid, and three crustaceans) and four species of fish from the continental shelf of the Georgia Bight were examined. The normal histology of these species is described and illustrated in Volume 4. There were no new histological findings of great consequence, but histopathological findings of infectious agents were striking. Animal parasites, particularly helminths, were common, and often the incidence of infection was high. There was considerable variation with species, presumably reflecting the role that the host plays in the life cycle of the parasite, the hosts' diet and consequent opportunity for infection, the hosts' longevity, and other factors (Collard, 1970). For example, squid sampled on the spring cruise contained cestodes (for which they serve as first intermediate host); from six of seven areas the incidence of infection varied from 5 to 25%. Among fish (that serve as second intermediate hosts) from the same areas and cruise, the incidence of cestode infection varied from 20 to 100%, with a mean >50%. The differences probably reflect the dietary habits of these animals: squid feed on small fish, crabs, etc., in a discontinuous pattern; demersal fishes feed in a more continuous manner, thus having repeated or continuous opportunities for infection. Some fish feeding on both invertebrates and smaller fish have opportunities to become infected with several species of cestodes with different types of life cycles; this was seen in *Bothus ocellatus* where both larval trypanorhynchs and adult tetraphyllidean cestode infections were found.

The type and extent of pathology seen in host animals is a function of the type of parasite and its life-cycle stage, location in the host, and number of parasites. The conclusion reached after examination of the different specimens studied here is that infection is common but disease is uncommon. In invertebrates, large numbers of parasites in a single host were unusual; most commonly, one or two species of parasites were seen in a variety of tissues where they caused some local pathology but did not seriously inconvenience the host. Some individuals were heavily infected with one type of parasite, but even in those instances it was not obvious that the host was incapacitated. A mass of larval cestodes in the main nerve tract of a shrimp or the denudation of fish intestinal mucosa by adult cestodes clearly is pathological, and it is reasonable to assume that the animals are diseased, but it is not clear that they are less fit and unable to survive as well as undiseased members of the same population.

Trematode parasites were not common in invertebrates, presumably because molluscs serve as intermediate hosts and other invertebrates are only accidentally infected. Occasional individual fish were heavily parasitized with adult flukes; some local tissue damage was evident, but generally they did not seem to be very pathogenic.

Nematodes were frequently found in *S. brevirostris*, less commonly in penaeid shrimp, and rarely in squid. Because these worms cannot be identified to species, it cannot be certain if these differences are caused by the host or the parasite. In fish, on the other hand, nematodes were common and the incidence of infection high, regardless of season or location; the fish hosts were damaged by these worms as they moved through various tissues and responded strongly to the presence of larval worms by encapsulation. Fibrotic nodules were common, particularly in the gut wall, and usually contained several worms, some of which may have been undergoing

disintegration. Individual larvae in some tissues (e.g., liver) may elicit no host response and may be unimpeded in their migration. Some of the lack of host response may be caused by lack of recognition that the worm is foreign or by the fact that differential cellular responses are elicited by different species of parasites. This could explain the observation that a nematode and an acanthocephalan were seen lying side by side in the peritoneal cavity (Volume 4); the nematode was encapsulated but the acanthocephalan had no host cells around it despite its much larger mass.

The response of white shrimp (*P. setiferus*) to trypanorhynch larvae has been described by Sparks and Fontaine (1973). Shrimp in Galveston Bay, Texas, may have an incidence of infection with *Prochristianella penaei* of 50% (Aldrich, 1965) and as high as 94.4% according to Kruse (1959). The single collection from the SABP study had a cestode infection rate of 20%, not all of which was necessarily trypanorhynchs. Most larvae of this parasite were localized in the hepatopancreas and elicited a strong hemocytic response that resulted in encapsulation and destruction. Those in the hemocoel do not elicit such a reaction (Sparks and Fontaine, 1973), an observation which was confirmed in this study. Sparks and Fontaine (1973) suggest that brown shrimp (*P. aztecus*) do not destroy plerocercoids as effectively as do white shrimp (*P. setiferus*).

Respiratory tissue (gill or its equivalent) is exposed to the environment and is delicate in structure to ensure efficient gas exchange; this also makes it particularly susceptible to damage (Wood and Yasutake, 1957). Marine species pass large volumes of water over respiratory surfaces, and that water may contain infectious agents and toxic chemicals. A great variety of infectious agents was found on gill surfaces and in gill tissue; usually, these were localized infections with slight to moderate tissue pathology. This is interpreted to mean that these are healthy animals that live in clean waters and tolerate a small to moderate parasite load. Under conditions of severe pollution, a very different picture would be seen. For example, the gills of crabs caught in the New York Bight are covered with mats of bacteria and blue-green algae; ciliate protozoa are commonly seen in large numbers and respiration is undoubtedly affected (Sawyer, 1977, personal communication). Similar changes might occur if petroleum pollution occurred and resident invertebrates were stressed.

It is striking that no tumors were found by gross or microscopic examination of any invertebrate or fish species captured in this study. Neoplasms have been described in all major phyla, including those studied here (Dawe and Harshbarger, 1969; Dawe et al., 1976). The spontaneous appearance of tumors in important invertebrate phyla has been reported (Pauley, 1969), for example, in molluscs (Farley and Sparks, 1969; Farley, 1976) and in arthropods (Sparks and Lightner, 1973), but the etiology is not clear. In general, the species diagnosed as having tumors have been estuarine. Whether oceanic species have similar pathologies is unclear. With oil and gas production, it will be important to continue this search, particularly in view of the findings of Yevich and Barszcz (1977) where *Mya arenaria* exposed to leaking fuel oil developed neoplasia. In certain geographical regions, fish are known to develop skin tumors, particularly papillomas, not necessarily associated with oil or other types of pollution (Dawe et al., 1976; Dawe and Harshbarger, 1975). The role of pollutants in the induction of these conditions is not understood (Wedemeyer, 1970), and careful attention to this problem will be warranted in any future field survey.

Virology of marine invertebrates and fish is in a primitive state. Several viruses have been isolated in three classes of molluscs, but their interrelationships are not clear (Hill, 1976). Of particular interest is the question of whether environmental stress can induce or enhance disease

in molluscs. One such report by Farley et al. (1972) claims that elevated water temperature (28° to 30°C) is associated with the presence of a herpes-like virus and a lethal disease of oysters. In crustaceans, at least 10 viruses are known (Johnson, 1977; Bonami, 1976). As in molluscs, the host species are largely estuarine and it is not known if similar infections will be found in offshore marine forms. The question of environmental stress is pertinent here also in light of Couch's (1974) finding of baculovirus infections of pink shrimp (*Penaeus duorarum*) naturally and when stressed with Aroclor 1254 (Couch and Nimmo, 1974). It is possible that virus diseases not seen in marine invertebrates in unpolluted areas may be induced or enhanced by chemical stressors, including oil.

The histopathological effects of chemicals on marine organisms have not been well studied. Attempts to induce tumors by adding chemicals to water containing marine animals have led to equivocal results (Couch, 1977). Some hydrocarbons (e.g., phenol) damage marine invertebrates (Fries and Tripp, 1977), but whether these are general effects has not been demonstrated. Heavy metals (e.g., cadmium) may damage selected tissues and make certain invertebrates more susceptible to infection (Nimmo et al., 1977). High heavy-metal (e.g., zinc) concentrations have been associated with tumors of certain fish—but other pollutants also were present (Bucke, 1976). Experimental exposure of fish to heavy metals shows that specific lesions (Trump et al, 1975; Gardner, 1975) or nonspecific effects (Tafanelli and Summerfelt, 1975) may be induced by different substances; hydrocarbons, especially pesticides, induce a variety of lesions in fish, but attempts to associate a particular compound and a specific lesion have been futile (Gardner, 1975; Walsh and Ribelin, 1975). Studies of chronic exposure of fish to sublethal doses of hydrocarbons have not been reported, but such studies are essential to the understanding of any field observations associated with oil pollution.

This study marks the beginning of a comprehensive histopathologic examination of certain key species of benthic macroinvertebrates and fishes. Continuation and refinement of such studies are necessary to understand which are the normal conditions, including infection and disease. Whether these conditions will change significantly in oil- and gas-producing areas cannot be predicted with present knowledge. Chemical stressors may damage animals directly, but attributing such damage to specific chemicals on histological evidence alone is not possible. Parasitized animals stressed by pollutants may become diseased and die. With parasite loads as common as reported here, this could be a significant problem with both ecological and economical consequences. Continuing studies to examine these questions are needed.

SECTION 5
CONCLUSIONS

- Animal parasites were common among the benthic invertebrates and demersal fishes examined.
- Infection rates were often high, but pathology was usually not extensive.
- Infection with some parasites varied somewhat with season and location, but parasite burdens generally were only moderately variable throughout the year at all stations where a given species was collected.
- There was no conclusive evidence that the species sampled are now affected by environmental chemicals.
- No tumors were discovered in invertebrates or fish.
- The species examined appeared to be normal members of a healthy benthic community.

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CHAPTER 11

MICROBIOLOGICAL RESEARCH FOR THE BLM SOUTH ATLANTIC BENCHMARK PROGRAM, 1977

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ABSTRACT

Microbial community composition, density, and oil-degrading capacity and rate on th South Atlantic Outer Continental Shelf (OCS) were assessed during 1977 to facilitate predictio of the ecosystem's potential for assimilating petroleum. Hydrocarbon-using bacteria were preser in both the water and sediment at all stations tested off North Carolina, South Carolina, Georgi and Florida during the four seasonal cruises. Numbers were low relative to those reported i other geographic areas but were proportional to low indigenous hydrocarbon concentrations.

Surface-water biochemical oxygen demand (BOD) tests indicated that hydrocarbon-usin bacteria populations were sufficient to respond effectively to the addition of South Louisian crude oil (SLCO) and decane. Ten taxonomic strains of bacteria were identified from the stud area; mixed and pure cultures of these microorganisms demonstrated active oil degradation unde culture conditions.

Gas chromatographic (GC) analysis of molecular change during the culture of hydrocarbo using forms on SLCO indicated that pristane and phytane accumulated as by-products of th degradation processes but that all other molecules in the hexane fraction were rather uniforml reduced with no apparent sparing action. Hydrocarbons in the aromatic fractions showed n preferential degradation, nor were any specific by-products accumulated. Both nitrate an phosphate were shown to be essential to hydrocarbon degradation. Tests of the effects of varyin regimes of nutrient availability on the rate of bacterial decomposition of SLCO showed that th maximum rate was achieved at 1.0 ppm phosphate and between 25 and 100 ppm nitrate for th various cultures. No additional increases in degradation rate or cell proliferation were observed a higher concentrations, nor was growth or hydrocarbon degradation observed in culture incubated at low temperatures (9°C).

SECTION 1
INTRODUCTION

Hydrocarbon compounds, it is theorized, originated as a by-product of life activitie: approximately 3.5 billion years ago. Some of these hydrocarbons, such as alpha and bet: carotene, became accessory photosynthetic pigments, further contributing to the incorporation o solar energy into living matter. A variety of hydrocarbons, including complex waxes, steroids and low molecular weight gases such as methane and butane, were produced and slowl accumulated to become the petroleum reserves of today. The undoubtedly complex mechanisn by which these products of protoplasm were transformed into crude oil is not known, but som believe that organic matter produced by living systems was entrapped in shallow ocean sediment and, through some combination of the forces of time, catalysis, pressure, nuclear bombardment and temperature, were transformed into petroleum. A second theory proposes that preforme organic molecules were present in high concentrations and, when subjected to the same physica forces, produced the petroleum deposits. Still others are inclined to believe that microbial actio on organic molecules in earth pools introduced biogenic components and varied the compositio of the materials to produce crude oil, which was then trapped and preserved.

In any case, the accumulation of petroleum reserves probably resulted from the lack of mechanism for anaerobic hydrocarbon degradation. Such a process has not been shown to exis but if it does, it proceeds very slowly. Thus, hydrocarbons derived from either biogenic o abiogenic sources that became trapped in the sediments were beyond the reach of oxidizin mechanisms and, hence, were preserved.

A. CRUDE OIL

Crude oil, a complex mixture of hydrocarbons and nonhydrocarbons, possesses a measurabl toxicity toward living systems at appropriate concentrations (Halstead, 1971). Although there i considerable laboratory evidence that oil is degraded in natural environments (Davis, 1967 extrapolation of such data to environmental conditions—especially when sublethal concentration are involved—is a formidable exercise. Therefore, while the toxicity of crude oil cannot b denied, it is clear that our knowledge is limited concerning (1) rates of oil removal in th environment resulting from natural biological and physical processes, (2) long-term effects c massive oil spills that may not be immediately recognized because of environmental "baseline variations, and (3) sublethal biological effects of chronic exposure to low levels of oil.

B. DEGRADATION PROCESSES

The microorganisms, bacteria, yeasts, and certain fungi, possess enzyme systems that perm the aerobic degradation of hydrocarbons. In addition, although very little research has bee directed toward hydrocarbon oxidation by higher organisms, such processes have bee demonstrated. While it is impossible to determine when such metabolic processes developed, w can theorize that it must have been relatively early in the evolution of life. Today, hydrocarbo concentrations in protoplasm are found to vary from 1.0 to 10,000 ppm dry weight. It seem obvious that similar rates of production over the vast periods of geological time would hav yielded a far greater accumulation of hydrocarbons than actually exists if aerobic degradatio had not been occurring.

The analysis of naturally produced hydrocarbons in living organisms (Patterson, 1967) eveals a wide range of molecules with high levels of hydrocarbons in the C17 range. Hydro-:arbons extracted from natural waters show no preferential concentration, indicating that ›iologically produced hydrocarbons are oxidized in the energy and carbon cycles of the :nvironment.

The literature shows that each specific hydrocarbon molecule can be metabolically oxidized. This indicates that the natural microflora are actively oxidizing all hydrocarbons. Since our :nvironment receives continuous inputs of hydrocarbons as a consequence of life processes, nicrobial activity must continually degrade hydrocarbons, preventing their accumulation to a ›oint that is detrimental to life. This conclusion is supported by recent information on the low evels (parts per trillion) of specific hydrocarbons in the waters of the Gulf of Mexico and the ›ther oceans of the world (Myers and Gunnerson, 1976).

C. HYDROCARBON DISTRIBUTION

Studies of the distribution of hydrocarbon-using bacteria in the environment suggest their presence in sufficient numbers to support a constant degradation mechanism for naturally produced hydrocarbons, natural seeps, and low-level spillage by man. Biological oxygen demand (BOD) experiments, in which natural untreated surface seawater of the North Sea and the Gulf of Mexico was seeded with various hydrocarbons at 60 mg/l, reveal the scope of this active microbial process (Oppenheimer, unpublished). The hydrocarbons were oxidized at varying rates, but even such compounds as toluene, which is normally considered toxic, were metabolized.

It has been suggested that observed low levels of hydrocarbons in the ocean approximate the threshold of biological uptake. Thus, the rather consistent low concentrations of hydrocarbons in natural waters represent a submicrobial reservoir. However small, the concentrations represent a substantial amount of material if taken for the whole ocean. Multiplying the ocean volume by the total hydrocarbon value of 10 parts per billion (which has been shown to be average) gives a figure of 8.6×10^9 barrels—and this does not include reported sediment hydrocarbon contents. When related to the volume of oil reported to be spilled by man (9×6 10^6 barrels annually), these concentrations of hydrocarbons in the water column would require more than 900 years to accumulate, a period that greatly exceeds the time in which petroleum products have been used by man. If, as evidence shows, the introduced oil is continually being degraded, accumulation to such levels would take longer, suggesting that the background of hydrocarbons found in the oceans today (1 to 30 parts per billion) may well have existed during geological time before man.

