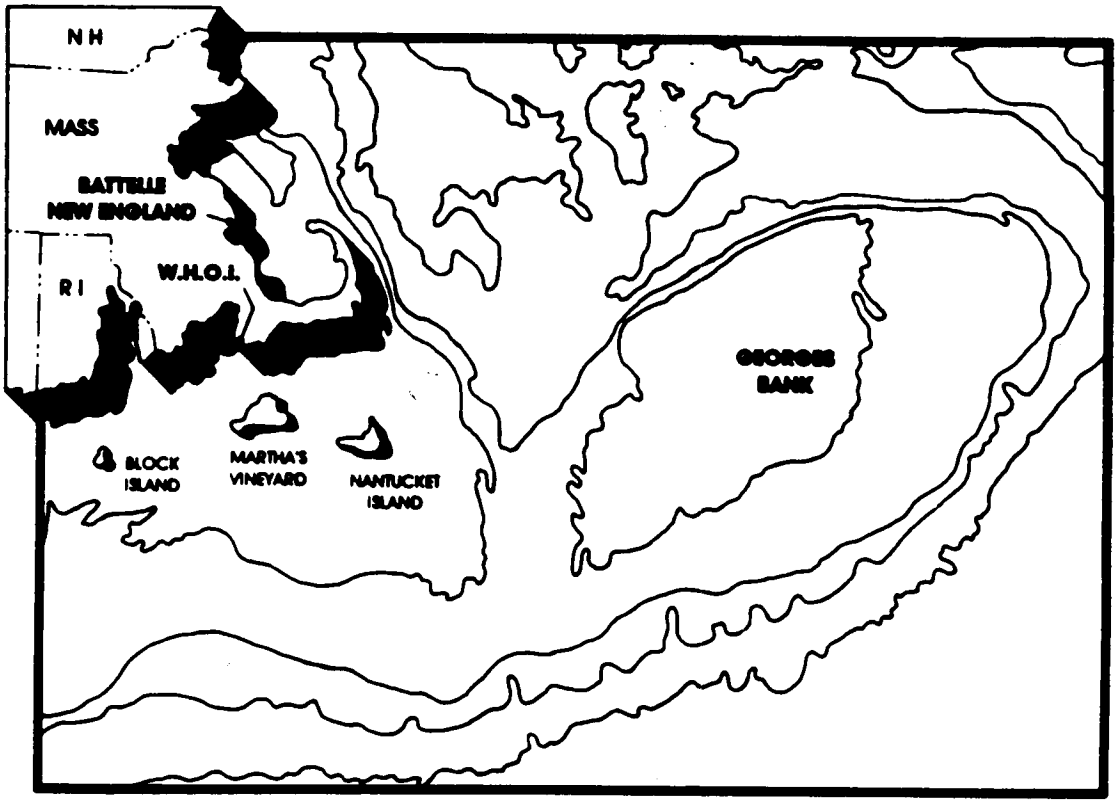
Georges Bank Benthic Infauna Monitoring Program

VOLUME 2 FINAL REPORT



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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

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April 15, 1985

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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

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CHAPTER 1. INTRODUCTION

by

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OBJECTIVES

This report constitutes the third and final annual report for the Georges Bank Benthic Infauna Monitoring Program performed by Battelle New England Marine Research Laboratory and Woods Hole Oceanographic Institution (W.H.O.I.) for the U.S. Department of the Interior, Minerals Management Service (MMS). The contents of this report include a presentation and synthesis of data generated over the entire course of the Program, rather than data developed only in Year 3.

The Georges Bank Benthic Infauna Monitoring Program was a multidisciplinary field monitoring program which was initiated in July 1981 by the U.S. Department of the Interior, Bureau of Land Management (now MMS) in response to concerns about the potential effects of oil and gas exploratory activities in the Lease Sale 42 area on the highly productive Georges Bank environment. Specific questions addressed by this 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 and W.H.O.I. was to link the fate of discharges (primarily drilling fluids and cuttings) from oil and gas exploratory operations in the Lease Sale 42 area to effects on

benthic species and communities. 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, 1984) and by Science Applications, Inc., 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, 1984). A third 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 reported herein, which constituted the fourth component of the Program.

DRILLING DISCHARGES TO GEORGES BANK

Exploratory drilling started in Block 410 near Regional Station 16 in July 1981, shortly after the first sampling cruise and continued intermittently until March 31, 1982. Exploratory drilling started in Block 312, the location of the site-specific array, on December 8, 1981, shortly after the second sampling cruise and continued until June 1982, shortly before the fifth cruise.

The total amounts of drilling fluid solids used to drill the wells in Blocks 410 and 312 were 1,193.6 and 1,524.0 metric tons (mt), respectively (E.P. Danenberger, MMS, personal communication). The muds contained 510 and 1,083 mt, respectively, of barium sulfate (barite). In addition, approximately 16,200 liters of diesel fuel were used in the drilling fluids in Block 312 to aid lubrication and to free stuck pipe. As much as 50 percent of the drilling mud for each well could have been either left in the hole or lost to permeable formations.

It is estimated that approximately 600 mt of drilling fluid solids containing 250 mt of barite were discharged from the rig in Block 410 and approximately 750 mt of drilling fluid solids containing 500 mt of barite were discharged from the rig in Block 312. Payne et al (1982, 1983) estimated that approximately 525 liters of diesel fuel were discharged with the drilling fluids from the rig in Block 312. Several samples of drilling fluid collected at different times during drilling in Block 312 contained 23-1,130 mg/liter (ppm) total hydrocarbons (Payne et al, 1982). Approximately 1,200 mt of drill cuttings were discharged during drilling of each of these two exploratory wells.

A total of eight exploratory wells were drilled in the Lease Offering 42 area during 1981-1982. Neff (1984) estimated that a total of approximately 9,200 mt of drill cuttings and approximately 5,000 mt of drilling fluid solids containing 3,000 mt of barite and 1,500 mt of bentonite clay were discharged to Georges Bank during 1981-1982. By comparison, the rate of deposition of fine-grained sediments in the Mud Patch (in the vicinity of Regional Stations 13 and 13A), which is considered a major site of deposition of fine-grained sediments swept off Georges Bank (Twichell et al, 1981; Bothner et al, 1981), is about 84 million mt per year (Neff, 1984).

BASIC STUDY DESIGN

The basic design of the Monitoring Program was proposed by the Biological Task Force (BTF), a multiagency panel chartered to recommend to the U.S. Department of the Interior, Supervisor of Oil and Gas Operations in the North Atlantic, the design of environmental studies and surveys as well as periodic sampling of environmental conditions to provide warning of adverse effects of OCS oil exploration. The program recommended by the BTF was implemented by the Department of the Interior in July 1981, with some modifications in sampling stations and methodology.

An original group of 46 sampling stations was established on and adjacent to Georges Bank. These included a group of regional stations (Figure 1) established to assess potential impacts of drilling activities over a broad expanse of the Bank. Three transects of three stations each were set up perpendicular to local isobaths, approximately in a north-south direction. The transects were located west of, east of, and directly through the Lease Sale 42 blocks, with the three stations on each transect located at approximately 60, 80, and 100 m 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, and was considered a reference transect. The western Transect III was downcurrent of the drilling activity where drilling discharges might accumulate. Additional regional stations were located at sites of possible deposition of drilling muds and cuttings discharged from the rigs. These included stations at the heads of Lydonia and Oceanographer Canyons, at the shelf/slope break, in the Gulf of Maine, in the shallow part of the Bank, and in the Mud Patch, an area of fine-grained sediments south of Cape Cod.

Two groups of stations were located in close proximity to two exploratory drilling rigs in order to assess near-field impacts of drilling discharges on the benthos.

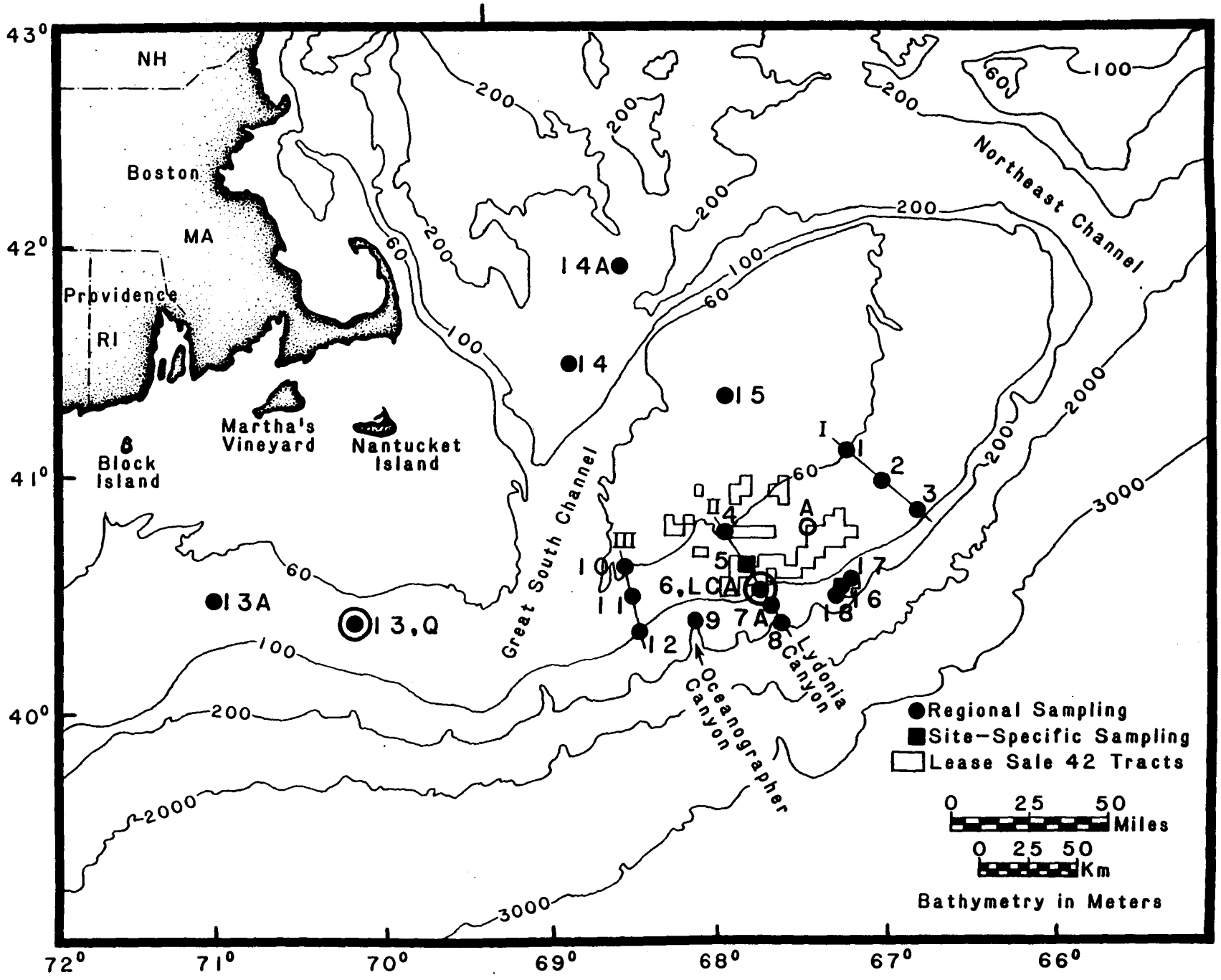

Figure 1. Long-term regional stations and U.S.G.S. Stations A, Q, and LCA.

Three stations were located in the vicinity of the drilling rig 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 2,000 m upstream and downstream, respectively, of the rig site. A larger site-specific array of 29 stations was located in a radial pattern around Regional Station 5 at the rig in Block 312 (Figure 2). Stations were located within 200 m and at distances of 0.5, 1, 2, 4, and 6 km from the rig. 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 samples collected from those stations were archived.

All stations were sampled four times per year on a seasonal basis. At each station six replicate biology samples and three replicate chemistry samples of undisturbed bottom sediments 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 for analysis of infauna. Bottom 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. Measurements of salinity, temperature, and dissolved oxygen were taken at all regional stations. Dredge and trawl samples were collected at certain regional and site-specific stations to obtain fish and mollusc samples for chemical analysis and to obtain representative specimens of epifauna and demersal fish for a voucher collection to be used in identifying species observed in bottom photographs.

In June 1982, after the first four monitoring cruises had been conducted and initial results were available, a meeting of the Scientific Review Board was convened in Woods Hole to review the program to date. In addition to the Principal Investigators involved in all components of the program, members of the Review Board included Drs. Donald J. Boesch (LUMCON), Marvin Grosslein (NMFS) and John Teal (W.H.O.I.). At that time, some changes in sampling stations and sampling methodology were instituted. In addition, three new components were added, including 1) a detailed analysis of the size-class structure of populations of selected species at certain stations (the Life History task), 2) a study to determine the linkage of benthic infaunal production to demersal fish populations (the Benthic Production and Fish Feeding task), and 3) an analysis of samples collected at USGS stations on Georges Bank prior to the commencement of drilling (the Benthic Infauna at Long-Term Mooring Sites task). Details of the methods and results of each of these components are presented in the chapters which follow.

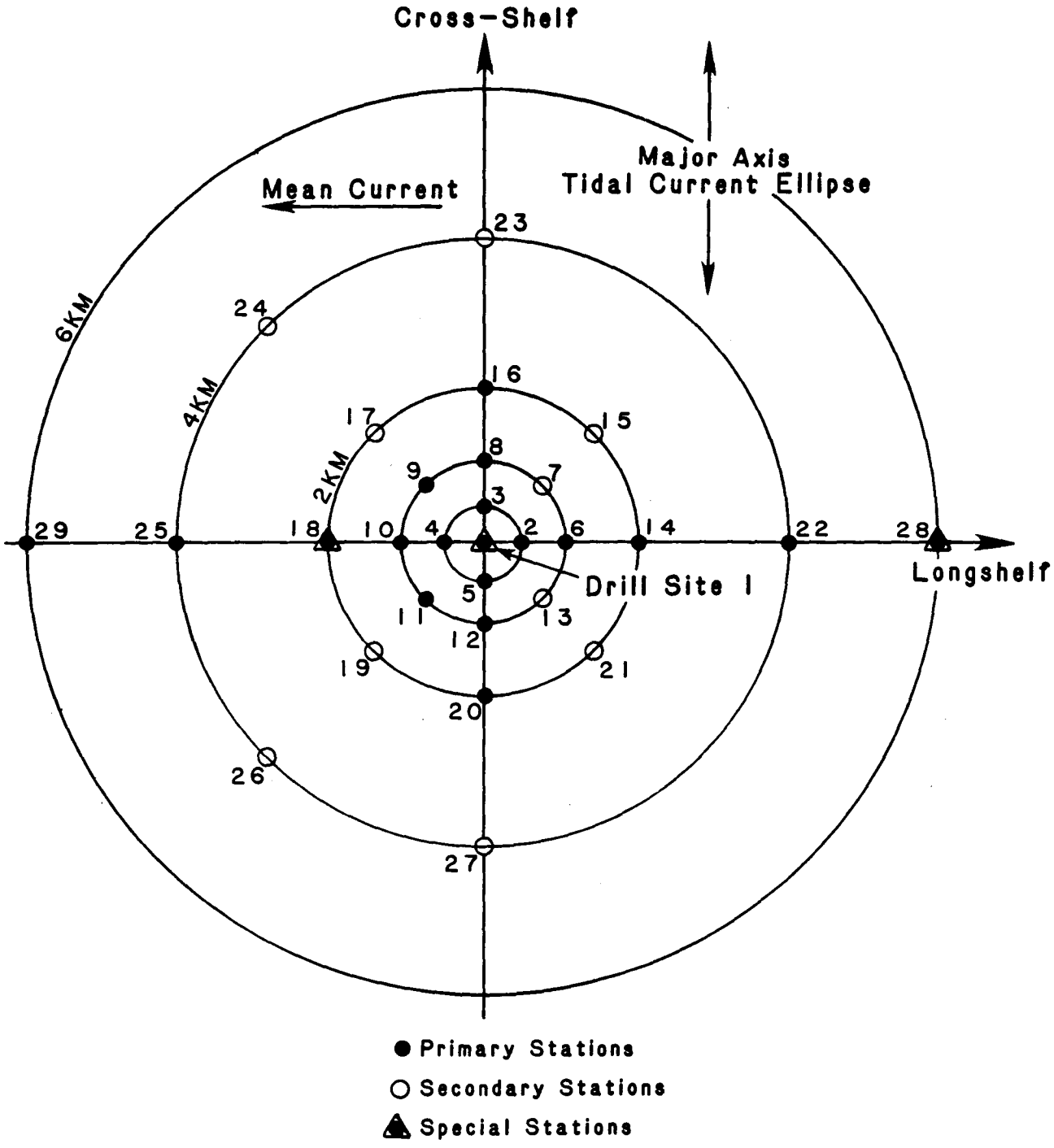

Figure 2. **Site-specific stations central around Regional Station 5.**

ACKNOWLEDGMENTS

A large number of people have contributed their talents to the Georges Bank Benthic Infauna Monitoring Program over the last several years. Specific individuals involved in each of the tasks have either authored chapters in this report or are acknowledged in those chapters. We would like to express our appreciation to everyone who has worked with us on the project and to acknowledge the importance of the contribution that each of these individuals and organizations has made to the success of this program. Special thanks are due to Eiji Imamura and Jeffrey L. Hyland, both formerly with the Minerals Management Service when the study was initiated; Rosalind E. Cohen, currently the MMS C.O.R. for this project, and Jeffrey P. Petrino, the MMS Contracting Officer. Their encouragement, assistance, and attention to detail has been greatly appreciated.

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CHAPTER 2. FIELD PROGRAM

by

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INTRODUCTION

The basic design of the Monitoring Program was presented in Chapter 1, including two figures indicating the general station positions. In this chapter, we present in greater detail the methods used to collect the various types of samples.

The first two cruises of the program, conducted in July and November 1981, were staged for MMS by the Lamont-Doherty Geological Observatory of Columbia University, with Mr. Michael Rawson as Chief Scientist and additional scientists from USGS and W.H.O.I. Beginning with the third cruise in February 1982, Battelle and W.H.O.I. assumed responsibility for staging the cruises. Representatives from the laboratory of Dr. Michael Bothner, USGS (Woods Hole), participated in all twelve cruises. Representatives from the laboratory of Dr. James R. Payne, Science Applications, Inc. (SAI) participated in the last ten cruises.

METHODS

General Methods

Twelve sampling cruises were conducted on a seasonal basis. Cruises M3 through M12 were staged out of Woods Hole with Ms. Rosemarie Petrecca of W.H.O.I. serving as general cruise coordinator, Mr. George Hampson of W.H.O.I. as Chief Scientist and Mr. Paul Perra or Mr. Paul Banas of Battelle as Second Scientist. Each cruise was planned for an average of 10 days in length, although extra shiptime was normally requested for cruises conducted during the months of November and February in the event that bad weather conditions caused a loss of working time while at sea.

Two watches were maintained and rotated on a six-hours on, six-hours off schedule. Sampling efforts were continued 24 hours a day while on station.

Navigation

A NORTHSTAR 6000 LORAN-C receiver integrated with a Texas Instrument Silent 700 series microcomputer was used for station positioning throughout the program. The microcomputer was used to record time, date, latitude, longitude, and LORAN time delays. An Epsco plotter was incorporated into this navigation system on the third cruise and used for all subsequent cruises. The plotter was used to provide a visual plot of each replicate sample taken in reference to the actual station position. Stations were located using time delays established on Cruise M1, or on the first cruise on which a station was sampled. The 13K and 43K lines of the Northeast 9960 LORAN-C net provided the most reliable signal for accurate station positioning. A range of $\pm$ 0.3 microsec, which is a distance of approximately 140 m, was established as the acceptable criterion for being "on-station". Any attempt to reoccupy a Monitoring Program station should be made using the LORAN time delays (Table 1).

Sample Collection

The several types of samples collected at each regional and site-specific station are summarized in Table 2.

Six replicate 0.04-m^2 Van Veen grabs were taken for infaunal analysis and three large (0.1-m^2) grab samples for trace metal and hydrocarbon analyses were taken at all regional and primary site-specific stations. On Cruises M1 through M4, an additional six replicate 0.1-m^2 Van Veen grab samples were collected and archived at the regional stations.

Core subsamples for CHN and sediment grain-size analyses were taken from each 0.04-m^2 grab sample immediately after collection. A plastic syringe with an inside diameter of 2.54 cm was used. No cores were removed from M1 samples; four cores were removed from each M2 sample, and three cores (one for CHN, two for sediment grain size) were removed from each sample on Cruises M3 through M12. Cores were frozen in labelled Whirlpak® bags immediately after collection.

After the subsamples were removed, each 0.04-m^2 sample was placed in a 9.5-l bucket with pour spout. Filtered seawater was added to the bucket, swirled gently, then decanted onto a 30.5-cm diameter screen with 0.3-mm mesh. This procedure was repeated as long as a low-density organism fraction (animals with a specific gravity close to that of seawater) was present in the water being poured off. The portion remaining on the screen was then transferred to a 0.45-l jar, preserved with 10 percent buffered

TABLE 1. REFERENCE COORDINATES AND DEPTHS OF GEORGES BANK MONITORING PROGRAM STATIONS.

Station	Approx. Depth (m)	Time Delay	Latitude	Longitude
Regional Stations				
1	55	13172.3 43615.2	41°13.0'N	67°15.3'W
2	79	13156.5 43532.0	40°59.0'N	66°55.8'W
3	100	13144.2 43496.7	40°53.7'N	66°46.5'W
4	67	13464.5 43529.2	40°50.7'N	68°00.2'W
6	102	13465.9 43425.5	40°34.3'N	67°45.3'W
7A	167	13470.3 43411.5	40°32.15'N	67°44.2'W
8	152	13459.8 43379.1	40°27.1'N	67°37.4'W
9	144	13604.1 43394.2	40°26.7'N	68°09.8'W
10	66	13661.8 43502.7	40°42.0'N	68°35.3'W
11	86	13698.0 43433.5	40°30.8'N	68°33.7'W
12	108	13712.9 43378.0	40°22.2'N	68°30.2'W
13	70	14201.9 43496.1	40°29.5'N	70°12.6'W
13A	80	14464.0 43544.0	40°30.0'N	71°00.5'W
14A	168	13299.3 43931.3	41°57.5'N	68°31.0'W
15	38	13302.4 43735.3	41°27.5'N	68°00.7'W
16	142	13328.3 43406.8	40°34.2'N	67°12.3'W
17	141	13320.5 43409.5	40°35.0'N	67°11.7'W
18	152	13335.8 43402.6	40°33.5'N	67°13.7'W
Primary Site-Specific Stations				
5-1	84	13447.8 43454.9	40°39.5'N	67°46.2'W
5-2	82	13446.0 43455.2	40°39.6'N	67°45.8'W
5-3	82	13446.4 43456.9	40°39.8'N	67°46.1'W
5-4	82	13449.3 43455.3	40°39.5'N	67°46.5'W
5-5	82	13448.8 43453.6	40°39.3'N	67°46.2'W
5-6	82	13444.7 43454.6	40°39.5'N	67°45.4'W
5-8	80	13445.3 43458.3	40°40.1'N	67°46.1'W

TABLE 1. (Cont'd)

Station	Approx. Depth (m)	Time Delay	Latitude	Longitude
5-9	84	13448.6 43457.7	40°39.9'N	67°46.7'W
5-10	86	13451.4 43455.4	40°39.4'N	67°46.9'W
5-11	86	13451.3 43453.4	40°39.2'N	67°46.6'W
5-12	86	13449.7 43452.2	40°39.0'N	67°46.1'W
5-14	86	13441.6 43454.2	40°39.5'N	67°44.7'W
5-16	78	13443.3 43461.1	40°40.6'N	67°46.1'W
5-18	84	13453.8 43456.2	40°39.6'N	67°47.6'W
5-20	84	13452.0 43448.4	40°38.5'N	67°46.1'W
5-22	84	13435.9 43453.5	40°39.5'N	67°43.3'W
5-25	89	13459.7 43457.1	40°39.5'N	67°49.0'W
5-28	84	13429.6 43452.4	40°39.5'N	67°41.9'W
5-29	86	13466.5 43459.1	40°39.5'N	67°50.4'W
Secondary Site-Specific Stations				
5-7	75	13443.9 43457.1	40°39.9'N	67°45.7'W
5-13	71	13447.1 43452.7	40°39.2'N	67°45.6'W
5-15	72	13440.3 43458.8	40°40.3'N	67°45.2'W
5-17	74	13448.3 43460.0	40°40.3'N	67°47.1'W
5-19	76	13455.2 43451.4	40°38.8'N	67°47.2'W
5-21	70	13446.3 43450.3	40°38.8'N	67°45.1'W
5-23	77	13438.8 43467.5	40°41.7'N	67°46.1'W
5-24	78	13449.9 43465.3	40°41.1'N	67°48.1'W
5-26	76	13462.5 43447.7	40°38.0'N	67°48.1'W
5-27	75	13456.4 43442.8	40°37.4'N	67°46.1'W

TABLE 2. SUMMARY OF SAMPLES COLLECTED AT GEORGES BANK MONITORING STATIONS ON CRUISES M1 THROUGH M12 (JULY 1981 - JUNE 1984).

	Regional Stations	Site-Specific Stations	
		Primary	Secondary
0.10m^2 Van Veen Grab Samples*	6 Replicates	Sta. 5-1 Only	
0.04m^2 Van Veen Grab Samples	6 Replicates	6 Replicates	6 Replicates+
CHN Subsamples**	6 Replicates	6 Replicates	6 Replicates+
Grain-Size Subsamples**	6 Replicates	6 Replicates	6 Replicates+
Epifaunal Samples	3 Stations Only	3 Stations Only	
Hydrographic Measurements	D.O. - 3 Salinity - 2 XBT - 1	Sta. 5-1 Only: D.O. - 3 Salinity - 2 XBT - 1	
Bottom Still Photographs	20 Frames	20 Frames	
Geology and Geochemistry Grab Samples	3 Replicates	3 Replicates	3 Replicates++

* Collection discontinued after May 1982 (M4).
** Not collected in July 1981 (M1).
\+ Collection discontinued after July 1983 (M9).
++ Not collected in November 1983 (M10) or February 1984 (M11).

formalin in seawater and labelled both inside and outside the container. The heavy sediment residue was placed in a 3.8-l plastic jar and similarly preserved and labelled. The large (0.1-m^2) biology grab samples were transferred unsieved to a muslin bag, stored individually in labelled 3.5-gal buckets, with 10 percent buffered formalin added as a fixative. Large grab samples collected on Cruise M1 were stored in nine 30-gal drums rather than in individual containers.

Epifaunal samples were collected during Cruises M1 through M4 at Regional Stations 2, 7 and 13 and at Site-Specific Stations 5-1, 5-18, and 5-28. Various types of sampling gear were used, including an epibenthic sled, a Blake trawl, a Day dredge and an otter trawl. These samples were collected primarily to provide specimens for analysis of the metal and hydrocarbon concentrations in selected tissues of particular species, but also to provide biological voucher specimens, especially to assist in the analyses of the bottom photographs.

None of these collecting devices was consistently successful in fishing for the required specimens. The otter trawl was the best gear for obtaining fish, and after Cruise M4, it was used exclusively for that purpose at Stations 1, 2, 13, 13A and between Site-Specific Stations 5-14 and 5-22. Beginning on Cruise M5, a Rocking Chair Dredge was used exclusively to collect Arctica islandica for hydrocarbon and metals analyses from Site-Specific Stations 5-3, 5-15, and 5-18, and Regional Stations 1 and 11.

Specimens for chemical analysis were removed, labelled, and frozen by the chemistry contractors. Only a few specimens, primarily species of fish, were retained as epifaunal voucher specimens from Cruises M5 through M8, and none were retained on Cruises M9 through M12.

Bottom still photographs were taken at each regional and primary site-specific station in order to record surface topography and visible epifauna. A Benthos® Model 372 underwater camera and strobe unit were mounted on a steel frame which was raised and lowered using a hydro-winch. The camera was triggered by a bottom switch coupled with an auto-advance. A minimum of 20 color frames were exposed at each station.

Hydrographic measurements, including dissolved oxygen, salinity and water temperature profiles were made at all regional stations. Bottom water was collected by attaching a Niskin bottle to the winch wire above the grab sampler. After the grab sample was obtained, a messenger was sent down the wire to trigger the Niskin bottle. When the water sample was received on deck, three replicate samples were taken for

determination of dissolved oxygen, and immediately fixed with manganous sulfate and alkaline iodide solutions. A Winkler titration was performed using an automated burette within three hours of sample collection. On Cruises M7-M9, an oxygen electrode coupled with a pH/mV meter was used in addition to the standard Winkler titration to measure dissolved oxygen.

Surface water samples for salinity measurements were collected using a bucket. Bottom water samples for salinity were obtained from the Niskin bottle. For Cruises M1, M2, and M5 through M12, an AUTOSAL® 8400 at W.H.O.I. was used to determine conductivity. For Cruises M3 and M4, either a Hydrolab® Model IIB conductivity probe or American Optical® refractometer was used to take one measurement each for surface and bottom salinity.

Temperature profiles were obtained via expendable bathythermograph (XBT) casts. A deck-mounted launcher was used to deploy the XBT and a strip chart recorder was used to record the temperature profile with depth.

RESULTS

General

Actual cruise dates and the ship used for all Monitoring Program cruises are listed in Table 3. Severe weather conditions during M7 prevented the collection of samples at all stations. However, M7 was the only cruise on which this occurred. In general, all required samples were successfully obtained on all other cruises.

Navigation

The average positions for the six biology replicate grab samples collected on each of the 12 cruises at all regional and three of the site-specific stations are plotted in Appendix A, Figures A-1 through A-20. The plots were made using LORAN time delays with a time delay lattice overlay. Station positions fell within the $\pm$ 0.3 microsec range with only a few exceptions. Average station positions and depths for the 12 cruises are listed in Table 1.

TABLE 3. SCHEDULE OF SAMPLING CRUISES FOR THE GEORGES BANK BENTHIC INFAUNA MONITORING PROGRAM.

Cruise	Date	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

ACKNOWLEDGMENTS

We are indebted to the captains and crews of the several ships used in this program for their assistance in making each of our cruises successful. Special thanks also to Dr. Brad Butman and Mr. William Strahle of USGS for assistance with the camera system. Many individuals from Battelle, W.H.O.I., USGS and S.A.I. participated in these cruises, and the success of the field sampling effort is due directly to their enthusiasm and willingness to work long and hard hours.

CHAPTER 3. BENTHIC INFAUNAL COMMUNITY STRUCTURE: THREE YEARS OF SAMPLING AT THE GEORGES BANK MONITORING PROGRAM STATIONS.

by

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INTRODUCTION

The infaunal analysis of replicate benthic samples was the major task of the Monitoring Program, since the major objective of the study was to link the fate of discharges from oil and gas exploratory operations to effects on benthic communities. Benthic environments are potential sinks for discharged materials, and because of their relative immobility, benthic organisms are susceptible to exposure. It was hypothesized that any impacts due to drilling activities would be reflected in changes in the species composition of the benthic communities and/or densities of individual infaunal species.

Before the present investigation, few quantitative surveys of benthic populations on Georges Bank had been made. It is difficult to make comparisons among those that do exist because sample processing techniques differed, notably in the mesh size through which samples were sieved. In much of the early work, mainly that of Wigley (1956, 1961, 1965, 1968), a 0.1-m^2 Smith-McIntyre grab was used for sampling and coarse screens of 1.0 mm or more were used for sieving samples. In the more recent New England OCS Benchmark Study sponsored by the Minerals Management Service and the Northeast Monitoring Program sponsored by NOAA/NMFS, a 0.1-m^2 grab was used for sampling, and 0.5-mm mesh for screening samples. The Benthic Infauna Monitoring Program incorporated gear and methods originally used by Grassle (unpublished) at three stations on Georges Bank: small grabs which sample a surface area of 0.04-m^2 and sieves with meshes of 0.3-mm and 0.5-mm. These techniques have furnished improved estimates of density and seasonal fluctuations at the population and community level because the infaunal populations are more completely sampled with the finer mesh screen.

METHODS

Laboratory Processing

All grab samples were individually logged into the Battelle laboratory when they were received upon completion of each cruise. Each sample was logged on a "Sample Tracking Sheet" which could then be used to determine the location of any particular sample or portion thereof at any time. These sheets were initialled by each technician who handled the sample. The large 0.1-m^2 grab samples collected on Cruises M1 through M4 (July 1981 - May 1982) were transferred to 70 percent alcohol (denatured ethanol or isopropanol) and originally archived at Battelle. The muslin bag containing the sample was removed from each 3.5-gallon bucket and the bag plus sample rinsed several times in fresh water to remove the formalin. Each bag was then returned to the properly labelled bucket, and the bucket filled with 70 percent alcohol. Each sample was labelled inside the muslin bag with a tag tied around the neck of the bag and on the outside of each bucket. Samples collected in July 1981 (M1) were removed from the large drums in which they were stored and placed in individual buckets in August 1982. Labels had been written on wooden sticks and several had faded to the point where they could not be read, but where the labels were clear, the information was transferred to 100 percent rag paper. These samples have all been transferred to the National Museum of Natural History, Smithsonian Institution, where they have been archived under the direction of Dr. Meredith L. Jones.

Each sample to be analyzed was resieved before sorting. For samples collected between July 1982 (M5) and June 1984 (M12), all regional and site-specific samples were rescreened through a nest of 0.5-mm and 0.3-mm screens (for collections made during the first year of sampling, July 1981 through May 1982, only samples from regional stations were sieved through both screens; those from site-specific stations were resieved only through the 0.3-mm screen). The heavy sediment residue from each sample was elutriated with fresh water to remove low-density organisms which might not have been removed during shipboard handling. The sediment residue was then checked under low magnification to ensure that all organisms had been removed. The two resultant fractions of each sample (0.5 and 0.3 mm) were kept separate during sorting, identification and biomass procedures.

Each sample was stained with a solution of Rose Bengal at least four hours prior to sorting. All fractions of each sample were examined under a dissecting microscope and each organism or fragment was removed. Organisms were sorted to basic taxonomic groups such as polychaete families, Amphipoda, Isopoda, other crustacea,

Mollusca, Echinodermata and "miscellaneous", which included Porifera, Cnidaria, Bryozoa, Sipunculida, Oligochaeta, and Chordata.

A minimum of 10 percent, and an average of 20 percent, of the sample residues sorted were subjected to a quality control check before the vials containing organisms were released for final identifications. In this check, the sample residues were partly or completely reexamined by the sorting laboratory supervisor or by a technician other than the one who originally sorted the sample. At least 10 percent of the samples sorted by any one technician were completely resieved and resorted. When the sorting of each sample was finished, the low density or light fraction residue was stored in 70 percent alcohol in a Zip-loc® bag which was then placed inside the 1-gallon jar containing the heavy sediment residue, also in 70 percent alcohol. All sample residues from Cruises M5 through M12 will be archived at Battelle, until authorization is received from MMS to discard them. Residues from samples analyzed from M1 through M4 were discarded after permission to do so was received from MMS.

Identifications were made to the lowest possible taxon, usually to species. For most major taxonomic groups (i.e., Arthropoda, Mollusca, Echinodermata), a single identifier was responsible for the entire sample. However, the Polychaeta, which represents the single most complex and difficult group of organisms present in the samples, were identified by a series of individuals each experienced with a particular group of families. In only a very few cases, for example with juvenile polychaetes, were we unable to distinguish separate species and forced to use a category which might include two or more species. In some cases, early problems with identifications were worked out during the course of the program. Voucher specimens of molluscs, arthropods, oligochaetes, anthozoans and aplacophorans were submitted for verification to Dr. Robert C. Bullock, University of Rhode Island, Dr. Leslie G. Watling, University of Maine, Dr. Christer Erséus, University of Göteborg, Sweden, Dr. Kenneth Sebens, Harvard University and Ms. Amalie Scheltema, W.H.O.I., respectively. Taxonomic problems were also discussed with Dr. John Dearborn, University of Maine, Dr. David Pawson, Dr. Gordon Hendler and Ms. Maureen Downey, all of the Smithsonian Institution (echinoderms) and Dr. Kristian Fauchald, Smithsonian Institution (polychaetes).

Counts of individuals were recorded separately for the 0.5 and 0.3-mm screens. Notations were also made as to visible reproductive condition and presence of juveniles where appropriate. A detailed life history analysis of several species was made (Chapters 6 and 7).

Wet-weight biomass was determined separately for each species. All organisms from each of the six replicate samples were weighed for samples from Cruises M1 through

M8 (July 1981-May 1983). Wet weights were measured on three replicates collected in July 1983 (M9) and only one replicate for samples collected between November 1983 and June 1984 (M10-M12). In addition, ash-free dry weights were determined for three replicate samples from July 1983 (M9). Details of the biomass procedures and results can be found in Chapter 4 of this report.

Data Reduction and Analysis

Completed data sheets were coded at Battelle and entered into the VAX 11/780 computer at Woods Hole Oceanographic Institution (W.H.O.I.). Verification of hard copy printout and correction of any errors was conducted jointly by Battelle and W.H.O.I. Some errors extant in the data set generated for the first two years of the project were corrected during this process during Year 3. Such errors included the misidentification of a few specimens, and also erroneous numbers mistakenly keypunched and not corrected during data verification last year.

Statistical treatment of the infaunal data set included an agglomerative clustering technique (Williams, 1971) to determine similarity between samples. The first step in this classification was to measure similarity between all pairwise combinations of samples, starting with the most similar pairs, and subsequently combining samples until they all combined into one large group. The similarity measure used was NESS, the Normalized Expected Species Shared (Grassle and Smith, 1976), where the comparison of expected species shared was between random samples of 50 individuals from the initial collection of individuals in each grab. Since two samples of 50 drawn from within each of the samples are required for normalization, samples with less than 100 individuals were excluded from the analysis. The method was also used with m (i.e., sample size) set at 200 individuals. NESS is more sensitive to the less common species than other commonly used methods. The clustering strategy was flexible sorting with β set at the commonly used value of -0.25 (Boesch, 1977; Williams, 1971). Flexible sorting allows more intense clustering than the other commonly used methods, such as the group average or unweighted pair-group method. Boesch (1977) pointed out that intense clustering strategies are often prone to misclassifications and "one often has to choose between non-classifications due to weakly clustering strategies or misclassifications due to intensely clustering strategies". This is not the case with NESS. We also used the Bray-Curtis or percent similarity coefficient (Boesch, 1977) as a similarity measure with group average sorting. This multivariate analysis procedure was performed on raw data, on log transformed data,

and also on a fourth root transformation of the data set. The few individuals where the species identification was uncertain (juveniles, fragments, etc.) were not used in the analysis. The animals attached to hard surfaces such as rocks and shells and parasitic or planktonic species were also excluded from the analyses. These species are indicated by an asterisk on the species list in Appendix B.

The program DECORANA in the Cornell Ecology Program series was used for a detrended correspondence analysis of the data. This method derives new axes to account for a cloud of points in multidimensional space and presents the data in a two-dimensional plot. A reciprocal weighting of species and samples and distances based on chi-square are used in this method. The advantages of this approach were discussed by Gauch (1982).

Shannon-Wiener diversity (H') was calculated:

$$H'_{(s)} = -\sum_{j} p_j \log p_j$$

in which s is the total number of species, and p_j is the observed proportion of individuals belonging to the j^{th} species (j = 1,2,....,s).

Hurlbert's modification (1971) of the rarefaction method (Sanders, 1968) was used to predict the number of species in a random sample without replacement, given a population N:

$$E\left[S_n/N\right] = \sum_{i=1}^{k} 1 - \frac{(N_n - N_i)}{\binom{N}{n}}$$

in which N_i is the finite population of species i; N is $(N_1, N_2,....,N_k)$, a vector representing the entire finite population; and N is the total number of individuals in the finite population,

$$\sum_{i=1}^{k} N_i;$$

and S_m is the random variable denoting the number of species in a sample of size m (Smith and Grassle, 1977). For the species diversity results presented, we have used m=50 or the number of species per 50 individuals, m=100 or the number of species per 100 individuals, m=500, and m=1,000.

Spearman rank correlation (Siegel, 1956) was used to test the association between biological variables such as density of individual species or community similarity indices and physical variables such as sediment grain size.

RESULTS

Taxonomy

The species found in all infaunal samples analyzed during the three-years of the program are listed in Appendix B, and all species from epifaunal samples are given in Appendix C. The annotated species list (Appendix D) contains comments or descriptions of species designated as new-to-science or those which are rare in the samples or otherwise interesting.

Excluding categories labelled "sp. juvenile" or "spp.", which might represent two or more taxa which cannot be separated because of lack of development of diagnostic characters, a total of 959 taxa were identified during the three years of the program. Some identifications have been refined, resulting in the deletion of some species from the lists given in the Final Reports for Years 1 and 2 (Appendices A, Battelle and W.H.O.I., 1983 and 1984), but the total at the end of Year 3 represents a net addition to the list of nearly 100 taxa. Of the species listed, 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 epizooic. Several species are found only on hard substrates such as rocks, including Filograna implexa, nudibranchs, a few amphipod species and species of Crepidula and Anomia. Three pelagic species of Limacina, an opisthobranch gastropod, and several pelagic arthropods are listed. Also, the seven species of fish listed are clearly not usual members of the soft sediment benthos. A total of 218 such species were excluded from the statistical analysis of the infaunal samples. The only two abundant species excluded were Filograna implexa and Dacrydium vitreum, which ranked 41st and 45th among species in regional samples (totals in all samples were 3197 and 2510 individuals,

respectively). The next five most abundant species were amphipods associated with rocky surfaces (particularly hydroids). These occur rarely and for each of those species the total number collected in all regional samples was on the order of 200 - 300 individuals.

Polychaetes were represented by 372 species, and accounted for 38.8 percent of all taxa identified and 50.2 percent of all infaunal species. During Year 1, 39.1 percent of recorded taxa were polychaetes, and during Year 2, 40.8 percent. Of the total 49 families recorded, the spionids, syllids, maldanids and paraonids continued to be the best represented with 34, 32, 28, and 25 species respectively. Together these four families accounted for 32 percent of all polychaete species recorded. Other families represented by a high number of species included terebellids (21 species), ampharetids (18 species), phyllodocids (17 species), sabellids (16 species), and cirratulids (16 species). Fourteen families were represented by a single species. A total of 124 polychaete species which are new to science have been identified, some of which also represent new genera. One manuscript, on a new species of Polydora (Polychaeta: Spionidae) has recently been published in Sarsia (Maciolek, 1984).

Following review and revision by Dr. Christer Erséus of the University of Göteborg in Sweden, the oligochaetes from our Georges Bank stations totaled 32 species. Of those, 18 represent previously undescribed species and one represents a new family. Four manuscripts have published based on the oligochaete collections, including one by Erséus (1984), two by Davis (1985, and in press) and one by Erséus and Davis (1984).

Arthropods were represented by 189 species accounting for 19.7 percent of all taxa identified and 25.5 percent of all infaunal species. Amphipods, the dominant group, accounted for 98 species, over half of all arthropod species recorded. The identification of the amphipod species Erichthonius rubricornis was recently reevaluated after publication of a review by Myers and McGrath (1984). Based on that version, the designation of this common amphipod has been changed to E. fasciatus. Citations of E. rubricornis in Year 1 and Year 2 reports (Battelle and W.H.O.I., 1983, 1984) should be referred to E. fasciatus. At least one new species of amphipod from these collections will be described by Dr. Les Watling, University of Maine (Watling, personal communication). Molluscs were represented by 144 species and therefore accounted for 15.0 percent of all taxa identified and 19.4 percent of all infaunal species. A total of 24 echinoderm species were identified, representing 2.5 percent of all recorded taxa.

Representatives of lesser known phyla included a new species of the priapulid genus Tubiluchus. This represents only the 14th species known in this phylum, and is a significant range extension as well, since the genus has not been recorded previously from

boreal waters. Similarly, several range extensions of species of anthozoans have been recorded based on the collections verified by Dr. Sebens.

Density

The average number of individuals per $0.04 m^2$ (i.e., one grab sample), plus or minus one standard deviation, is graphed for all regional stations and Site-Specific Stations 5-1, 5-18 and 5-28 for each of the twelve sampling periods in Figures 3 through 7.

At many stations, particularly the deeper ones, average densities remained rather constant over all twelve sampling periods (e.g., Stations 3, 8, 9, Figures 3 and 5). The greatest fluctuations occurred at Stations 10 (Figure 5) and 13 (Figure 6). At Station 10, and to a lesser extent at Station 4 (Figure 3), samples were occasionally dominated by large numbers of the sand dollar, Echinarachnius parma, or the archiannelid Polygordius sp. A. These patchily distributed species accounted for the large standard deviations associated with Station 10, especially for M2 (November 1981) and M6 through M10 (November 1982 - November 1983), and Station 4, M6 (November 1982).

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. Several possible explanations for the abrupt decline in May 1982 (M4) were considered. It appears that differences in station position over subsequent cruises resulted in differences in sediment grain size composition (see Chapter 10). These differences, however subtle, could account for the significantly lower numbers in May 1982 of many of the species typically associated with Station 13. Although there does not appear to be any size-selective mortality, the decline in May 1982 might have been a short-term effect of a storm.

Patterns of seasonal fluctuations were not obvious, although annual differences were detected at some stations. At Station 5-1, for example, average densities during Years 2 and 3 were higher than during Year 1 (Figure 4). Station 7A was sampled only during Years 2 and 3, and the average densities during Year 3 were clearly higher than during Year 2 (Figure 5). Biomass values were also higher in Years 2 and 3; this is discussed in greater detail in Chapter 4.

Also illustrated in Figures 3 through 7 are the relative contributions to the total density of the 0.5-mm and 0.3-mm screens. Results indicate that the use of the 0.3-mm mesh resulted in greater efficiency in sampling the populations of several benthic species. In particular, small syllid polychaetes such as Exogone hebes, E. verugera, and

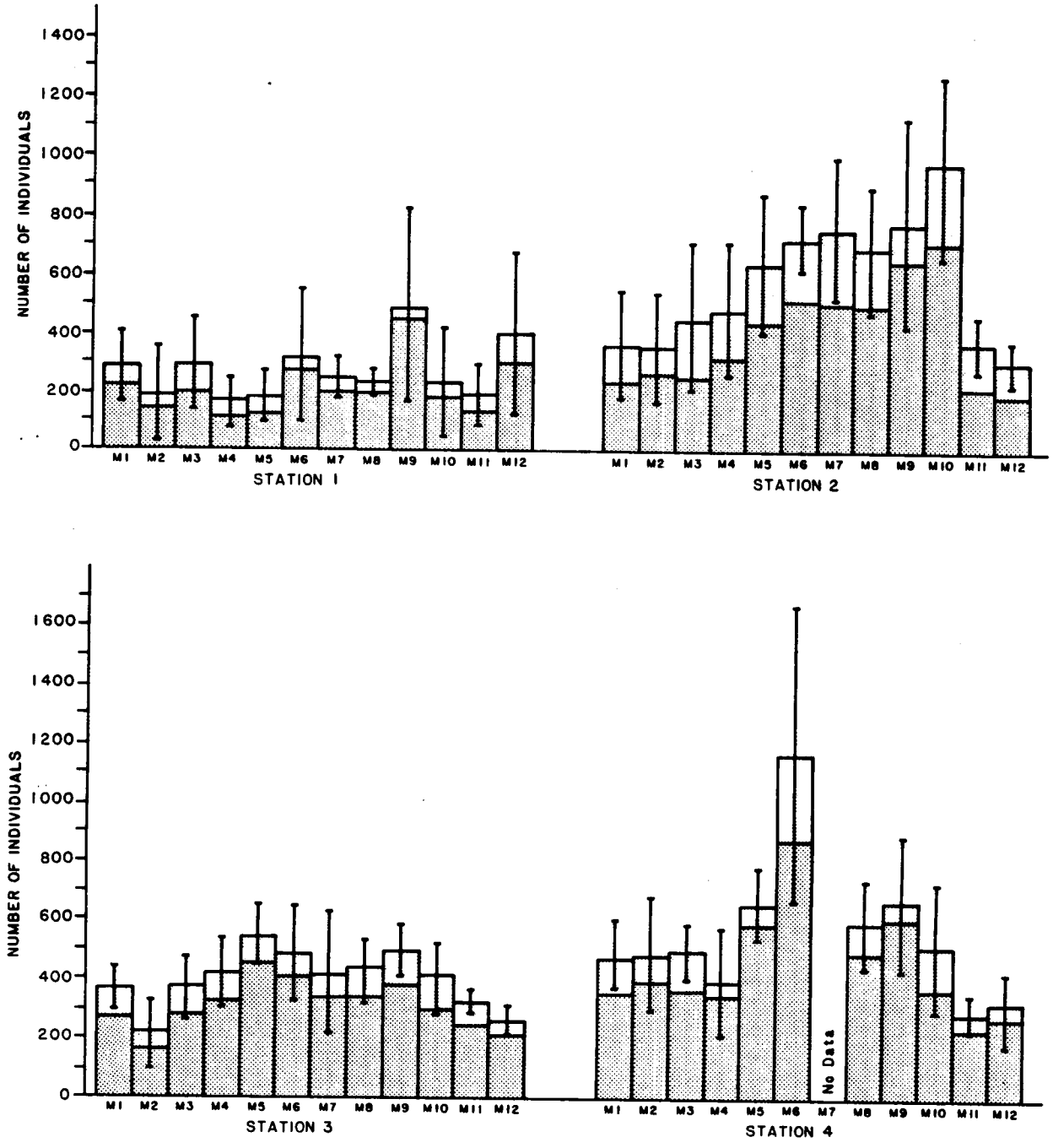

Figure 3. Average number of individuals per 0.04 m^2 $\pm$ one standard deviation at Regional Stations 1 through 4 for sampling seasons M1-M12 (see Table 3 for corresponding dates). Darker portion of histogram indicates individuals retained on the 0.5-mm screen; lighter portion indicates those retained on the 0.3-mm screen.

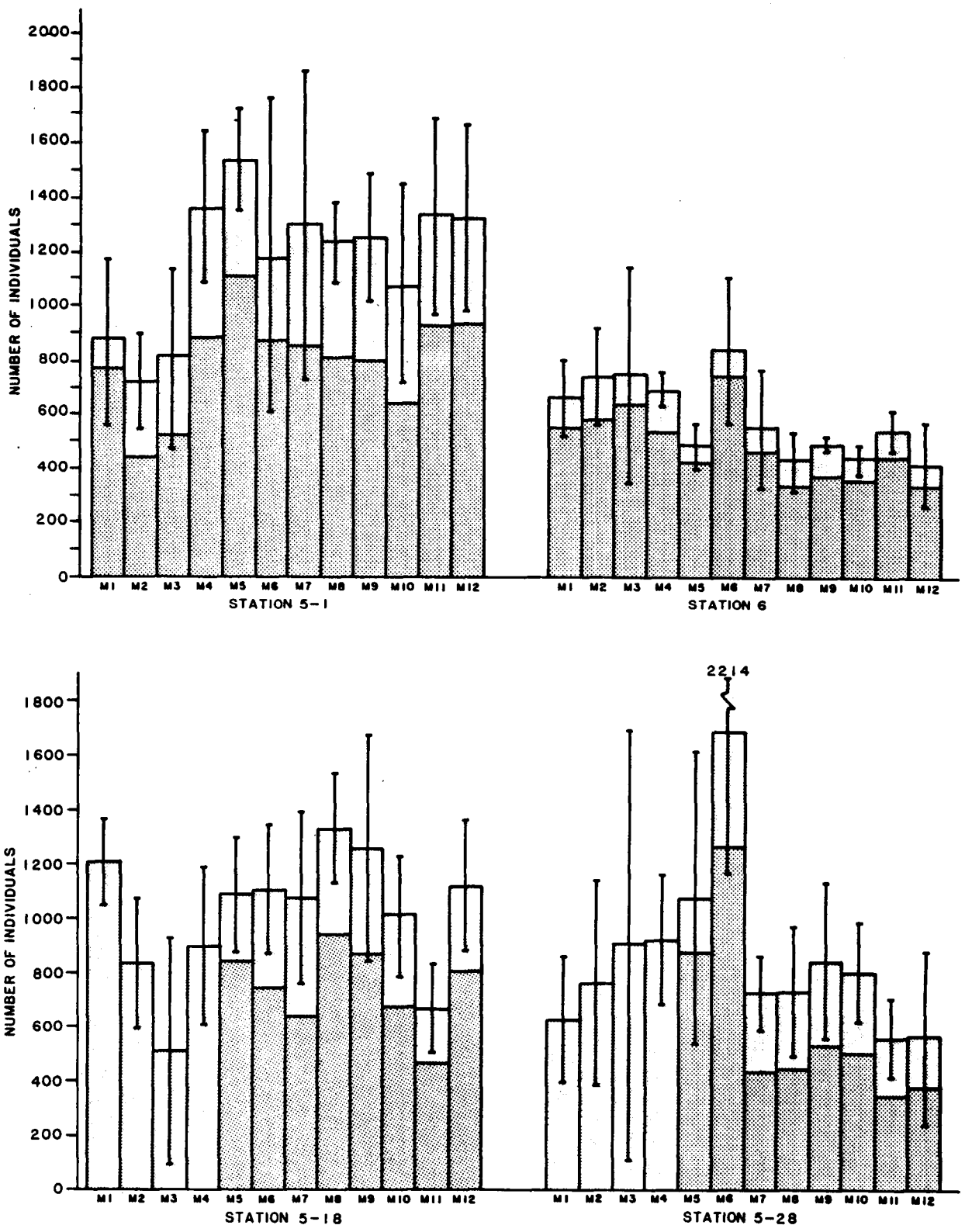

Figure 4. Average number of individuals per 0.04 m^2 ± one standard deviation at Site-Specific Stations 5-1, 5-18 and 5-28 and Regional Station 6 for sampling seasons M1-M12 (see Table 3 for corresponding dates). Darker portion of histogram indicates individuals retained on the 0.5 mm screen; lighter portion indicates those retained on the 0.3-mm screen. From July 1981 to May 1982 (M1-M4), samples from Stations 5-18 and 5-28 were sieved only on the 0.3-mm screen.

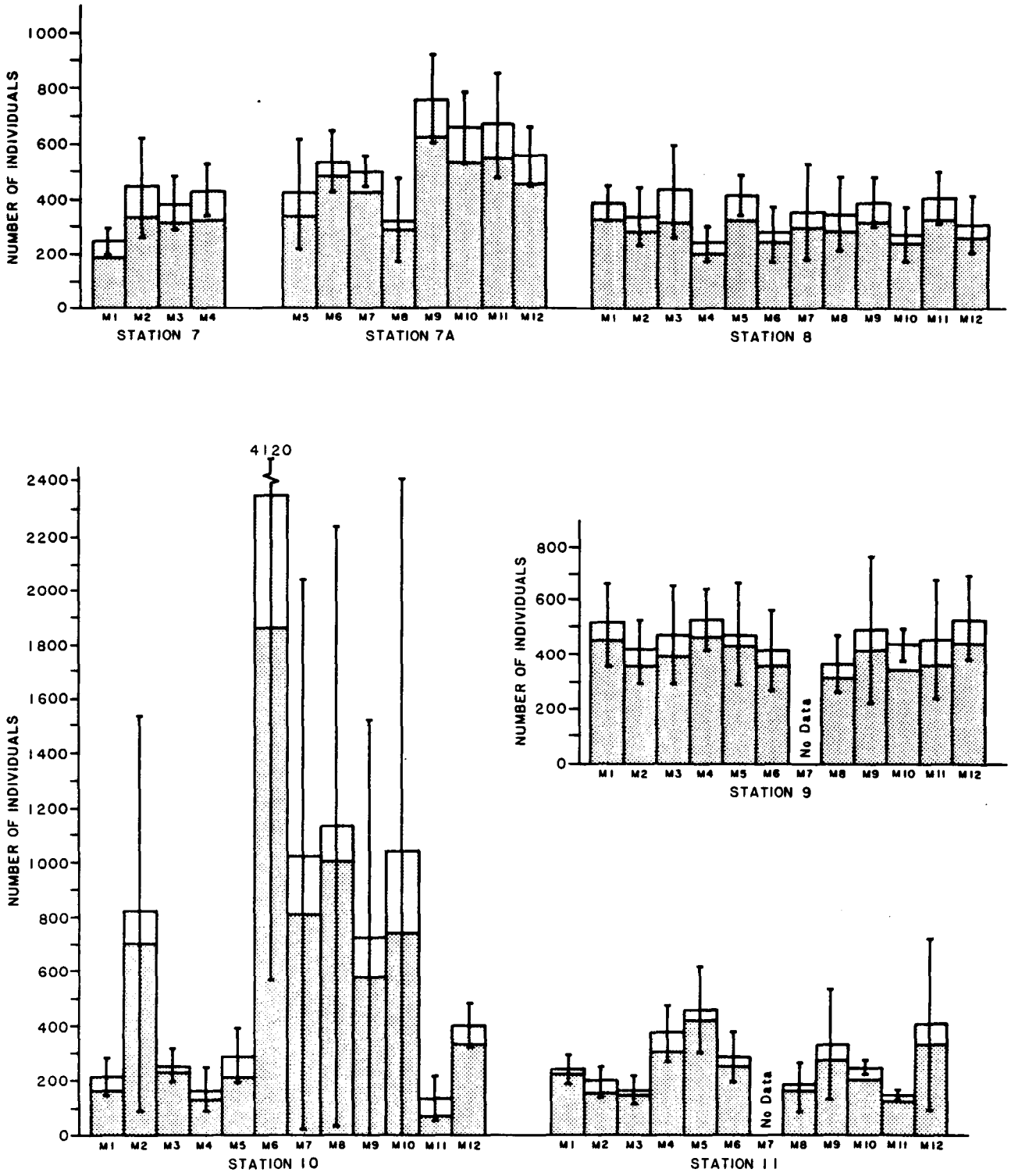

Figure 5. Average number of individuals per 0.04 m^2 ± one standard deviation at Regional Stations 7 through 11 for sampling seasons M1-M12 (see Table 3 for corresponding dates). Darker portion of histogram indicates individuals retained on the 0.5-mm screen; lighter portion indicates those retained on the 0.3-mm screen.

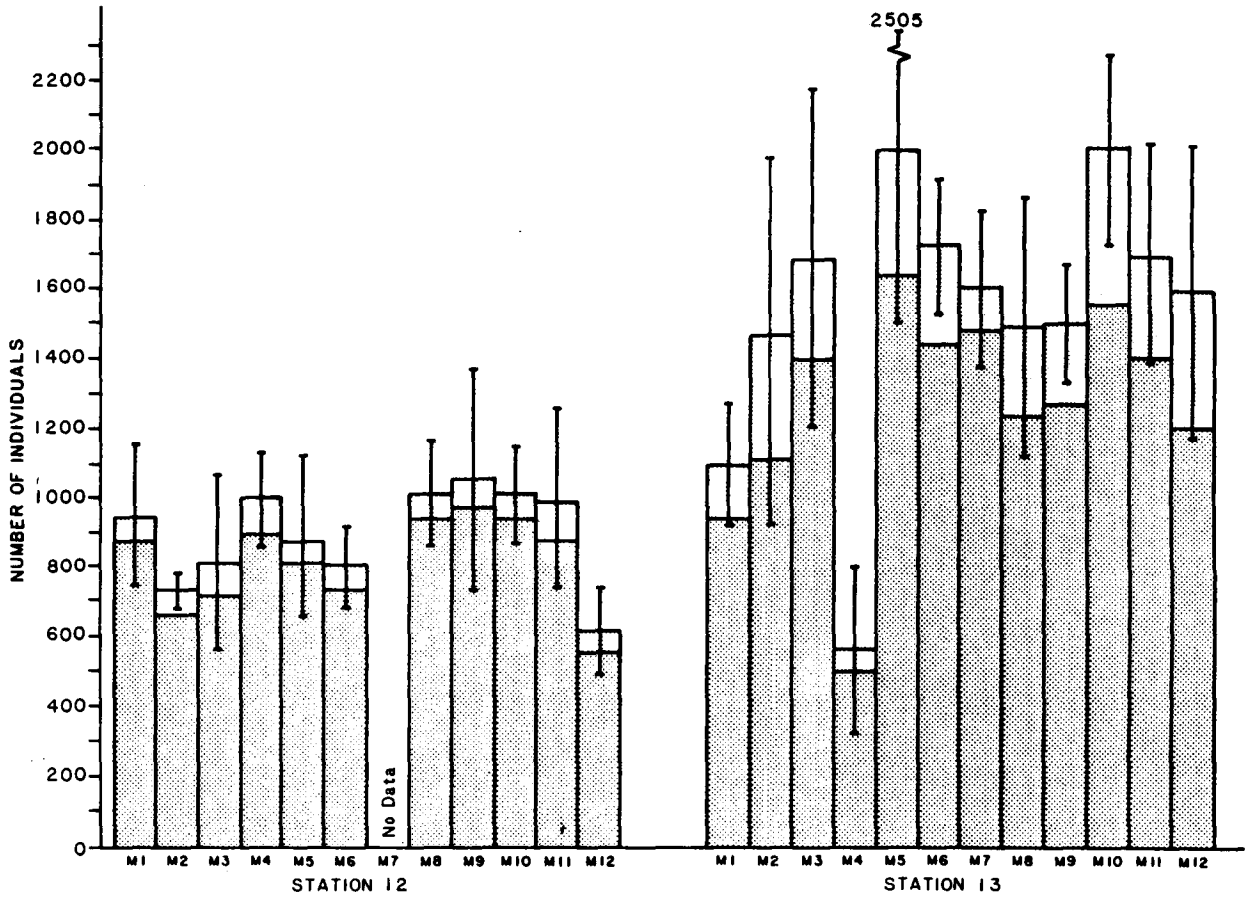

Figure 6. Average number of individuals per 0.04 m^2 $\pm$ one standard deviation at Regional Stations 12 and 13 for sampling seasons M1-M12 (see Table 3 for corresponding dates). Darker portion of histogram indicates individuals retained on the 0.5-mm screen; lighter portion indicates those retained on the 0.3-mm screen.

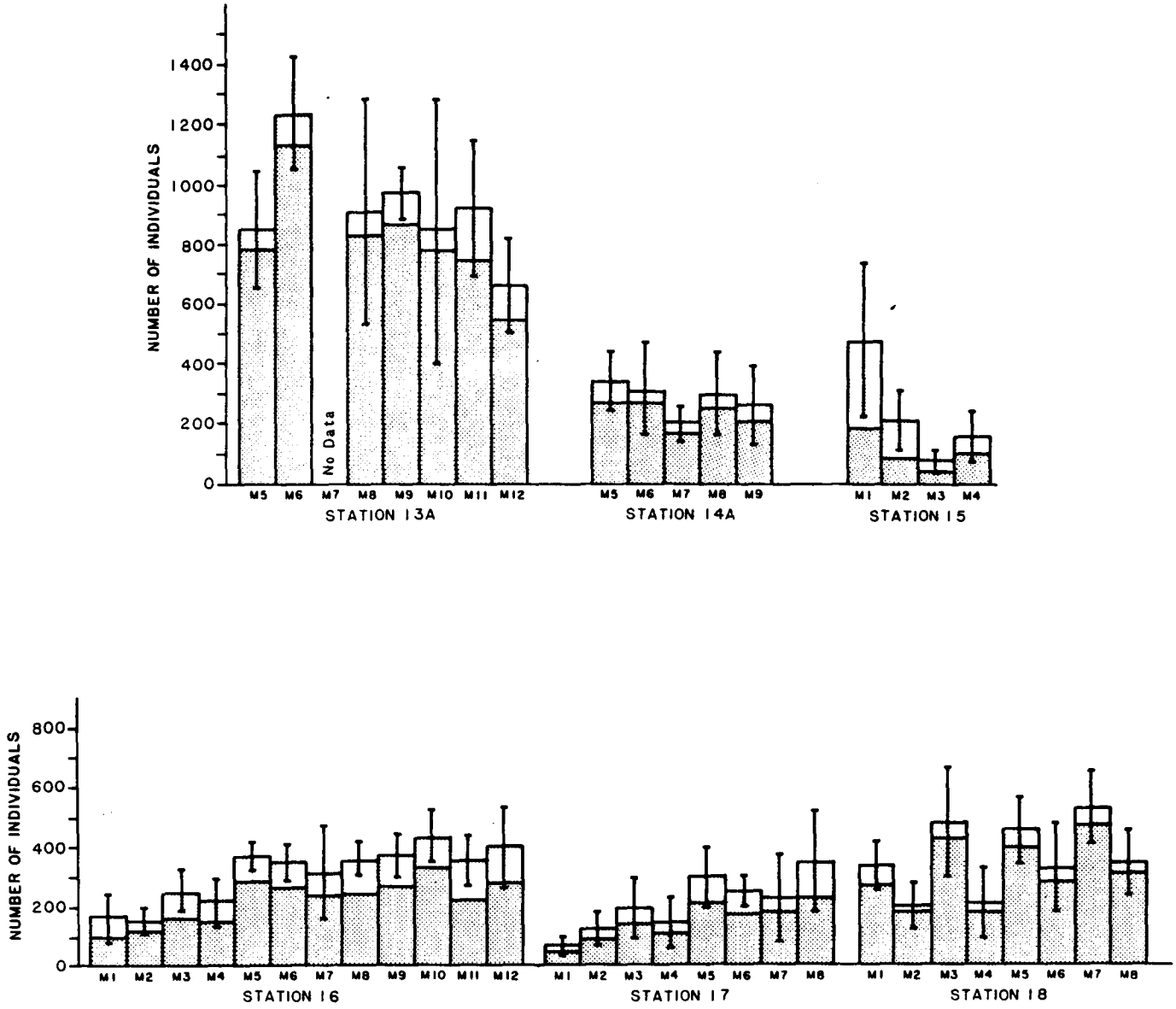

Figure 7. Average number of individuals per 0.04 m^2 $\pm$ one standard deviation at Regional Stations 13A through 18 for sampling seasons M1-M12 (see Table 3 for corresponding dates). Darker portion of histogram indicates individuals retained on the 0.5-mm screen; lighter portion indicates those retained on the 0.3-mm screen.

Sphaerosyllis cf. brevifrons occurred in almost equal numbers on each screen, implying that these species would be drastically undersampled if only the 0.5-mm mesh had been used. Reproductive individuals of some species were caught on the finer screen, and some very small species such as Paradoneis n. sp. A were retained almost entirely on the 0.3-mm screen. This was the dominant species at Stations 16 and 17, and probably would not have been collected at all if only the coarser screen had been used.

The recently hatched young (first or second instar) of most of the common arthropod species were retained only by the 0.3-mm mesh screen. For example, during Year 1, the percentage of arthropods retained on the 0.3-mm screen varied from 21 percent in November (M2) when recently hatched young were most abundant to 3 percent in February (M3). In November (M2) and May (M4), when recently hatched young were most abundant, the 0.5-mm screen undersampled arthropods by 16 to 21 percent. Long, thin, smooth species such as Tanaissus lilljeborgi and Ericthonius fasciatus were especially susceptible to slipping through the 0.5-mm screen, and would have been the most severely undersampled. Thirty-seven percent of the T. lilljeborgi and 17 percent of the E. fasciatus were retained on the 0.3-mm screen. Species such as Unciola inermis which has pointed coxal plates, were retained primarily on the 0.5-mm screen: only 4 percent of all U. inermis collected were found on the 0.3-mm screen.

Dominant Species

Dominant Species at Each Station. The ten dominant species at each station are listed separately for each cruise in Appendix E, and are presented in Table 4 for samples summed over all twelve sampling cruises. In this table, stations are grouped according to their similarity as defined by NESS (see below). Inspection of the individual lists for each sampling occasion reveals a remarkable stability at any given station over the three years of sampling. However, there were occasions when a species which does not appear in the consolidated list of dominants (Table 4) was a dominant on a single sampling occasion (Appendix E). For example, Nephtys bucera is listed as a dominant at Station 1 for February 1982, May 1983 and June 1984 as the tenth, sixth and fifth most abundant species, respectively. Similarly, Sthenelais limicola is listed as a dominant at Station 4 for November 1981, July 1982, and July 1983 and Nemertea sp. A at Station 10 for November 1981, February and November 1982, and May and November 1983 (Tables E-1, E-4, and E-13). None of these species appear on the summary lists of dominants for those stations.

TABLE 4. DOMINANT SPECIES AT REGIONAL STATIONS SUMMED OVER ALL TWELVE SAMPLING CRUISES. STATIONS ARE GROUPED ACCORDING TO MAJOR CLUSTERS AS DELIMITED BY NESS SIMILARITY.

