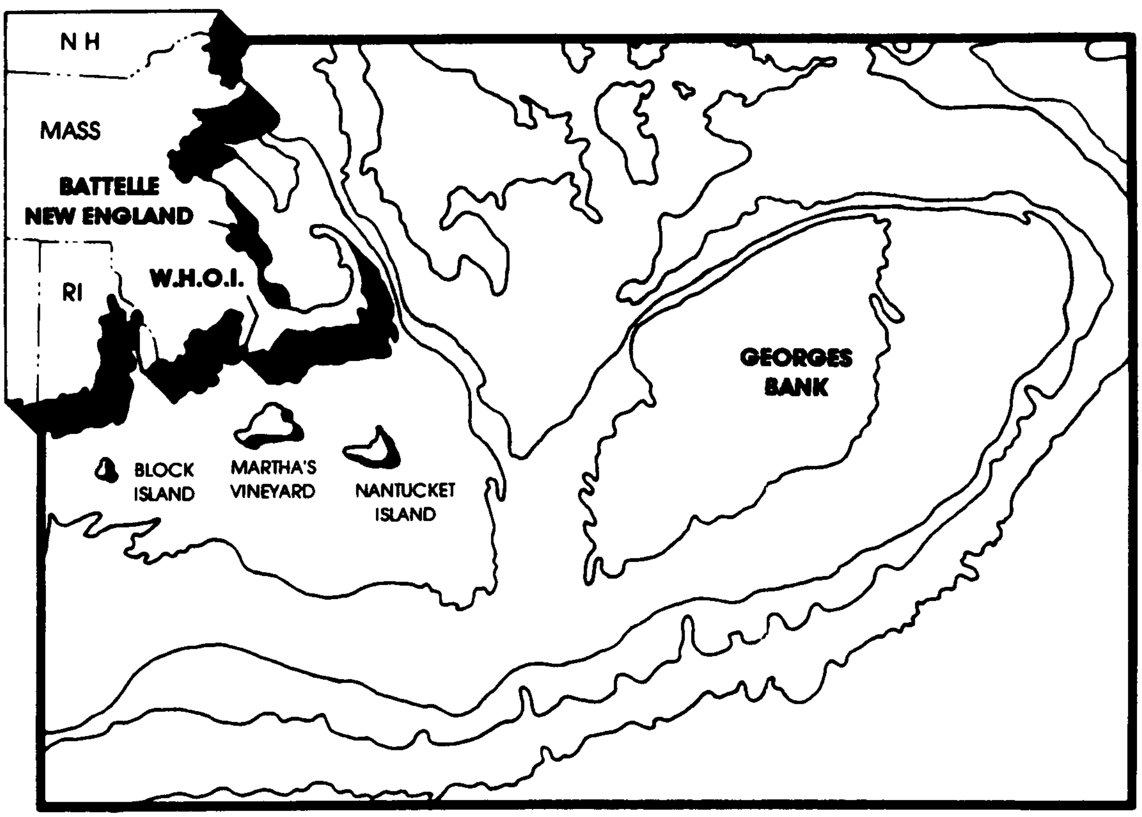
Georges Bank Benthic Infauna Monitoring Program

VOLUME 1 **FINAL EXECUTIVE SUMMARY**



PREPARED BY

Battelle New England
Marine Research Laboratory
Duxbury, Massachusetts

and

Woods Hole
Oceanographic Institution
Woods Hole, Massachusetts

GEORGES BANK BENTHIC INFAUNA MONITORING PROGRAM

FINAL REPORT

FOR THIRD YEAR OF SAMPLING

Prepared for

UNITED STATES DEPARTMENT OF THE INTERIOR

MINERALS MANAGEMENT SERVICE

Washington, D.C. 20240

under Contract No. 14-12-0001-29192

Battelle New England Marine Research Laboratory
397 Washington Street, Duxbury, Massachusetts 02332
and
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

April 30, 1985

DISCLAIMER

This report has been reviewed by the Minerals Management Service (MMS) and has been approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the MMS, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO.	2.	3. Recipient's Accession No.
4. Title and Subtitle Georges Bank Benthic Infauna Monitoring Program: Final Report for the Third Year of Sampling			5. Report Date April 15, 1985
			6.
7. Author(s) Editors: Nancy Maciolek-Blake, J. Frederick Grassle, and Jerry M. Neff			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Battelle New England Marine Research Laboratory 397 Washington Street, Duxbury, MA 02332 and Woods Hole Oceanographic Institution Woods Hole, MA 02543			10. Project/Task/Work Unit No.
			11. Contract(C) or Grant(G) No. (C) 14-12-0001-29192 (G)
12. Sponsoring Organization Name and Address U.S. Department of the Interior Minerals Management Service, Procurement Division, Procurement Operations Branch B, Mail Stop 635 12203 Sunrise Valley Drive, Reston, VA 22091			13. Type of Report & Period Covered Final (1981-1985)
			14.

15. Supplementary Notes

A three volume set: Vol. 1 Final Executive Summary, Vol. 2 Final Report, Vol. 3 Appendices

16. Abstract (Limit: 200 words)

Concerns about the potential effects of oil and gas exploration activities on Georges Bank led to the initiation of a monitoring program in July 1981. The program included sampling of the benthic communities near, upcurrent, and downcurrent of drilling rigs, analysis of bottom photographs for epifauna and microtopography, trawl collections, total organic carbon and sediment grain-size analysis. Twenty-nine stations were positioned in a tight radial array around a rig at 80 m. A second group of three stations were near a rig at 140 m. The remaining 14 stations covered a broad expanse of the Bank and nearby areas of potential deposition of drilling materials. Results from 12 biological collections indicated little heterogeneity within stations, with good replication between samples. A strong relationship between faunal composition and both sediment type and depth was indicated by cluster analysis. Biomass varied over time and among stations, with a significant increase at some stations between the first and second years.

Eight dry wells have been drilled to date in the Lease Sale 42 area. No biological impacts which could be attributed to drilling activities were detected at any station including the site-specific array in 80 m, the three stations near the drill rig in 140 m, or any regional station monitored in this program.

17. Document Analysis a. Descriptors

Georges Bank, exploratory drilling, benthic infauna, community structure, life history analysis, benthic production, sediment texture, total organic carbon.

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Availability unlimited	20. Security Class (This Page)	22. Price

(See ANSI-Z39.18) *See Instructions on Reverse* OPTIONAL FORM 272 (4-77) (Formerly NTIS-35) Department of Commerce

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

VOLUME 2: FINAL REPORT FOR THIRD YEAR OF SAMPLING

VOLUME 3: APPENDICES

BACKGROUND

The Georges Bank is a large plateau lying under 3 to 200 m of water, 80 to 325 km east-southeast of the Massachusetts coast. It is one of the most productive commercial fishery areas in the world. Many species of finfish and shellfish, including codfish, haddock, flounder, ocean scallops, and lobster, with a market value in excess of 165 million dollars are harvested from Georges Bank each year. In addition, the geologic structures underlying the Bank are of the type that may contain substantial reservoirs of petroleum and/or gas. As a result, the oil industry has for many years been interested in exploring for oil and gas on Georges Bank.

Preparations for Lease Offering No. 42 of 206 blocks, each 3 x 3 miles (23.3 km^2), on the south-central Georges Bank began in June 1975, with a Call for Nominations and Comments (Bureau of Land Management, 1981). The sale, originally scheduled for January 1978, was delayed by several legal suits and injunctions until December 18, 1979. Of the original 206 blocks, 90 were withdrawn before the lease sale, bids were received for 73 of the remaining 116 blocks, and 63 of these bids were accepted and leased. Exploratory drilling began on July 22, 1981, and the last of eight exploratory wells was completed on September 27, 1982 (Figure 1). The eight wells were drilled by five oil companies or consortia and were all reported to be dry.

Two additional lease offerings were scheduled for the North Atlantic Outer Continental Shelf, including Georges Bank. Lease Offering No. 52, originally scheduled for November 1980, was rescheduled for March 1983. It was delayed further by court injunctions and finally cancelled. Lease Offering No. 82 was to include any unleased blocks in Lease Area No. 42 plus all of Lease Area No. 52 and much of the remainder of Georges Bank and adjacent continental slope in U.S. waters. This sale also was delayed and finally cancelled as a result of legal suits by the Commonwealth of Massachusetts and environmental groups.

The basis of the legal actions has been the concerns of environmentalists and the commercial fishing industry that oil and gas exploration, and possible later fossil fuel resource development and production on Georges Bank, would seriously damage this complex and highly productive ecosystem and the commercial fisheries dependent upon it. Because of these concerns, a Biological Task Force for Outer Continental Shelf Lease Sale No. 42 was established by the Federal Government to recommend to the U.S. Department of the Interior (USDI), Supervisor of Oil and Gas Operations in the North Atlantic, the design of an environmental monitoring program which would provide an early warning of adverse effects of oil exploration on the Georges Bank environment (Biological Task

Force, 1981). The Bureau of Land Management (now Minerals Management Service) of the U.S. Department of the Interior implemented the monitoring program recommended by the Biological Task Force, with some slight modifications. The results of that monitoring program are the topic of this report.

PURPOSE AND SCOPE OF THE MONITORING PROGRAM

The major environmental concern arising from exploration for oil and gas on Georges Bank was that intentional discharges of materials (mainly drilling fluids and cuttings) from oil rigs during normal exploratory activities might damage the Georges Bank environment, particularly the animals living on or in the bottom sediments upon which commercial species depend for food. If commercial quantities of oil or gas were found, the major concern during the development and production phases of the Georges Bank field would be that accidental spills of crude oil and operational discharges of petroleum hydrocarbon-laden produced water would harm the marine biota, particularly the floating or pelagic eggs and larvae of commercial fisheries species. Other concerns related to possible impacts of increased ship traffic over the Bank, disruption of the bottom by pipelines, anchors, and rig structures, and disturbances to migrating and feeding whales by noise and surface pollution.

The Georges Bank Monitoring Program was designed to address the concerns related to the initial exploratory phase of Georges Bank development. Specific questions addressed by the Program included the following:

1. What are the quantities, the physical characteristics, and the chemical composition of materials discharged during Outer Continental Shelf (OCS) drilling operations?

2. Where do discharged materials accumulate and in what concentrations?

3. What are the existing background levels of trace metals and hydrocarbons in the sediments and biota and what levels above background can be detected with existing technology?

4. Do benthic populations change at selected regions on Georges Bank during various stages of OCS oil and gas exploratory activity? Can these changes be related to observed changes in levels of trace metals or hydrocarbons associated with discharges, and what are the concentrations of these drilling-related discharges associated with the changes?

The primary objective of the portion of the Monitoring Program performed by Battelle New England Marine Research Laboratory and Woods Hole Oceanographic Institution (W.H.O.I.) was to determine if there was a link between the discharge of drilling fluids and cuttings from oil and gas exploratory operations in the Lease Sale 42 area and variations in benthic species and communities as well as the demersal fish relying upon them as a source of food (Battelle and W.H.O.I., 1983, 1984, 1985). Questions dealing with the characterization and accumulation of drilling-related discharges were addressed by the U.S. Geological Survey (USGS), which analyzed the trace metals in bottom sediments (Bothner et al., 1982, 1983, 1985) and by Science Applications International Corporation, which performed the analysis of hydrocarbons in drilling muds and bottom sediments and the analysis of hydrocarbons and trace metals in benthic fauna (Payne et al., 1982, 1983, 1985). A fourth component of the Program was the analysis of historical benthic infaunal samples collected in 1977 as part of the New England OCS Benchmark Study. This analysis was completed by Taxon, Inc. (Michael et al., 1983) and provided background information for comparison with the results of the benthic infaunal analyses.

PROGRAM DESIGN AND IMPLEMENTATION

The Georges Bank Monitoring Program was designed to determine both near-rig and regional environmental impacts of oil exploration activities in Lease Area 42. An original group of 46 sampling stations was established on and adjacent to Georges Bank. These included a group of regional stations established to assess potential impacts of drilling activities over a broad expanse of the Bank (Figure 1). Three transects of three stations each were established approximately in a north-south direction perpendicular to local depth profiles.

The transects were located east of, west of, and directly through the Lease Sale 42 blocks, with the three stations on each transect located at approximately 60, 80, and 100 m water depth. Because net water movement over the southern flank of the Bank at all depths is toward the southwest, the eastern Transect I was upcurrent of the lease area and was considered a reference transect. The western Transect III was downcurrent of the drilling activity where drilling discharges might accumulate on the bottom. Additional regional stations were located at sites of possible deposition of solids from drilling discharges. These included stations at the heads of Lydonia and Oceanographer Canyons (Stations 7 and 9), at the shelf/slope break (Station 8), in the Gulf of Maine (Station 14), at the top of the Bank in shallow water (Station 15), and in the Mud Patch, an area of fine-grained sediments south of Cape Cod (Station 13). After completion of the first year of sampling, Station 7 was moved from the side to the axis of Lydonia Canyon (Station 7A), a second station was established in the Mud Patch (Station 13A), and Station 14 was relocated in an area of finer-grained sediments (Station 14A).