D. BIOLOGICAL EFFECTS OF HYDROCARBONS

The uptake and release of hydrocarbons by marine animals is not clearly defined. Blumer et al. (1970) indicated that oysters from the West Falmouth spill retained hydrocarbons for several months after the accident; on the other hand, Lee et al. (1972) showed that certain C14 labeled straight chain and aromatic hydrocarbons, while rapidly taken up by a marine mussel, were rapidly released when the organism was placed in fresh seawater, dropping 80 to 90% in 24 hrs. There was no evidence of straight chain or aromatic hydrocarbon metabolism by the organism.

To place the problem of massive oil spills in perspective, we should first review reports summarizing recent major accidents. Data from fish catches and the subtidal and intertidal

benthic communities involved in two major crude oil spills [Torrey Canyon (Spooner, 1969) an Santa Barbara (Straughan, 1971)] indicated that marine life other than waterfowl experience only slight acute damage; benthic organisms in both areas recolonized within a year following th accident. In contrast, a barge accident that released 162,000 gallons of No. 2 fuel oil in Buzzard Bay, Massachusetts, was reported to have caused a massive mortality of fish and benthos in th immediate area of the spill. Gas chromatographic (GC) analyses of sediment hydrocarbon revealed the presence of No. 2 fuel oil 2 years after the spill (Blumer et al., 1969). GC analyse also showed that the oil was taken up and retained by oysters and scallops in the area of th spill. It is significant to note that No. 2 fuel oil is generally treated to prohibit microbia contamination and that the presence of such microbial inhibitors in spilled materials may be a important limiting factor in the ability of the aquatic environment to assimilate introduce hydrocarbons.

An oily taste in oysters exposed to oil spills has been observed for several years in Louisian (Menzel, 1948; Mackin, 1948) but has been considered to be a temporary nuisance having n long-term adverse effects. However, the much studied concentration of DDT in the marine foo chain (Risebrough, 1971) raises questions of whether hydrocarbons behave in a similar manne

E. ENVIRONMENTAL SIGNIFICANCE OF HYDROCARBONS

The presence of hydrocarbons in the environment has only recently been quantified as result of the development of chemical techniques that permit detailed analysis of comple hydrocarbon molecules. As recently as 1942, Trask and Patnode stated that hydrocarbons wer not present in any significant amounts in recent marine sediments. Smith (1952), howeve demonstrated that hydrocarbons were, in fact, present in recent marine sediments and indicate (1954) that they comprised 120 to 1400 ppm of the organic fraction of the sediments; fron this, he calculated that 1 mi^3 of recent sediment may contain as many as 13×10^6 barrels o petroleum. Orr and Emery (1956) found significant amounts of paraffinic hydrocarbons i surface sediments off California and suggested, based on the depths of the hydrocarbons in th sediments, that recent oil activities could not be responsible for their presence. Clark (1966 showed the abundance of normal hydrocarbons (C14 to C32) in marine plants and animals to b between 34 and 120 ppm dry weight. Hydrocarbons also comprise a significant portion o protoplasm in terrestrial plants, and these materials become a portion of the hydrocarbo materials introduced to the environment.

Living systems are constantly subjected to the addition of hydrocarbons. The tremendou expanse of asphaltic roads and parking lots in the world may be releasing significant amounts o hydrocarbons to the environment as they weather, break down, and are otherwise disseminated To this may be added the tons of protective asphaltic coatings used for roofs, pipes, etc.; the oil used in 2-cycle engines (especially outboard motors); unburned hydrocarbons in exhaust fume and finally, the inert carriers in aerosol dispensers. While these materials may not equal th effects of a massive oil spill in a given area, they may well be significant when criteria are set fo hydrocarbon content in living systems.

Since hydrocarbons are a natural entity, it is perhaps a contradiction that these essenti molecules, which were originally part of living systems (Calvin, 1956), are now considered to b "pollution." On the basis of our previous discussion of natural hydrocarbon levels, it seems quit obvious that our planet must be considered to have been "polluted" with oil, coal, and lignite long before man's habitation. What must be recognized is the fact that it is only the catastrophi

eleases and/or continued high-level introduction of hydrocarbon materials in restricted areas that xceeds the natural assimilative capacity of the system and contributes to its long-term letriment.

In addition to the daily production of natural hydrocarbons, nearly 3 billion gallons of ıydrocarbons in the form of crude oil, refined products, and waste materials are moved daily ›ver the surface of the earth by man. It is difficult to conceive of a group of materials more ssential to our way of life and progress. We must, then, assess all facets of the situation arefully to understand the true impact of hydrocarbons on our daily lives. To place in proper ›erspective the fact that use of vast amounts of hydrocarbons produces a net loss to our nvironment, we must integrate potential loss with time, limited oil resources, and daily energy equirements. We must realize that there are inherent risks to many of our activities, that we nust coexist with our environment, and that some changes may be necessary.

The following sections discuss studies conducted during 1977 to describe the distribution ınd potential environmental significance of heterotrophic and hydrocarbon-using microorganisms of the continental shelf off North Carolina, South Carolina, Georgia, and northern Florida. Analyses included:

- Enumeration of the microbes in the surface microlayer, water column, and sediments of the study area during the four seasons
- Taxonomic identification of dominant microbial forms
- Calculation of the ratio of hydrocarbon-using to total heterotrophic microbes
- Determination of the hydrocarbon oxidation potentials of mixed and pure microbial cultures from the study area under varying nutrient and temperature regimes
- Evaluation of the oxidation of total and specific hydrocarbon components of crude oil and/or production of intermediate compounds by mixed and pure microbial cultures.

SECTION 2
MATERIALS AND METHODS

The assessment of microbial oil ecology in the South Atlantic OCS involved both shipboarc and laboratory analyses. The study area and the sampling regime and procedures employed ar detailed in Volume 2.

A. SHIPBOARD ANALYSES

1. Enumeration

Microbial populations from the surface microlayer, the near-surface water, and sediments ir the study area were cultured for the enumeration of heterotrophic and hydrocarbon-usin microorganisms. The ratio of mean number of hydrocarbon-using bacteria to mean number o total heterotrophic bacteria was calculated for each habitat and station. Cultures which showec rapid growth or oil degradation were selected for further analyses ashore.

2. Biochemical Oxygen Demand

Surface waters for the determination of biochemical oxygen demand (BOD) were collectec seasonally at six stations using a floating surface skimmer (Figure 3.11-1) that allowed wate from the upper 1 cm of the water column to collect in a stainless steel funnel assembly and b pumped to a receiving vessel aboard ship. Approximately 15 l of water composed of 1 par surface seawater and 4 parts sterile, organic-free, artificial seawater were pumped into a singl glass bottle and the sample was agitated vigorously to ensure O_2 saturation. Oxygen wa determined on the composite water sample. From the composite sample, water was drawn int fifteen 500-ml BOD bottles. There were three replicates for each of four experimental dosages o hydrocarbon and a control. For the four dosages, the samples were inoculated with Soutl Louisiana crude oil (SLCO), decane, cyclooctane, and toluene, respectively, and incubated ir darkness for 5, 10, and 15 days. Initial oxygen concentration and residual oxygen in the tes bottles following incubation were determined by the Winkler method.

B. LABORATORY ANALYSES

Shipboard most probable number (MPN) hydrocarbon dilution bottles were returned to th University of Texas Marine Science Institute Laboratory at Port Aransas, Texas, for continuin experiments. Cultures that showed low growth during the initial incubation were reexaminec after 30, 60, and 90 days of incubation. Cultures that showed rapid growth aboard ship and/o produced large numbers of organisms over longer periods of incubation were used for pur culture isolation and taxonomic analyses, determination of hydrocarbon degradation potentia under varying nutrient and temperature regimes, and evaluation of the preferential oxidation o specific hydrocarbons and/or production of intermediate compounds.

1. Procedures for Isolating Pure Cultures

Microorganisms from hydrocarbon enumeration cultures that showed greatest hydrocarbo degradation were isolated by streak plate procedures (APHA, 1976) to provide pure cultures fo

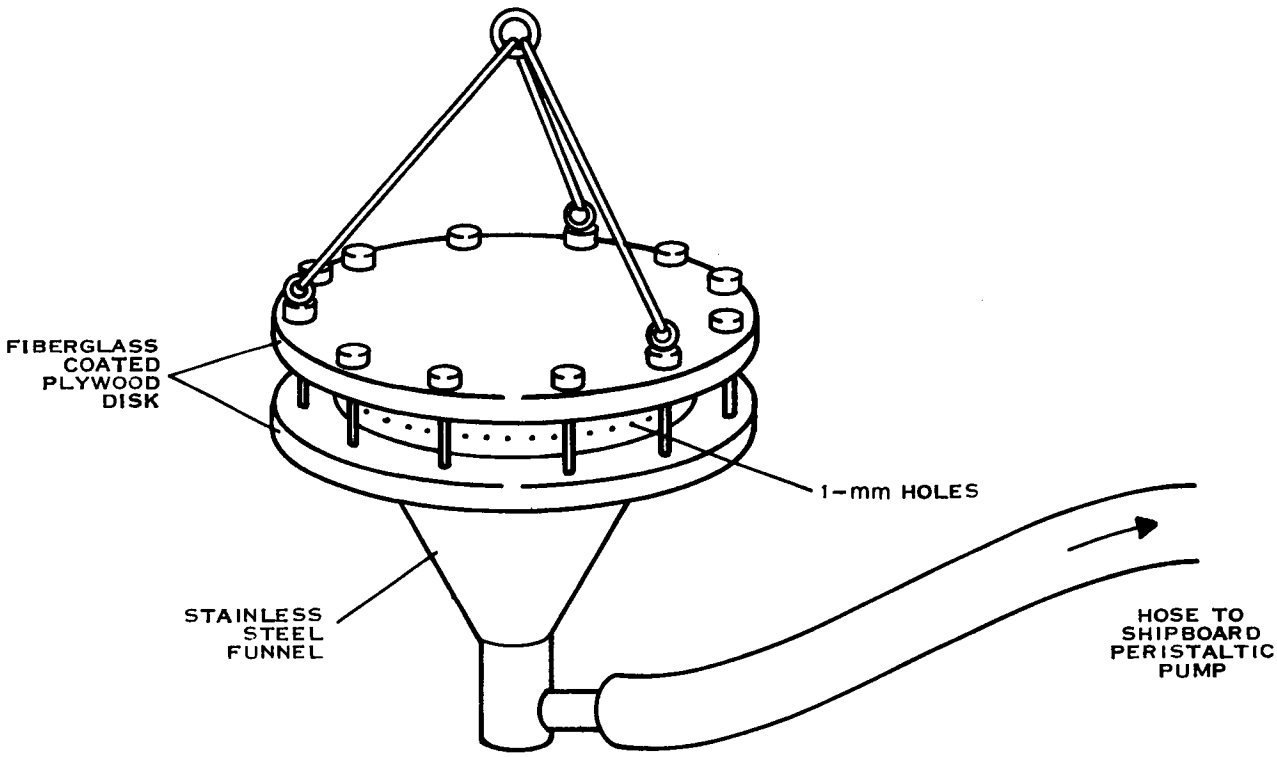

Figure 3.11-1. Floating Surface-Water Skimmer System

taxonomic analyses and determination of degradation rates. In this procedure, the culture from MPN bottles is streaked in enriched seawater (ESW) plates and incubated for 24 hr at 35° ±0.5°C. A single well-isolated colony is then fished to a fresh plate for maintenance. Enriched seawater medium comprised 75% aged filtered seawater, 25% distilled water, 66 ppm NO_3 (NH_4NO_3) and 18 ppm PO_4 (K_2HPO_4).

2. Taxonomic Analyses

Pure cultures of Georgia Bight hydrocarbon-using microorganisms were sent to the National Marine Collection Laboratory in Aberdeen, Scotland, for taxonomic identification. Aliquots from the various pure cultures were placed on glucose MOF medium, Kovacs medium, and glucose O-F medium and their culture characteristics were described. Cultures were variously tested for (1) gram positive/negative response; (2) sensitivity to penicillin, novobiocin, polymixin B, and 0/129; (3) proteolytic, caseolytic, and haemolytic activity; (4) DNAase reaction; and (5) general colony characteristics. Identification was accomplished by comparing the subject cultures with the culture characteristics of known taxa.

3. Hydrocarbon Oxidation Potential

The hydrocarbon-degrading ability of mixed and pure cultures of Georgia Bight microorganisms was assessed by observing changes in weight and molecular composition of SLCO and selected hydrocarbons in controlled media. The process consisted of:

- Screening mass cultures for degradation potential
- Determining rate of degradation and molecular modification of SLCO by selected mixed and pure cultures
- Assessing the effects of nitrate and phosphate concentrations on degradation rate
- Evaluating the effect of low temperature on degradation rate.

a. Screening for Degradation Potential

Replicate bacterial cultures were prepared from field samples by introducing 0.1-ml aliquots of the original sample to 50 ml of ESW with SLCO. Following various incubation periods, residual hydrocarbons were extracted from the entire sample by triplicate washings with Freon 113* in order to determine the percentage of SLCO remaining after various periods of incubation. The hydrocarbon-containing Freon washes were pooled, evaporated to 1 to 2 ml, and layered on an 11-mm X 300-mm chromatography column packed with 16 cm of activity-1 silica gel (80- to 200-mesh) topped with 3 cm of activated alumina. The column was packed wet using a hexane slurry.

The saturated hydrocarbon fraction was eluted with two column volumes of hexane. The aromatic hydrocarbons were eluted with two column volumes of a 1:1 benzene:hexane mixture, and the asphaltenic fraction was removed by elution with methanol. All three fractions were dried for gravimetric analysis.

*Trademark of E.I. DuPont de Nemours & Co.

b. Determining Degradation Rate and Molecular Modification

Mixed and pure cultures of microorganisms from Georgia Bight samples that had initially shown active hydrocarbon degradation (stations 3D, 2E, 7D, and 5G) were tested for their ability to degrade SLCO. Inoculated and uninoculated flasks of ESW having 0.5% SLCO were mechanically shaken during a 30-day incubation period to simulate wave action. After 3, 6, 9, 15, and 30 days, replicate samples were extracted by the procedure described for screening the degradation potential. Gravimetric and gas chromatographic (GC) analyses of the various fractions provided data on degradation rate, selective decomposition of SLCO fractions, and production of intermediate hydrocarbon compounds during degradation. Gas chromatograms of the SLCO fractions were obtained on a Hewlett-Packard 7620A gas chromatograph equipped with dual flame ionization detectors using packed 0.32-cm X 2-m stainless-steel column(s) of 5% FFAP on 80/100-mesh Gas Chrom Q. Helium was the carrier gas; the flow rate was 30 ml/min. Temperature was held at 70°C for 6 min after injection of a sample, then programmed from 70° to 270°C at 8°C/min and held at 270°C for 15 min. Individual hydrocarbons were quantified using a Hewlett-Packard Model 3352B integrator. Column efficiency and detector response were measured with a mixture of C16–C32 saturated and unsaturated hydrocarbons. A DuPont Model 21-49 GC/MS with DuPon Model 21-094B MS Data System was used for gas chromatographic/mass spectroscopic (GC/MS) analyses. The instrument has a unit resolution at M/E 600 to 1000 with a sensitivity of 1.5 ng of hydrocarbon at molecular weight 282.

All solvents used in the studies were chromatographic grades or were glass-distilled. All glassware was washed; rinsed with tap water, distilled water, and acetone; and heated at 200°C for 2 hr to remove any traces of hydrocarbons.

c. Effects of Nitrogen and Phosphorus on Degradation Rate

Four pure cultures were selected at random from the hydrocarbon-using isolates following the observation of their rapid degradation of SLCO in ESW media. These cultures were tested for nitrogen and phosphorus requirements on four filter-sterilized (0.45-μm pore size) hydrocarbon sources: SLCO, decane, cyclooctane, and toluene. Cultures were grown in 50 ml of aged sand- and charcoal-filtered seawater with the following KNO_3 and K_2HPO_4 concentrations:

- 0 ppm NO_3^-/10 ppm PO_4^{-3}
- 5 ppm NO_3^-/10 ppm PO_4^{-3}
- 25 ppm NO_3^-/10 ppm PO_4^{-3}
- 100 ppm NO_3^-/0.1 ppm PO_4^{-3}
- 100 ppm NO_3^-/1 ppm PO_4^{-3}
- 100 ppm NO_3^-/10 ppm PO_4^{-3}
- 0 ppm NO_3^-/0 ppm PO_4^{-3} (nonenriched).