Station 1	Station 4[a]	Station 10
1. Tanaissus lilljeborgi	1. Polygordius sp. A	1. Polygordius sp. A
2. Polygordius sp. A	2. Protohaustorius wigleyi	2. Echinarachnius parma
3. Echinarachnius parma	3. Tellina agilis	3. Tannaissus lilljeborgi
4. Protohaustorius wigleyi	4. Rhepoxynius hudsoni	4. Exogone hebes
5. Pseudunciola obliquua	5. Echinarachnius parma	5. Rhepoxynius hudsoni
6. Spiophanes bombyx	6. Pseudohaustorius caroliniensis	6. Protohaustorius wigleyi
7. Bathyporeia quoddyensis	7. Aglaophamus circinata	7. Tellina agilis
8. Tellina agilis	8. Spiophanes bombyx	8. Streptosyllis varians
9. Capitella jonesi	9. Bivalvia sp. F	9. Schistomeringos caeca
10. Rhepoxynius hudsoni	10. Erichthonius fasciatus	10. Paraonis n. sp. A
Station 2	**Station 5**	**Station 11[a]**
1. Parapionosyllis longicirrata	1. Erichthonius fasciatus	1. Polygordius sp. A
2. Erichthonius fasciatus	2. Exogone verugera	2. Erichthonius fasciatus
3. Byblis serrata	3. Sphaerosyllis cf. brevifrons	3. Aglaophamus circinata
4. Sphaerosyllis cf. brevifrons	4. Exogone hebes	4. Tubificoides n. sp. A
5. Exogone hebes	5. Unciola inermis	5. Arctica islandica
6. Exogone verugera	6. Parapionosyllis longicirrata	6. Protodorvillea gaspeensis
7. Phallodrilus biprostatus	7. Euclymene sp. A	7. Levinsenia gracilis
8. Streptosyllis arenae	8. Phallodrilus biprostatus	8. Nucula delphinodonata
9. Polygordius sp. A	9. Aricidea (Acmira) catherinae	9. Nucula proxima
10. Echinarachnius parma	10. Tharyx acutus	10. Rhepoxynius hudsoni
Station 3	**Station 6**	**Station 12[a]**
1. Erichthonius fasciatus	1. Ampelisca agassizi	1. Ampelisca agassizi
2. Notomastus latericeus	2. Exogone hebes	2. Polygordius sp. A
3. Protodorvillea gaspeensis	3. Erichthonius fasciatus	3. Protodorvillea gaspeensis
4. Ampelisca agassizi	4. Protodorvillea gaspeensis	4. Ophelina cylindricaudata
5. Polygordius sp. A	5. Polygordius sp. A	5. Exogone hebes
6. Aglaophamus circinata	6. Notomastus latericeus	6. Notomastus latericeus
7. Paraonis n. sp. A	7. Euchone hancocki	7. Unciola irrorata
8. Unciola inermis	8. Aglaophamus circinata	8. Chone duneri
9. Exogone hebes	9. Paraonis n. sp. A	9. Paraonis n. sp. A
10. Tubificoides n. sp. A	10. Tubificoides n. sp. A	10. Aricidea (Acmira) catherinae
Station 7[b]	**Station 8**	**Station 9[a]**
1. Lumbrineris latreilli	1. Ampelisca agassizi	1. Ampelisca agassizi
2. Olavius tenuissimus	2. Aricidea (Acmira) catherinae	2. Protodorvillea gaspeensis
3. Eclysippe sp. A	3. Lumbrineris latreilli	3. Aricidea (Acmira) catherinae
4. Protodorvillea gaspeensis	4. Tharyx marioni	4. Eclysippe sp. A
5. Chone duneri	5. Aricidea (Acmira) neosuecica	5. Paraonis n. sp. A
6. Polygordius sp. A	6. Paraonis n. sp. A	6. Tubificoides n. sp. A
7. Aricidea (Acmira) neosuecica	7. Chone duneri	7. Polygordius sp. A
8. Tharyx marioni	8. Wireniidae spp.	8. Lumbrineris latreilli
9. Aricidea (Acmira) catherinae	9. Nothria britannica	9. Tharyx annulosus
10. Tharyx acutus	10. Chaetozone n. sp. B	10. Euchone hancocki

TABLE 4. (Continued)

Station 13	Station 13A[a d]	Station 7A[d]
1. Cossura longocirrata	1. Ampelisca agassizi	1. Ampelisca agassizi
2. Levinsenia gracilis	2. Aricidea (Allia) suecica	2. Aricidea (Allia) suecica
3. Tubificoides n. sp. A	3. Cossura longocirrata	3. Cossura longocirrata
4. Euchone incolor	4. Tharyx annulosus	4. Levinsenia gracilis
5. Ampelisca agassizi	5. Tubificoides n. sp. A	5. Tubificoides n. sp. A
6. Ninoe nigripes	6. Myriochele sp. A	6. Aricidea (Allia) quadrilobata
7. Aricidea (Acmira) catherinae	7. Exogone verugera	7. Lucinoma filosa
8. Mediomastus fragilis	8. Protodorvillea gaspeensis	8. Periploma papyratium
9. Aricidea (Allia) suecica	9. Terebellides stroemi	9. Ninoe nigripes
10. Lumbrineris impatiens	10. Maldanidae sp. G	10. Prionospio cirrifera

Station 16	Station 17[c]	Station 18[c]
1. Paradoneis n. sp. A	1. Paradoneis n. sp. A	1. Ampelisca agassizi
2. Chone duneri	2. Notomastus latericeus	2. Tharyx annulosus
3. Notomastus latericeus	3. Chone duneri	3. Chaetozone n. sp. B
4. Enteropneusta sp. E	4. Tharyx marioni	4. Notomastus latericeus
5. Tharyx marioni	5. Phallodrilus biprostatus	5. Thyasira sp. B
6. Ampelisca agassizi	6. Polycirrus sp. F	6. Lumbrineris latreilli
7. Tharyx annulosus	7. Aricidea (Acmira) neosuecica	7. Aricidea (Acmira) catherinae
8. Aricidea (Acmira) neosuecica	8. Wireniidae spp.	8. Aricidea (Acmira) neosuecica
9. Chaetozone n. sp. B	9. Enteropneusta sp. E	9. Paraonis n. sp. A
10. Schistomeringos caeca	10. Polycirrus sp. A	10. Wireniidae spp.

Station 14A[e]	Station 15[b]
1. Tharyx annulosus	1. Exogone hebes
2. Euchone incolor	2. Spisula solidissima
3. Protodorvillea gaspeensis	3. Polygordius sp. A
4. Ophiura robusta	4. Echinarachnius parma
5. Nuculana messanensis	5. Phallodrilus biprostatus
6. Terebellides stroemi	6. Tanaissus lilljeborgi
7. Paradoneis lyra	7. Grania n. sp. A
8. Cossura longocirrata	8. Streptosyllis websteri
9. Lumbrineris sp. C	9. Parapionosyllis longicirrata
10. Ophelina abranchiata	10. Nemertea sp. B

[a] No data for M7.
[b] Data include M1 through M4 only.
[c] Data include M1 through M8 only.
[d] Data include M5 through M8 only.
[e] Data include M5 through M9 only.

The twenty most abundant species at our Georges Bank stations are given in Table 5, summed over all regional stations and over all sampling cruises. The list is comprised of 14 polychaete species of which four are syllids and three are paraonids; four arthropod species of which three are amphipods and one is a tanaid; one as yet undescribed species of oligochaete; and one species of echinoderm. The amphipod, Ampelisca agassizi, dominant at seven of the 20 regional stations, was also the overall most abundant species identified from all Georges Bank samples.

Stations 1, 4, and 10 on the 60 m isobath were consistently similar to each other in terms of dominant species (Table 4; Appendix E). Although the order of dominance of some species changed over the three years of sampling, and name changes occurred as identifications were refined, essentially the same species occurred as dominants over all three years. These stations are dominated by the archiannelid Polygordius sp. A, the arthropods Tanaissus lilljeborgi and Protohaustorius wigleyi, the sand dollar Echinarachnius parma, and the bivalve Tellina agilis.

Stations 2 and 5 at approximately 80 m depth were dominated by amphipods and syllid polychaetes. The syllid Parapionosyllis longicirrata was the most abundant species at Station 2 and four other syllid species were among the top ten dominants. Erichthonius fasciatus, previously listed among the dominants at Station 2 for July 1982 only, became the most abundant species at Station 2 during July and November 1983, and subsequently outranked Byblis serrata on the summary list. E. fasciatus was the most abundant species at Station 5, followed by three syllid species. At Station 2 Echinarachnius parma replaced Syllides benedicti as the tenth most abundant species, while at Station 5 only minor shifts in ranking occurred between Years 2 and 3.

Station 11 had a higher percentage of fine sand sediment than did Stations 2 and 5 but Erichthonius fasciatus ranked second in dominance (Table 4). The syllid polychaetes dominant at Stations 2 and 5, however, were replaced at Station 11 by the archiannelid Polygordius sp. A, the oligochaete Tubificoides n. sp. A, and three bivalves, including Artica islandica and two species of Nucula. Echinarachnius parma dropped from the top ten dominant species between Years 2 and 3 while the amphipod Rhepoxynius hudsoni was added.

The amphipod Erichthonius fasciatus, was the overall dominant species at Station 3 (Table 4). Ampelisca agassizi, another amphipod, ranked fourth at Station 3, and first at Stations 6 and 12, also at the 100 m depth contour. Other dominants at these stations included Notomastus latericeus, Exogone hebes and Polygordius sp. A.

TABLE 5. DOMINANT SPECIES SUMMED OVER ALL REGIONAL STATIONS AND OVER ALL SAMPLING CRUISES.

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

Stations 8 and 9, at 145 m depth, were also dominated by Ampelisca agassizi although they had only three other species in common, including Aricidea (Acmira) catherinae, Lumbrineris latreilli, and Paraonis n. sp. A. Station 7, sampled during Year 1 only, was dominated by the polychaete Lumbrineris latreilli, which is the only species it had in common with both Stations 8 and 9, at similar depths. Station 7 did, however, have four polychaete species in common with Station 8, and five polychaete in common with Station 9.

Both Station 7A (167 m) and Station 13A (80 m), established during Year 2, had very high percentages of fine silt/clay sediments and shared the same three most abundant species: Ampelisca agassizi, Aricidea (Allia) suecica, and Cossura longocirrata as well as the oligochaete Tubificoides n. sp. A. Station 13 (70 m) had slightly coarser sediments but shared these four dominant species with Stations 7A and 13A although in a different order of rank.

Station 14A, at 168 m in the Gulf of Maine, resembled none of the other sampling locations in terms of faunal assemblages. This station, established during Year 2 northeast of the abandoned Station 14, was sampled on five occasions only (May 1982 through July 1983). Cossura longocirrata was the only dominant species shared with Stations 13 and 7A. Three other species found at Station 14A occurred at Station 13A, including Tharyx annulosus, Protodorvillea gaspeensis and Terebellides stroemi. Station 14A was the only station with an ophiuroid, Ophiura robusta, among the ten most abundant species. Many of the polychaete species found at Station 14A are thought to be more typical of the deeper, cold water fauna to be found on the North Atlantic slope and rise. Station 14 in the Gulf of Maine (not listed in Table 4 or Appendix E) was abandoned after being sampled only during Year 1. Three samples were analyzed from each of the first two cruises, and these were dominated by high numbers of sabellid polychaetes, including undescribed species of Euchone and Chone.

Station 15 at the top of the Bank was the shallowest station (38 m) and was sampled only during Year 1. This station showed some faunal affinities with stations at 60 m and 80 m. The dominant species was a syllid polychaete, Exogene hebes, and two other syllids were among the top ten dominants, similar to Stations 2 and 5. The oligochaete, Phallodrilus biprostatus, was a dominant common to Stations 2, 5, and 15. The dominant arthropod at Station 15 was Tanaissus lilleborgi (in sixth position), which was the top dominant at Station 1. Polygordius sp. A was the third most abundant species at Station 15, and ranked first or second at Stations 1, 4, and 10. Echinarachnius parma, the sand dollar, was ranked fourth at Station 15 and was also dominant at Stations 1, 2, 4, and 10.

Of the Block 410 Stations 16, 17, 18, only Station 16 samples were processed for Year 3 while samples from Stations 17 and 18 were collected but archived. Station 16 continued to be dominated by the paraonid polychaete Paradoneis n. sp. A, with two other polychaetes, Chone duneri and Notomastus latericeus, being second and third most abundant. Others of the top ten dominants at Station 16 shifted position from Year 2. Two species, the oligochaete Phallodrilus biprostatus and the polychaete Polycirrus sp. A were no longer among the overall ten most abundant species, but were replaced by two polychaetes, Chaetozone n. sp. B and Aricidea (Acmira) neosuecica. Station 17 was also dominated by Paradoneis n. sp. A, with N. latericeus and C. duneri following as second and third most numerous. At Station 18, Ampelisca agassizi was dominant for all eight sampling cruises analyzed, while Paradoneis n. sp. A and Chone duneri were never among the ten dominants. Tharyx annulosus, Chaetozone n. sp. A, Notomastus latericeus, and Thyasira sp. B were the second, third, fourth, and fifth most numerous species respectively at Station 18 as a result of data base corrections during Year 3.

Distribution Patterns of Selected Species. The average seasonal abundance per $0.04m^2$ at all regional Monitoring Program stations (except Stations 14A and 15) are plotted for four amphipod species in Figures 8 through 11. Ampelisca agassizi, the overall most common invertebrate in all of the samples analyzed, was most abundant at the deeper stations, particularly those deeper than 100 m and with finer-grained sediments (Figure 8). Densities were often high at these stations during the winter (e.g., Station 18, M3 (February 1982) and M7 (February 1983) when large numbers of juveniles were seen in the population.

Erichthonius fasciatus is an epifaunal species associated with coarse sediments and was most abundant at Station 5-1 (Figure 9). This species disappeared from that station in February 1982 (M3) but later recolonized the area. This disappearance has been linked to a shift in sediment grain size composition rather than to any impacts of drilling (Battelle and W.H.O.I., 1983, p. 93).

Unciola inermis was also common at Station 5-1 and, to lesser extent, at Stations 2, 3 and 6, all between 80 and 100 m depth (Figure 10). The highest densities of this species occurred in the spring (M4, M8, M12) and summer (M1, M5, M9) collections of all three years. A similar seasonal pattern was seen for Unciola irrorata (Figure 11). This species was a little more widely distributed over the Bank but was more common at the stations below 80 m than at the 60 m stations.

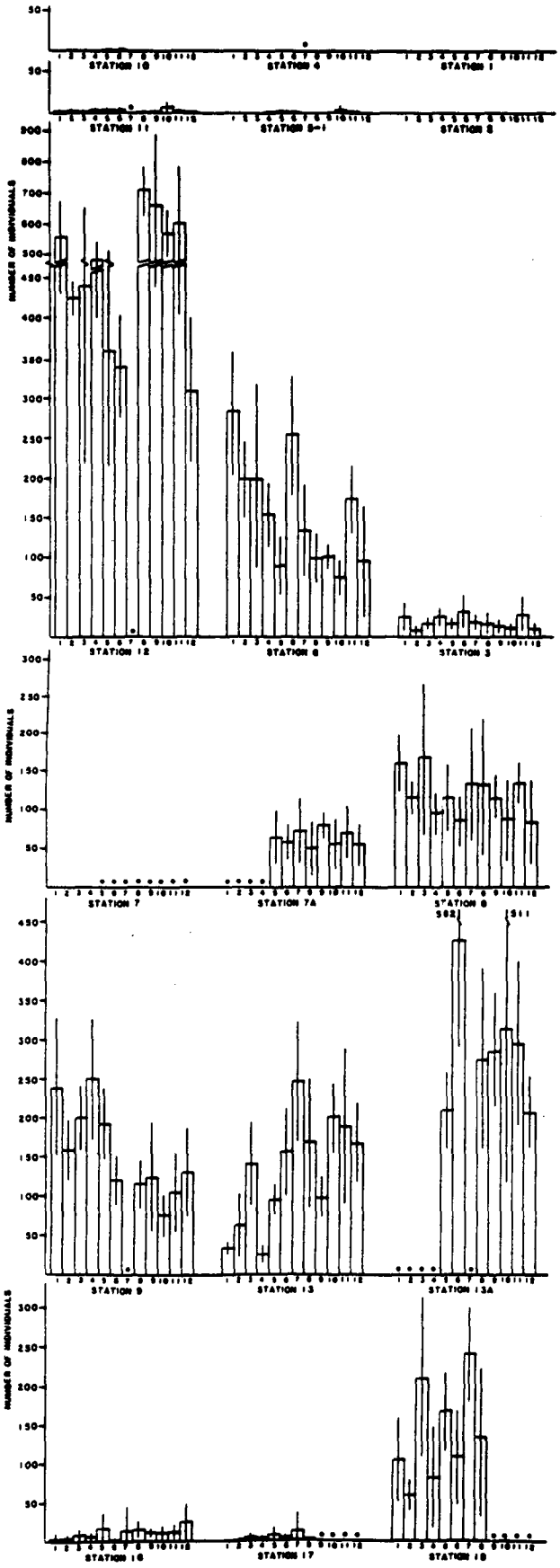

Figure 8. Average population density per 0.04 m^2 ± one standard deviation of Ampelisca agassizi at the Georges Bank regional stations for sampling Cruises 1-12 (see Table 3 for corresponding dates). An * indicates no data.

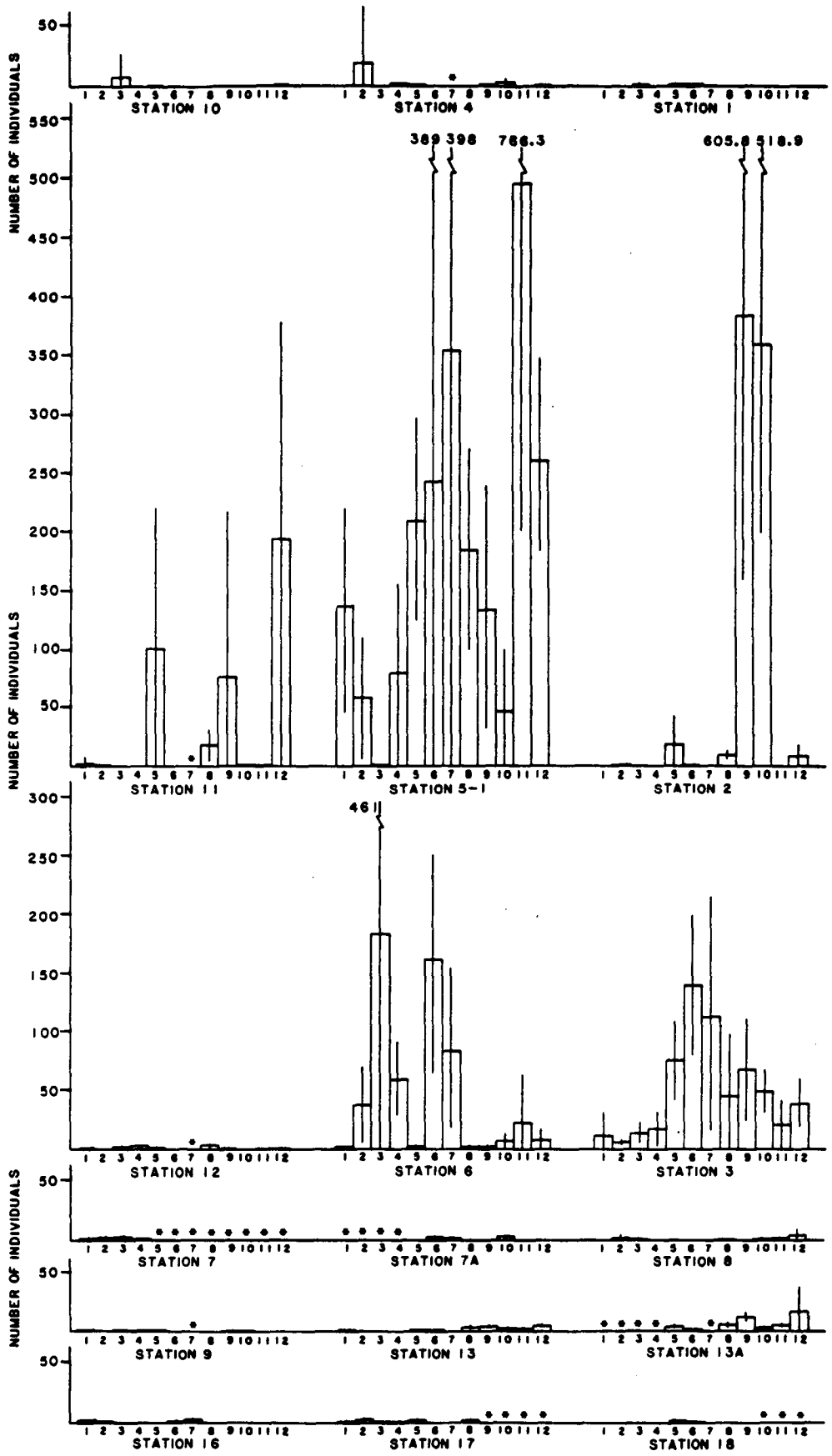

Figure 9. Average population density per 0.04 m^2 ± one standard deviation of Erichthonius fasciatus at the Georges Bank regional stations for sampling Cruises 1-12 (see Table 3 for corresponding dates). An * indicates no data.

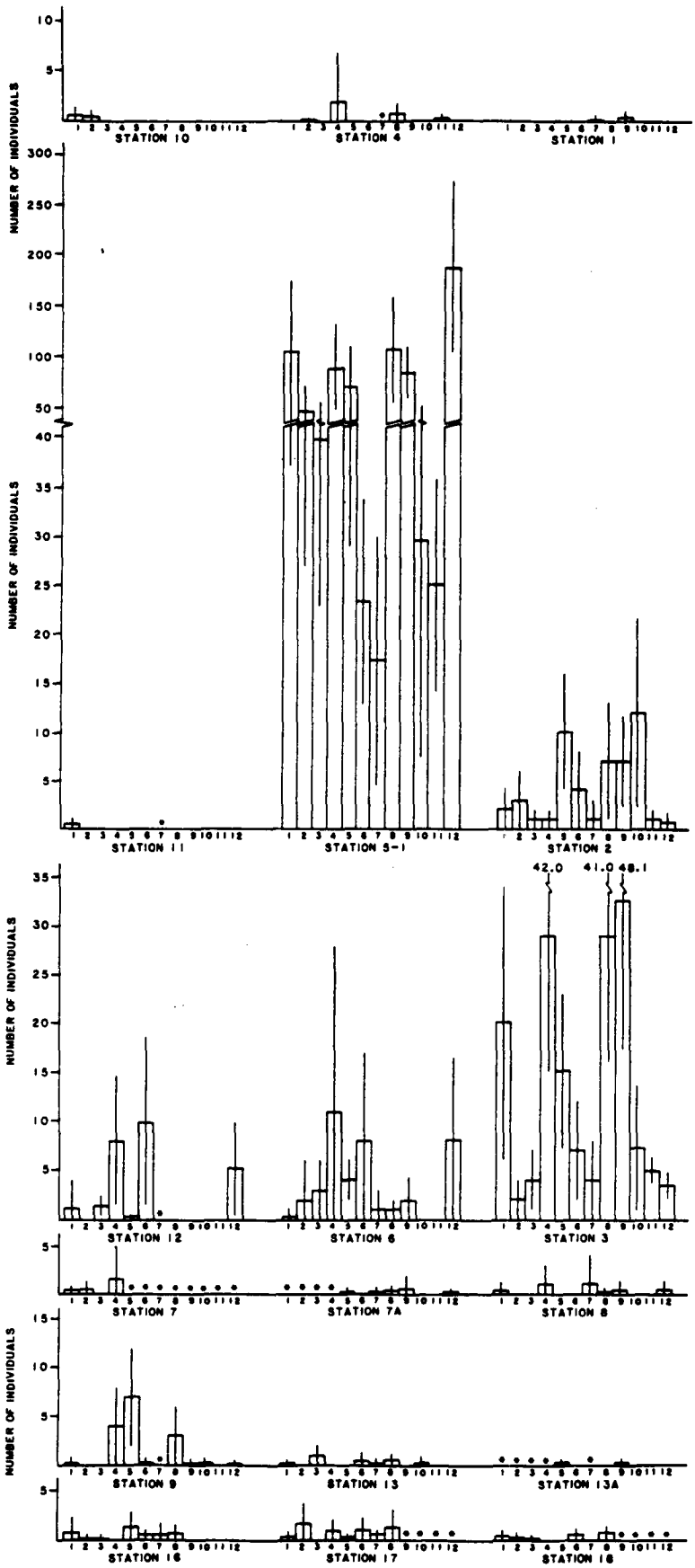

Figure 10. Average population density per 0.04 m^2 ± one standard deviation of Unciola inermis at the Georges Bank regional stations for sampling Cruises 1-12 (see Table 3 for corresponding dates). An * indicates no data.

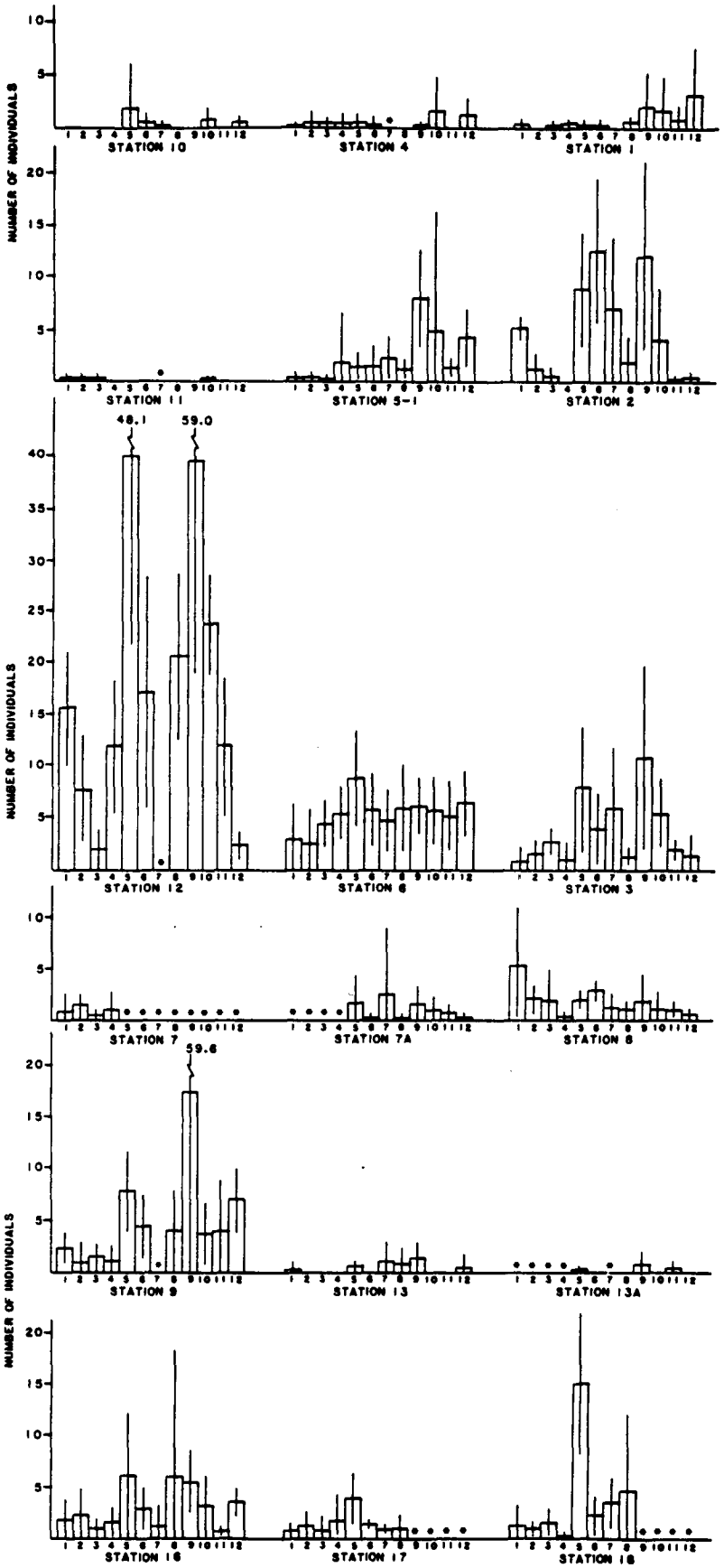

Figure 11. Average population density per 0.04 m^2 ± one standard deviation of Unciola irrorata at the Georges Bank regional stations for sampling Cruises 1-12 (see Table 3 for corresponding dates). An * indicates no data.

Three species of paraonid polychaetes belonging to the genus Aricidea are plotted in Figures 12 through 14. Aricidea catherinae, a species which is also common in inshore waters, had the widest distribution over all depths, but was most abundant at the Mud Patch Station 13. It was equally abundant at Station 5 (84 m) and Stations 8 and 9 (145-150 m). No clear seasonal pattern of abundance was seen for this species. Aricidea neosuecica occurred in low densities at those stations where it was present, and was clearly limited to stations deeper than 140 m (Figure 14). A. suecica had the most limited distribution of the three species, appearing to be abundant only at Stations 7A and 13A, which both have fine-grained sediments (Figure 13).

Of the remaining five polychaete species shown in Figures 15 through 19, only the capitellid, Notomastus latericeus, occurred regularly at Station 5-1 (Figure 16). The distributions of Nereis grayi, Exogone naidina, Euchone hancocki, and Prionospio cirrifera are apparently limited to stations 100 m or deeper.

The oligochaete Phallodrilus coeloprostatus was most abundant at Stations 5-1 and 2, both at about 80 m depth (Figure 20). This species has been noted to prefer coarse to medium-grained sandy sediments (Cook, 1969) which are typical of those stations. The appearance of this species at other stations was spotty, with no apparent correlation with depth.

The bivalve Tellina agilis is a deep-living infaunal species which is a surface deposit feeder. It was common at the 60 m Stations 1, 4 and 10 but occurred only rarely at the other stations (Figure 21). No clear seasonal peaks were apparent, and the total densities appear to decline over the three-year period of sampling. All of the specimens in our samples were small, and probably not mature. Either the grab sampler missed deep-dwelling adults or the populations at these stations are maintained by recruitment of juveniles from other areas.

The commercially important species Arctica islandica lives near the sediment surface. It was most common at Stations 3 and 11, but was also found at a few other stations between 60 and 100 m (Figure 22). At Station 11, the average density appeared to increase in Year 3, while at Station 3 it appeared to decrease. Although Mann (1982) indicated an autumn peak in recruitment of juveniles, our data do not indicate any seasonal trends. In all sampling periods, both small and large specimens were found, with the sizes ranging from 0.5 mm to 2 mm or over 80 mm, but with the intermediate sizes absent from the collections.

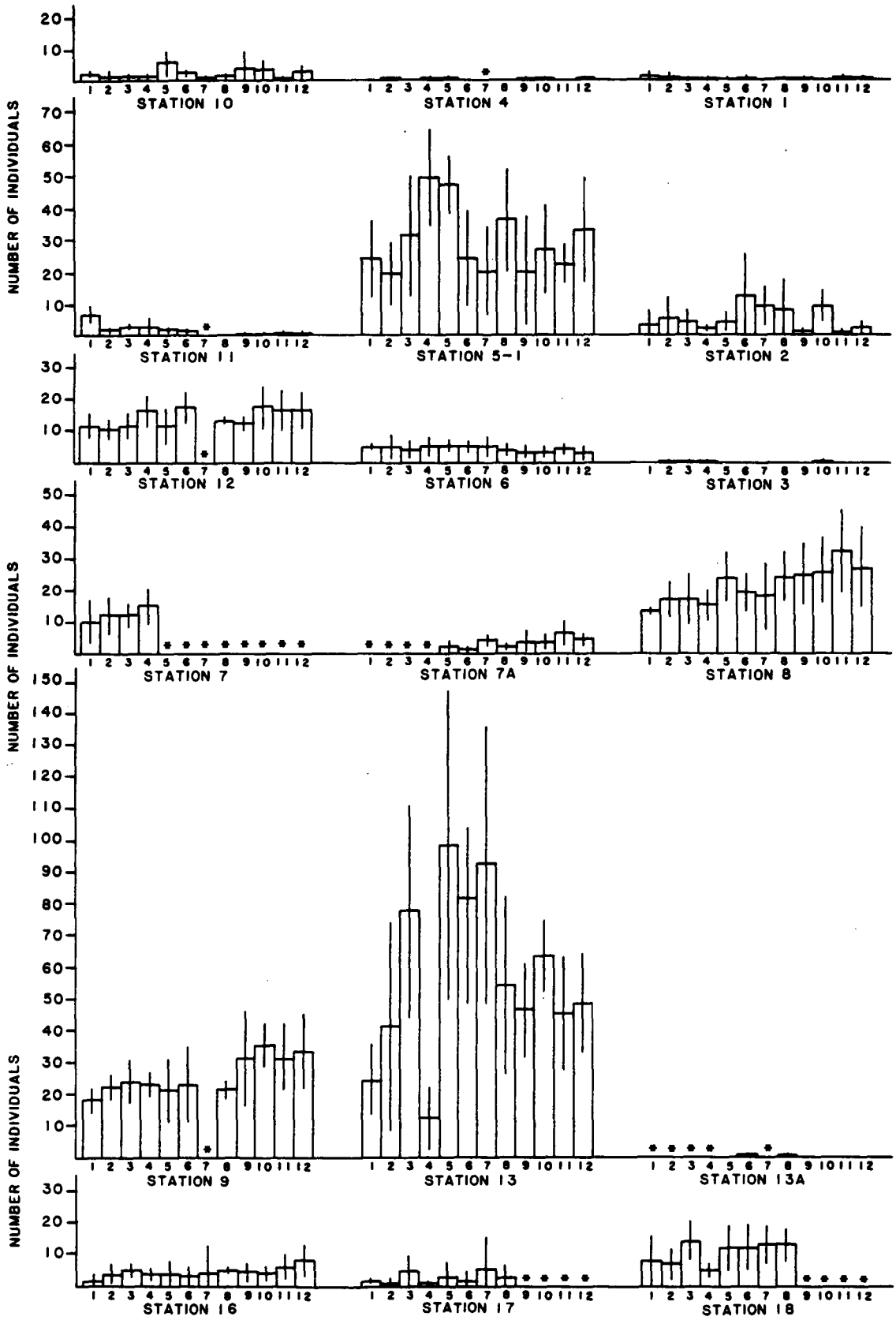

Figure 12. Average population density per 0.04 m^2 ± one standard deviation of Aricidea catherinae at the Georges Bank regional stations for sampling Cruises 1-12 (see Table 3 for corresponding dates). An * indicates no data.

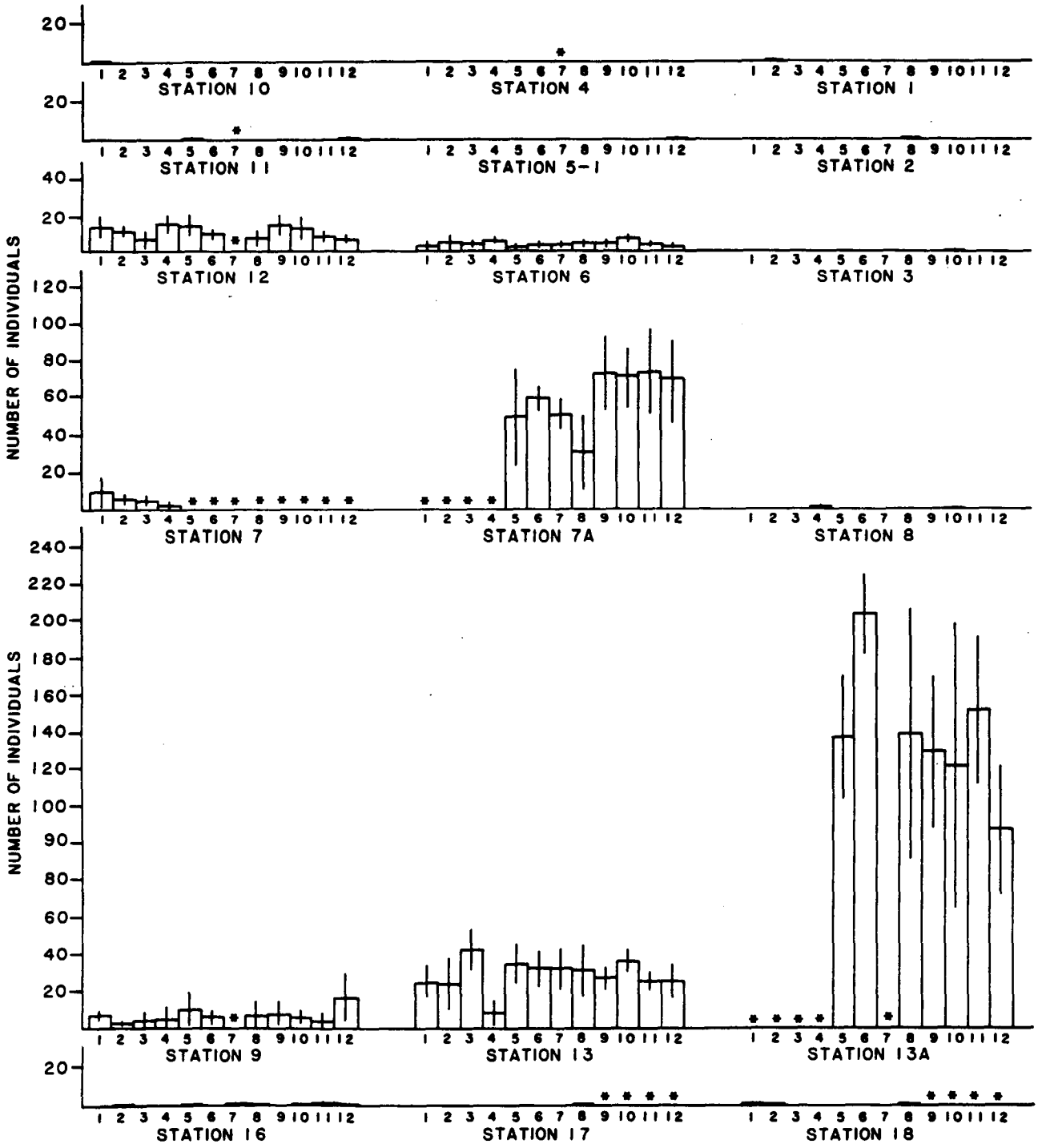

Figure 13. Average population density per 0.04 m^2 ± one standard deviation of Aricidea suecica at the Georges Bank regional stations for sampling Cruises 1-12 (see Table 3 for corresponding dates). An * indicates no data.

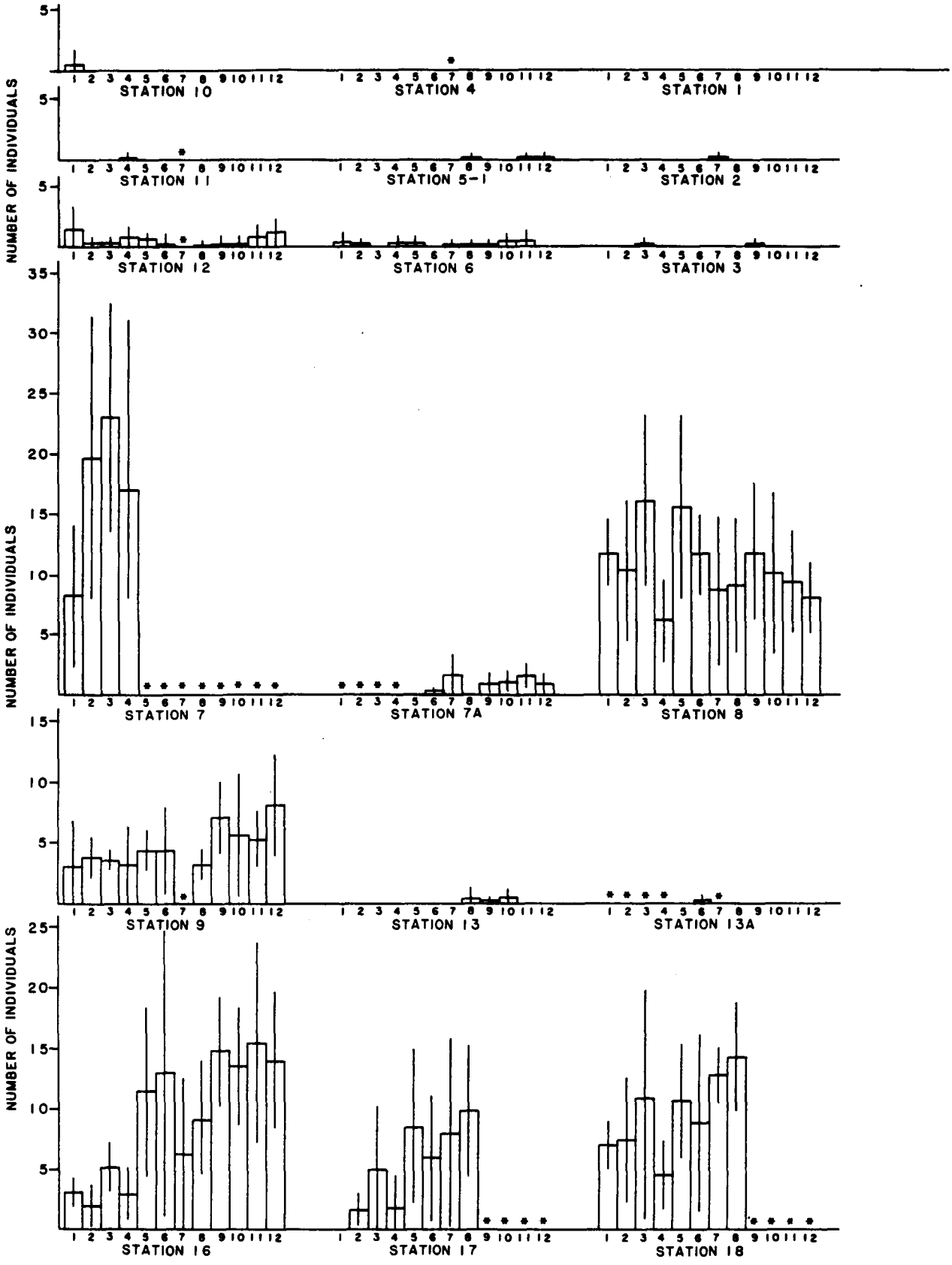

Figure 14. Average population density per 0.04 m^2 ± one standard deviation of Aricidea neosuecica at the Georges Bank regional stations for sampling Cruises 1-12 (see Table 3 for corresponding dates). An * indicates no data.

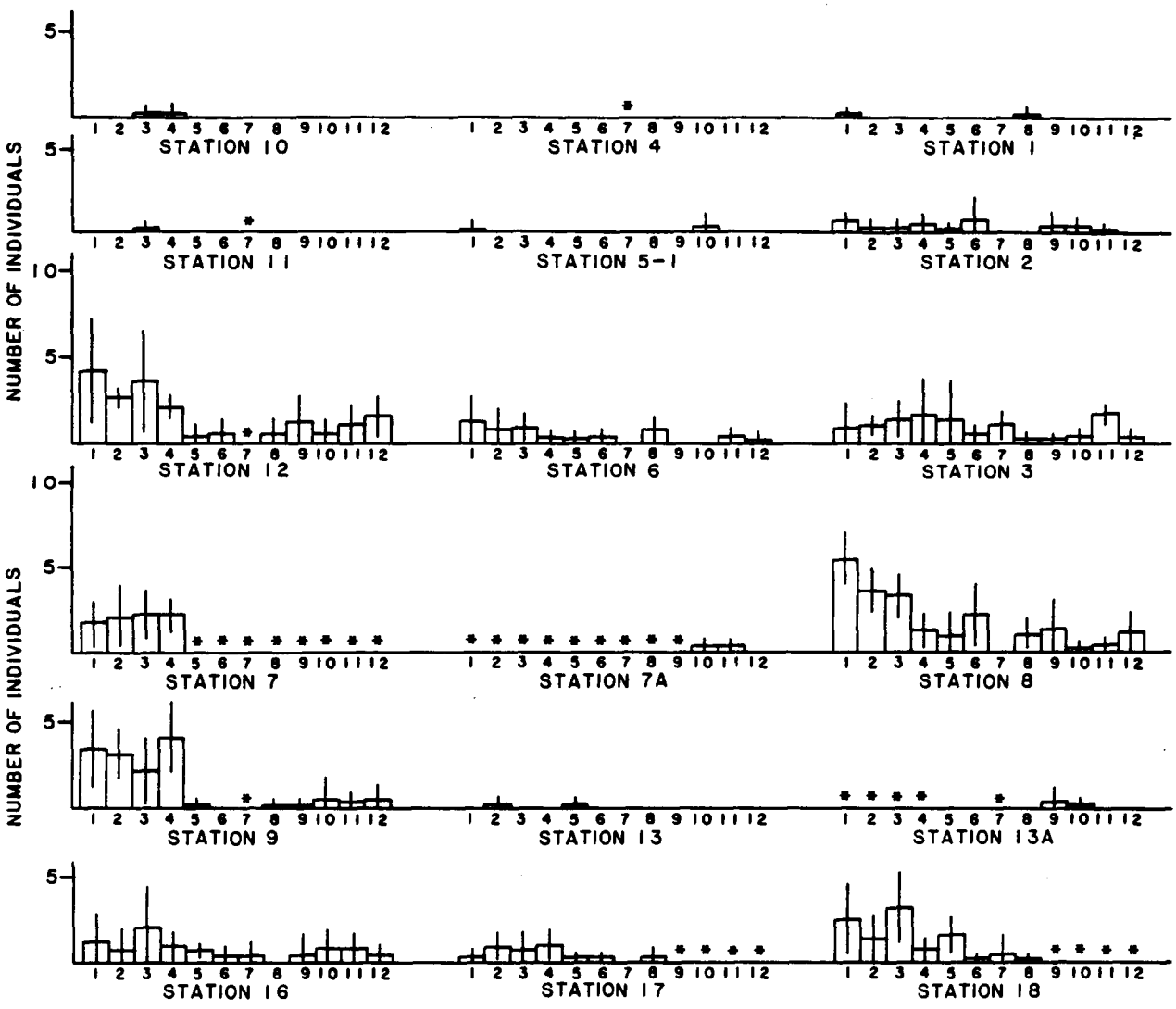

Figure 15. Average population density per 0.04 m^2 ± one standard deviation of Nereis grayi at the Georges Bank regional stations for sampling Cruises 1-12 (see Table 3 for corresponding dates). An * indicates no data.

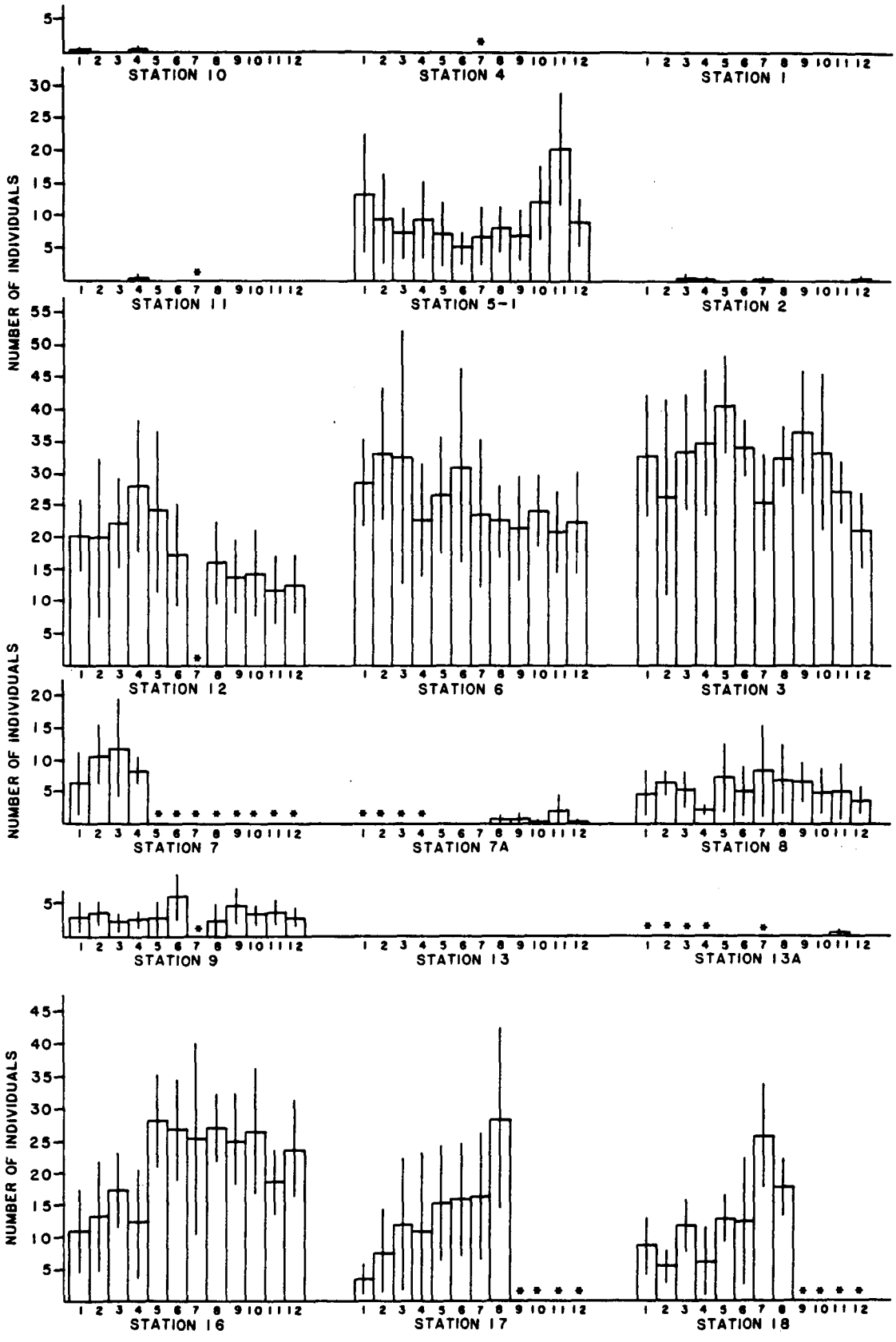

Figure 16. Average population density per 0.04 m^2 + one standard deviation of Notomastus latericeus at the Georges Bank regional stations for sampling Cruises 1-12 (see Table 3 for corresponding dates). An * indicates no data.

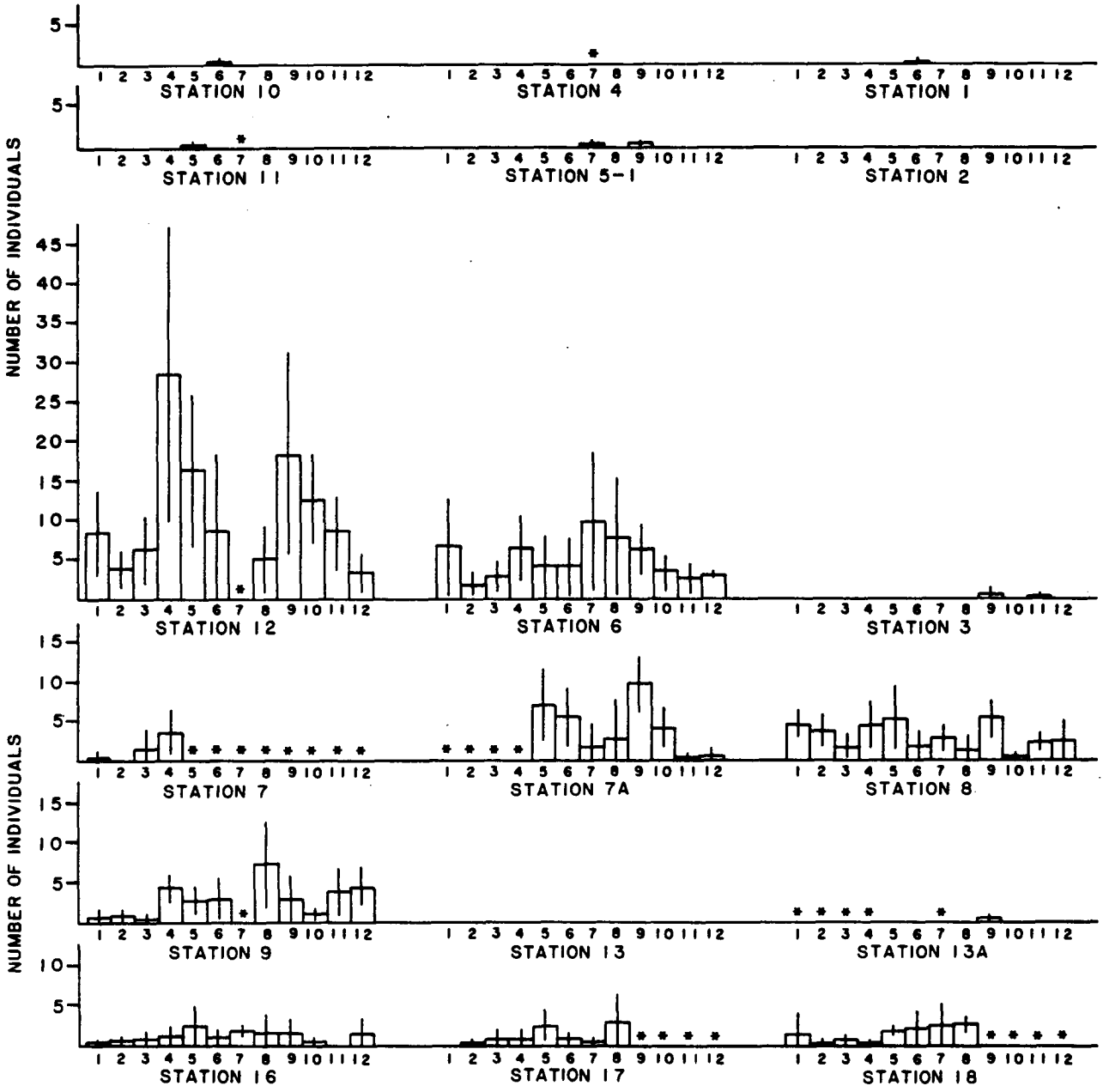

Figure 17. Average population density per 0.04 m^2 ± one standard deviation of Exogone naidina at the Georges Bank regional stations for sampling Cruises 1-12 (see Table 3 for corresponding dates). An * indicates no data.

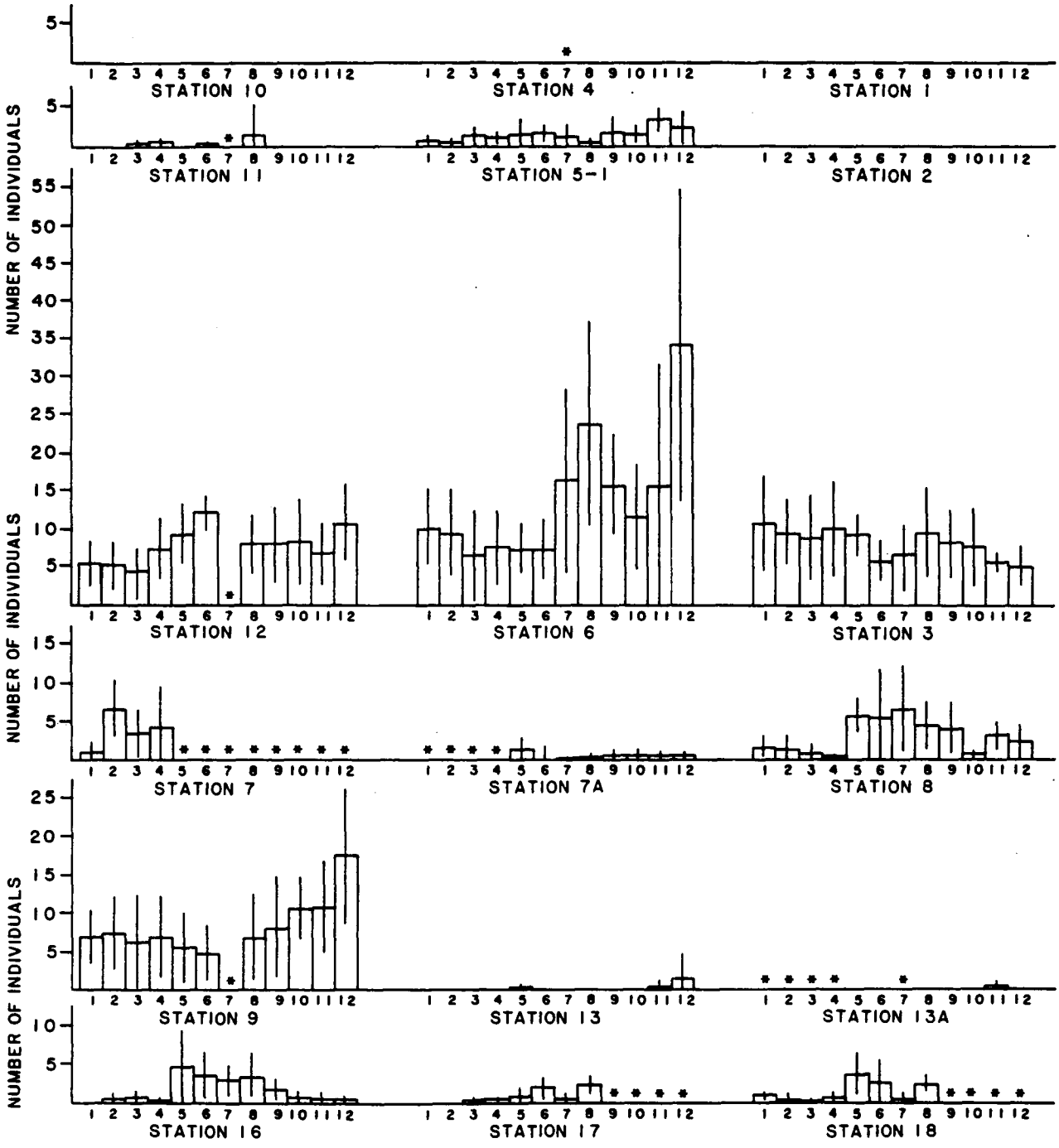

Figure 18. Average population density per 0.04 m^2 ± one standard deviation of Euchone hancocki at the Georges Bank regional stations for sampling Cruises 1-12 (see Table 3 for corresponding dates). An * indicates no data.

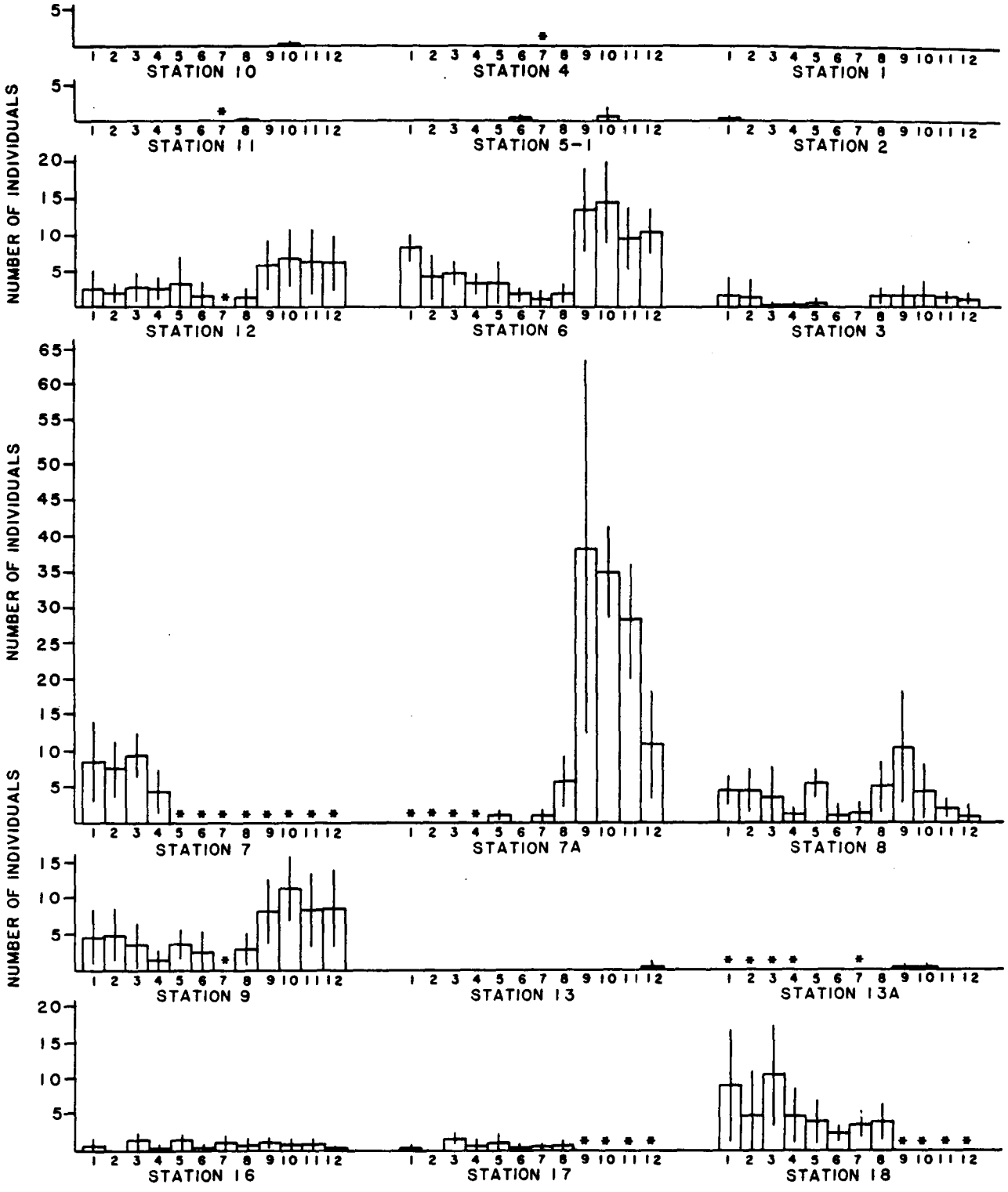

Figure 19. Average population density per 0.04 m^2 ± one standard deviation of Prionospio cirrifera at the Georges Bank regional stations for sampling Cruises 1-12 (see Table 3 for corresponding dates). An * indicates no data.

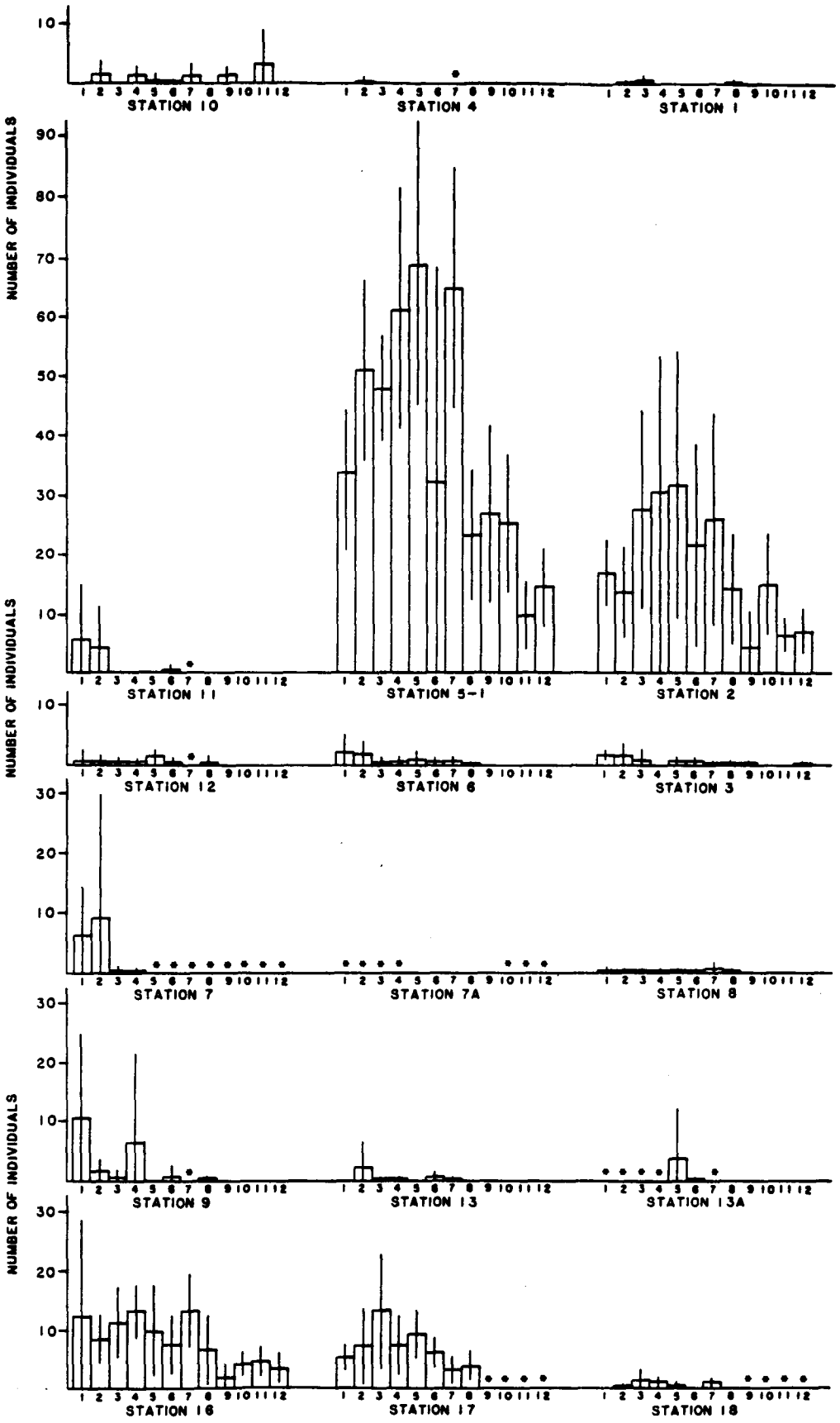

Figure 20. Average population density per 0.04 m^2 ± one standard deviation of Phallodrilus coeloprostatus at the Georges Bank regional stations for sampling Cruises 1-12 (see Table 3 for corresponding dates). An * indicates no data.

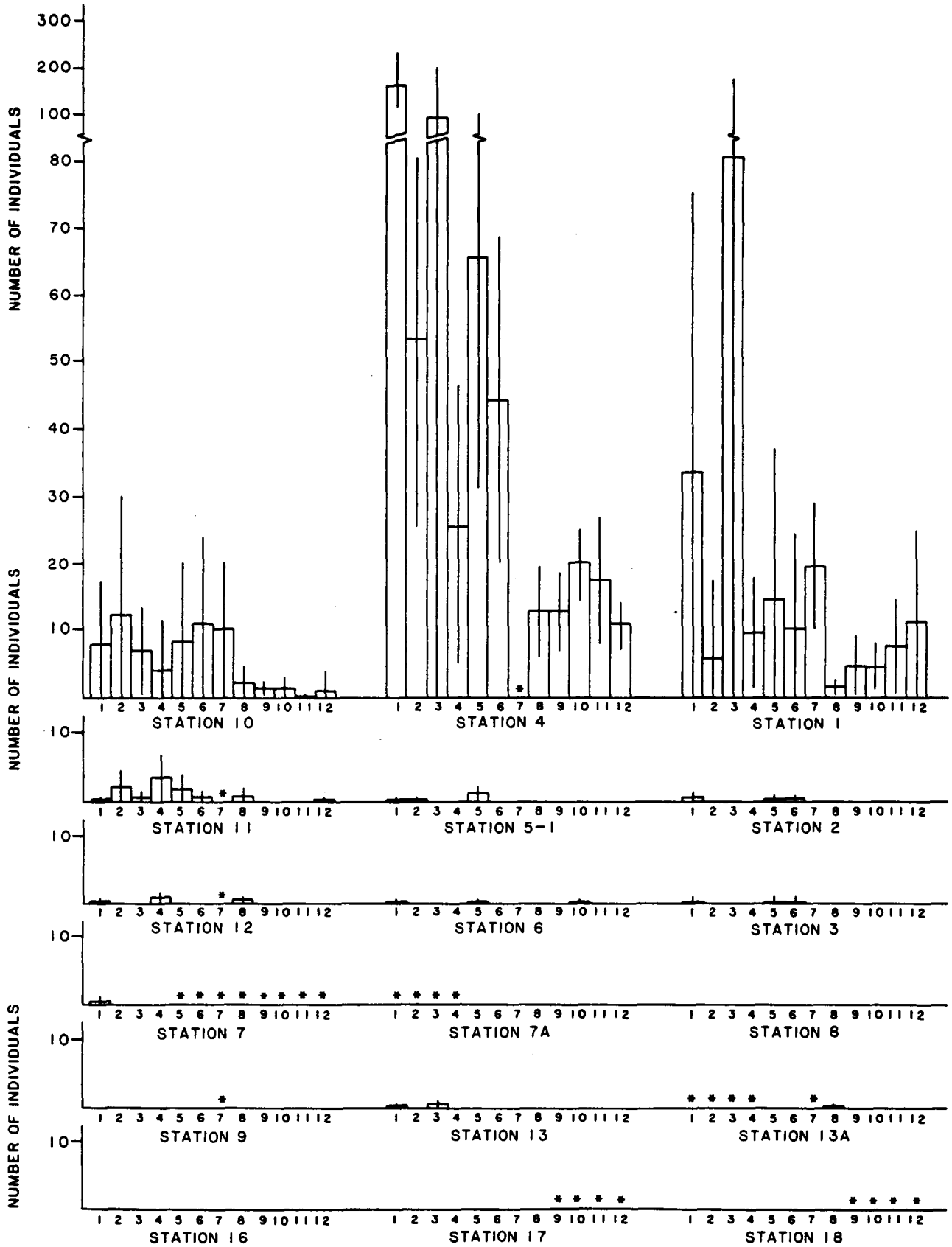

Figure 21. Average population density per 0.04 m^2 ± one standard deviation of Tellina agilis at the Georges Bank regional stations for sampling Cruises 1-12 (see Table 3 for corresponding dates). An * indicates no data.

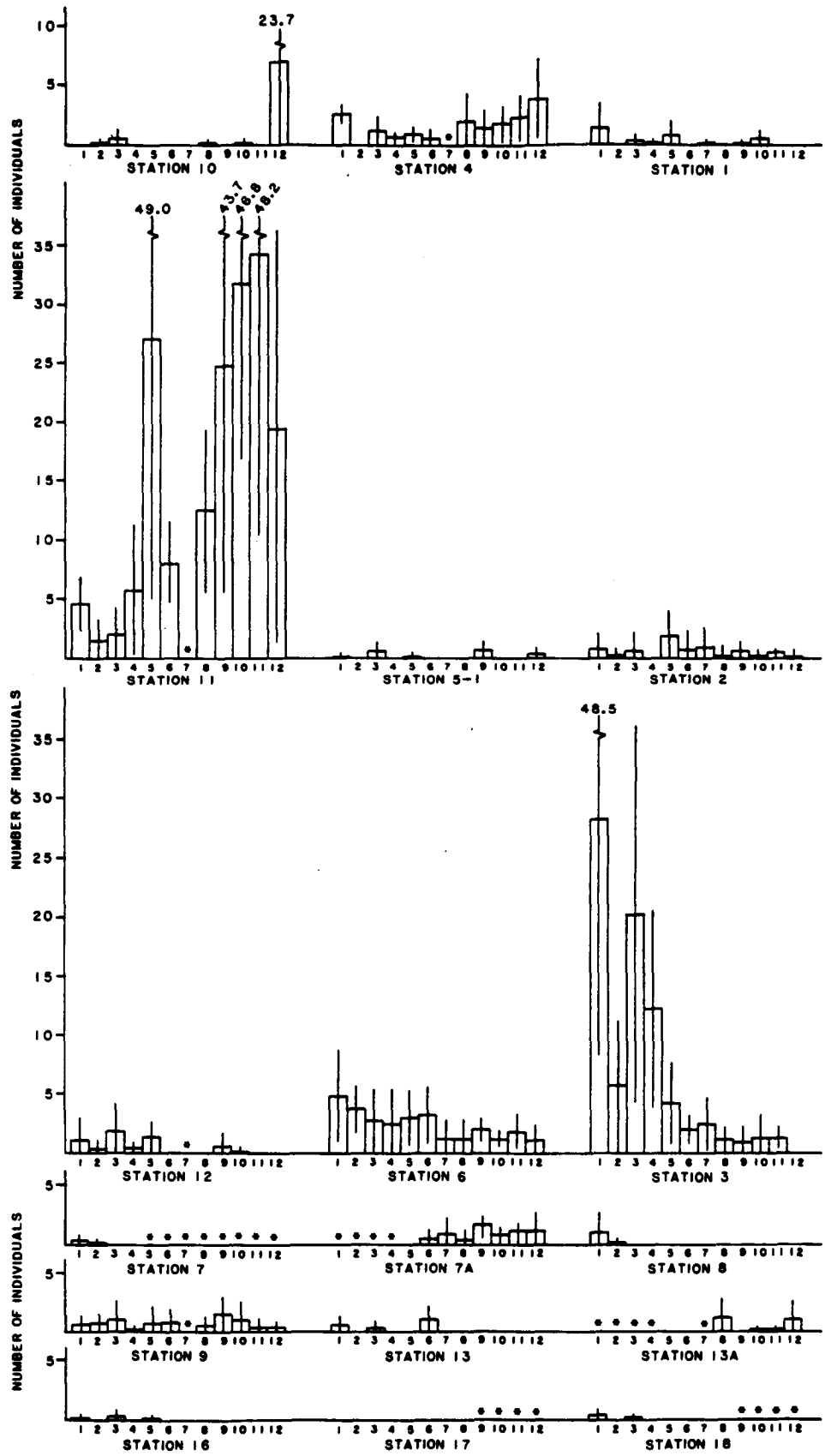

Figure 22. Average population density per 0.04 m^2 ± one standard deviation of Arctica islandica at the Georges Bank regional stations for sampling Cruises 1-12 (see Table 3 for corresponding dates). An * indicates no data.