Two groups of stations were located in close proximity to two exploratory drilling sites in order to assess near-field impacts of drilling discharges on the benthic environment. Three stations were located near the drilling site in Block 410 in about 140 m of water. Station 16 was located within 200 m of the rig and Stations 17 and 18 were located approximately 2 km upcurrent and downcurrent, respectively, of the rig site. A site-specific array of 29 stations was located in a radial pattern around Regional Station 5, the site of exploratory drilling in Block 312, in 70-86 m of water (Figure 2). Regional Station 5 was therefore also referred to as Site-Specific Station 5-1, and additional stations were located at distances of 0.2, 0.5, 1, 2, 4, and 6 km from the rig site. Nineteen of the stations were designated as primary stations and all samples from these stations were analyzed. The remaining ten stations were designated as secondary stations and all samples collected at those stations were archived.

All stations were sampled four times per year on a seasonal basis for three years (Table 1). At each station, six replicate 0.04-m^2 biology samples and three replicate 0.1-m^2 chemistry samples of undisturbed bottom sediment were collected with Van Veen grabs. Subsamples of the biology grabs were taken for carbon-hydrogen-nitrogen (CHN) and sediment grain-size analysis, and the remainder of the sample was washed through 0.3-mm screens and preserved for analysis of the infauna. Bottom still photographs were taken at each station to document microtopography and epifaunal densities, and in an effort to detect possible accumulations of drilling mud and/or cuttings. Dredge and trawl samples were collected at certain regional and site-specific stations to obtain fish and mollusc (ocean quahog Arctica islandica) samples for chemical analysis, and to obtain representative specimens of epifauna and demersal fish for a voucher collection and to be used in identifying species observed in bottom photographs. Measurements of salinity, temperature, and dissolved oxygen in surface and bottom water were taken at all regional stations.

In June 1982, after completion of the first year of the Monitoring Program, a meeting of the Scientific Review Board was convened in Woods Hole to review the Program to date. At that meeting, some changes in sampling stations and sampling methodology were instituted. In addition, three new components were added to the Program: a detailed analysis of the size-class structure of populations of selected species at certain stations (the Life History Task); a study to determine the linkage of benthic infaunal production to demersal fish populations (the Benthic Production and Fish

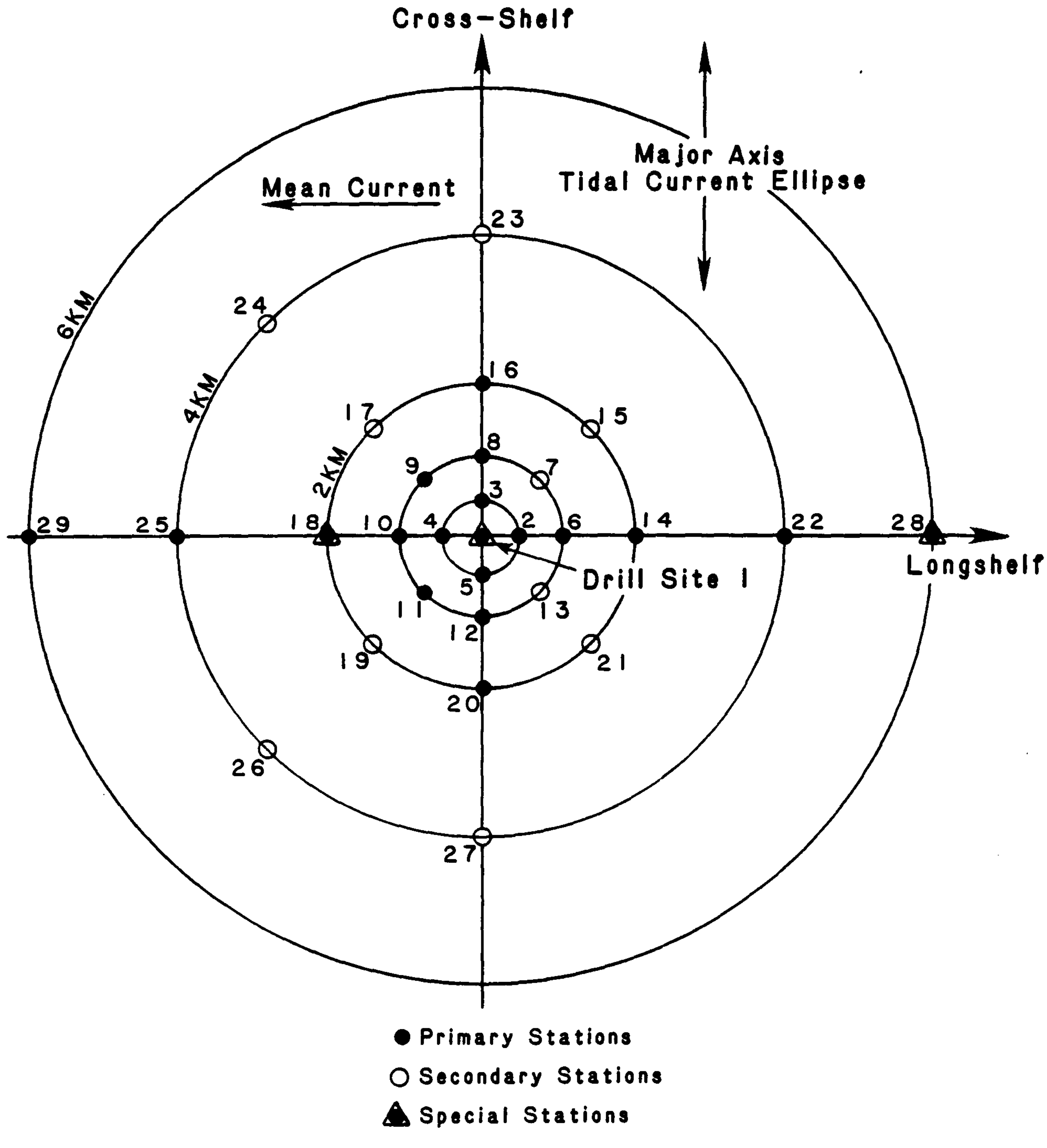


Figure 2. Site-specific stations centered around Regional Station 5.

TABLE 1. SCHEDULE OF SAMPLING CRUISES FOR THE GEORGES BANK MONITORING PROGRAM.

Cruise	Dates	Ship
M1	Jul 6-23, 1981	R/V Eastward
M2	Nov 9-21, 1981	R/V Oceanus
M3	Feb 10-21, 27, 1982	R/V Endeavor and R/V Asterias
M4	May 10-18, 1982	R/V Cape Henlopen
M5	Jul 21-28, 1982	R/V Oceanus
M6	Nov 19-28, 1982	R/V Oceanus
M7	Feb 5-11, 1983	R/V Endeavor
M8	May 13-21, 1983	R/V Gyre
M9	Jul 13-20, 1983	R/V Gyre
M10	Nov 13-19, 1983	R/V Oceanus
M11	Feb 1-7, 1984	R/V Oceanus
M12	Jun 2-9, 1984	R/V Gyre

Feeding Task); and analysis of infaunal samples collected at three USGS stations on Georges Bank prior to commencement of drilling (the Benthic Infauna at Long-Term Mooring Sites task).

THE BENTHIC INFAUNA MONITORING PROGRAM

METHODS

In the laboratory, each infaunal sample was resieved through nested 0.5-mm and 0.3-mm screens and transferred to 70 percent alcohol. It then was stained with Rose Bengal and all organisms were sorted to basic taxonomic groups under a dissecting microscope. Identifications were made to the lowest possible taxon, usually to species, using compound microscopes. Verification of the identity of voucher specimens of several groups, including molluscs, arthropods, oligochaetes, and anemones, was provided by outside taxonomic experts. Wet-weight biomass was determined to the nearest 0.1 mg for each species from samples from the first eight cruises, and for a portion of the samples collected on the last four cruises. Ash-free dry weight was determined for species from three replicates collected on the ninth cruise and correlated with wet-weight biomass. This was done to provide a better estimate of productivity than is provided by wet-weight biomass, which includes measurement of water content in addition to the organic and inorganic content of the organisms.

All data from each cruise were coded at Battelle and entered into the VAX 11/780 computer at W.H.O.I. Statistical treatment of each data set included an agglomerative clustering technique to determine similarity among samples. The similarity measure used was NESS, the Normalized Expected Species Shared (Grassle and Smith, 1976), in which comparison of expected species shared is between random samples of 50 individuals drawn from each sample. NESS is more sensitive to the less common species than the other commonly used methods. The clustering strategy was flexible sorting with β set at the commonly used value of -0.25. The Bray-Curtis or percent similarity coefficient also was used as a similarity measure with group average sorting (Boesch, 1977). In addition, detrended correspondence analysis was applied to the data using the DECORANA program in the Cornell Ecology Program series. This technique presents data in a two-dimensional plot and derives new axes to account for a cloud of points in multidimensional space. The method uses a reciprocal weighting of species and samples, and distances are based on chi-square. The Shannon-Wiener diversity index (H') and the associated evenness value (E) was calculated, and Hurlbert's (1971) modification of the rarefaction method (Sanders,

1968) was used to predict the number of species in a random sample without replacement. Spearman rank correlation (Siegel, 1956) was used to test the association between variables such as density of individual species or community similarity indices and physical variables such as sediment grain size.

A suite of 19 polychaetes, three amphipods, and one echinoderm was selected for study of life history parameters. For each species, size-class frequency distributions were calculated for samples from several stations and all cruises. In addition, all specimens were examined under the dissecting and compound microscopes for evidence of reproductive characteristics and/or gametes. Annual production of infauna was estimated by the increment-summation method described by Crisp (1971).

Yellowtail flounder, Limanda ferruginea, were collected by the National Marine Fisheries Service, Northeast Fisheries Center at the approximate times of Cruises M5 through M8 (July 1982 - May 1983) from the vicinity of Regional Stations 5-1, 10, and 13. The fish stomachs were preserved in formalin and the stomach contents were analyzed by the same methods used for infaunal sample analysis. Length-frequency measurements were made on the polychaetes and amphipods found in the stomachs for comparison with similar measurements on benthic infauna. Ivlev's (1961) electivity index was used to compare the species composition of the stomach contents to that of the macrofauna. The rate of food consumption by flounder was estimated to link fish-feeding with benthic production.

RESULTS

Taxonomy

A total of 959 taxa of benthic marine animals was identified during the three years of the Program. Of the species identified, over 100, including the poriferans, hydrozoans, and ectoprocts, are entirely epifaunal. A few species, such as the bivalve Dacrydium vitreum and the two hyperiid amphipods Hyperia galba and Parathemisto gaudichaudii are epizoic. Several species, including the serpulid polychaete Filograna implexa, nudibranchs, the bivalve Anomia, the slipper limpet Crepidula, and a few species of amphipods, were found only on hard substrata such as rocks and shells. Several species of demersal and pelagic invertebrates and fish also were collected in the grabs. A total of 218 such species was excluded from statistical analyses of infaunal community structure. The only epifaunal species that was studied in detail was the amphipod Erichthonius fasciatus.

Polychaetes were represented by 372 species, accounting for 38.8 percent of all taxa identified. A total of 49 polychaete families was recorded, with spionids, syllids, maldanids, and paraonids best represented. A total of 124 polychaete species new to science has been identified, some of which also represent new genera. Thirty-two species of oligochaetes were identified, 18 of them previously undescribed and one representing a new family.

The arthropods were represented by 189 species, and accounted for 19.7 percent of all taxa identified. Amphipods were the dominant group of arthropods with 99 species, at least one of which is new. Molluscs were represented by 144 species, accounting for 15.0 percent of all taxa identified. A total of 24 species of echinoderms was identified, representing 2.5 percent of all recorded taxa.

Abundance and Diversity

The average number of individuals per 0.04-m^2 sample ranged from 100-400 at some stations (e.g., Stations 1, 11, and 17) to 1000-2000 at others (e.g., Stations 5-1 and 13). At many stations, particularly the deeper ones, average densities remained relatively constant over the 12 sampling periods. The greatest fluctuations occurred at Stations 10 and 13. At Station 10, samples were occasionally dominated by large numbers of the sand dollar, *Echinarachnius parma*, or the archiannelid, *Polygordius* sp. A. At Station 13, the pattern of increasing density over the first three sampling seasons, followed by a sharp decline in the fourth, was not repeated in the second or third years. The samples taken at Station 13 on Cruise M4 were taken at a slightly different location, to the east of the reference coordinates, than the Station 13 samples on other cruises. Sediments were slightly different in these samples and this difference could account for the significantly lower numbers in May 1982 of many of the species typically associated with Station 13.