Each culture series was inoculated with SLCO, decane, or cyclooctane as the sole carbon source. SLCO concentrations of 0.1%, 0.5%, and 1.0% (v/v) and other hydrocarbon concentrations of 0.5% were tested. Uninoculated controls were incubated to demonstrate weathering loss of hydrocarbons. After 12 days on a shaker, the cultures were extracted as described for

screening degradation potential. SLCO degradation was determined by gravimetric analysis, bu gravimetric analysis could not be accurately used for decane, cyclooctane, and toluene residue because of their volatility. Therefore, cell counts were taken on these compounds before and a the end of a 12-day incubation period. This allowed the comparison of increase or decrease i the number of viable cells with the amount of nitrate or phosphate present in the cultur medium.

d. Effect of Temperature on Degradation Rate

The effects of low temperature on oil degradation rates were determined by the metho used for screening oil degradation. Cultures from stations 2E and 7D were grown on 0.5% SLC(in ESW for 12 days at 9°C before extraction and gravimetric analyses.

SECTION 3
RESULTS

A. ENUMERATION OF HETEROTROPHIC AND HYDROCARBON-USING BACTERIA

Mean numbers of heterotrophic and hydrocarbon-using bacteria in the surface microlayer, near-surface waters, and sediments of the SABP study area were derived as the average of cell counts from replicated cultures. The results are presented in Table 3.11-1 as cells per milliliter of water or grams of wet sediment for each of the four seasonal cruises. The tables also provide hydrocarbon-using: total heterotrophic bacteria ratios.

B. BIOCHEMICAL OXYGEN DEMAND

The 5-, 10-, and 15-day BOD of fall untreated surface water inoculated with SLCO, decane, cyclooctane, or toluene is shown in Figure 3.11-2. Oxygen uptake at each sampling station was plotted against incubation time for an uninoculated control and the four hydrocarbons. Winter, spring, and summer BOD data were inconclusive because the unexpectedly large background of organic matter in the surface water exceeded available oxygen in the BOD bottles. The added hydrocarbons were an insignificant part of the total oxidizable material, and no difference between test and control oxygen could be determined.

C. PURE CULTURE ISOLATION AND TAXONOMIC ANALYSIS

Of approximately 300 pure cultures isolated from most probable number field cultures returned to the laboratory, 50 pure cultures were selected on the basis of colony characteristics and morphology for identification at the National Marine Collection Laboratory, Aberdeen Scotland. Of the 50, 43 were identified by comparison with known marine forms (Table 3.11-2) Five cultures were unidentifiable (and perhaps new) forms. Two of the initial 50 cultures did not reach Aberdeen in viable condition.

D. SCREENING MASS CULTURES FOR OIL DEGRADATION

Cultures for detailed studies of degradation rate were selected on the basis of SLCC degraded after 3, 6, and 12 days of incubation. An example of the results of the screening procedures appears in Table 3.11-3.

E. DEGRADATION RATE AND MOLECULAR MODIFICATION

Figure 3.11-3 shows representative SLCO weight losses with time for mixed and pure cultures. Figure 3.11-4 shows a chromatograph of SLCO used as a standard, as well as representative GC printouts of residual hycrocarbons following bacterial activity for various incubation periods. This figure shows gas chromatographs (GCs) of beginning control and 9-, 15- and 30-day incubation residual SLCO fractions and SLCO in the control and test cultures.

These chromatograms were obtained at different sensitivity settings and are thus directly comparable for relative abundance of the various hydrocarbons but not for estimates of total oil loss across time. Residual oil following various incubation periods was calculated to determine

and Sediments of Stations in Georgia Bight During 1977

Station	Winter Het (cells/ml)	Winter Oil (cells/ml)	Winter O:H	Spring Het (cells/ml)	Spring Oil (cells/ml)	Spring O:H	Summer Het (cells/ml)	Summer Oil (cells/ml)	Summer O:H	Fall Het (cells/ml)	Fall Oil (cells/ml)	Fall O:H
Surface Microlayer												
1D	NG	NG	–	–	–	–	–	–	–	5.16×10^{3}	1.59×10^{3}	0.31
2E	NG	NG	–	1.05×10^{4}	1.60×10^{1}	0.002	1.21×10^{1}	2.55×10^{0}	0.21	–	–	–
4E	NG	NG	–	2.17×10^{4}	1.02×10^{0}	0.000047	6.52×10^{1}	0	–	–	–	–
5B	NG	NG	–	–	–	–	5.02×10^{4}	2.85×10^{0}	0.06	–	–	–
5E	NG	NG	–	–	–	–	–	–	–	1.68×10^{3}	8.01×10^{0}	0.05
5G	NG	NG	–	2.17×10^{4}	1.09×10^{1}	0.000005	1.09×10^{1}	2.30×10^{0}	0.21	–	–	–
6D	NG	NG	–	2.16×10^{3}	7.40×10^{-1}	0.006	1.30×10^{0}	4.80×10^{-1}	0.37	–	–	–
1-Meter Subsurface Water Column												
1D	7.90×10^{-1}	1.78×10^{2}	–	8.86×10^{1}	2.84×10^{1}	0.32	7.32×10^{1}	7.91×10^{0}	0.03	5.74×10^{3}	6.82×10^{2}	0.12
2E	7.79×10^{0}	2.00×10^{2}	–	5.83×10^{1}	1.41×10^{1}	0.24	3.40×10^{1}	1.89×10^{0}	0.06	6.55×10^{3}	1.24×10^{2}	0.01
2F	2.52×10^{0}	2.00×10^{2}	–	4.54×10^{1}	1.28×10^{1}	0.28	5.68×10^{1}	2.73×10^{0}	0.05	5.50×10^{3}	1.30×10^{2}	0.02
3D	5.92×10^{0}	2.13×10^{2}	–	1.21×10^{3}	1.25×10^{1}	0.1	7.81×10^{1}	1.81×10^{0}	0.02	5.10×10^{3}	8.78×10^{1}	0.02
4D	–	–	–	2.20×10^{1}	6.52×10^{0}	0.3	7.38×10^{1}	3.31×10^{0}	0.04	4.88×10^{3}	3.39×10^{2}	0.07
4E	2.91×10^{0}	1.96×10^{2}	–	2.61×10^{1}	4.70×10^{-1}	0.02	1.19×10^{3}	1.60×10^{-1}	0.001	4.58×10^{3}	6.13×10^{2}	0.13
5A	4.77×10^{1}	1.83×10^{2}	–	6.17×10^{3}	9.27×10^{0}	0.02	1.19×10^{3}	8.50×10^{-1}	0.007	3.75×10^{4}	7.44×10^{2}	0.02
5B	1.01×10^{3}	1.85×10^{2}	–	2.81×10^{3}	3.00×10^{-1}	0.001	3.68×10^{3}	3.38×10^{0}	0.009	3.25×10^{4}	2.05×10^{3}	0.06
5E	4.47×10^{0}	1.75×10^{2}	–	3.21×10^{3}	1.8×10^{-1}	0.006	7.37×10^{1}	4.20×10^{-1}	0.006	1.32×10^{4}	1.18×10^{3}	0.09
5G	–	–	–	2.44×10^{1}	1.94×10^{0}	0.08	5.62×10^{1}	2.32×10^{0}	0.04	2.74×10^{3}	1.27×10^{3}	0.46
6D	2.27×10^{0}	1.86×10^{2}	–	2.69×10^{1}	2.60×10^{-1}	0.01	3.56×10^{1}	4.60×10^{-1}	0.01	6.21×10^{4}	1.69×10^{3}	0.03
7D	NG	1.97×10^{2}	–	2.31×10^{1}	8.60×10^{-1}	0.04	2.78×10^{1}	2.20×10^{-1}	0.008	3.91×10^{3}	2.14×10^{2}	0.05
Sediments												
1B	1.56×10^{4}	0	–	1.97×10^{5}	1.51×10^{0}	0.004	4.70×10^{5}	4.94×10^{2}	0.001	2.83×10^{4}	1.22×10^{3}	0.04
1C	1.63×10^{5}	0	–	1.69×10^{5}	1.86×10^{2}	0.001	3.25×10^{4}	6.17×10^{1}	0.0002	6.83×10^{4}	2.31×10^{3}	0.03
1D	1.93×10^{4}	0	–	1.90×10^{4}	1.89×10^{2}	0.0001	1.23×10^{4}	1.27×10^{3}	0.001	1.73×10^{5}	2.30×10^{2}	0.001
1E	3.65×10^{4}	5.96×10^{0}	0.0002	1.98×10^{5}	1.36×10^{2}	0.0007	1.94×10^{4}	3.73×10^{2}	0.0002	3.19×10^{4}	3.19×10^{3}	0.001
1F	1.00×10^{0}	0	–	1.69×10^{5}	6.67×10^{2}	0.004	6.50×10^{4}	4.24×10^{1}	0.0007	1.76×10^{4}	1.46×10^{2}	0.008
2B	2.03×10^{5}	0	–	1.38×10^{4}	3.40×10^{3}	0.002	2.73×10^{4}	7.55×10^{2}	0.0003	1.05×10^{5}	1.46×10^{4}	0.014
2C	9.10×10^{4}	5.96×10^{1}	0.00007	1.13×10^{5}	1.80×10^{3}	0.02	2.28×10^{4}	9.49×10^{2}	0.0004	2.52×10^{5}	1.27×10^{3}	0.005
2D	1.80×10^{4}	2.3×10^{1}	0.0001	3.34×10^{5}	3.70×10^{2}	0.001	2.66×10^{4}	1.10×10^{3}	0.0004	5.95×10^{4}	3.94×10^{3}	0.07
2E	1.77×10^{4}	5.96×10^{0}	0.0003	1.77×10^{4}	6.17×10^{1}	0.00003	4.88×10^{4}	7.14×10^{3}	0.002	9.72×10^{5}	2.30×10^{4}	0.02
2F	6.10×10^{4}	2.3×10^{1}	0.0004	7.47×10^{5}	1.16×10^{1}	0.00002	6.50×10^{5}	8.89×10^{2}	0.001	3.28×10^{5}	6.17×10^{2}	0.002
2G	–	–	–	1.64×10^{4}	1.19×10^{1}	0.001	4.70×10^{4}	2.38×10^{3}	0.05	1.31×10^{4}	6.17×10^{2}	0.05
2H	NS	NS	–	1.50×10^{4}	1.45×10^{4}	0.96	NS	NS	–	NS	NS	–
3D	NS	NS	–	NS	NS	–	2.40×10^{3}	2.30×10^{2}	0.1	NS	NS	–
5A	1.75×10^{4}	1.45×10^{1}	0.0008	NS	NS	–	NS	NS	–	NS	NS	–
5B	3.25×10^{5}	1.16×10^{0}	0.000004	6.85×10^{5}	1.17×10^{2}	0.0002	2.04×10^{5}	2.37×10^{2}	0.001	6.43×10^{5}	9.70×10^{3}	0.02
5C	2.35×10^{4}	2.30×10^{1}	0.001	3.36×10^{5}	4.23×10^{1}	0.0001	5.85×10^{5}	3.26×10^{3}	0.006	4.76×10^{4}	2.31×10^{3}	0.05
5D	4.85×10^{4}	5.96×10^{0}	0.0001	4.08×10^{5}	3.20×10^{0}	0.000008	1.30×10^{5}	6.34×10^{1}	0.0005	2.79×10^{4}	1.26×10^{3}	0.05
5E	2.27×10^{5}	6.17×10^{0}	0.0003	2.80×10^{5}	3.89×10^{2}	0.001	2.17×10^{4}	1.57×10^{2}	0.00007	1.72×10^{5}	1.46×10^{3}	0.008
5F	1.14×10^{4}	0	–	7.34×10^{5}	4.40×10^{2}	0.0006	3.25×10^{4}	5.80×10^{1}	0.00002	2.41×10^{5}	1.27×10^{5}	0.53
5G	4.03×10^{4}	0	–	2.68×10^{5}	3.20×10^{3}	0.01	8.37×10^{5}	4.13×10^{3}	0.005	1.12×10^{5}	1.46×10^{4}	0.13
5H	2.95×10^{4}	9.38×10^{0}	0.0003	2.52×10^{5}	2.70×10^{2}	0.001	4.00×10^{5}	6.17×10^{3}	0.002	2.53×10^{4}	1.30×10^{3}	0.0005
5I	NS	NS	–	9.17×10^{3}	1.26×10^{1}	0.001	3.55×10^{4}	2.06×10^{1}	0.0006	4.37×10^{2}	5.96×10^{0}	0.01
7B	5.70×10^{4}	1.79×10^{1}	0.0003	2.56×10^{4}	2.31×10^{3}	0.0009	1.10×10^{4}	1.74×10^{3}	0.0002	3.30×10^{4}	1.46×10^{3}	0.04
7C	3.25×10^{5}	2.30×10^{1}	0.00007	1.43×10^{4}	1.22×10^{2}	0.00008	8.57×10^{5}	2.30×10^{1}	0.00003	1.46×10^{5}	9.65×10^{1}	0.0007
7D	7.00×10^{4}	6.17×10^{1}	0.0009	1.60×10^{4}	1.16×10^{3}	0.0004	2.39×10^{4}	6.12×10^{1}	0.00003	1.25×10^{5}	1.17×10^{5}	0.94
7E	3.26×10^{5}	2.30×10^{1}	0.00007	8.48×10^{4}	1.18×10^{4}	–	2.06×10^{5}	1.45×10^{1}	0.00007	1.00×10^{1}	2.30×10^{1}	2.3
7F	4.55×10^{3}	0	–	1.14×10^{5}	1.18×10^{4}	–	2.90×10^{4}	5.30×10^{0}	0.0001	1.00×10^{1}	2.30×10^{1}	2.3