Amphipholis squamata is a littoral ophiuroid generally considered to have a cosmopolitan distribution. It is found throughout the world including subarctic and subantarctic areas and from the intertidal zone to 250 m (Hyman, 1965). Its feeding habits, which involve a combination of ingestion of bottom material and carnivorous feeding, undoubtedly enable A. squamata to adapt to a wide range of conditions. In the Georges Bank area A. squamata also exhibited a wide distribution, being found at stations between 84 and 152 m (Figure 23).

The populations of A. squamata were comprised of adults as well as a significant number of juveniles year round suggesting a self-sustaining population on Georges Bank. A. squamata, a brooding species, has a more extended breeding period than oviparous species and is known to breed throughout the year (MacBride, 1982; Fell, 1941).

The distribution of the northern sand dollar Echinarachnius parma on Georges Bank appears to be associated with depth and sediment characteristics (Figure 24). E. parma was a dominant species at Stations 1, 4, and 10 along the 60 m depth contour which were characterized by 72-100 percent fine or fine-medium sand. E. parma also occurred occasionally as a dominant at Station 2 and to a lesser extent at Stations 11 and 5-1. The correlation of E. parma with sediment grain size is probably related to its mechanism of deposit feeding and size selection of ingested particles. Although clear seasonal patterns were not readily apparent, the highest numbers of individuals occurred during, but were not limited to, May and July. A patchy distribution may account for the high standard deviations around the mean and also for irregularities observed between spatially related stations. Juveniles occurred in large numbers during May and July 1982 and during February, May, and July 1983, but did not co-occur with large populations of adults, possibly due to adult inhibition or predation. Intermediate sizes (2-8 mm) of E. parma were conspicuously absent from many samples and are known to be preyed upon by yellowtail flounder and possibly other species (Chapter 7).

Figure 25 shows the distribution of the aplacophoran family Wireniidae at our stations. These specimens were previously thought to represent only a single species but this could not be confirmed by our consultant, Ms. Amelie Scheltema. These animals were most common at stations deeper than 100 m and especially those deeper than 145 m. Densities were low and variable, and no distinct trends were seen.

Population Fluctuations of Selected Species at Stations 5-1, 13, and Block 410. In order to gain further insight into the community dynamics at the drilling sites, Stations 5-

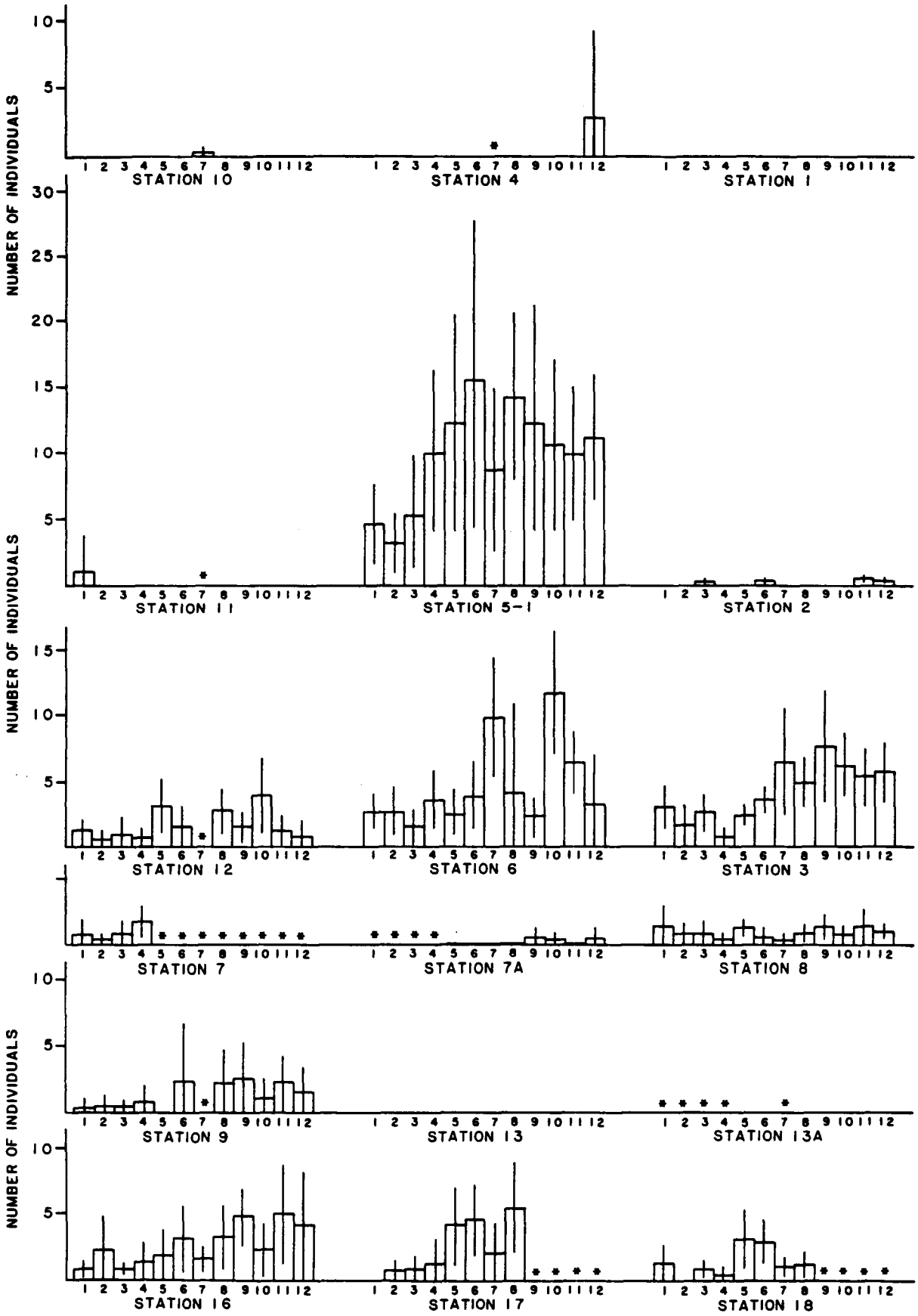

Figure 23. Average population density per 0.04 m^2 ± one standard deviation of Amphipholis squamata at the Georges Bank regional stations for sampling Cruises 1-12 (see Table 3 for corresponding dates). An * indicates no data.

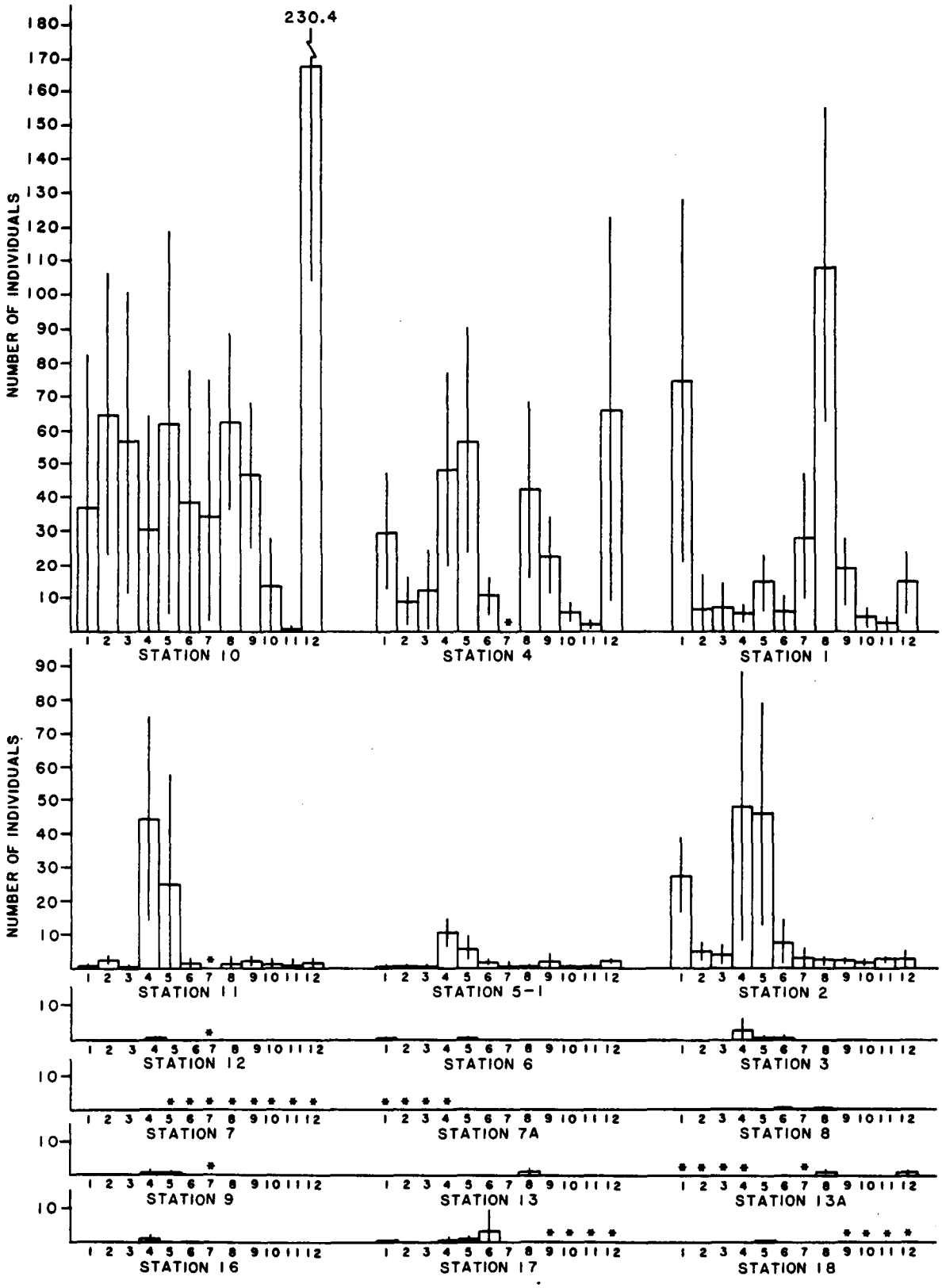

Figure 24. Average population density per 0.04 m^2 ± one standard deviation of Echinarachnius parma at the Georges Bank regional stations for sampling Cruises 1-12 (see Table 3 for corresponding dates). An * indicates no data.

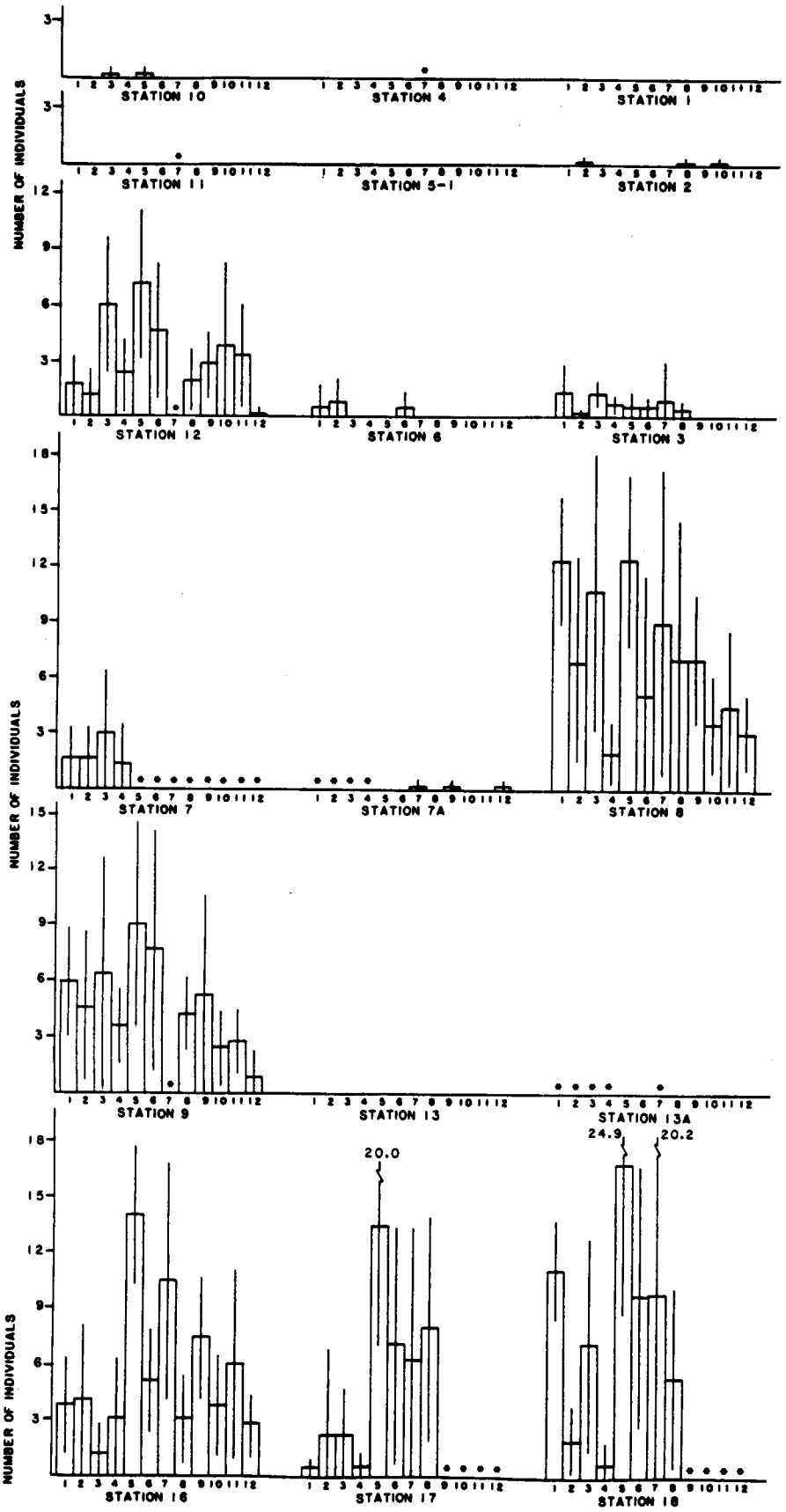

Figure 25. Average population density per 0.04 m^2 ± one standard deviation of Wireniidae spp. at the Georges Bank regional stations for sampling Cruises 1-12 (see Table 3 for corresponding dates). An * indicates no data.

1 and 16, and the Mud Patch Station 13, the average densities of several species common at these stations were plotted.

A total of 21 polychaete and one amphipod species were plotted for Station 5-1 (Figures 26 through 34). In Year 2 (July 1982 - May 1983), most species were at or above the average densities recorded in Year 1 (July 1981 - May 1982). This trend was generally continued through Year 3 (July 1983 - June 1984) with population densities remaining comparable to those seen in Year 2. Densities of the amphipod species Unciola inermis (Figure 28) fluctuated widely but somewhat predictably over time, with the highest densities recorded in the spring (May 1982, May 1983, and June 1984) and summer (July 1981, July 1982, and July 1983) collections. Some of the polychaete species, including Tharyx sp. A, T. acutus, T. annulosus, Aricidea catherinae, and Aglaophamus circinata, showed peak abundances in May 1982 and July 1982 (Figures 30-34). These two collections correspond to the periods of highest overall density and species richness at this station (Appendix Table F-2).

The remaining species plotted for Station 5-1 exhibited a fairly low but stable average density over all 12 sampling periods. Such species include Streptosyllis arenae, Euclymene sp. A, Schistomeringos caeca, Aricidea cerruti, Notomastus latericeus, and Caulleriella sp. B (Figures 26-30).

Average seasonal densities of ten species common at the Block 410 Stations 16, 17 and 18 are plotted in Figures 35-40. Samples were collected but not analyzed from Stations 17 and 18 during Year 3 (July 1983 - June 1984), therefore data on these species for the final four seasons is available only for Station 16. Many of the species plotted had slightly higher average densities in Year 3 than in the preceding two years of sampling, although these differences appeared to be subtle rather than significant. The species Paraonis sp. A, Protodorvillea gaspeensis, and Tharyx marioni in particular showed this pattern (Figures 35, 35, and 40). No repeatable seasonal trends were detected for any of the species.

At Station 13 in the Mud Patch, the very sharp decline in overall densities between February 1982 (M3) to May 1982 (M4) was not repeated in either Year 2 or Year 3, nor was such a significant change in density evident in the population fluctuations of the species plotted in Figures 41-45. It is possible that the differences seen in samples collected on Cruise M4 were due to subtle differences in the station position on that cruise, with the result that we were not sampling the same populations as on all other cruises (see Chapter 10). Several species had fairly stable average densities over all remaining sampling

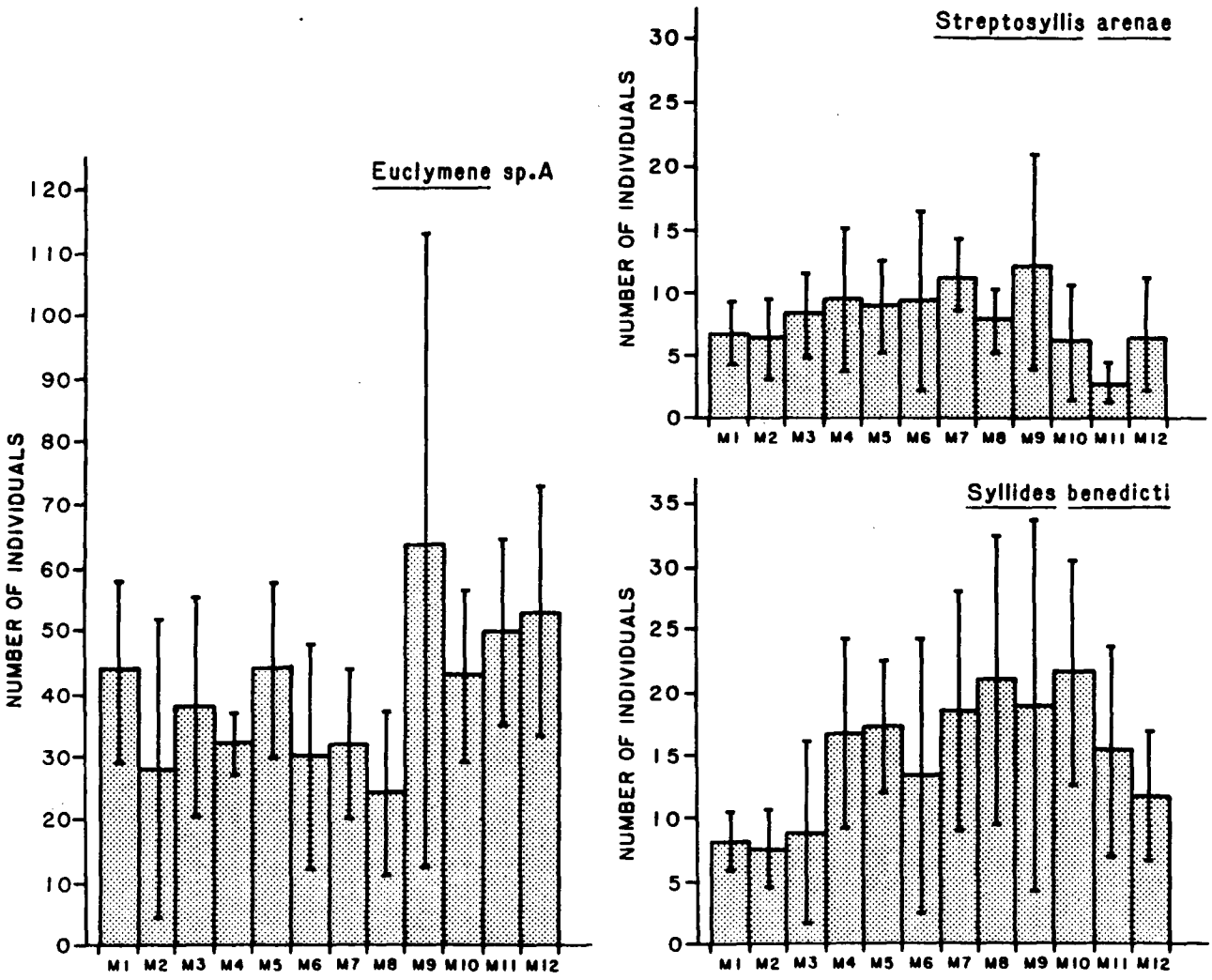

Figure 26. Average number of individuals per 0.04 m^2 ± one standard deviation of Euclymene sp. A, Streptosyllis arenae and Syllides benedicti at Site-Specific Station 5-1 for Cruises M1-M12 (see Table 3 for corresponding dates).

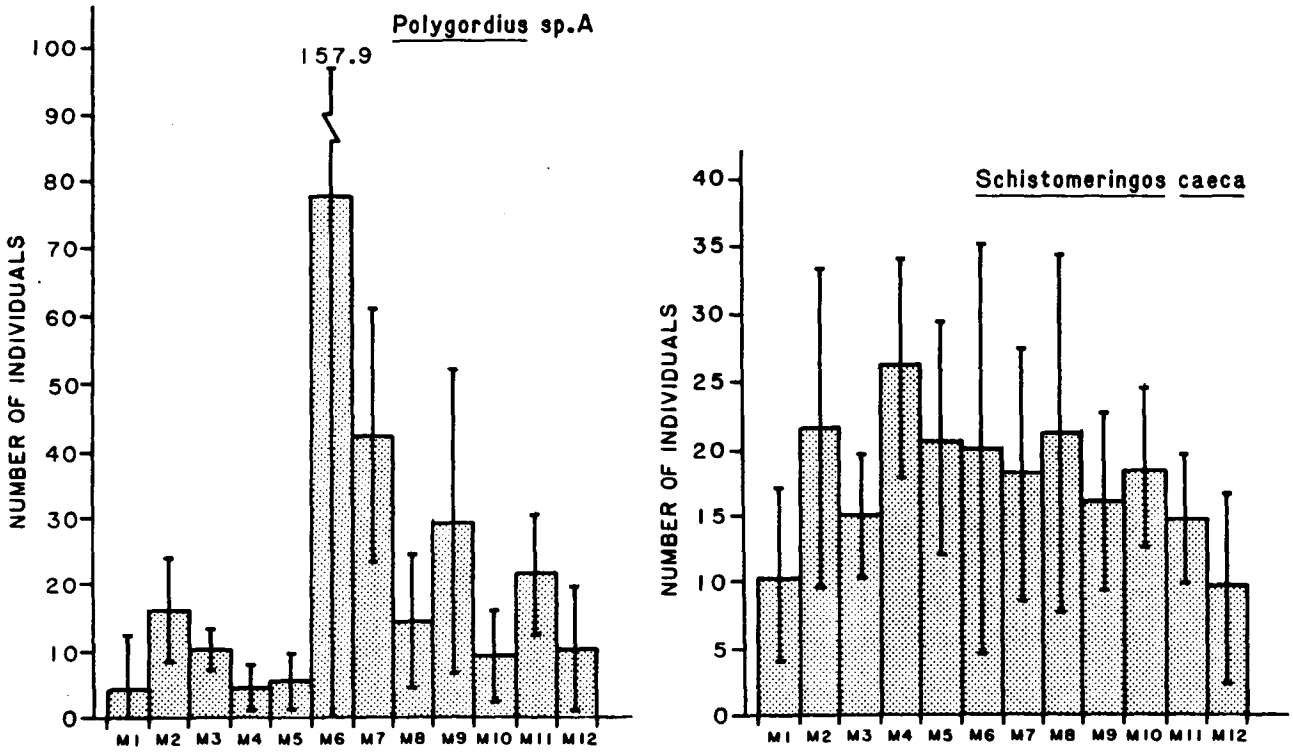

Figure 27. Average number of individuals per 0.04 m^2 ± one standard deviation of Polygordius sp. A and Schistomeringos caeca at Site-Specific Station 5-1 for Cruises M1-M12 (see Table 3 for corresponding dates).

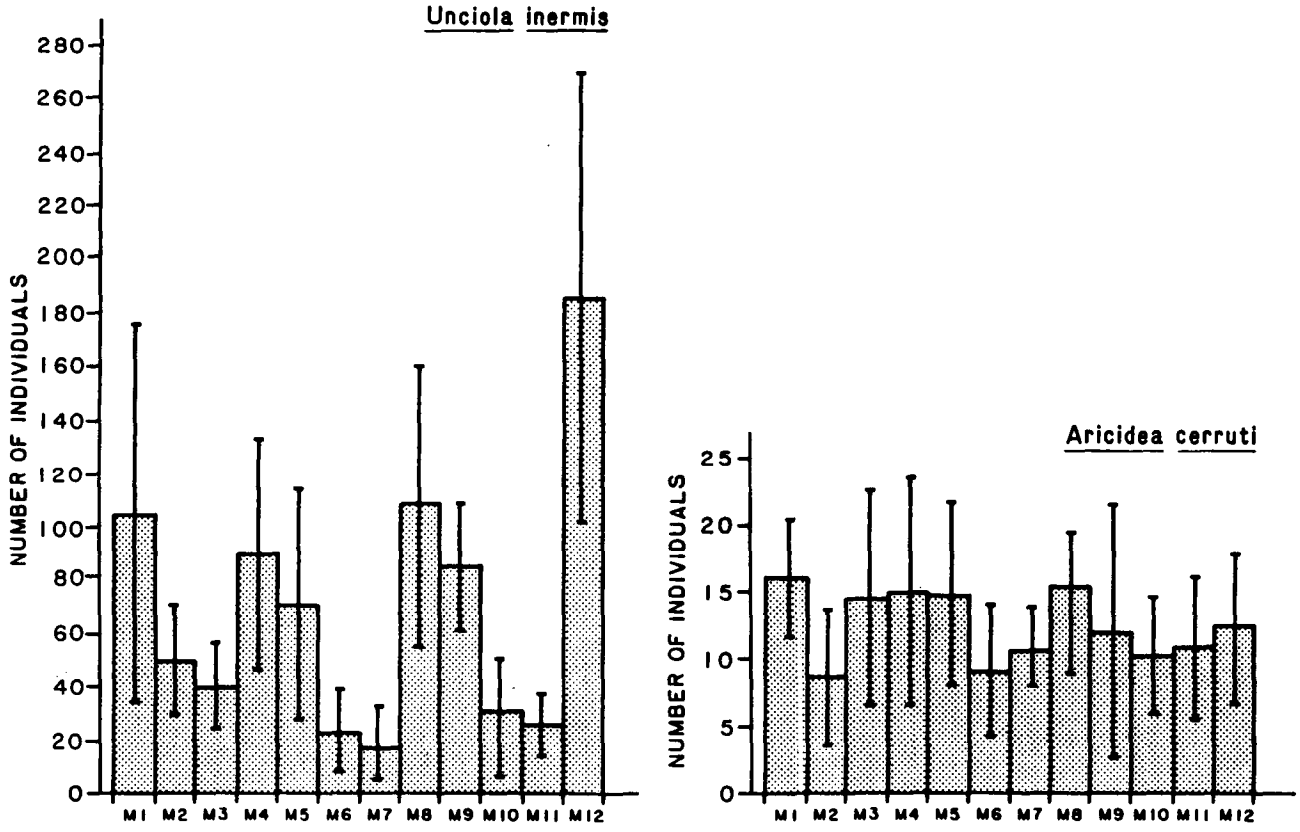

Figure 28. Average number of individuals per 0.04 m^2 $\pm$ one standard deviation of Unciola inermis and Aricidea cerruti at Site-Specific Station 5-1 for Cruises M1-M12 (see Table 3 for corresponding dates).

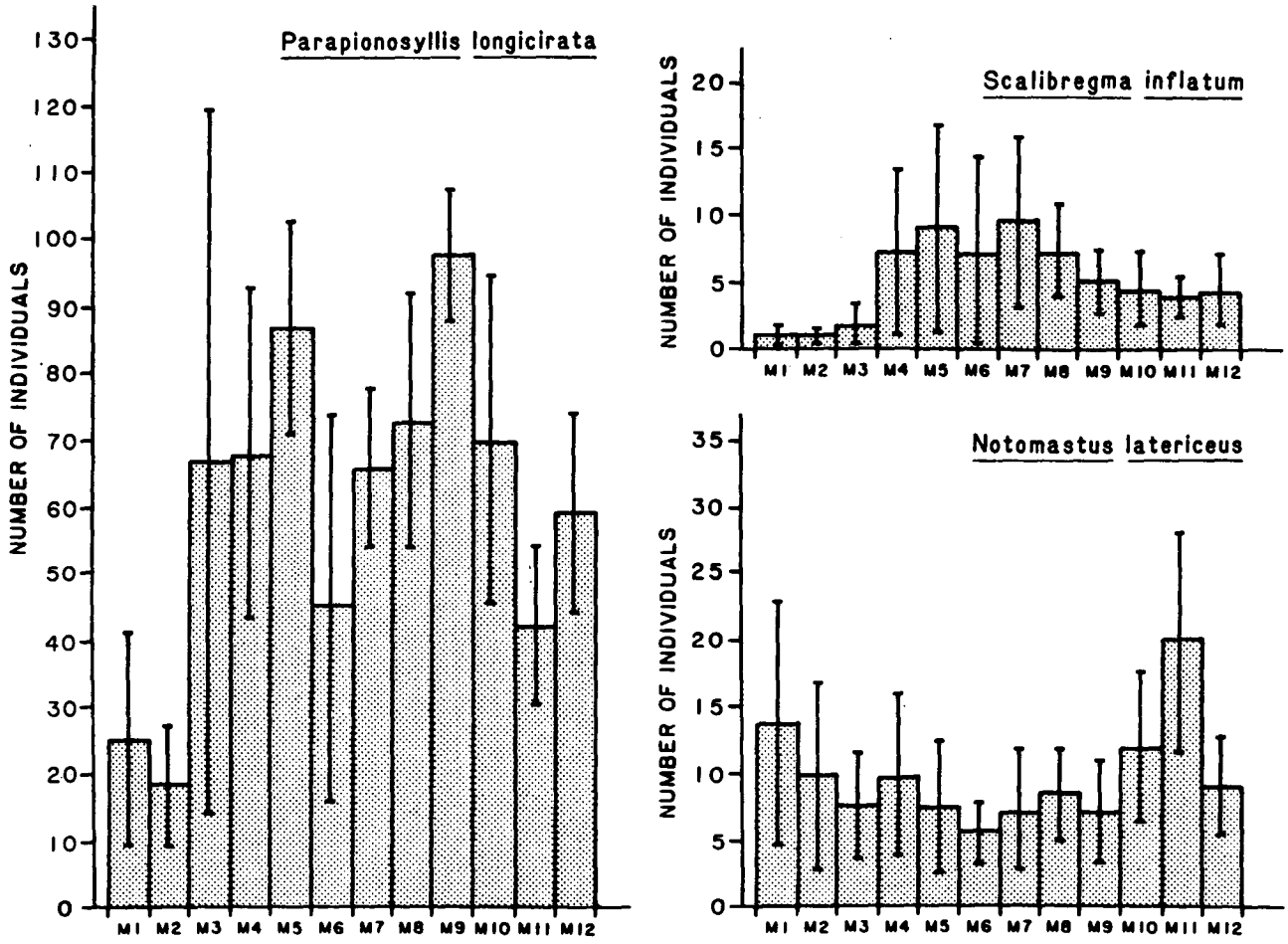

Figure 29. Average number of individuals per 0.04 m^2 ± one standard deviation of Parapionosyllis longicirrata, Scalibregma inflatum and Notomastus latericeus at Site-Specific Station 5-1 for Cruises M1-M12 (see Table 3 for corresponding dates).

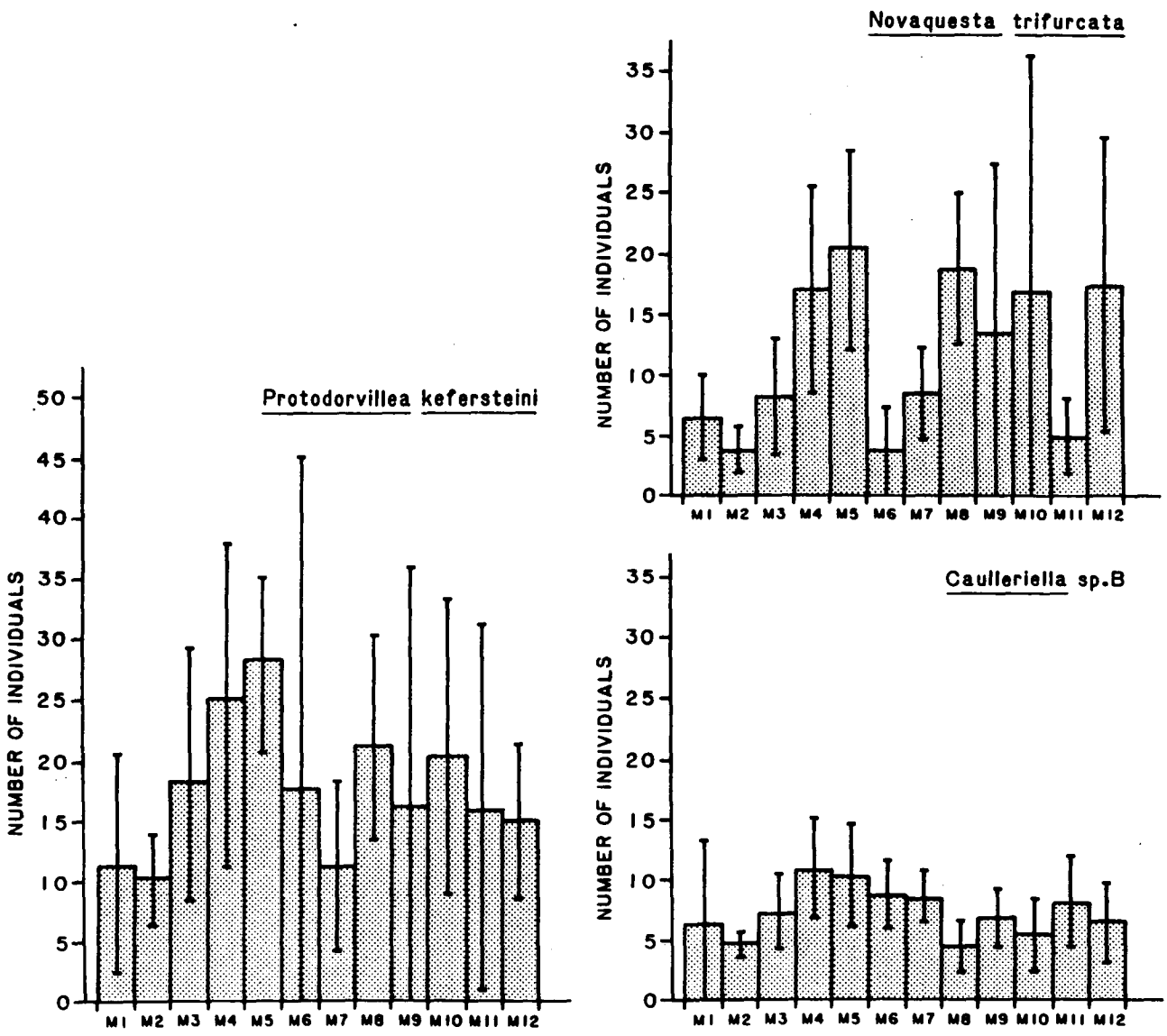

Figure 30. Average number of individuals per 0.04 m^2 ± one standard deviation of Protodorvillea kefersteini, Novaquesta trifurcata and Caulleriella sp. B at Site-Specific Station 5-1 for Cruises M1-M12 (see Table 3 for corresponding dates).

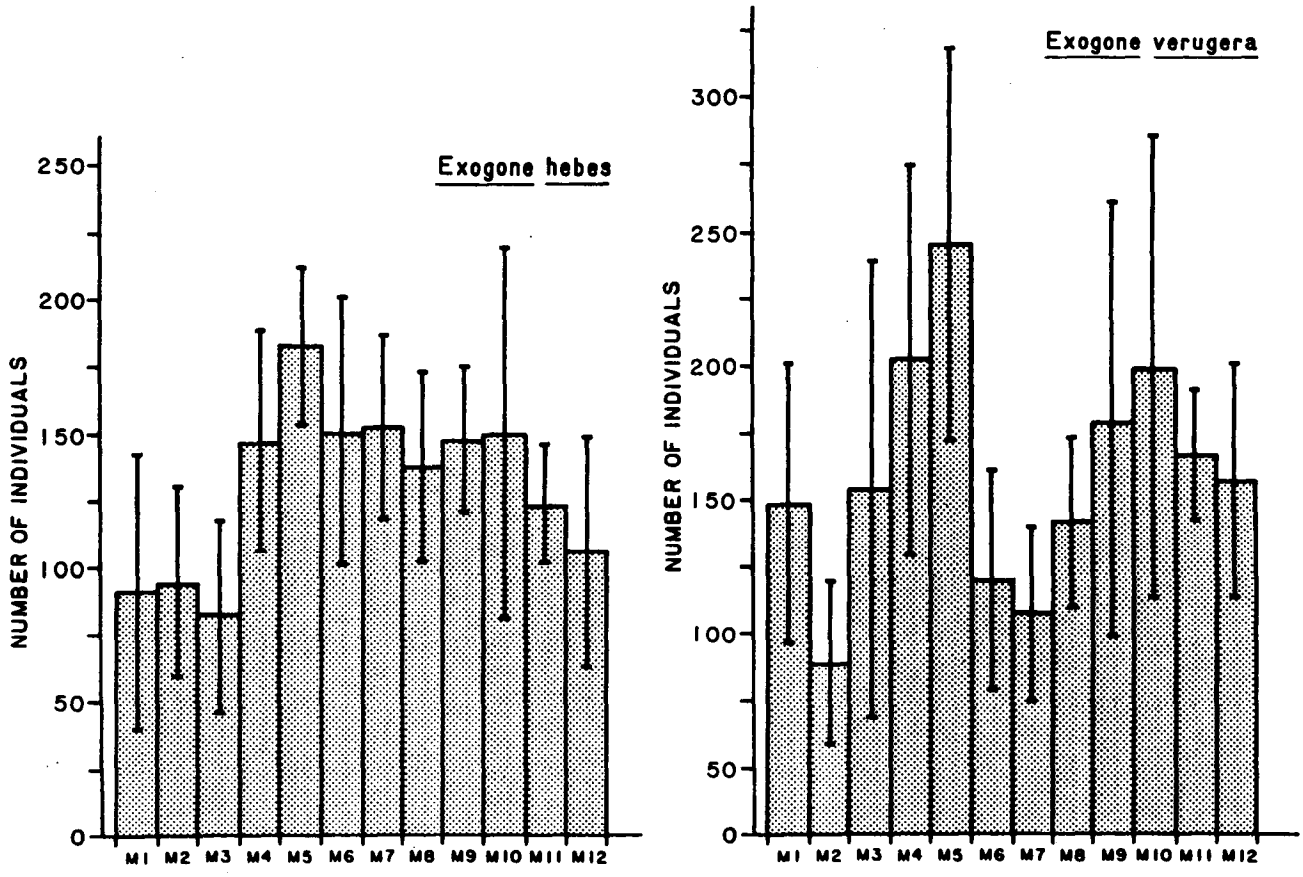

Figure 31. Average number of individuals per 0.04 m^2 ± one standard deviation of Exogone hebes and E. verugera at Site-Specific Station 5-1 for Cruises M1-M12 (see Table 3 for corresponding dates).

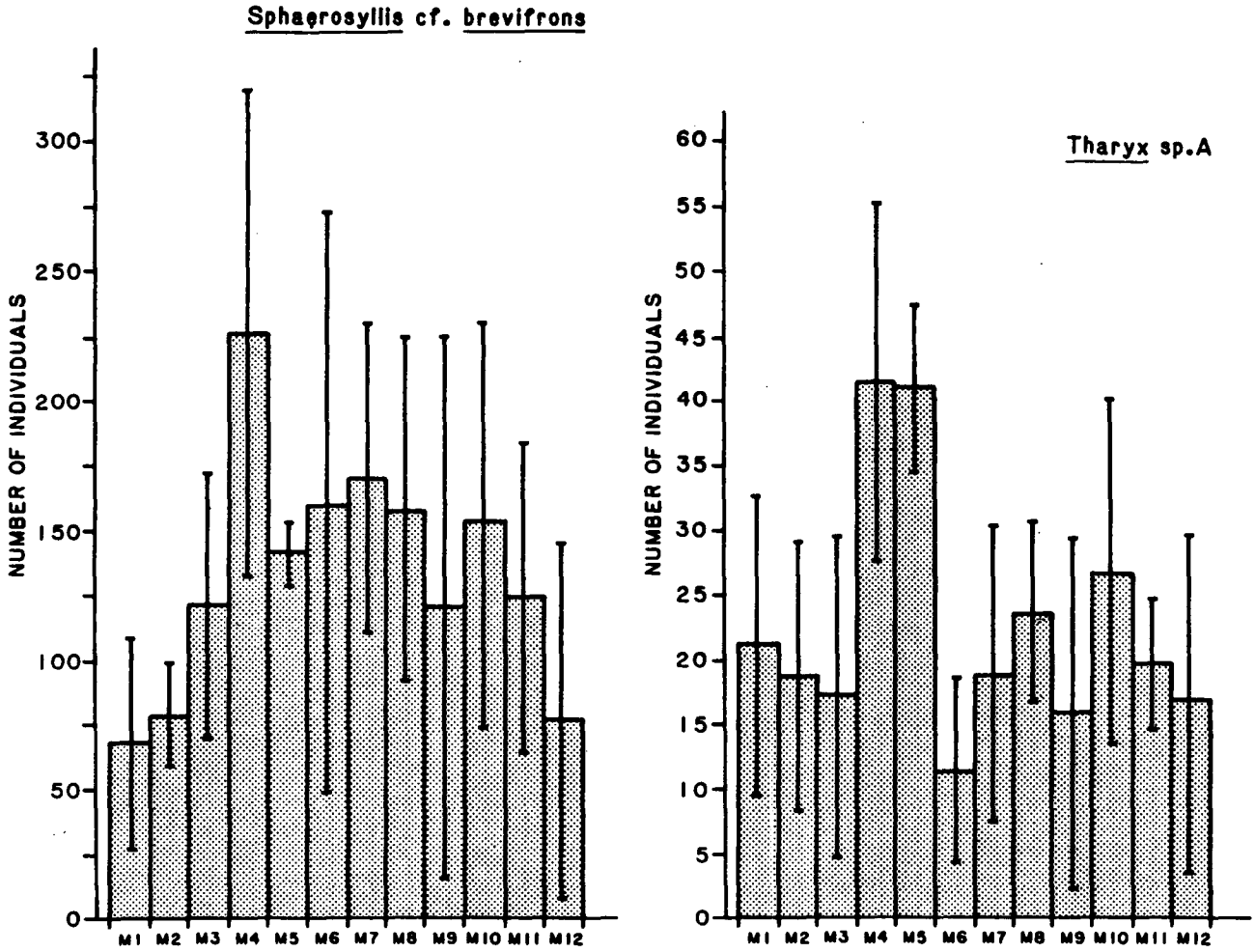

Figure 32. Average number of individuals per 0.04 m^2 ± one standard deviation of Sphaerosyllis cf. brevifrons and Tharyx sp. A at Site-Specific Station 5-1 for Cruises M1-M12 (see Table 3 for corresponding dates).

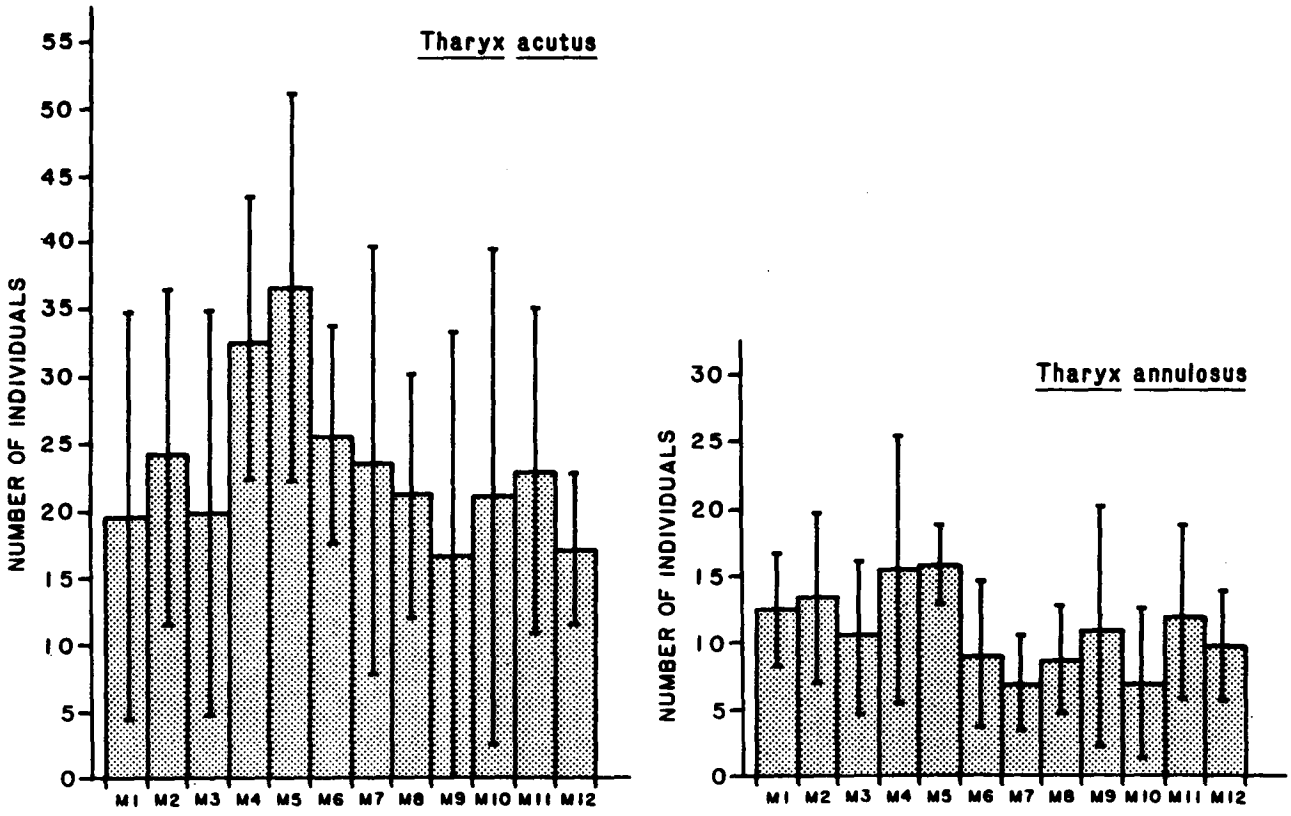

Figure 33. Average number of individuals per 0.04 m^2 $\pm$ one standard deviation of Tharyx acutus and T. annulosus at Site-Specific Station 5-1 for Cruises M1-M12 (see Table 3 for corresponding dates).

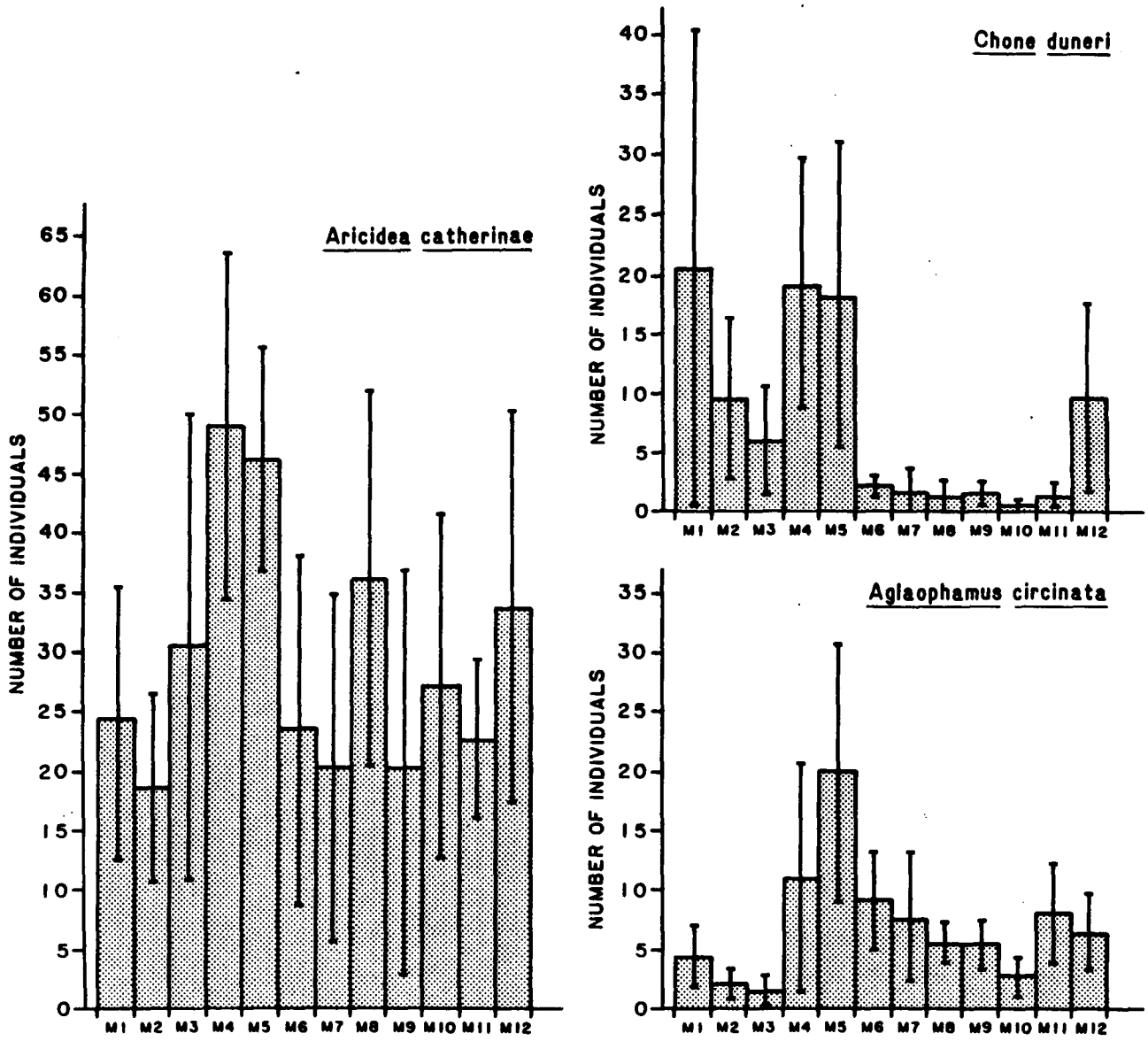

Figure 34. Average number of individuals per 0.04 m^2 $\pm$ one standard deviation of Aricidea catherinae, Chone duneri and Algaophamus circinata at Site-Specific Station 5-1 for Cruises M1-M12 (see Table 3 for corresponding dates).

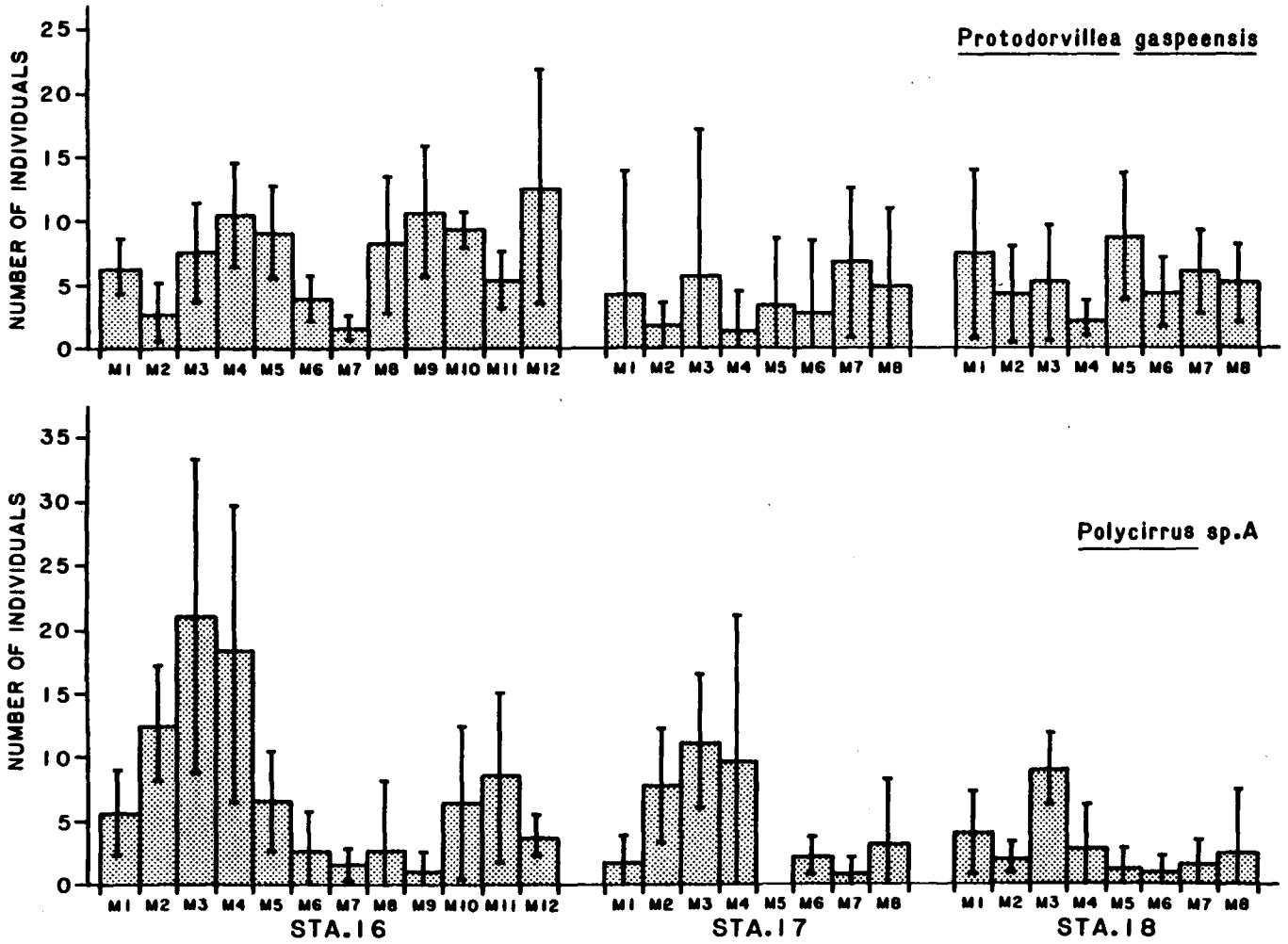

Figure 35. Average number of individuals per 0.04 m^2 ± one standard deviation of Protodorvillea gaspeenis and Polycirrus sp. A at the Block 410 Stations 16, 17 and 18 for Cruises M1-M12 (see Table 3 for corresponding dates).

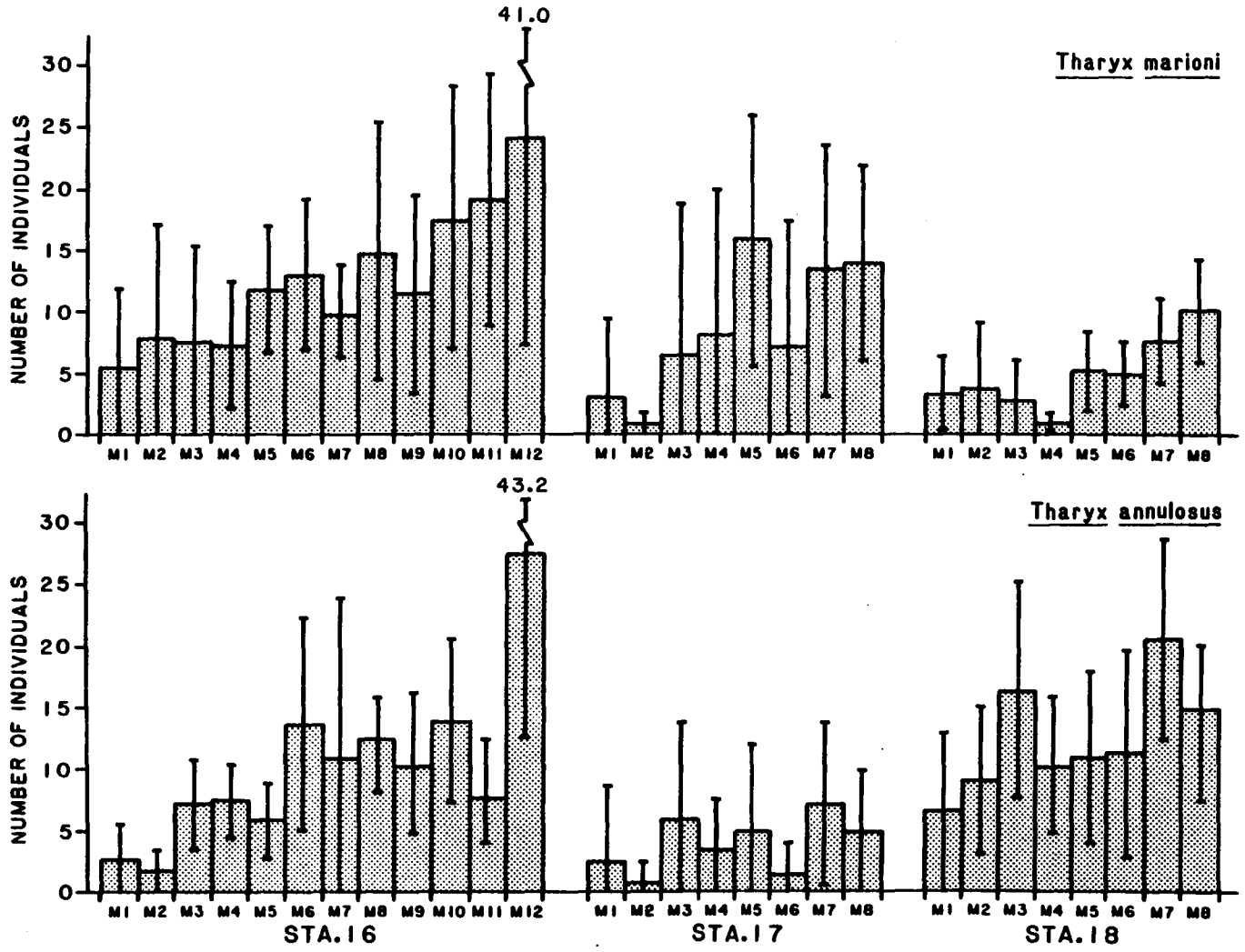

Figure 36. Average number of individuals per 0.04 ^{2} ± one standard deviation of Tharyx marioni and T. annulosus at the Block 410 Stations 16, 17 and 18 for Cruises M1-M12 (see Table 3 for corresponding dates).

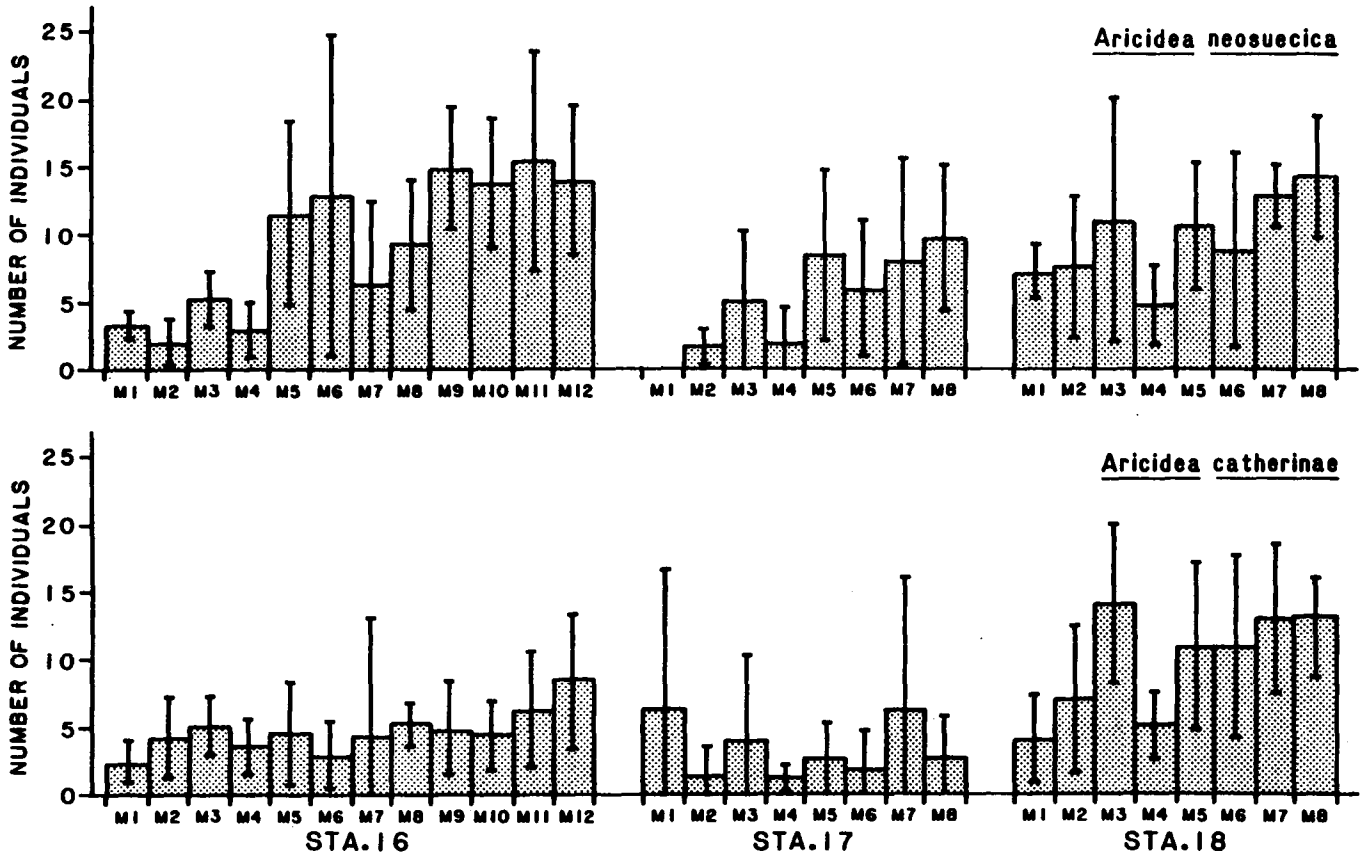

Figure 37. Average number of individuals per 0.04 m^2 ± one standard deviation of Aricidea neosuecica and A. catherinae at the Block 410 Stations 16, 17 and 18 for Cruises M1-M12 (see Table 3 for corresponding dates).

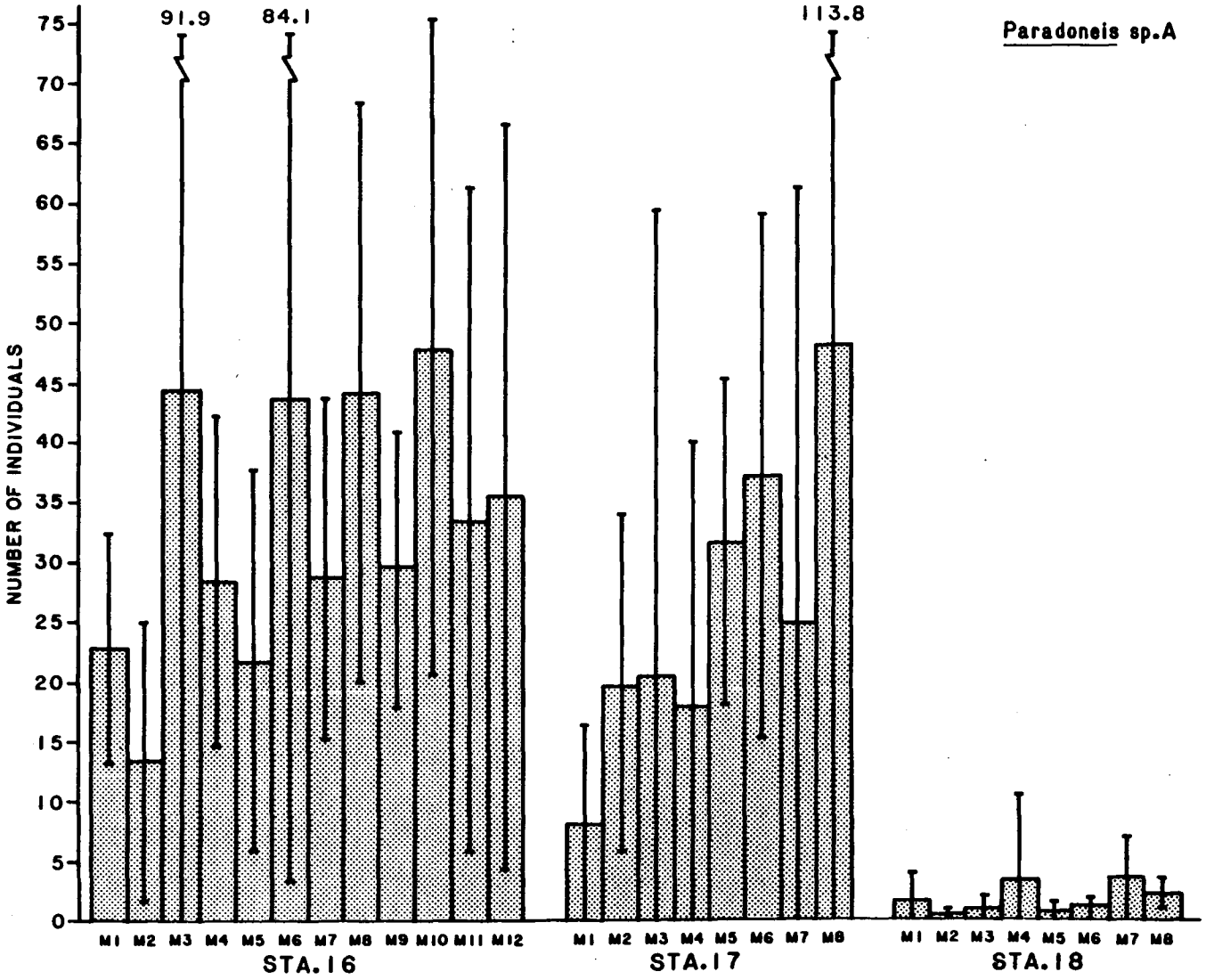

Figure 38. Average number of individuals per 0.04 m^2 ± one standard deviation of Paradoneis sp. A at the Block 410 Stations 16, 17 and 18 for Cruises M1-M12 (see Table 3 for corresponding dates).

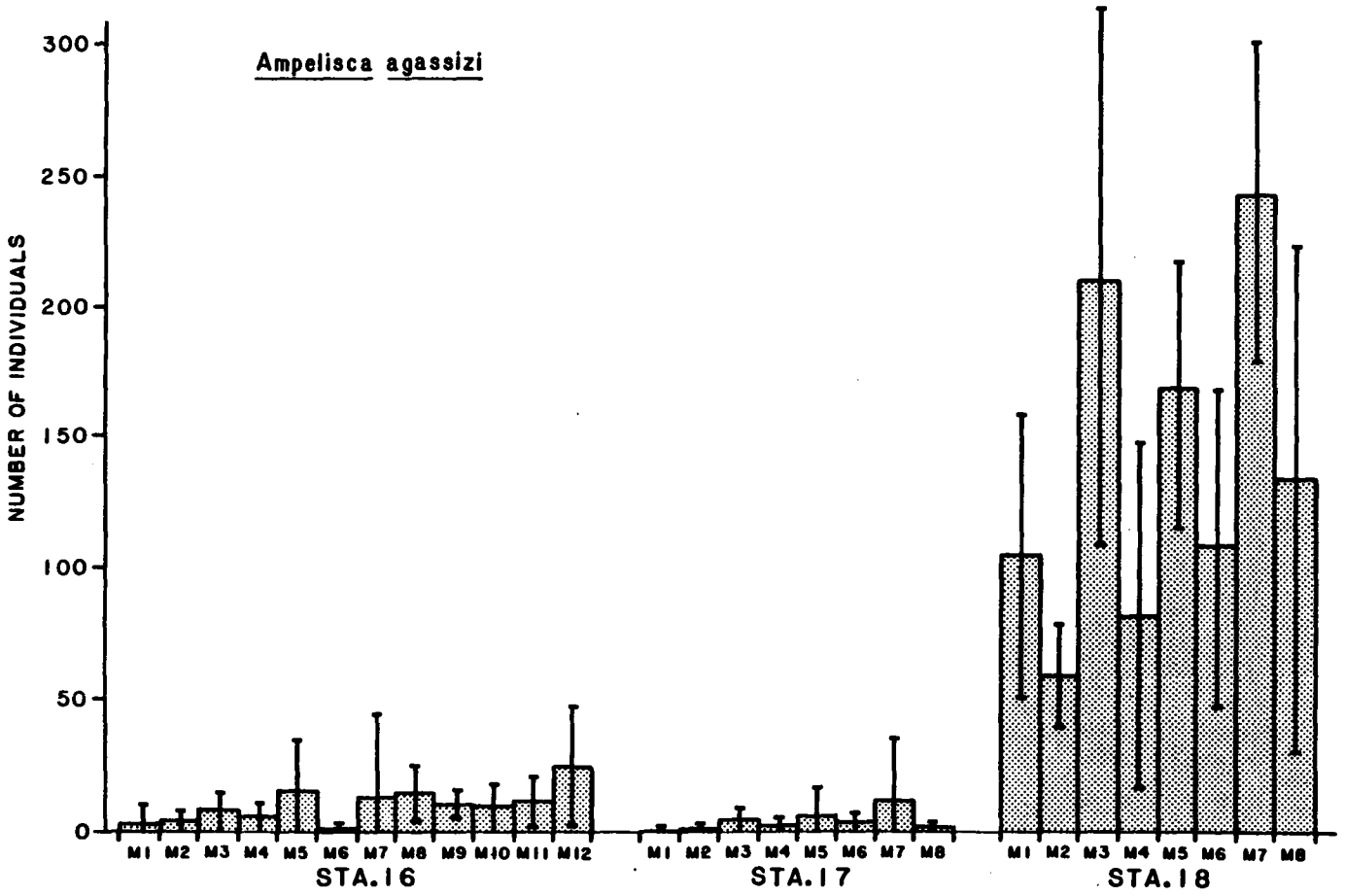

Figure 39. Average number of individuals per 0.04 m^2 $\pm$ one standard deviation of Ampelisca agassizi at the Block 410 Stations 16, 17 and 18 for Cruises M1-M12 (see Table 3 for corresponding dates).