Clear seasonal patterns of density were not apparent at most stations. However, longer-term fluctuations were observed at some stations. For example, average densities at Station 5-1 (site of drilling in Block 312) were higher in Years 2 and 3 (after drilling) than in Year 1 (before and during drilling) (Figure 3). In contrast, there was little variation in density over the 12 sampling cruises at Station 16, the site of exploratory drilling in Block 410 (Figure 4).

Use of the 0.3-mm mesh screen resulted in greater efficiency than use of the 0.5-mm screen in sampling populations of several benthic species. When samples were sieved with nested 0.5-mm and 0.3-mm screens, small syllid polychaetes such as *Exogone hebes*, *E. verugera*, and *Sphaerosyllis* cf. *brevifrons* occurred in almost equal numbers on both screens. Some small species such as the paraonid polychaete *Paradoneis* n. sp. A were

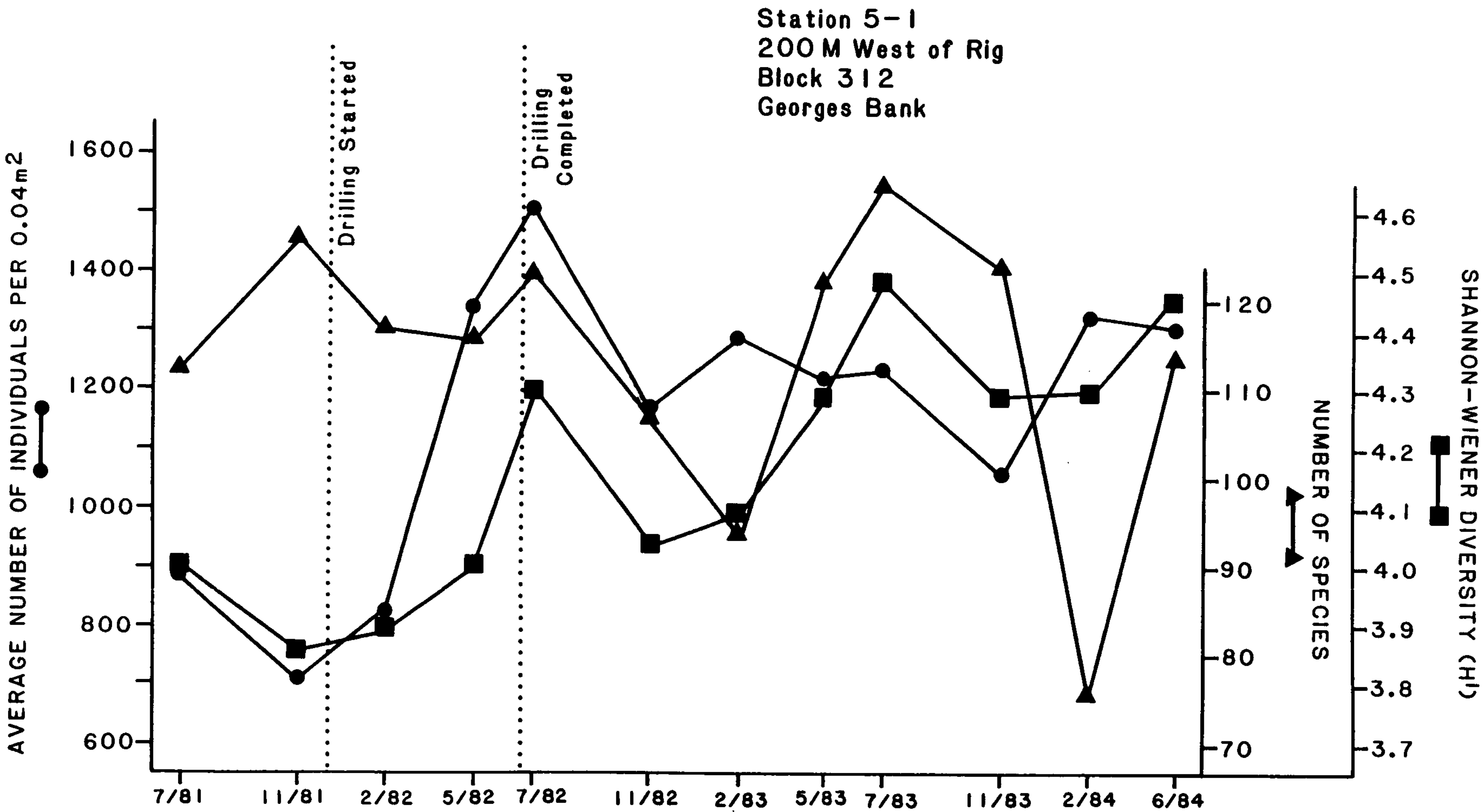


Figure 3. Average number of individuals per 0.04 m^2, total number of species in six replicate grab samples, and Shannon-Wiener diversity index (H') at Site-Specific Station 5-1 on 12 sampling occasions.

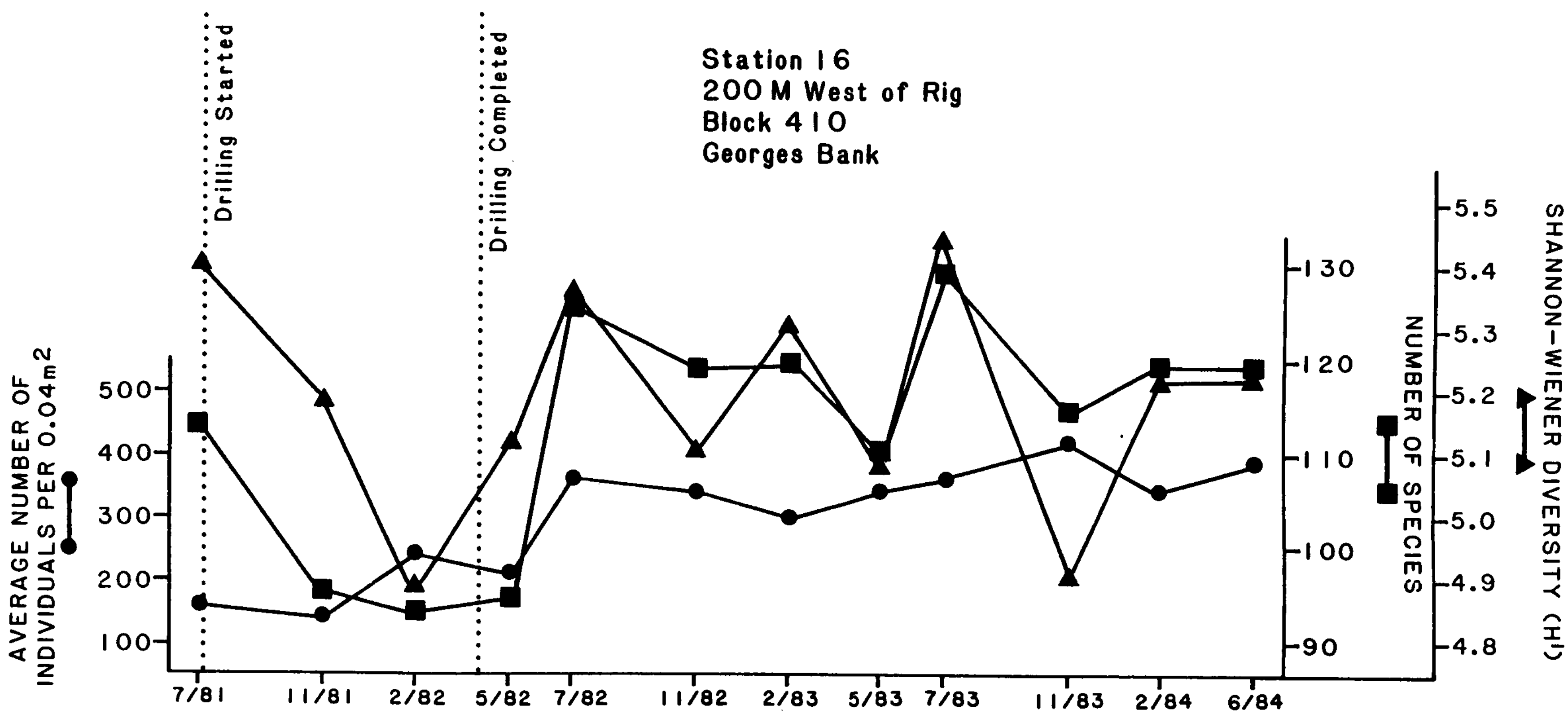


Figure 4. Average number of individuals per 0.04 m^2, total number of species in six replicate grab samples, and Shannon-Wiener diversity index (H') at Regional Station 16 on 12 sampling occasions.

retained almost entirely on the 0.3-mm screen. This was the dominant species at Stations 16 and 17. In addition, recently-hatched young (first and second instar) of most of the common arthropod species were retained only or primarily by the 0.3-mm screen.

At most stations, the ten dominant species varied little from one season to another over the three years of the Monitoring Program. The 20 most abundant species at our Georges Bank stations are listed in Table 2, summed over all regional stations and over all sampling cruises. Included on the list are 14 species of polychaetes, including four syllids and three paraonids, four species of arthropods, including three amphipods and one tanaid, one as yet undescribed species of oligochaete, and one species of echinoderm. The amphipod, *Ampelisca agassizi*, the dominant at seven of the 20 regional stations, also was the most abundant species overall in all Georges Bank samples.

For the most part, stations at similar water depths had similar benthic communities. Stations 1, 4, and 10 along the 60-m isobath were consistently similar to each other in terms of dominant species. At approximately 80-m water depth, Stations 2 and 5 were quite similar to one another, while Station 11, characterized by finer sediments than those found at Stations 2 and 5, was slightly different. Syllid polychaetes and the amphipod, *Erichthonius fasciatus*, were the dominant species at these stations. The dominants at Stations 3, 6, and 12 at about 100-m depth included the amphipods *E. fasciatus* and *Ampelisca agassizi* and the polychaetes *Notomastus latericeus*, *Exogone hebes*, and *Polygordius* sp. A. Stations 7A and 13A, with fine-grained sediments, had faunas similar to one another. However, the other station with fine-grained sediments, Station 14A in the Gulf of Maine, had a suite of species that did not resemble that at any other sampling location, although it shared some dominants with Stations 7A and 13A. Of the three Block 410 stations in 140-150 m of water, Stations 16 and 17 were similar, while Station 18 had a somewhat different fauna. Dominant species at Stations 16 and 17 included the polychaetes *Paradoneis* n. sp. A, *Chone duneri*, and *Notomastus latericeus*. At Station 18, dominant species included *Ampelisca agassizi* and the polychaetes *Tharyx annulosus*, *Chaetozone* n. sp. A, and *Notomastus latericeus*.

In order to gain further insight into the benthic community dynamics at the two drilling sites monitored, the temporal pattern of abundance of several dominant polychaete and amphipod species at Stations 5-1 and 16 were examined closely. At Station 5-1, most species showed the same trend as total numbers of individuals, with an increase in average abundance in Years 2 and 3 in comparison to Year 1.

The amphipod, *Erichthonius fasciatus*, an epifaunal species associated with coarse sediments, completely disappeared from Station 5-1 and some nearby site-specific stations in February 1982 (M3), shortly after drilling began. It reappeared in May 1982 (M4) and then experienced another sharp decline in abundance in November 1983 (M10).

TABLE 2. DOMINANT SPECIES SUMMED OVER ALL REGIONAL STATIONS AND OVER ALL SAMPLING CRUISES.

	Species	Phylum: Class
1.	Ampelisca agassizi	Arthropoda: Crustacea
2.	Polygordius sp. A	Annelida: Polychaeta
3.	Cossura longocirrata	Annelida: Polychaeta
4.	Erichthonius fasciatus	Arthropoda: Crustacea
5.	Tubificoides n. sp. A	Annelida: Oligochaeta
6.	Levinsenia gracilis	Annelida: Polychaeta
7.	Exogone hebes	Annelida: Polychaeta
8.	Exogone verugera	Annelida: Polychaeta
9.	Sphaerosyllis cf. brevifrons	Annelida: Polychaeta
10.	Aricidea (Allia) suecica	Annelida: Polychaeta
11.	Parapionosyllis longicirrata	Annelida: Polychaeta
12.	Protodorvillea gaspeensis	Annelida: Polychaeta
13.	Aricidea (Acmira) catherinae	Annelida: Polychaeta
14.	Euchone incolor	Annelida: Polychaeta
15.	Notomastus latericeus	Annelida: Polychaeta
16.	Tharyx annulosus	Annelida: Polychaeta
17.	Echinarachnius parma	Echinodermata: Echinoidea
18.	Ninoe nigripes	Annelida: Polychaeta
19.	Protohaustorius wigleyi	Arthropoda: Crustacea
20.	Tanaissus lilljeborgi	Arthropoda: Crustacea

These shifts in abundance appeared to be linked to changes in sediment grain size, probably storm-induced, and not specifically to drilling activities.