NG = no growth NS = no sample

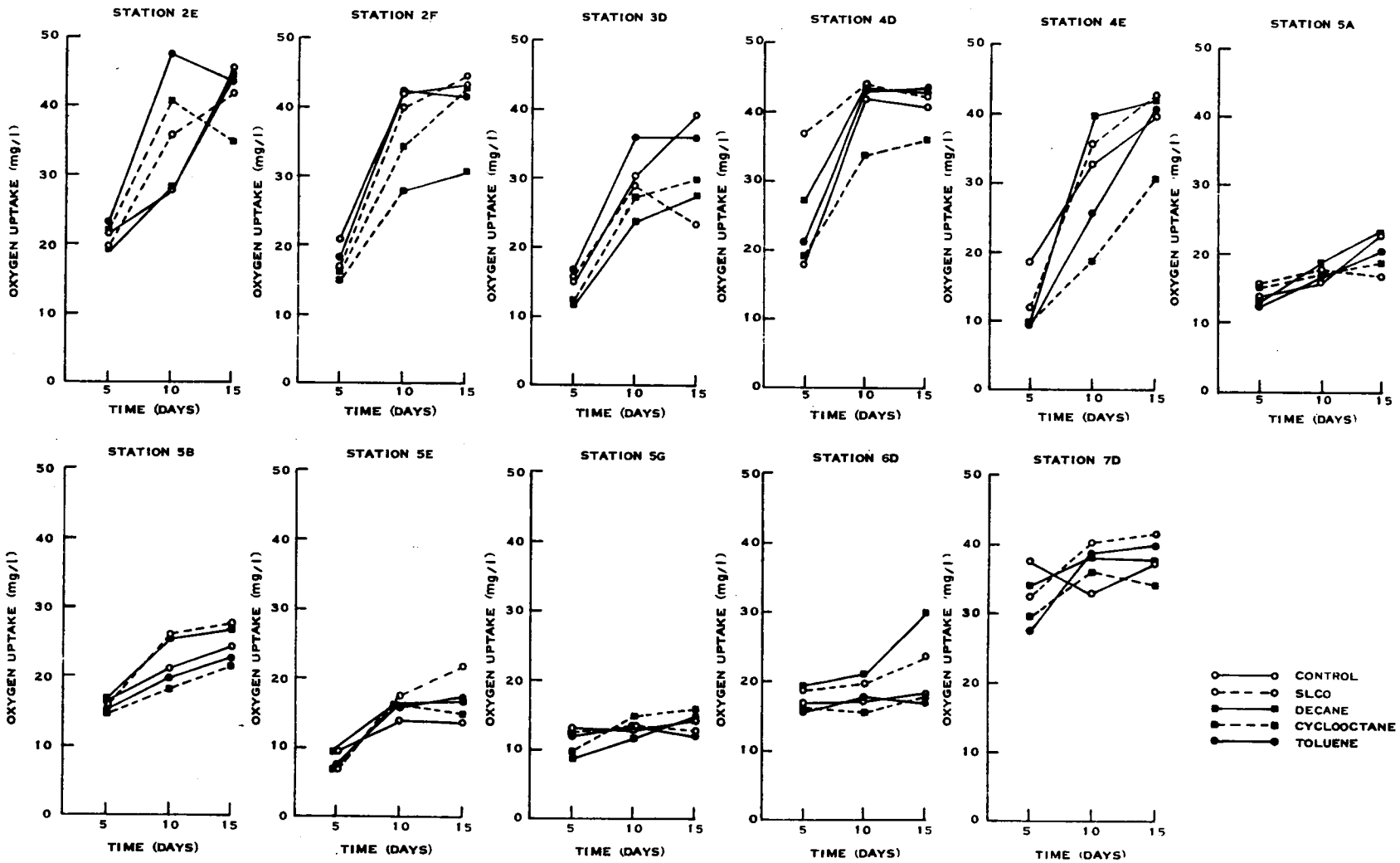
STATION 2E
STATION 2F
STATION 3D
STATION 4D
STATION 4E
STATION 5A
STATION 5B
STATION 5E
STATION 5G
STATION 6D
STATION 7D
OXYGEN UPTAKE (mg/l)
TIME (DAYS)
CONTROL
SLCO
DECANE
CYCLOOCTANE
TOLUENE

Table 3.11-2. Microbial Taxonomic Strains Identified From Georgia Bight Surface Microlayer, Near-Surface Water Column, and Sediment Samples

	Cruise 1 Water Column	Surface	Cruise 2 Water Column	Sediment	Total
Vibrio alginolyticus	7D	5G			2
V. parahaemoliticus			5B	2D	2
Lucibacterium harveyi	4E		4E	5C	3
Alteromonas sp. or *Pseudomonas* sp.	5B		4E		2
Pseudomonas sp.	2F (2)		4E		3
Pseudomonas or *Alteromonas*	3D, 5A, 5B, 5E (2)	5F (2)	2E (2), 3D, 4D, 4E, 6E	2B, 2D	15
Moraxella Group	5A				1
Cytophaga/Flexibacteria Group			1D, 3D		2
Alteromonas sp.	1D (2), 5A		1D, 3D, 4D, 4E, 5B (2), 5E (3)		12
Alteromonas putrifaciens			3D		1
Unidentified	5A		1D, 5B, 6D	2D	5
Total (Identified)	14		29		43
Total (All)	15		33		48

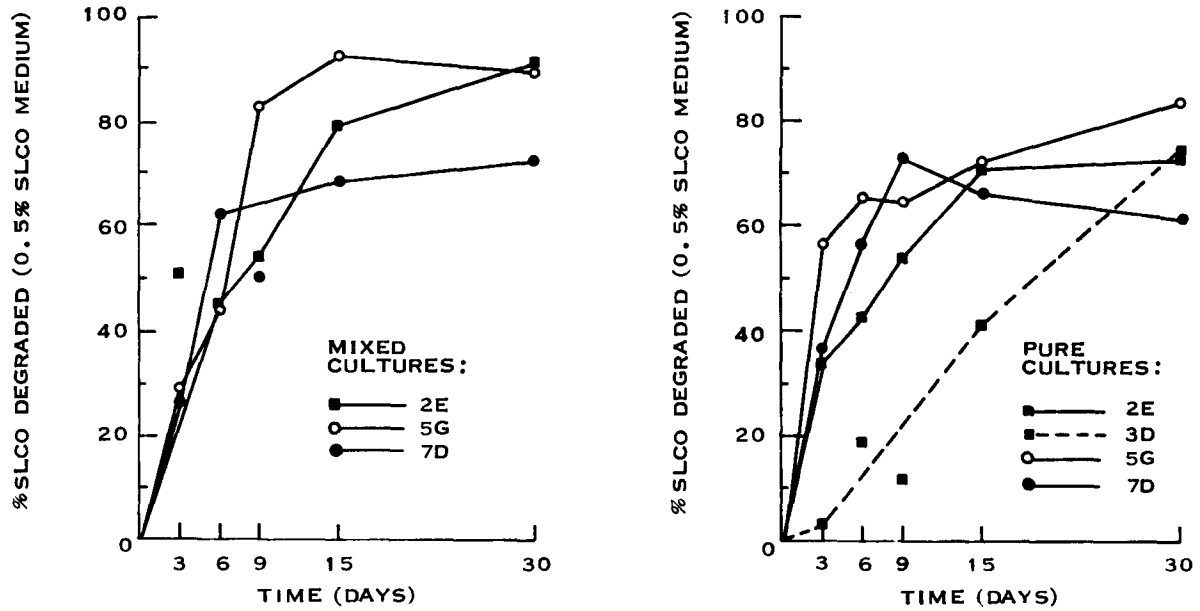

Figure 3.11-3. SLCO Degradation Rates of Three Mixed and Four Pure Cultures of South Atlantic OCS Bacteria

Table 3.11-3. 3-, 6-, 12-, and 30-Day Mass-Culture Hydrocarbon Degradation of 0.2% SLCO in ESW Medium by Extract Weight

		Winter				Spring				Summer			
Station[a]	Day	Freon (mg)	Benzene (mg)	Methanol (mg)	% SLCO Remaining (Freon)	Freon (mg)	Benzene (mg)	Methanol (mg)	% SLCO Remaining (Freon)	Hexane (mg)	Benzene (mg)	Methanol (mg)	% SLCO Remaining (Hexane)
1D	3	40.0	4.0	1.0	77.3	NS	NS	NS	NS	NS	NS	NS	NS
	6	24.0	3.0	1.0	65.4	NS	NS	NS	NS	NS	NS	NS	NS
	12	23.0	3.0	1.0	57.5	NS	NS	NS	NS	NS	NS	NS	NS
2E	3	32.2	4.5	1.0	80.1	36.5	4.0	4.5	90.6	NS	NS	NS	NS
	6	19.0	6.3	2.0	51.8	NS	3.0	1.0	NS	NS	NS	NS	NS
	12	18.6	6.7	2.5	46.5	30.0	3.0	2.0	75.0	NS	NS	NS	NS
	30	14.0	4.5	3.0	35.9	NS	NS	NS	NS	NS	NS	NS	NS
2F (1)	3	36.3	3.0	1.0	NS	NS	NS	NS	NS	NS	NS	NS	NS
	6	33.0	3.0	3.0	59.9	NS	NS	NS	NS	NS	NS	NS	NS
	12	28.0	5.0	0.0	70.0	NS	NS	NS	NS	32.5	9.0	2.5	92.9
2F (2)	3	35.3	3.5	1.0	87.6	NS	NS	NS	NS	NS	NS	NS	NS
	6	39.0	6.0	2.0	100.0	NS	NS	NS	NS	NS	NS	NS	NS
	12	32.0	3.0	3.0	80.0	NS	NS	NS	NS	31.5	11.0	2.0	90.0
3D	3	38.8	4.0	1.3	96.3	14.8	0.5	0.0	36.7	NS	NS	NS	NS
	6	32.0	7.0	1.0	87.2	14.0	1.5	1.5	38.1	NS	NS	NS	NS
	12	24.0	NS	NS	60.0	10.0	2.5	1.5	25.0	NS	NS	NS	NS
4D	12	NS	NS	NS	NS	NS	NS	NS	NS	32.0	7.5	1.5	87.2
4F	12	NS	NS	NS	NS	NS	NS	NS	NS	17.0	5.0	2.5	48.6
5A	3	25.4	2.7	2.7	63.0	39.5	3.5	1.0	98.0	NS	NS	NS	NS
	6	18.3	2.0	3.0	49.9	39.0	5.0	2.0	100.0	NS	NS	NS	NS
	12	14.0	3.0	2.0	35.0	40.0	3.0	1.0	100.0	36.5	10.5	1.5	>100.0
5B (1)	3	40.8	11.0	1.5	101.2	NS	NS	NS	NS	NS	NS	NS	NS
	6	22.0	5.0	0.0	59.9	NS	NS	NS	NS	NS	NS	NS	NS
	12	16.0	2.0	1.0	40.0	NS	NS	NS	NS	40.5	8.0	3.0	>100.0
5B (2)	3	27.0	4.5	1.5	67.0	NS	NS	NS	NS	NS	NS	NS	NS
	6	17.0	3.3	1.3	46.3	NS	NS	NS	NS	NS	NS	NS	NS
	12	11.0	2.3	1.5	27.5	NS	NS	NS	NS	38.0	10.0	2.5	>100.0
5D	3	25.7	4.0	1.0	63.8	NS	NS	NS	NS	NS	NS	NS	NS
	6	14.0	2.7	2.5	38.1	NS	NS	NS	NS	NS	NS	NS	NS
	12	13.3	2.5	1.5	33.3	NS	NS	NS	NS	NS	NS	NS	NS
	30	4.0	1.0	1.0	10.3	NS	NS	NS	NS	NS	NS	NS	NS
5E	3	11.0	6.0	1.0	27.3	NS	NS	NS	NS	NS	NS	NS	NS
	6	5.0	2.5	2.0	13.6	NS	NS	NS	NS	NS	NS	NS	NS
	12	8.0	2.5	2.5	20.0	NS	NS	NS	NS	NS	NS	NS	NS
5G	12	NS	NS	NS	NS	NS	NS	NS	NS	24.0	7.0	2.0	68.6
6D	3	NS	NS	NS	NS	11.5	6.0	4.0	28.5	NS	NS	NS	NS
	6	NS	NS	NS	NS	12.5	3.5	1.5	34.1	NS	NS	NS	NS
	12	NS	NS	NS	NS	7.5	2.0	1.5	17.5	NS	NS	NS	NS
7D	3	NS	NS	NS	NS	47.0	3.5	1.0	116.6	NS	NS	NS	NS
	6	NS	NS	NS	NS	38.0	5.0	1.0	100.0	NS	NS	NS	NS
	12	NS	NS	NS	NS	36.0	2.0	1.0	90.0	33.0	8.5	2.5	94.3
Control	0	40.7	8.0	1.0		40.7	8.0	1.0		36.0	12.0	1.0	
	3	40.3	9.0	1.5		40.3	9.0	1.5					
	6	36.7	6.0	3.0		36.7	6.0	3.0					
	12	40.0	6.0	2.0		40.0	6.0	2.0					
	30	39.0	5.0	2.5		39.0	5.0	2.5					

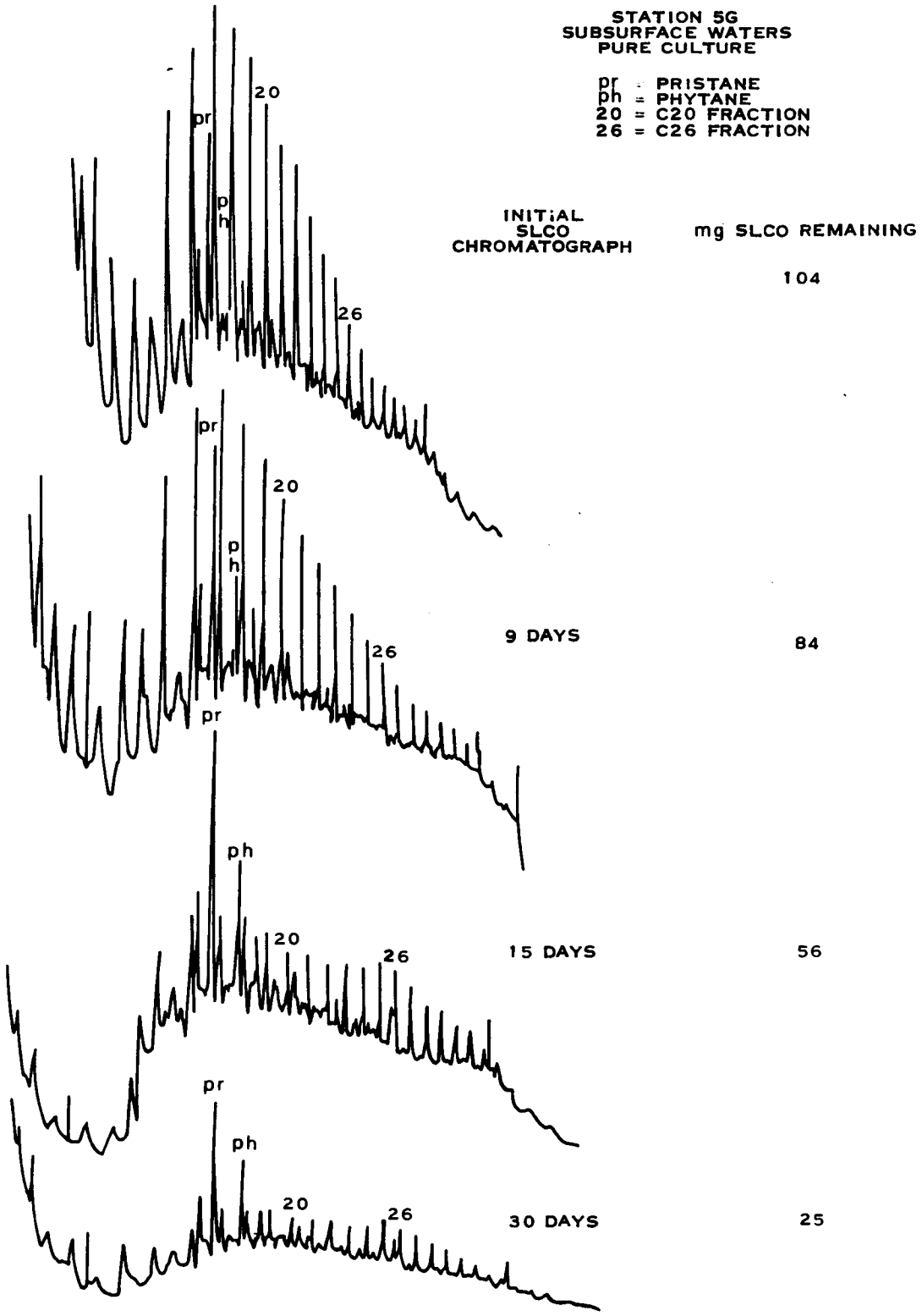

Figure 3.11-4. Representative Gas Chromatographs of Residual SLCO Following 9, 15, and 30 Days of Incubation

loss resulting from degradation. The area under the chromatograph curve represents that portion of the petroleum sample that could not be resolved under the conditions of the analysis. Other than pristane and phytane, no sparing action on any specific molecule was observed in the chromatographic records. At intermediate stages (9 days), there was indication of use of the normal hydrocarbons faster than the isoprenoid hydrocarbon fractions, but after 30 days, there were no substantial amounts of any specific hydrocarbon other than pristane and phytane.