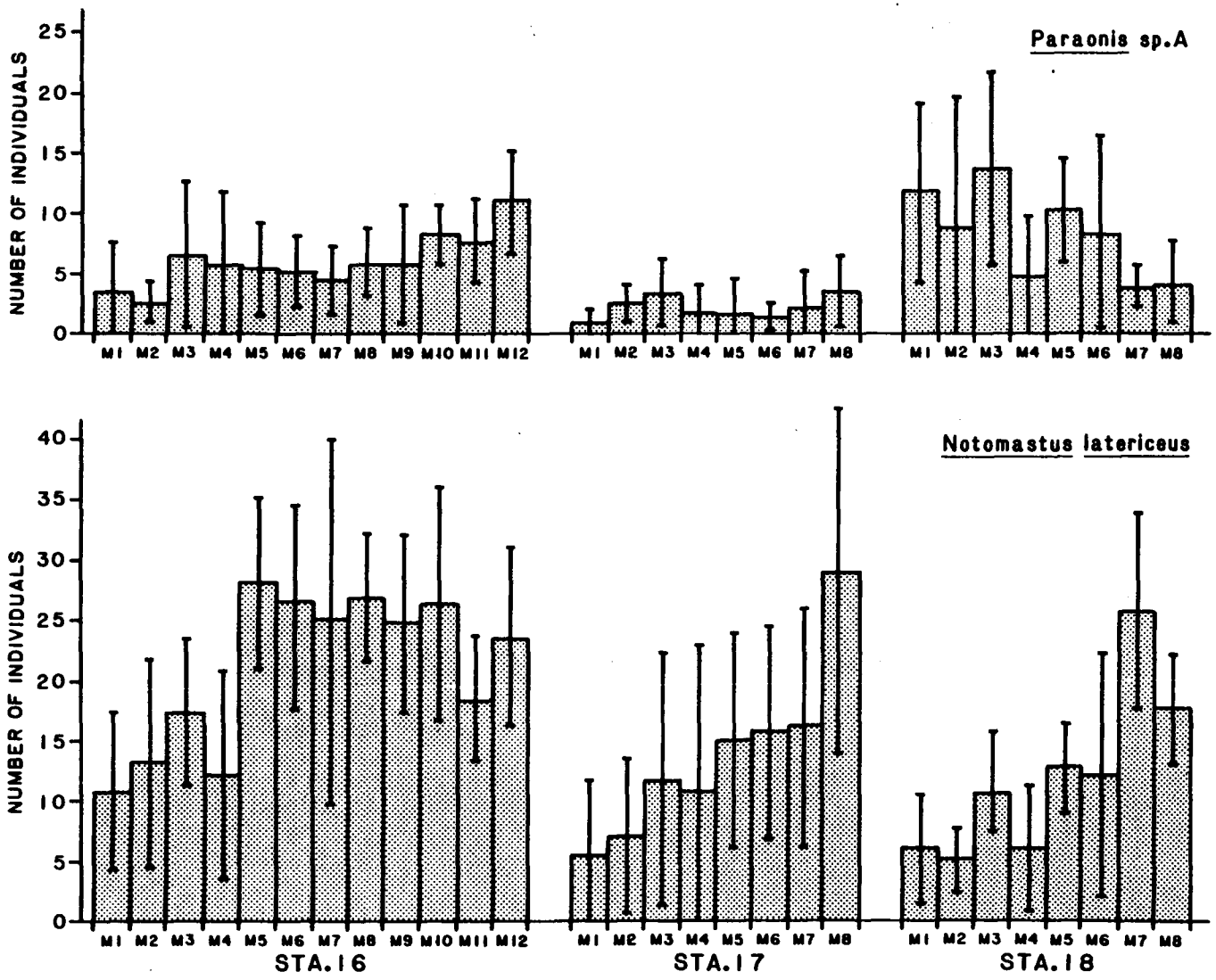

Figure 40. Average number of individuals per 0.04 m^2 ± one standard deviation of Paraonis sp. A and Notomastus latericeus at the Block 410 Stations 16, 17 and 18 for Cruises M1-M12 (see Table 3 for corresponding dates).

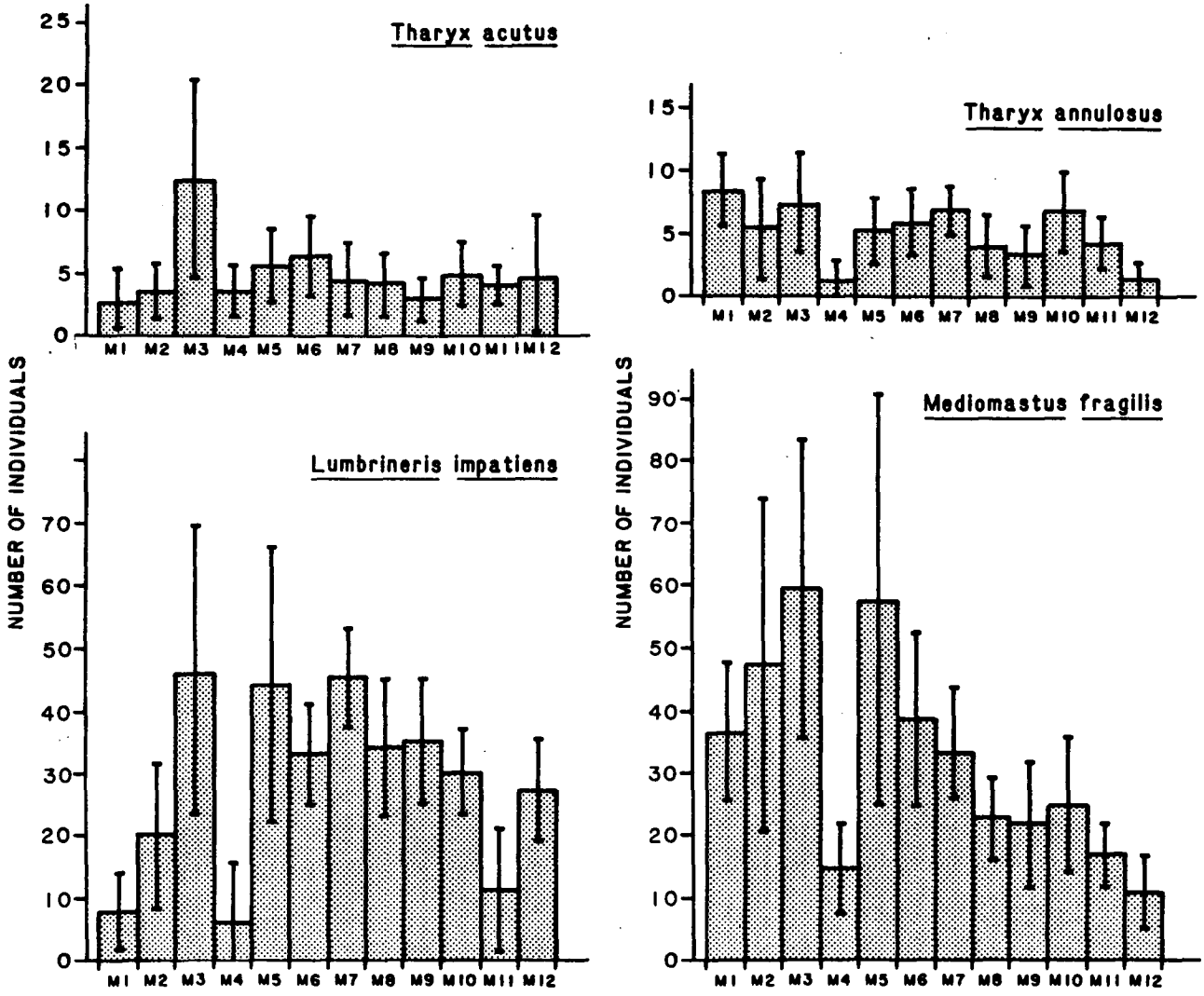

Figure 41. Average number of individuals per 0.04 m^2 ± one standard deviation of Tharyx acutus, T. annulosus, Lumbrineris impatiens and Mediomastus fragilis at Regional Station 13 for Cruises M1-M12 (see Table 3 for corresponding dates).

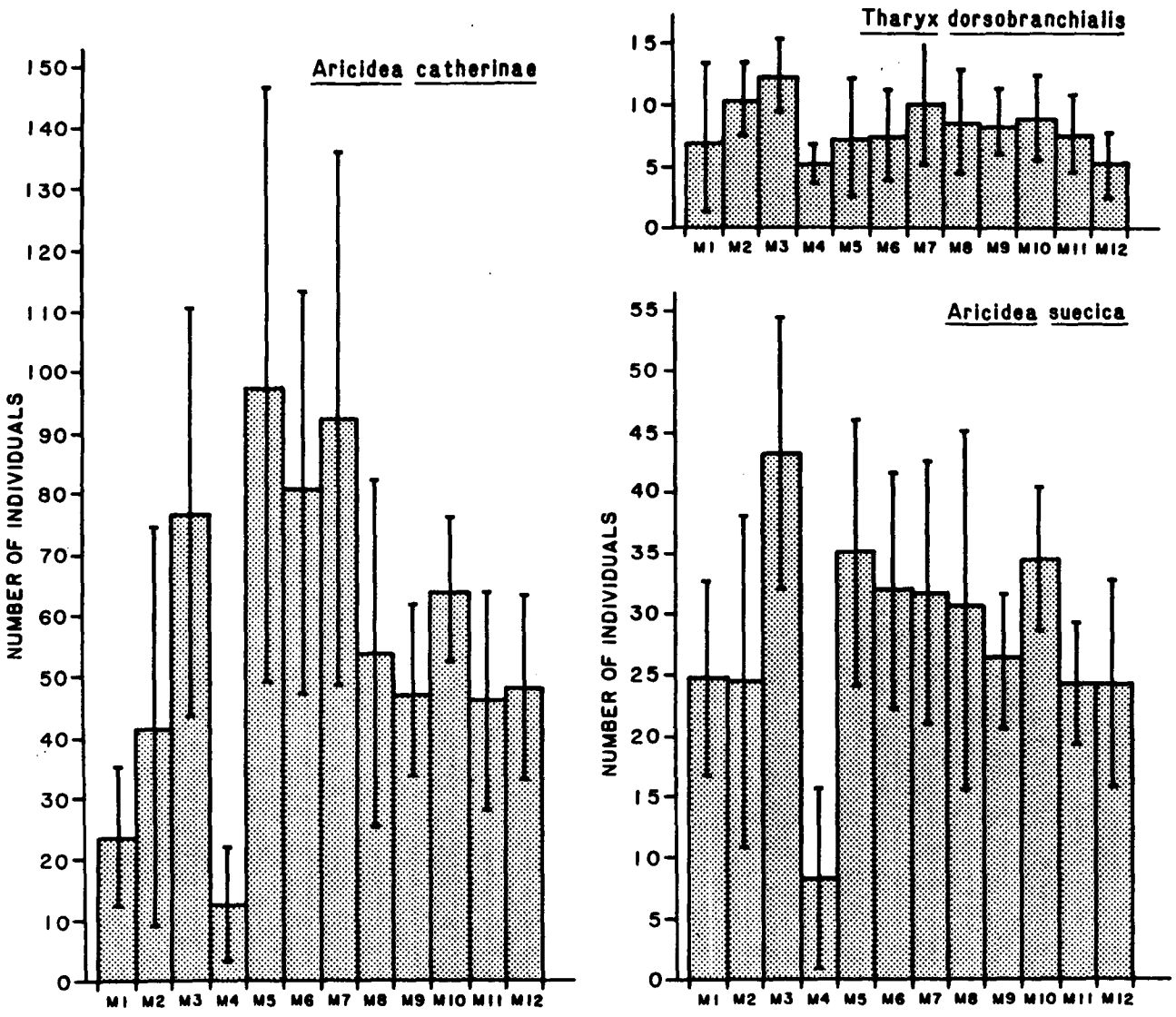

Figure 42. Average number of individuals per 0.04 m^2 ± one standard deviation of Aricidea catherinae, A. suecica and Tharyx dorsobranchialis at Regional Station 13 for Cruises M1-M12 (see Table 3 for corresponding dates).

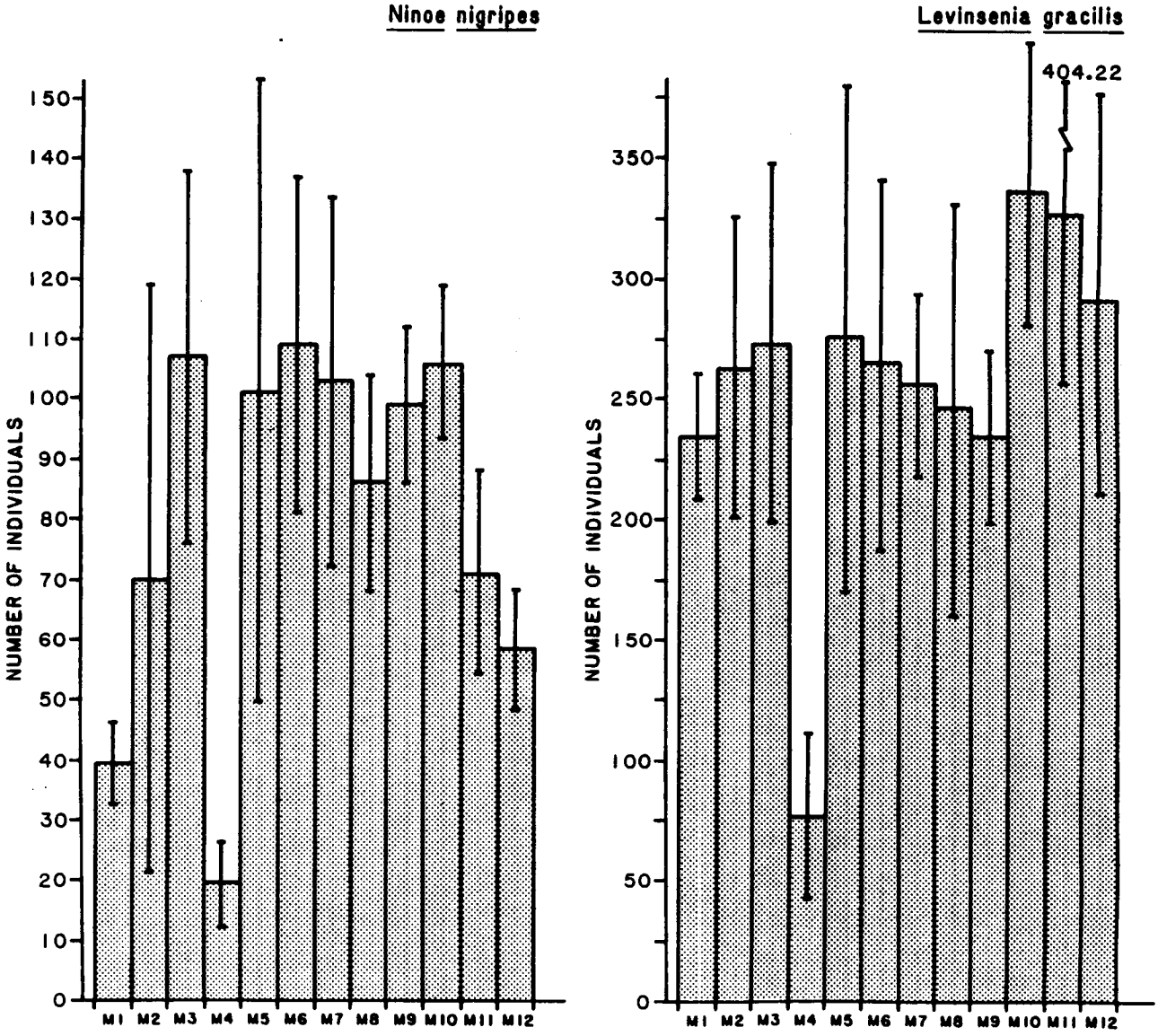

Figure 43. Average number of individuals per 0.04 m^2 ± one standard deviation of Ninoe nigripes and Levinsenia gracilis at Regional Station 13 for Cruises M1-M12 (see Table 3 for corresponding dates).

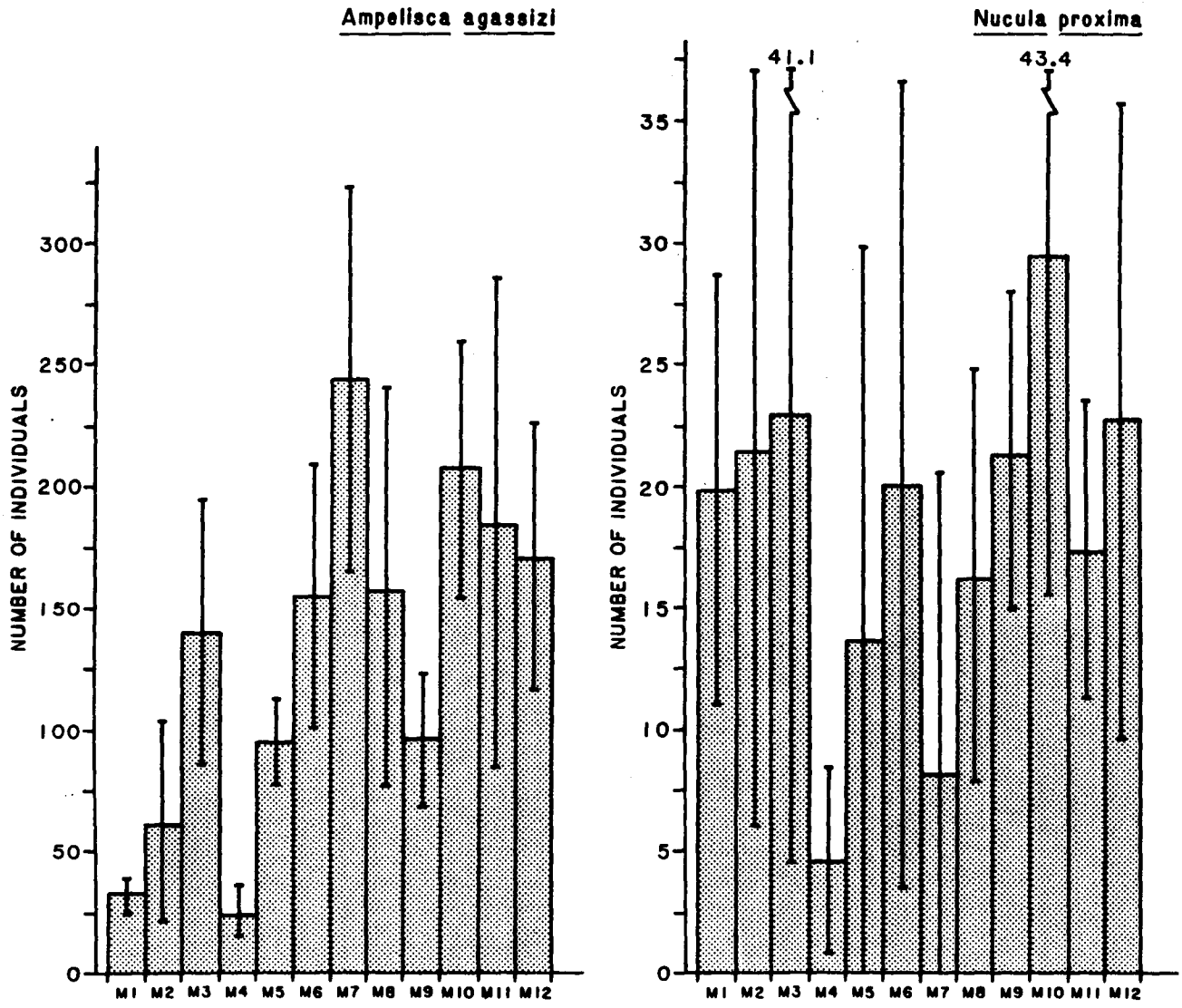

Figure 44. Average number of individuals per 0.04 m^2 $\pm$ one standard deviation of Ampelisca agassizi and Nucula proxima at Regional Station 13 for Cruises M1-M12 (see Table 3 for corresponding dates).

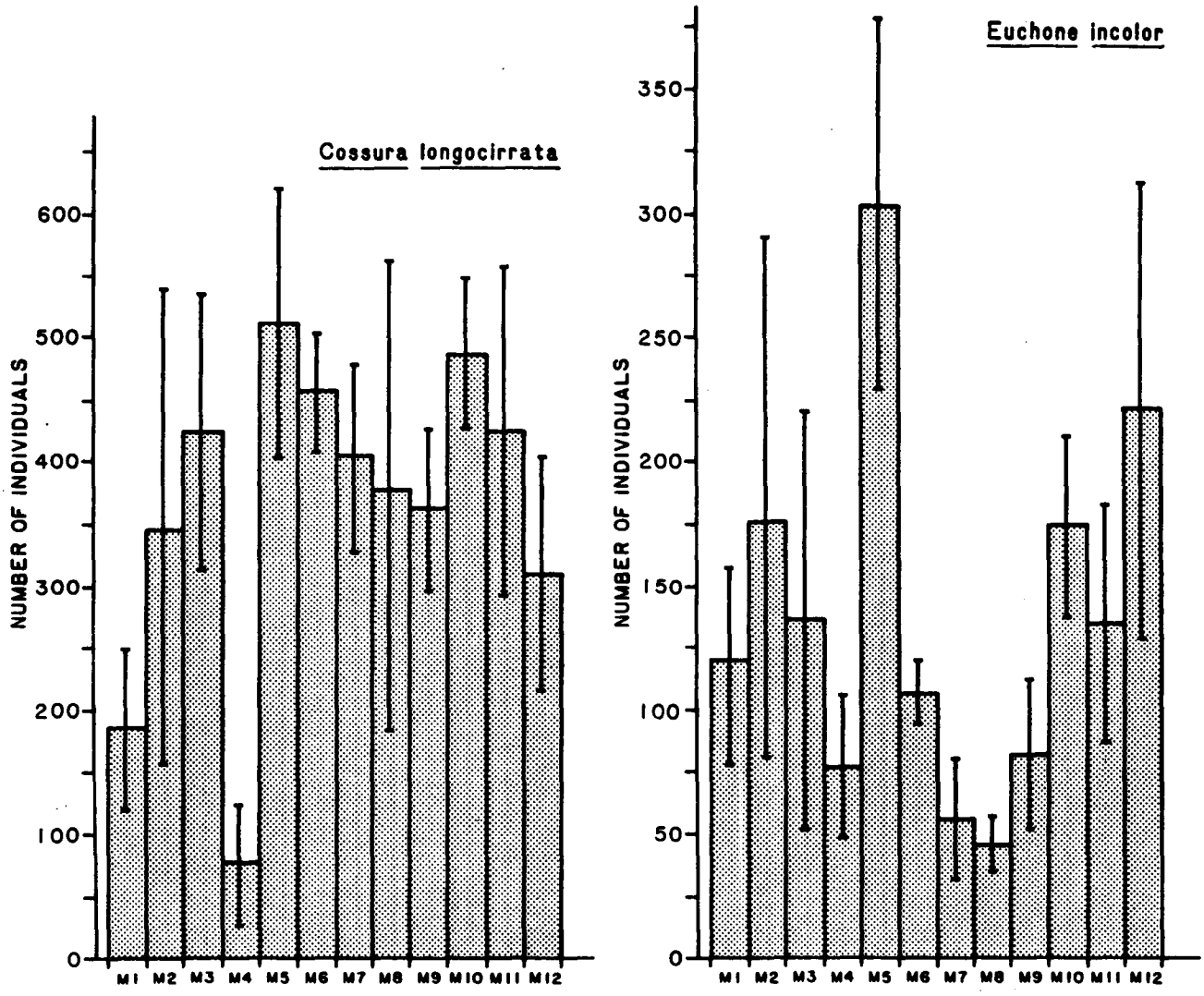

Figure 45. Average number of individuals per 0.04 m^2 $\pm$ one standard deviation of Cossura longocirrata and Euchone incolor at Regional Station 13 for Cruises M1-M12 (see Table 3 for corresponding dates).

periods, especially those occurring in low densities, such as Tharyx acutus, T. annulosus, and T. dorsobranchialis (Figures 41-42). The average densities of species such as Mediomastus fragilis, Aricidea catherinae, and Ninoe nigripes appeared somewhat lower in Year 3 than in the previous year (Figures 41-42). Others either remained as high as in Year 2, or slightly higher. No real seasonal trends were evident for any species.

Community Parameters

Community parameters, including the total number of individuals and species, Shannon-Wiener diversity (H') and its associated evenness value (E), and Hurlbert's rarefaction or number of species expected per 100 or 1,000 individuals, are presented in Appendix F, Tables F-1 and F-2.

The number of species present in six combined replicates (i.e., species per 0.24 m^2) are plotted for seven stations for all twelve sampling occasions in Figure 46. With some exceptions (e.g., Station 12), the highest number of species recorded was in July (M1, M5, M9) of each year. This peak was clearer in Year 2 (M5) than in Year 3 (M9), and was accounted for by a difference of from 2 to 25 species over the course of any one year.

The patterns in diversity observed in Years 1 and 2 (July 1981 - July 1983) were maintained in Year 3 as well (Figure 47). The shallower Stations 1, 4 and 10 had the lowest diversities, while those stations at 100 m or deeper had the highest diversities. Differences noted at the two drilling sites, Stations 5-1 and 16, are not considered to be significant. The lowest H' value at Station 5-1 occurred in February 1984, but did not correspond to the sampling period with the lowest densities or number of species. The value calculated for June 1984 was similar to that recorded for most other sampling dates. At Station 16, the lowest diversity value occurred in February 1982. At both drilling sites, most parameters, including total number of species and diversity, were generally higher in Years 2 and 3 than in Year 1, and essentially similar between Years 2 and 3.

The greatest variability in diversity was seen at the shallow Station 4 (Figure 47) which exhibited the lowest diversity of all the stations sampled. The lowest value at this station, H' = 1.11, occurred in November 1982 and the highest value, 3.07, was calculated for samples from June 1984.

Trends similar to those seen for the Shannon-Wiener index were also seen for species expected per 100 individuals (Figure 48) and for species expected per 1,000 individuals (Figure 49).

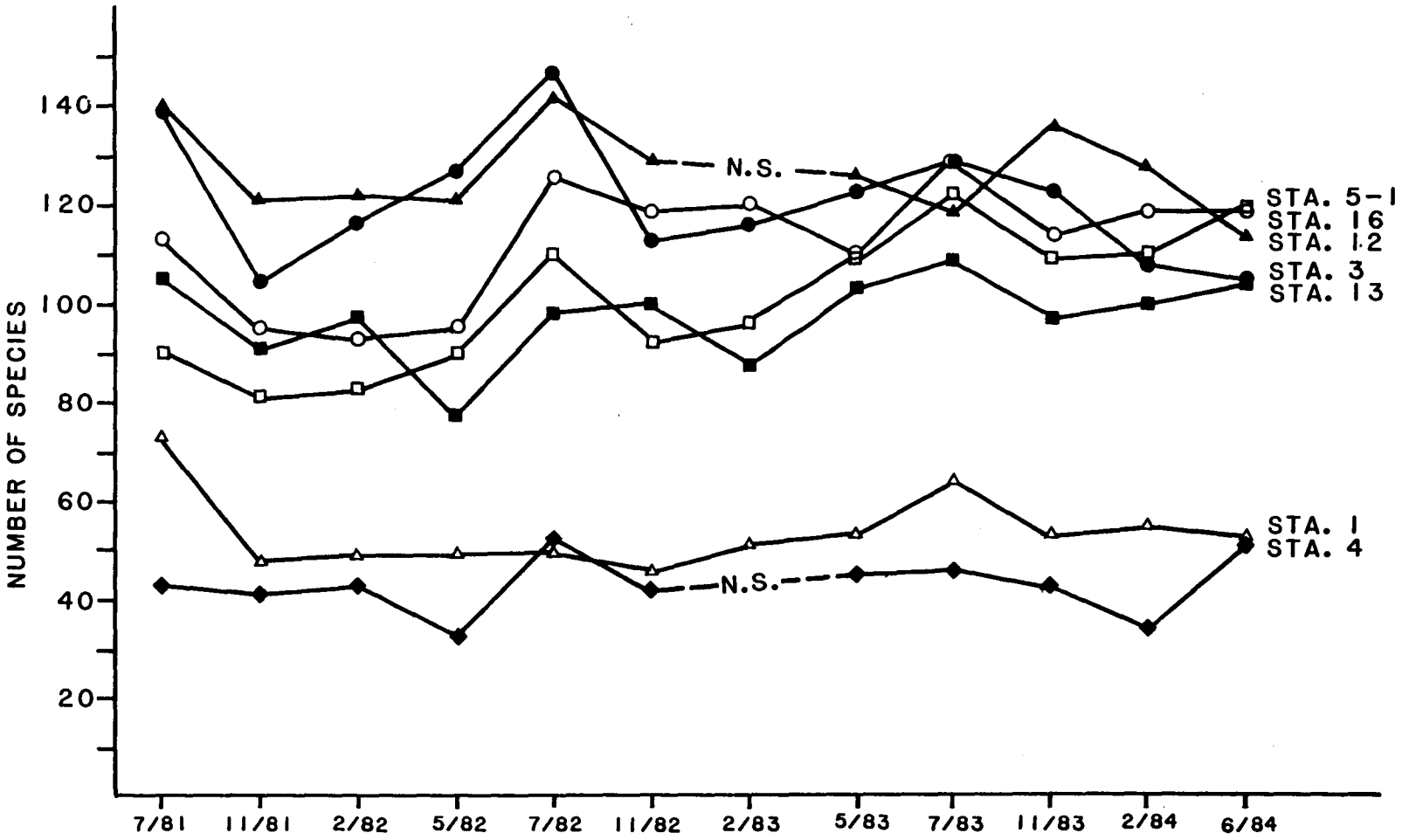

Figure 46. Number of species present in six combined replicates (species per 0.24 m^2) for each sampling occasion at selected Georges Bank monitoring stations.

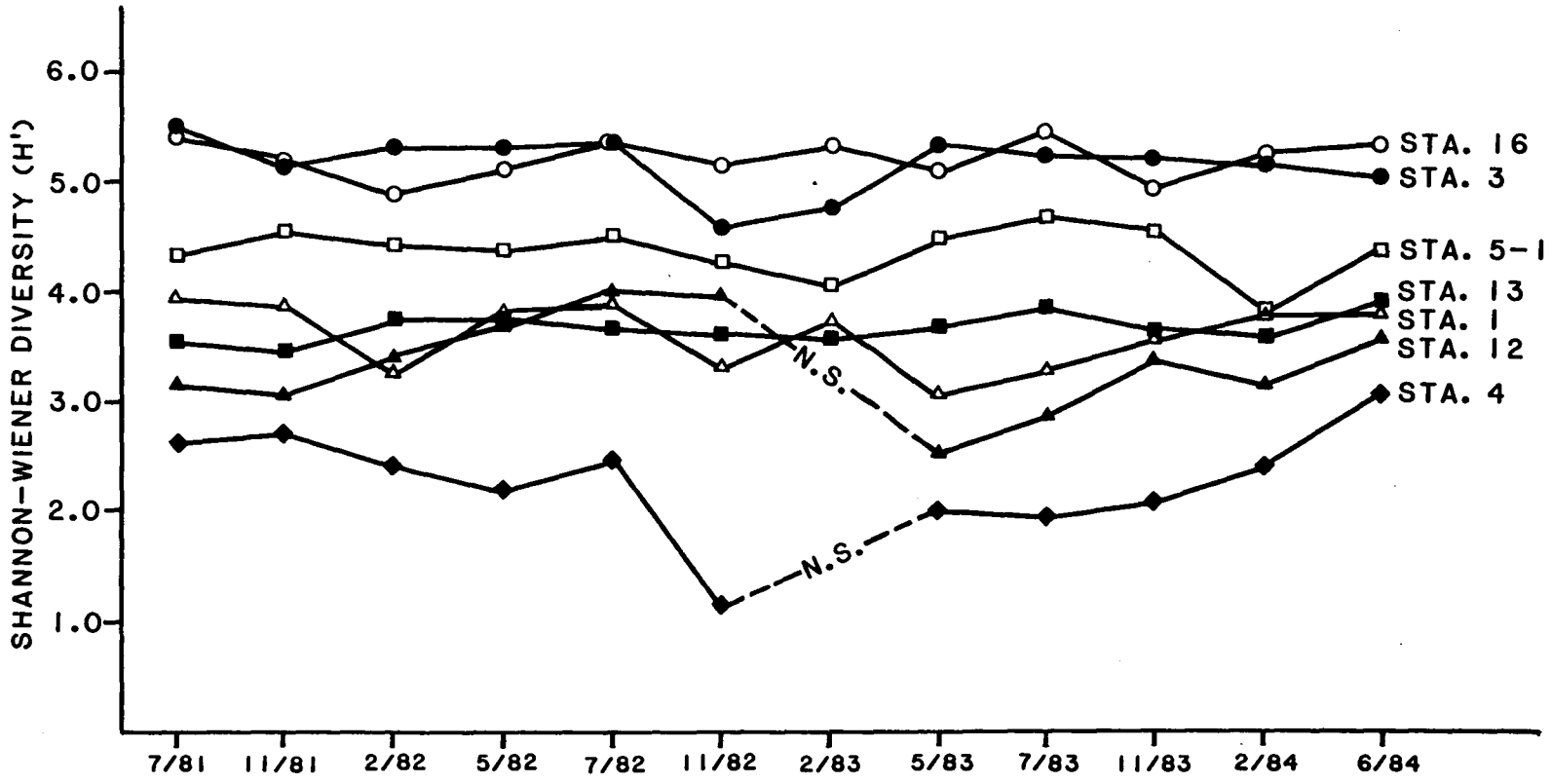

Figure 47. Shannon-Wiener diversity (H') for each sampling occasion at selected Georges Bank monitoring stations.

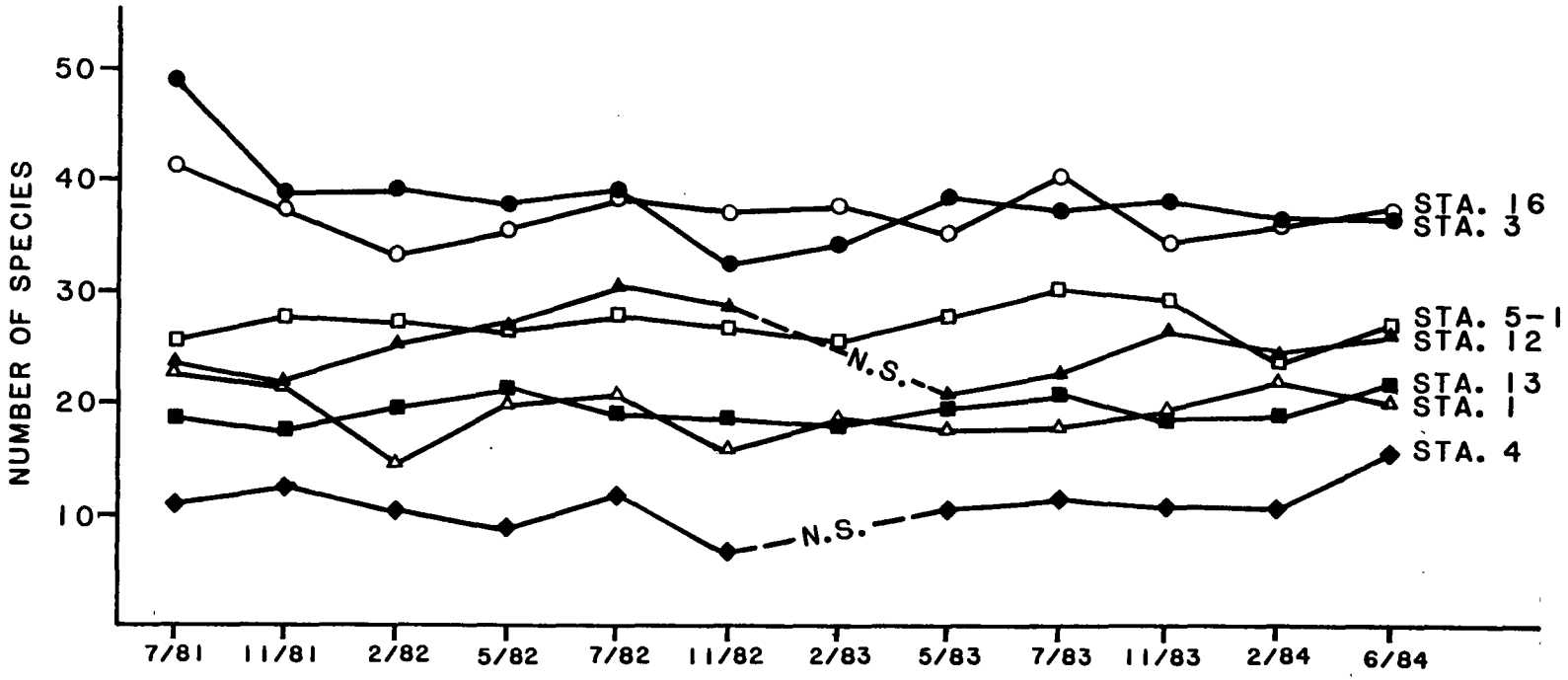

Figure 48. Number of species expected per 100 individuals for each sampling occasion at selected Georges Bank monitoring stations.

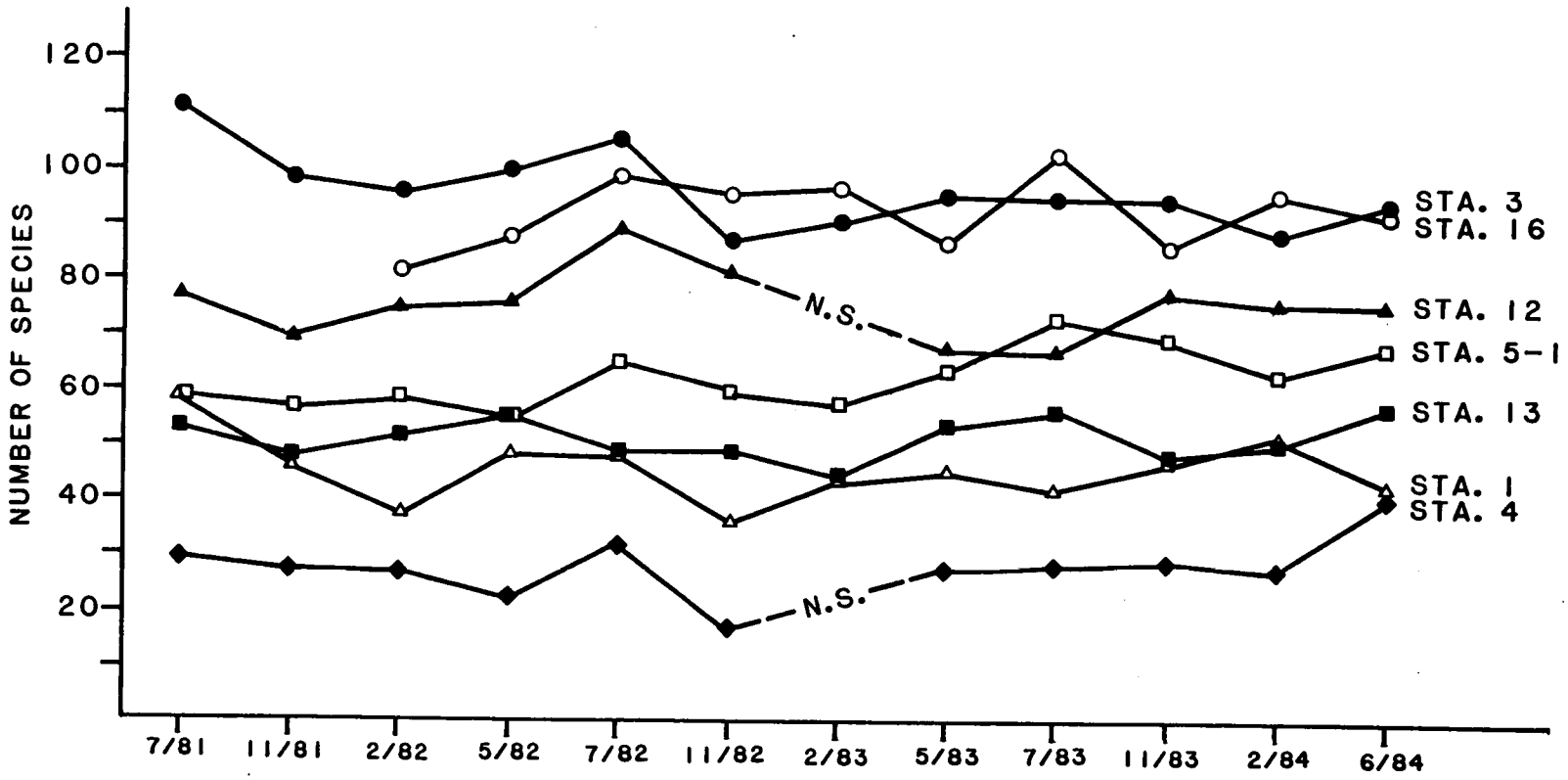

Figure 49. Number of species expected per 1000 individuals for each sampling occasion at selected Georges Bank monitoring stations. Insufficient sample size precluded calculation of this parameter for Station 16 in July and November 1981 (M1 and M2).

Cluster Analysis and Correspondence Analysis

Cluster Analysis. The very large number of individual samples necessitated a two-step process of analysis. Within a sampling date, the six replicates at each station were analyzed as independent samples. We were pleased to find that all of the replicates were more similar to each other than to 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 Stations 16 and 17. Since many of the stations are quite similar this indicates excellent replication of samples within stations. The examples of similarity between replicates from July 1983 - June 1984 (M9-M12) are illustrated in the figures in Appendix G. At the next step in the classification, Stations 2 and 5 have always grouped together as have Stations 1, 10 and 4 on the 60 m contour. 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 of the cluster analyses examined the relationship between samples formed by adding together the six replicates within each sampling date. These analyses are summarized in Figures 50-55 which are abbreviations of the corresponding complete cluster diagrams in Appendix G. The Georges Bank stations were sufficiently invariant over the entire three year period that every sampling date showed more affinity with the other samples from that station regardless of time despite faunal similarities with other stations. The deeper stations showed some differences after the first year but there is little evidence of seasonality in the data despite the obvious formation of sediment ripples during the winter.

To show the effects of different approaches to clustering, the stations were divided into two groups with overlap of Stations 3, 6, 12, and 13. NESS with m = 200 individuals gave essentially the same results as NESS with m = 50 individuals (Figures 51 and 53). By using a fourth root transformation on the data, percent similarities gave results similar to NESS except the difference between the first year and subsequent years at the deep stations was less obvious (Figures 52 and 54).

As shown in Figure 55, Stations 5-1, 5-18, and 5-28 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 station of the site-specific array, formed a discrete cluster in 1982 and 1983-84. In comparison to neighboring Station 5-28, Stations

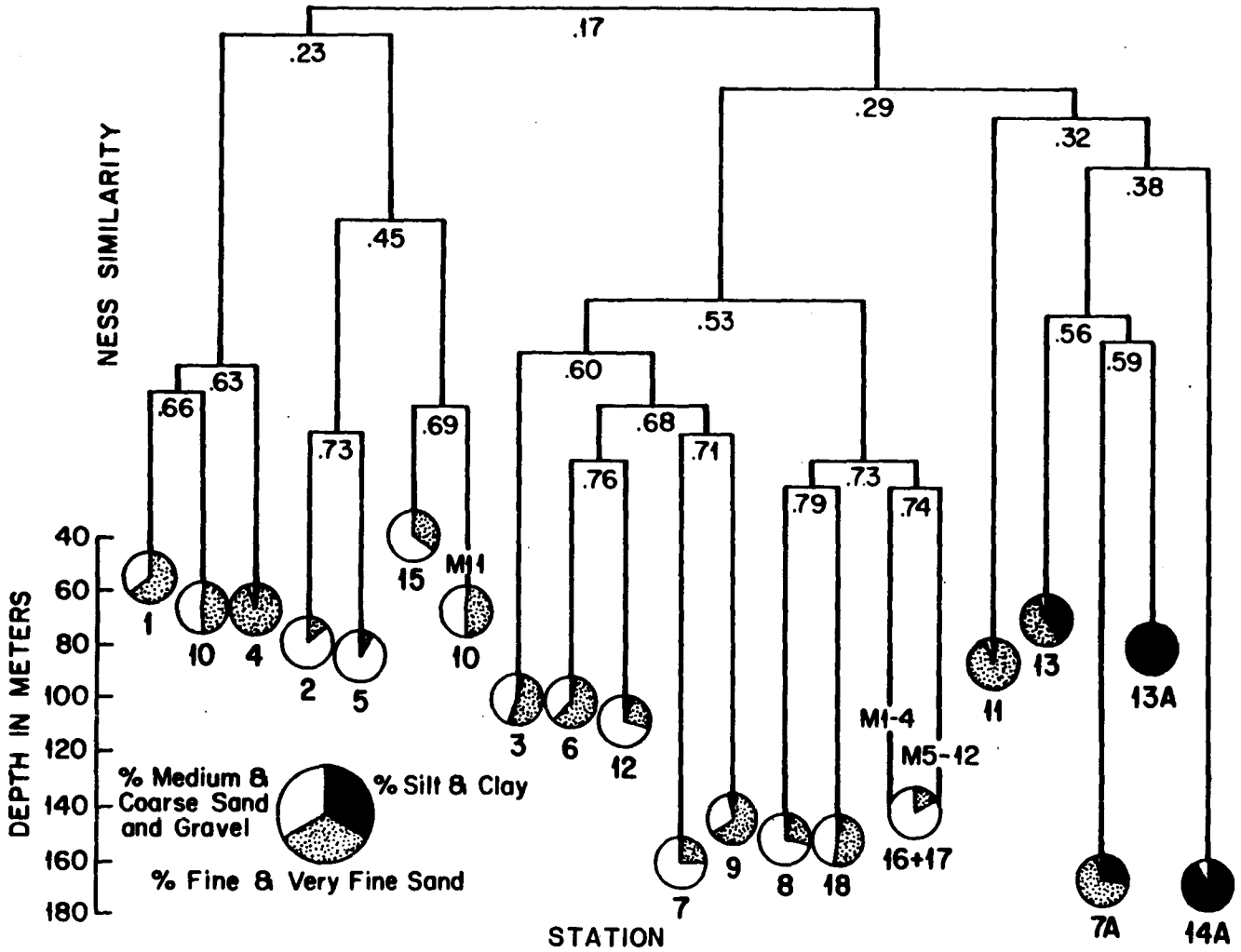

Figure 50. Summary of agglomerative cluster analysis using the sum of six replicates within each sampling date with NESS at 50 individuals and group average sorting. Results are related to station depth and sediment type. Except Station 10, February 1983 (M11), all of the samples at a given station cluster together regardless of season or year (Appendix G). Most stations had 11 to 12 sampling periods (see Table 3 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.

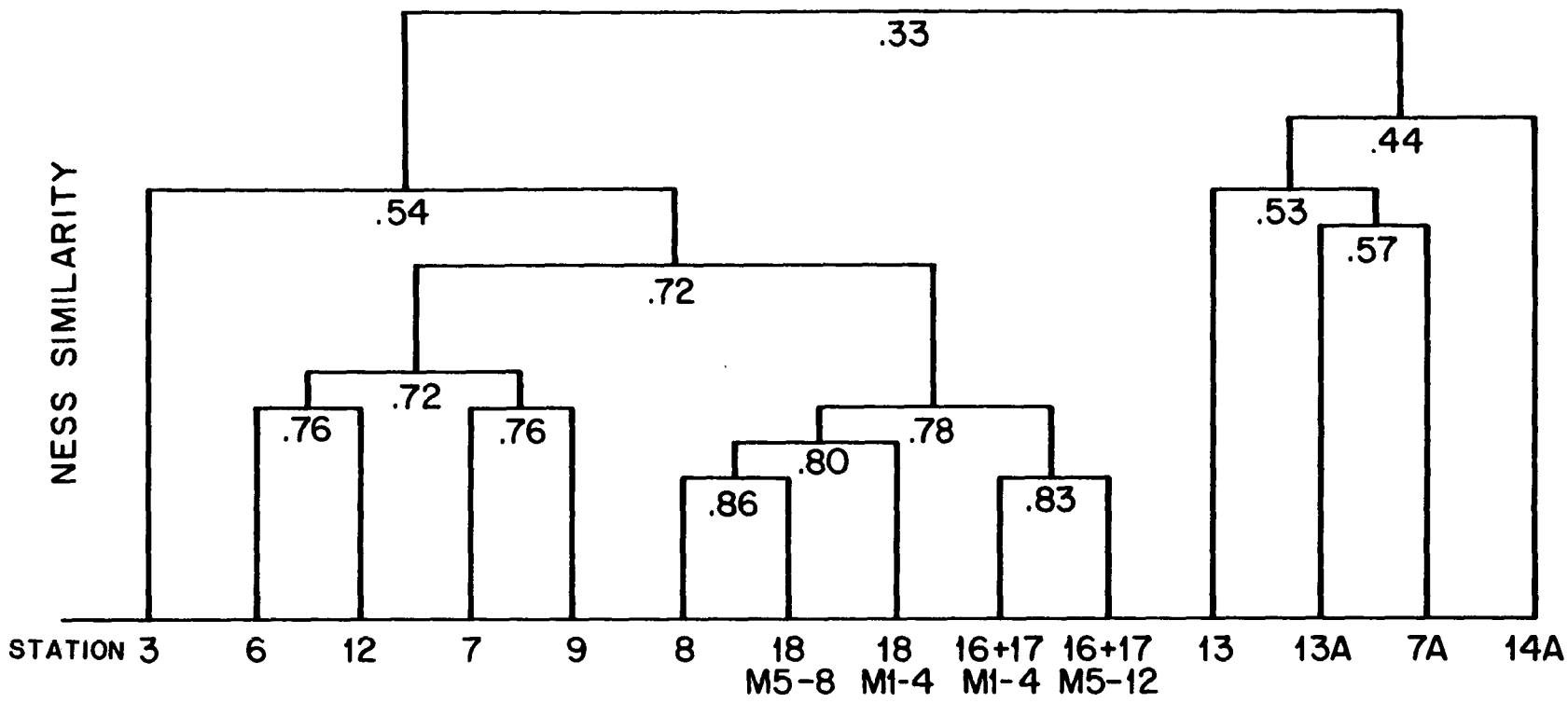

Figure 51. Summary of cluster analysis of the sum of six replicates within each sampling date using NESS similarity at 200 individuals and group average sorting. Shallow sandy Stations 1, 10, 4, 2, 5, 11 and 15 were excluded from this analysis. Stations 17 and 18 were sampled only on Cruises M1-M8 (see Table 3 for corresponding dates).

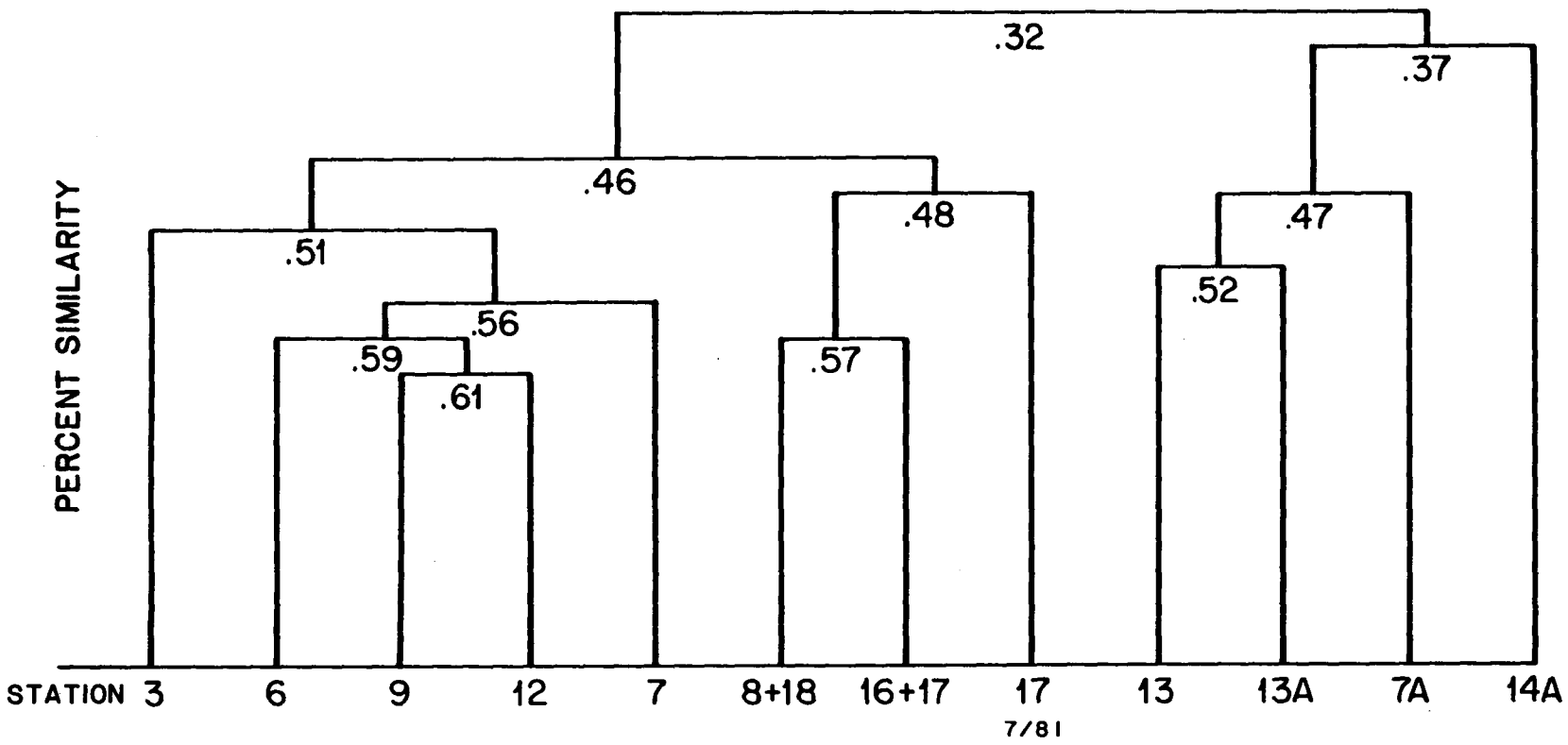

Figure 52. Summary of cluster analysis using the sum of six replicates within each sampling date. A fourth root transformation was used and the stations were clustered using percent similarity and group average clustering. Shallow sandy Stations 1, 2, 4, 5, 10, 11 and 15 were excluded from this analysis.

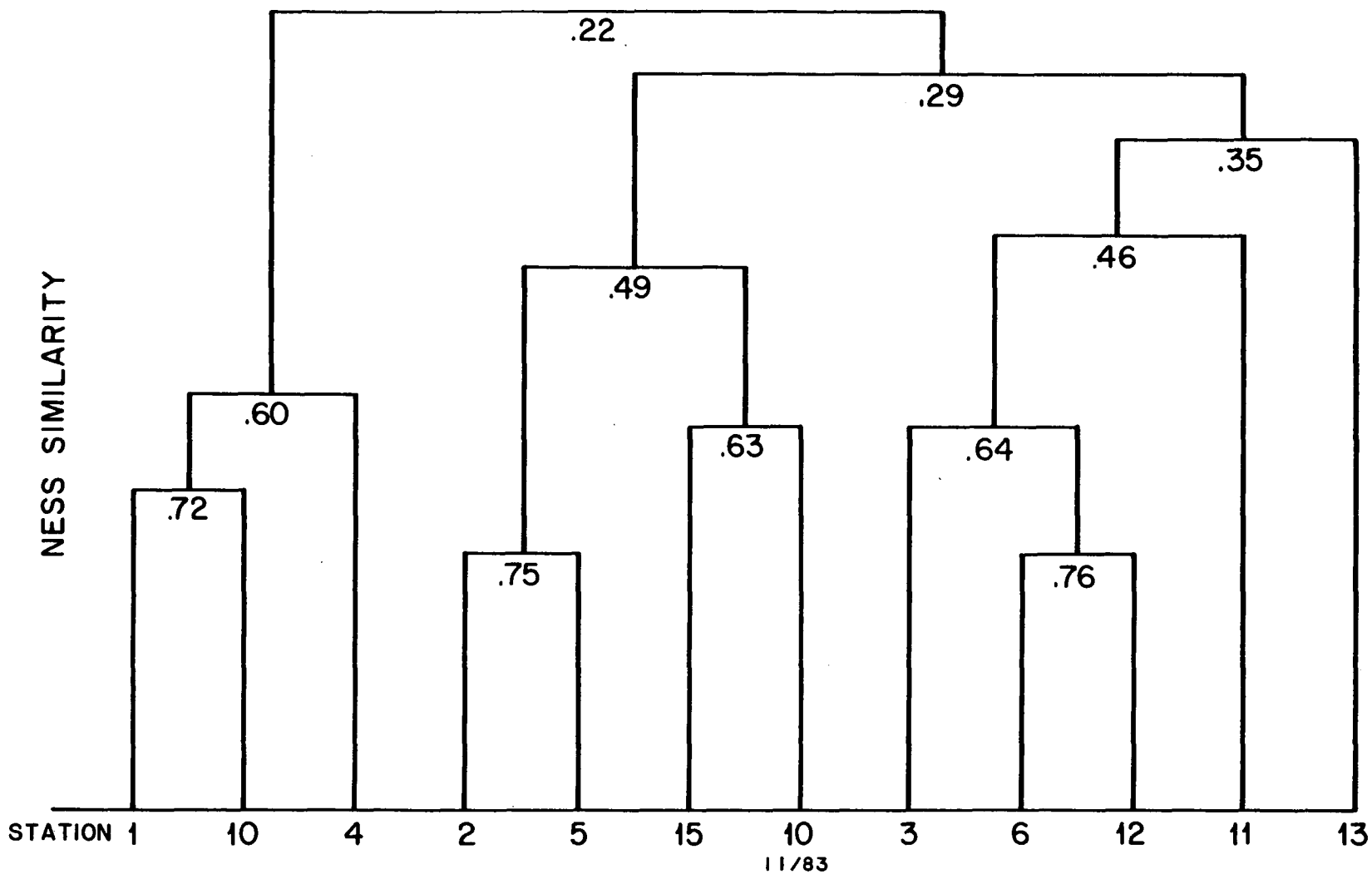

Figure 53. Summary of cluster analysis of the sum of six replicates within each sampling date using NESS similarity at 200 individuals and group average sorting. Deep Stations 7, 8, 9, 16, 17, 18 and muddy Stations 13A, 7A and 14A were excluded from this analysis.

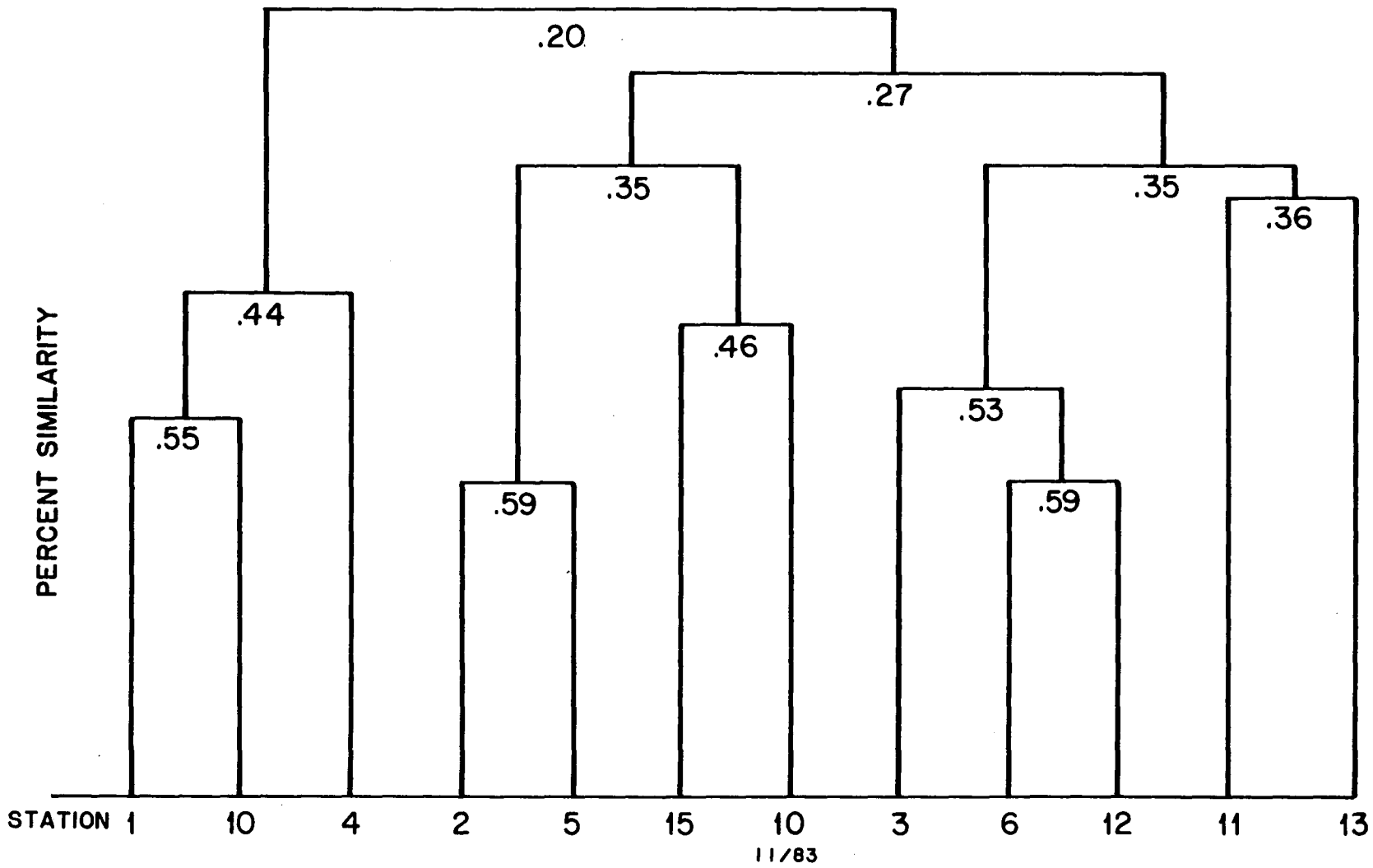

Figure 54. Summary of cluster analysis using the sum of six replicates within each sampling date. A fourth root transformation was used and stations were clustered using percent similarity and group average sorting. Deep Stations 7, 8, 9, 16, 17 and 18 and muddy Stations 13A, 7A and 14A were excluded from this analysis.

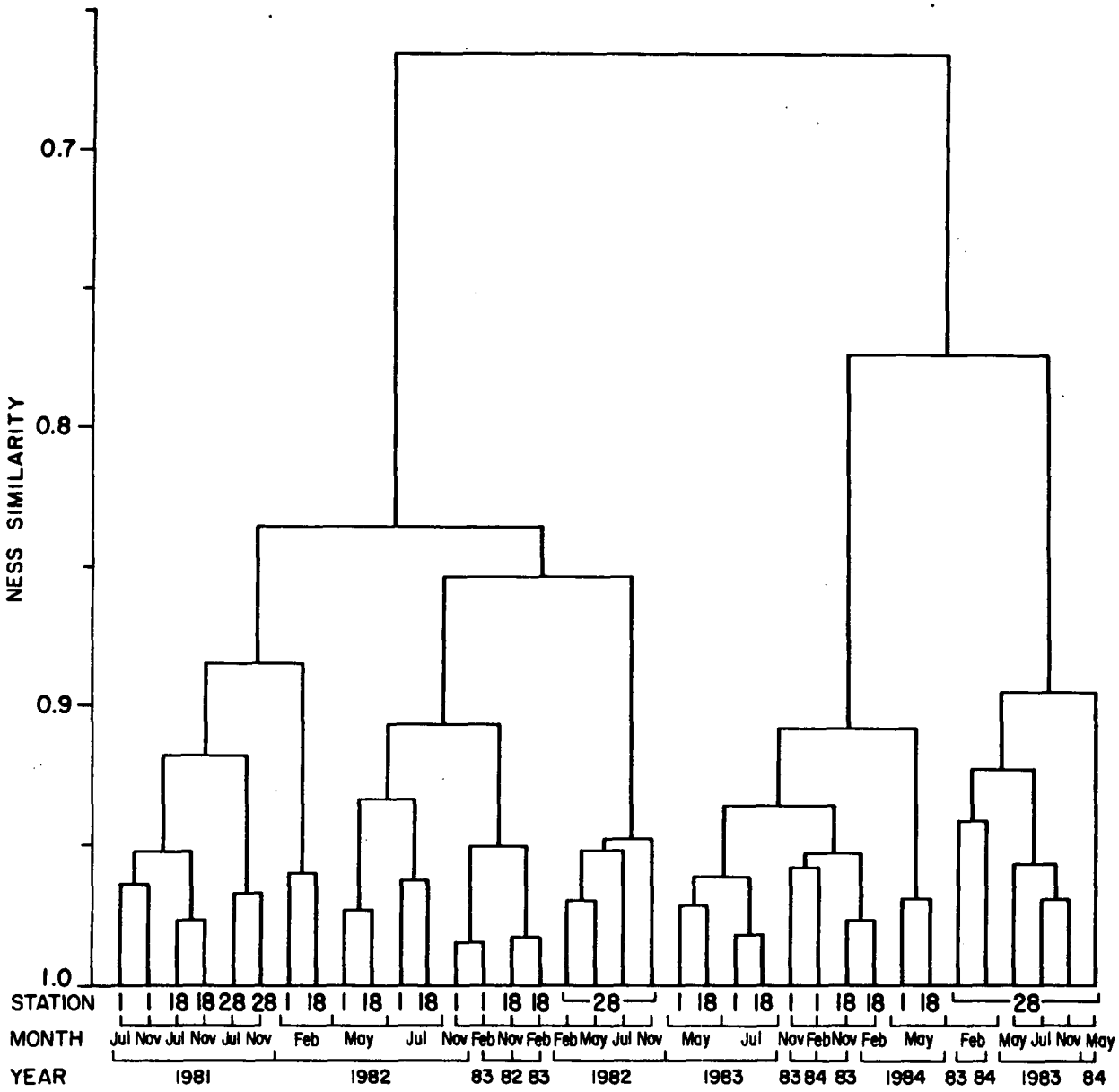

Figure 55. The sum of six replicates of samples taken at Stations 5-1, 5-18, and 5-28 for four seasons for three years. The agglomerative cluster analysis was based on NESS similarities at 200 individuals and flexible sorting (β = -0.25).

5-1 and 5-18 clusters included an earlier sampling period in February 1982 in the 1982 cluster and February 1983 in the 1983-84 cluster. This suggests that year to year changes in fauna occurred first at this station.

Detrended Correspondence Analysis. This approach to ordering the relationship between stations gave results similar to the cluster analysis (Figure 56). Each station is plotted as a cloud of points. For the deeper stations, the first year is generally on the right hand side of the cloud as another indication that year-to-year differences are more important than seasonal differences on Georges Bank.

DISCUSSION

The patterns of distribution of species on Georges Bank can be related to depth and sediment grain size. These two features of the physical environment may be associated with water movements and, particularly, sediment resuspension during winter storms. These dominant physical features of the environment led to earlier speculation that the fauna of Georges Bank would be extremely variable both as a result of local patchiness of the sediment and mortality following storms. Our data indicate a very different pattern. The communities at particular stations are remarkably homogeneous and the populations stable despite drastic seasonal fluctuations in the environment. The overall higher densities in Years 2 and 3 and shifts in the abundance of species from year to year may reflect trends in larval abundance or gradual shifts in sediment composition. Chapters 6 and 7 indicate that many species live longer than one year but even populations of annual species vary surprisingly little during the year. The stability of the Georges Bank communities is even more remarkable considering the year to year differences in biomass that may reflect changes in organic input to the bottom (Chapter 4).

Eleven stations sampled in the present study correspond to sites sampled in the New England OCS Benchmark study which was initiated in 1977 by the Department of the Interior, Bureau of Land Management (now the Minerals Management Service). Taxon, Inc. was contracted to complete the analysis of these samples and to analyze all data from those eleven stations which coincided with Monitoring Program station. These data provided information on seasonal variation, and provided a long-term base for comparison with data generated in the current study. A final report on the Georges Bank Benthic Infauna Historical Study was submitted in March 1983 (Michael et al, 1983).

Dominant species reported by Michael et al (1983) at the eleven corresponding stations generally agreed with the dominant species reported here, with at least four

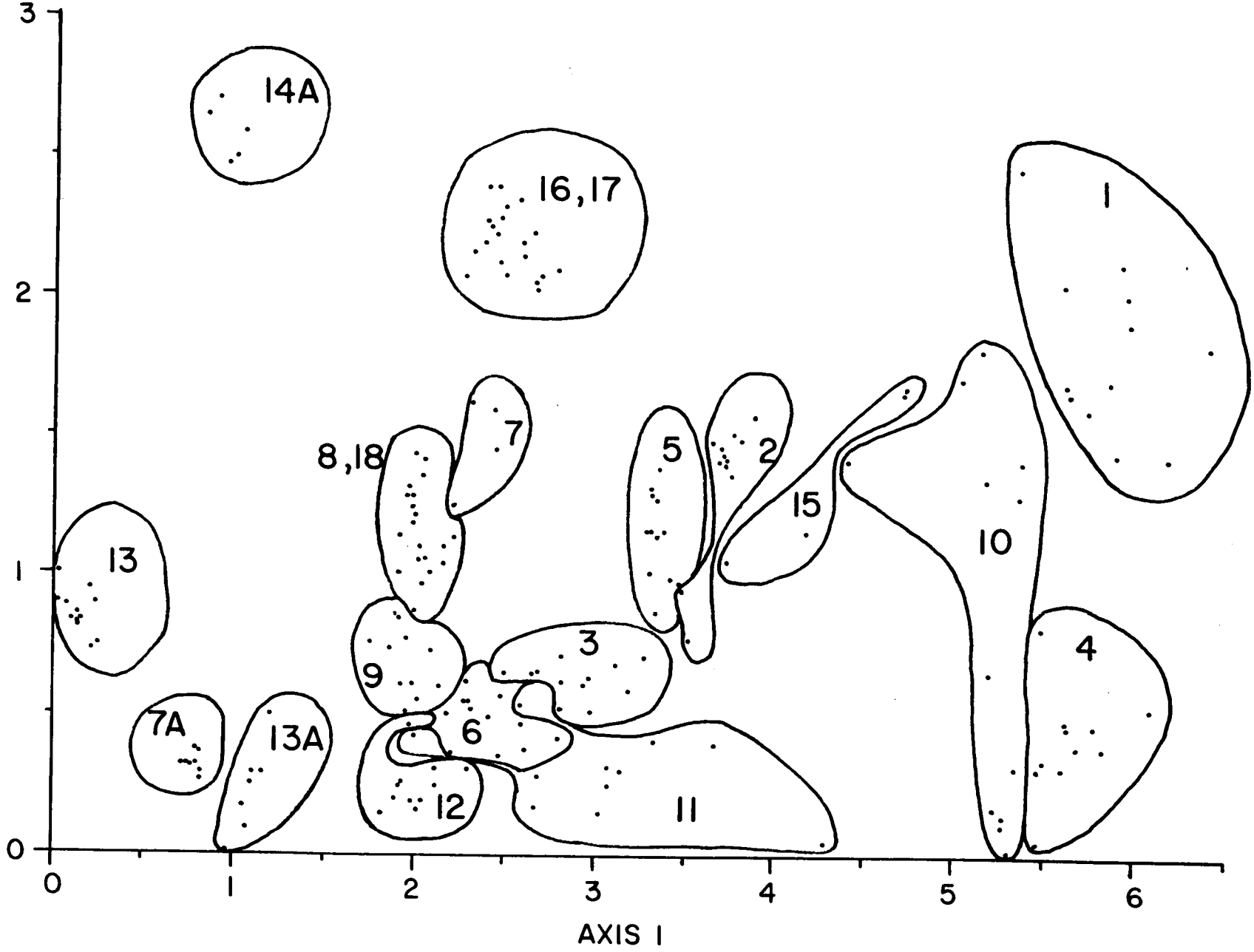

Figure 56. Detrended correspondence analysis of six replicate sums from each sampling date.

reported in common by both studies for most stations. There was particularly good correspondence for dominant species recorded at the Block 312 drilling site, Station 5-1, with seven species reported in common.