Another amphipod, Unciola inermis, showed large temporal fluctuations in abundance at Station 5-1. Highest densities were recorded in spring (M4, M8, and M12) and summer (M1, M5, and M9) collections. Several polychaete species showed peak abundances in samples from Cruises M4 and M5, corresponding to the period of highest overall density and species richness at this station.

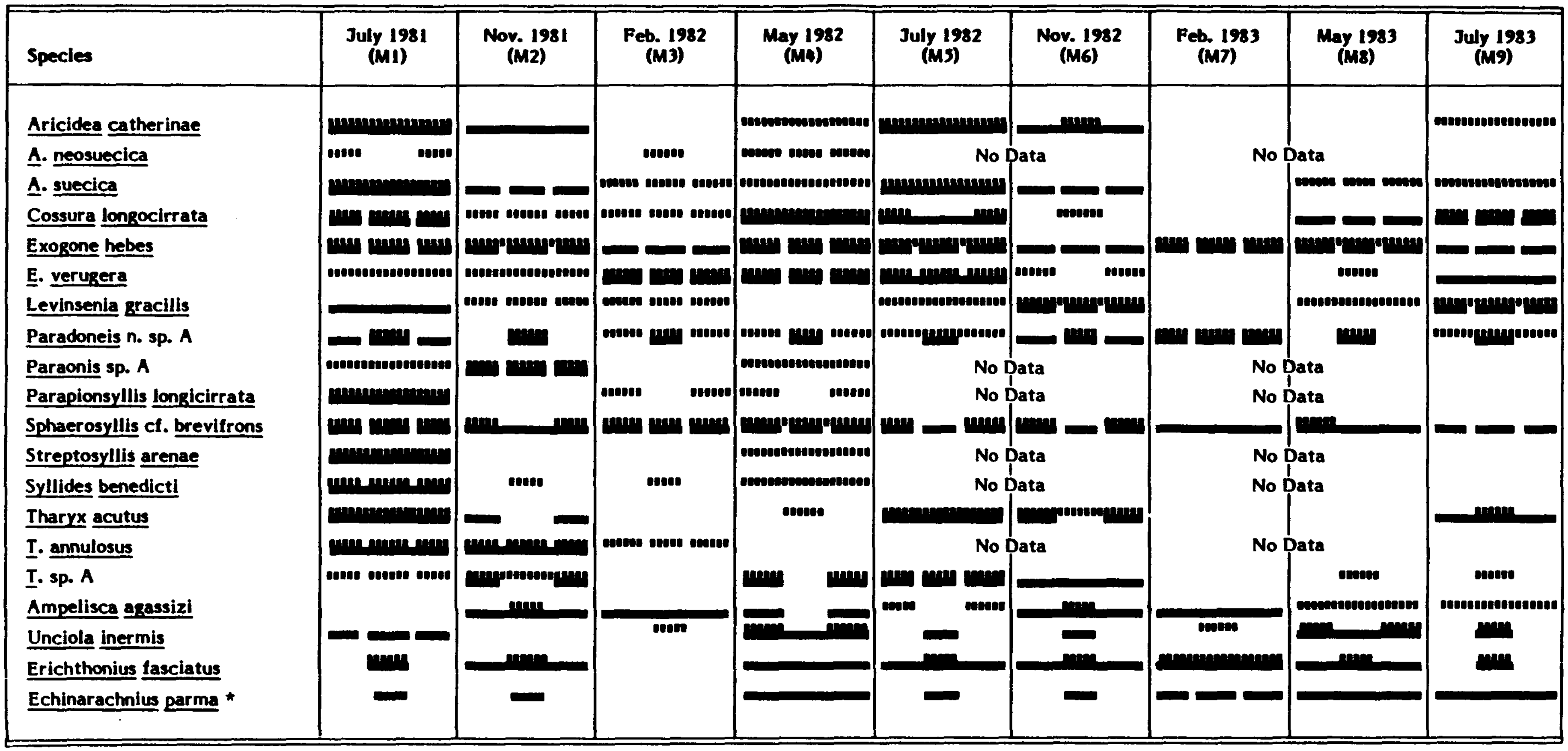
At Station 16, many of the dominant species had slightly higher average densities in Year 3 than in the preceding two years of the Monitoring Program. However, these differences were quite small. There were no repeatable seasonal trends in abundance of any species.

At Station 13 in the Mud Patch, several of the dominant species exhibited the large drop in density in May 1982 (M4) recorded for the benthic community as a whole. Recovery was complete by July 1982 (M5) and subsequently only moderate changes in the density of most species occurred for the remainder of the Program. Densities of some species, such as the polychaetes Mediomastus fragilis, Aricidea catherinae, and Ninoe nigripes, appeared to be somewhat lower in Year 3 than in the previous year. There were no clear-cut seasonal trends for any species.

Mean biomass, measured as wet weight or ash-free dry weight per 0.24 m^2, varied significantly over time at Stations 5-1 and 13, but not at Station 16. At Stations 5-1 and 13, the variation was due to a large increase in biomass in Year 2 (July 1982 to May 1983) compared to Year 1 (July 1981 to May 1982). Mean ash-free dry weight biomass for all cruises varied from 1.38 g/m^2 at Station 9 to 23.86 g/m^2 at Station 1. Mean values for all cruises at Stations 5-1 and 16 were 4.29 g/m^2 and 2.03 g/m^2, respectively.

The examination of life-history patterns of dominant species of polychaetes and amphipods helped to explain some of the patterns of change or lack of change in density of these species on Georges Bank. Of the polychaete species examined, four species appeared to be capable of year-round reproduction; 11 species showed reproductive activity during all or part of an extended period between spring and fall; and two species showed most reproductive activity in a winter/spring sequence (Figure 5). The three amphipod species studied had different reproductive patterns: Erichthonius fasciatus is a semi-annual species; Unciola inermis is an annual species; and Ampelisca agassizi is a biennial species (Figure 5).

Benthic communities also were examined in samples collected in 1980, 1981, and 1982 near three long-term U.S. Geological Survey moorings used to study near-bottom currents and sediment movement. The stations were located near Stations 6 and 13, and



* No data collected on presence of ovigerous females. Previous studies along the U.S. South Atlantic coast suggest a fall spawning in E. parma.

Major Recruitment — Major Reproductive Events

Some Recruitment — Reproductive Individuals Present

Figure 5. Summary of timing of reproduction and recruitment of some species studied in the life history analysis.

32.2 km northeast of Station 5-1. Patterns of mean numbers of individuals and mean numbers of species at Stations 6 and 13 showed patterns similar to those described above for samples collected from these locations in the Monitoring Program, including the sharp decline in mean density of individuals at Station 13 in May 1981. Densities of some dominant species at Station 13, such as Cossura longocirrata and Aricidea catherinae, showed a decline between May 1980 and September 1981, followed by a sharp increase to July 1982, interrupted by a decline in May 1982. There was a general trend of declining abundance of these species between July 1982 and June 1984.

There were no obvious seasonal or year-to-year trends in numbers of individuals or species at Station 6.

Station A, the station located at 85 m depth northeast of Station 5-1, had a benthic fauna that was more similar to that of Station 6 in 104 m of water than to the community of Stations 2 and 5-1 in 80 m of water. Dominant species at Station A included Ampelisca agassizi, Polygordius sp. A, Erichthonius fasciatus, and Exogone hebes. The densities of dominant species were relatively constant between October 1980 and May 1984.

A total of 31 taxa was identified in bottom photographs. These included 15 species of invertebrates and 16 species of fish. At regional stations, the most abundant animals were asteroid echinoderms (starfish) which were present at all but one station. Other taxa which occurred frequently included hake (Urophycis spp.), cancer crabs (Cancer sp.), hydroid colonies, and sponges. Sand dollars (Echinarachnius parma) had the greatest densities where they occurred, but occurred at relatively few stations. They were most abundant at Stations 1, 4, and 10 in 60 m of water.

Site-specific stations were dominated by starfish of the genera Asterias and Leptasterias. Other species which appeared frequently in bottom photographs from the site-specific stations included the sea scallop (Placopecten magellanicus), the cancer crab (Cancer sp.), and the skate (Raja sp.).

Community Parameters

Patterns of benthic infaunal diversity were similar for all three years of the Monitoring Program. The shallower Stations 1, 4, and 10 had the lowest diversities, while stations at 100 m or deeper had the highest diversities. At the two stations within 200 m of rig sites (Stations 5-1 and 16), Shannon-Wiener diversity (H') was lowest in February (M7) and November (M10) 1983 at Station 5-1, and in February 1982 (M3) and November 1983 (M10) at Station 16. At both drilling sites, most parameters, including total number of species and diversity, generally were higher in Years 2 and 3 than in Year 1, and were essentially similar between Years 2 and 3 (Figures 3 and 4). The lowest diversity and greatest variability in H' were observed at Station 4 in 67 m of water. At this station, H' ranged from 1.11 in November 1982 (M6) to 3.07 in June 1984 (M12).

The very large number of individual samples necessitated a two-step process of statistical analysis. Within a sampling date, the six replicates at each station were analyzed as independent samples. All of the replicates from a station were more similar to each other than to replicates from any other station, with the exception of Stations 16 and 17 (separated by 2 km in Block 410), and a single instance in February 1982 when one of the Station 8 replicates clustered with replicates from Stations 16 and 17. This similarity among replicates at a station indicates excellent replication of samples within a station.

At the next step in the classification, Stations 2 and 5 in 80 m of water always grouped together, while the other station at this depth, Station 11, grouped separately. Stations 1, 4, and 10 along the 60-m contour also grouped together. The deeper Stations 6, 9, and 12 clustered together except on a few occasions when Stations 3 and 6 grouped together. Station 8 clustered with Station 18 which also grouped with Stations 16 and 17.

The second stage in the cluster analysis examined the relationship among samples formed by summing the six replicates for a station within each sampling date (Figure 6). The Georges Bank regional stations were sufficiently invariant throughout the entire three-year Monitoring Program that every sample showed more affinity with other samples from that station than with samples from any other station regardless of sampling time and despite faunal similarities with other stations. Fauna at deeper stations showed some differences after the first year. However, there was little evidence of seasonality in the data despite the obvious formation of sediment ripples during the winter.

Detrended correspondence analysis gave similar results to cluster analysis in ordering the relationships among stations (Figure 7). Each station is plotted as a cloud of points, each point representing a specific sampling data. For the deeper stations, the data for the first year generally are on the right-hand side of the cloud. This is another indication that year-to-year differences are more important than seasonal differences in the benthic fauna of Georges Bank.