GC/MS data for SLCO control and for 6- and 30-day aromatic hydrocarbon degradation extracts are given in Figure 3.11-5. Benzene extract weights were as follows:

Days of Degradation	Benzene Extract (g)	SLCO Extract Control (g)
0	0.024	0.024
6	0.01	0.025
30	0.004	0.026

Peaks associated with the major resolvable aromatic hydrocarbons and isomers in SLCO were identified by GC/MS. Volume 6 includes the complete file of chromatographic plots. A significant reduction of SLCO was observed in all cultures.

F. EFFECTS OF NITRATE AND PHOSPHATE CONCENTRATIONS ON DEGRADATION RATES OF SLCO

The typical growth curves for pure cultures grown on enriched and nonenriched seawater (Figure 3.11-6) illustrate the microbial requirement for nitrate and phosphate nutrients. Three analyses of oil degradation by pure cultures with different concentrations of nitrate and phosphate during 12 days of incubation are presented in Table 3.11-4. The results of 12 days' growth of cultures on nutrient enriched and nonenriched seawater are also given in Table 3.11-4. Figures 3.11-7 and 3.11-8 show degradation rates that occurred under varying nitrate and phosphate concentration regimes, respectively. Similar results using decane and cyclooctane as the sole carbon sources appear in Figures 3.11-9 and 3.11-10.

A critical minimum concentration of phosphate required for hydrocarbon degradation was not established. The following observations were made: the percentage of SLCO degraded in media of 0.1 percent and 0.5 percent SLCO reached an apparent maximum at a phosphate concentration of 1.0 ppm, and raising the phosphate concentration to a level of 10 ppm did not significantly increase the percentage of SLCO degraded. As expected, SLCO degradation increased as a function of the amount of nitrate present. Of the three hydrocarbon fractions separated from residual SLCO, the aromatic and asphaltenic fractions were present in very small amounts and their weight variation could not be significantly interpreted. The total amount of SLCO degraded was calculated from the amount of SLCO present in the weathering control following the 12-day incubation period.

None of the organisms tested were able to use toluene as a carbon source. In fact, a 0.5 percent toluene concentration appeared to be toxic to the four species and no growth of less than 100 cell forming units (CFU)/ml was observed after 12 days of incubation following an initial inoculum size of 10^4 to 10^5 CFU/ml.

Very little growth, if any, occurred in cyclooctane experiments in which phosphate was varied, but good growth occurred at nitrate concentrations of 5 to 10 ppm. The number of viable cells present following the 12-day incubation period with phosphate was found to be in the general range of the original inoculum. These data indicate that the combination of species present in the mixed cultures from station 5G was able to use cyclooctane more effectively than was the single species in nutrient experiments with phosphate.

The test cultures used decane. Cell number increased as nitrate or phosphate concentrations were increased. Cultures from stations 2E and 7D became asymptotic at nitrate concentrations of 25 to 100 ppm. Culture 5G, which had earlier been found to be extremely slow in its rate of hydrocarbon degradation, increased to 10^6 CFU/ml, an increase by a factor of 10 from the original inoculum size. Culture 3D showed increased cell numbers at nitrate concentrations of 100 ppm.

For most cultures tested, 0.1 to 0.5% of SLCO provided microbial response. Percent SLCO used was generally somewhat lower at SLCO concentrations of 1%. Nitrogen was limiting below 25 ppm, and phosphate was limiting at some point below 1 ppm. A critical minimum concentration of phosphate could not be determined under the conditions of the experiments. Decane and cyclooctane were degraded by the test cultures and indicated nitrogen and phosphorus limiting values similar to those determined for the SLCO.

G. EFFECT OF LOW TEMPERATURE ON OIL DEGRADATION

When cultures were incubated at 9°C, there was no growth or hydrocarbon degradation. Table 3.11-5 indicates the results of a typical test. Mean hydrocarbon values after 3, 6, and 9 days of incubation were derived from duplicate runs; the 12-day means were derived from four runs.

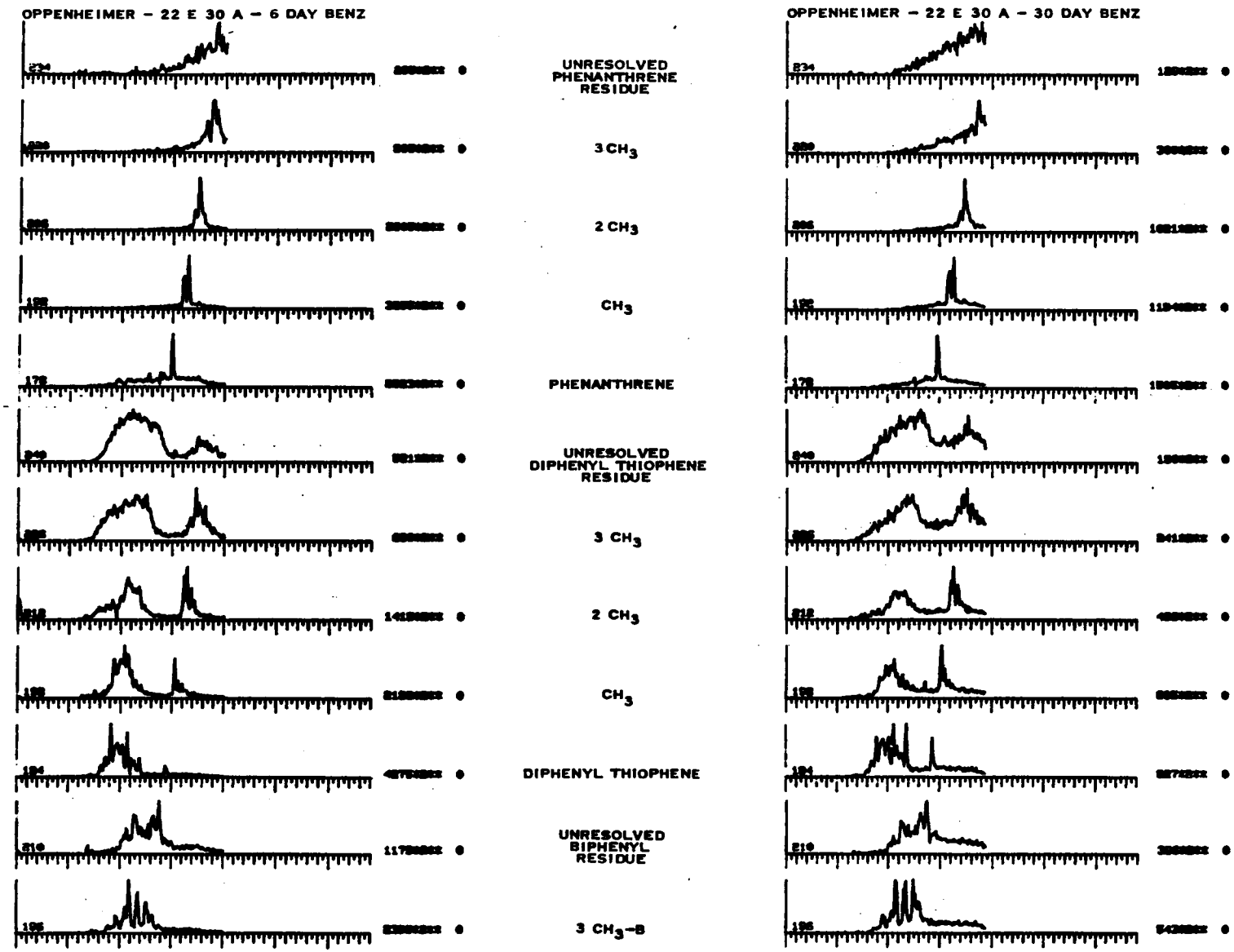

Figure 3.11-5. 6- and 30-Day Aromatic Hydrocarbon Extract GC/MS Traces for Station 2E Subsurface Mixed Cultures (Sheet 1 of 2)

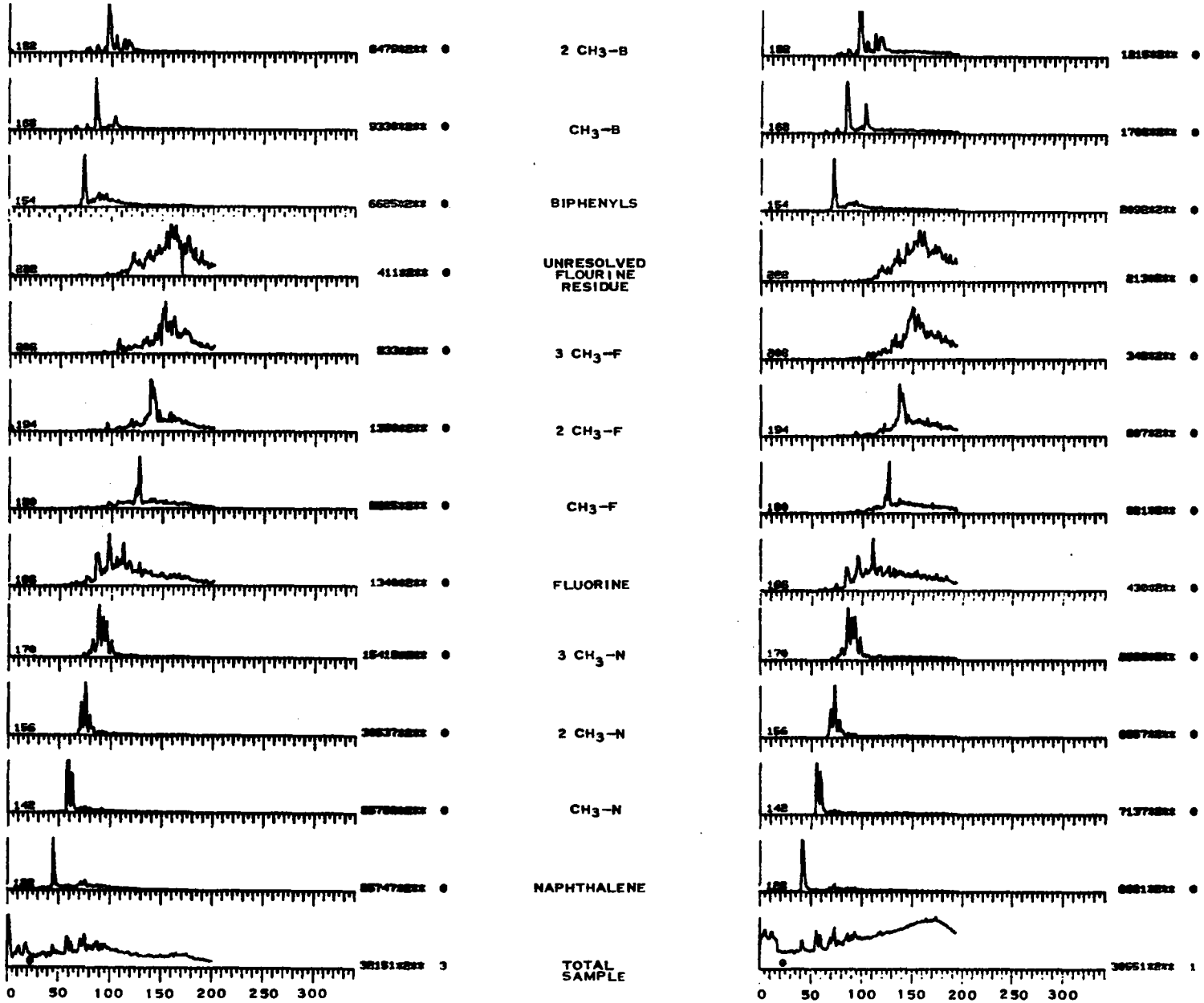

Figure 3.11-5. 6- and 30-Day Aromatic Hydrocarbon Extract GC/MS Traces for Station 2E Subsurface Mixed Cultures (Sheet 2 of 2)

Table 3.11-4. 12-Day Oil Degradation of Four Pure Cultures–Average Weight (g) of Residual SLCO

Nutrient Test Concentrations–ppm

Station		0 NO_3 10 PO_4	5 NO_3 10 PO_4	25 NO_3 10 PO_4	100 NO_3 10 PO_4	100 NO_3 1 PO_4	100 NO_3 0.1 PO_4	Aged Sea Water With No Nutrient Enrichment	Enriched Sea Water*
Experiment 1: 0.1% SLCO									
3D	Hexane	0.011	0.005	0.002	0.0015	0.002	0.009	0.011	0.001
	Benzene	0.002	0.0025	0.0015	0.001	0.0015	0.003	0.0035	0.0005
	Methanol	0.001	0.002	0.003	0.002	0.001	0.0015	0.001	0.001
2F	Hexane	0.0125	0.0105	0.005	0.003	0.003	0.006	0.0095	0.0035
	Benzene	0.0055	0.0025	0.003	0.001	0.0015	0.003	0.004	0.003
	Methanol	0.003	0.002	0.001	0.002	0.002	0.0025	0.001	0.002
7D	Hexane	0.0125	0.013	0.003	0.005	0.011	0.011		0.0035
	Benzene	0.004	0.004	0.002	0.0015	0.003	0.0045		0.0025
	Methanol	0.002	0.001	0.0015	0.001	0.001	0.001		0.0015
5G	Hexane	0.011	0.009	0.009	0.006	0.011	0.006	0.018	0.007
	Benzene	0.0035	0.0035	0.004	0.003	0.004	0.004	0.004	0.0015
	Methanol	0.001	0.001	0.001	0.005	0.002	0.0015	0.001	0.002
Experiment 2: 0.5% SLCO									
3D	Hexane	0.085	0.0975	0.0555	0.0135	0.0155	0.077	0.105	0.026
	Benzene	0.0205	0.0175	0.0145	0.004	0.0045	0.019	0.019	0.007
	Methanol	0.004	0.005	0.0025	0.002	0.0015	0.0055	0.0045	0.0015
2E	Hexane	0.072	0.066	0.0375	0.0455	0.0265	0.0745	0.080	0.0265
	Benzene	0.020	0.013	0.0115	0.013	0.0105	0.020	0.0185	0.0065
	Methanol	0.004	0.0035	0.0025	0.0035	0.004	0.005	0.0055	0.0015
7D	Hexane	0.0755	0.0505	0.047	0.0355	0.037	0.071	0.077	0.024
	Benzene	0.0175	0.013	0.0115	0.013	0.0085	0.018	0.015	0.006
	Methanol	0.004	0.003	0.003	0.0035	0.003	0.0045	0.005	0.0015
5G	Hexane	0.099	0.0845	0.0795	0.0775	0.0705	0.0705	0.099	0.050
	Benzene	0.017	0.019	0.0195	0.020	0.0185	0.0165	0.0175	0.0115
	Methanol	0.004	0.005	0.004	0.004	0.007	0.0055	0.007	0.003
Experiment 3: 1.0% SLCO									
3D	Hexane	0.194	0.1675	0.1515	0.109	0.138	0.133	0.186	0.080
	Benzene	0.030	0.037	0.033	0.026	0.031	0.030	0.032	0.023
	Methanol	0.011	0.010	0.009	0.006	0.009	0.009	0.008	0.008
2E	Hexane	0.201	0.182	0.194	0.130	0.136	0.164	0.132	0.118
	Benzene	0.044	0.034	0.043	0.030	0.035	0.035	0.030	0.024
	Methanol	0.008	0.008	0.009	0.008	0.009	0.008	0.009	0.007
7D	Hexane	0.164	0.159	0.138	0.118	0.147	0.168	0.179	0.091
	Benzene	0.037	0.034	0.029	0.023	0.033	0.024	0.036	0.022
	Methanol	0.009	0.009	0.012	0.008	0.008	0.008	0.010	0.007
5G	Hexane	0.136	0.168	0.165	0.167	0.158	0.164	0.173	0.134
	Benzene	0.030	0.036	0.039	0.036	0.038	0.036	0.033	0.026
	Methanol	0.008	0.009	0.008	0.009	0.009	0.008	0.008	0.006