Some differences can be explained by differences in taxonomic designations: for example, Michael et al's (1983) Euclymene collaris is our Euclymene new sp. A. Specimens collected during both studies have been compared, and they are in fact the same species, which we believe to be undescribed. Similarly, the authors use the older names Exogone brevicornis (a polychaete), Trichophoxus epistomius (an amphipod) and Leptochelia savigny (a tanaid) for Exogone verugera, Rhepoxynius hudsoni, and Tanaissus lilljeborji, respectively. Some higher taxa reported by Michael et al (1983) are speciated in our data, including Archiannelida, Oligochaeta and bipalpate Cirratulidae. Some parallels between the two studies can be implied for these taxa. For instance, Michael et al (1983) reported Oligochaeta as dominant at the Mud Patch (Historical Station 6), while we have recorded Tubificoides new sp. A at our corresponding Station 13. In other cases, translation between studies is not clear. Thus, the ampharetid polychaete Eclysippe new sp. A is a dominant at our Station 7, while Michael et al (1983) report another ampharetid, Anobothrus gracilis as a dominant at the corresponding station (Station 23). A direct comparison of the specimens in question must be made before it is clear whether we are referring to the same species. The different sieve size used in the studies may also have contributed to the difference in species reported as dominants. The 0.3-mm screen retains not only more individuals, including juveniles, of those species found on the 0.5-mm screen, but also retains small-bodied species which are not present at all, or only rarely, on the larger screens. The dominant species reported at Stations 16 and 17, Paradoneis new sp. A, is such a species with over 95 percent of all individuals collected found on the 0.3-mm screen.

Average densities, extrapolated for comparison to density per square meter, were generally higher in the present study than in the Historical Study, even when only the 0.5-mm fractions were compared (Battelle and W.HO.I., 1984, Table 18). Densities recorded in the present study were often two or three times the average densities recorded in the Historical Study. These differences may be due to natural differences between year.

While the cruises of the two studies occurred in similar months, the density patterns of the same species at the same stations did not fluctuate similarly between the two studies. For example, at the Historical Study Station 20, Exogone hebes was most abundant in fall and winter, while in the current study E. hebes at the corresponding station (Station 5-1) was most abundant in the spring of Year 1 (M4), and in the summer in Years 2 and 3 (M5 and M9). At the Historical Study's Station 29, densities of E. hebes did

not vary much among winter, summer and spring but were quite low in the fall, whereas at the corresponding Station 2 in the present study, E. hebes did not vary much at all in abundance throughout the three years of sampling. Differences between annual density patterns of Exogone verugera, Euclymene sp. A, and Erichthonius fasciatus also existed at Station 5-1.

For any particular species population density patterns vary among seasons, years and stations and differences are due probably not just to recruitment but also differential mortality and mobility. Although species abundances change according to sediment type, there are few examples of closely related species that show niche diversification associated with sediment differences. The more common feature of species distribution is to have congeners co-occur (e.g., Tharyx spp. at Stations 7 and 16, and Aricidea spp. at Stations 7, 7A, 13 and 18; Table 4). This suggests that similarities in feeding type do not result in intense interspecific competition in this environment. A species by species discussion of possible generalizations concerning feeding types and potential interrelationships between species is beyond the scope of the present analysis.

Effects of drilling eight exploratory wells were not observed during this study but would not be expected considering the spread of discharged materials over very large areas of the Bank. The spread of drilling fluid solids indicates that the potential for site-specific effects of any contaminant associated with sediments is reduced because of very active sediment resuspension and redistribution on Georges Bank. If Georges Bank communities were to change as a result of sediment contamination, the changes would be widespread. For this reason, future monitoring of Georges Bank should pay particular attention to any gradual increases in sediment contamination that may occur from a variety of sources.

ACKNOWLEDGEMENTS

The data reported on in this chapter was generated by several tens of researchers and research assistants over the three years of the Monitoring Program. We regret that there is not enough space to list everyone by name, but the contribution of each is appreciated and acknowledged. Phillip Nimeskern, Robert Williams, Russ Winchell, Janet Kennedy, Nancy Alff, Betsy Broughton, Debra McGrath, Cameron Calkins, and Judy Scanlon contributed to the preparation of this chapter.

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CHAPTER 4. BIOMASS

by

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INTRODUCTION

An additional component of the Georges Bank Benthic Infauna Monitoring Program was to determine how the standing stock or biomass at each station varied throughout the three-year, 12-cruise sampling period and how it compared among stations. While this measurement does not result in an estimate of productivity (sensu Crisp, 1971), it does give valuable insights as to the amounts of organic matter present on Georges Bank and how these amounts change over time. This is especially important because often a sample is comprised of many small species and a few very large ones. Biomass data frequently provide results considerably different from density data at identical stations, consequently providing further insights into biological processes occurring there. Results from this study are also of interest as they include infauna as small as 300 μm.

Wet-weight biomass was measured for the first eight cruises for all species in each replicate. Species were measured as a group rather than as individuals. Because of the limited value of wet-weight data, it was decided to establish the relationship between wet weight and ash-free dry weight (AFDW) of each species. Wet-weight biomass is considered to be unreliable because it represents measurement of water content in addition to the organic and inorganic content. Specimens must be blotted prior to weighing to remove excess external liquid, but one cannot use a uniform blotting time and remove the same amount of water from different sized specimens. If one blots specimens by eye, one cannot be sure that a uniform amount of water is removed from different types (i.e. taxa) of specimens. Further, evaporation occurs throughout the weighing process. Thus, it is no surprise that if an animal (especially a small one) is blotted dry, weighed, and returned to alcohol repeatedly, the resultant series of weights can be quite variable. Wet weight of animals in formalin is less than the wet weight before preservation (Howmiller, 1972; Mills, 1982). For all the reasons presented above, AFDW is considered a more reliable estimate of weight and more appropriate for comparisons between taxa (Rowe, 1983). Using three replicates only from Cruise M9 (July 1983), the wet weight and AFDW of each species was measured to establish the relationship between these two parameters. These relationships were used to calculate AFDW of taxonomic groups from wet weights for all other cruises.

The approach taken in the Georges Bank Benthic Infauna Monitoring Program provides a basis for drawing some general conclusions about biomass on the Bank. It is beyond the scope of this chapter to work with data on a species-by-species basis; instead taxa were lumped into ten large taxonomic groups. Because many species occurred only a few times throughout the study and because some stations were added or dropped during the program, it was not possible to extrapolate the July 1983 AFDW data to all other samples on a species-by-species basis. We could not assume that AFDW:wet weight ratios were similar for all species within a taxonomic group. This meant, therefore, that only the most generalized comparisons could be made and that only the two heaviest species could be isolated for study.

METHODS AND MATERIALS

Wet Weight Measurements

Wet weights were determined for all species on all cruises throughout the project. For Cruises M1 (July 1981) through M8 (May 1983), wet weight was measured for all species in all replicates. Wet weight was measured from three replicates for Cruise M9 (July 1983) and only one replicate for Cruises M10 (November 1983), M11 (February 1984), and M12 (June 1984). The 0.5-mm and 0.3-mm fractions of each species were weighed separately in all cases except at the site-specific stations for the first four sets of samples where the two fractions were weighed together. All weights included all the specimens of a species in any one sample; specimens were weighed together, not individually.

To determine wet weights, soft-bodied animals were removed from their vials with forceps and blotted dry on a screen-covered blotting pad. Hard-bodied animals (i.e., molluscs and echinoderms) were rinsed from their vials onto a screen, blotted dry, and handled only with soft forceps to avoid crushing the specimens. Drying time depended upon the size of the animal because it was important to avoid dehydration. Specimens were usually blotted for 15-30 sec until all visible alcohol was removed. The specimens were then placed in a petri dish containing a small piece of screening to facilitate later removal of the animals. The dish was covered to reduce fluctuations due to evaporation of alcohol during weighing.

All specimens less than 82 g were weighed to the nearest 0.1 mg and rounded to the nearest mg on a Mettler® AC 100 electronic analytical balance. Specimens greater than 82 g (primarily Arctica islandica) were weighed to the nearest 0.001 g and rounded to the

nearest 0.01 g on a Mettler® P1200 top loading balance. Both balances were tared before each weighing and both were calibrated annually. All specimens were returned to containers with 70 percent alcohol after being weighed.

Ash-free Dry Weight Measurements

Preliminary Tests. Several preliminary tests were conducted to determine the best procedure for determining AFDW. Four types of tests were conducted, testing in each case both soft-bodied (annelids, nemerteans) and hard-bodied (echinoderms, molluscs, amphipods) animals. The four factors tested were:

1) Time to dry samples to constant weight at 60°C,

2) Time to stabilize weights in a dessicator after drying,

3) Methods of ashing samples, and

4) Time to stabilize weights in a dessicator after ashing.

These tests were conducted using specimens from Boston Harbor and Massachusetts Bay in order to burn as little Georges Bank material as possible.

1) Time to Dry Samples to Constant Weight at 60°C. To determine time to dry samples to a constant weight, each sample was blotted dry for 30 sec. Molluscs and echinoderms were cracked open and then blotted for 30 sec. Samples were placed in an oven at 60°C for 24 hr, put in a dessicator for 1 hr, then weighed and returned to the oven. All animals were reweighed at 48 and 72 hr. Soft-bodied animals were also weighed at 54 hr. In the case of both soft- and hard-bodied samples, 24-hr dry weights were within two percent of the 72-hr dry weights.

2) Time to Stabilize Weights in a Dessicator after Drying. To determine the amount of time necessary to stabilize weights in a dessicator after drying for 72 hr at 60°C for the soft-bodied animal experiment, samples were placed in a dessicator and weighed after 1, 2, 3, 4, 6, 8, 26, and 72 hr. Samples were kept in the dessicator between weighings. Samples were stable at about 8 hr and varied only 2-3 percent after that. In the hard-bodied animal experiment, sample containers were weighed after 1, 3, 6, 9, 12, and 26.5 hr. Samples were stable after 3 hr and varied within one percent from the 12-hr samples in the 3, 6, 9, and 26.5 hr sampling periods.

3) Methods for Ashing Samples. Techniques for ashing samples differ considerably in the literature. Due to time constraints, only one type of methods test was conducted. Samples were placed in a muffle furnace at 450°C for 4 hr, removed from the furnace,

cooled momentarily and weighed. The samples were returned to the furnace, ashed for an additional hour at 500°C and reweighed. In general, the sample weight decreased between the first and second weighings, usually about 2-3 percent. Considerable variation from this occurred in only a few cases.

4) Time to Stabilize Weights in a Dessicator after Ashing. The time needed for weights to stabilize after being removed from the furnace and placed in a dessicator was tested. Soft-bodied animals were weighed after 0.5, 1, 2, 3, 18, 24, and 44 hr had elapsed. Soft-bodied and hard-bodied samples did not vary more than one and two percent, respectively, unless the weights were very small, when a small difference in weight changed the percentage difference considerably. In most cases, variability was less than one percent.

We also tested the variability in repeated weighings of one container. Two types of containers were used, depending on the sample size: aluminum pans (57 mm diameter) and microbalance weighing boats (1 ml). All containers were placed in a muffle furnace for 2 hr at 500°C to remove any organic material. When either type of container was measured five times, its weight did not vary by more than 0.01 percent in the case of the large containers and two percent in the case of small containers.

Methods Used for AFDW Measurements. AFDW was measured only for species collected during Cruise M9 (July 1983). Three replicates were chosen from each station for ashing of specimens. Care was taken in choosing the replicates and all specialists involved in identifications reviewed the replicates to ensure that no rare species were ashed. In a few cases, a rare species was not included in the process even though the rest of the replicate was ashed. These rare species were usually small and comprised only a very small fraction of the total weight of the taxa to which they belonged (see below). Therefore, leaving them out had little impact on the conclusions drawn from the data. All 0.5-mm and 0.3-mm fractions were weighed separately for each species.

To obtain AFDW, all specimens of each species were wet weighed to the nearest mg as described above and then placed in a preweighed organic-free aluminum container. The type of weighing container used depended on the sample size: aluminum pans (57 mm diameter) and microbalance weighing boats (1 ml). All containers were placed in a muffle furnace for 2 hr at 500°C to remove any organic material. All pans were weighed on a Mettler® analytical balance (weighs to 0.01 mg) and boats on a Cahn® 28 automatic electrobalance (weighs to 0.1 µg). The Cahn® balance was zeroed before use and calibrated with standard weights. Weights and forceps used for handling weights and boats were always cleaned with an organic solvent (i.e., hexane or CH_3Cl) prior to use.

The Mettler® balance was calibrated according to a routine maintenance schedule, so it was just zeroed prior to use. After every five samples weighed on both balances, the balance was re-zeroed. When weighing on either balance, a reading was taken 30 sec after placing the sample on the balance. After weighing, all containers were returned to the dessicator until used.

Specimens were placed in containers and dried at 60°C for at least 24 hr to remove water, after which samples were placed in a dessicator for at least 12 hr. The containers were weighed and then ashed in an oven at 450°C for 4 hr. After ashing, containers were placed in a dessicator for 12 hr, after which the ash was weighed. After subtraction of the container weight from the wet, dry, and ash weights, AFDW was calculated as follows for each sample:

AFDW = dry weight - ash weight

Data Reduction and Analyses

Only epibenthic or pelagic species were excluded from the data base. Biomass estimates therefore included all fragments and indeterminate taxa of any taxonomic group. Once weights were determined, they were corrected for volume loss when CHN and grain-size subsamples were taken from samples collected on the last eleven cruises. Once AFDW was determined for all species in three replicates of each station of Cruise M9 (July 1983), the species were grouped into the following taxonomic categories:

Taxon No.	Taxon Label
1	All echinoderms except Echinarachnius parma
2	Echinarachnius parma
3	Crabs
4	All other arthropods except crabs
5	Arctica islandica
6	All bivalves except A. islandica
7	Gastropods
8	All other molluscs
9	Annelids
10	All other groups

After these taxonomic groups were established, regression curves were run to generate the AFDW:wet weight ratios for each group. Next, species in all other cruises were

lumped into taxonomic groups as above and the AFDW calculated from the AFDW:wet weight ratios determined for the Cruise M9 (July 1983) samples.

Analysis of variance was used to compare changes in biomass over time (i.e., among cruises) at selected stations. Student-Newman-Keuls a posteriori tests were used to determine for which cruises biomass was statistically different. The coefficient of variation (C.V.) for the total AFDW for each station over all cruises was determined as follows:

$$C.V. = S.D.\left(\frac{100}{\bar{x}}\right),$$

where $\bar{x}$ is the mean of the total AFDW for all cruises and S.D. is the standard deviation.

RESULTS

In addition to the results presented here, biomass data generated during this program are presented in the Final Reports for Year 1 and Year 2 (Battelle and W.H.O.I., 1983; 1984).

AFDW:wet weight ratios are presented in Table 6. All correlation coefficients (r^2) were greater than 0.9 and all were statistically significant. Biomass ranged from 12.30 mg AFDW/0.24 m^2 at Station 1 in November 1983 to 35,403 mg AFDW/0.24 m^2 at Station 1 in July 1982 (Table 7). This is equivalent to 51.25 mg/m^2 and 147,512 mg/m^2. Values were usually greater than 100 mg AFDW/0.24 m^2 and less than 2,000 mg AFDW/0.24 m^2. Biomass varied considerably among cruises at any particular station and among stations. There appeared to be a general trend from lower biomass in July 1981 and May 1982, to higher biomass in July 1982 through July 1983, followed by a decrease in November 1983 through June 1984 (Table 8, Figures 57-60).

One must remember that only three replicates were analyzed for Cruise M9 (July 1983) and only one replicate each for Cruises M10 through M12 (November 1983 - June 1984). Tables 7 and 9 indicate that after being corrected for number of replicates, biomass was lower for the period November 1983 through June 1984, and that the number of taxa represented appeared lower as well. It is difficult to determine whether the low numbers resulted from fewer replicates being measured or whether biomass actually decreased during the last three cruises as compared to Cruises M5-M9 (July 1982 - July 1983). Nevertheless, the increase in biomass between Cruises M4 and M5 (i.e., May and July 1982) was real.

TABLE 6. ASH-FREE DRY WEIGHT:WET WEIGHT RATIOS BY TAXA FROM SAMPLES COLLECTED JULY 1983 (M9).

TAXON NUMBER	TAXON DESIGNATION	RATIO
1	All echinoderms except Echinarachnius parma	0.08774
2	Echinarachnius parma	0.03634
3	Crabs	0.09108
4	All arthropods except crabs	0.15401
5	Arctica islandica	0.07542
6	All bivalves except Arctica islandica	0.07015
7	Gastropods	0.10391
8	All other molluscs	0.10669
9	Annelids	0.16353
10	All other groups	0.07314

TABLE 7. TOTAL ASH-FREE DRY WEIGHT (mg/0.24 m^2) FOR EACH STATION AND CRUISE, SIX REPLICATES SUMMED. (Cruises M9-M12 corrected for fewer replicates measured.)

	SAMPLING DATE											
STATION	7/81	11/81	2/82	5/82	7/82	11/82	2/83	5/83	7/83	11/83	2/84	6/84
1	537.95	132.82	2421.61	653.24	35403.27	3265.48	18075.95	2992.72	2403.02	12.30	107.22	2664.96
2	136.64	103.54	91.94	112.29	712.21	1430.56	24507.88	1731.92	1664.58	137.28	45.48	41375.28
3	183.36	76.69	776.47	441.59	1588.24	680.86	2058.99	423.02	785.32	228.18	216.72	394.62
4	1317.40	187.63	3163.82	1728.26	4426.99	1354.31	-	26821.20	4002.02	128.88	405.90	764.52
5-1	340.75	395.04	395.25	492.30	2946.83	1323.26	1851.67	2379.94	840.12	285.36	470.76	650.04
5-2	167.26	133.82	683.39	140.72	1580.82	1484.71	-	1362.18	-	-	-	-
5-3	634.25	1175.95	104.13	214.10	8172.19	1085.84	-	579.25	-	-	-	-
5-4	223.77	464.06	73.37	243.38	1134.57	881.29	-	634.07	-	-	-	-
5-5	406.36	1135.74	931.47	204.11	925.67	545.73	-	5414.26	-	-	-	-
5-06	415.71	1189.94	1371.39	1833.20	1267.09	957.16	-	498.94	-	-	-	-
5-08	467.29	194.69	873.41	340.01	1505.67	864.37	-	1213.34	-	-	-	-
5-09	599.02	165.13	3592.15	299.35	1942.74	3971.26	-	3579.87	-	-	-	-
5-10	322.92	1990.49	108.42	318.70	14382.78	1247.41	-	3946.77	-	-	-	-
5-11	1643.39	1189.20	2768.75	194.96	1257.80	1003.52	-	526.66	-	-	-	-
5-12	324.24	129.58	115.20	145.13	1316.25	646.92	-	534.89	-	-	-	-
5-14	267.50	139.96	6064.19	147.16	10634.59	672.91	-	16309.76	-	-	-	-
5-16	281.17	208.01	469.19	271.71	2028.07	1077.09	-	10844.53	-	-	-	-
5-18	255.98	4218.51	116.23	2535.32	11241.53	1017.39	6083.75	828.22	1013.96	263.88	97.74	828.66
5-20	228.69	91.30	67.55	131.33	782.57	302.18	-	13164.70	-	-	-	-
5-22	181.49	1014.86	2065.81	200.10	1348.76	1176.68	-	820.92	-	-	-	-
5-25	895.45	103.95	1321.95	304.64	1075.04	9497.31	-	906.56	-	-	-	-
5-28	173.50	82.34	146.42	229.98	8499.22	16039.16	460.27	8265.99	388.86	265.44	116.88	684.12
5-29	2585.64	378.46	279.53	372.13	8240.29	11539.06	-	858.86	-	-	-	-
6	276.99	387.68	166.38	165.67	1088.47	1305.65	790.73	941.53	2907.90	159.18	603.36	501.30
7	322.47	96.28	97.64	61.34	-	-	-	-	-	-	-	-
7A	-	-	-	-	828.94	910.67	650.02	621.05	240.80	452.58	802.38	463.08
8	238.58	69.47	44.16	35.31	691.44	249.80	313.35	470.14	318.08	86.40	246.00	389.16
9	216.86	54.48	45.59	122.89	487.32	1020.06	-	483.40	553.36	90.66	121.92	439.62
10	466.75	1353.76	836.91	410.51	6721.82	6320.05	3866.26	15711.99	6703.40	215.28	47.10	1404.54
11	1678.06	76.82	2084.00	207.63	3265.69	2777.59	-	6400.37	17687.56	89.52	169.56	7263.30
12	401.77	256.44	142.25	262.52	1604.16	2358.42	-	1853.04	659.78	177.79	615.42	660.12
13	173.88	84.20	99.80	62.37	1841.78	816.82	1008.42	1460.56	1469.38	326.64	553.74	1713.72
13A	-	-	-	-	999.83	1104.70	-	1849.23	1389.92	771.72	632.52	1341.78
14A	-	-	-	-	707.57	540.08	439.32	485.67	323.38	-	-	-
15	314.04	15.03	18.80	48.32	-	-	-	-	-	-	-	-
16	323.55	32.50	1862.21	31.10	946.33	328.81	450.33	330.38	534.16	151.38	241.32	604.80
17	44.19	41.36	29.17	53.43	283.57	303.87	263.27	537.58	-	-	-	-
18	181.37	42.02	55.09	31.07	653.45	299.00	275.43	490.95	-	-	-	-

- indicates no sample

TABLE 8. MEAN ($\bar{X}$), STANDARD DEVIATION (S.D.), AND COEFFICIENT OF VARIATION (C.V.) OF TOTAL ASH-FREE DRY WEIGHT (MG/0.24 M^2) FOR EACH STATION FOR ALL CRUISES.

STATION	$\bar{x}$	S.D.	C.V.
1	5722.54	10558.35	184
2	6004.13	13102.22	218
3	654.51	600.97	92
4	4027.36	7706.77	191
5-1	1030.94	898.26	87
5-2	793.27	669.16	84
5-3	1709.39	2877.70	168
5-4	522.07	384.73	74
5-5	1366.19	1815.12	133
5-06	1076.20	498.87	46
5-08	779.83	476.83	61
5-09	2021.36	1690.10	84
5-10	3188.21	5115.73	160
5-11	1226.33	832.49	68
5-12	458.89	431.92	94
5-14	4890.87	6442.03	132
5-16	2168.54	3881.05	179
5-18	2375.10	3350.83	141
5-20	2109.76	4880.88	231
5-22	972.66	661.52	68
5-25	2014.99	3326.87	165
5-28	2946.02	5175.96	176
5-29	3465.00	4560.57	132
6	774.57	773.45	100
7	144.43	119.87	83
7A	621.19	226.38	36
8	262.66	194.79	74
9	330.56	299.91	91
10	3671.53	4622.62	126
11	3790.92	5235.58	138
12	817.43	762.69	94
13	800.94	679.02	85
13A	1155.67	412.01	36
14A	499.20	141.22	28
15	99.05	144.10	145
16	486.41	503.02	103
17	194.56	183.46	94
18	253.55	226.04	89

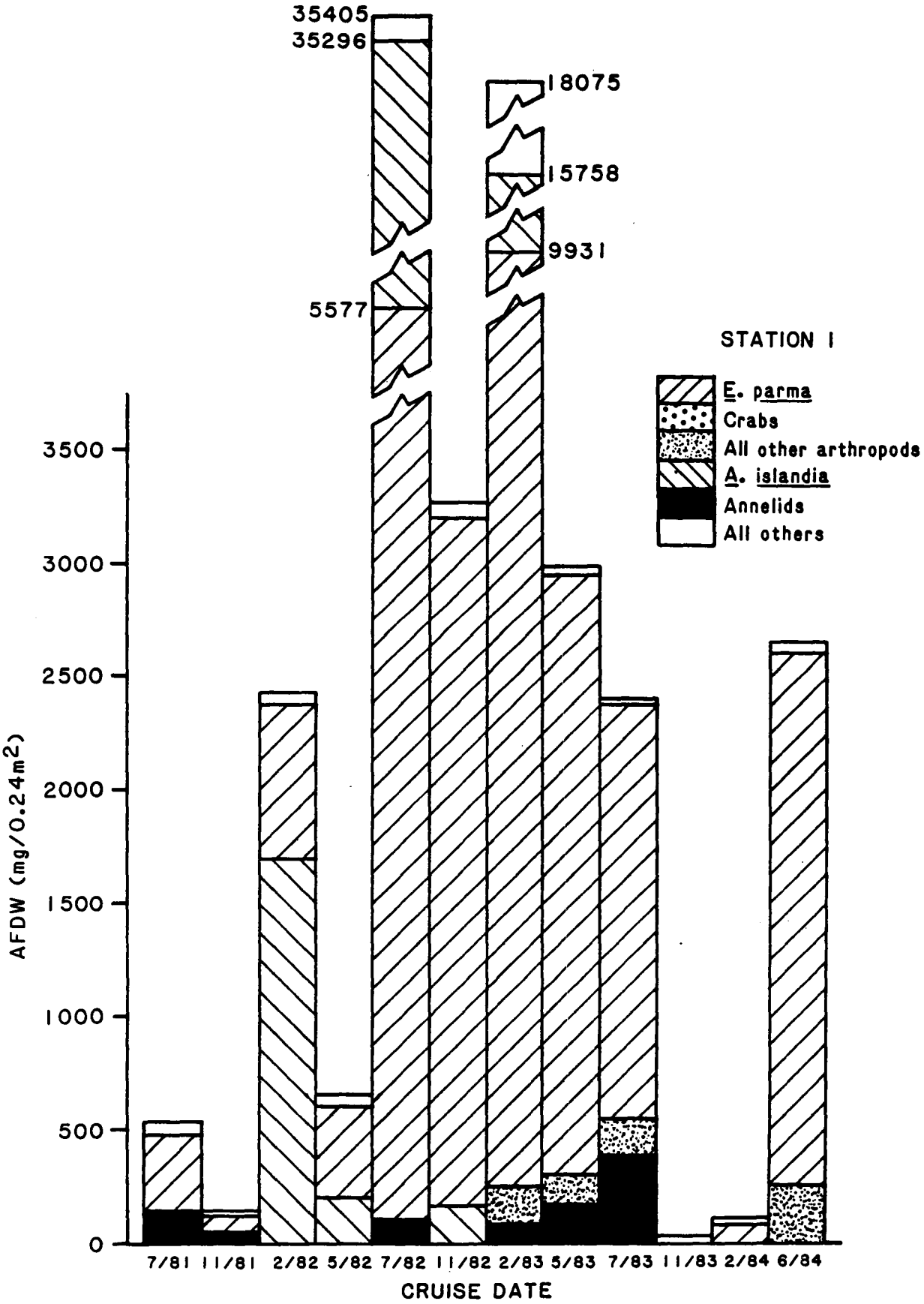

Figure 57. Ash-free dry weight from Station 1 over time. Values represent mg/0.24 m^2.

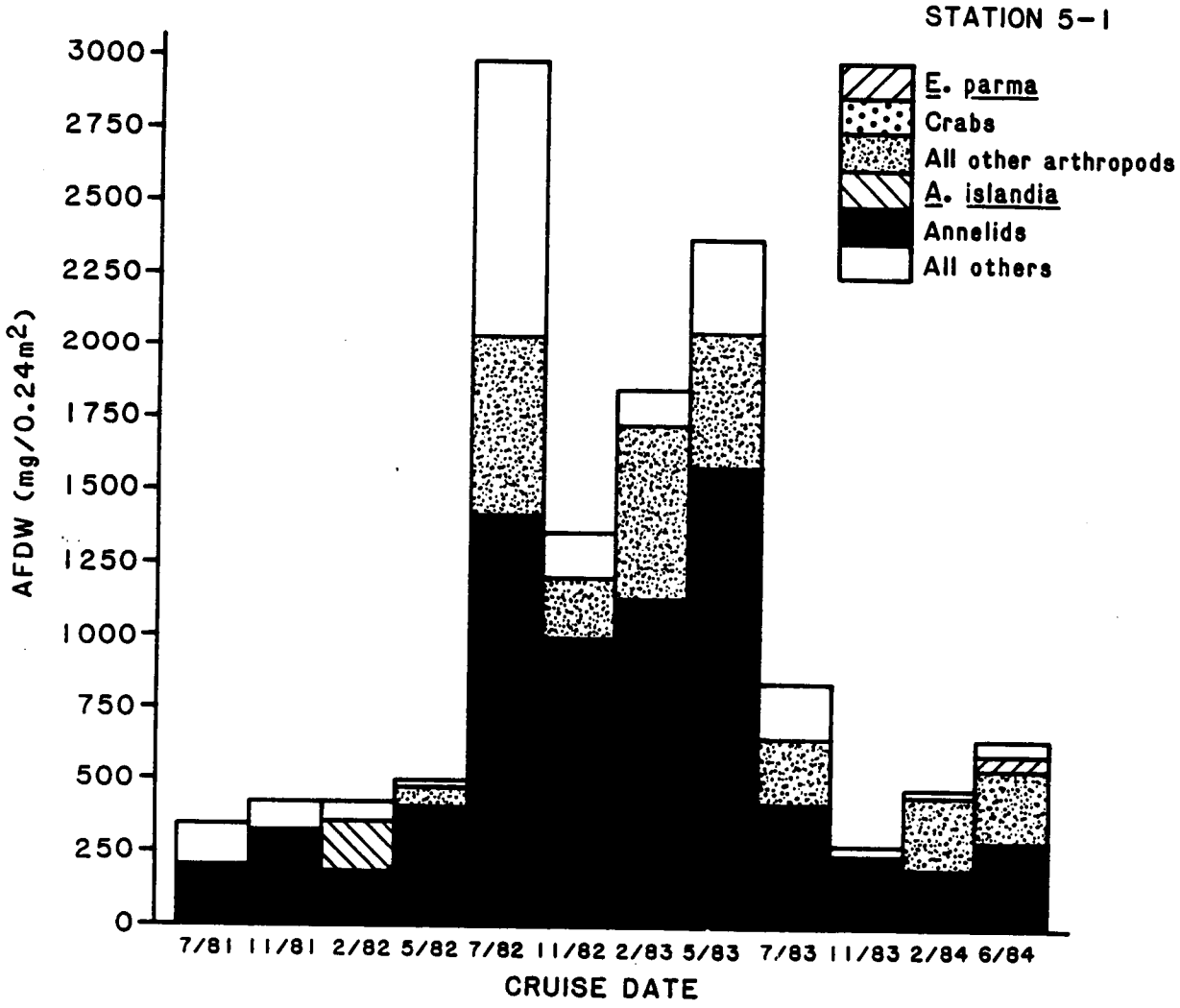

Figure 58. Ash-free dry weight from Station 5-1 over time. Values represent mg/0.24 m^2.

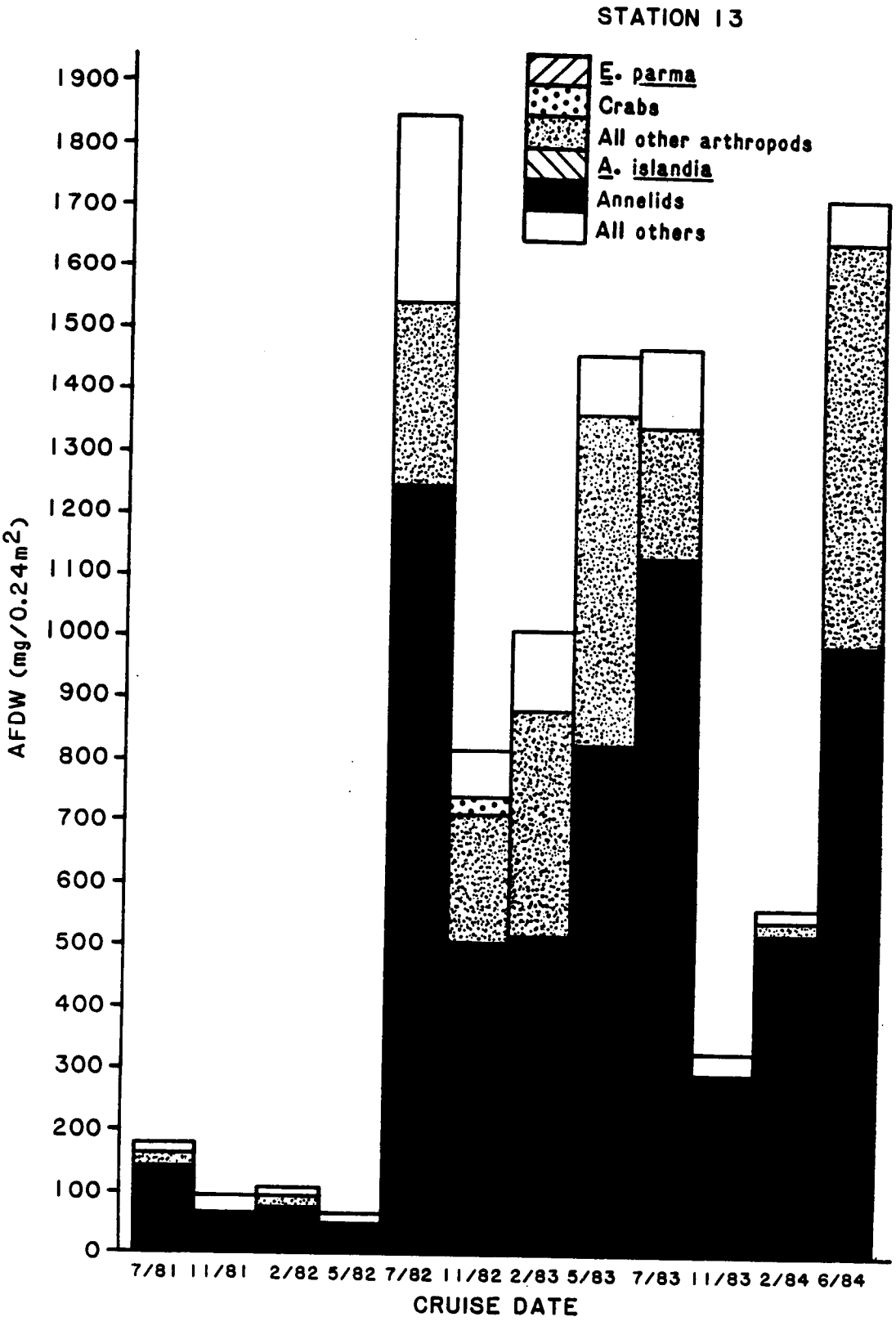

Figure 59. Ash-free dry weight from Station 13 over time. Values represent mg/0.24 m^2.

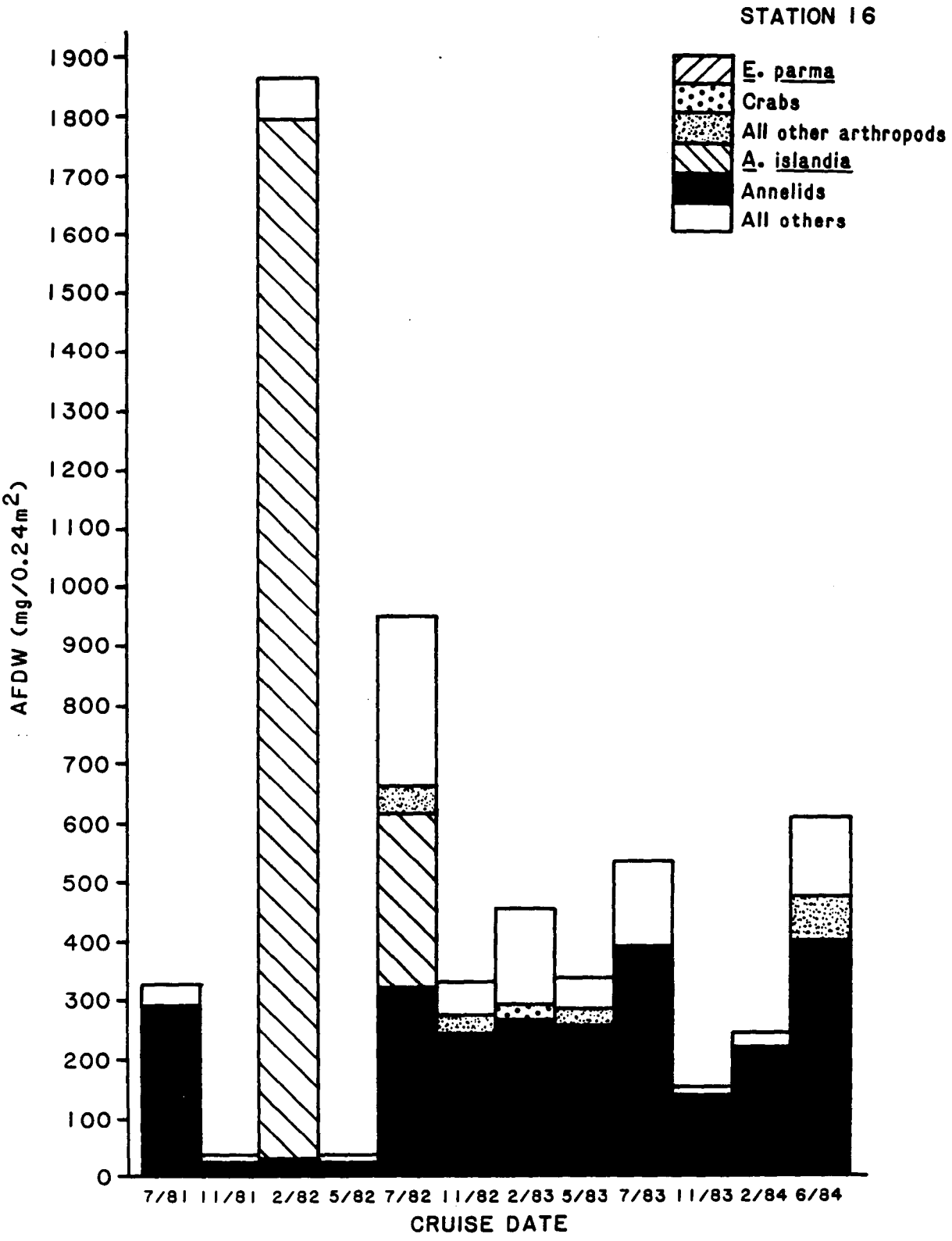

Figure 60. Ash-free dry weight from Station 16 over time. Values represent mg/0.24 m^2.

TABLE 9. ASH-FREE DRY WEIGHT (MG/0.24 M^2) AT SELECTED STATIONS BY TAXON (TAXONOMIC GROUPINGS PRESENTED IN TEXT).

		9/81	11/81	2/82	5/82	7/82	11/82	2/83	5/83	7/83	11/83	2/84	6/84
STATION 1													
TAXON	1	9.47	0.17	0.13	0.16	0.83	0.69	0.33	3.55	0.70	0.11	-	3.44
	2	346.57	62.92	691.76	432.80	5478.40	3042.04	5826.71	2942.05	1834.66	-	78.85	2358.08
	3	15.72	3.98	-	-	-	-	-	0.57	2.24	-	-	-
	4	19.62	11.44	17.15	11.25	90.90	168.06	165.59	142.01	170.36	8.54	20.05	242.21
	5	8.35	-	1693.01	172.20	29719.72	-	9679.28	37.40	0.04	-	-	-
	6	5.84	0.24	0.42	0.52	11.91	10.74	2297.76	-	0.38	0.35	0.74	0.26
	7	-	0.33	12.48	-	-	0.03	-	-	-	-	-	-
	8	-	-	-	-	-	-	-	-	-	-	-	-
	9	131.94	53.73	6.30	35.07	96.89	39.89	86.50	163.63	375.78	3.05	6.52	20.88
	10	0.45	0.32	0.14	1.24	4.62	4.02	19.79	3.52	18.86	0.28	1.05	40.68
STATION 5-1													
TAXON	1	63.12	42.60	17.18	1.91	849.10	17.98	9.73	246.48	8.10	0.44	0.44	7.43
	2	0.43	-	0.45	0.71	18.18	28.89	34.85	4.30	-	-	-	62.69
	3	-	-	-	0.87	0.95	1.51	1.13	-	-	-	-	-
	4	53.10	30.14	14.58	66.73	609.49	213.70	627.04	453.02	237.22	20.14	266.08	254.85
	5	0.05	-	186.10	-	0.05	-	-	-	0.04	-	-	-
	6	14.96	1.64	1.34	1.56	29.29	30.12	14.61	69.12	3.26	5.24	0.70	26.48
	7	0.06	-	0.37	0.13	11.69	5.18	14.73	6.32	4.12	-	-	-
	8	-	-	0.13	-	0.60	0.20	0.13	0.13	*	-	0.20	0.40
	9	207.36	319.23	173.89	416.37	1412.24	1008.55	1115.83	1589.04	437.52	257.77	202.78	296.78
	10	1.68	1.43	1.22	4.02	15.25	17.13	33.60	11.53	149.86	1.78	0.59	1.41
STATION 5-18													
TAXON	1	0.30	0.30	14.02	0.47	9.87	156.70	108.48	9.00	8.18	0.38	0.16	10.00
	2	0.15	0.17	1.19	2.01	10.60	11.20	-	-	-	-	-	-
	3	0.15	0.88	0.27	0.38	4.07	28.93	-	0.38	-	-	-	-
	4	35.25	13.69	5.53	20.24	260.78	107.96	124.92	273.72	353.72	15.06	16.69	423.76
	5	0.02	2958.22	0.04	2407.94	10306.35	0.39	3519.00	0.02	-	-	-	-
	6	2.27	1015.41	0.38	0.37	17.85	7.17	1774.26	14.89	6.54	0.26	3.45	1.57
	7	0.10	0.03	0.09	0.45	3.73	3.76	3.41	14.59	5.16	-	-	7.12
	8	0.15	0.10	0.10	0.17	0.13	0.03	0.10	0.17	*	*	-	-
	9	213.80	288.93	93.87	102.46	619.02	690.10	549.56	509.08	620.82	245.14	76.39	383.86
	10	3.79	0.78	0.74	0.83	9.13	11.15	4.02	6.37	19.54	3.01	1.05	2.37

Table 9. (Continued).

STATION 5-28												
TAXON	1	1.61	0.16	0.51	0.36	4.63	7.55	5.47	1.42	4.10	0.28	0.33	5.24
	2	-	-	-	0.89	2.83	33.72	11.35	-	-	8.44	-	-
	3	-	0.44	-	2.06	0.38	74.59	-	-	-	-	-	-
	4	38.92	32.70	33.97	51.01	376.86	550.29	117.90	99.64	142.82	17.84	6.04	182.72
	5	-	0.02	0.02	0.07	7507.67	14835.21	0.02	7687.68	2.00	-	-	-
	6	1.07	1.61	1.43	3.08	16.45	52.91	7.20	15.46	11.88	2.05	10.88	0.65
	7	0.06	0.07	0.10	0.05	3.56	0.46	0.14	-	0.12	-	-	55.01
	8	0.26	1.68	0.10	0.17	0.17	0.17	0.13	0.13	*	*	0.40	0.20
	9	128.40	46.87	109.69	171.93	527.55	478.27	315.78	460.62	218.86	221.62	98.79	439.67
	10	3.17	0.32	0.59	0.35	59.13	5.98	2.28	1.03	9.08	7.61	0.41	0.60
STATION 13													
TAXON	1	-	-	-	-	156.56	-	-	0.08	-	6.68	0.16	-
	2	-	-	-	-	-	-	-	-	-	-	-	-
	3	-	-	-	-	-	26.57	-	-	-	-	-	-
	4	29.85	10.44	21.57	6.20	295.12	166.64	319.18	529.51	212.26	16.31	22.73	659.72
	5	0.29	-	0.05	-	-	0.09	-	-	-	-	-	-
	6	3.15	2.06	2.22	2.52	36.74	37.41	87.93	28.20	50.04	2.01	9.17	36.96
	7	0.07	0.03	0.03	0.05	0.54	0.21	0.16	0.32	4.82	0.32	0.32	4.08
	8	0.14	7.23	0.08	0.84	0.92	7.78	5.42	17.59	6.38	0.26	0.67	-
	9	137.87	56.70	68.24	51.50	1245.70	555.40	563.06	830.47	1128.44	294.54	518.60	984.45
	10	2.52	7.74	7.62	1.25	106.21	22.72	32.67	54.37	67.44	6.65	2.05	28.52
STATION 16													
TAXON	1	12.76	1.61	65.64	0.97	194.64	9.45	6.99	5.93	13.22	-	0.11	-
	2	-	-	-	-	-	-	-	-	-	-	-	-
	3	-	2.17	-	-	1.13	-	25.15	-	-	-	-	-
	4	2.50	2.06	1.90	1.52	47.35	22.19	16.08	25.75	13.14	2.21	14.58	70.88
	5	0.02	-	1761.06	-	292.87	-	-	-	-	-	-	-
	6	8.69	0.14	0.35	4.28	4.49	15.53	14.91	5.30	14.46	0.96	1.18	13.37
	7	0.01	-	-	-	3.02	0.10	0.11	0.82	-	-	0.19	0.19
	8	0.79	0.58	0.39	0.58	11.61	2.68	7.24	1.23	1.14	0.80	1.33	0.60
	9	286.23	20.52	28.09	17.21	324.11	242.63	262.00	256.				
	10	12.56	5.41	4.78	6.54	67.11	36.23	117.85	35.10	106.10	9.34	5.15	119.30

- indicates no sample

* indicates value less than 0.01 mg

Stations with high biomass included Stations 1, 2, 4, 5-10, 5-14, 5-18, 5-28, 5-29, 10 and 11 (Tables 7 and 8). A dominant group or species usually comprised a large part of the total amount of biomass present at a station. A great deal of variation in mass resulted from fluctuations in the densities and weights of species that dominated at any particular station (Tables 9 and 10, Figures 57-60). The degree of variability of total AFDW for any one station can be ascertained by examining the coefficient of variation over all cruises (Table 8). The highest values at the regional stations were at Stations 1, 2, 4, 10, 11 and 15 where the coefficients of variation were 184, 218, 191, 126, 138, and 145, respectively. These were also the stations where Echinarachnius parma and Arctica islandica were present and where their presence or absence strongly influenced biomass variability. Site-specific stations with high variability were Stations 5-3, 5-5, 5-10, 5-14, 5-16, 5-18, 5-20, 5-25, 5-28, 5-29 with coefficients of 168, 133, 160, 132, 179, 141, 231, 165, 176, and 132, respectively. While the reason for such variability at these site-specific stations is uncertain, the variation may have resulted from considerable movement of sand during winter storms. E. parma and A. islandica both contributed large amounts of biomass to stations that otherwise would have been predominantly composed of annelids and arthropods (e.g., compare Figure 57 to Figures 58-60). However, E. parma did so more predictably than A. islandica (Table 11). That is, E. parma routinely appeared at particular stations and was absent from others, deviating little from this pattern, whereas A. islandica appeared at a number of stations, but never predictably (Table 11). E. parma was found primarily at Stations 1, 2, 4, and 10. A. islandica occurred at many stations and was the major factor contributing to large biomass values at Stations 5-10, 5-14, 5-18, 5-28, and 5-29. When the mean weight per specimen of E. parma and A. islandica present at a particular station was calculated, it became clear that the weight of the animals sampled varied widely and by orders of magnitude (Table 11). The mean weight of A. islandica ranged from less than 1 mg AFDW per animal to 15,712 mg AFDW per animal for the stations studied (Table 11). The mean weight for E. parma ranged from less than 1 mg AFDW per animal to 89 mg AFDW per animal. It is important to remember in interpreting results that no hard-bodied animals were decalcified.

Three stations were chosen to ascertain if statistically significant differences in biomass occurred over time. These were Station 5-1 at the Block 312 drill site, Station 16 at the Block 410 drill site, and Station 13 at the Mud Patch. Stations 13 and 16 were chosen as they were considered to be downstream and upstream, respectively, of the site-specific station array. Only data from the first eight cruises were used in this test because data from all six replicates were available for each station for these cruises. At

TABLE 10. ASH-FREE DRY WEIGHT (AFDW) (MG) FOR SAMPLES COLLECTED JULY 1983 (M9) BY STATION AND BY TAXON. (TAXONOMIC GROUPS GIVEN IN TEXT).

			AFDW	Percent AFDW
STATION 1		Total	2403.02	100.00
	TAXON	1	0.70	0.03
		2	1834.66	76.35
		3	2.24	0.09
		4	170.36	7.09
		5	0.04	*
		6	0.38	0.02
		7	-	-
		8	-	-
		9	375.78	15.80
		10	18.86	0.78
STATION 2		Total	1664.58	100.00
	TAXON	1	-	-
		2	707.82	42.52
		3	-	-
		4	724.18	43.51
		5	0.02	*
		6	-	-
		7	1.14	0.07
		8	-	-
		9	159.48	9.58
		10	71.94	4.32
STATION 3		Total	785.34	100.00
	TAXON	1	2.98	0.38
		2	-	-
		3	5.32	0.68
		4	119.20	15.18
		5	-	-
		6	113.16	14.41
		7	-	-
		8	-	-
		9	541.22	68.92
		10	3.46	0.44
STATION 5-28		Total	388.86	100.00
	TAXON	1	4.10	1.29
		2	-	-
		3	-	-
		4	142.82	36.73
		5	2.00	0.51
		6	11.88	3.55
		7	0.12	0.03
		8	*	*
		9	218.86	53.64
		10	9.08	2.34
STATION 6		Total	2907.90	100.00
	TAXON	1	1.38	0.05
		2	-	-
		3	2.00	0.07
		4	2010.04	69.12
		5	1.20	0.04
		6	20.06	0.69
		7	1.40	0.05
		8	0.18	0.01
		9	849.26	29.21
		10	22.38	76.96
STATION 7A		Total	1142.70	100.00
	TAXON	1	1.30	0.11
		2	-	-
		3	0.90	0.08
		4	64.80	5.67
		5	243.70	21.33
		6	203.52	17.81
		7	12.30	1.08
		8	6.36	0.56
		9	574.84	50.31
		10	32.98	3.06
STATION 11		Total	17687.56	100.00
	TAXON	1	0.06	*
		2	-	-
		3	-	-
		4	94.10	0.53
		5	17022.80	96.24
		6	45.72	0.26
		7	0.26	*
		8	-	-
		9	469.12	2.65
		10	55.50	0.31
STATION 12		Total	759.78	100.00
	TAXON	1	7.16	1.09
		2	-	-
		3	-	-
		4	273.56	41.46
		5	-	-
		6	68.52	10.39
		7	-	-
		8	2.12	0.32
		9	284.88	43.18
		10	23.54	3.57
STATION 13		Total	1465.38	100.00
	TAXON	1	-	-
		2	-	-
		3	-	-
		4	212.26	14.45
		5	-	-
		6	50.04	3.41
		7	4.82	0.33
		8	6.38	0.43
		9	1128.44	76.80
		10	67.44	4.59

Table 10. (Continued)

			AFDW	Percent AFDW
STATION 4		Total	4002.02	100.00
	TAXON	1	0.44	0.01
		2	1523.56	38.07
		3	-	-
		4	136.72	3.42
		5	0.54	0.01
		6	2186.20	54.63
		7	-	-
		8	-	-
		9	140.74	3.52
		10	13.82	3.45
STATION 5-1		Total	840.12	100.00
	TAXON	1	8.10	0.96
		2	-	-
		3	-	-
		4	237.22	28.24
		5	0.04	*
		6	3.26	0.39
		7	4.12	0.49
		8	*	*
		9	437.52	52.08
		10	149.86	17.83
STATION 5-18		Total	1013.96	100.00
	TAXON	1	8.18	0.81
		2	-	-
		3	-	-
		4	353.72	34.86
		5	-	-
		6	6.54	0.64
		7	5.16	0.51
		8	*	*
		9	620.82	61.23
		10	19.54	1.93
STATION 8		Total	318.08	100.00
	TAXON	1	3.04	0.96
		2	-	-
		3	-	-
		4	56.24	17.68
		5	-	-
		6	10.68	3.36
		7	-	-
		8	4.82	1.52
		9	199.78	62.81
		10	43.52	13.68
STATION 9		Total	553.36	100.00
	TAXON	1	1.56	0.28
		2	-	-
		3	-	-
		4	109.56	19.80
		5	0.28	0.05
		6	5.34	0.97
		7	3.38	0.61
		8	1.56	0.28
		9	348.80	63.03
		10	82.88	14.98
STATION 10		Total	6703.40	100.00
	TAXON	1	0.62	0.01
		2	5883.82	87.80
		3	8.50	0.13
		4	108.68	1.62
		5	-	-
		6	0.12	*
		7	-	-
		8	-	-
		9	554.98	8.28
		10	146.68	2.19
STATION 13A		Total	1389.92	100.00
	TAXON	1	452.74	32.57
		2	-	-
		3	-	-
		4	324.20	23.33
		5	-	-
		6	275.66	19.83
		7	1.98	0.14
		8	8.50	0.61
		9	254.90	18.34
		10	71.94	5.18
STATION 14A		Total	323.34	100.00
	TAXON	1	13.32	4.12
		2	-	-
		3	-	-
		4	1.23	0.39
		5	-	-
		6	7.52	2.33
		7	2.52	0.77
		8	0.16	0.05
		9	295.64	92.66
		10	2.96	0.91
STATION 16		Total	534.14	100.00
	TAXON	1	13.22	2.48
		2	-	-
		3	-	-
		4	13.14	2.46
		5	-	-
		6	14.46	2.71
		7	-	-
		8	1.14	0.21
		9	386.10	72.28
		10	106.10	19.86

- indicates no sample
* indicates value less than 0.01 percent

TABLE 11. BIOMASS (mg/0.24 m^2 ASH-FREE DRY WEIGHT) OF ARCTICA ISLANDICA AND ECHINARACHNIUS PARMA AT SELECTED STATIONS.

	Jul 1981		Nov 1981		Feb 1982		May 1982		Jul 1982		Nov 1982		Feb 1983		May 1983	
Station	Total AFDW	Mean Weight per Specimen	Total AFDW	Mean Weight per Specimen	Total AFDW	Mean Weight per Specimen	Total AFDW	Mean Weight per Specimen	Total AFDW	Mean Weight per Specimen	Total AFDW	Mean Weight per Specimen	Total AFDW	Mean Weight per Specimen	Total AFDW	Mean Weight per Specimen
							Arctica islandica									
1	8	1	0	0	1693	847	172	172	29720	5944	0	0	9676	9676	0	0
2	*	*	*	*	7	2	0	0	*	*	*	*	23030	3838	*	*
4	548	37	0	0	2712	387	1339	335	*	*	*	*	-	-	21800	1982
5-1	*	*	0	0	186	47	0	0	*	*	0	0	0	0	0	0
6	*	*	*	*	12	*	4	*	2	*	*	*	*	*	1	*
10	0	0	807	807	*	*	0	0	0	0	0	0	0	0	15712	15712
11	1503	54	*	*	2019	168	*	*	2440	15	2500	51	-	-	5878	78
16	*	*	0	0	1761	880	0	0	293	293	0	0	0	0	0	0
							Echinarachnius parma									
1	347	*	63	1	692	15	433	13	5478	61	3042	89	5827	33	2642	4
2	11	*	8	*	18	*	24	*	193	*	813	17	455	27	585	42
4	722	4	147	3	391	5	258	*	4022	12	1055	15	-	-	2144	8
5-1	*	*	*	*	*	*	*	*	18	*	29	3	35	6	4	2
6	*	*	0	0	0	0	0	0	*	*	0	0	0	0	0	0
10	356	2	511	1	643	2	383	3	6354	17	6038	26	3552	17	6668	18
11	5	*	3	*	3	3	3	*	*	*	4	*	-	-	*	*
16	0	0	0	0	0	0	0	0	0	0	*	*	0	0	0	0

- indicates no sample
* indicates value less than 1 mg

Station 5-1 total biomass per replicate differed significantly over time ($p < 0.001$). In this case, the first four cruises (M1 - M4; July 1981 - May 1982) were different from all other cruises but not from each other. Biomass in July 1982 (M5) differed from November 1982 (M6) and February 1983 (M7), but not May 1983 (M8). At Station 13, total biomass per replicate also differed significantly over time ($p < 0.001$). As for Station 5-1, biomass measured for Cruises M1 - M4 differed from all other cruises but not from each other. Biomass measured for July 1982 (M5) and May 1983 (M8) did not differ from each other, but did differ from that measured for November 1982 (M6) and February 1983 (M7). At Stations 5-1 and 13 the increases in biomass in Year 2 (July 1982 -May 1983) over Year 1 (July 1981 - May 1982) were due for the most part to increases in weights of Taxa No. 1, 4, and 9 (echinoderms except E. parma, arthropods except crabs, and annelids) (Table 9, Figures 58-59). Biomass at Station 16 did not vary significantly over time. At Station 16, increases in biomass occurred in Year 2 (July 1982 - May 1983) and were due to higher biomass for annelids and arthropods exclusive of crabs. The large amount of biomass at Station 16 in February 1982 (M3) was due to two specimens of A. islandica (Table 9, Figure 60).

DISCUSSION

Several conclusions can be drawn from the biomass data, even with species grouped into major taxa. First, biomass varied considerably over time and among stations. Michael (1977) found in his analysis of Georges Bank infauna that of the three parameters he discussed (numbers of species, numbers of individuals, and biomass), biomass was the most variable. Second, the amount of total biomass at almost all stations on Georges Bank fluctuated annually. This is not surprising since benthic invertebrate populations are known to fluctuate widely from year to year. These fluctuations occurred in all the dominant groups examined, and could not be explained by an increase in biomass of one group of species over another. Some unknown factor (e.g., higher nutrient inputs, suitable settling or growth temperatures, etc.) may have affected the organisms on Georges Bank as a whole. Third, Site-Specific Station 5-1 and Mud Patch Station 13 varied significantly over time, while Station 16 did not. These results cannot be explained as an impact of drilling activities because (1) Station 16 was also located at a drill site, and (2) biomass at the upstream Station 1 varied more widely over time than at any other station and would undoubtedly have varied significantly had it been tested (Tables 7-9). The primary reason for the difference in biomass over time at Stations 5-1 and 13 was the increase in biomass in the second year, discussed above. Station 16 was the unusual case in having lower variability among cruises.

Arctica islandica and Echinarachnius parma dominated the biomass when present. Similar results were found by Michael (1977) and Steimle (in press). E. parma had a higher degree of fidelity (i.e., restriction to a particular community) than did A. islandica. Even within a station where A. islandica occurred, it occurred less consistently than did E. parma at the stations where it occurred. This suggests that A. islandica was more patchily distributed than E. parma. Neither species was predictable in terms of the size of the individuals encountered at any station or at any time (Table 11). Where E. parma and A. islandica were absent, arthropods and annelids usually predominated. Because so much of the biomass of A. islandica and E. parma is inorganic matter, the results would be far more interesting if that inorganic material had been removed prior to weighing.

Biomass levels on Georges Bank found in this study are comparable to those found on the Bank during other studies. During the New England OCS Environmental Benchmark Study of Georges Bank, wet-weight biomass was found to average 290 g/m^2 for the total fauna and 26.4 g/m^2 for infauna minus the molluscs (Michael, 1977). Steimle (in press) estimated wet-weight biomass to be 222 g/m^2 or 102 g/m^2 minus the echinoderms. Maurer (1982, reported in Steimle, in press) found 313 g/m^2 wet-weight biomass or 30 g/m^2 minus the molluscs. Maurer and Leathem (1981) studied the polychaetes from the 1977 Benchmark Study in some detail and found that wet-weight biomass ranged from 1.1 to 74.4 g/m^2. In the present study, Stations 1, 5-1, 13, and 16 had 2.2, 15.2, 13.7, and 5.5 g/m^2 wet-weight polychaete biomass, respectively. Table 12 presents our biomass data as g/m^2 for selected stations, both in terms of AFDW and wet-weight. At these stations, total wet-weight biomass for all phyla combined ranged between 11 g/m^2 and 426 g/m^2.

The most common purpose for conducting biomass measurements is to determine productivity and production:biomass ratios of one or more species in a habitat. To do this, it is necessary to study individual organisms of a species to determine growth rates and weights for year classes present. This approach, though time consuming, can provide very meaningful data relevant to production, energy cycles, and food chains in benthic habitats. This type of approach coupled with benthic monitoring studies can prove to be very fruitful.

A better approach to coupling benthic monitoring and biomass estimates would be to first complete the monitoring phase of a program in which all species are identified and counted. Once the fauna is known, a few dominant species in terms of numbers and/or biomass could be identified and designated for detailed production research in which individual organisms are weighed and measured rather than the species as a whole. There are advantages to this approach. While the same amount of time and money might be

TABLE 12. MEAN ASH-FREE DRY WEIGHT (AFDW) AND WET WEIGHT (G/M^2) AT SELECTED STATIONS ON GEORGES BANK.

STATION	MEAN AFDW FOR ALL CRUISES	MEAN WET WEIGHT FOR ALL CRUISES
1	23.861	426.00
4	16.781	280.07
5-1	4.291	31.44
9	1.377	11.46
11	15.796	202.06
13	3.338	15.98
16	2.026	19.48

necessary, the results are far more interpretable and comparable to production research conducted by other investigators. Many bottom predators feed primarily on the numerically dominant species and the less numerous ones are not as relevant to food chain analyses. By using this approach, specimens of less common and rare species need not be destroyed during the ashing process. In the deep sea, because many species occur in low densities and are poorly known to science, it is undesirable to burn them when they belong in museums. In addition, few species in the deep sea are numerically dominant (Sanders and Hessler, 1969) and these few are the only ones that might be suitable for production estimates. Even then, densities may be too low to adequately identify year classes for generating production estimates. In continental shelf and shallower waters, this approach is quite useful (e.g., see Chapter 7 by J. Collie and M.C. Curran) because densities of dominant species are high enough to generate good life history and year class estimates.

In cases where densities of dominant species are too low to generate reliable production estimates, an alternative approach can be taken to gather order-of-magnitude estimates for total biomass of the benthos. The approach entails taking extra samples at designated stations and/or times to be used solely in the destructive AFDW analyses. These samples would be sorted to the level of major taxa and the AFDW measured for each major taxa. While this approach does not provide production estimates for individual species, it does provide AFDW data for deep-water benthic regions about which relatively little is known. Most biomass estimates on continental shelves and in deeper waters are wet-weight estimates. Very little work has been conducted using AFDW measurements and such information is valuable to have.

ACKNOWLEDGMENTS

Several persons were instrumental in making this chapter possible. Debra McGrath and Paula Courchaine conducted most of the ash-free dry weight determinations with painstaking care. Richard McGrath and Cathy Cetta assisted and advised throughout the data processing. Jane Boslet, David Cheda, and Cameron Calkins helped with preparation of tables and figures.

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CHAPTER 5. BENTHIC INFAUNA AT LONG-TERM MOORING SITES

by

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INTRODUCTION

Two of the Georges Bank Monitoring Program stations were chosen to coincide with sites of long-term U.S. Geological Survey (USGS) moorings used to study near-bottom currents and sediment movement (Butman and Folger, 1979; Butman and Moody, 1983; Butman et al., 1983). Station 6 was the same as USGS Station LCA at the head of Lydonia Canyon and Station 13 was the same as USGS Station 13A on the eastern edge of the Mud Patch south of Nantucket. A third USGS long-term mooring site at Station A (40°51.0N, 67°24.4W) was approximately 20 miles northeast of Station 5-1 and 24 miles west-southwest of Station 2 at a depth of 85 m. Grab samples were taken at this site in 1980, 1981, and 1982.

METHODS

Experience gained in 1980 and 1981 with sampling at the USGS sites led to the methods adopted in the Monitoring Program. The procedures were the same as those outlined in Chapter 2, Field Program, with the exception that only five grabs were taken each sampling period. On the first sampling date at Station 13, a 0.25-m^2 U.S. Naval Electronics Laboratory (USNEL) box core was used to obtain two 900-cm^2 samples each divided into 100-cm^2 subunits. Even though the results from those two samples can be corrected for surface area, these samples are not strictly comparable to the later grab samples. Since the USNEL box corer does not work well in sand, it was not used at other stations or on subsequent cruises.

The identification of species in those samples was done independently from the Monitoring Program samples analyzed at Battelle. In comparing results, the only differences pertained to a few new species of oligochaetes and nemerteans that have been the subject of more intensive investigations at Battelle.

RESULTS

Station 13

The number of individuals and species at Station 13 are shown throughout the period from May 1980 to the end of the Monitoring Program in Figure 61. The higher densities in the initial samples probably reflect the greater volume of sediment from a rectangular bite of the box core instead of the half-circle bite of the jaws of the grab. A greater volume of sediment results in increased numbers of subsurface burrowers and tube dwellers. Aside from the general reduction in numbers in May 1982 discussed in Chapter 3, the most interesting feature of the data was an increased number of individuals in November 1981. The increase in species was not obvious until February 1982.

Figures 62 through 65 show changes in the abundance of individual species over the same period. Cossura longocirrata, the most abundant species at this site, showed the trend most clearly. Aricidea catherinae and, to a lesser extent, Ninoe nigripes and Ampelisca agassizi showed the same trend. Mediomastus fragilis increased in November 1981 and February 1982 but differed from the other species in declining in November 1982 and maintaining relatively low densities through 1983 and early 1984.

Station 6

There were no very obvious seasonal or year-to-year trends in the results from Station 6 illustrated in Figures 66 through 70. Densities of Ampelisca agassizi and Polygordius sp. A declined in 1983-1984 and Euchone hancocki appeared to increase.

Station A

The same four species were most common at Station A on all seven sampling dates regardless of season: Ampelisca agassizi, Polygorius sp. A, Erichthonius fasciatus, and Exogone hebes (Table 13). The dominance of these species indicates that Station A was more similar to the 104-m Monitoring Program Station 6 than to Stations 5 and 2 along the 80-m contour (Table 13). Densities of species and individuals (Figures 71 through 74) were constant throughout the sampling period and did not fluctuate seasonally. Erichthonius fasciatus and Notomastus latericeus were maximally abundant during September-October 1981 and Photis pollex and Clymenella torquata were most abundant at the first sampling date in May 1980.

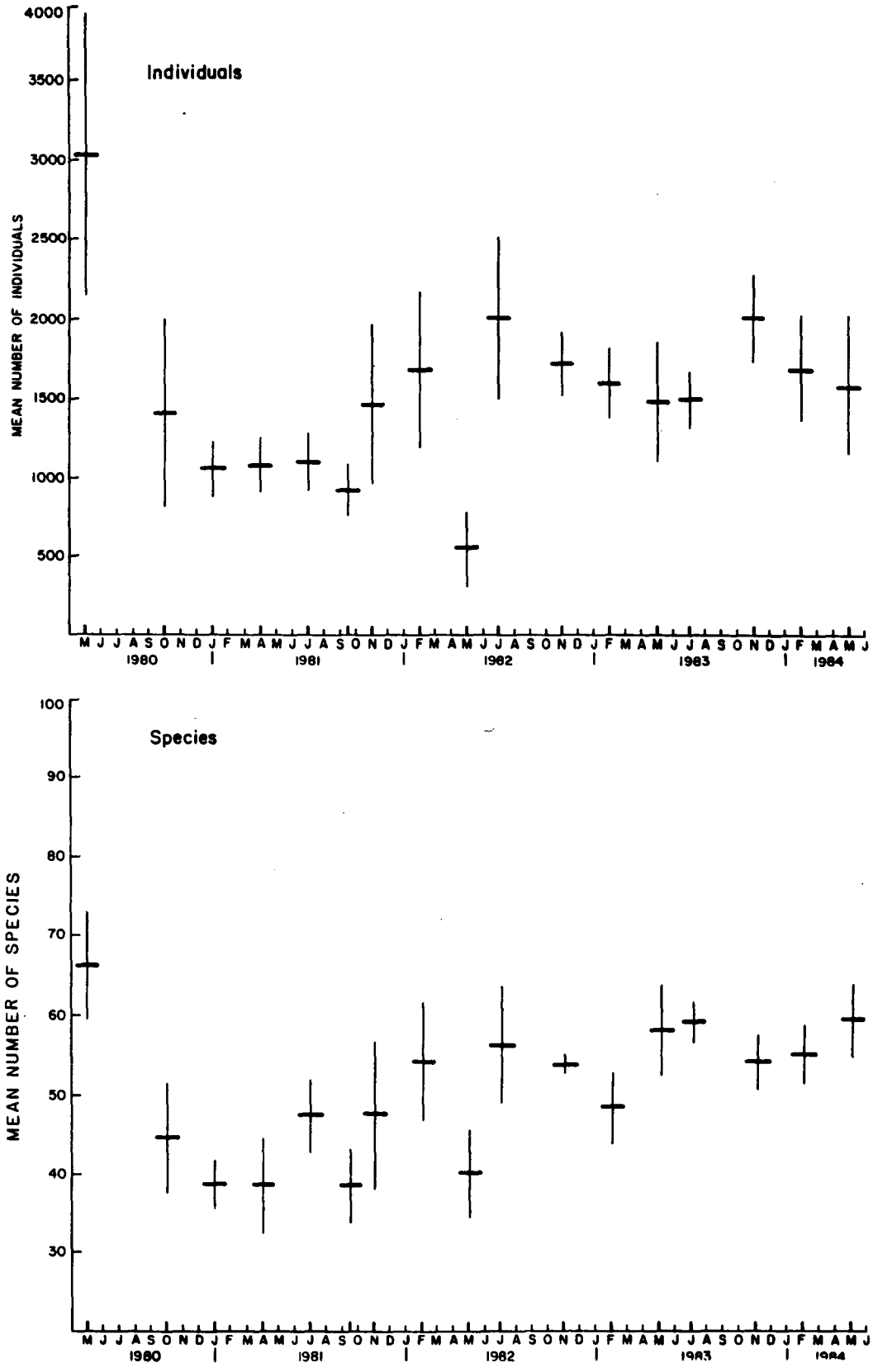

Figure 61. Average number of individuals per 0.04 m^2 $\pm$ one standard deviation and average number of species per 0.04 m^2 $\pm$ one standard deviation at Station 13.