Within the site-specific array, Stations 5-1, 5-18 (2 km west of the rig site), and 5-28 (6 km east of the rig site) were compared. The stations formed three clusters corresponding to 1981, 1982, and 1983-84, with Stations 5-1 and 5-18 behaving like replicates. Station 5-28, the easternmost site-specific station, formed a discrete cluster in 1982 and 1983-84. In contrast to Station 5-28, Stations 5-1 and 5-18 clusters included an earlier sampling period in February 1982 in the 1982 cluster and February 1983 in the

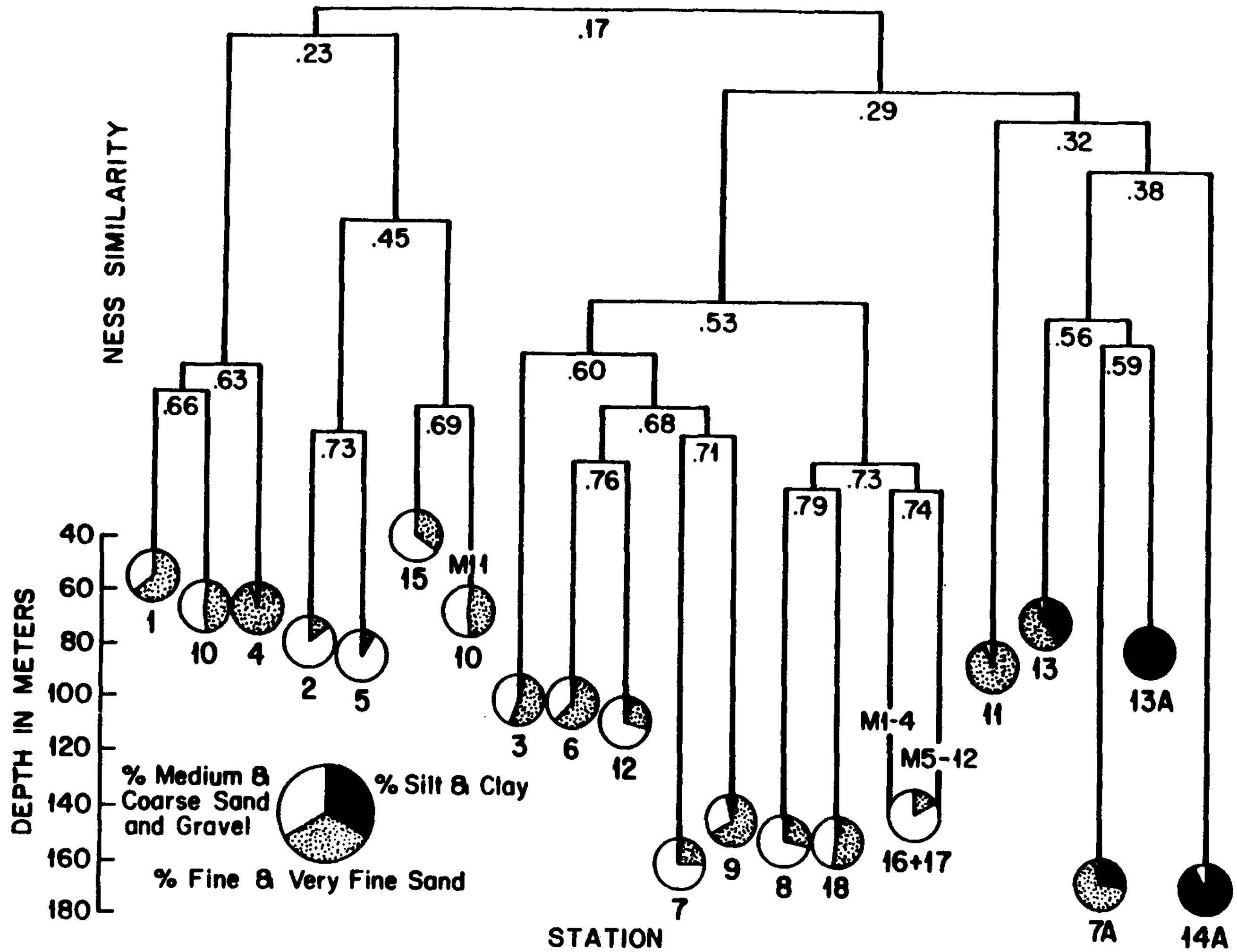


Figure 6. Summary of agglomerative cluster analysis using the sum of six replicates within each sampling date with NESS at 50 individuals and group average sorting. Results are related to station depth and sediment type. Except Station 10, February 1983 (M11), all of the samples at a given station cluster together regardless of season or year. Most stations had 11 to 12 sampling periods (see Table 1 for cruise dates). Stations 7 and 15 were dropped in the last two years and had four and five sampling periods respectively. Stations 7A, 13A, and 14A were added in the second year and had eight sampling periods.

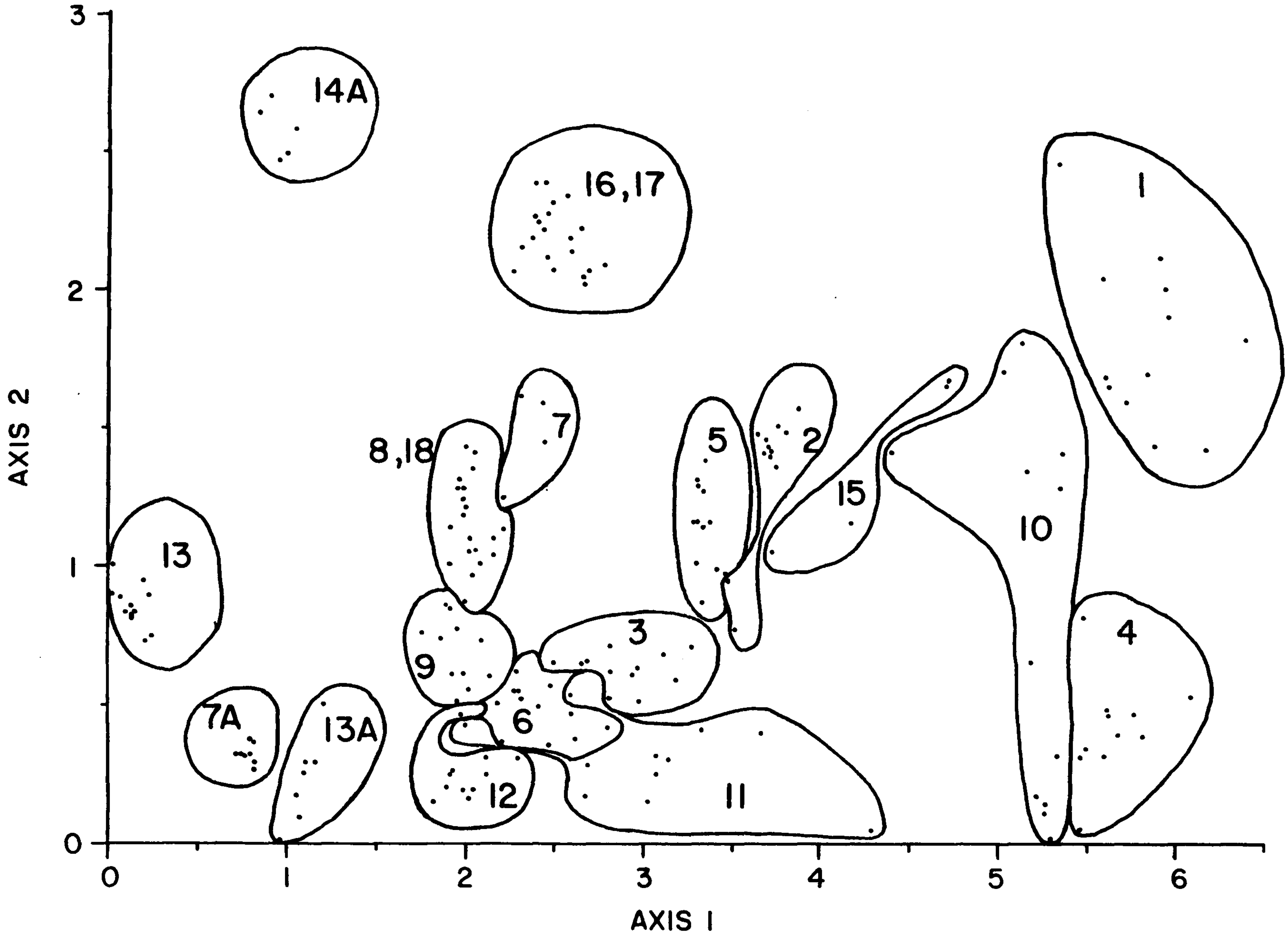


Figure 7. Detrended correspondence analysis of six replicate sums from each sampling date. Each station is plotted as a cloud of points, each point representing one sampling period.

1983-84 cluster. This suggests that year-to-year changes in benthic infauna occurred first at Station 5-28.

No effects of exploratory activities and drilling discharges were detected in the community structure of the benthic infauna of Georges Bank. This is not surprising, since discharged materials were dispersed over a large area of the Bank and were diluted rapidly to very low concentrations both before and after deposition in bottom sediments (Bothner et al., 1985). The spread and dilution of drilling fluid solids indicates that the potential for site-specific biological effects of any contaminant associated with sediments is reduced because of very active sediment resuspension and redistribution in the high-energy environment of Georges Bank. If Georges Bank communities were to change as a result of sediment contamination from some source, the changes would be widespread. For this reason, any future monitoring program on Georges Bank should pay particular attention to any gradual trends toward increases in sediment contamination that might originate from a variety of sources.

Benthic Production and Fish Feeding

A total of 594 yellowtail flounder (Limanda ferruginea) stomachs were examined. Fish caught at Station 5-1 had the highest mean number of prey per stomach, followed by those caught at Stations 10 and 13. This is explained in part by the observation that fish at Station 10 consumed larger-sized prey items than those at Station 5-1. The five most numerous prey species of yellowtail flounder accounted for 96 percent, 70 percent, and 89 percent of the total identifiable prey species in flounder from Stations 5-1, 10, and 13, respectively (Figure 8). The diet of fish from Station 5-1 was dominated by tubicolous amphipods and to a lesser extent by polychaetes. At Station 10, the dominant prey included fish larvae, amphipods, shrimp, and crabs. Amphipods and polychaetes were the dominant prey of flounder at Station 13.

At Station 5-1, the same prey items dominated the diet of flounder in all seasons. In contrast, there was considerable seasonal variation in the diet of flounder at Station 10. The diet was dominated by larval fish in summer, shrimp in fall and winter, and amphipods in spring.

Electivity indices (Ivlev, 1961) were calculated to determine if changes in prey composition reflected seasonal changes in benthic community composition. This analysis showed that the diet of yellowtail flounder was quite plastic, in that the dominant prey species varied from station to station, due in part to differences among stations in benthic community structure. However, electivity values were consistent among stations. For

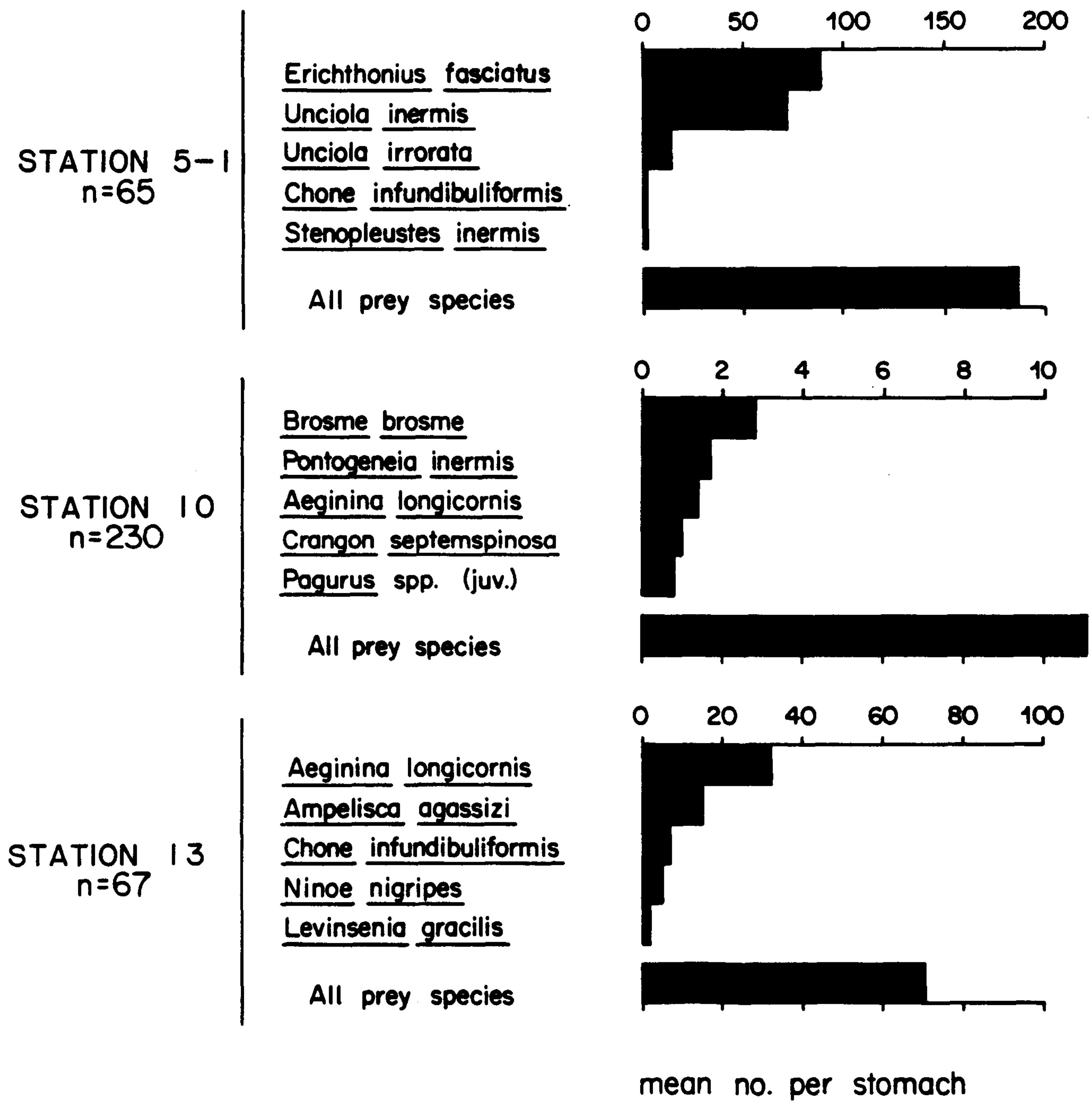


Figure 8. Five most numerous prey species of yellowtail flounder, *Limanda ferruginea*, at Stations 5-1, 10, and 13. Data are expressed as mean prey numbers taken over four quarterly collecting cruises.

example, Chone infundibuliformis, C. duneri, and Aeginina longicornis were always positively selected, while Aricidea catherinae was always negatively selected.