Weathering Control**

Hexane	0.0805
Benzene	0.021
Methanol	0.005

*ESW medium
66 ppm NO_3 (NH_4 NO_3)
18 ppm NO_4 (K_2H PO_4)

**Sterile control following 12-day weathering. Initial concentration of SLCO 0.1%.

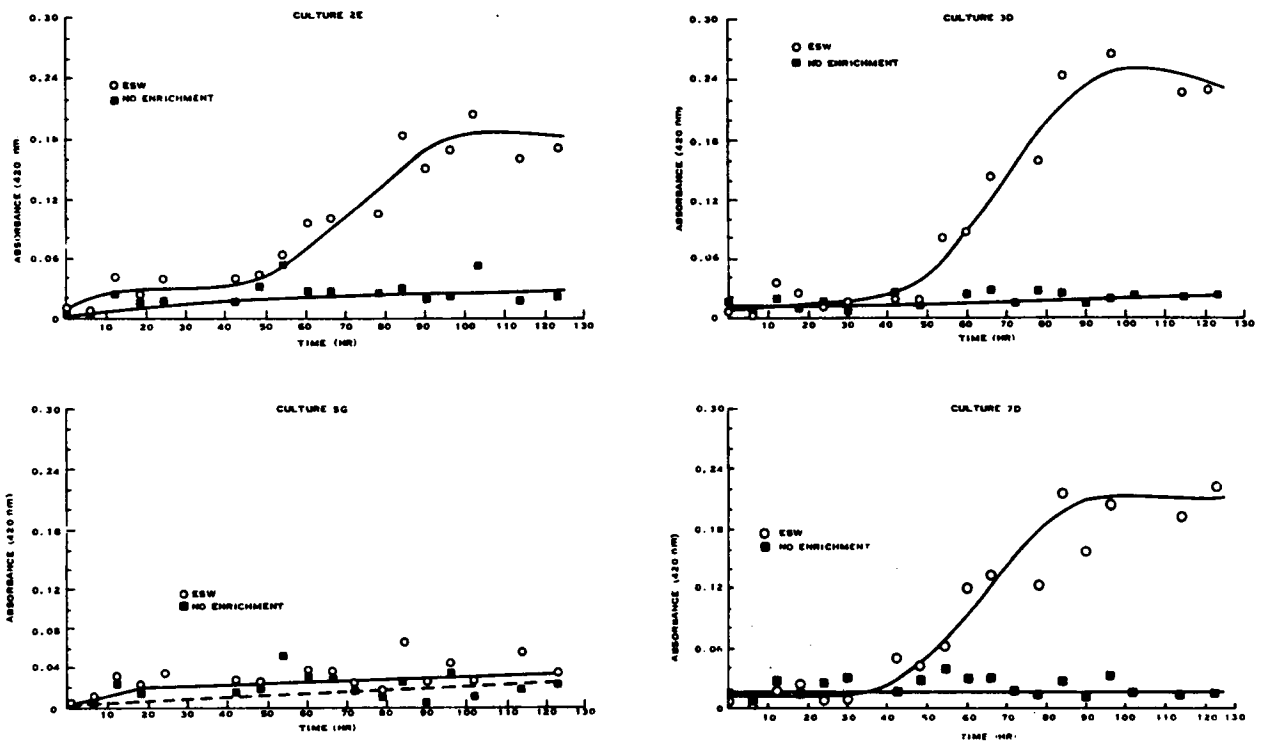

Figure 3.11-6. 5-Day Growth Curves of Four Pure Cultures With and Without Nitrate and Phosphate Enrichment

Table 3.11-5. Mean Weight of Various Oil Fractions in Control and Culture Flasks Following Incubation at 9°C

		Weight (g)			
Sample	**Days**	**Hexane**	**Benzene**	**Methanol**	
Control	3	0.160	0.052	0.007	
	6	0.160	0.044	0.008	No evident growth in any flask
	9	0.176	0.044	0.009	
	12	0.187	0.038	0.008	
2E	3	0.176	0.035	0.009	
	6	0.169	0.042	0.009	No growth in any flask
	9	0.178	0.044	0.008	
	12	0.165	0.040	0.006	
7D	3	0.164	0.031	0.008	
	6	0.178	0.036	0.007	No growth in any flask
	9	0.176	0.037	0.008	
	12	0.169	0.040	0.007	

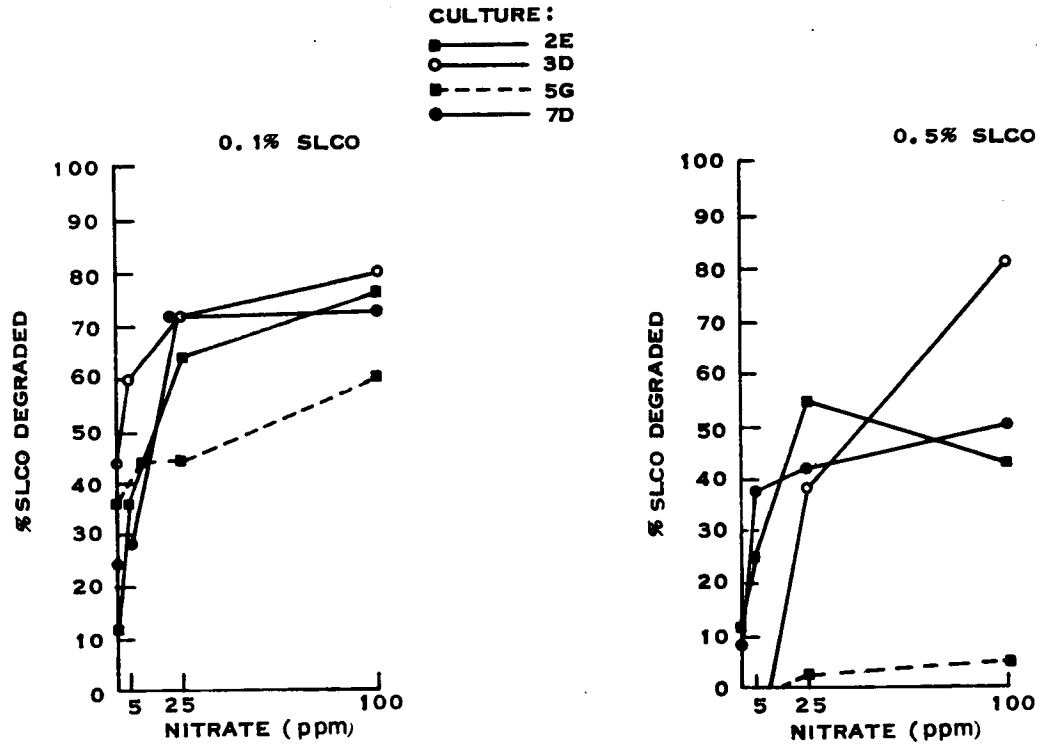

Figure 3.11-7. Degradation Rates of Pure Cultures With Varying Nitrate and 10-ppm Phosphate Concentrations

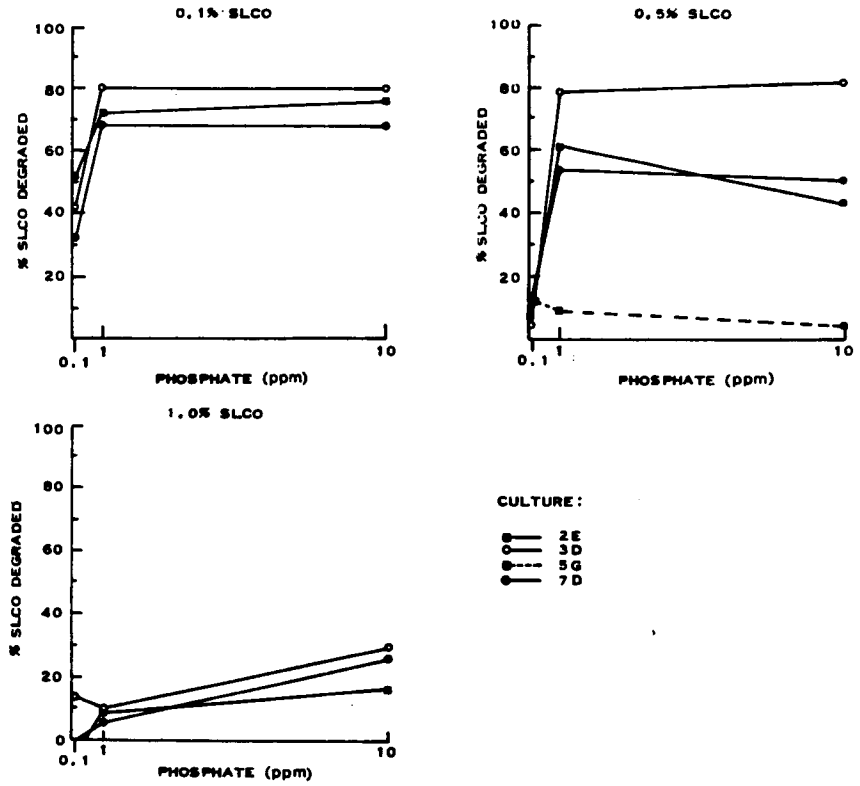

Figure 3.11-8. Degradation Rates of Pure Cultures With Varying Phosphate and 100-ppm Nitrate Concentrations

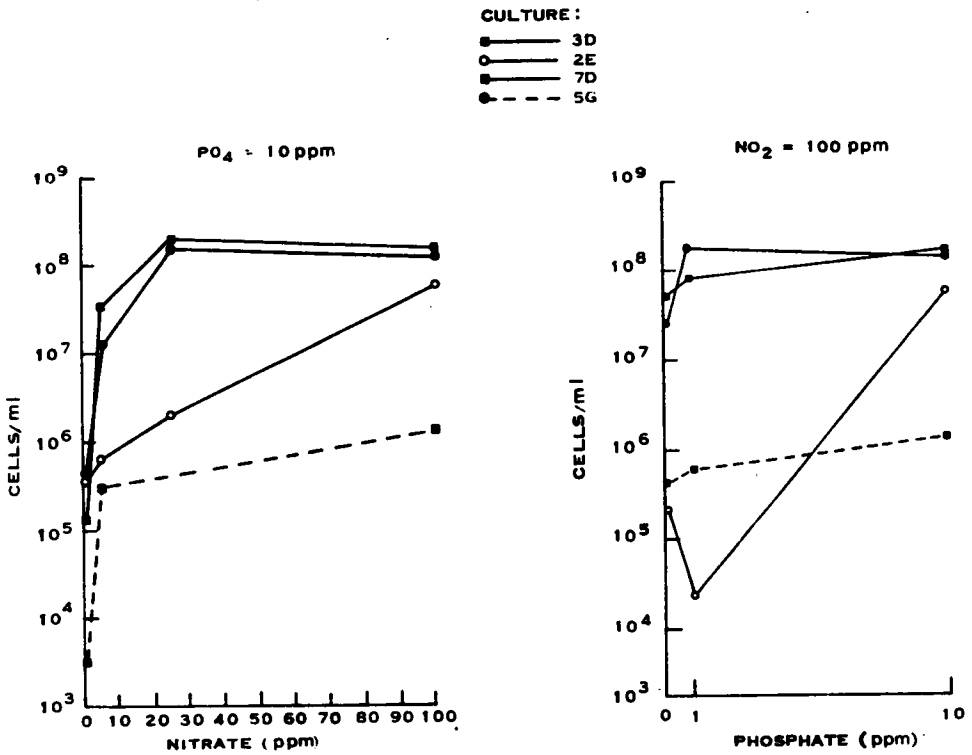

Figure 3.11-9. Rates of Growth During 12 Days' Incubation on 0.5% Decane With Varying Nitrate and Phosphate Concentrations

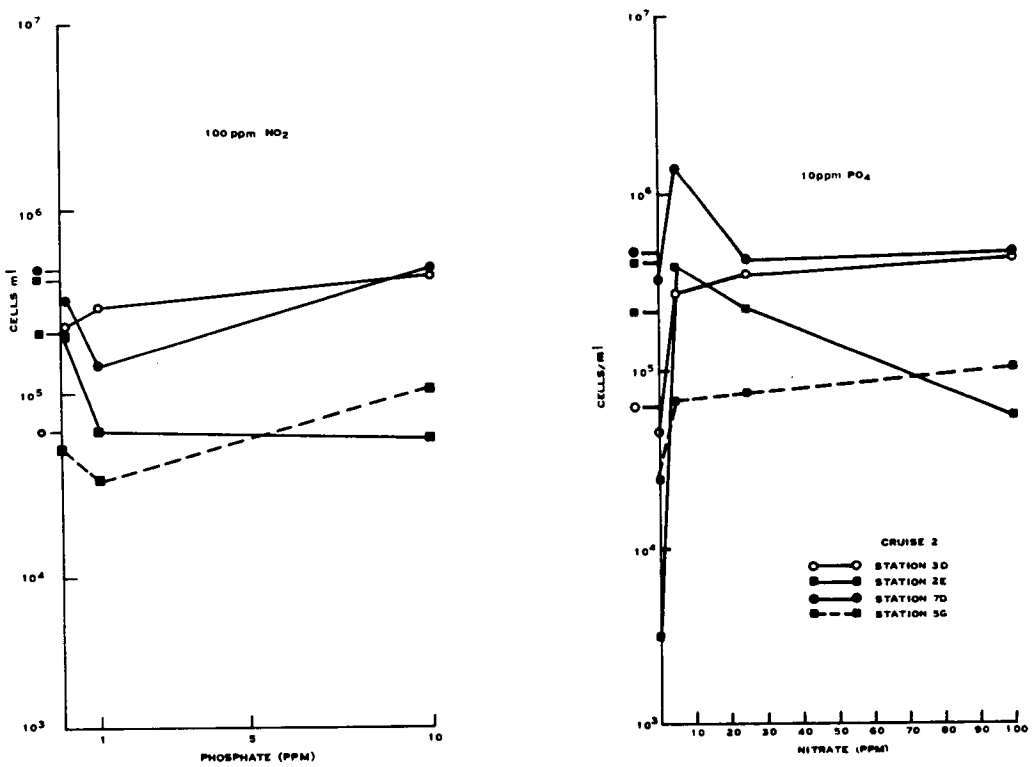

Figure 3.11-10. Rates of Growth During 12 Days' Incubation on 0.5% Cyclooctane With Varying Nitrate and Phosphate Concentrations

SECTION 4
DISCUSSION

Microbial community composition and density may be used as initial indications of an ecosystem's potential to assimilate petroleum. Once microbial abundance has been established, the available species' capacity to degrade petroleum hydrocarbons, the rates at which this function is performed, and the effects of temperature and mineral nutrient concentrations on rates can be determined. Preliminary studies of the microbial flora of the South Atlantic OCS followed this sequence and provided a significant basis for the assessment of potential environmental response to petroleum activities on the outer continental shelf.

A. DISTRIBUTION OF BACTERIA, NUTRIENTS, AND HYDROCARBONS IN THE SOUTH ATLANTIC OCS

The role of bacteria in nature, disregarding public health aspects, is one of recycling the materials bound by photosynthesis and incorporated into protoplasm and the weathering and precipitation of materials in water and sediments. The term mineralizer or decomposer is commonly used to describe the ecological role of bacteria.

Bacteria are present in water and sediments in numbers related to the presence of their food. Many species of bacteria are present, each with a specific role in the mineralization processes that is regulated by cell membrane permeability, enzyme site and action, solubility, and the many other parameters that regulate the metabolic activity of living cells. Thus, numbers of bacteria can be related to these facts: (1) the food is available (inasmuch as the bacteria can multiply by cell division in periods as short as 30 min) or (2) the food has already been used and the numbers reflect past availability. It is impossible to determine where in the food availability/community response cycle a particular population may be.