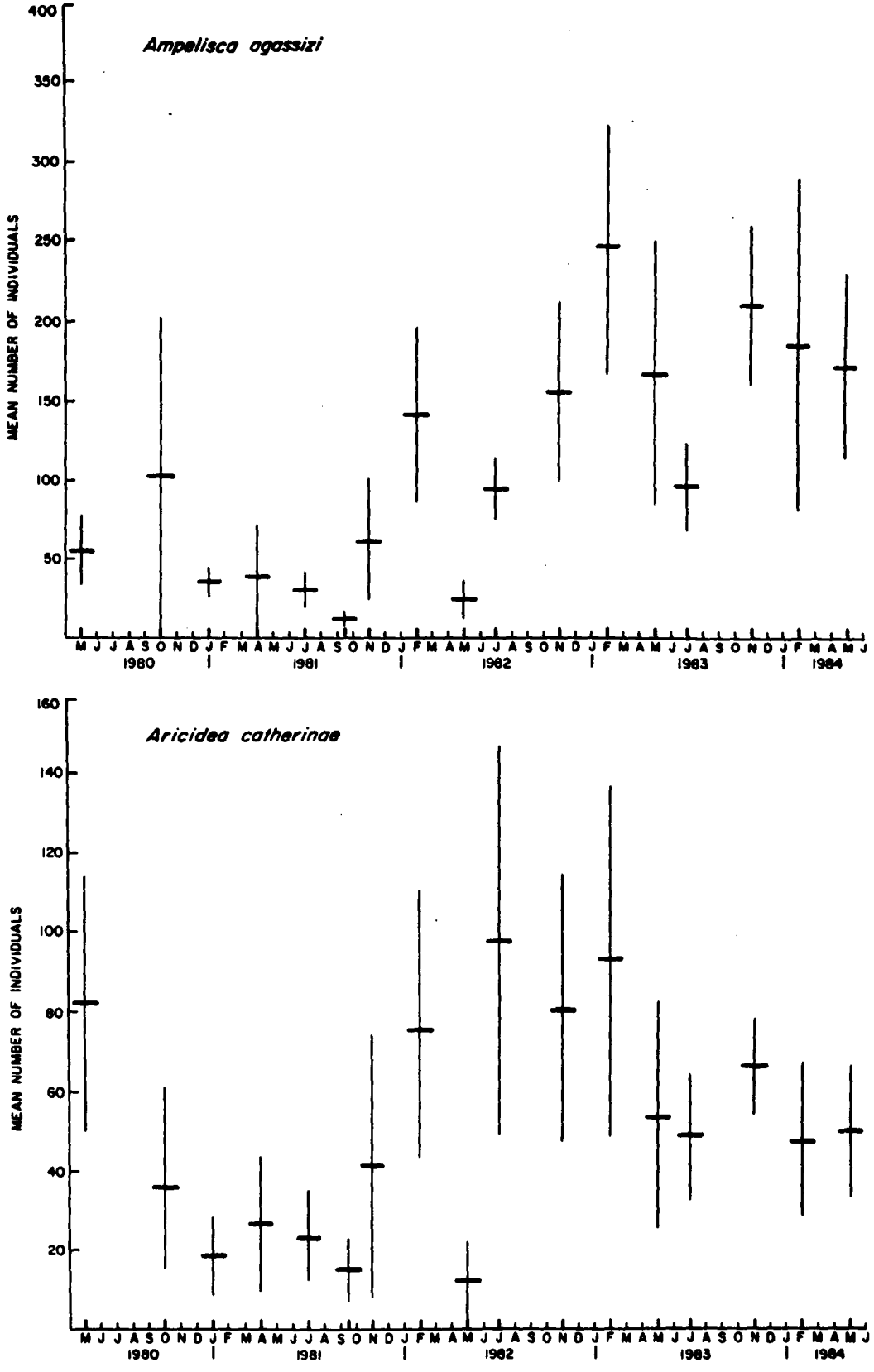

Figure 62. Average number per 0.04 m^2 $\pm$ one standard deviation of Ampelisca agassizi and Aricidea catherinae at Station 13.

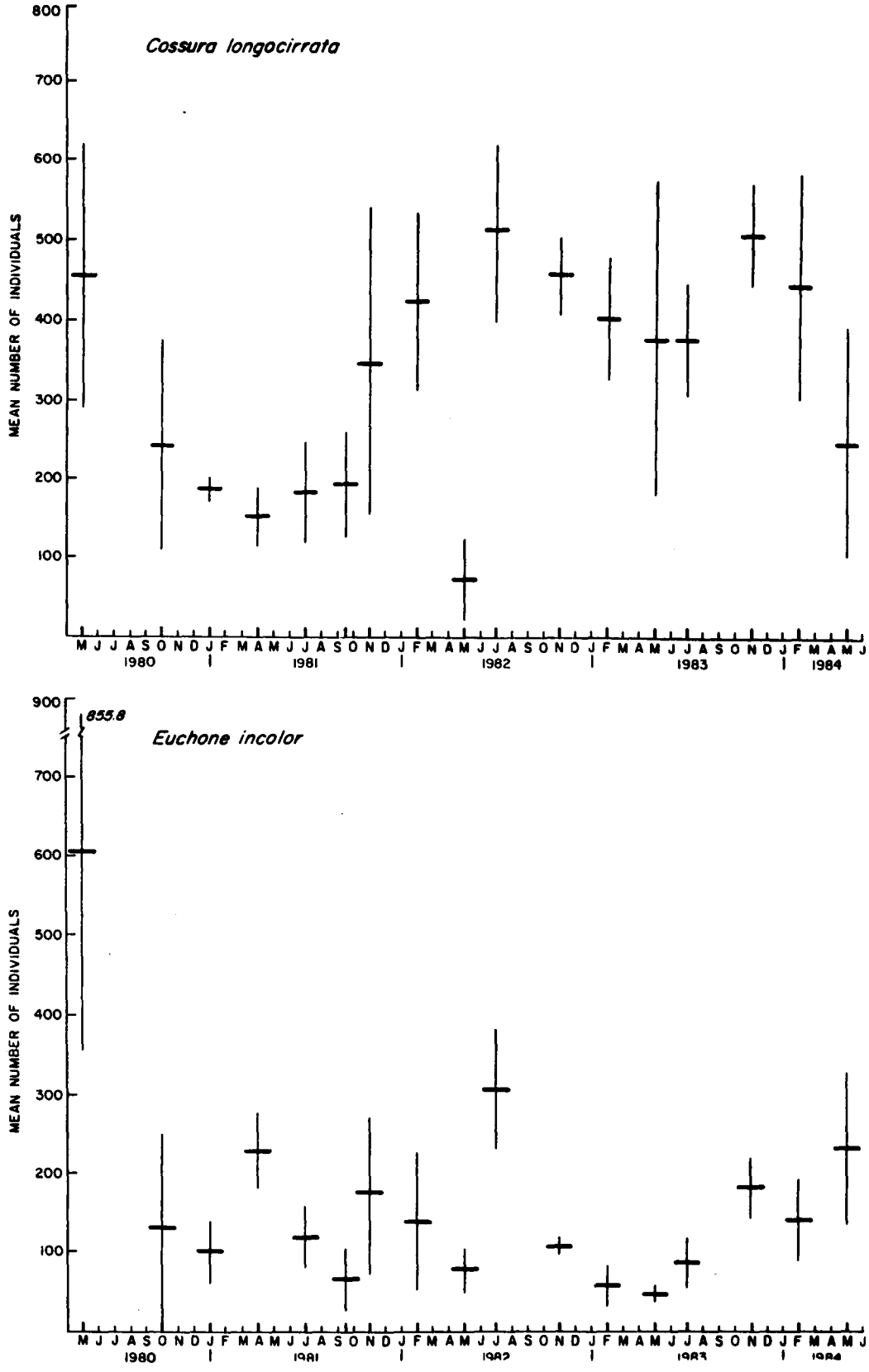

Figure 63. Average number per 0.04 m^2 ± one standard deviation of Cossura longocirrata and Euchone incolor at Station 13.

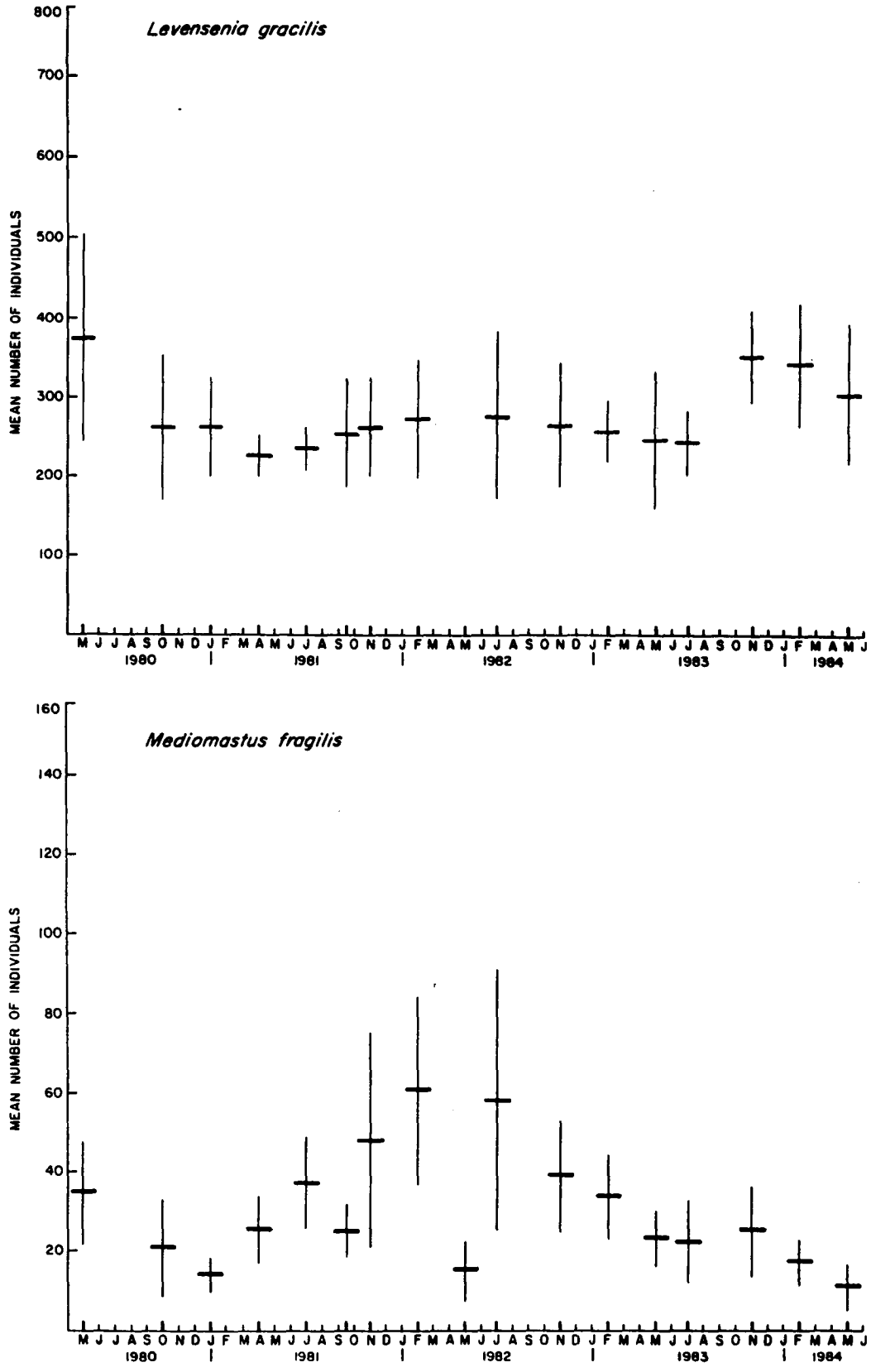

Figure 64. Average number per 0.04 m^2 ± one standard deviation of Levinsenia gracilis and Mediomastus fragilis at Station 13.

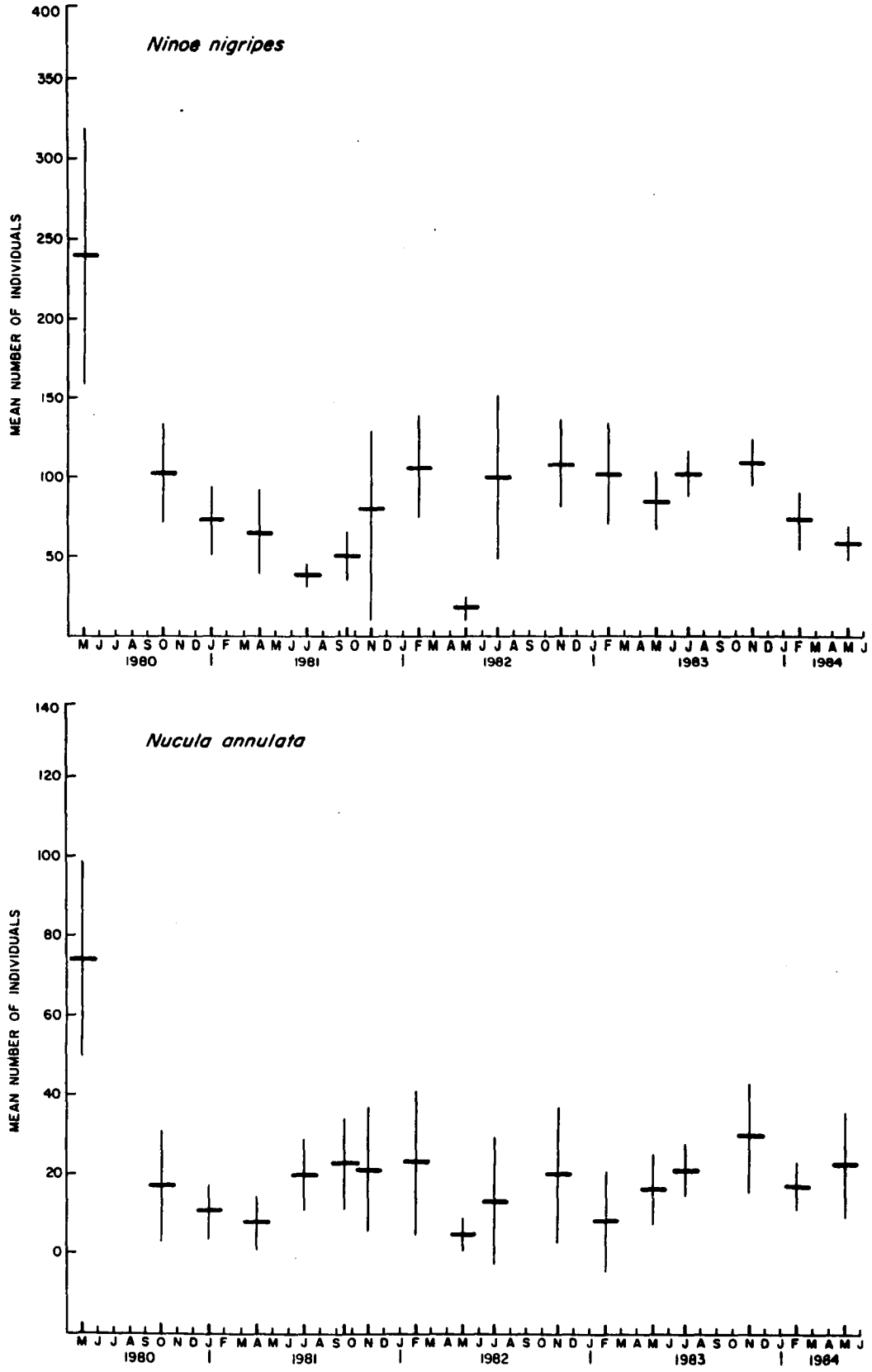

Figure 65. Average number per 0.04 m^2 $\pm$ one standard deviation of Ninoe nigripes and Nucula annulata at Station 13.

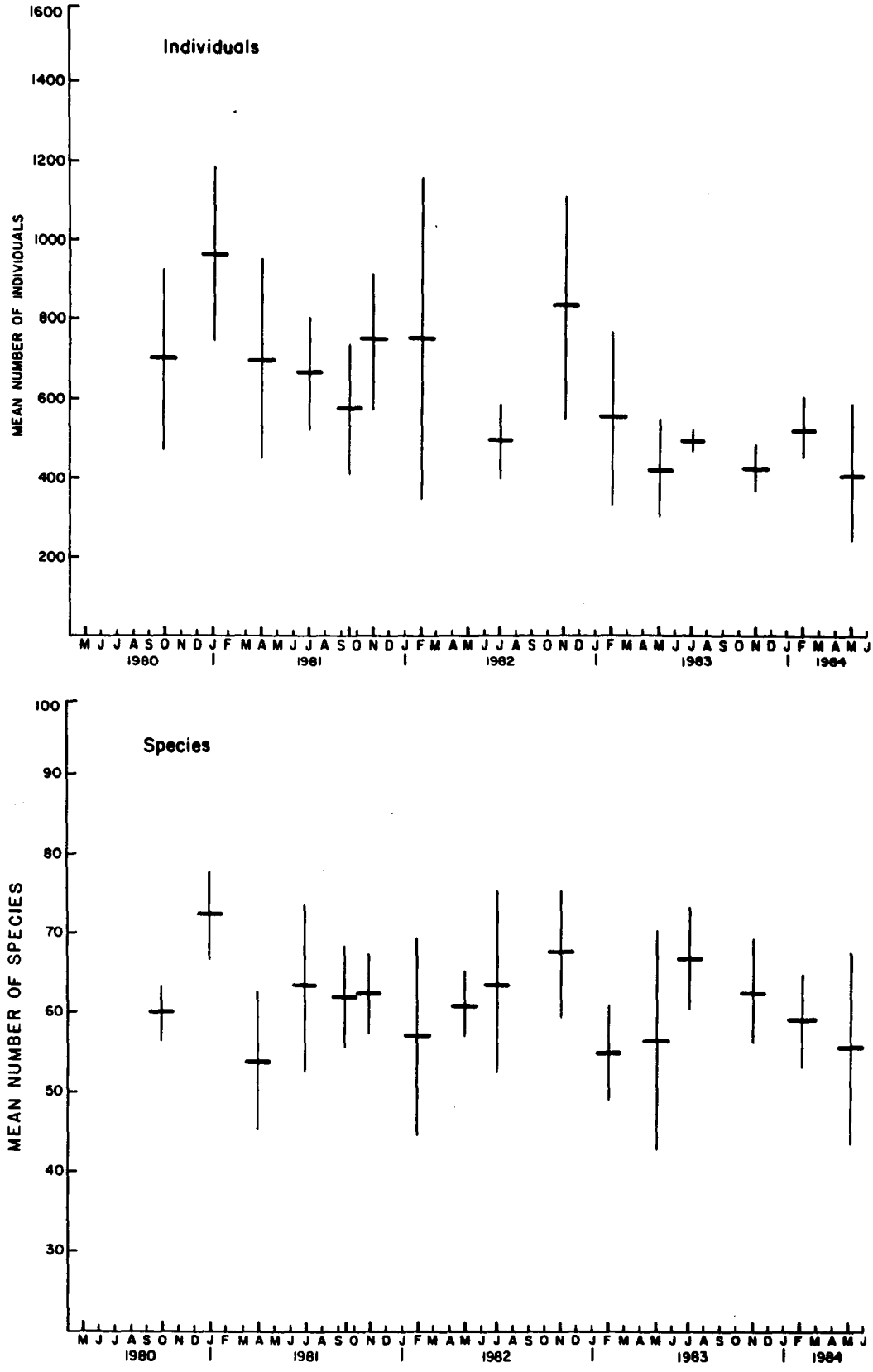

Figure 66. Average number of individuals per 0.04 m^2 $\pm$ one standard deviation and average number of species per 0.04 m^2 $\pm$ one standard deviation at Station 6.

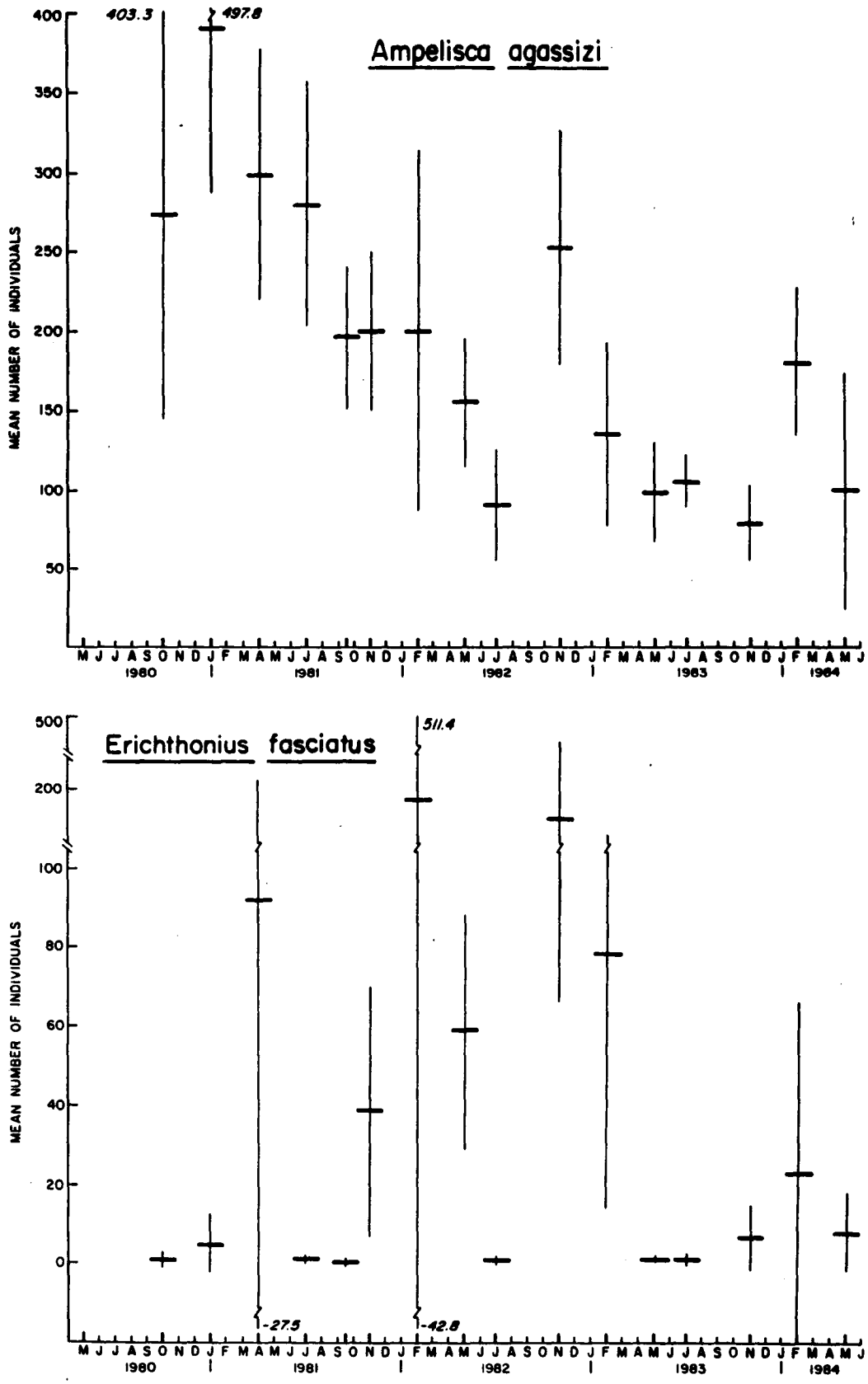

Figure 67. Average number per 0.04 m^2 ± one standard deviation of Ampelisca agassizi and Erichthonius fasciatus at Station 6.

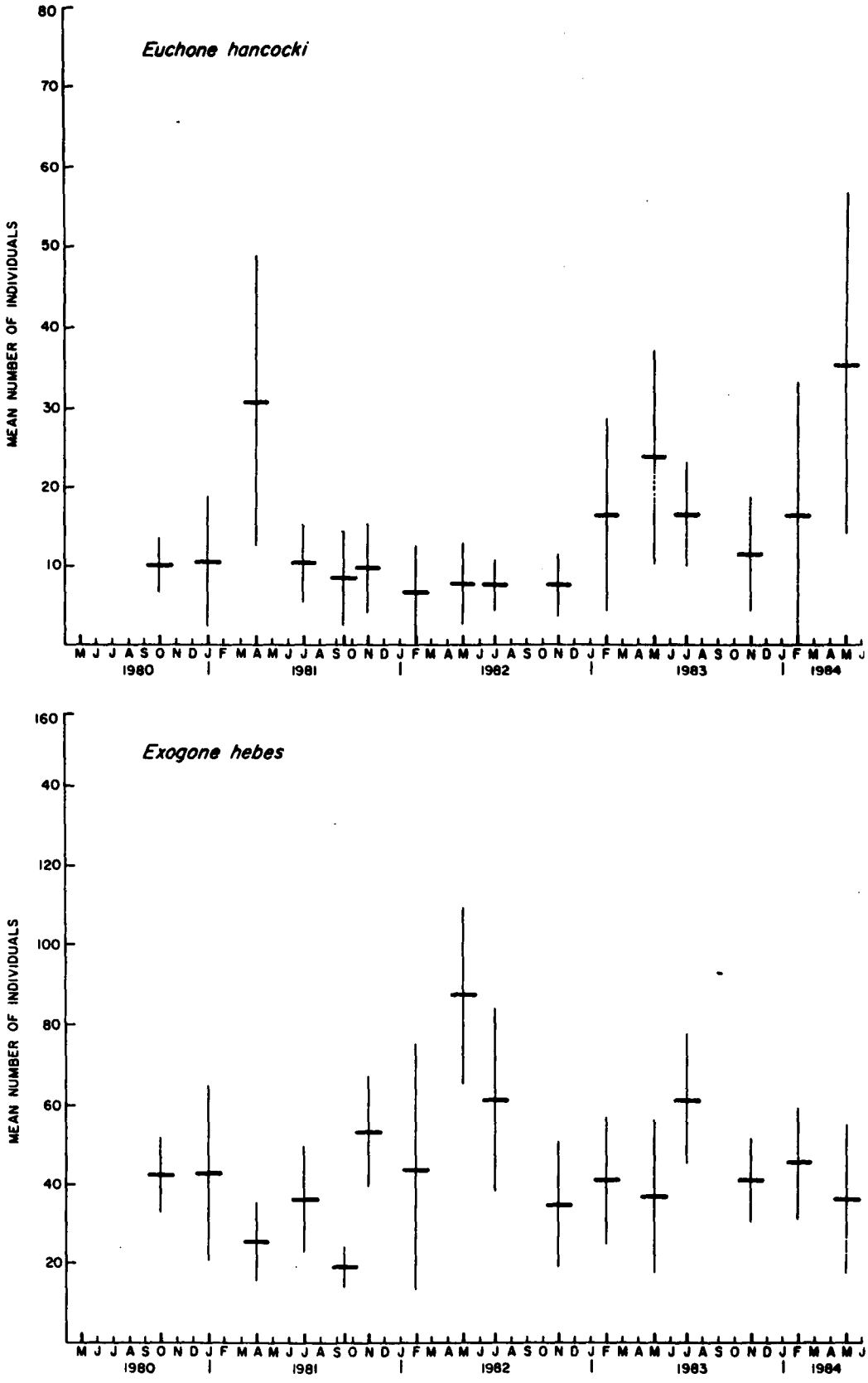

Figure 68. Average number per 0.04 m^2 $\pm$ one standard deviation of Euchone hancocki and Exogone hebes at Station 6.

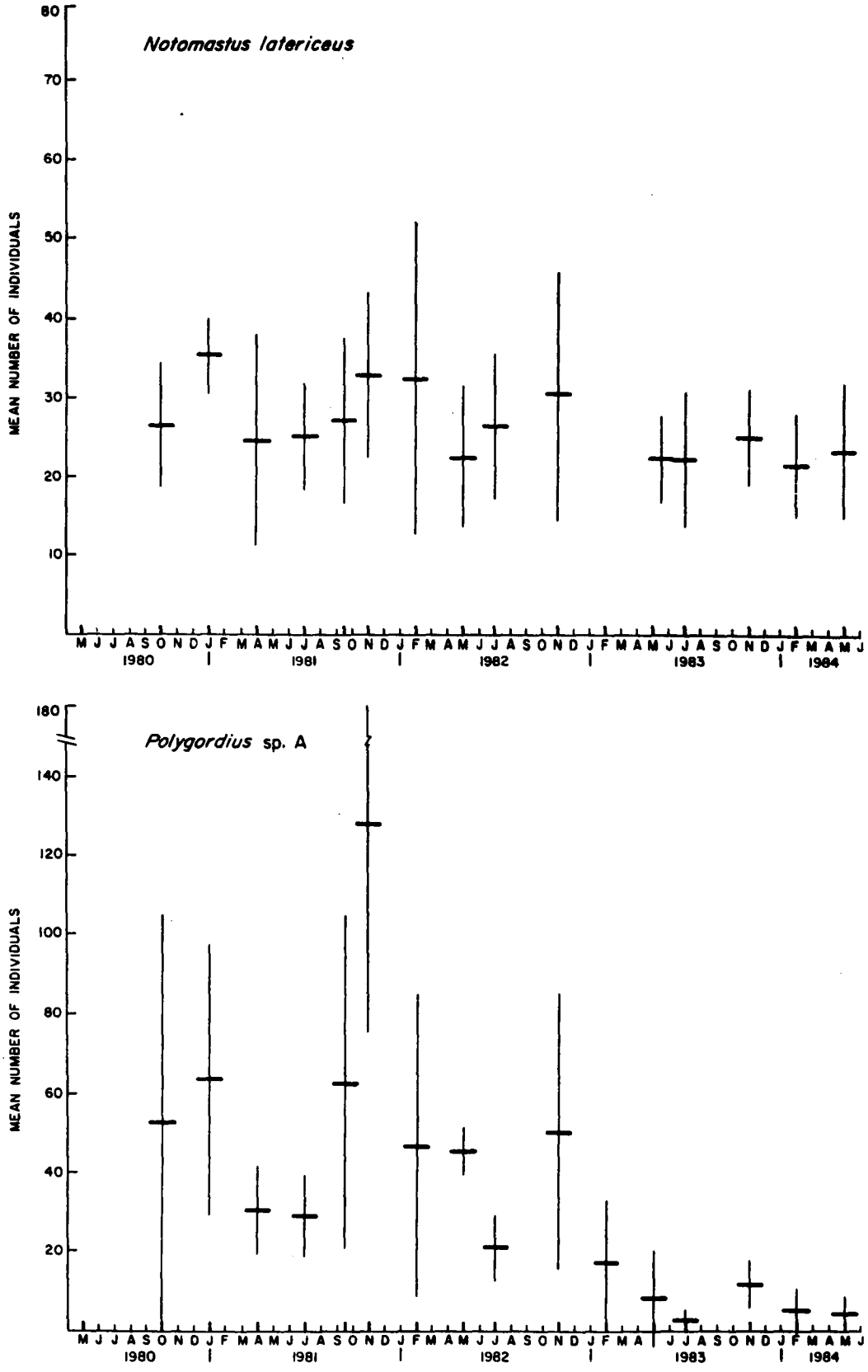

Figure 69. Average number per 0.04 m^2 $\pm$ one standard deviation of Notomastus latericeus and Polygordius sp. $\bar{A}$ at Station 6.

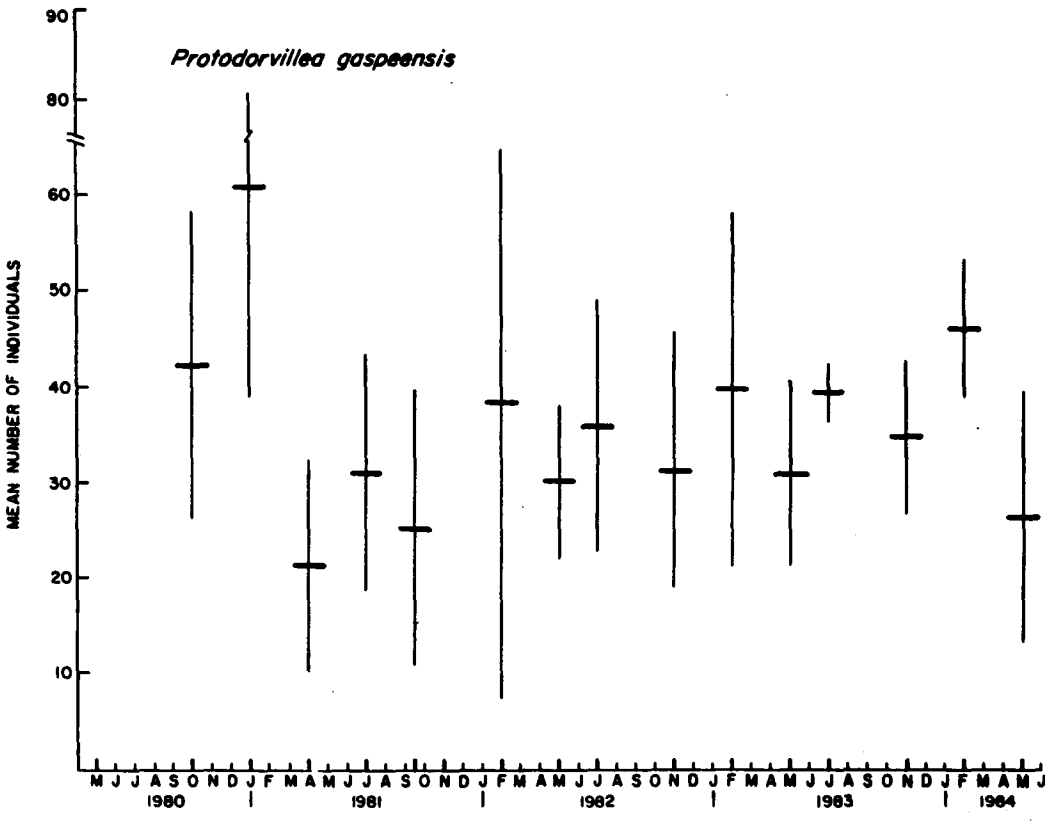

Figure 70. Average number per 0.04 m^2 ± one standard deviation of Protodorvillea gaspeensis at Station 6.

TABLE 13. DOMINANT SPECIES AT STATION A FOR EACH SAMPLING OCCASION.

May, 1980	December, 1980
Ampelisca agassizi	Ampelisca agassizi
Exogone hebes	Polygordius sp.
Erichthonius fasciatus	Exogone hebes
Polygordius sp.	Erichthonius fasciatus
Arctica islandica	Harpinia propinqua
Photis pollex	Arctica islandica
Harpinia propinqua	Tubificoides n. sp. A
Aglaophamus circinata	Clymenella torquata
Chone duneri	Photis pollex
Tubificoides n. sp. A	Eudorella pusilla
Clymenella torquata	
January, 1981	**April, 1981**
Ampelisca agassizi	Ampelisca agassizi
Polygordius sp.	Polygordius sp.
Exogone hebes	Exogone hebes
Erichthonius fasciatus	Erichthonius fasciatus
Arctica islandica	Tubificoides n. sp. A
Tubificoides n. sp. A	Harpinia propinqua
Harpinia propinqua	Notomastus latericeus
Notomastus latericeus	Aglaophamus circinata
Photis pollex	Eudorella pusilla
Cirrophorus furcatus	Arctica islandica
Sept-Oct, 1981	**Jan-Feb, 1982**
Ampelisca agassizi	Ampelisca agassizi
Polygordius sp.	Erichthonius fasciatus
Exogone hebes	Polygordius sp.
Erichthonius fasciatus	Exogone hebes
Aglaophamus circinata	Notomastus latericeus
Harpinia propinqua	Harpinia propinqua
Notomastus latericeus	Tubificoides n. sp. A
Tubificoides n. sp. A	Eudorella pusilla
Eudorella pusilla	Arctica islandica
Chone duneri	Aglaophamus circinata
July, 1982	
Ampelisca agassizi	
Erichthonius fasciatus	
Exogone hebes	
Polygordius sp.	
Harpinia propinqua	
Aglaophamus circinata	
Notomastus latericeus	
Eudorella pusilla	
Tubificoides n. sp. A	
Arctica islandica	

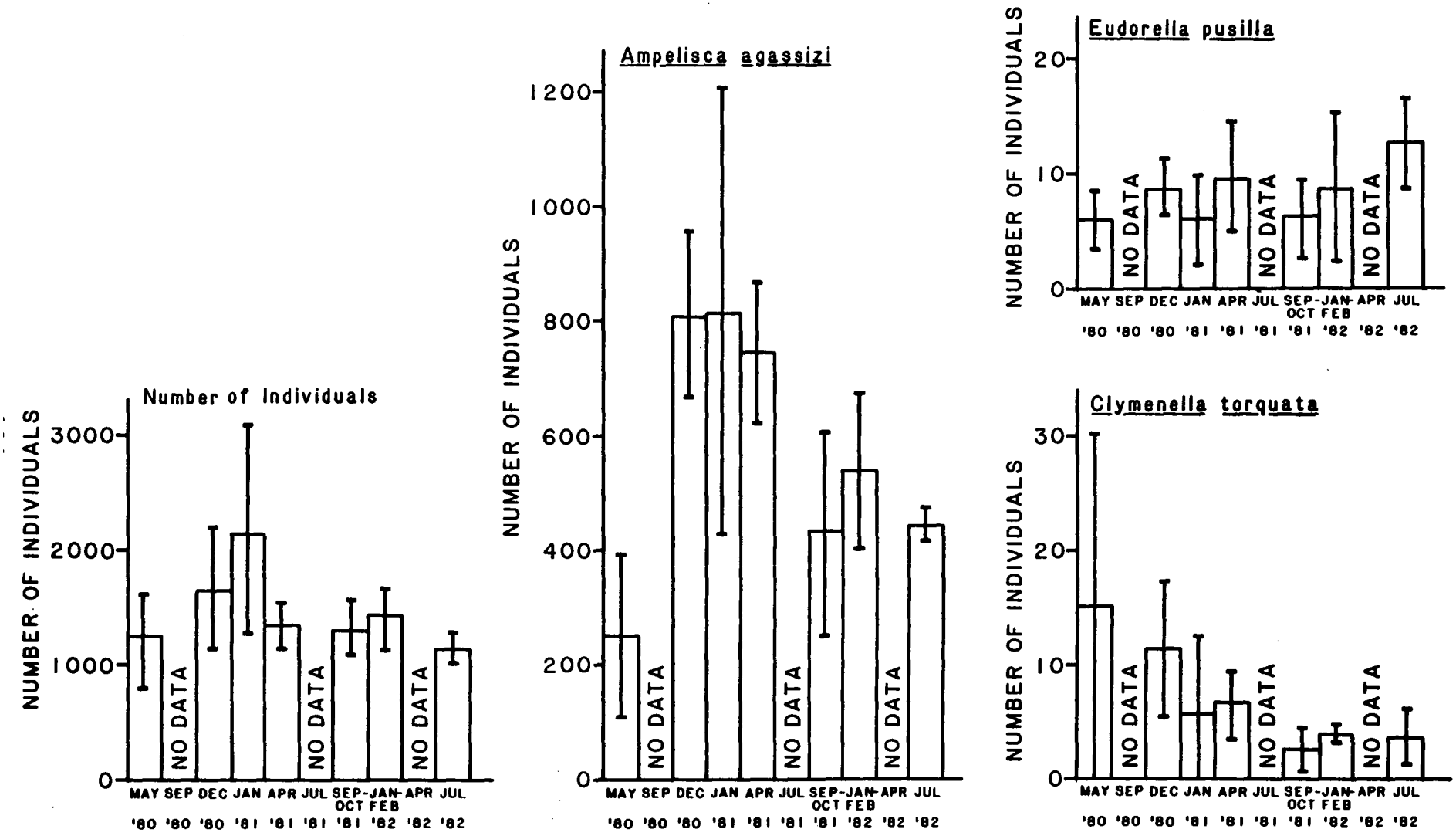

Figure 71. Average number of individuals per 0.04 m^2 ± one standard deviation, and average number per 0.04 m^2 ± one standard deviation of Ampelisca agassizi, Eudorella pusilla and Clymenella torquata at Station A.

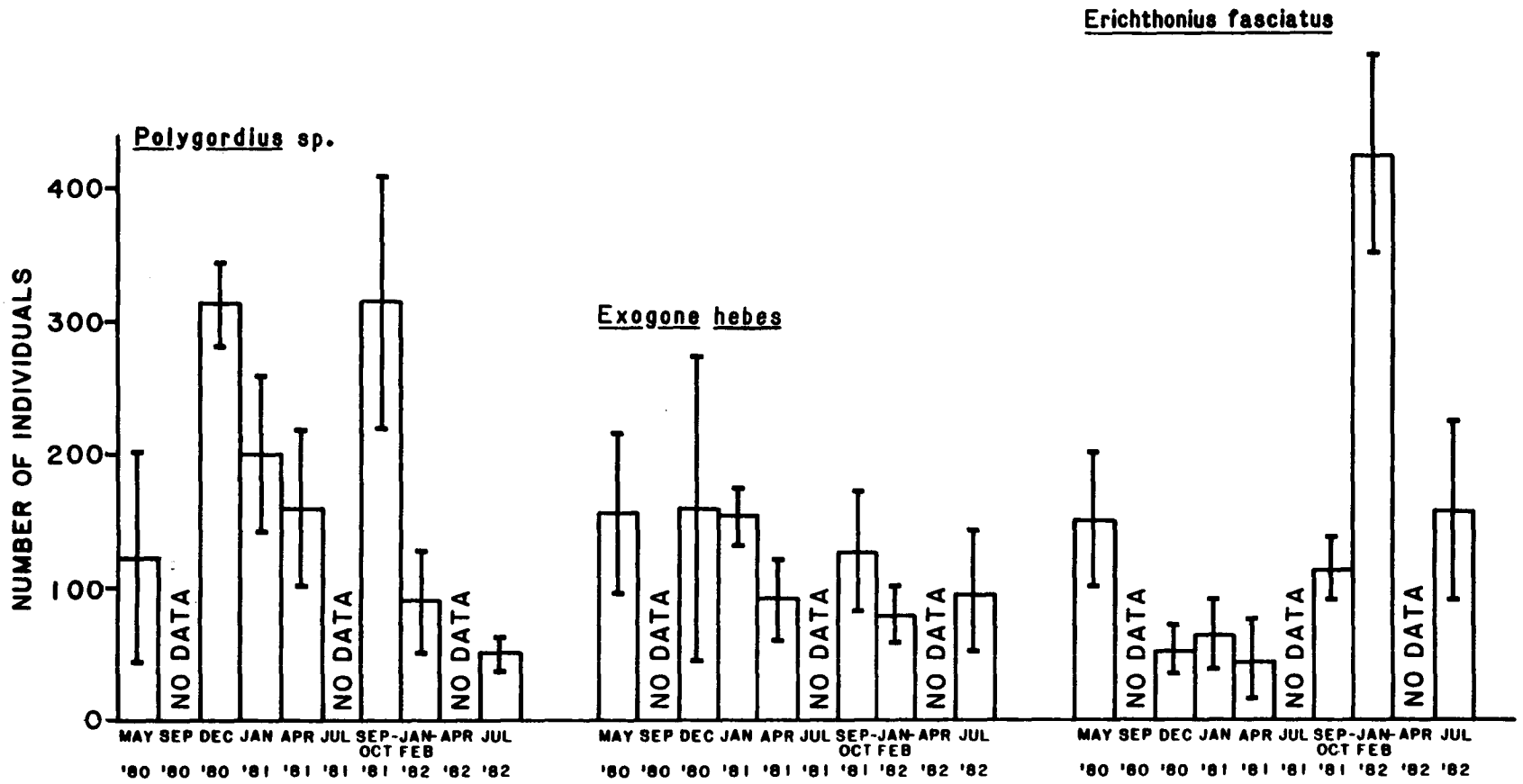

Figure 72. Average number per 0.04 m^2 ± one standard deviation of Polygordius sp. A, Exogone hebes and Erichthonius fasciatus at Station A.

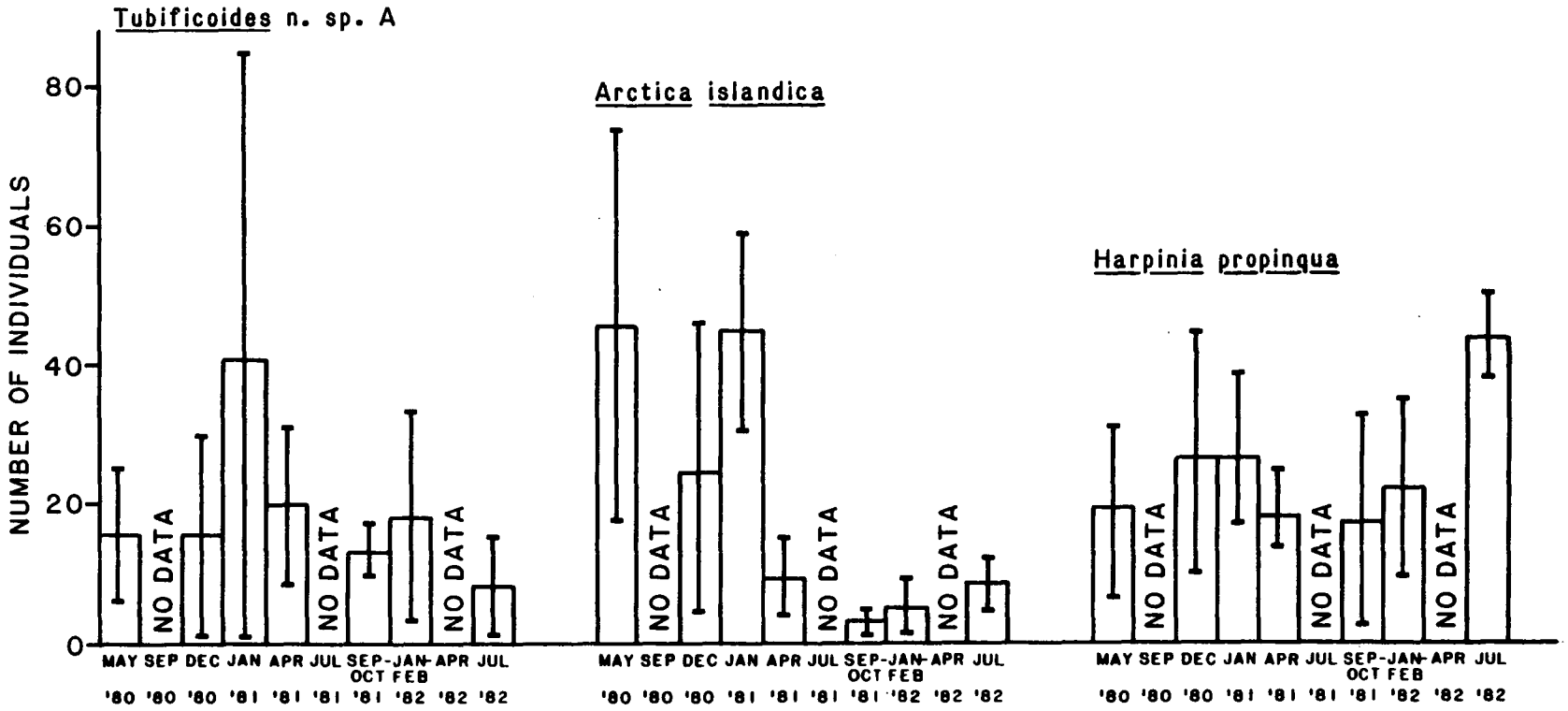

Figure 73. Average number per 0.04 m^2 + one standard deviation of Tubificoides n. sp. A, Arctica islandica and Harpinia propinqua at Station A.

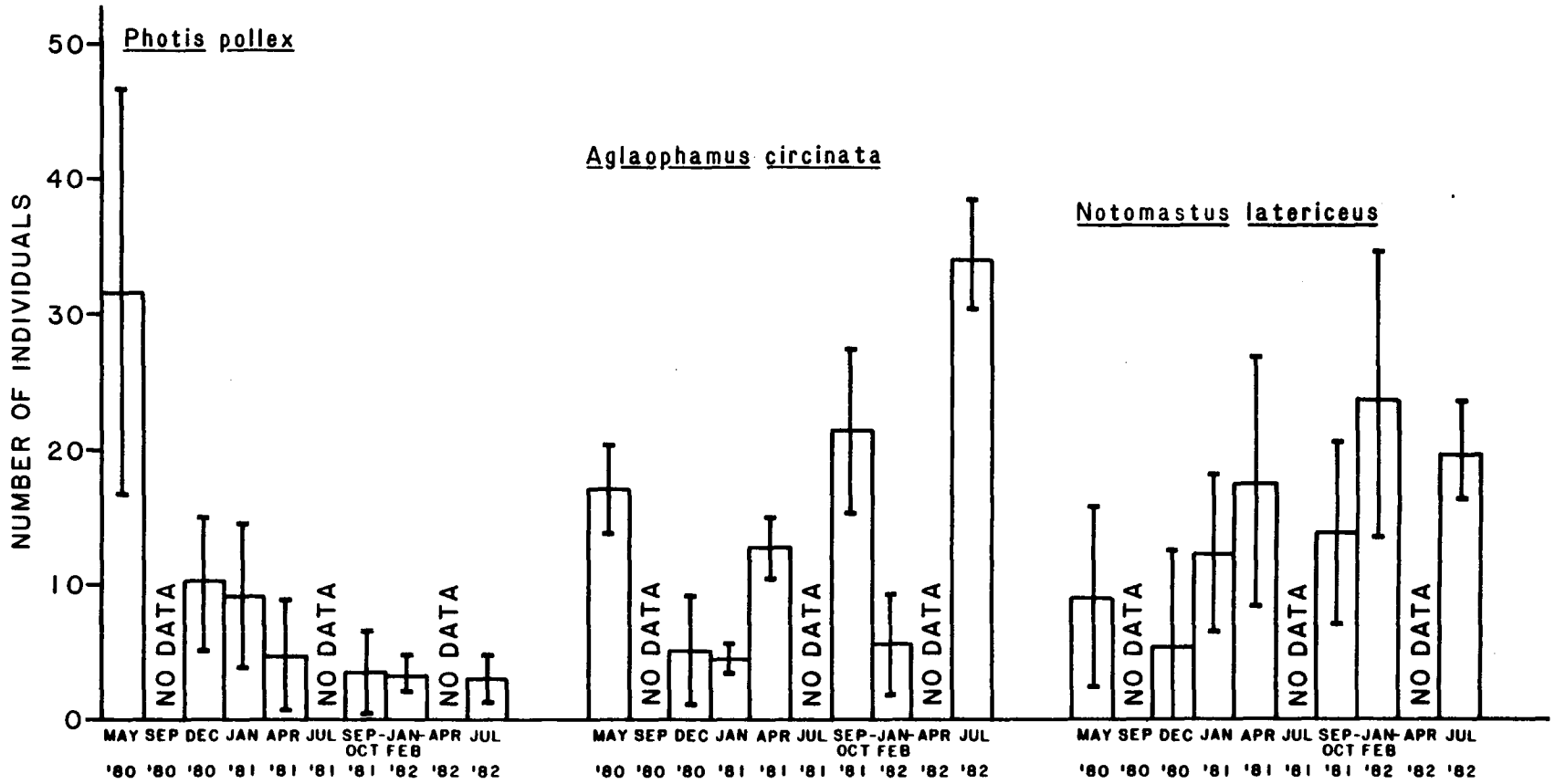

Figure 74. Average number per 0.04 m^2 ± one standard deviation of Photis pollex, Aglaophamus circinata and Notomastus latericeus at Station A.

DISCUSSION

The change in fauna seen at Station 13 preceded the change in sediments observed starting in November 1981 (see Chapter 10). If the increase in silt-clay fraction was not an artifact (see Chapter 10), it is hard to explain the gradual increase in fine fraction of sediments by a physical process. However, the activities of selective deposit feeders could have resulted in a net increase in fine material at the surface. Aricidea catherinae is probably a subsurface deposit feeder whereas Cossura longocirrata, Ninoe nigripes and Ampelisca agassizi probably feed near or on the surface. A detailed study of feeding has not been undertaken for any of these species. Although a change in fauna is sufficient reason for a shift in sediment composition, the reasons for the change in fauna are unknown. The change occurred before the commencement of drilling at Block 312.

At Station 6 more subtle changes occurred in 1983 and early 1984. Ampelisca agassizi showed considerable variation in 1983 making it difficult to attach much significance to the more consistently low numbers in 1983 and early 1984. The decline in Polygordius sp. A is statistically significant since the means in 1983 and early 1984 are all lower than mean densities recorded in earlier years. Although there were no data on the fine fraction from Station 6, Bothner et al (1984) reported sharp increases in barium early in 1983 at a number of stations, so this might be an effect of drilling. Increases in the surface-feeding Euchone incolor coincided with the declines in the other two species.

The time series at Station A was not long enough to identify trends. Despite drastic changes in bottom conditions and sediment movements in winter storms (Butman and Moody, 1983) seasonal oscillations in abundance did not occur.

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CHAPTER 6. LIFE HISTORY STUDIES ON DOMINANT POLYCHAETE SPECIES FROM GEORGES BANK

by

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and

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INTRODUCTION

As part of the laboratory analysis of the Georges Bank Benthic Infauna Monitoring Program, a task was included to collect data on the life history parameters of some dominant invertebrate species from selected stations. The purpose of these studies was to determine times of settlement and recruitment as well as size frequency distributions of populations of each species on a seasonal basis. The use of 0.3-mm screens to sieve the benthic samples made it possible to detect the earliest settling stages of many species. Through careful observation of a series of growth stages, it has also been possible to identify the earliest juvenile stages of some species. If juvenile cohorts are identified and followed over time, then it should be possible to detect any impact of drilling-related activities on individual year-classes. The data were also developed to provide supplementary information for the Secondary Production and Fish Feeding Task (Chapter 7).

A suite of 19 polychaetes, three amphipods, and one echinoderm were selected for study. The polychaetes are treated in this chapter, while the amphipods and echinoderms are treated in Chapter 7 by J. Collie and M.C. Curran.

METHODS AND MATERIALS

Size Frequency Analyses

Polychaete species selected for length-frequency analysis included species primarily from Stations 5-1, 13, 16 and 18. Populations of Tharyx acutus, T. annulosus, T. dorsobranchialis, Aricidea catherinae, A. suecica, Levinsenia gracilis, Cossura longocirrata, and Chone infundibuliformis were examined at Station 13. Species studied

from Station 5-1, one of the drilling sites on the Bank, included Tharyx acutus, T. sp. A, Exogone hebes, E. verugera, Sphaerosyllis cf. brevifrons, Parapionosyllis longicirrata, Streptosyllis arenae, and Syllides benedicti. In some cases, individuals collected at the nearby Stations 5-2, 5-3, and 5-4 were combined with those from Station 5-1 to make up an adequate sample size. From the Block 410 Stations 16 and 18, Aricidea neosuecica, Paradoneis sp. A, and Paraonis sp. A were chosen for analysis. Individuals of one additional species, Aglaophamus circinata, were studied at Stations 3 and 6. A minimum sample size of 100 individuals of each species was measured when possible, although this number was not always available.

Eleven species were analyzed for nine seasons (M1-M9, July 1981 - July 1983); one species, Chone infundibuliformis, was studied for five seasons (M5-M9, July 1982 - July 1983); and seven species were measured for four seasons (M1-M4, July 1981 - May 1982). Although direct length measurements were made for Chone infundibuliformis, the number of setigers rather than the measured length was the parameter of choice for determining size class frequencies for the other species. Setigers were counted for each whole specimen collected in July 1981 (M1). Only entire individuals were measured for abundant species; for less abundant species, measurements were made on all specimens, including anterior fragments. Length measurements could not always be substituted for setiger counts because of differential contraction of individuals during fixation. Specimens were often fragmented or coiled, precluding complete and accurate setiger counts as well as measurements. Therefore, a series of measurements of additional morphological characters were made for each species studied. Such measurements included: thorax width, prostomial length, proventricle length (in syllids), and number of branchiae. These measurements were then used to develop regression equations to calculate number of setigers (see below). This proved to be an especially valuable technique for those species which tended to fragment.

All data were coded and entered into the VAX/11-780 computer at Woods Hole Oceanographic Institution. Subprogram NEW REGRESSION of SPSS (Statistical Package for the Social Sciences; Hull and Nie, 1981) was used to fit the "best" regression equation relating setiger count to the measured variables. In addition to the original linear scale variables, the natural $\log_e(X)$, square (X^2), and cube (X^3) of each variable were calculated and also entered into the analysis. The resulting regression equations and their associated coefficients of determination (r^2) are shown in Table 14.

The regression equations were used to calculate number of setigers for those specimens of 14 species for which direct counts of setigers were lacking for collections from November 1981 through July 1983. For specimens which were used to fit the

TABLE 14. FITTED REGRESSION EQUATIONS USED TO EVALUATE NUMBER OF SETIGERS FOR LIFE HISTORY ANALYSIS.

Species	Regression	r^2
Tharyx acutus	SETIGERS = 107.8 + 38.2 $\log_e$ (thorax width)	0.75
Tharyx annulosus	SETIGERS = 101.2 + 32.8 $\log_e$ (thorax width)	0.64
Tharyx dorsobranchialis	SETIGERS = 10.8 + 252.1 (thorax width)	0.46
Aricidea catherinae	SETIGERS = 14.3 + 0.2 (number of gills^2) + 150.9 (thorax width^2)	0.75
Aricidea suecica	SETIGERS = 121.8 + 43.9 $\log_e$ (thorax width)	0.64
Levinsenia gracilis	SETIGERS = 19.3 + 7.7 (number of gills) - 0.038 (thorax width^3)	0.64
Exogone hebes	SETIGERS = 82.9 (length of proventricle) + 2.3	0.78
Exogone verugera	SETIGERS = 128.2 (length of proventricle) - 6.8	0.87
Sphaerosyllis cf. brevifrons	SETIGERS = 121.3 (length of proventricle) - 2.0	0.91
Parapionosyllis longicirrata	SETIGERS = 10.3 (total length) + 9.2	0.83
Streptosyllis arenae	SETIGERS = 8.2 (total length) + 13.2	0.92
Syllides benedicti	SETIGERS = 9.0 (length of proventricle) + 10.9	0.83
Aglaophamus circinata	SETIGERS = 36.53 + 19.65 (thorax width) + 14.83 (ln thorax width)	0.80
Chone infundibuliformis	Length = 4.65 (length thorax) - 3.84	0.90

regressions (i.e., those for which the setigers were counted) the actual counts are presented rather than calculated values. For Chone infundibuliformis, regression equations were used to calculate length rather than number of setigers. For the remaining five species (Cossura longocirrata, Aricidea neosuecica, Paradoneis sp. A, Paraonis sp. A, and Tharyx sp. A) regression analysis did not suggest a good alternate measurement. Sufficient specimens were available for which counts of setigers could be obtained directly.

Subprogram FREQUENCIES of the SPSS package (Nie et al., 1975) was used to generate frequency distributions for each species by cruise at five-setiger intervals. For Levinsenia gracilis, a 7.5-setiger interval was used.

Reproductive Characteristics

In addition to determining size class frequency of each species, all specimens were examined under the compound microscope for evidence of reproductive characteristics. The presence of eggs (or oocytes), their size and location in or on the body, the presence, location and arrangement of sperm or spermatophores, the presence and degree of development of brooded young, and the presence of any obvious or unusual reproductive structures were recorded. In order to enhance the ability to interpret the nature of reproductive structures or products, both whole mount and thin section preparations were made. Specimens stained in haematoxylin were mounted in glycerine from 70 percent isopropanol. Unstained specimens were cleared and mounted in Euparal (GBI Laboratories, Inc., Denton, U.K.) directly from 99 percent isopropanol. Thin sections of several particularly unusual specimens were made. The specimens were embedded in formalin-agar (Boldorac, 1979), cut at 5 µm, and stained with hematoxylin and eosin, using standard histological procedures.

RESULTS

Polychaete Species from Station 5-1

Nine species were analyzed from Station 5-1, including six Syllidae and three Cirratulidae. Three of the syllids and two cirratulids were studied for nine seasons (July 1981 - July 1983). The remaining species were analyzed only for four seasons, July 1981 - May 1982. Results for T. annulosus from Station 5-1 are presented with the results for that species from Station 13 in order to make direct comparisons.

Exogone hebes (Webster & Benedict)

Exogone hebes is a viviparous species, with young developing within the female's body and emerging as a fully functional juvenile. Details of this development were presented by Pocklington and Hutcheson (1983). These authors reported a spring spawning maximum, but noted year-round presence of incubating females.

In the present study, we have also found good evidence for year-round reproduction. The data indicate three distinct periods of gamete development in females over nine seasons. These seasons and the percent females in the population are: July 1981 (4.2 percent) - November 1981 (6.4 percent); May 1982 (3.5 percent) - July 1982 (8.6 percent); February 1983 (2.4 percent) - May 1983 (9.3 percent). Since each of these three sequences represents a different seasonal pattern, it is obvious that reproduction is not dependent upon any one seasonal sequence in E. hebes. The size frequency data also support a year-round reproductive pattern (Figure 75). Large numbers of juveniles in the 10-25 setiger range are present in all nine collections. There is no significant recruitment event evident in any of the nine collections. There are also consistent numbers of larger specimens in the 35-40 setiger range present throughout the year.

Exogone verugera (Claparède)

Exogone verugera undergoes a type of reproduction in which the eggs move to an attachment point on the ventral surface of the female following fertilization and the embryos develop externally on the female's body. These larvae can be observed attached in rows. They eventually break loose and move off to continue as independent individuals. The size-frequency data do not include those larvae which were attached to the bodies of females.

Exogone verugera undergoes sexual development in the spring and normally spawns in the summer. Recruitment was in the fall (November 1981) or summer (July 1982, July 1983) (Figure 76). The highest percentage of juveniles in the < 20 setiger range occurred in November 1981 (0.9 percent), February 1982 (8.3 percent), July 1982 (20.1 percent), and July 1983 (33.3 percent). Mature males were observed in July 1981 (52 percent) and July 1982 (<.1 percent) and females in July 1981 (39 percent), November 1981 (40 percent), July 1982 (14 percent), and November 1982 (12 percent). Mature egg diameters averaged 205.4 µm x 160.8 in 54 measurements taken from six individuals in November 1982.

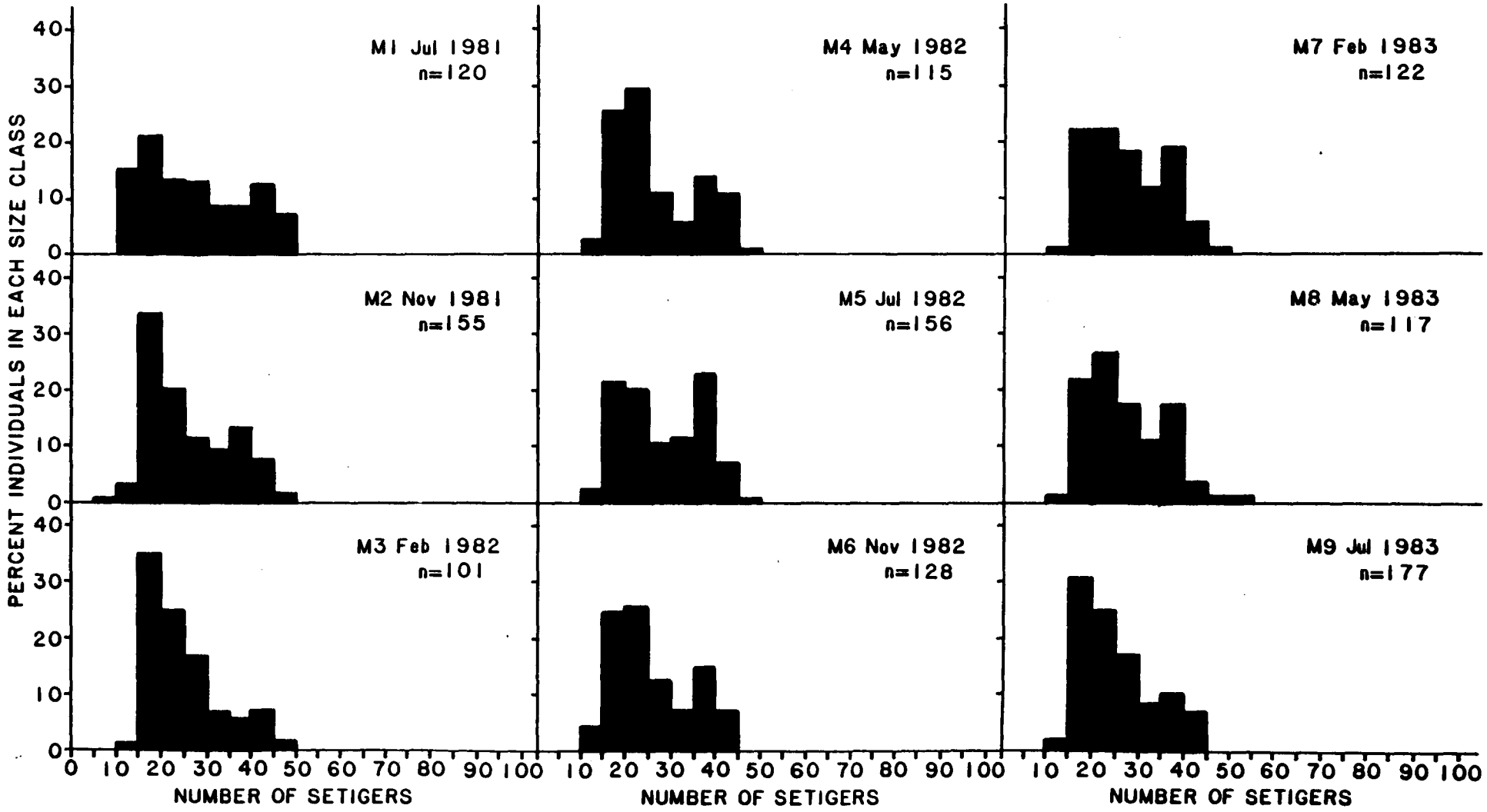

Figure 75. Size-class frequency of Exogone hebes at Station 5-1.

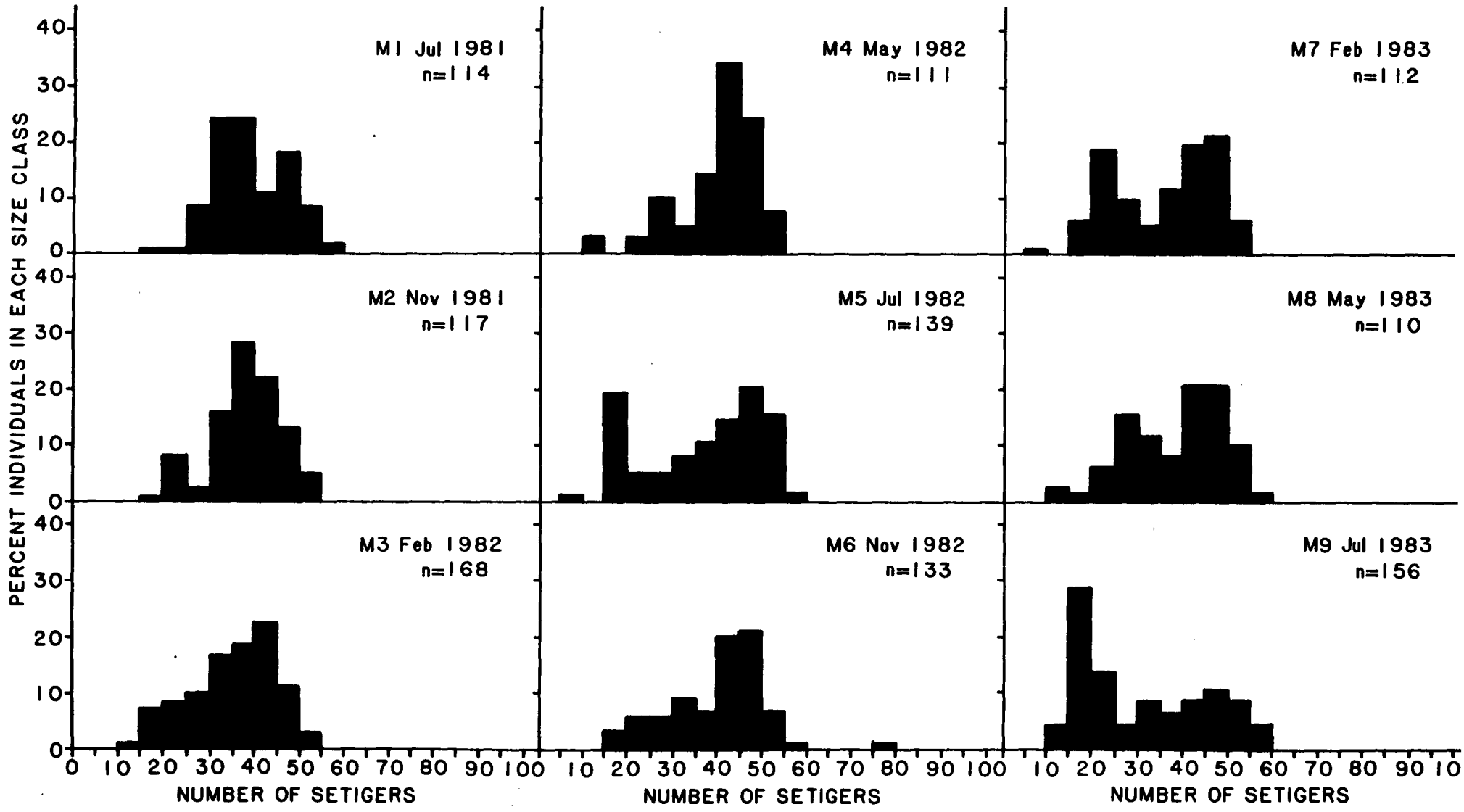

Figure 76. Size-class frequency of Exogone verugera at Station 5-1.

Parapionosyllis longicirrata (Webster & Benedict)

Measurements of Parapionosyllis longicirrata were taken only for July 1981 through May 1982. This species exhibited the most recruitment in the summer (July), with a significant increase in juveniles in the 10-20 setiger range (Figure 77), representing 14.4 percent of the population in that collection. Percentages of 12.0, 1.9, and 2.6 were found in November, February and May, respectively, for those same sizes. Males were observed only in July (3.6 percent), while females were recorded in July (11.9 percent), February (30.3 percent) and May (28.1 percent). Sex could not be determined in any specimen collected in November. In most cases, females carried internal oocytes; five specimens, however, were observed with early embryos attached externally to their bodies: three in November and two in February. The latter observation and the presence of individuals in the 15-20 setiger range year-round suggests that some specimens are spawning in winter and spring.

Sphaerosyllis cf. brevifrons (Webster & Benedict)

Larvae of Sphaerosyllis cf. brevifrons were found attached in pairs along the dorsal side of the body of adults. Data suggest that this species is sexually active year-round. Females bearing either internal oocytes or externally attached embryos were found in all nine collections. External embryos, however, were found in only four collections (July 1981, February 1982, July 1982 and July 1983). Mature egg diameters from specimens collected in July 1982 averaged 107.7 µm x 76.0 µm based on 78 measurements from 11 individuals. Size frequency measurements indicated that a significant recruitment of individuals less than 20 setigers was present in the November 1982 collection (Figure 78). This represented 66.4 percent of the population, compared with 33.3 percent in July 1981 and 22.6 percent in February 1982. These data suggest that substantial recruitment occurred in late summer or early fall in 1982. There was another increase in the percentage of juveniles in February 1983 and May 1983, with 32.7 percent in November 1982 and 27.5 percent in July 1983. All of these results suggest a pattern whereby S. cf. brevifrons undergoes some reproduction on a year-round basis, but has occasional peaks in late summer or late winter.