Some differences in electivity among prey species at different stations or at a station in different seasons may be due to size-selective feeding. At Station 13, flounder preferred Ampelisca agassizi in the 6-8 mm size range, even though the dominant size class of this species in the benthos was about 3.5 mm. Similarly, flounder at Station 5-1 selected against juveniles, feeding most heavily on adult amphipods, Unciola inermis and Erichthonius fasciatus. At Station 10, flounder preferentially selected small (8-10 mm) sand dollars, Echinarachnius parma, over the more abundant larger (15-20 mm) ones.

The mean consumption rate (Table 3) and mean consumption rate as percentage of production of dominant prey species (Table 4) for yellowtail flounder also were estimated. The yellowtail flounder consumption rate is a first approximation based on published information. The predation rates account for less than 10 percent of prey production for the prey species examined. Nevertheless, they are not insignificant. Yellowtail flounder is a major predator of amphipods, but it is only one of several demersal fish and invertebrate predators that feed on benthic macrofauna. The total predation rates by all predator species on the four prey species included in Table 4 probably are considerably higher than the predation rates cited in Table 4. Red hake (Urophycis chuss), little skate (Raja erinacea), and witch flounder (Glyptocephalus cynoglossus) all are known to feed on the three amphipod species. American plaice (Hippoglossoides platessoides) and ocean pout (Macrozoarces americanus) feed heavily on sand dollars.

The stomach contents analysis confirmed the importance of benthic macrofauna in the diet of yellowtail flounder on Georges Bank. Electivity indices indicated that prey composition changed seasonally in relation to variations in benthic species abundances. Production of benthic amphipods appeared to be quite high at the stations investigated. A significant proportion of this amphipod production may be consumed by yellowtail flounder and other demersal fish species. No patterns of change in these predator/prey relationships attributable to drilling activities could be discerned.

Sediment Characteristics

Surficial sediments of the study area on the southern flank of Georges Bank are predominantly (>95 percent) quartz sand with minor amounts of gravel, pelecypod shell and echinoderm test fragments, silt, and clay. The sands are non-cohesive, medium to

TABLE 3. YELLOWTAIL FLOUNDER CONSUMPTION RATE.

Georges Bank population size	5×10^{7} fish (Collie and Sissenwine, 1983)
Area of Georges Bank	5.3×10^{4} km^2
Yellowtail flounder density	1×10^{-3} fish m^{-2}
Consumption to biomass ratio	4.6 yr^{-1} (Grosslein et al., 1980)
Yellowtail flounder mean wet weight	310.9 ± 7.4*g $fish^{-1}$
Consumption rate	1.4×10^{3} g $fish^{-1}$ yr^{-1} (wet weight)
Consumption rate per unit area	1.4 g m^{-2} yr^{-1} (wet weight)

* standard error of mean

TABLE 4. YELLOWTAIL FLOUNDER CONSUMPTION AS A PERCENTAGE OF PREY PRODUCTION (GWW = GRAMS WET WEIGHT).

Prey Species:	Ampelisca agassizi	Unciola inermis	Erichthonius fasciatus	Echinarachnius parma
Station:	13	5	5	10
Production (gww m^{-2} yr^{-1}): July 1982-July 1983	13.3	8.7	13.3	4.9
Percent of flounder diet (by weight):	5.2	31.8	18.8	2.6
Consumption/production (%):	0.6	5.2	2.0	0.8

fine-grained, rounded to subangular in shape, and translucent (clean) to light brown (iron oxide-coated). Areas of unusually high (25-90 percent) silt + clay content, presumably depositional areas, include the head of Lydonia Canyon (Station 7A), the region west of the Bank known as the Mud Patch (Stations 13 and 13A), and the area north of Georges Bank in the southern Gulf of Maine (Station 14A).

At Stations 5-1 and 16, within approximately 200 m of the rig sites in Blocks 312 and 410, respectively, a small portion of the sand (0.063-2.00 mm) and gravel (>2.00 mm) fractions consisted of dark gray, calcareous (effervesces in 10 percent HCl), angular rock fragments. This material probably was drill cuttings. Bothner et al. (1983, 1985) observed similar material in sediments at Station 16, at Station 17, located 2 km east of the drill site in Block 410, and at all stations within 0.5 km of the rig site in Block 312. Bothner et al. (1985) estimated that no more than 1.5 percent of the sand-gravel fraction was composed of drill cuttings.

There was a slight increase in the percentage of material finer than 0.125 mm in sediments with increasing water depth. Fine-grain sediments were particularly abundant at the heads and on the flanks of Lydonia and Oceanographer Canyons (Figure 9). There also was a clear gradient of increasing silt + clay in sediments from northeast to southwest along the 70-80 m depth contours (Stations 2, 5-1, 11, 13, and 13A). Sediments at Station 5-29 had a higher mean percent silt + clay than sediments at other site-specific stations.

During the three years of the Monitoring Program, there was a 10-20 percent by weight increase of finer fractions of sediment (<0.125 mm) at the canyon head stations (Station 7A and 9), the Mud Patch stations (Stations 13 and 13A), and at Station 16 near the rig site in Block 410. Increases of 2-5 percent by weight of very fine sediment were observed at all site-specific stations (Stations 5-1 through 5-28) and at Regional Station 12 since the beginning of the Monitoring Program. These increases in fine-grain sediments near rig sites and in depositional areas could be due to accumulation of drilling mud solids or to long-term storm-induced trends in sediment resuspension and transport. However, successive samplings along local gradients or in areas of patchy sediments could also account to some degree for these trends. At several stations, there also were clear seasonal trends in sediment grain-size distribution, with the percentage of the coarse fractions increasing in winter months and decreasing in summer months. These seasonal patterns undoubtedly reflect storm-induced resuspension and transport of fine-grain sediments during winter months.

Bottom still photographs taken at most stations on most cruises showed that stations at similar depths exhibited similar patterns of microtopography and sediment type. The

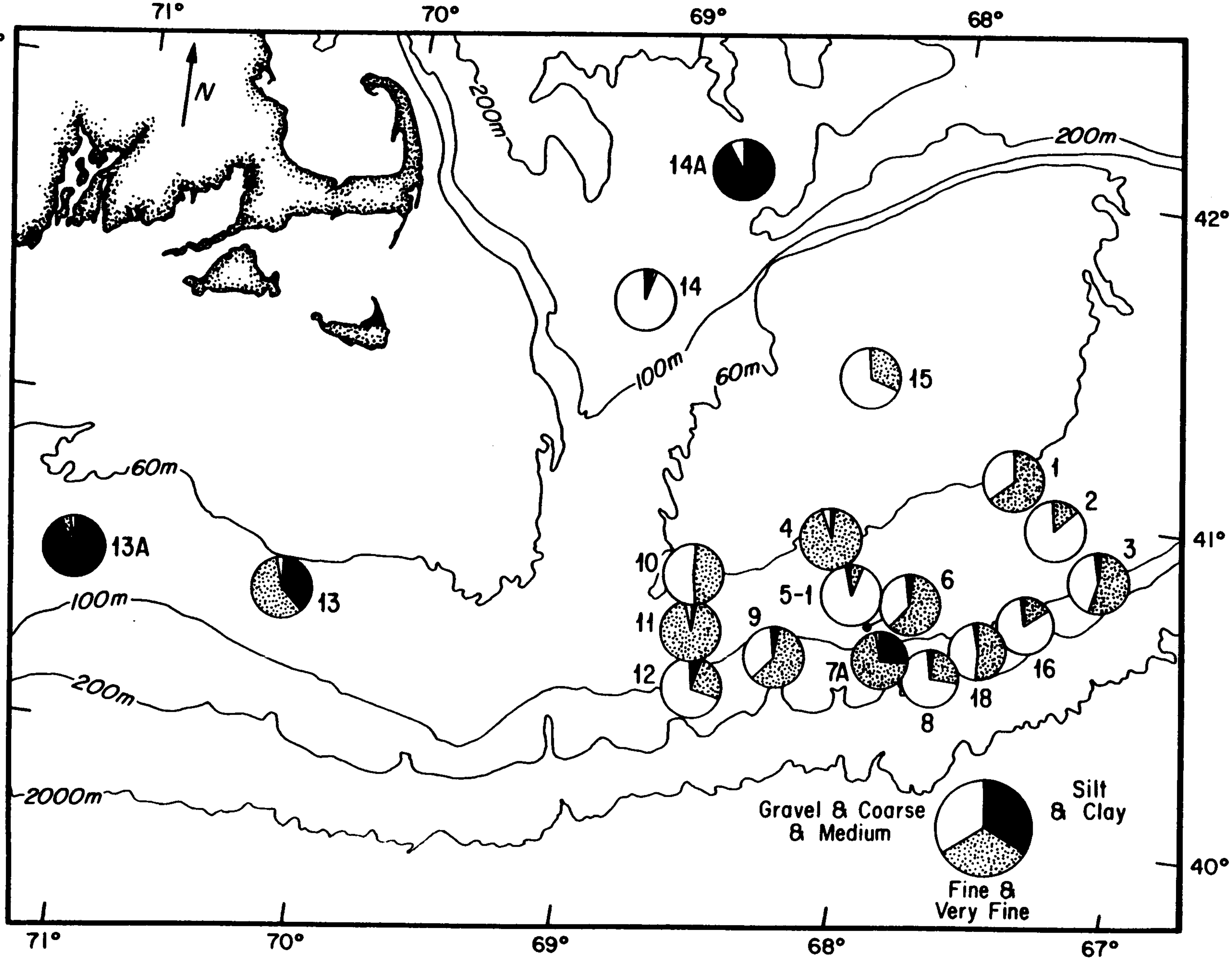


Figure 9. Sediment grain-size composition at Georges Bank regional stations.

bottom at Stations 16, 17, and 18 in 140 m of water near the rig site in Block 410 had similar surficial features. The sediment was a silty sand containing small to medium-sized shell fragments. A uniform cover of coarse detritus and/or biological material was present. The bottom was flat, but with many disturbed areas and biotic features.

The bottom at site-specific stations located around the rig site in Block 312 in approximately 80 m of water all had similar microtopographic features, except Station 5-29, located six km west of the rig site. The sediment appeared to be sand covered by a fairly uniform layer of coarse detritus and/or biological material. Scattered shell fragments also were present. At Station 5-29, sediments were silty sand with many large shell fragments.

There was a seasonal pattern of change in sediment microtopography at many stations, primarily the deeper ones (Figure 10). In spring and summer, sediments had smooth and unsculptured surfaces with fairly uniform detritus coverage. In fall and winter, the sediment surfaces often were rippled and sculptured. Detritus was absent or present in a clumped, patchy distribution. Sediments were rippled at the 60-m stations during all seasons of the year. There was no visible evidence of accumulation of drilling mud or cuttings on the bottom in any bottom photograph.

Concentrations of total organic carbon were low in sediments at most stations. Sandy sediments usually had organic carbon concentrations below 0.2 percent and nitrogen concentrations below 0.02 percent. Organic carbon concentrations were much higher in sediments with a high concentration of silt + clay (Stations 7, 7A, 13, 13A, and 14A). The highest values were recorded at Stations 13A ($\bar{x}$ = 1.97 percent) and 14A ($\bar{x}$ = 1.94 percent). There was little seasonal variation in sediment organic carbon concentration at these stations.

Bothner et al. (1985) and Payne et al. (1985) reported that concentrations of barium, chromium, other metals, and petroleum hydrocarbons in bulk sediments of regional stations did not change significantly during the three years of the Monitoring Program. Barium is a widely-used tracer of the fate of drilling mud solids in the ocean because it is extremely dense and insoluble and is present in most water-base drilling muds at concentrations many orders of magnitude higher than in most marine sediments.

By analyzing barium concentration in the fine fraction of surficial sediments, however, Bothner et al. (1985) were able to detect a temporal pattern of net westward transport of barium-rich fine sediment. The authors were able to detect a small deposition of drilling mud barium at stations 35 km to the east (Stations 2 and 3) and west (Station 12) of the Block 312 drilling site six to twelve months after completion of drilling. This barium could have come from any of the eight rigs on the Bank. There also was an increase in barium concentration in sediments collected in sediment traps deployed at the head of Lydonia Canyon during drilling, indicating that some drilling mud discharged from the exploratory rigs was finding its way to this depositional area. Pre-drilling concentrations of barium and hydrocarbons were high in sediments from depositional sites (Stations 7A, 13, and 13A) and did not change significantly during or after drilling.