The microorganisms sampled during this study were heterotrophs that will grow on a general nutrient seawater medium with peptone as a carbon source and hydrocarbon-using forms that will use seawater enriched in nitrogen and phosphate with SLCO as a sole carbon source. Because of the response time of bacteria to the presence of food and the continuity of the marine environment, statistical analyses of the distribution of bacteria may be misleading or entirely wrong. Numerical data, however, may be used to show that the potential for oil degradation does exist and to show the relationship between the presence of hydrocarbons and nutrients; this relationship, added to BOD and laboratory experiments, may indicate how mixed and pure cultures of microorganisms affect the test oil in terms of total degradation and molecular change.

The primary processes of hydrocarbon metabolism are well documented. In general, the oil molecule is changed to a fatty acid, which may be used by the bacteria or may enter the water column. Fatty acids in the water aid in emulsifying other oil. Thus, natural emulsification of oil may take place at the surface microlayer where the fatty materials and oil collect (Gibson, 1971; ZoBell, 1971). If wave action is present, the emulsion may be moved below the surface of the water as a function of the size of the waves and the velocity of the wind to be dispersed to some degree in the near-surface waters.

The processes by which hydrocarbons reach the sediments in deep water are not well understood. Most surface hydrocarbons are less dense than water and form colloidal micelles when emulsified. Thus, hydrocarbons reaching the bottom must have changed in density through oxidation, be adsorbed to particulate matter, or accumulate in the remains of organisms that fall to the bottom. Because of the hydrophobic nature of oils, the majority of initial microbial degradation and emulsion formation occurs at the surface microlayer.

As a result of the almost universal distribution of food materials in the oceans, hydrocarbon-using bacteria are essentially ubiquitous and, therefore, are always ready if oil becomes available because of natural productivity, seeps and land runoff, or, more recently, man's introduction of oil to the environment.

Bacteria in the offshore waters of the South Atlantic OCS are generally comparable in number with those reported in the literature for other shelf areas. Sufficient numbers of oil-degrading bacteria are present to respond to the addition of hydrocarbons. Hydrocarbon concentrations in the study area (Chapter 3, Section 3) are very low but are consistent with the numbers of oil-degrading bacteria observed. Nutrients (nitrates and phosphates) are uniformly low in number but sufficient to support a bacterial increase to approximately 10^4 cells/ml. The presence of only a few hydrocarbon-using bacteria clearly represents a dormant or relatively inactive state since hydrocarbon concentrations in the study area are low enough to be considered at the lower limits for uptake by the bacteria. For comparison, if all the carbon of the hydrocarbons present (0.3 ppb) could be converted to bacterial cells, about 3,000 cells/ml of water would be present.

Table 3.11-6 compares bacteria and other hydrographic parameters for subsurface water during summer and fall. There are more bacteria in the fall, suggesting that they are playing the part of mineralizers for the summer productivity. The data from the winter cruise (Table 3.11-1) seem to indicate that the oil-degrading bacteria outnumber the heterotrophs. Perhaps organic matter from summer production is completely degraded by this time and the apparent continued presence of oil bacteria is indicative of earlier degradation.

Although the water column was low in bacteria during all cruises, there is a clear indication that sufficient oil bacteria were present to respond to the addition of oil. This is confirmed by fall BOD data in which SLCO oxidation in excess of controls and increased numbers of oil bacteria were observed.

During the summer, zooplankton samples showed elevated hydrocarbon content while bacterial numbers were low (Table 3.11-7). This trend was reversed during the fall as hydrocarbons in the zooplankton decreased and numbers of oil bacteria increased. This perhaps indicates that oil bacteria increased in response to the die-off of zooplankton following the summer bloom.

The ratio of heterotrophic:oil bacteria for Cruise-1 sediments showed a relatively uniform low number of oil bacteria relative to heterotrophs. In the spring (Cruise 2), the relative number of oil bacteria increased at stations 2C, 2H, and 5G; in the summer (Cruise 3), stations 5G and 3D had a relatively high number of oil bacteria. In the fall (Cruise 4), there was an indication that the hydrocarbons produced by photosynthesis and zooplankton were reaching the sediment surface since the relative numbers of oil bacteria clearly increased at all stations except 5H and 7D. High numbers of oil bacteria at stations 7D, 7E, and 7F seemed to correspond to high sediment hydrocarbon content at these stations.

Table 3.11-6. Comparison of Bacteria, Oil, NO_3, and Carbon in Subsurface Samples During Summer and Fall Cruises

Station	Het Bact (No./ml)	Oil Bact (No./ml)	Total HC ppb (Diss.-Part.)	NO_3 (μgA/l)	TOC (μg/l)	BOD O_2 Uptake/ Control SLCO
Summer Cruise						
1D	73.2	1.91	0.33	0	0.30	
2E	34.0	1.89	0.39	0	0.56	
3D	78.1	1.81	0.54	0	2.45	
4D	73.8	3.31	0.41	0	0.81	
5E	73.7	0.42	0.69	0	0.60	
6D	35.6	0.46	0.51	0	0.82	
7D	27.8	0.22	5.31	0.2	0.66	
Winter Cruise						
1D	5,740	682	0.34	0.35	1.23	No Data
2E	6,550	124	0.35	0.35	0.34	±
3D	5,100	88	0.17	0.32	0.22	–
4D	4,880	336	12.42	0.26	0.41	+
5E	13,200	1,180	0.43	0.28	0.77	‡
6D	62,100	1,690	0.39	0.38	0.90	‡
7D	3,910	214	5.19	0.40	0.22	‡

Table 3.11-7. Summary of Hydrocarbon Concentrations in Zooplankton Samples and Bacteria

Season	Net Size (μm)	Total Hydrocarbons (μg/g)	Het Bact (No./ml)	Oil Bact (No./ml)	O:H
Winter	202	107			
	505	27	–	–	–
Spring	202	118			
	505	104	138	7.3	0.12
Summer	202	517			
	505	364	67	1.6	0.02
Fall	202	133			
	505	116	15,358	760	0.09

B. LABORATORY EXPERIMENTS

Laboratory experiments were designed to assess the ability of hydrocarbon-using mixed and pure cultures from the study area to use total hydrocarbons and specific molecule types from SLCO and the effects of various concentrations of nutrients and temperature on degradation rate. Mixed and pure cultures of microorganisms were randomly selected from enumeration-study oil-positive dilutions to represent the various seasons and stations.

Weight-loss data, as well as chromatograph results showing molecular change with time, indicated hydrocarbon use. The chromatograms also indicated a minor preferential uptake of specific molecules. Analysis of percent of various peaks (Table 3.11-8) indicated that, while pristane and phytane increased, other parameters varied with time and culture. Pristane increased

Table 3.11-8. Changes in Different Hydrocarbons[a] During Decomposition of South Louisiana Crude Oil by Mixed and Pure Cultures

Change in Weight (mg) After Various Incubation Periods

	Incubation Period (Days)									
	6	30	3	6	9	15	30	30	30	30
	Control		Mixed Culture						Pure Culture	
Retention Index			7D	7D	7D	7D	7D	2E	1E	7D
1100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1150	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1200	17.3	13.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1253	0.0	0.0	0.0	0.0	3.5	0.0	0.0	0.0	0.0	0.0
1300	13.7	12.9	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0
1356	6.7	6.7	7.4	3.9	6.2	3.9	0.0	0.0	13.3	10.0
1400	7.0	6.7	8.4	6.2	4.7	6.2	0.0	0.0	0.0	6.2
1440	4.3	4.7	7.2	4.2	9.8	4.2	0.0	0.0	21.5	13.0
1500	6.4	6.8	9.1	7.1	5.4	7.1	0.0	0.0	0.0	7.1
1551	1.2	1.3	3.6	0.0	0.0	0.0	0.0	0.0	0.0	3.5
1600	5.0	5.3	6.7	5.9	2.4	5.9	2.8	3.7	0.0	5.2
1620	1.9	1.9	3.1	3.1	2.0	3.1	11.1	5.5	9.9	5.8
1670[b]	1.6	1.9	3.6	9.5	9.7	9.5	26.7	13.4	25.3	10.8
1700	3.4	3.9	5.7	5.5	5.5	5.5	0.0	0.0	2.6	3.8
1780[c]	0.5	0.6	1.3	4.7	4.6	4.7	12.6	6.4	12.3	4.8
1800	3.5	3.9	5.0	4.7	5.1	4.7	1.8	3.3	0.0	3.6
1851	1.2	1.3	1.9	4.7	3.7	4.7	5.1	3.2	4.8	3.0
1900	4.2	4.4	5.5	4.2	4.2	4.2	1.4	2.4	1.7	3.7
2000	3.4	3.5	4.4	2.8	3.5	2.8	0.0	1.9	1.0	2.8
2100	2.8	2.9	3.8	2.8	3.7	2.8	0.0	1.6	0.0	2.3
2200	2.5	2.7	3.5	3.0	3.6	3.0	1.9	2.8	0.0	2.4
2300	2.1	2.2	3.0	3.1	3.1	3.1	2.9	3.9	1.6	1.9
2400	1.9	2.0	2.5	2.8	3.0	2.8	3.1	4.7	1.5	1.6
2500	1.7	1.8	2.4	3.4	3.0	3.4	4.5	7.4	1.4	1.5
2600	1.7	1.7	2.4	3.5	2.1	3.5	5.1	7.7	0.0	1.7
2700	1.2	1.3	1.8	3.2	3.2	3.2	5.1	7.7	1.4	1.0
2800	0.9	1.1	1.6	2.8	0.0	2.8	4.7	6.8	0.9	0.7
2900	1.0	1.1	1.6	2.5	1.8	2.5	3.5	4.8	0.9	0.8
3000	1.1	1.2	1.5	2.1	1.2	2.1	4.0	3.9	0.0	0.9
3100	1.0	1.3	1.5	1.9	1.7	1.9	2.2	3.1	0.0	1.3
3200	0.9	1.0	1.4	2.5	0.9	2.5	1.6	5.9	0.0	0.9
Total HC per mg	101.0					32.0	28.0	8.0	26.0	37.0

[a]Derived from % change of original level

[b]Pristane.

[c]Phytane.

from 1.61 to 7.47 mg in 30 days of incubation in the mixed culture from station 7D, while the pure culture from station 7D changed from 1.61 to 3.99 mg. Pristane and phytane were shown by Patterson (1967) to be produced by bacteria in oil-free media. In the mixed culture of 7D, an isomer (1620) increased from 1.9 to 3.1 mg, whereas the C17, C20, and C21 peaks decreased to 0.

Table 3.11-8 shows the percentage change of carbon numbers with change in time and different mixed and pure cultures. Weight loss is also shown relative to controls so that all data may be compared. The methods used for all tests were identical; only incubation time and inoculation cultures varied. The cultures were selected to show general relative changes. Except for the increase in pristane and phytane, there was a general decrease in other carbon numbers. No definite sparing action of molecules could be detected. Under laboratory conditions, the various mixed and pure cultures showed only slight differences in response relative to carbon numbers. This corresponded to data from other areas in which no buildup of specific molecules was noted. Apparently, mixtures of bacteria are capable of grazing the hydrocarbons down to parts per billion.

GC/MS data for major aromatic compounds compared with weight loss during degradation suggest that the compounds identified as naphthalenes, fluorines, biphenyls, diphenyl thiophenes, phenanthrenes, and their methyl or ethyl derivatives were not selectively changed by the culture. The ion absorption graphs show similar patterns for the 6- and 30-day extracts. These data agree with the hexane chromatographs (Figure 3.11-5), suggesting that mixed cultures are not exclusively selective on the molecular level other than for pristane and phytane, as previously discussed. Some mixed cultures were more active than others, possibly as a function of the numbers of bacterial species in the sample selected. Data on hydrocarbon uptake support the concept that the entire area has a microbial reservoir of adequate size to respond to the addition of hydrocarbons.

C. BIOLOGICAL OXYGEN DEMAND

In addition to the data that support the ability of surface microorganisms to respond to crude oil, the uptake of hydrocarbons in BOD experiments is significant. The test hydrocarbons were selected to represent straight-chain, cyclic, and branched-chain hydrocarbons of low molecular weight. The data clearly show a variation in the ability of certain microorganisms and types of microorganisms to use specific hydrocarbon types. All the hydrocarbons were used at one station or another, proving the ability of the microbial community to respond to different molecular configurations. This was also shown in chromatographs from mixed-culture and pure-culture experiments. Variability between stations may have been caused by the distribution of specific bacteria in the collected water mass or by their initial numbers. The activity of smaller populations of hydrocarbon-using forms may have been masked by the oxygen uptake of heterotrophic forms acting on organic matter in the water.

Stations 5E and 6D appeared to show enhanced oxygen uptake, corresponding to the presence of SLCO and/or decane. Several other stations exemplified repression relative to the control oxygen uptake value, which may have been caused by the presence of the added hydrocarbons.

D. PURE-CULTURE STUDIES

From approximately 300 isolates, 50 pure cultures (at least one from each station and each transect) were selected on the basis of their active oil-degrading ability and screened by colony characteristics, staining response, and cellular morphology. Since there is not as much knowledge about marine microorganisms as for those from other habitats, most of the cultures could be identified only to genus. Ten different groups of organisms were identified. *Alteromonas* and *Pseudomanas* were the most common genera, representing approximately half of those identified. Significantly, each station had very active hydrocarbon-degrading cultures that could be identified during the first two cruises.

Since the 50 cultures analyzed were selected to evaluate forms exhibiting hydrocarbon-degrading capability, they provide only an overview of bacterial distribution in the study area.

E. NITROGEN-PHOSPHORUS REQUIREMENTS

When phosphate concentrations were varied, decane use curves were similar to those obtained for SLCO. Cell number reached a plateau at phosphate concentrations of 1.0 ppm. Increasing phosphate concentrations to 10 ppm appeared to have no additional effects.

Growth curves of pure cultures from stations 3D and 7D (Figure 3.11-5) showed a typical response to enriched seawater and nonenriched seawater containing SLCO, which clearly indicated the need for nutrients. After an apparent initial lag time that was actually a function of the sensitivity of the spectrophotometer, the growth of the organisms clearly indicated the requirement for nitrate and phosphate to provide optimal growth and oil degradation.

Whether there is sufficient nutrient phosphate or nitrate in natural oceanic waters for extensive oil degradation cannot be completely resolved by these laboratory studies. The BOD study indicated a variable microbial response among stations. The concentrations of nutrients used in the laboratory tests were several orders of magnitude higher than those found in the study area. The question of dynamics of nutrient exchange in living communities, the rates of recycling, and the additional question of ion-sharing among organisms complicate the nutrient-requirement picture.

The concentration of nitrate and phosphate nutrients in the study area may be related to cell mass if it is assumed that all nutrients are incorporated. On the basis of the microbial environment, this mathematical exercise shows whether the indigenous nutrients will support significant cell masses and whether the organisms might respond to hydrocarbon input as a result of man's actions or accidents. The calculations indicate that nutrients would probably be required in restricted areas for microbial response to massive oil contamination. However, as oil spreads on the water surface, it will collect the nutrients present in the surface microlayer. Since there are no data in the literature as to the amounts of nutrients in the water/air interface of the world's oceans, it is impossible to assess the contribution of surface-layer nutrients. Evidence from field research on the Ekofisk accident (personal correspondence) indicates that the oil was rapidly disbursed and, after a few days, effectively disappeared. This corresponds to the results of Oppenheimer et al. (1977) that sufficient hydrocarbon-using bacteria were available to respond to the added hydrocarbons and indicates that sufficient nutrients are available in the natural environment to support their proliferation.

Tests to determine the effects of low temperature on the rate of oil degradation indicated that the bacteria did not respond at a temperature of 9°C.

SECTION 5
CONCLUSIONS

The marine microbial community of the surface microlayer, near-surface waters, and bottom sediments of the continental shelf off North Carolina, South Carolina, Georgia, and northern Florida is capable of actively responding to the introduction of hydrocarbons. Populations of hydrocarbon-using bacteria, especially representatives of the genera *Alteromonas* and *Pseudomonas*, were broadly distributed in the study area during 1977.