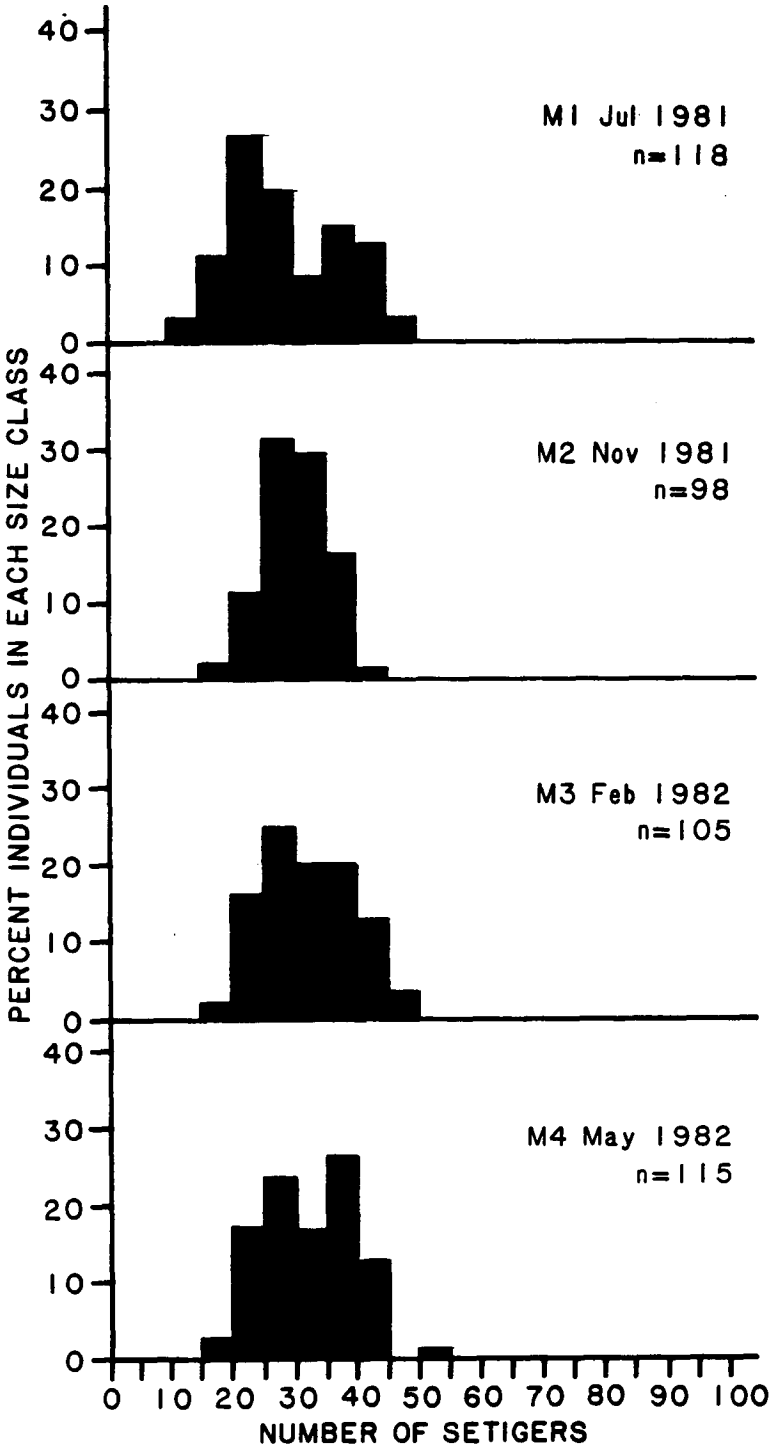

Figure 77. Size-class frequency of Parapionosyllis longicirrata at Station 5-1.

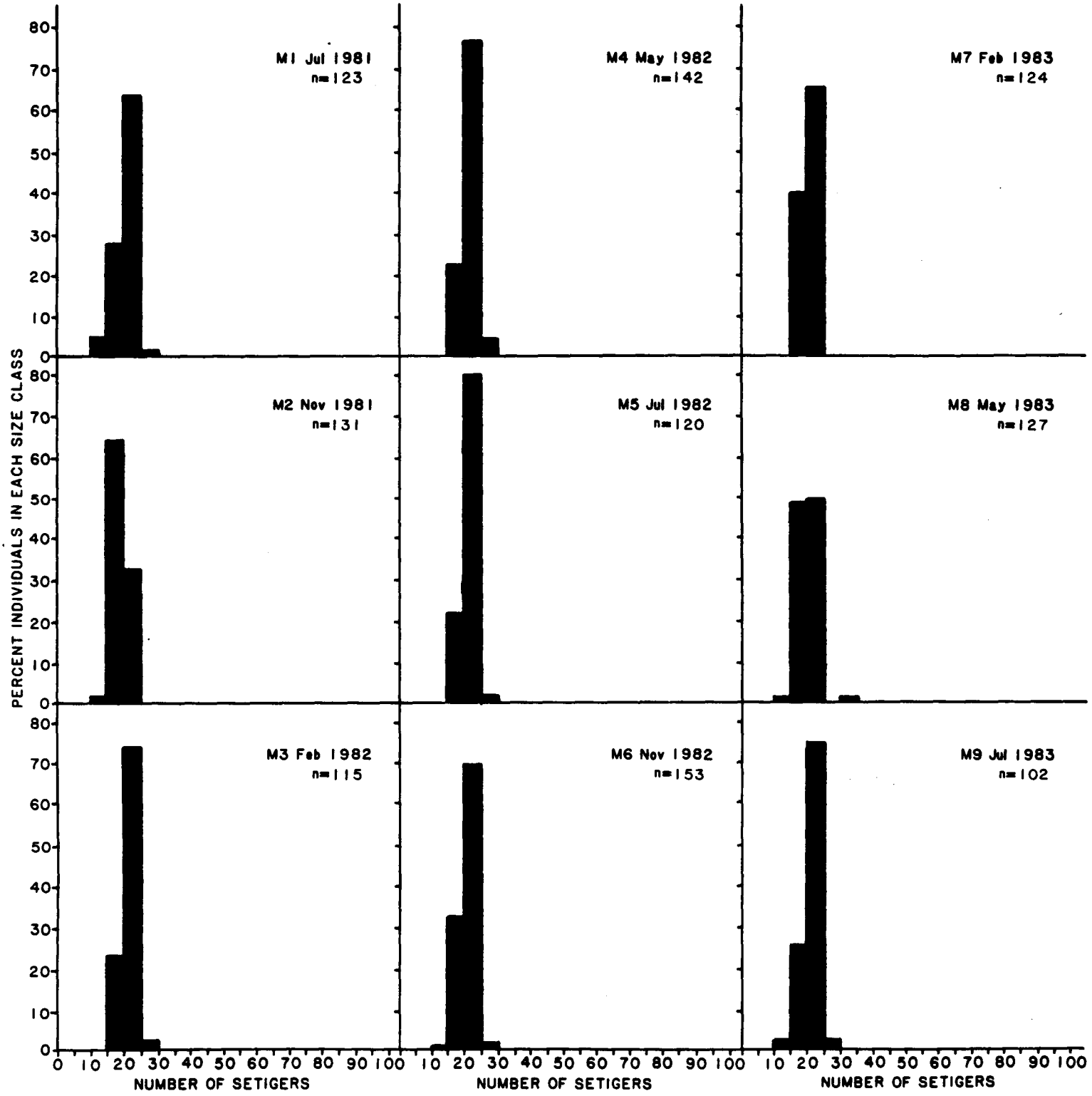

Figure 78. Size-class frequency of Sphaerosyllis cf. brevifrons at Station 5-1.

Streptosyllis arenae (Webster & Benedict)

It is not known how Streptosyllis arenae reproduces. Data were collected for S. arenae from July 1981 through May 1982. The species appeared to reproduce in the spring and summer and internal oocytes were observed in specimens from all four collections. The smallest juveniles were present in July (M1), but no specimens of that size group were present in later collections. Two distinct size classes were present in the February (M3) collections, the first of which corresponds to the settling forms found in July (Figure 79).

Syllides benedicti (Banse)

Externally attached embryos were observed for this species. This is the second reported case of brooding in a species of Syllides, the first being for the Pacific species S. japonica Imajima (Heacox and Schroeder, 1979). For S. benedicti, recruitment appeared to take place in the summer, with 32.7 percent of the specimens having less than 25 setigerous segments (Figure 80). Reproductive data supported a spring spawning and summer recruitment pattern. Internal oocytes were present in specimens from all collections (M1 through M4), but externally attached embryos were present only in collections from May 1982 (M4).

Tharyx sp. A

Reproductive data suggest that Tharyx sp. A became mature in spring and summer. Males and females in the population were most important in spring and summer collections (Table 15).

The size frequency data indicated that recruitment took place in late summer and early fall, with the highest numbers of juveniles (less than 25 setigers) present in November (M2, 24.5 percent) and February (M3, 27.4 percent) and again in July (M5, 26.7 percent) and November (M6, 20.9 percent) (Figure 81). T. sp. A therefore underwent gonadal development in the spring, spawned in the summer and exhibited recruitment into the population in late summer and early fall.

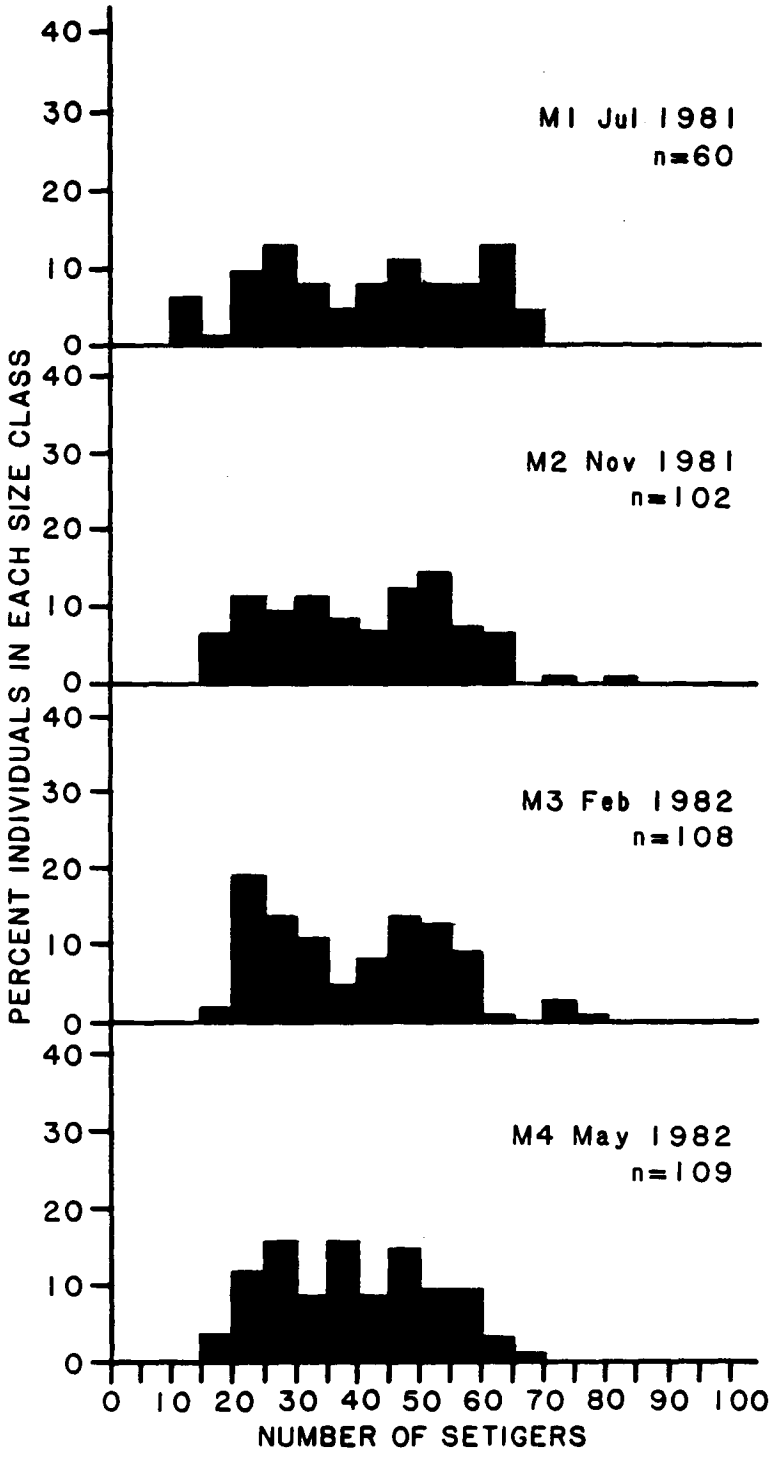

Figure 79. Size-class frequency of Streptosyllis arenae at Station 5-1.

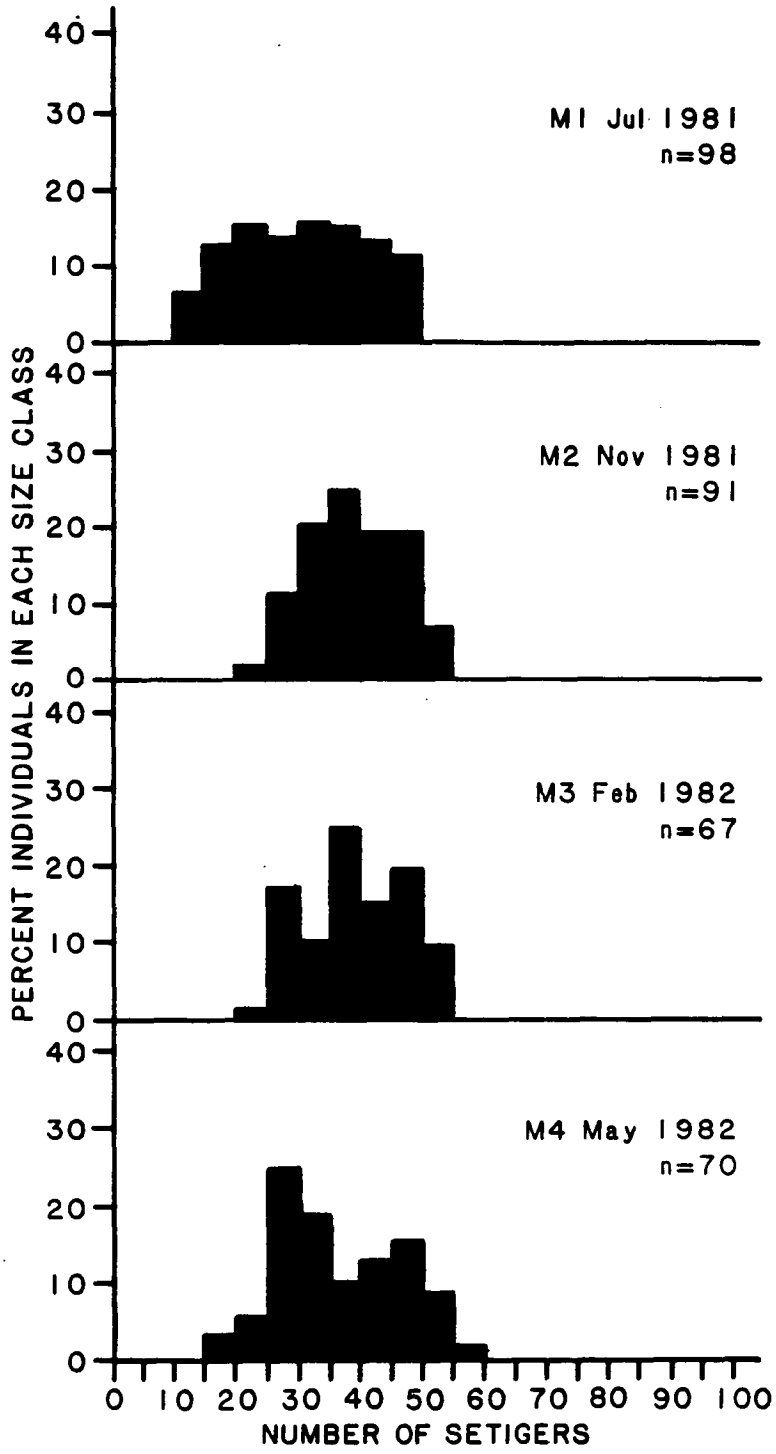

Figure 80. Size-class frequency of Syllides benedicti at Station 5-1.

TABLE 15. PERCENT MALES AND FEMALES IN THARYX SP. A.

Cruise	Month	Percent Males	Percent Females
M1	July	9.3	14.0
M2	November	0	3.2
M3	February	0	0
M4	May	1.2	9.7
M5	July	3.8	13.3
M6	November	0	0
M7	February	0	1.1
M8	May	0	4.5
M9	July	1.3	5.3

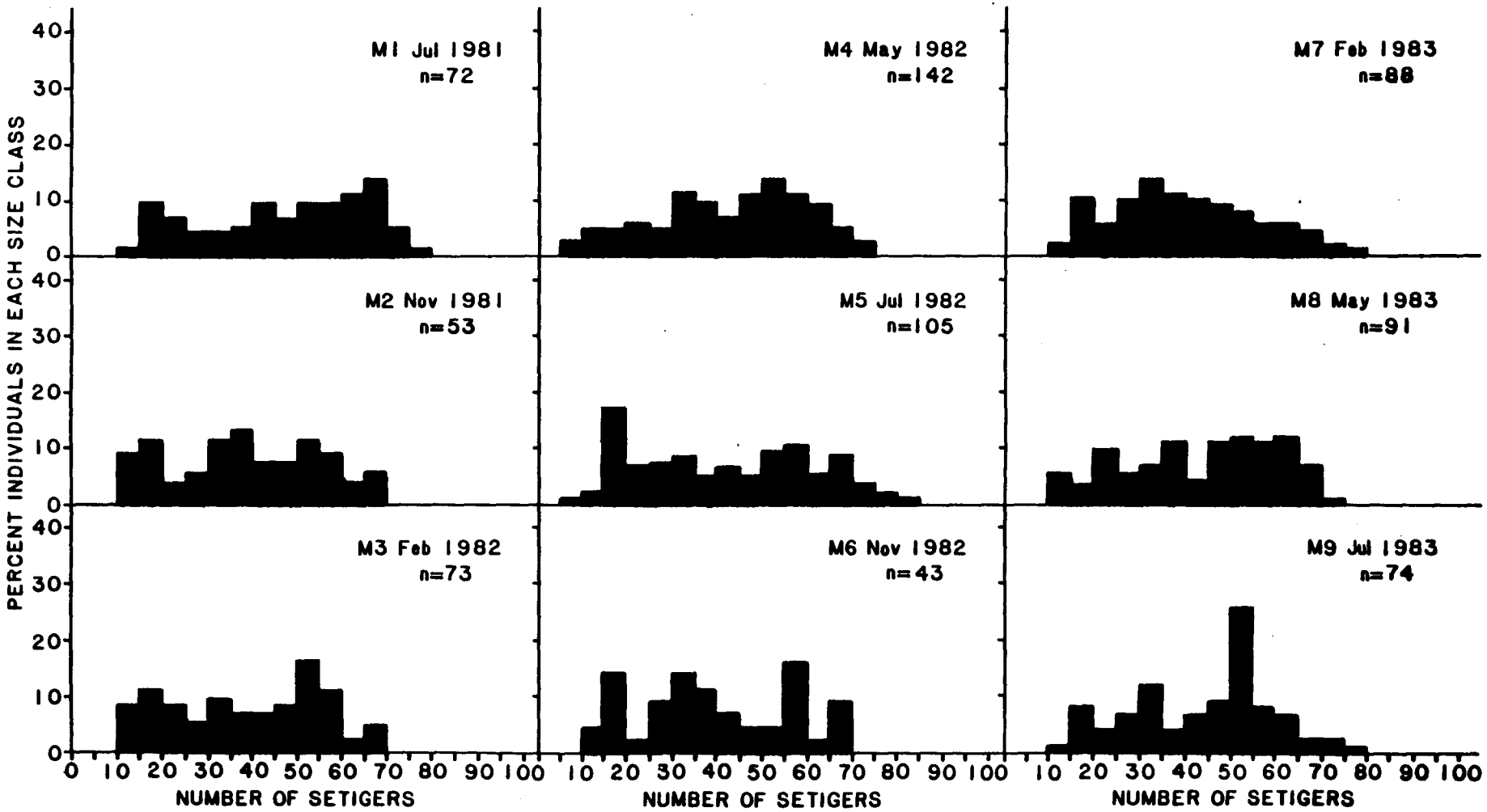

Figure 81. Size-class frequency of Tharyx sp. A at Station 5-1.

Tharyx acutus (Webster & Benedict)

Age/size data for T. acutus indicated recruitment in July 1981 (M1) and November 1981 (M2) (Figure 82). This recruitment produced a cohort which included 10-45 setiger individuals which could be followed clearly through May 1982 (M4) and somewhat less distinctly through May 1983 (M8). A similar but less distinct pattern was evident in the second year (Cruises M5 through M8, July 1982 - May 1983). A similar recruitment sequence appears to have been initiated in July 1983 (M9) with a large percentage of the population represented by individuals of less than 30 setigers (33 percent). In most of the seasonal collections, two size groups were evident.

The data suggest a two-year life cycle in which a newly settled individual does not produce progeny until a 24 month interval has passed. Data on reproduction indicated that the highest percentages of males and females in the population occurred in spring and summer months, which agrees with a summer and fall recruitment sequence.

Polychaete Species from Regional Station 13

Six species were selected for study from Station 13. These included three species of the family Paraonidae and one each of the Cossuridae, Cirratulidae and Sabellidae. Results presented for Tharyx annulosus include comments and data for that species from Station 5-1 as well as Station 13. T. annulosus was analyzed over four seasons (July 1981 - May 1982, M1-M4); the sabellid Chone infundibuliformis for five seasons (July 1982 - July 1983, M5-M9); and the paraonid species for nine seasons (July 1981 - July 1983, M1-M9). Early in the program, it was decided not to work up data for T. dorsobranchialis, a large cirratulid found at Station 13. This was due to the few specimens available and poor correlations in the regression analysis, which did not allow us to use fragmented specimens.

Tharyx annulosus (Hartman)

Tharyx annulosus appeared to build up gametes in the winter and spawn in the spring. Reproductive data included the presence of males in November 1981 (19.2 percent) and February 1982 (27.9 percent) and females in July (22.2 percent), November (42.3 percent) and February (32.6 percent). No gametes were observed in individuals

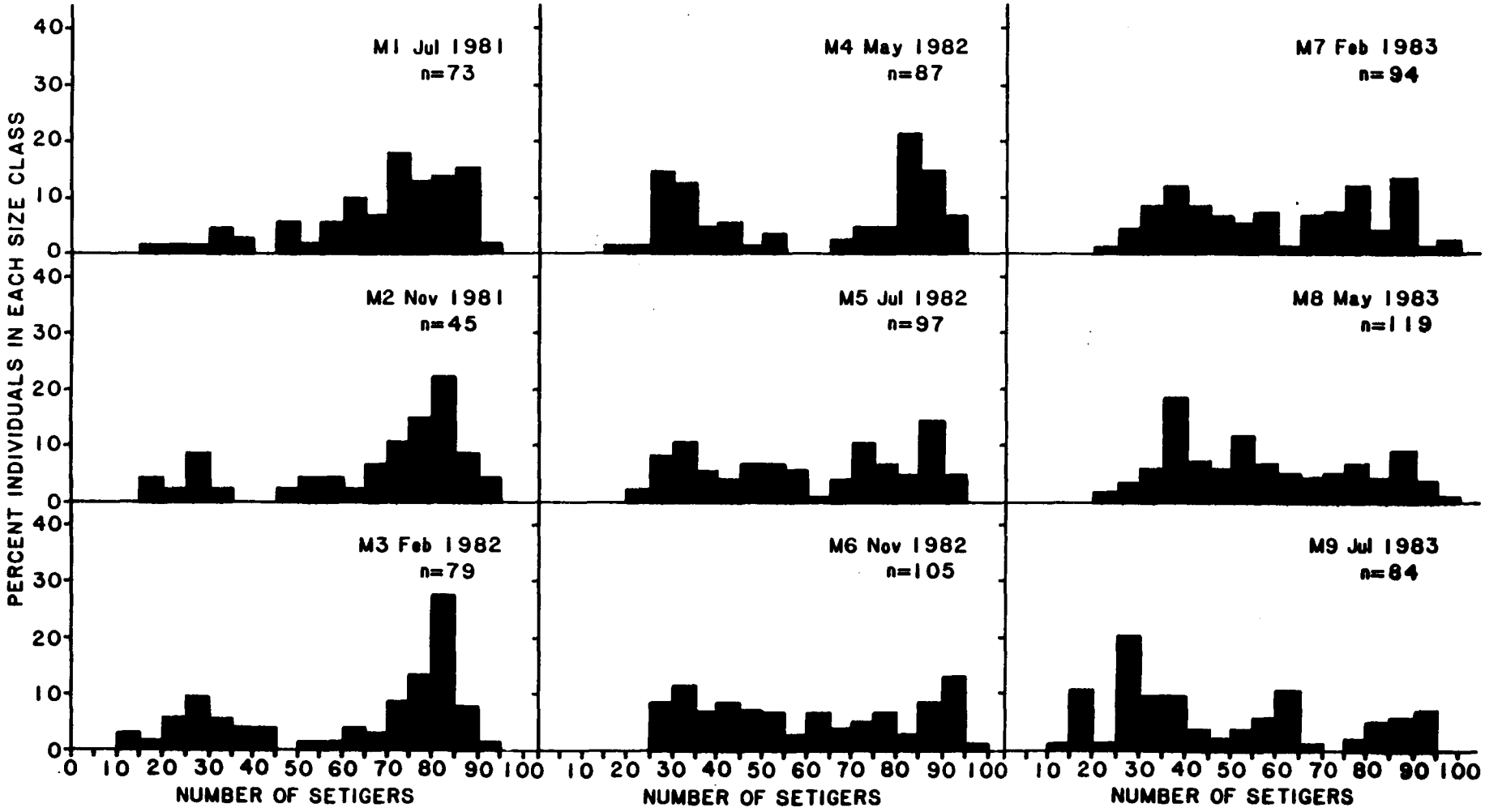

Figure 82. Size-class frequency of Tharyx acutus at Station 5-1.

collected in May 1982 (M4). Size frequency data followed this sequence of reproductive data with the highest percentage of juveniles (6.6 percent) present in the July collection (Figure 83).

A similar pattern was observed for T. annulosus collected at Station 5-1, except that some males and females were observed in samples from May 1982 (M4). A distinct difference, however, was observed in the population structure. All collections at Station 5-1 included fewer specimens but larger individuals than those found at Station 13. These data are summarized in Table 16.

Cossura longocirrata (Webster and Benedict)

Cossura longocirrata was a dominant species at Station 13. Morphologically, the species develops a beaded abdominal region with the onset of sexual maturity. The specimens frequently break at the point where the beaded abdominal segments attach to the thorax. Some specimens were observed to have a swollen region preceding the beaded region. This swollen area was found most prominently on females and appeared to be the site of oogenesis. It is hypothesized that with the onset of egg maturation the eggs move posteriorly; the segments become beaded and the swollen area becomes less prominent. The males do not appear to exhibit a swollen stage.

Sexually mature females were most abundant in the population in July 1981 (21.1 percent), November 1981 (15.4 percent), May 1982 (17.8 percent) and July 1983 (17.5 percent). Collections made in February 1982, July 1982, and November 1982 had only a few females present, and no females were observed in samples from February or May 1983. These results are somewhat conflicting, and suggest that C. longocirrata is capable of reproducing in spring, summer and/or fall, probably depending upon local environmental or climatic conditions. Size-frequency data provided the best evidence for recruitment in May and July 1982 (Figure 84). This spring-summer sequence had the highest numbers of juveniles less than 25 setigers: 23.2 percent in May and 16.8 percent in July. The May population data was somewhat unusual in that a major crash in the total population density occurred at the same time. The initial thought was that the oldest specimens died following spawning, but the simultaneous decrease in many unrelated species suggested some other explanation, perhaps some local environmental event which might have been responsible for the observed mortalities (see Chapter 3).

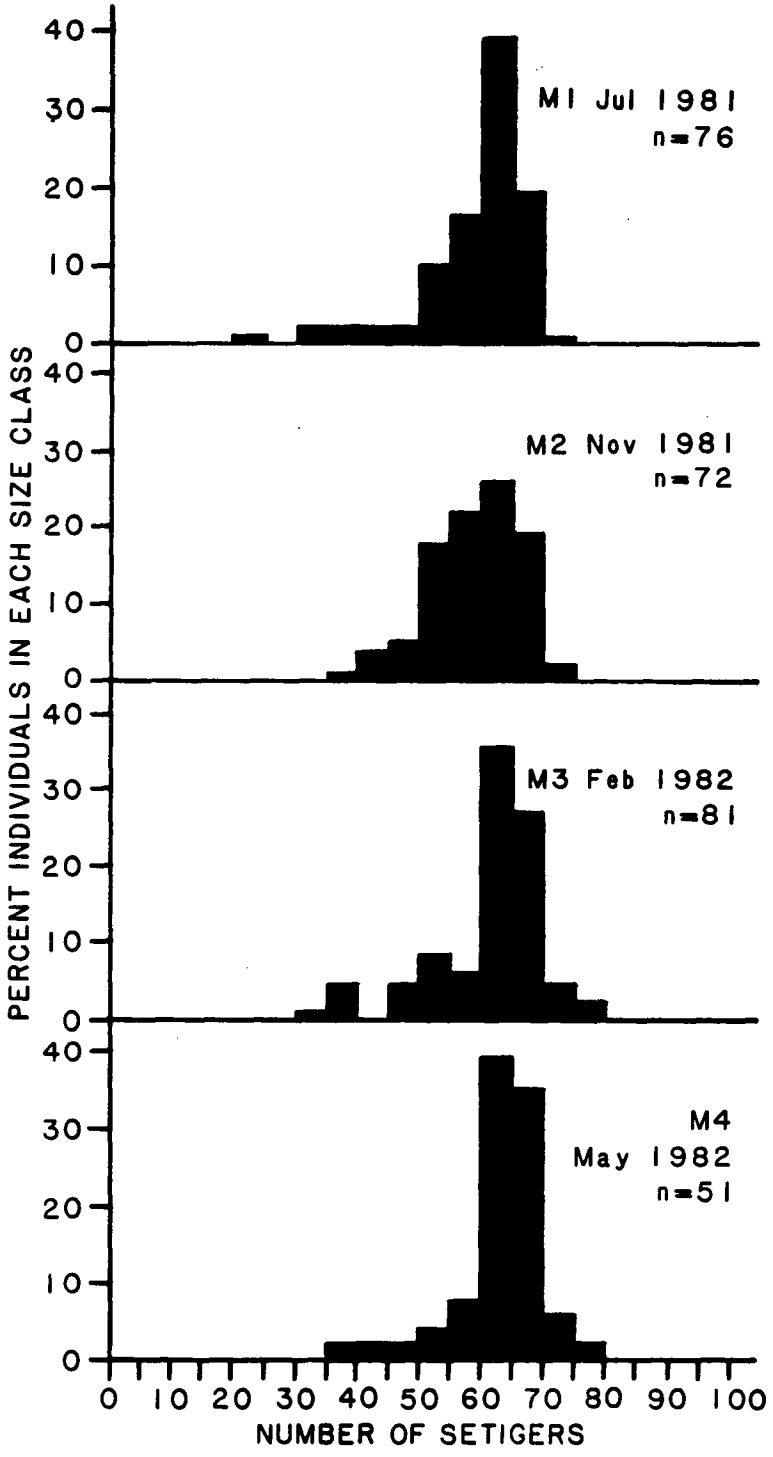

Figure 83. Size-class frequency of Tharyx annulosus at Station 5-1.

TABLE 16. RANGE, MEAN AND STANDARD DEVIATION OF NUMBER OF SETIGERS FOR THARYX ANNULOSUS AT STATIONS 5-1 AND 13.

Station	Date	Range	Mean ($\bar{x}$)	Std. Dev.	n	Percent Males	Percent Females
5-1	Jul 1981	23-120	78.8	27.4	31	0.0	41.9
	Nov 1981	34-114	80.0	23.8	31	3.2	22.6
	Feb 1982	26-108	61.7	26.3	18	5.6	11.1
	May 1982	29-113	70.9	23.7	30	3.3	16.7
13	Jul 1981	21-75	59.6	9.28	76	0.0	22.2
	Nov 1981	36-75	59.9	7.44	72	19.2	42.3
	Feb 1982	31-80	61.5	9.47	81	27.9	32.6
	May 1982	36-80	64.2	7.14	51	0.0	0.0

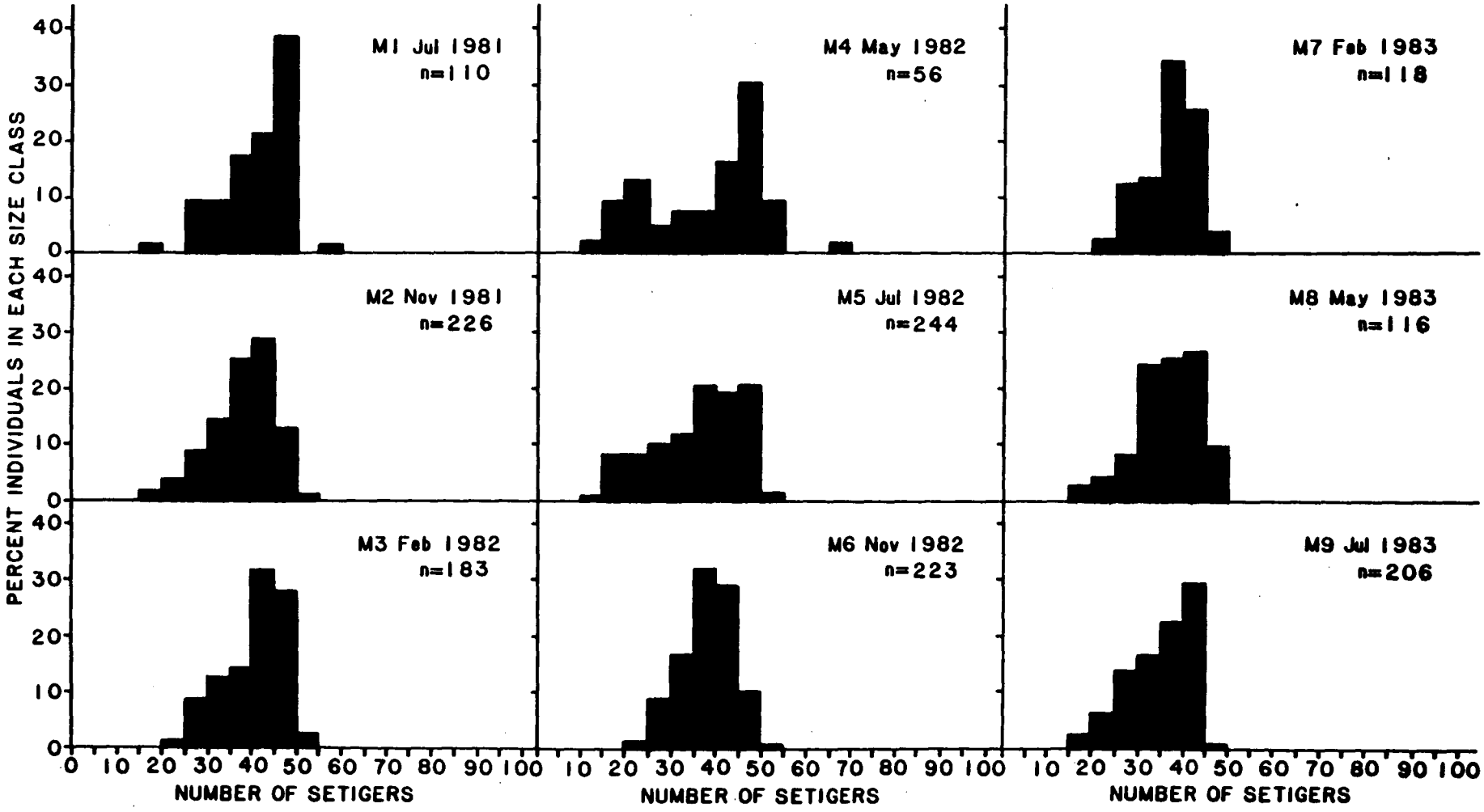

Figure 84. Size-class frequency of Cossura longocirrata at Station 13.

Aricidea catherinae (Laubier)

Data on A. catherinae indicated that maximal reproductive activity occurred in the summer. For the three summer collections (M1, M5 and M9), 27.4 percent, 51.0 percent, and 32.0 percent of the population, respectively, were females. In the May 1982 collection, 19.1 percent females were recorded. A high percentage of males were identified in July 1982 (25 percent) and July 1983 (23.7 percent). Size frequency data indicated that juveniles recruited into the population heavily in July and November 1981, with the cohort readily identifiable in February 1982 (Figure 85). There was a substantial disappearance of individuals larger than 60 setigers after May 1982, with the mean population size dropping from 59.8 setigers in May to 45.4 setigers in July. This average size remained essentially unchanged through May 1983 ($\bar{x}$ = 48.3 setigers), with larger individuals not reappearing until July 1983. Juveniles did recruit into the population in July and November 1982, repeating to some extent the 1981 sequence, but the disappearance of the larger specimens was unique to that period. In summary, Aricidea catherinae underwent reproduction during later spring and summer, with spawning and recruitment evident in summer and fall months. The species may have a two-year life cycle, as evidenced by the total disappearance of the larger size classes during 1982. These larger sizes were present in 1981 and began to reappear in 1983.

Aricidea suecica (Eliason)

Data on reproduction indicated that A. suecica underwent most of its reproductive activity in the spring and summer months. Highest numbers of females with eggs were found in July 1981 (38.8 percent), May 1982 (56.2 percent), July 1982 (58.0 percent), May 1983 (20 percent) and July 1983 (52.1 percent). Size frequency data indicated that a light recruitment occurred in July and November 1981, with a large average size developed by May 1982 (58.95 setigers) (Figure 86). This population was nearly totally replaced in July 1982 by smaller animals having an average size of 39.18 setigers. This settling cohort remained more or less intact through an entire summer-to-summer sequence, with the July 1983 population again reaching an average size of 57.08 setigers or very similar to that of animals collected in May 1982.

It is not known if the loss of the larger size classes in May was a normal event or merely the result of some environmental aberration which similarly influenced the populations of other species at Station 13 at that time. The data seem to suggest a spring/summer reproduction, with recruitment in summer and fall.

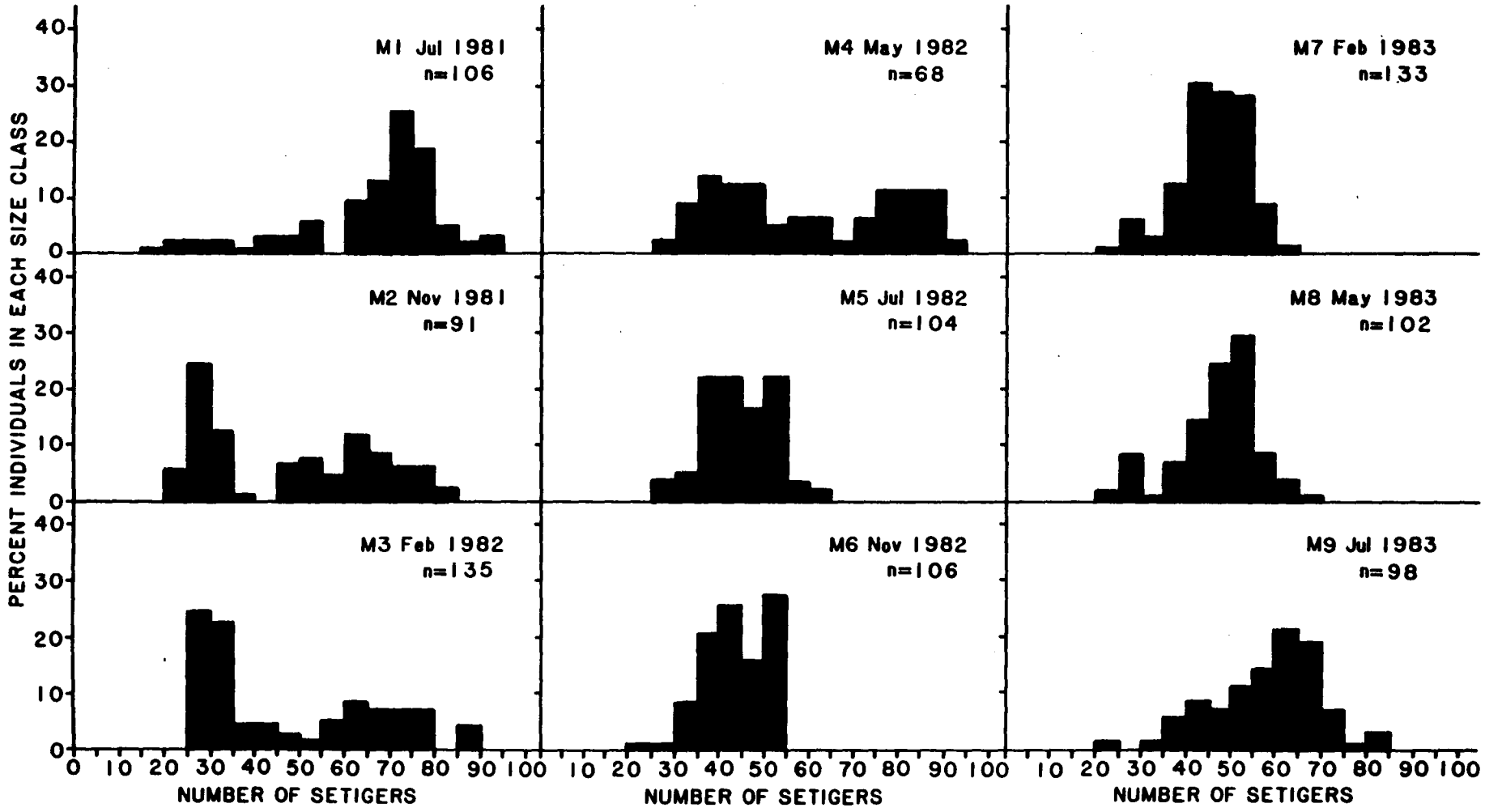

Figure 85. Size-class frequency of Aricidea catherinae at Station 13.

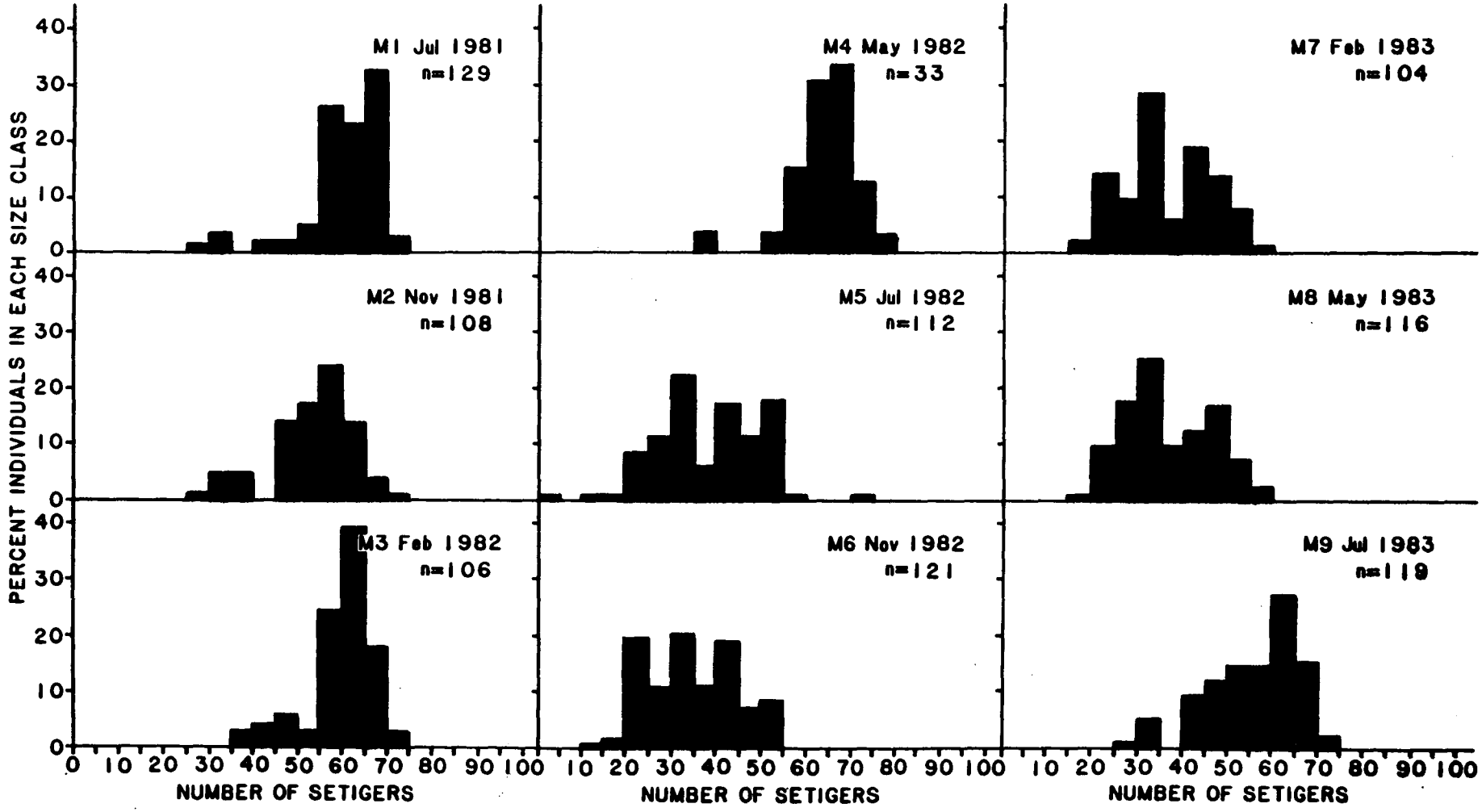

Figure 86. Size-class frequency of Aricidea suecica at Station 13.

Levinsenia gracilis (Tauber)

Data on reproduction indicated that the highest percentage of females having eggs occurred in May 1982 (33.3 percent), July 1982 (50.2 percent), May 1983 (40.6 percent), and July 1983 (62.5 percent). Males were not seen, although one specimen collected in July 1983 was observed to have both eggs and sperm. Size frequency data indicated that recruitment occurred in July 1981, November 1982, and July 1983. These data correlated well with the reproductive data (Figure 87).

Chone infundibuliformis Krøyer

Data for Chone infundibuliformis were collected only for July 1982 through July 1983 and are too scanty to draw firm conclusions concerning the recruitment pattern for this species. Size frequency data for July 1982 and May 1983 suggest that the smaller size classes are more important in those collections (Figure 88), although we are aware that juveniles <15 setigers were not identified to species in the original work-up, and fine details of recruitment are not available. No specimens were observed with sexual products.

Polychaete Species from the Block 410 Stations and from Regional Stations 3 and 6.

Three species of Paraonidae were characteristic of the Block 410 stations (Stations 16, 17 and 18). For Aricidea neosuecica and Paraonis sp. A, we were unable to obtain sufficient specimens and the analysis of these species was discontinued after May 1982 (M4). Paradoneis sp. A occurred in sufficient numbers for long term analysis and was therefore measured for nine seasons, from July 1981 through July 1983. A species of the Nephtyidae, Aglaophamus circinata, was selected for study from Stations 3 and 6. Specimens from these two stations were composited in order to obtain a larger sample size. Both stations are along the same depth contour and have similar sediment and topographical characteristics.

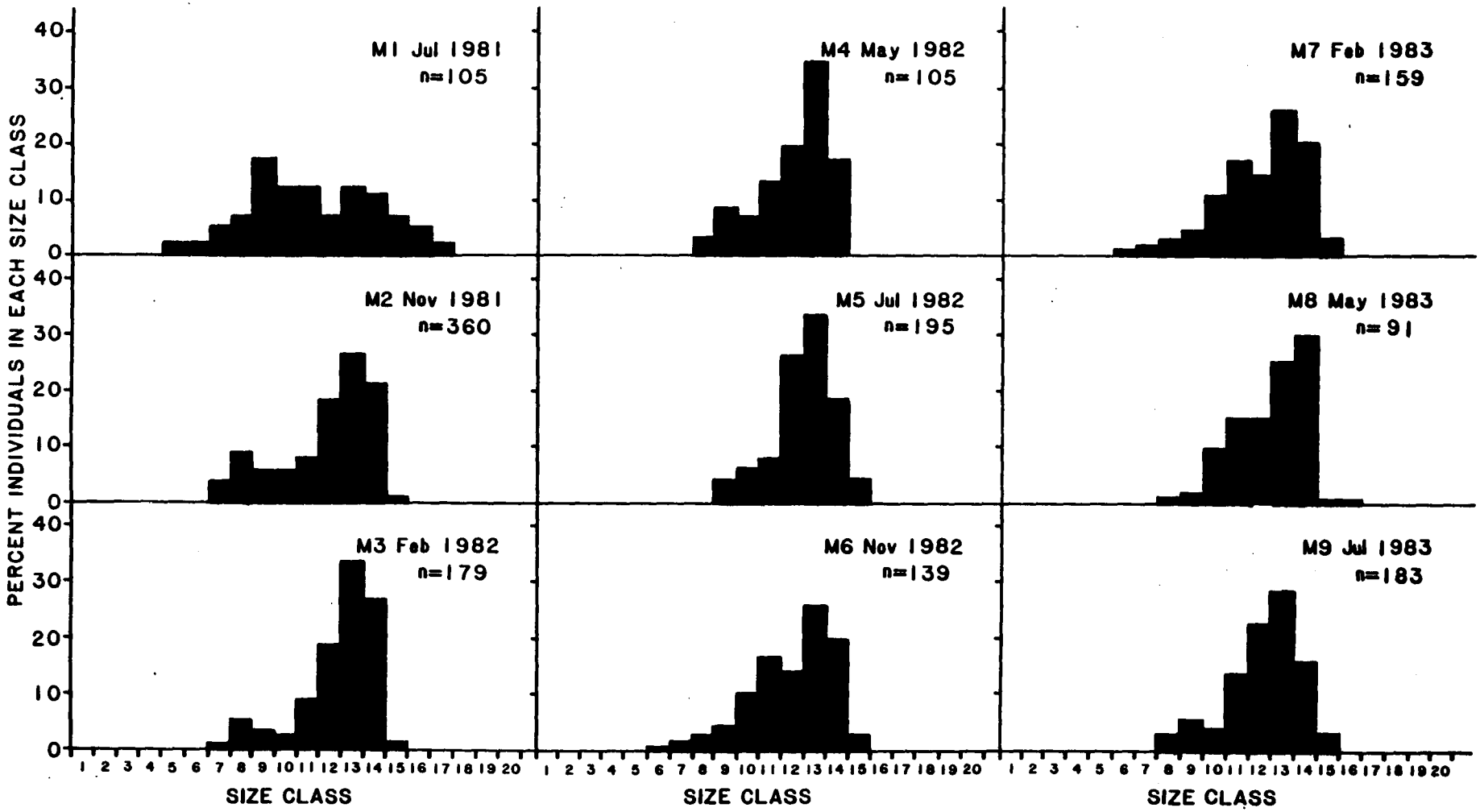

Figure 87. Size-class frequency of Levinsenia gracilis at Station 13. Each size class is 7.5 setigers.

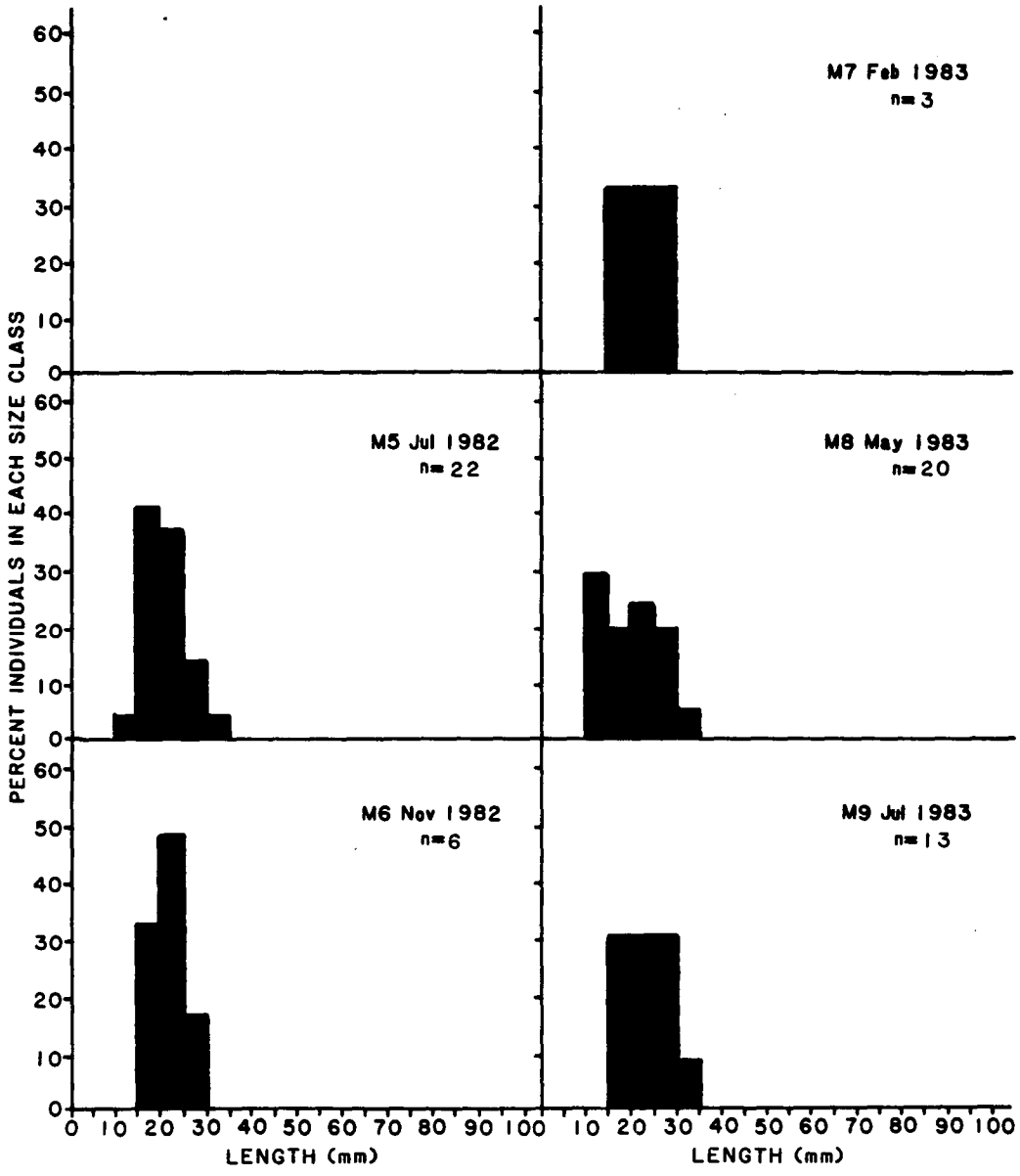

Figure 88. Size-class frequency of Chone infundibuliformis at Station 13.

Aricidea neosuecica Hartman

Data are fragmentary for this species, since relatively few specimens were available from Station 18. Eggs were present in specimens collected in November 1981 (7.1 percent), February 1982 (1.6 percent), and May 1982 (8.7 percent). Natatory setae were observed in individuals from November (9.8 percent) and February (24.2 percent). Since presence of eggs and natatory setae usually denote periods of reproductive activity, these data suggest that reproduction and spawning take place at times other than summer months. Size frequency data were too scanty (Figure 89) to allow any other conclusions about this species.

Paraonis sp. A

Data for this species were also scanty. Reproductive observations indicated the presence of reproductive males and females year-round, with the highest numbers of males and females (combined) present in July 1981 (80.9 percent), November 1981 (82.7 percent), and May 1982 (75 percent). This suggests that the most reproductive activity took place over an extended period between spring and fall. No trends are evident from the size frequency data (Figure 90).

Paradoneis sp. A

Paradoneis sp. A is a small threadlike species, known only from the Block 410 stations. Although females in various stages of maturation were found year-round, spawning probably took place more regularly in the summer months, since there was a higher percentage of females in the population during those months: July 1982 (19.8 percent) and July 1983 (21.3 percent). Egg diameter data for seven of the nine seasons studied show that large eggs were present during most of the year:

Feb (M3)	-	120.4	µm x	55.4	µm
May (M4)	-	111.1	µm x	78.2	µm
Jul (M5)	-	138.4	µm x	104.7	µm
Nov (M6)	-	154.0	µm x	92.4	µm
Feb (M7)	-	129.4	µm x	68.9	µm
May (M8)	-	142.1	µm x	107.1	µm
Jul (M9)	-	114.7	µm x	72.3	µm

The eggs numbered only 1-3 per female and their size in relation to the small size of

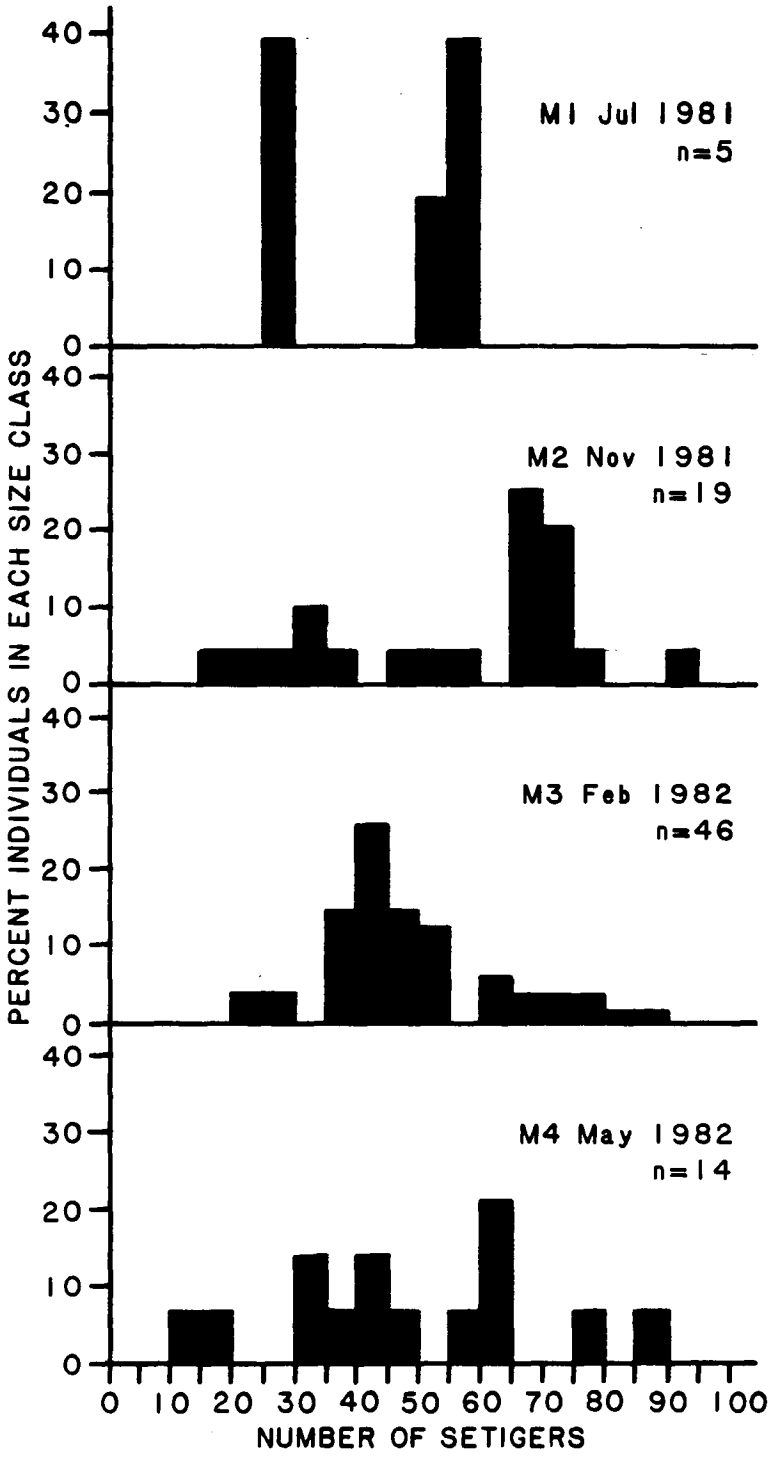

Figure 89. Size-class frequency of Aricidea neosuecica at Station 18.

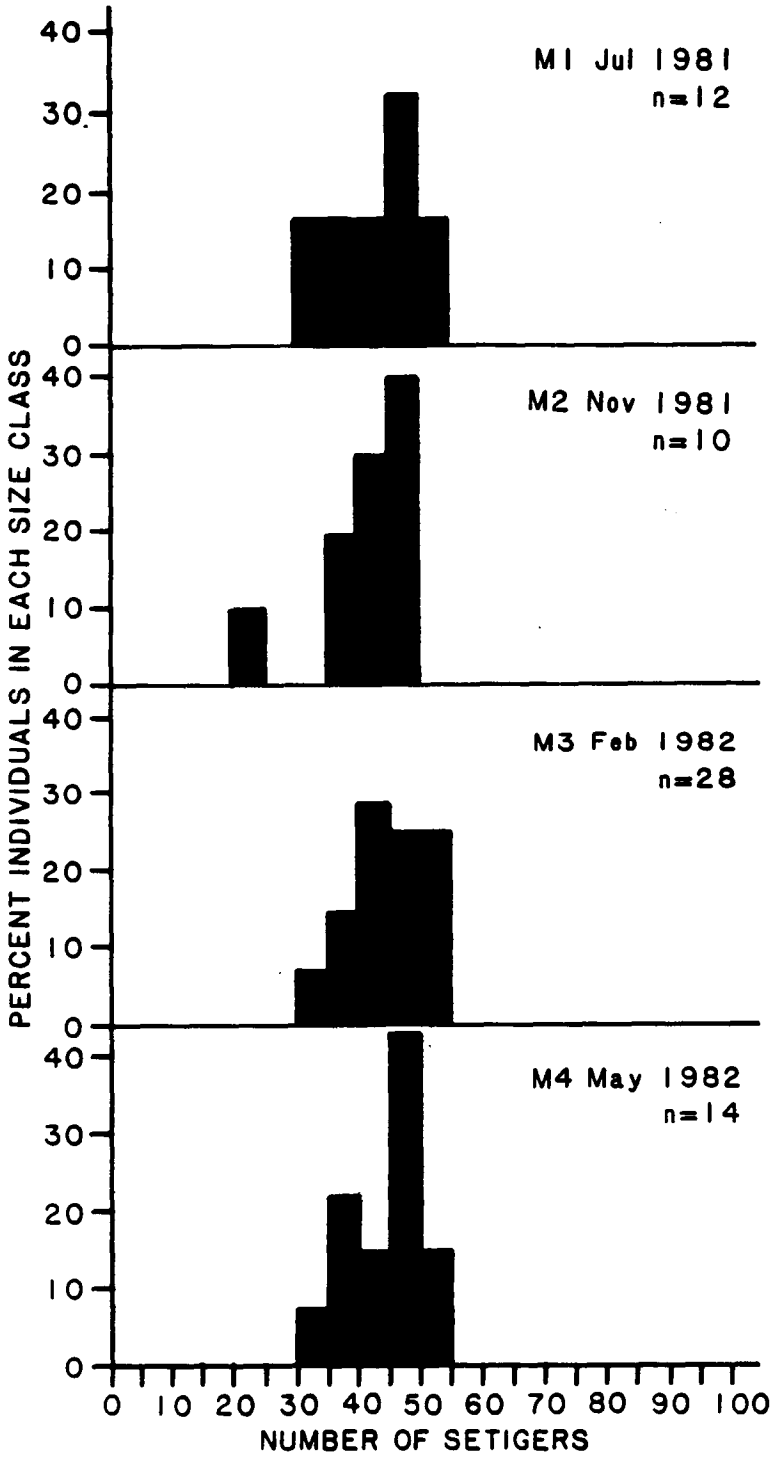

Figure 90. Size-class frequency of Paraonis sp. A at Station 18.

the worm indicateed a direct development. These data suggest a year-round pattern of reproduction, with some increase in activity in the summer.

Size frequency data did not reveal much about the population structure except that a large percentage of the population was consistently in the 25-30 setiger range (Figure 91). There were more individuals with fewer than 25 setigers in July 1981, November 1982, and February 1983. The smallest average size for the population occurred in November 1982 (28.15 setigers).

Aglaophamus circinata (Verrill)

Data on reproduction was incomplete for Aglaophamus circinata. Eggs were noted in some specimens in July (M5) and February (M7), but no percentages are available. Size frequency data indicated that juveniles of 25 setigers or less were present in the population year-round, with the highest percentages present in July 1981 (82.6 percent), November 1981 (72.7), and May 1982 (87.8) (Figure 92). The lowest percentage was in February 1982 (51.2 percent).

DISCUSSION

Important reviews of polychaete reproduction include those by Schroeder and Hermans (1975) and Olive and Clark (1978). Some aspects of life history studies of polychaetes are reviewed by Fauchald (1983). The two most prevalent reproductive patterns in polychaetes are termed monotelic and polytelic. In monotelic reproduction, the majority of species undergo a pronounced metamorphosis of the body during gametogenesis in preparation for spawning. Such species breed only once and die shortly after spawning. Nereid polychaetes which develop epitokes are classic examples of this type of reproduction. In the present study, Cossura longocirrata may be a monotelic species. This conclusion is supported by the precipitous decline in density in May 1982, which corresponded to the heaviest juvenile recruitment (but see discussion in Chapter 3).

In polytelic reproduction, gametes are released in one or a few large batches, with adult survival and additional breeding occurring in the following year. Polytelic species may also produce more than one batch of gametes in a single season. The latter situation is relatively common in nearshore species of polychaetes. Most of the polychaetes in the present study are probably polytelic.

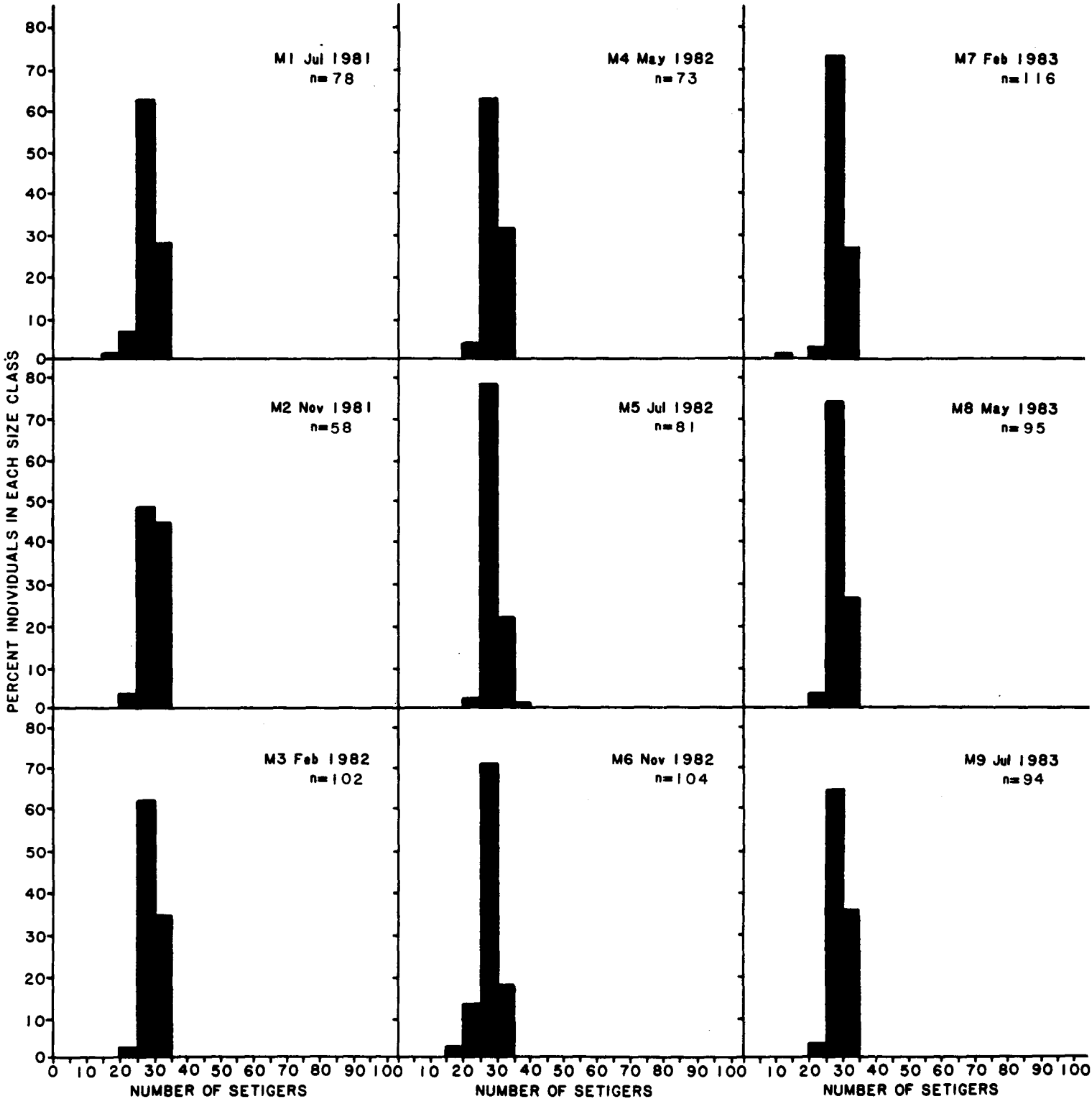

Figure 91. Size-class frequency of Paradoneis sp. A at Station 16.