At Station 16 within 200 m of the rig site in Block 410, the concentration of barium in the upper 2 cm of bulk sediment increased by a factor of 5.7 (from 32 to 183 ppm) between the first (pre-drilling) and sixth (post-drilling) cruises (Bothner et al., 1985). Barium concentration in sediments from this station tended to decrease with time after November 1982 (M6), with the exception of a sharp rise in sediment barium concentration in June 1984 (Figure 11).

In the site-specific array of stations in Block 312, the concentration of barium in bulk surficial sediment from several stations around the rig site increased during and immediately after drilling (Bothner et al., 1985). The largest increase was 4.7-fold (from 28 ppm in July 1981 to 131.6 ppm in February 1983) at Station 5-1 within 200 m of the rig site (Figure 12). At stations where barium accumulated during or immediately after drilling, there was a trend for mean sediment barium concentrations to decrease to near background levels by Cruises M6 to M8 (November 1982 to May 1983).

Payne et al. (1985) reported a slight but statistically significant increase in the concentration of aromatic hydrocarbons (as analyzed by UV fluorescence) in sediments from Station 5-1 during drilling (Figure 12). Methylnaphthalenes through perylene were detected in quantifiable concentrations by GC/MS in sediment samples taken during drilling, suggesting a petroleum origin of the hydrocarbons, probably from the diesel fuel added to the drilling mud on the rig. The increase was small, from a pre-drilling concentration of 0.007 to 0.102 ppm total aromatics to a range of 0.097 to 0.572 ppm after drilling. Mean total aromatics concentrations remained elevated (0.30 to 0.56 ppm) after drilling. These concentrations of low-to-medium molecular weight aromatic hydrocarbons in sediments are not considered toxic to benthic organisms (Neff and Anderson, 1981). Boehm and Farrington (1984) recently reported concentrations of two- to five-ring aromatics in sediments collected from the study area in 1977, in the range of 0.001 to 0.10 ppm, similar to the pre-drilling values reported by Payne et al. (1985).

Hydrography

Distribution of bottom-water temperature in the study area showed characteristic seasonal patterns. Bottom-water temperature fluctuated most on a seasonal basis at the

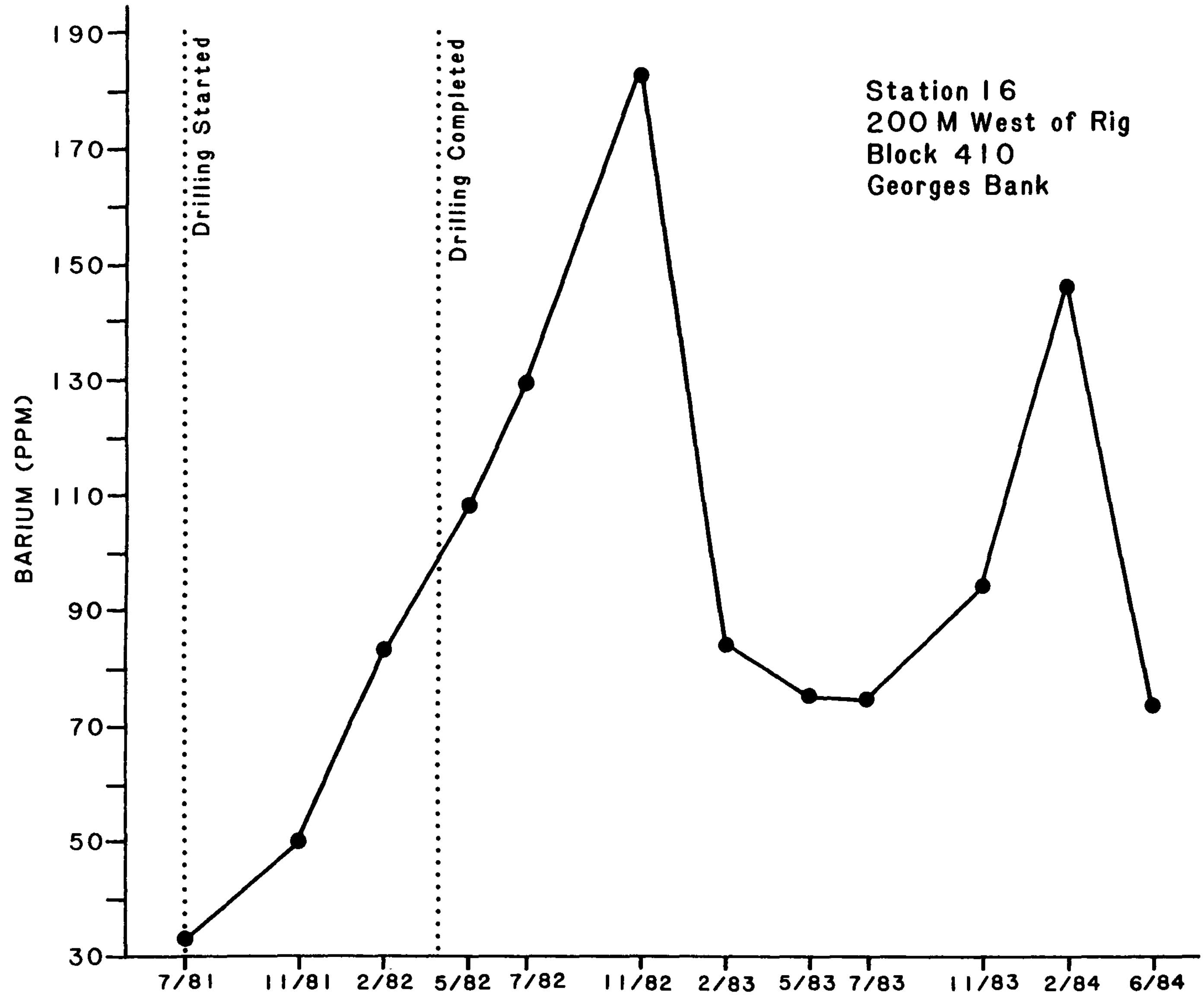


Figure 11. Mean barium concentration in bulk surficial sediments at Regional Station 16 on 12 sampling occasions. Values are in mg/kg dry weight. (Data from Bothner et al., 1985).

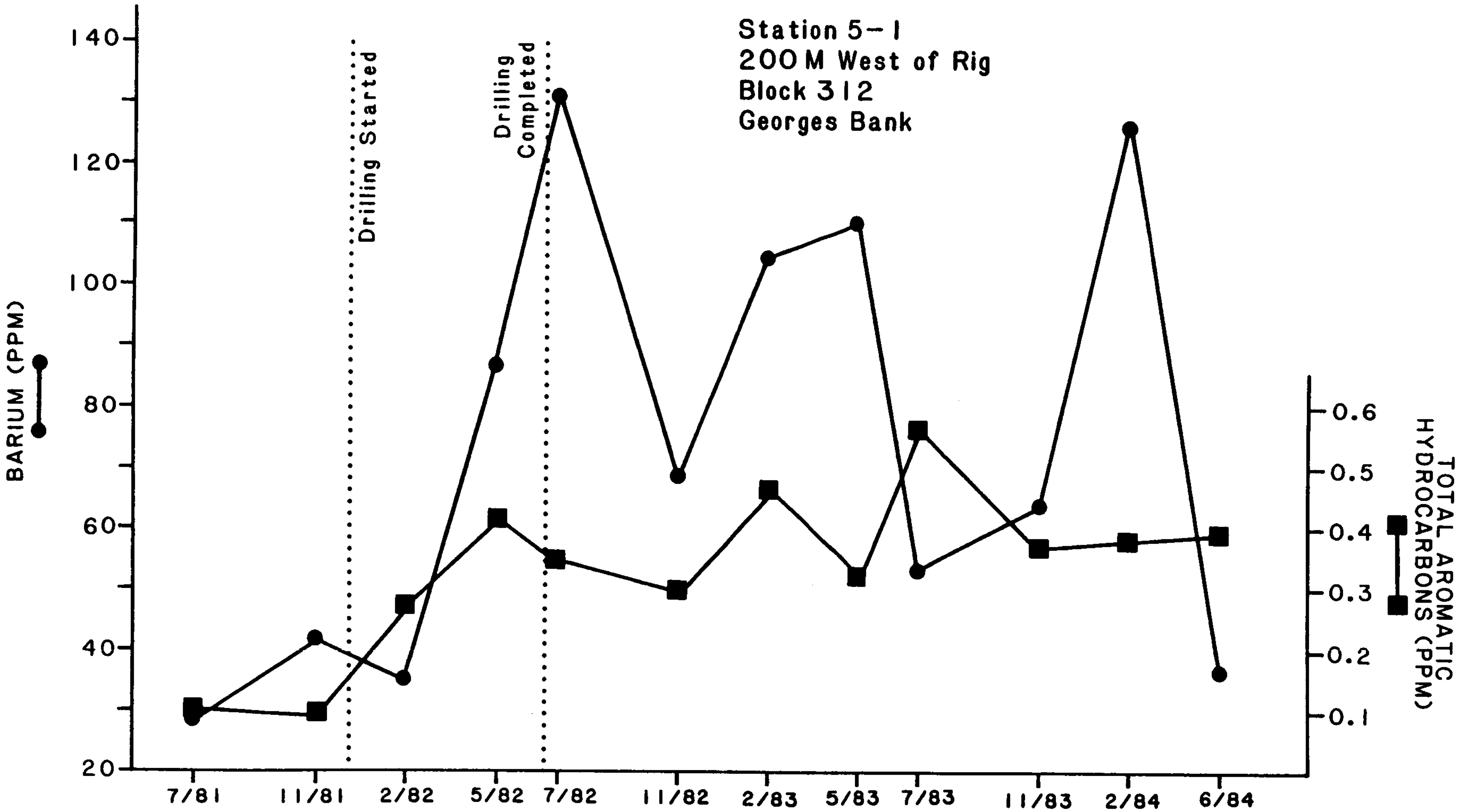


Figure 12. Mean barium and total aromatic hydrocarbon concentrations in bulk surficial sediments at Site-Specific Station 5-1 on 12 sampling occasions. Aromatic hydrocarbon values for the first four cruises (July 1981 to May 1982) are based on a single analysis of a pooled sample of three replicates. Other data points are the means of three replicate samples (barium data from Bothner et al., 1985; hydrocarbon data from Payne et al., 1985).

shallowest stations and became more stable at deeper stations. Bottom-water temperature varied seasonally by more than 13°C (3.8-17.3°C) at Station 15, but remained near 10°C throughout the three years of the Program at deeper stations (below 130 m). Stations at similar water depths (e.g., Stations 2, 5-1, and 11 at approximately 80 m) had similar seasonal patterns of bottom-water temperature.

The salinity of bottom water ranged between 31.0 and 35.5 parts per thousand among all stations. At any one station, salinity of bottom water varied seasonally by no more than 2-3 parts per thousand.

The dissolved oxygen concentration of bottom water was highest at all stations in winter and declined gradually with season from spring to summer to fall. At most sampling stations and times, percent oxygen saturation of bottom water ranged from 60 to 80 percent, which is sufficiently high to be non-stressful to nearly all benthic and demersal marine animals.

CONCLUSIONS

General

- No significant changes in benthic infaunal community structure which can be attributed to the drilling of eight dry wells on Georges Bank were detected during and for at least two years after drilling by the methods of analysis used.

- Biological patterns in benthic infauna were similar throughout the three years of the Monitoring Program. Abundance of individual species and overall benthic community structure changed very little with season at any station. At stations at or deeper than 100 m (e.g., Stations 3, 6, 8, 9, and Block 410), the samples were very homogeneous within years and it was possible to resolve subtle differences between years.

- During the three years of the Monitoring Program, the replicate infaunal samples from each regional station showed an exceptionally high degree of homogeneity. Cluster analysis demonstrated that all of the replicates of any one regional station were more similar to each other than to replicates from any other station. The benthic community of any particular station was always distinct from the community at any other station. When replicates from each sampling date were summed, the samples from each of the 12 sampling periods clustered together before joining with samples from any other station.

• Biomass varied over time and among stations. At some stations there were significant increases in biomass between the first and second years. Clams (Arctica islandica) and sand dollars (Echinarachnius parma) dominated the biomass when they were present. When A. islandica and E. parma were absent, polychaetes and arthropods dominated the biomass. Levels of wet-weight biomass found in this study were similar to estimates from other studies.