Indigenous hydrocarbon concentrations in the South Atlantic OCS region were generally quite near those reported to be the threshold of biological availability. Hydrocarbon-degrading bacterial populations in the area must, then, represent a microbial reservoir capable of oxidizing the normal biotic hydrocarbon inputs to the system, as well as the current anthropogenic load.

Cell proliferation and hydrocarbon degradation by test cultures, while variable in rate and degree of reduction, clearly show the ability of the community to adjust to increased hydrocarbon levels. This was supported by increases in the density of hydrocarbon-using forms in the study area when hydrocarbon concentrations increased during the fall.

The presence of nitrates and phosphates is essential to the metabolic degradation of hydrocarbons. Concentrations of these nutrients in the study area were generally sufficient to support increased populations of petroleum-degrading microbes on addition of hydrocarbons (BOD experiments). It appears, however, that nutrient availability might become limiting in the event of massive oil spills in restricted areas.

Cultures of hydrocarbon-using bacteria that were active at 22°C (72°F) showed no growth or reduction of available hydrocarbons at 9°C (48°F). While water temperatures in the study area during the winter of 1977 (a particularly cold year) were generally higher than 9°C, it is possible that the ability of the microbial community to degrade hydrocarbons introduced to the OCS region could be reduced during the late fall and winter.

SECTION 6
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CHAPTER 12

OVERVIEW OF BENTHIC STUDIES IN THE GEORGIA BIGHT DURING 1977

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ABSTRACT

The various components of the South Atlantic Outer Continental Shelf (OCS) benthic community (meiofauna, foraminifera, macroinfauna, epibenthic megafauna and demersal fish) were studied during 1977. The results of concurrent seasonal sampling for the several benthic categories have been assembled to provide an integrated overview of area benthos.

The study area was broadly divided into three faunal/habitat regions on the basis of community structure and sedimentary and hydrographic characteristics (near shore, middle shelf, outer shelf/slope). A fourth community type, hard bottom/reef, was associated with intermittent rock outcroppings in the mid- and outer-shelf regions. Species diversity was quite high throughout the study area with few forms present in sufficient numbers to constitute community dominance, although characteristic assemblages were associated with each of the habitat zones.

While holobenthonic forms, primarily the foraminifera and meiofauna, showed little seasonal change in spatial distribution and dominance, the predominantly merobenthonic macroinfauna and motile epibenthos clearly showed the effects of planktonic larval distribution and migration.

SECTION 1
INTRODUCTION

Benthic studies for the South Atlantic Benchmark Program (SABP) followed the traditional divisions:

- Meiobenthos and foraminifera
- Infaunal macrobenthos
- Epifaunal megabenthos
- Demersal fish

This chapter provides a general overview and compares the effects of varying sedimentary and hydrographic conditions on the spatial and temporal distribution and associated changes in dominance, density, and species diversity of the various benthic groups.

Arbitrary classification of the benthos into size categories does not facilitate delineation or understanding of general characteristics and regulatory principles significant to the entire community. The traditional categories of meiobenthos, macrobenthos, and megabenthos are not, however, solely divisions of organism size but are predicated on fundamental differences in spatial distribution patterns. These differences have led not only to differential sampling gear and approaches to sample handling but also to varying emphasis on the role of environmental parameters in regulating faunal distribution patterns. For example, although meiofaunal size is such that physical size of the sample can be small, sample handling must be particularly careful and a high level of taxonomic expertise is required. Identification problems that occur are not only the result of the paucity of available experts but also of inherent difficulties in identifying nematode and harpacticoid copepod taxa.

Because foraminifera are of particular interest in geological investigations, both living and dead organisms are frequently examined. Practical physical limitations on the size of a sample that may be collected complicate the problem of sampling macrobenthic forms that are more broadly distributed because of their larger size. Tendencies of species to cluster on this broader scale result in high replicate sample variability. This sampling problem is intensified when dealing with motile epibenthos. These differences have led to distinct subdivisions of expertise in the field of benthic ecology, which must obviously be combined if an integrated view of processes affecting the total benthos is to be achieved.

This study provides a rare opportunity to examine the total benthos in terms of related distributional patterns. The particular value of the SABP is threefold:

- The sampling of all benthic divisions (meio-, macro-, and megabenthos) occurred at the same sampling sites at the same time.
- Sampling was repeated in time (i.e., expressed seasonally).
- The area represents a unique shelf environment.

The value of concurrent sampling of all the benthic groups is obvious. Such coordinated activity is rare because of time and manpower constraints; even for studies of individual size

components of the benthos, repeated sampling across time to provide data on temporal changes in distribution, faunal composition, and density is uncommon, especially for open-water systems such as the continental shelf. Available data, especially from recent broadscale surveys related to other offshore benchmark studies, indicate that the benthic environment of the South Atlantic Outer Continental Shelf (OSC) is different from that of other continental shelf regions.

Benthic community distribution on the South Atlantic OCS generally conforms to the broad habitat categories defined by the following conditions.

The continental shelf of the Georgia Bight is bordered by a vast coastal marshland ecosystem and, at its oceanic extreme, by the meandering Gulf Stream, the winter offshore movement of which produces a southward circulation of northern water masses near the coast. The SABP study area constitutes the interface between the more boreal faunal provinces off Cape Hatteras, North Carolina, to the north and the more tropical fauna in Florida to the south. Shallow water in the inshore regions results in broad variations during the year in bottom-water temperature, whereas the waters of continental slope are consistently cold. Offshore sediments of the broad shallow shelf are strongly affected by tidal and wind-induced scouring, so the sediments generally are medium to coarse sands that undergo considerable transport; their general homogeneity is interrupted by intermittent outcropping of hard bottom. Nearshore sediments are fine to medium sands with a high silt-clay content. A nearshore density front essentially prevents the outwelling of organic and inorganic nutrients to the midshelf region from the coastal marsh ecosystem. Thus, even the low nutrient input characteristic of such marsh systems is restricted to the inshore (<20-km) region of the shelf. Gulf Stream intrusions onto the outer regions of the shelf introduce some inorganic nitrogen to the system; in general, however, primary production is low and, as a result, the contribution of organic matter from overlying waters to the benthos and to sediment organic levels is also generally low.

The remaining sections of this chapter summarize the overall similarity, spatial delimitations, and differences in the community characteristics (dominance, diversity, and density) of the various size components of the benthos and illustrate the varying effects of recruitment and migration on temporal changes in benthic distribution.

SECTION 2
COMMUNITY DELIMITATION

Several different statistics were used for clustering analyses in the benthic study; all essentially delimit groupings of stations that exhibit faunal homogeneity. Analyses based on simple presence or absence (i.e., the Jaccard index) define faunal discontinuity, while clustering based on density-determined indices (Morisita and Canberra Metric) indicate changes in dominance. For each major category of benthos, there is a general latitudinal homogeneity but a marked variation with distance from shore (i.e., inshore, midshelf, and outer-shelf/slope assemblages) that reflects sedimentary and hydrographic changes.

A. FORAMINIFERA

The foraminifera showed distinct depth-related areal delimitations; particularly conspicuous was an inner-shelf zone (15 to 20 m isobath) over the total latitudinal extent of the study area. This clustering was strongest using the principal component analysis (PCA); Jaccard clustering delineated only the foraminifera assemblage of the slope. This suggests that changes in dominance regulate spatial delimitation. Two species, *Elphidium excavitum* forma *clavatum* and *Ammonia beccarii*, dominated most inner-shelf stations. *Planulina exorna* was clearly the most widespread dominant species on the middle and outer parts of the shelf. Typically dominating the slope stations was *Bolivina lowmani*.

Because of such clear dominance patterns, foraminiferan species diversity was relatively low; outer-shelf values (based on ln) averaged 2.5 to 3, while the inshore average was lower (<2). Foraminiferan density was generally high, the values being greater than those recorded for the mid-Atlantic shelf. Overall, the order of increasing density was midshelf < inner shelf < slope. There was also a general increase in total abundance from north to south. Within these broad generalizations, higher densities correlated with increasing percentages of silt-clay in the sediment. Opposite trends in densities with latitude for the meiofauna and foraminifera did not correlate with any physical parameter (e.g., sediment composition) and might indicate competitive interactions between these two groups.

B. MEIOFAUNA

Clustering was not stringently applied in assessing meiofaunal community homogeneity because of the use of the familial taxonomic level; even at this level, however, a distinct slope faunal assemblage was delimited from those of the other shelf stations. As would be expected normally, nematodes and harpacticoid copepods dominated. Nematode dominance in the study area (51% of all fauna) was relatively weak compared with that of other geographic areas because of the variety of meiofaunal organisms encountered on the shelf, while harpacticoids comprised 19% of the total fauna, a level generally comparable with that of other geographic areas. The nematode families Desmodoridae, Monohysteridae, Chromodoridae, Cyatholimidae, and Ceramonematidae are typical inhabitants of sandy sediments in shelf environments. Of the copepods, the five dominant families—Diosaccidae, Paramesochridae, Cylindrosyllidae, Ameiridae, and Ectinosomitidae—are typically found in fine to medium sand and are distributed globally.

Overall, meiofaunal density was slightly higher than that reported for other shelf environments. For the three faunal assemblages, the order of increasing density was slope < inner shelf < midshelf. Abundance (total numbers) generally increased from south to north; the lower numbers in the south are similar to those from Bermuda and the Bahamas.

C. MACROINFAUNA

The macroinfauna showed marked inshore and midshelf zonation, but the outer-shelf/slope stations were disjunct and did not cluster, even by Jaccard techniques. Small, active, burrowing (mostly polychaetes) or episubstrate dwellers that typically inhabit unstable and shifting sediments dominated. No species dominated consistently, and diversity (based on $\log_2$) was generally around 3, although 22% of the total stations showed values >5. Most of the species were rare, and only 18 comprised more than 0.2% of the mean total density. Total macroinfaunal ash-free dry weight (AFDW) biomass (~3 g/m^2) was low compared with that of other shelf regions. The order of increasing biomass was slope < inner shelf < midshelf. There was no general latitudinal trend in density changes, but transect 7 was generally high because of enrichment by fairly regular upwelling.

D. EPIFAUNA

The study area exhibited three broad depth-related assemblages of demersal fishes and macroinvertebrates. In the open-shelf region, there were some latitudinal changes, with one or two more "cold-temperate" fish species at northern stations and "Caribbean-type" fish species at southern stations. The demersal fish assemblages–inshore (dominated by croakers and catfishes), and mid- to outer-shelf (dominated by sand perch, scup, eyed and dusky founder, and offshore lizard fish)–were characteristic of sand bottoms. Two changes in dermersal fish dominance were related to hard-bottom outcropping and Gulf Stream effects. Hard-bottom (stations 2D and 2E) fish assemblages were typical of tropical reef environments; the dominants were tomtate, bank seabass, butterfly fish, and angel fish. Outer-slope fauna were similar to the archibenthal fauna common from the Straits of Florida to Cape Hatteras. Infaunal sampling at stations 2D and 2E did not reflect biotype difference since box-core samples could not be taken directly from the hard-bottom site because of the necessity of penetrating the substrate. Even so, such samples were close to outcroppings and suggest a limited areal effect of such outcroppings on surrounding sediments. Inshore epibenthic invertebrates were characterized by penaeid shrimp; the open shelf was characterized by the starfish *Luidia* and *Astropecten*, the crab *Portunus* spp., the rock shrimp *Sicyonia brevirostris*, and the squid *Loligo pealei*. Sample variation for the epifauna was high and precluded any significant assessment of geographic trends in density.

SECTION 3
DISCUSSION

Differences in seasonal distribution patterns among the benthic groups illustrated not only responses to physical factors such as water temperature but also differences in the relative importance of the two major mechanisms of faunal change—larval distribution and migration—which are suggested as factors in the seasonal variations found in the faunal assemblage of the South Atlantic OCS. Many benthic species are merobenthonic, spending a portion of their lives in the water column; during this period, movements of the water mass may significantly disperse the larvae, effecting the colonization of previously unoccupied regions. Migration of motile species may also change faunal assemblages. Thus, the meiofauna and foraminifera, both essentially holobenthonic, showed stable distributional patterns and persistent faunal composition throughout the year, while the macroinfauna (predominantly merobenthonic) showed significant changes in spatial distribution and faunal composition with season. For example, only two species of the dominant foraminifera changed during the four seasonal samplings, and the relative abundance of each of the other dominant species was greater than 20% throughout the seasons. Although there was little seasonality in the familial change of the meiofauna, there was a distinct drop in winter densities, which might have been related to predation pressure (recent work has indicated that meiofauna may be fed upon by bottom-feeding fish: Sibert et al., 1977). The reduced density of the meiofauna may have been caused by feeding pressure exerted by spotted hake larvae, which are offshore in summer but are distributed throughout the shelf region in winter. Macroinfaunal community composition showed distinct seasonal changes that differed for the three longitudinal delimitations. The inner near-coast stations clustered for all four samplings, even though species composition changed; the outer-shelf/slope stations continuously remained disjunct; and the midshelf region, although showing a significant clustering for each seasonal sampling, showed variations in subclustering patterns, probably associated with spatial variation in larval recruitment. Because merobenthonic larvae are not self-mobile and their dispersion depends on the movement of the water mass in which they are contained, seasonal patterns of the Gulf Stream and related changes in coastal water mass movements greatly influence recruitment of larvae to given bottom areas; for example, the latitudinal subclustering apparent in the midshelf area during the fall larval reproduction may have indicated not a stable, persistent assemblage but an imbalance because of larval set. Certainly continual change in dominance is a major characteristic of the shelf macroinfauna of the Georgia Bight.

Seasonal changes in macroinfaunal densities also showed contrasting patterns: the mid- and outer-shelf/slope regions showed little change, while the inner region near the coast dropped during spring sampling, possibly reflecting the adverse effects of a particularly harsh winter in 1977 or predation by demersal fish such as spot and croaker that migrate to the estuaries during the winter. The inner-shelf demersal fish cluster was distinct throughout the region from north to south only in winter; it was absent during the spring and present only in the south during the summer. The midshelf assemblage was present throughout the year but also clustered with the inner shelf during the spring. The outer-shelf/slope assemblage was always present. Species dominance in the three strata changed, largely because of seasonal migration patterns; for example, juvenile spotted hake, which dominated the shelf assemblage in winter, comprising 23–61% of the faunal density, migrated offshore in spring to become a dominant component of the slope fauna in summer. Similar changes occurred for spot and croakers, which wintered in estuaries and then migrated to dominate the inner-shelf assemblage in spring and summer.

Migration patterns associated with reproductive strategy were responsible for changes in the seasonal distribution patterns of demersal fish. Epifaunal invertebrates showed seasonal taxa differences associated with either migrational or reproductive distribution effects. The inshore cluster in the fall included half of the trawl stations; reproductive recruitment was credited with this spatial expansion. The midshelf area, clustering throughout the winter, was restricted to two stations in the fall. Similarly, the outer-shelf/slope area, most extensive in spring and summer because of Gulf Stream influences, was much more restricted in winter and fall. While many of the epifaunal invertebrates are not extremely mobile, the substantive migration of the decapods accounted for much of the seasonal changes in spatial delimitations. Epifaunal invertebrate density varied between a spring high of 821 kg (20,195 individuals) and a fall low of 111 kg (20,915 individuals). The fewest species were in spring (111); the most were in summer (241).

In view of SABP results, future studies in the South Atlantic OCS should emphasize:

- The relationship of larval transport and recruitment to water mass movements and other hydrographic features of the Georgia Bight
- Population dynamics of macroinfauna, including size-class data to ascertain the role of larval recruitment in changes of faunal composition with time
- The microdistributional effects of hard bottoms on surrounding sediment fauna.

Additional studies should also be directed toward the inner shelf as a distinct and differentiable community.

SECTION 4

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