• Bottom photographs taken during the Monitoring Program revealed depth-related patterns of microtopography. On the 60-m contour, well-defined ripples were present most of the year. Seasonal differences in ripple patterns were seen at stations along the 70-80 m contour, including the site-specific array in Block 312. Such differences were not seen at stations along the 100-m contour, where little rippling of sediments was noted. Seasonal differences in sediment microtopography were seen at the Block 410 stations at 145 m. Results of the faunal analysis of the photographs corroborated the results of the grab sample analysis. For example, the patchy distribution of the sand dollar Echinarachnius parma at the 60-m stations was obvious in both analyses.

Block 312

• Drilling began in Block 312 on December 8, 1981 and continued until June 1982. There was no statistical correlation between benthic infaunal community parameters at site-specific stations and the increase in barium concentration of bulk surficial sediments observed between Cruises M1 (before drilling) and M5 (after drilling), or percent silt-clay in sediments. A highly significant correlation between community parameters and percent fine sand was observed. Although stations within the site-specific array in Block 312 had a homogeneous community structure over most of the area, species composition was different at two stations located to the west of the rig site where the proportion of fine sand was higher than at other stations in the array. These results indicate that discharges of drilling fluids and cuttings did not have a measurable impact on the benthic fauna in Block 312.

• Patterns of fluctuation in the number of individuals per grab sample (0.04 m^2) and the abundance of certain dominant species, such as the amphipods Erichthonius fasciatus and Unciola inermis, in November 1981 (M2) or February 1982 (M3) at stations near the rig site in Block 312, at which barium subsequently accumulated, were repeated but at a lesser magnitude in November 1982 (M6), February 1983 (M7), November 1983 (M10), and

February 1984 (M11). These results indicate that the fluctuations are mostly seasonal, and cannot be attributed to drilling activities.

• The apparent small accumulation of petroleum hydrocarbons in sediments at Site-Specific Station 5-1 and possibly Station 5-18 (less than one-half part per million) (Payne et al., 1985), had no measurable impact on the benthic infauna of those stations.

Block 410

• Drilling occurred in Block 410 between July 1981 and March 1982. No measurable impact on the benthic fauna due to drilling activities was detected after analysis of 12 seasonal samples from the rig site itself (Station 16) with the statistical methods used.

Life History Analysis

• Results from the life-history analysis aided in interpreting observed changes in species abundance. For the three amphipod and one echinoderm species studied, much of the variation in abundance could be explained on the basis of recruitment and mortality, although adult migration was also important in explaining population changes in the amphipod, *Erichthonius fasciatus*. Data on several polychaete species were more difficult to interpret in explaining patterns of abundance. Four species were determined to reproduce year-round; 11 species showed reproductive activity during all or part of an extended period; and two species were reproductively active during the winter-spring period.

Benthic Production and Fish Feeding

• Yellowtail flounder on Georges Bank feed primarily on macrobenthic species. The dominant prey species varied seasonally and between stations. Predation was strongly species dependent and size dependent. Flounder appeared to accommodate changes in the abundance of their preferred prey species. Demersal fish, including yellowtail flounder, consume a significant fraction of the annual production of benthic amphipods of Georges Bank, documenting the importance of benthic infauna in supporting the commercial fishery of the Bank.

Sediment Grain-Size Analysis

• The predominantly medium to fine sand sediments of Georges Bank exhibited increases in finer size classes with depth, along a regional gradient from NE to SW, and on seasonal and two- to three-year time scales. Observed increases in fine sediments at several stations over time may be the result of biological processes (e.g., activites of increasingly dominant deposit feeders) and/or an analytical artifact (e.g., successive samplings along a local gradient). Drill cuttings were observed at the drill sites in Blocks 312 and 410.

Comparison with Historical Infaunal Samples

• At Station A (40°51.0'N, 67°24.4'W, 85 m depth), bottom observations and current meters maintained by the U.S. Geological Survey from May 1975 to March 1979 showed effects of winter storms on bottom surface topography and provided evidence that benthic macrofaunal communities may play an important role in maintaining bottom sediment stability during a storm event. Analysis of benthic samples collected between May 1980 and July 1982 showed little effect of such storms on benthic macrofaunal communities. Despite the erosion of sediments and disappearance of the surface biological mat observed by Butman (1982) at this station, the benthic populations did not show a sharp decline during the 1980-1982 winter periods.

• Eleven stations sampled during the New England OCS Benchmark Study in 1977-78 coincided with stations sampled during the Monitoring Program. Analysis of these historic samples was completed by Taxon, Inc. (Michael et al., 1983). The dominant species recorded from the 1977-78 samples generally agreed with the dominant species found in Monitoring Program samples. There was particularly good correspondence for dominant species recorded at the Block 312 drilling site, Station 5-1, with seven of the top ten species reported in common. The average density of individuals at the 11 stations was generally higher in the Monitoring Program samples, even when only individuals retained on the 0.5-mm screen were compared.

CHN Analysis

• Total organic carbon on Georges Bank was correlated with sediment grain size. Sandy areas exhibited organic carbon values below 0.20 percent. Stations located in areas of finer, predominantly silt-clay sediments indicative of net depositional areas had markedly higher percentages of organic carbon. A depth-related gradient was observed, with carbon generally increasing with depth.

RECOMMENDATIONS

- The large volume of complex multidisciplinary data generated should be combined and integrated into a single, comprehensive, multidisciplinary synthesis manuscript which would go beyond the basic correlations done as part of this project and the summary manuscript submitted for publication. Additional manuscripts should be prepared, based on the extensive data set generated during this Program. Such manuscripts would address in detail the benthic ecology of Georges Bank, variations in sediment texture, life history of polychaete and amphipod species, biomass of invertebrate species, and taxonomic and zoogeographic details concerning the infaunal organisms collected during the project.

- Sampling and benthic infaunal and metals analysis should continue at a reduced number of Monitoring Program stations in order to extend the three-year database already established and to correlate with the recently initiated North Atlantic Slope and Rise Study.

- We recommend continued sampling at seven stations, including the deeper Regional Stations 7A, 8, 9, and 16; the Mud Patch Stations 13 and 13A; and the center of the site-specific array, Station 5-1. Sampling could be reduced to twice a year.

LITERATURE CITED

Battelle and Woods Hole Oceanographic Institution. 1983. Georges Bank Benthic Infauna Monitoring Program. Final Report, Year 1 to USDI, Minerals Management Service, Washington, D.C. 153 pp. and Appendices A-G.

Battelle and Woods Hole Oceanographic Institution. 1984. Georges Bank Benthic Infauna Monitoring Program. Final Report, Year 2 to USDI, Minerals Management Service, Washington, D.C. 173 pp. and Appendices A-I.

Battelle and Woods Hole Oceanographic Institution. 1985. Georges Bank Benthic Infauna Monitoring Program. Final Report for Third Year of Sampling to USDI, Minerals Management Service, Washington, D.C. 354 pp. and Appendices A-K.

Biological Task Force. 1981. Georges Bank monitoring program and related studies. Working Group of the Biological Task Force on Georges Bank for Lease Sale No. 42.

Boehm, P.D. and J.W. Farrington. 1984. Aspects of the polycyclic aromatic hydrocarbon geochemistry of recent sediments in the Georges Bank region. Environ. Sci. Technol. 18:840-845.

Boesch, D.F. 1977. Application of numerical classification in ecological investigations of water pollution. U.S. Departmentof Commerce, NTIS PB-269 604. EPA-600/3-77-033. 114 pp.

Bothner, M.H., R.R. Rendigs, E. Campbell, M.W. Doughten, P.J. Aruscavage, A.F. Dorrzapf, Jr., R.G. Johnson, C.M. Parmenter, M.J. Pickering, D.C. Brewster and F.W. Brown. 1982. The Georges Bank Monitoring Program. Analysis of Trace Metals in Bottom Sediments. First Year Final Report to USDI, Minerals Management Service, Washington, D.C. U.S. Department of the Interior, Geological Survey, Woods Hole, MA. 61 pp.

Bothner, M.H., R.R. Rendigs, E. Campbell, M.W. Doughten, C.M. Parmenter, J.J. Pickering, R.G. Johnson and J.R. Gillison. 1983. The Georges Bank Monitoring Program: Analysis of Trace Metals in Bottom Sediments During the Second Year of Monitoring. Final Report to USDI, Minerals Management Service, Washington, D.C. U.S. Department of the Interior, Geological Survey, Woods Hole, MA. 88 pp.

Bothner, M.H., R.R. Rendigs, E. Campbell, M.W. Doughten, C.M. Parmenter, C.H. O'Dell, G.P. DiLisio, R.G. Johnson, J.R. Gillison and N. Rait. 1985. The Georges Bank Monitoring Program: Analysis of Trace Metals in Bottom Sediments During the Third Year of Monitoring. Final Report to USDI, Minerals Management Service, Washington, D.C. U.S. Department of the Interior, Geological Survey, Woods Hole, MA. 99 pp.

Bureau of Land Management. 1981. A Regional Studies Plan for the North and Middle Atlantic Regions: FY-1982. U.S. Department of the Interior, Bureau of Land Management, New York OCS Office, New York, NY. 78 pp.

Butman, B. 1982. Current and sediment movement of Georges Bank. In: Georges Bank - Past, Present, and Future of a Marine Environment. G. McLeod and J.H. Prescott (Eds.). Westview Press, Boulder, CO. pp. 31-61.

Collie, J.S. and M.P. Sissenwine. 1983. Estimating population size from relative abundance data measured with error. Can. J. Fish. Aquat. Sci. 40:1871-1879.

Crisp, D.J. 1971. Energy flow measurements. In: Methods for the Study of Marine Benthos. 2nd ed. N.A. Holm and A.D. McIntyre (Eds.) IBP Handbook No. 16. Blackwell, Oxford. pp. 284-372.

Gauch, H. G., Jr. 1982. Multivariate Analysis in Community Ecology. Cambridge Studies in Ecology. Cambridge University Press, Cambridge. 298 pp.

Grassle, J.F. and W.L. Smith. 1976. A similarity measure sensitive to the contribution of rare species and its use in investigaton of variation in marine benthic communities. Oecologia 25:13-22.

Grosslein, M.D., R.W. Langton and M.P. Sissenwine. 1980. Recent fluctuations in pelagic fish stocks of the Northwest Atlantic, Georges Bank region in relation to species interactions. Rapp. P.-v. Reun. Cons. Int. Explor. Mer 177:374:404.

Hurlbert, S.H. 1971. The nonconcept of species diversity: a critique and alternative parameters. Ecology 52:577-586.

Ivlev, V.S. 1961. Experimental Ecology of the Feeding of Fish. Yale University Press, New Haven. 302 pp.

Michael, A.D., C.D. Long, D. Maurer, and R.A. McGrath. 1983. Georges Bank Benthic Infauna Historical Study. Final Report to USDI, Minerals Management Service, Washington, D.C. 171 pp.

National Academy of Sciences. 1983. Drilling Discharges in the Marine Environment. National Academy Press, Washington, D.C. 180 pp.

Neff, J.M. and J.W. Anderson. 1981. Response of Marine Animals to Petroleum and Specific Petroleum Hydrocarbons. Halstead Press, NY. 167 pp.

Payne, J.R., J.L. Lambach, R.E. Jordan, G.D. McNabb, Jr., R.R. Sims, A. Abasumara, J.G. Sutton, D. Generro, S. Gagner and R.F. Shokes. 1982. Georges Bank Monitoring Program. Analysis of Hydrocarbons in Bottom Sediments and Analysis of Hydrocarbons and Trace Metals in Benthic Fauna. First Year Final Report to USDI, Minerals Management Service, Washington, D.C. Science Applications, Inc., La Jolla, CA. 189 pp.

Payne, J.R., J.L. Lambach, R.E. Jordan, C.R. Phillips, G.D. McNabb, Jr., M.K. Beckel, G.H. Farmer, R.R. Sims, Jr., J.G. Sutton, C. de Otiveria and A. Abusamura. 1983. Georges Bank Monitoring Program: Year Two. Analysis of Hydrocarbons in Bottom Sediments and Analysis of Hydrocarbons and Trace Metals in Benthic Fauna. Final Report to USDI, Minerals Management Service, Washington, D.C. Science Applications, Inc., La Jolla, CA. 151 pp.

Payne, J.R., J.L. Lambach, G.H. Farmer, C.R. Phillips, M.K. Beckel, J.G. Sutton and R.R. Sims, Jr. 1985. Georges Bank Monitoring Program: Analysis of Hydrocarbons in Bottom Sediments and Analysis of Hydrocarbons and Trace Metals in Benthic Fauna During the Third Year of Monitoring. Final Report to USDI, Minerals Management Service, Washington, D.C. Science Applications, Inc., La Jolla, CA. 106 pp.

Sanders, H.L. 1968. Marine benthic diversity: a comparative study. American Naturalist. 102:243-282.

Siegel, S. 1956. Nonparametric Statistics for the Behavioral Sciences. McGraw Hill. New York. 312 pp.