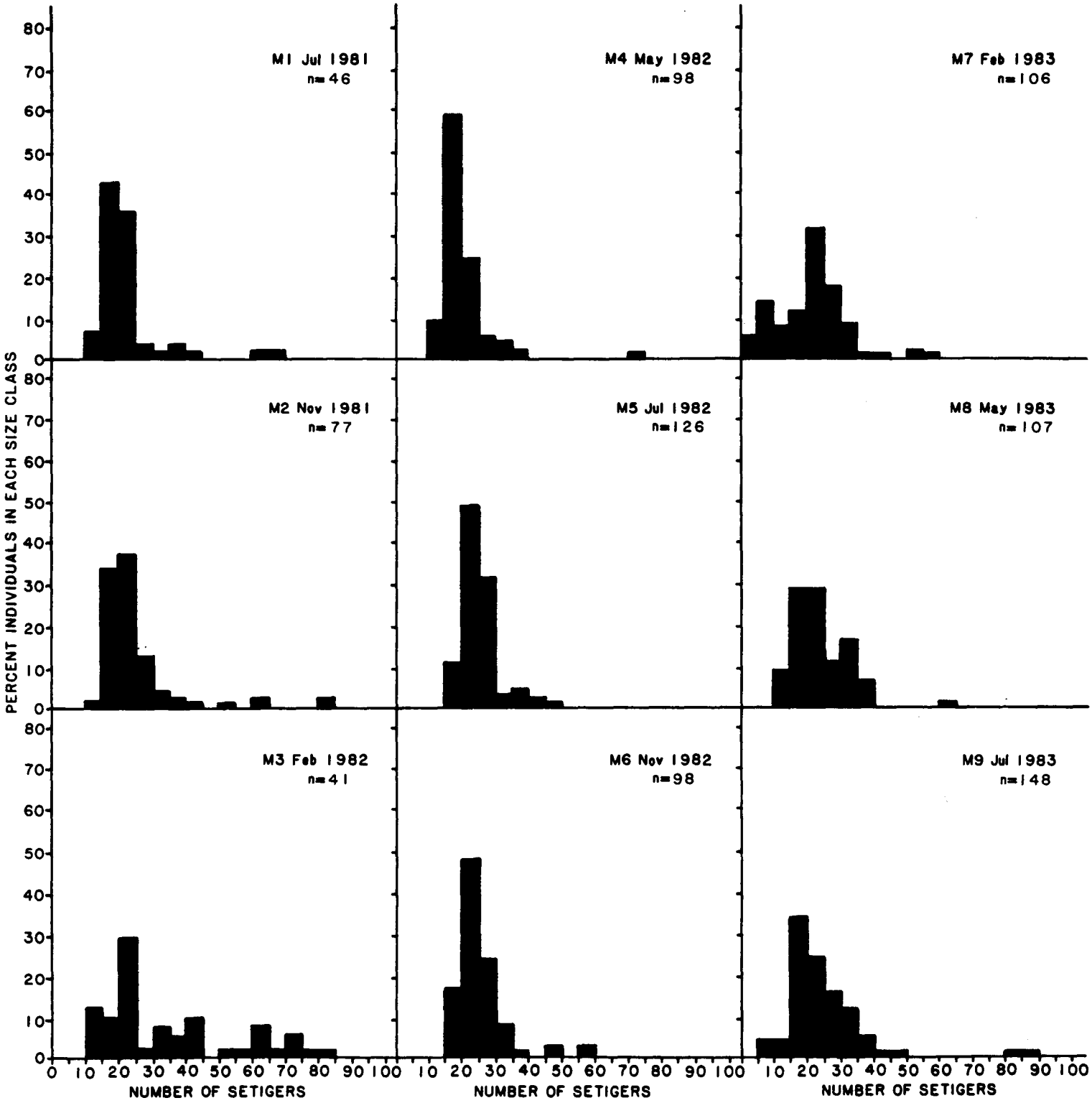

Figure 92. Size-class frequency of Aglaophamus circinata at Stations 3 and 6.

In a study of an intertidal population of Streptosyllis websteri at Northumberland in the U.K., Garwood (1982) found the species to exhibit epigamous reproduction. In this situation, the reproductive individual becomes pelagic at the time of sexual maturity. In epigamous species, long accessory capillary setae called natatory setae develop between the dorsal cirrus and setal lobe on a number of middle body segments. Garwood (1982) found evidence that S. websteri breeds twice during its spawning season, and speculated that a reversible epigamy was operative. He further suggested that reversible epigamy might be widespread among syllids of the subfamilies Eusyllinae and Exogoninae. Some additional evidence supporting this point of view includes that presented by Rasmussen (1973) who found Exogone naidina (as E. gemmifera) to have large oocytes while already brooding externally attached young. In the present study, evidence of epigamous setal development was present in all of the syllids examined. In some cases only one or two individuals were noted to have natatory setae. It is probable that the epigamous condition is brief, with natatory setae developing rapidly at the time of final gamete maturation. The animals swarm, undergo mating, return to the sediment, and lose the natatory setae. In such a situation, quarterly sampling would be too infrequent to observe large numbers of epigamous individuals except by the lucky chance of sampling at a time when some of the population was ready to swarm.

Cirratulids are also known to exhibit natatory setae during their reproductive cycle (Blake, unpublished). In the present study, we observed natatory setae on Tharyx acutus and Tharyx sp. A. We also observed natatory setae on Aricidea neosuecica in specimens collected in November 1981 and February 1982, which appears to be the first record of epigamous setae in a paraonid.

There is some correlation between the faunal density data and the life history data developed for individual species. At Station 13, the sharp declines in density of Cossura longocirrata in May 1982 correspond to the appearance of juveniles. This has already been suggested as possible evidence of monotelic reproduction in the species. At Station 5-1, Exogone verugera increased in density between February and July 1982 (Figure 31). This correlates with an observed recruitment in November 1981. For Sphaerosyllis cf. brevifrons, a large increase in population density in May 1982 (Figure 32), correlates with reproductive peaks in late fall.

In the present study, four species have been determined to be capable of year-round reproduction; eleven species showed activity during all or part of an extended period between spring and fall; two species showed most of their activity in a winter/spring sequence and for one species the data was insufficient to identify a reproductive period. A summary of the reproductive and recruitment events of the sixteen polychaete species

discussed above is presented in Figure 93. Table 17 summarizes the average sizes of all species for each cruise studied.

There is a significant body of literature on the reproductive biology of nearshore and intertidal species of polychaetes (eg. Olive, 1970, 1975, 1977; Gibbs, 1971; Gudmundsson, 1985; Christie, 1985). To date, however, few studies have emphasized continental shelf species. One important exception is the work of Hannan et al (1979) on life history and reproductive parameters of seven species from subtidal habitats off Moss Landing, California. This latter study was developed especially to respond to the need for additional or alternative data to assess impacts of man-made perturbations on benthic communities. An analysis of size frequency distribution or reproductive state in populations of individual species taken during the course of a benthic monitoring program may in itself be more sensitive to changes occurring in communities by detecting changes in population structure or reproductive ability before a population completely loses its ability to maintain itself. In the present study, where impacts from drilling-related activities were not apparent in the community analysis, seasonal changes in life history data were supplementary information on the natural history and ecology of some of the more important species. This data will be valuable in future studies where information on natural seasonal patterns is lacking. Since some of the species occur in other geographic areas, these results will form a point of comparison to other local results.

The use of regression analysis to select measurement parameters is unique on the scale presented here. Hannan et al (1979) demonstrated that length and width could be correlated, but did not emphasize the value of the technique in using fragmented specimens. The protocol for future investigations should be first to make a series of measurements on complete specimens for length, number of setigers, width of the thorax, length of the proventricle (syllids only), length of the prostomium, or some other measure appropriate to the particular species under consideration. From this initial data, the appropriate regression analysis can be run. We used the SPSS menus, but other statistical packages may be selected. Once an alternative measure is selected, it will be possible to use that measure in the future samples rather than laboriously measuring coiled specimens or counting numerous segments. It was only because of these alternative measurements that we were able to analyze so many species. Since the computer subsequently predicts the total number of setigers from the alternative measure selected, there was some concern that the regression coefficient would be a good fit. In cases where the appropriate r^2 value was somewhat low, it was in most cases due to the initially coiled nature of the specimens and effect of contraction during preservation. Paraonidae in particular coil during preservation making length measurements imprecise and setiger

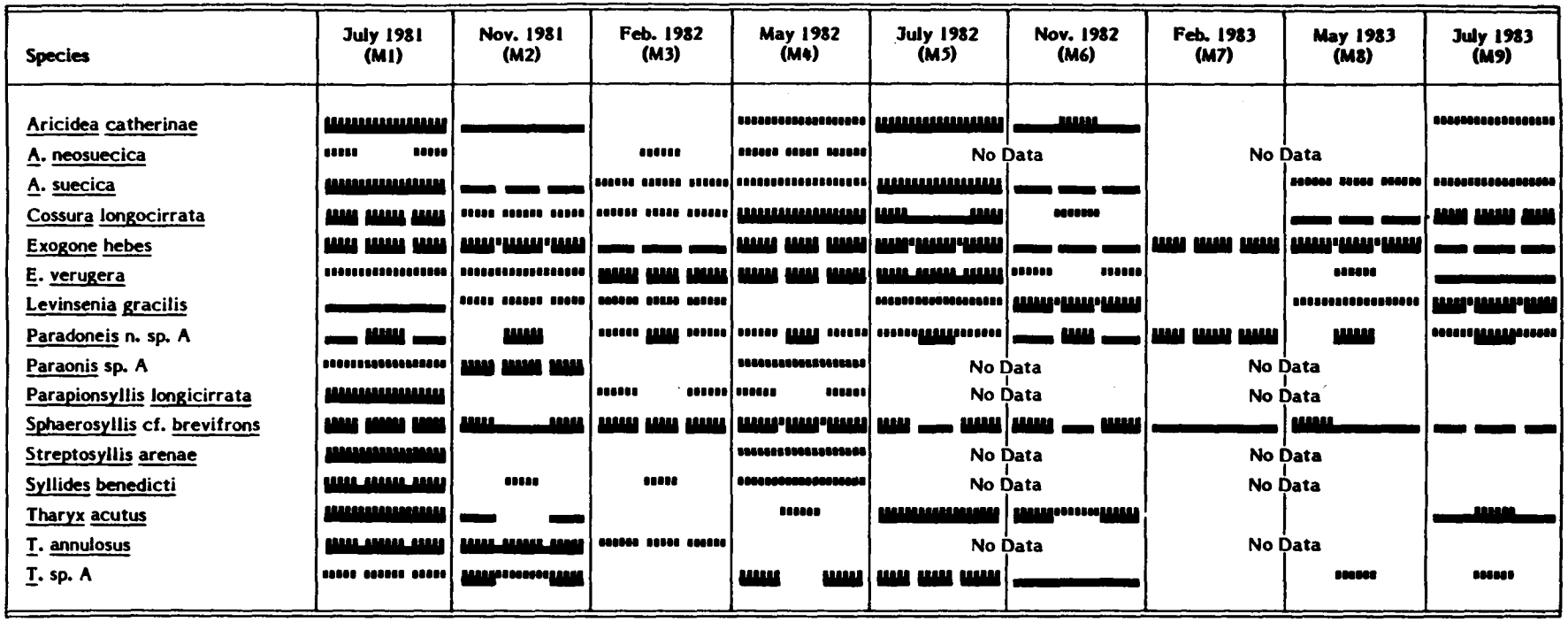

Figure 93. Summary of timing of reproduction and recruitment of some polychaete species studied in the life history analysis.

TABLE 17. AVERAGE NUMBER OF SETIGERS AND ONE STANDARD DEVIATION OF EIGHTEEN SPECIES OF POLYCHAETES FROM GEORGES BANK.

Species	Jul 1981		Nov 1981		Feb 1982		May 1982		Jul 1982		Nov 1982		Feb 1983		May 1983		Jul 1983	
	$\bar{x}$	σn	$\bar{x}$	σn	$\bar{x}$	σn	$\bar{x}$	σn	$\bar{x}$	σn	$\bar{x}$	σn	$\bar{x}$	σn	$\bar{x}$	σn	$\bar{x}$	σn
Tharyx acutus (Sta. 5-1)	57.06	21.13	51.88	13.71	65.49	12.15	77.64	17.17	60.28	22.75	60.70	23.32	60.62	21.26	57.84	20.00	48.22	24.95
Tharyx annulosus	59.63	9.28	59.92	7.44	61.52	9.47	64.25	7.14	-	-	-	-	-	-	-	-	-	-
Tharyx sp. A	48.43	18.31	39.64	17.06	39.96	17.24	43.53	16.86	42.88	19.72	40.23	17.05	40.97	15.99	44.75	16.68	45.23	15.77
Aricidea catherinae	67.94	15.84	48.68	19.78	49.44	20.42	58.95	19.58	45.44	8.08	44.66	7.48	45.78	8.47	48.28	9.57	59.16	11.93
Aricidea neosuecica	45.40	16.59	57.37	21.75	49.33	14.36	49.21	21.24	-	-	-	-	-	-	-	-	-	-
Aricidea suecica	61.47	9.28	52.72	9.62	61.26	7.90	65.52	7.25	39.18	11.14	35.47	9.87	37.00	9.86	38.06	9.38	57.08	10.44
Levinsenia gracilis	80.16	20.35	87.40	16.03	91.96	12.90	89.26	12.36	92.47	10.59	88.49	14.54	91.99	11.83	90.12	12.37	87.63	14.88
Paradoneis sp. A	28.79	2.62	30.28	2.35	29.80	2.15	29.51	2.14	29.36	1.98	28.15	3.19	29.04	2.63	29.29	1.96	29.97	2.17
Paraonis sp. A	44.08	7.40	41.70	7.56	45.39	6.20	45.64	5.53	-	-	-	-	-	-	-	-	-	-
Exogone hebes	27.39	11.45	26.24	9.34	24.75	8.41	27.04	9.30	28.77	9.12	26.86	8.70	28.15	8.39	27.79	8.46	25.83	8.07
Exogone verugera	39.63	8.15	39.69	8.27	36.69	10.25	41.65	8.84	37.78	13.25	37.77	11.21	36.63	11.41	39.24	10.63	32.00	14.12
Sphaerosyllis brevifrons	20.76	2.57	19.89	1.65	21.65	2.00	21.76	1.92	21.40	1.81	20.94	2.20	20.47	1.72	20.58	1.87	21.29	2.31
Streptosyllis arenae	42.52	16.60	41.66	15.14	40.21	14.78	39.78	12.91	-	-	-	-	-	-	-	-	-	-
Syllides benedicti	31.45	10.87	39.5	7.40	39.7	8.28	37.2	10.49	-	-	-	-	-	-	-	-	-	-
Parapionosyllis longicirrata	29.46	9.00	30.70	4.98	32.79	7.77	32.44	7.40	-	-	-	-	-	-	-	-	-	-
Cossura longocirrata	41.57	7.35	38.36	7.03	41.13	6.48	38.73	12.45	36.81	9.67	38.57	5.71	37.19	5.66	37.05	6.98	36.76	7.48
Aglaophamus circinata	25.18	10.74	27.00	12.76	37.10	20.36	22.22	6.98	26.69	5.31	26.72	7.01	21.96	10.60	25.24	7.59	24.13	10.33
Chone infundibuliformis*	-	-	-	-	-	-	-	-	21.28	4.18	21.78	3.86	22.50	6.06	20.54	6.77	23.92	4.61

* measurement given in mm
\- no specimens measured

counts difficult and laborious. In those cases we took the best fit available using the alternative measure, realizing the limitations of any measuring techniques on such material.

The effort to document reproductive periods and times of recruitment of offshore populations in the depths we were studying is also unique. The expense of taking samples far offshore and on a regular basis is prohibitive, even when sampled only four times a year. Four data points, however, are too few to document fine details of reproductive and recruitment events. Since some polytelic species may reproduce more than once during a season there is no way to determine the contribution of resident adults to overall seasonal recruitment patterns. It would be necessary to establish laboratory cultures of key species and to make careful observations on their reproductive habits in order to overcome those problems. The single quarterly sample while certainly better than nothing, is but a snapshot of a dynamic year-round process.

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CHAPTER 7. BENTHIC PRODUCTION AND FISH FEEDING

by

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INTRODUCTION

The goal of this component of the Monitoring Program was to investigate the linkage between benthic production and demersal fish feeding. Any significant change in the biomass, production, or species composition of the benthic fauna should be reflected in the food habits of demersal fish. Information on the degree of linkage between benthic fauna and demersal fish provides a more objective basis than heretofore available for estimating the vulnerability of benthic feeders to changes in the benthos.

The yellowtail flounder, Limanda ferruginea, was chosen for initial analysis because it was relatively abundant at stations where trawling occurred, it feeds primarily on macrobenthos, and it is a commercially important fish species. Specific objectives which were addressed included:

1. estimating the production of important benthic invertebrate species;
2. determining the diet and estimating the consumption rates of yellowtail flounder;
3. comparing the rate of consumption by fish to rates of benthic production;
4. calculating prey-selection indices by comparing fish stomach contents to the abundance of benthic species; and
5. correlating potential changes in benthic populations to changes in fish feeding.

MATERIALS AND METHODS

Life History and Production

Size-frequency analysis was used to elucidate the life histories of three species of amphipods (Ampelisca agassizi, Unciola inermis and Erichthonius fasicatus) and one sand

dollar (Echinarachnius parma). These four species were chosen for study because they are among the most numerous species on Georges Bank (see Table 4) and because they are important as fish prey (Bowman and Michaels, 1984). A. agassizi was analyzed from Station 13 for nine seasons (July 1981 - July 1983). U. inermis and E. fasciatus were analyzed from Station 5-1 for the same nine seasons and from Station 5-28 for five seasons (July 1982 - July 1983). Echinarachnius parma was analyzed from Stations 1, 4, and 10 for nine seasons (July 1981 - July 1983). Stations 5, 10, and 13 were chosen because fish stomachs were also collected from these locations. Additional stations were chosen to compare production rates of a given species at different sites.

The amphipod species were measured at W.H.O.I. using a Radio Shack digitizer coupled to a Radio Shack® TRS-80 Model II microcomputer. Sample sizes permitting, at least 200 animals of each species from each sampling date were digitized. Each animal was measured from the tip of the rostrum to the base of the telson (Bousfield, 1973) by tracing a camera lucida projection with the digitizer wand. An internal calibration factor allowed immediate conversion from digitizer units to length in millimeters. The eggs of these amphipod species develop and hatch in the marsupium formed by the oostegites of the female. Size selectivity should not be a problem here because the 0.3-mm sieve retained all life stages including dislodged eggs.

Echinarachnius parma were also measured at W.H.O.I. Sand dollars greater than 6.0 mm were considered "large", and those less than 6.0 mm were considered juveniles. Sand dollars greater than 5.0 mm were measured using a vernier caliper. The distance from the periproct through the center of the animal to the anterior end was considered the length. The width was considered to be the longest distance at a right angle to the length. After several hundred measurements, width was regressed on length; the correlation coefficient was large enough (r greater than 0.99) and the slope was close enough to 1.00 (1.01) to assume that only the length was necessary to accurately determine the size of an individual.

Echinarachnius parma less than 5.0 mm were measured using an ocular micrometer. The periproct was rarely seen, so the longest distance across the sand dollar was considered the length. The larvae of E. parma are planktonic and it is therefore only after metamorphosis that this species is represented in benthic samples. One hundred E. parma were measured from each station for each of the nine cruises analyzed, if that many were present. Replicate 1 was measured first and the process was continued through the replicates until the one containing the 100th specimen was completed. Data were obtained for nine seasons (M1 - M9) except February 1983 (M7) at Station 4 because poor weather conditions precluded sampling.

Size-frequency distributions were generated with the computer program SORTSTAN which sorts the measurements into size classes and multiplies each frequency by a scaling factor to determine the number of animals of that size expected to be present, had every individual been measured. Size classes of 0.4 mm for the amphipod species and 2.0 mm for the sand dollars were used.

Modal analysis was used to identify cohorts in the amphipod length-frequency data. The computer program NORMSEP separates length-frequency sampling distributions into component normal distributions (Tomlinson, 1971). The difference between observed and expected distributions is minimized using a maximum-likelihood function, and a chi-squared statistic measures goodness of fit. For each component distribution NORMSEP calculates mean length, standard deviation, and number of individuals. NORMSEP was not necessary for E. parma since the lengths of "juvenile" and "large" sand dollars did not overlap. The mean and standard deviation of length was calculated separately for the juvenile and the large sand dollars.

Growth and mortality rates were determined by following the mean length of and number in each cohort over time. Mean length of the animals in a cohort was converted to mean weight using length-weight regressions. To eliminate potential preservation bias, regressions were determined for each species using live animals collected in May 1983.

Live weight was obtained by damp drying individual animals and weighing to 0.01 mg for amphipods and 0.1 mg for sand dollars. The amphipods were anesthetized with FINQUEL® before measuring. Dry weight and ash-free dry weight were ascertained for individual sand dollars and for groups of amphipods with a total fresh weight between 20 and 30 mg. Each sample was dried to constant weight at 60°C and combusted at 450°C for 5 hours to determine ash weight.

A line of the form,

$$\log (w) = a + b \log (l),$$

where l is length, and w is the weight, was fitted for each species by linear regression. The regression was calculated on the basis of live weight for the amphipod species and dry weight for the sand dollars. Using the length-weight regressions and percent ash for each species, mean length was converted to mean ash-free dry weight. This is the preferred weight unit, especially for sand dollars where the calcareous test constitutes the bulk of the weight.

Annual production was calculated by the increment-summation method described by Crisp (1971). For each cohort, production (P) was calculated as the sum of weight increments over time (t) according to:

$$P = \sum_{t} \frac{N(t) + N(t+1)}{2} \quad (\bar{w}(t-1) - \bar{w}(t)),$$

where N(t) and $\bar{w}(t)$ are respectively, the number and mean weight of individuals in the cohort, at time t. Annual production for a given species is the sum of production by each cohort over a year.

Fish Stomach Content Analysis

Stomachs of the yellowtail flounder, Limanda ferruginea, were collected by the National Marine Fisheries Service (Northeast Fisheries Center) on a quarterly basis from Summer 1982 to Spring 1983. Stomach collection coincided as closely as possible to the dates and locations of benthic monitoring Cruises M5 through M8 (July 1982 - May 1983). Monitoring Stations 5, 10 and 13 were chosen for fish stomach analysis because the macrofaunal assemblages differ significantly between these stations. At Stations 10 and 13, trawling was conducted in a 6.5 km square centered at the station coordinates. At Station 5, to avoid disturbing the site-specific stations, trawling was conducted in the two rectangles shown in Figure 94. An otter trawl was towed at three-hour intervals, usually over a 24-hr period at each station. Tow duration was 30 min at a speed of 3.0 knots. Fish stomachs were excised at sea, preserved in 10 percent formalin in seawater and appropriately labelled.

The stomachs were transferred to Battelle for content analysis. Each stomach was cut longitudinally and the entire bolus removed, described according to the state of digestion, and wet-weighed to the nearest 1 mg after blotting. Stomach contents were sorted to species and enumerated. Partially digested polychaete fragments were counted if the head was present and an identification could be made. The same protocol was followed for amphipods, except for the species of Unciola. The taxonomic characters needed for species identification in this genus include the third epimeral plate and fifth coxa. Specimens lacking these characters could not be sorted to species and were recorded as Unciola spp. The wet weight of each taxon was estimated to the nearest 1 mg.

Arthropod species were then transferred to W.H.O.I. for length-frequency measurements. Polychaete species were retained at Battelle for similar measurements

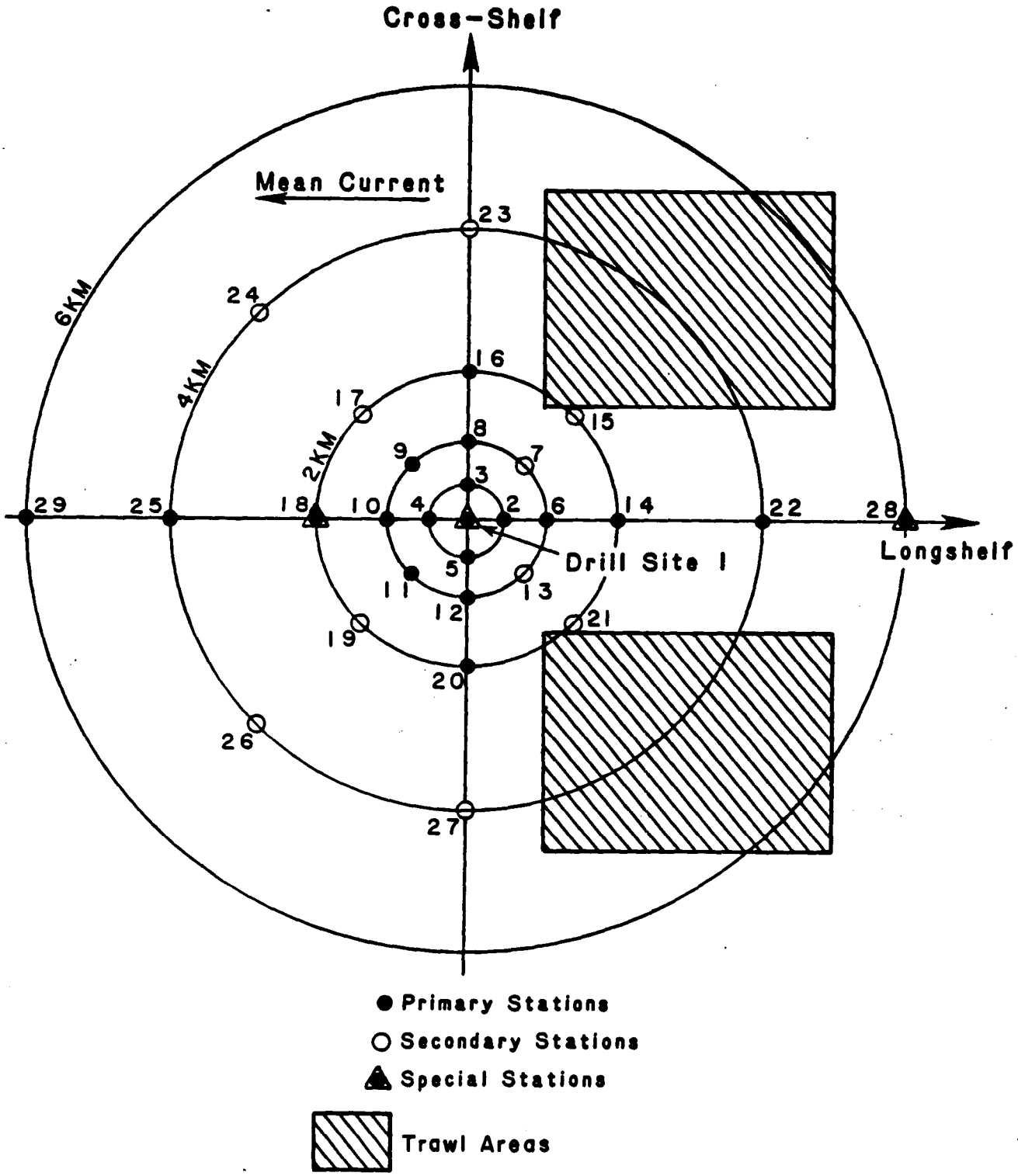


Figure 94. Location of trawling areas shown in relation to the site-specific stations.

(see Chapter 6). Echinarachnius parma found in the stomach samples were measured at Battelle, and the data were sent to W.H.O.I. for analysis. All data were coded and entered into the VAX 11/780 computer at W.H.O.I. Hard copy printout was verified and any errors corrected.

Prey-preference Analysis

Ivlev's (1961) electivity index was used to compare the species composition of the stomach contents to that of the macrofauna. Since prey weights are biased due to partial digestion and preservation, the index was calculated on the basis of prey numbers. For each date and station, species numbers were summed over all stomachs and all six replicates. Seventeen percent of prey items in the genus Unciola could not be identified to species. These individuals were assigned to U. inermis and U. irrorata according to the relative identifiable proportions of these two species in the diet at that station and date.

Of the site-specific stations, Stations 5-1, 5 -18, and 5-28 were the only three which were continuously sampled during the year the fish stomachs were collected. (The other site-specific stations were not sampled in February 1983 (M7) because of bad weather.) Since fish stomachs were collected in the area between Stations 5-1 and 5-28, the benthic data from these two stations were combined for the purpose of calculating the electivity index.

Electivity (E) by a given predator species for a given prey species is calculated as

$$E = (r-p)/(r+p),$$

where r and p are the identifiable proportions of the prey species in the fish species diet and in the benthos, respectively. E varies from 1 to -1 with 0 indicating neutral selection.

To investigate the importance of size selection, size measurements were made of six prey species: Unciola inermis and Erichthonius fasciatus from stomachs collected at Station 5, Echinarachnius parma from stomachs at Station 10 and Ampelisca agassizi, Chone infundibuliformis and Levinsenia gracilis at Station 13. These prey species were measured in the same manner as those from the benthic grab samples (see sections on life history and production). Ivlev's electivity index was again used to compare the size distributions of available and ingested prey.

Prey selection may vary, not only for fish of different lengths, but also because of behavioral differences among fish of a given length. To minimize this potential bias, at least for amphipod prey, all stomachs of 31 to 35 cm long flounder were examined for size

selection. The 31 - 35 cm size class was the most abundant flounder size class in all seasons. Stomachs containing large numbers of amphipods were subsampled using a plankton splitter such that a total of about 200 prey of each species were measured from each season.

To link fish feeding with benthic production, the rate of food consumption by flounder was estimated. Food consumption is the product of flounder density per unit area and consumption per fish. Yellowtail flounder population size was estimated by Collie and Sissenwine (1983). The ratio of consumption to biomass for yellowtail flounder, among other fish species, was estimated by Grosslein et al. (1980).

RESULTS

Life History and Production

Production estimates for the three amphipod species have been presented by Collie (in press). This section combines these previous results with additional amphipod and sand dollar data. Observed length-frequency distributions are plotted in Figures 95 - 98. The frequencies are based on six 0.04 m^2 grab samples, giving a total area of 0.24 m^2. For the amphipod species, white blocks in the histograms represent females with developing embryos in their marsupia. The mean size of juveniles still in the marsupium was 1.8 mm for Ampelisca agassizi, and 1.4 mm for both Unciola inermis and Erichthonius fasciatus; therefore peaks in the length-frequency distributions at these lengths correspond to newly released juveniles. Cohorts are identified according to the year and season in which they were released.

Ampelisca agassizi at Station 13 (Figure 95) appears to be a biennial species in that females of a given generation breed at age 1 and at least some survive to breed at age 2. For example, cohorts 80A and 80B had ovigerous females in November 1981 and again in July 1982 while cohort 81B had ovigerous females in November 1982 and again in May 1983. The timing of reproduction varied from year to year. In 1981 ovigerous females were found only in November and recruitment of juveniles occurred in the late fall. Recruitment was delayed in 1981 because cohort 79 did not survive to breed for a second year. In 1982 the breeding season was advanced with ovigerous females present in July and November and recruitment in the late summer. The breeding season was even more advanced in 1983 with ovigerous females present in May and July. Recruitment of juveniles had not occurred by July suggesting that either juveniles were released and lost from the sampling area or the development time of embryos is longer than two months.

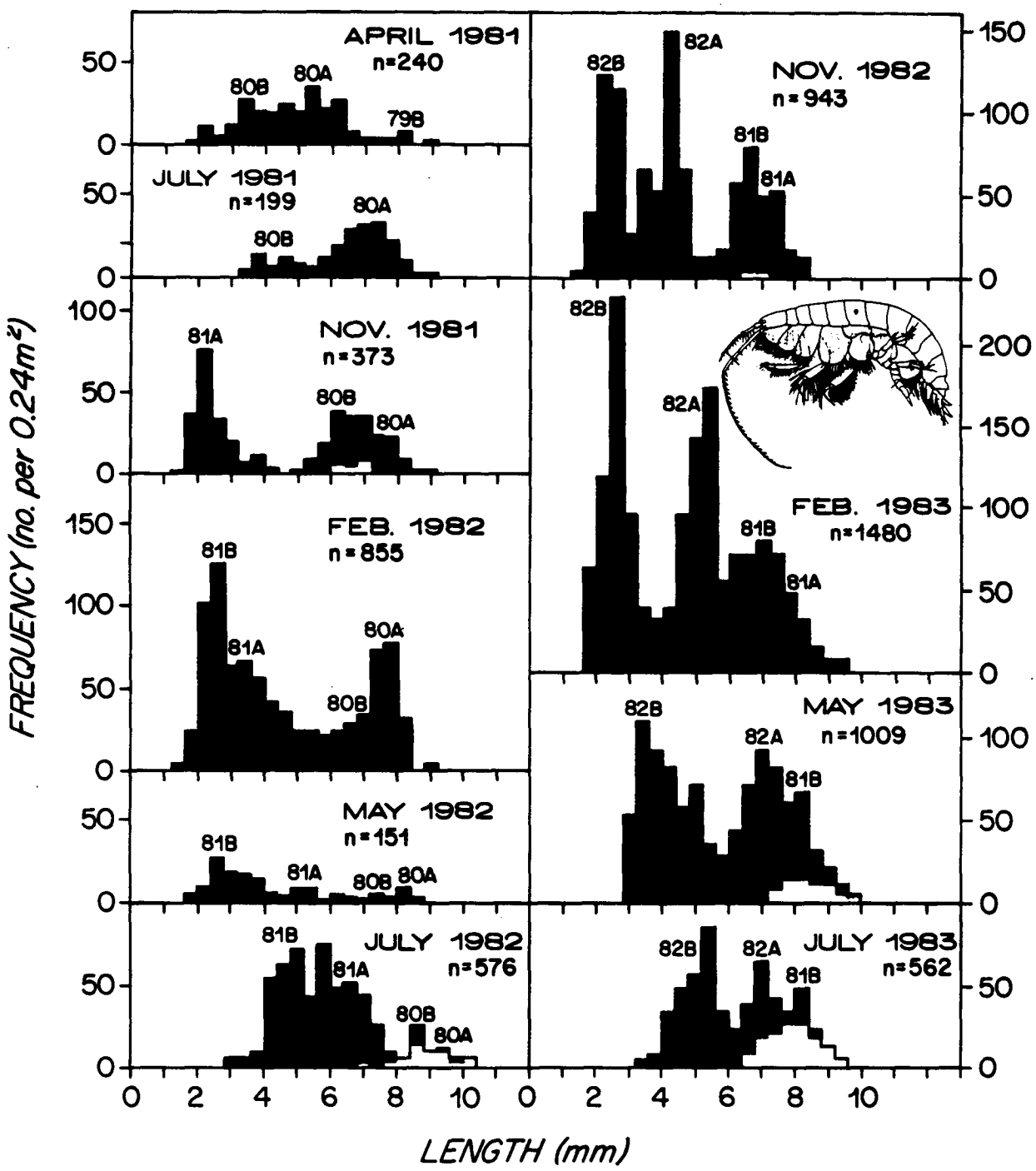


Figure 95. Length-frequency of Ampelisca agassizi at Station 13. White blocks in the histograms represent ovigerous females. From Collie (in press).

The minimum and maximum lengths of ovigerous females were 5.4 and 10.1 mm, respectively. A length of 10 mm may be reached after the maximum life span of two years.

Unciola inermis at Station 5-1 (Figure 96) is an annual species with ovigerous females present in February and May (a few in July 1983) and recruitment of juveniles in May. A length of 11 mm may be reached after the maximum life span of about 1.5 years. The minimum and maximum lengths of ovigerous females were 5.0 and 10.5 mm. A few individuals may survive for a second year (e.g., cohort 81B).

At the same station, ovigerous females of Erichthonius fasciatus (Figure 97) were present throughout the year but recruitment of juveniles was concentrated during the spring and fall, resulting in two generations per year. A striking feature of the distribution of E. fasciatus at this station was its virtual disappearance in February 1982 (M3) and subsequent recolonization in May (M4). The reasons for this disappearance and the source of colonists will be discussed below. Animals in the spring generation reach a maximum length of 7 mm in six months while those in the fall generation reach a maximum of 9 mm in eight months. Minimum and maximum lengths of ovigerous females were 4.8 and 8.4 mm, respectively.

In all three species, each generation appears to be composed of two modes (these cohorts are labeled A and B in Figures 95, 96, and 97). Bimodality is more distinct for Unciola inermis and Ampelisca agassizi where reproduction is more highly synchronous than for Erichthonius fasciatus. A and B cohorts are apparent for E. fasciatus in July but are less obvious at other times of the year.

To test whether these A and B cohorts are true modes, NORMSEP was run assuming either one or two modes per generation. In almost all cases, a better fit was obtained with two modes per generation. A and B cohorts were more difficult to separate for adults because variability in individual growth rates obscures the modes with time. An example of the fit obtained using NORMSEP for Unciola inermis in July 1981 is given in Figure 99.

Figure 98 is a composite of the size-frequency histograms for Echinarachnius parma at Station 10. In May 1982, and again in May and July 1983 there were large numbers of juveniles (0-2 mm). The large sand dollars were considered one cohort at all three stations because their distributions were unimodal. No obvious separation of length classes could be determined. At Station 4 (not shown), there was a large number of juveniles in May and July 1982, and again the following May and July. The large sand dollar cohort increased markedly in mean length over the two year period, but decreased sharply in number of individuals. Only two large E. parma were present in July 1983. At

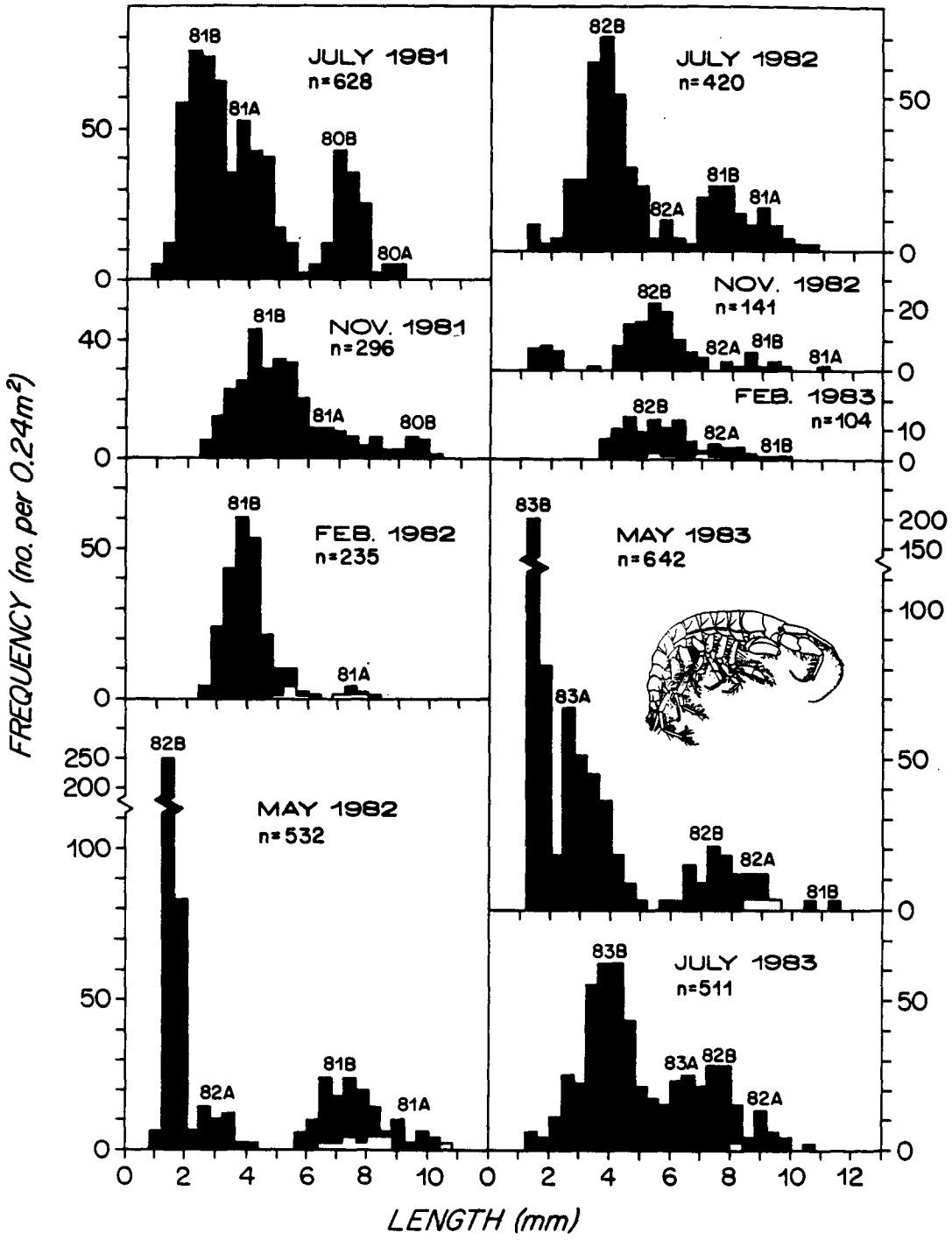


Figure 96. Length-frequency of Unciola inermis at Station 5-1. White blocks in the histograms represent ovigerous females. From Collie (in press).

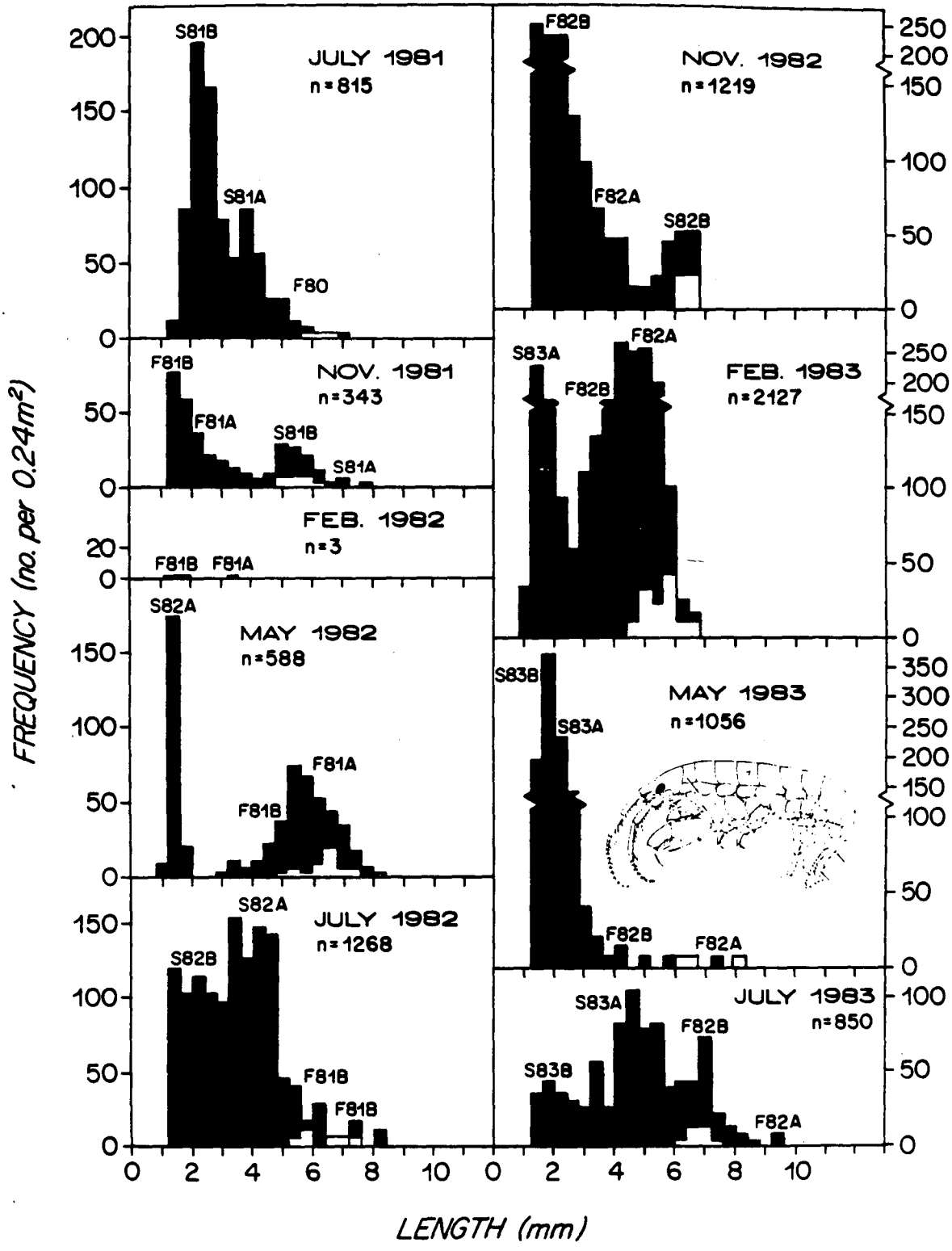


Figure 97. Length-frequency of Erichthonius fasciatus at Station 5-1. White blocks in the histograms represent ovigerous females. From Collie (in press).

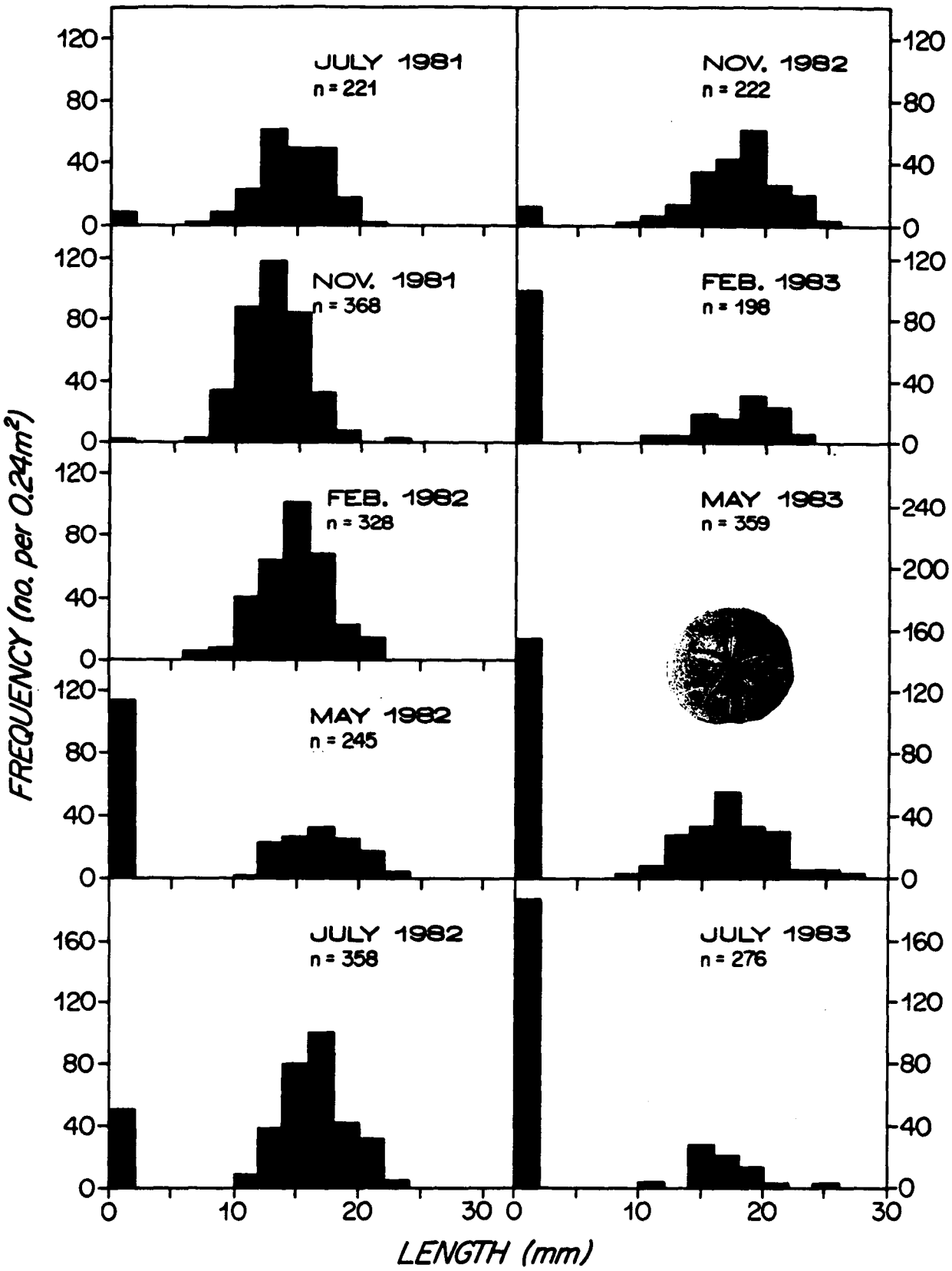


Figure 98. Length-frequency of Echinarachnius parma at Station 10.

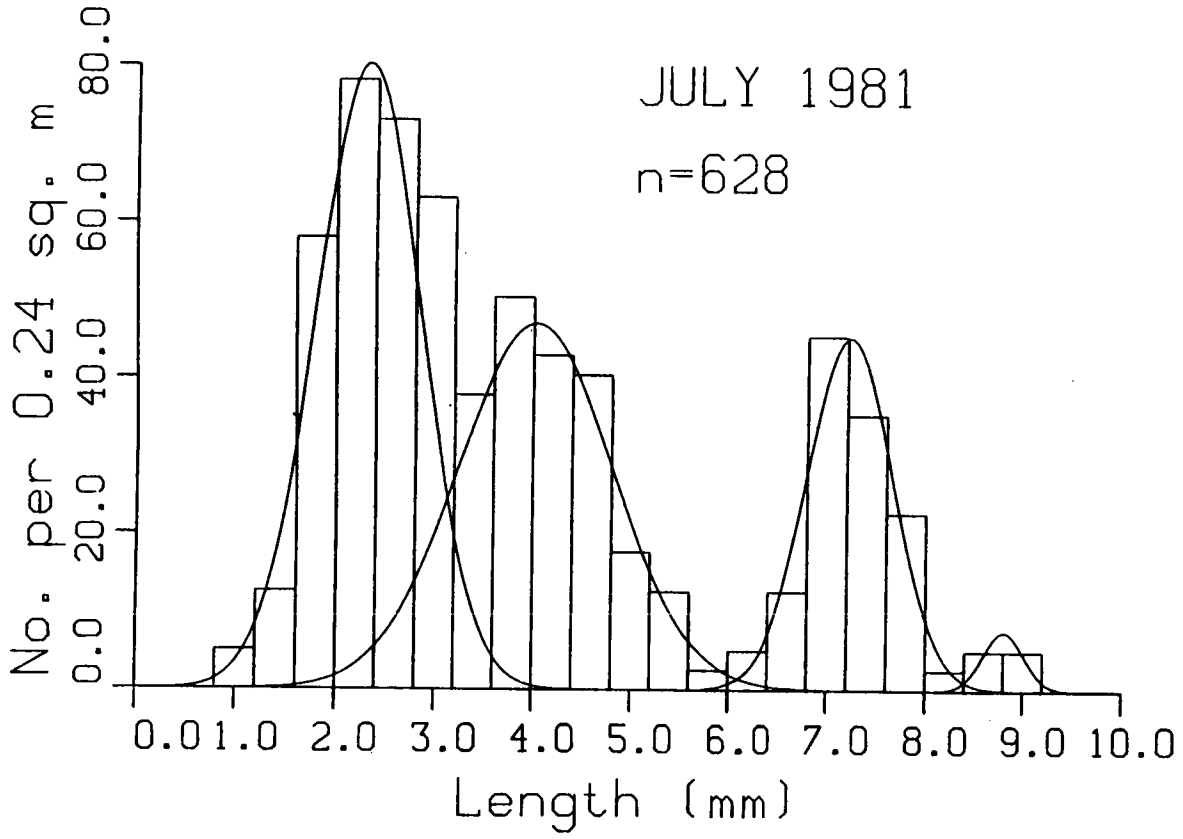


Figure 99. **Example using computer program NORMSEP to fit normal curves to the observed length-frequency distributions of Unciola inermis at Station 5-1. The chi-square of 4.6 with 8 degrees of freedom indicates that these data fit a group of normal distributions better than 80 percent of samples would be expected to by chance alone. From Collie (in press).**

Station 1 (not shown) juveniles were most abundant in July 1982, and again in February and May of 1983.

Figure 100 is a plot of the number of juveniles versus number of large Echinarachnius parma. There may be many juveniles in an area with few large sand dollars, or many large ones in an area with few juveniles, but never were there many large sand dollars and many juveniles in the same area. Station 1, for example, had the highest number of juveniles (445 in July 1981, and 627 in May 1983), and generally had the lowest number of large sand dollars.

Growth curves for each amphipod cohort are shown in Figure 101. The vertical bars equal ± one deviation as estimated by NORMSEP. Where vertical bars overlap, the modes are indistinct. A common feature of all species is that the growth rate decreases in the winter (for Unciola inermis, cohorts 81B and 82B, the mean length actually decreased between February and May), and also decreases with age. Erichthonius fasciatus had the fastest growth rate (max. 1 mm/mo) with U. inermis intermediate and Ampelisca agassizi the slowest. This is consistent with their relative life-spans.

Mean length versus time for the large Echinarachnius parma at the three stations is plotted in Figure 102. The vertical bars are 95 percent confidence intervals. The number below each bar is the actual number of sand dollars measured for each cruise at a given station. At Station 10 the cohort of large sand dollars increased slightly in mean length with time. The trends at Stations 1 and 4 were not as clear, but Station 4 appeared to have large sand dollars that were growing. Note that Station 10, which was the station with the largest number of individuals and the smallest confidence intervals, also had the most clearly defined trend.

Length-weight relationships are summarized in Table 18. Despite the inherent variability of wet weights, a significant fit was obtained for each amphipod species by using relatively large sample sizes. For the sand dollars, dry weight was regressed on length thus avoiding the variability of wet weights. For all four species the regression coefficient (b) was significantly less than 3.0. This indicates that growth in weight was not isometric; weight increased less rapidly than did length.

Table 19 summarizes the ash-free dry weight determinations. Compared to the other amphipod species, Erichthonius fasciatus not only had a lower weight for a given length, but it also had a higher percentage of water. This could explain how its rate of increase in length was greater than that of the other amphipod species; it produced less dry weight per unit length. The calcareous test accounted for most of the dry weight of Echinarachnius parma and therefore only a small percentage of the weight was organic material. These percent composition data allowed wet and dry weights to be converted to ash-free dry weight.

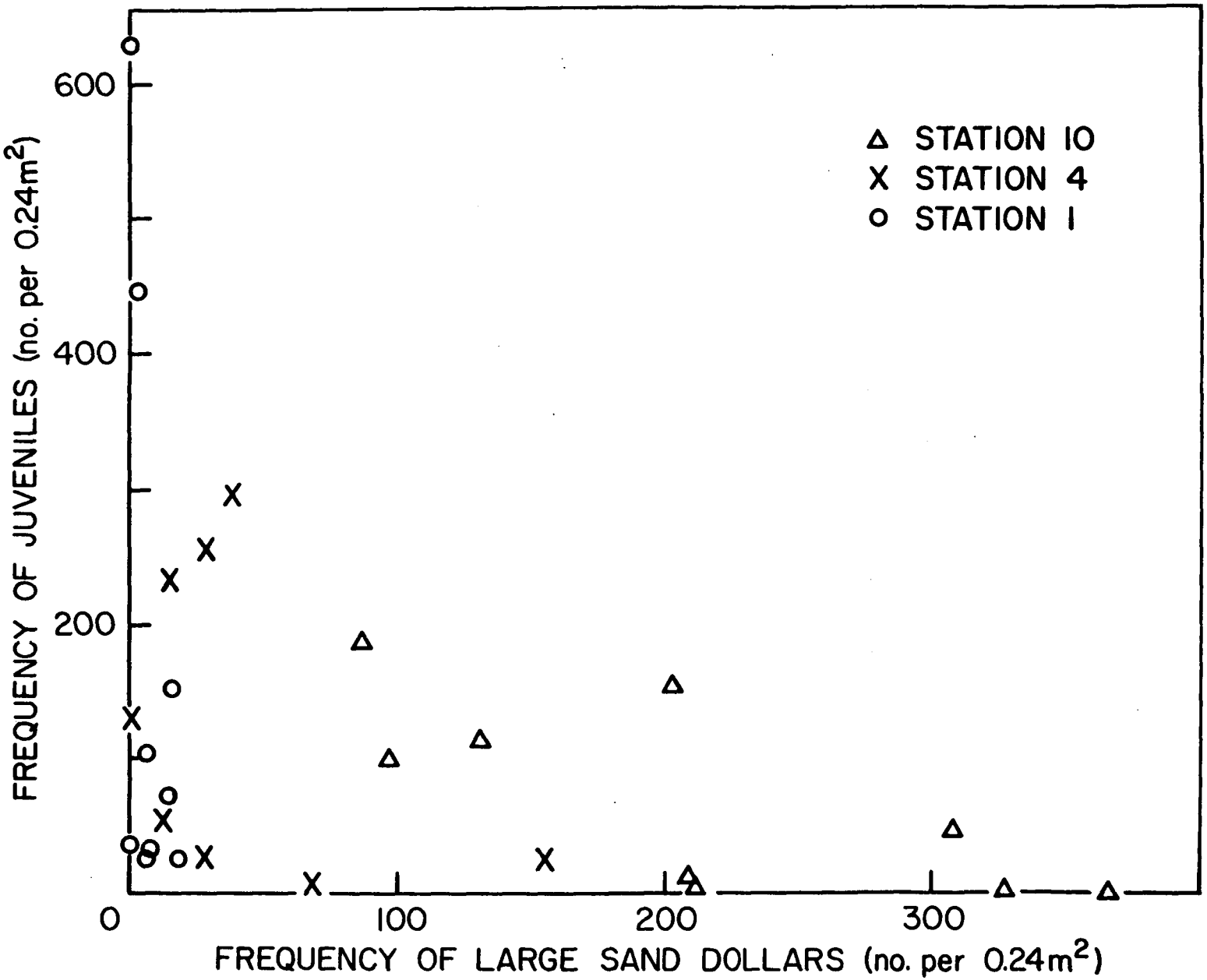


Figure 100. Number of juveniles versus number of large sand dollars.

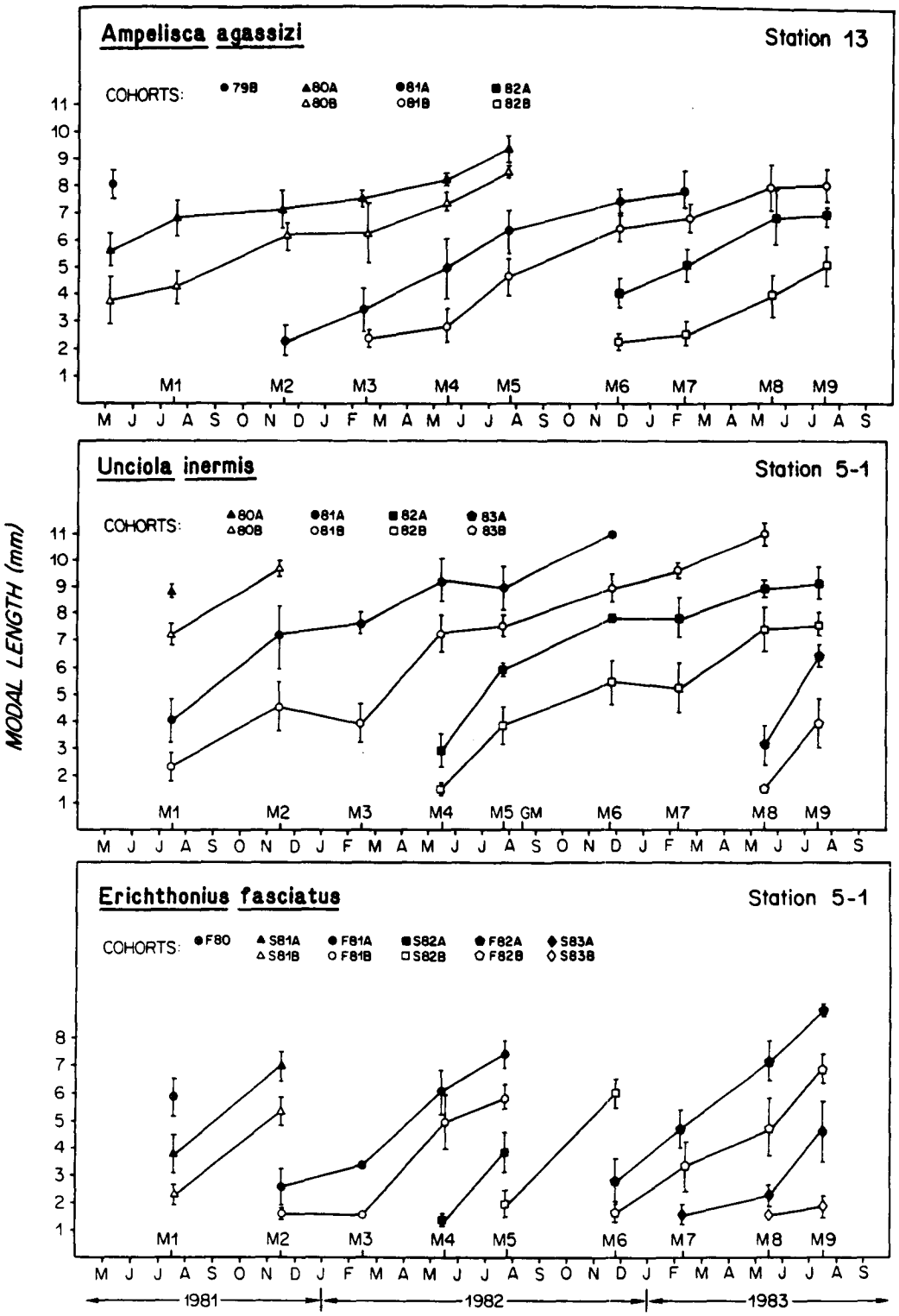


Figure 101. **Growth in mean length of each amphipod cohort. The vertical bars equal ± one standard deviation as estimated by NORMSEP. From Collie (in press).**

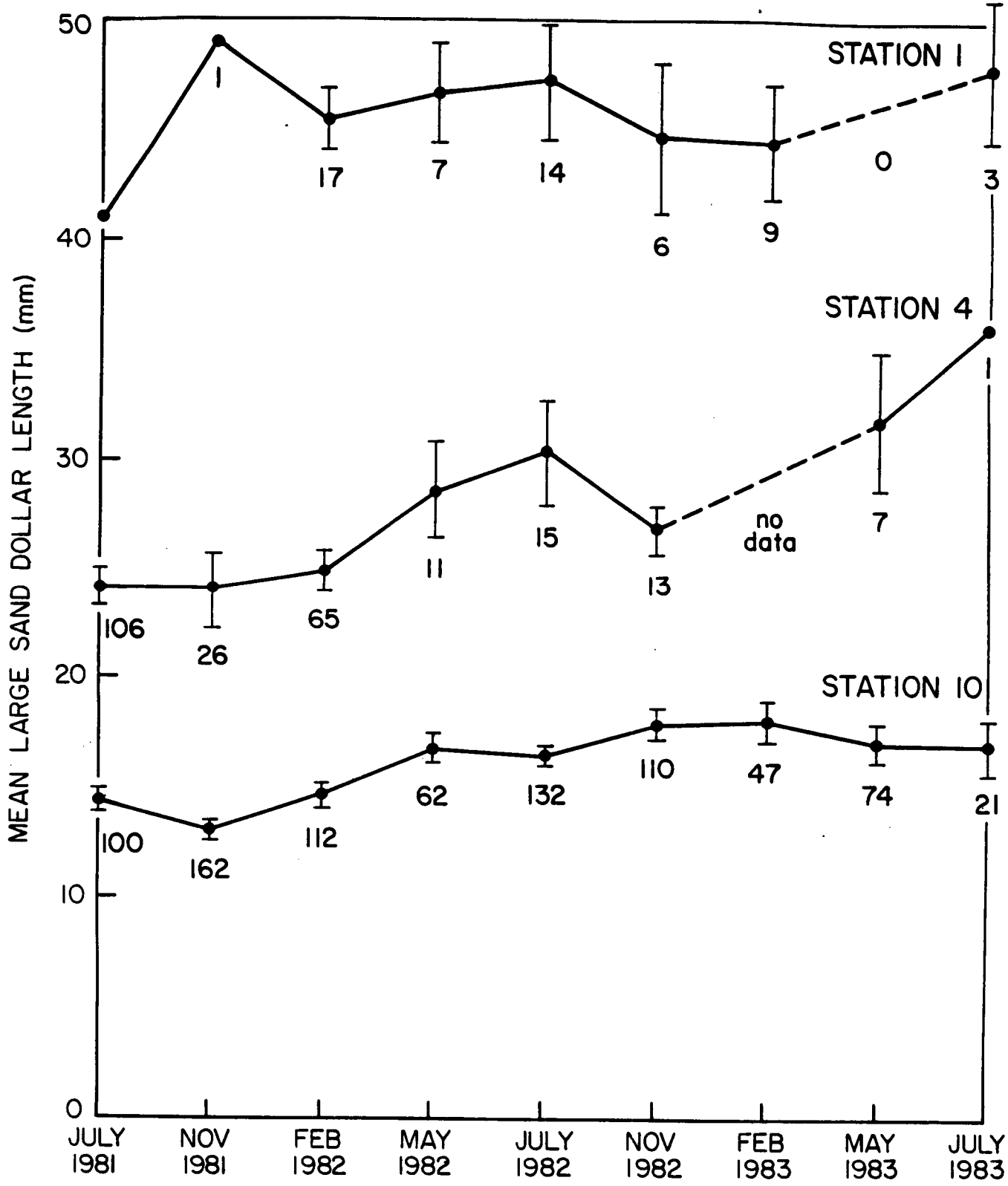


Figure 102. Growth curves for the large sand dollars at Stations 1, 4, and 10. The vertical bars are 95 percent confidence limits.

TABLE 18. RESULTS OF LINEAR REGRESSION FIT OF LENGTH-WEIGHT DATA TO THE EQUATION LOG(W) = A + B LOG(L), WHERE W IS WEIGHT (MG) AND L IS LENGTH (MM). NOTE THAT WET WEIGHTS WERE USED FOR THE THREE AMPHIPOD SPECIES WHILE DRY WEIGHTS WERE USED FOR ECHINARACHNIUS PARMA.

Species:	Ampelisca agassizi	Unciola inermis	Erichthonius fasciatus	Echinarachnius parma
n(individuals):	87	39	86	38
a:	0.02	0.05	0.03	0.21
b:	2.7	2.5	2.5	2.7
r^2:	0.97	0.97	0.98	0.90

TABLE 19. ASH-FREE DRY WEIGHT DETERMINATION. THE AMPHIPOD SPECIES WERE WEIGHED IN GROUPS WITH A TOTAL FRESH WEIGHT BETWEEN 20 AND 30 MG; SAND DOLLARS WERE INDIVIDUALLY WEIGHED.

Species:	Ampelisca agassizi	Unciola inermis	Erichthonius fasciatus	Echinarachnius parma
n(groups):	3	3	4	15
% water:	75.9	74.4	80.9	46.0
% ash:	7.1	8.5	6.1	50.5
% ash-free dry weight:	17.0	17.1	13.0	3.5

Production and biomass estimates are listed in Table 20. Erichthonius fasciatus had the highest P/B ratio followed by Unciola inermis, Ampelisca agassizi, and Echinarachnius parma. Comparing the two years of amphipod data from Station 5-1, the P/B ratios varied much less than did production and biomass. The maximum change in P/B was a 20 percent decrease for U. inermis while production and biomass changed by as much as 2.5 times. Interannual differences in P/B were also less than the differences among species. Compared to data for Station 5-1 for the period July 1982 to July 1983, the amphipod data from Station 5-28 varied with respect to production, mean biomass, and P/B ratio. At Station 5-28 the U. inermis growth rate (not shown) was lower than at Station 5-1.

Echinarachnius parma showed a trend in size and numbers among the three stations. At Station 1 there were a few large sand dollars while at Station 10 there were many smaller sand dollars; Station 4 was intermediate in both respects. As a result, mean biomass was similar for all three stations. However the large sand dollars at Station 1 grew only slightly and consequently, production and the P/B ratio were substantially lower than at Stations 4 and 10. Production of E. parma was highest at Station 4 by virtue of the higher growth rate there. For E. parma, interannual differences in P/B were not necessarily less than differences between stations. Both Stations 10 and 4 had considerably lower P/B values during the second year. This can be attributed to the lower production values in 1982-83 compared to 1981-82. Mean biomass for Station 4 was also lower in the second year, but this difference was not enough to offset the larger decrease in production. Since there were no large sand dollars found in May 1983 at Station 1 (Figure 102), production and biomass were determined using the difference in values between the February and July 1983 data. The biomass and production of the juvenile sand dollars were insignificant compared to the contribution of the large E. parma.

Table 21 compares a number of life-history traits among the four species. The coefficient of variation of sample means is a measure of the patchiness of the species distribution relative to the size of the grab and area over which the replicates were taken. Thus, Erichthonius fasciatus is the most patchily distributed and Ampelisca agassizi is the least so. Fish predation data are based on analysis of yellowtail flounder stomachs collected at the same stations. It should be stressed that results given here measure the mean number of prey per predator, not the predation rate. Nonetheless, these data suggest that flounder eat E. fasciatus most often and E. parma least often.

Fish Feeding and Prey Selection

A total of 594 yellowtail flounder stomachs were examined. The numbers of stomachs containing identifiable prey items are listed by season and station in Table 22.

TABLE 20. BIOMASS AND PRODUCTION ESTIMATES (GAFDW = GRAMS ASH-FREE DRY WEIGHT).

Species:	Ampelisca agassizi	Unciola inermis		Erichthonius fasciatus		Echinarachnius parma		
Station	13	5-1	5-28	5-1	5-28	10	4	1
Production (gafdw m^{-2} yr^{-1})								
July 81-July 82	0.90	2.08	-	0.97	-	8.1	10.0	0.58
July 82-July 83	2.27	1.65	1.30	2.13	1.32	3.4	1.4	0.84
July 81-July 83 (mean)	1.58	1.87	-	1.55	-	5.7	5.7	0.71
Mean biomass (gafdw m^{-2})								
July 81-July 82	0.65	0.78	-	0.21	-	20.3	20.4	13.8
July 82-July 83	1.40	0.77	1.01	0.52	0.33	19.8	8.8	16.6
July 81-July 83	1.03	0.75	-	0.35	-	18.9	14.7	14.0
P/B (1/yr)								
July 81-July 82	1.39	2.65	-	4.62	-	0.40	0.49	0.04
July 82-July 83	1.62	2.14	1.29	4.11	4.00	0.17	0.16	0.05
July 81-July 83	1.54	2.48	-	4.41	-	0.31	0.39	0.05

TABLE 21. SUMMARY OF LIFE-HISTORY TRAITS (CV = COEFFICIENT OF VARIATION).

Species:	Ampelisca agassizi	Unciola inermis	Erichthonius fasciatus	Echinarachnius parma
Generation time:	biennial	annual	semi-annual	greater than 2 yrs
P/B (yr^{-1}):	1.4 - 1.6	1.3 - 2.7	4.0 - 4.6	0.05 - 0.39
CV of sample means:	40.5	54.8	83.8	61.0
Mean per fish stom:	15.0	72.4	88.4	0.1
Sediment affinity:	fine sand	medium sand	shell frags.	fine to med. sand

TABLE 22. NUMBERS OF YELLOWTAIL FLOUNDER STOMACHS WITH IDENTIFIABLE PREY ITEMS.

Date	Station 5	Station 10	Station 13
9-15 August 1982 (M5)	11	150	4
24-28 October, 2 December 1982 (M6)	20	26	7
17-23 February, 7-8 March 1983 (M7)	11	6	36
2 May 1983 (M8)	23	48	20

In each case, a few prey species constituted the bulk of the diet. The five most numerous prey species of yellowtail flounder (Figure 103) accounted for 96 percent, 70 percent and 89 percent of the total identifiable prey species at Stations 5, 10, and 13, respectively. At Station 5 the diet was dominated by tubicolous amphipods and to a lesser extent by polychaetes. Pelagic prey were more important at Station 10 where the diet was dominated by fish larvae, amphipods, shrimps, and crabs. Amphipods and polychaetes were the dominant prey items at Station 13.

Fish caught at Station 5 had the highest mean number of prey per stomach, followed by those caught at Stations 13 and 10. Since the mean weight of stomach contents was only slightly greater at Station 5 (707 mg) than at Station 13 (680 mg) and Station 10 (528 mg), most of the differences in prey number are due to differences in mean prey weight. On the average, larger prey were eaten at Station 10 (54 mg) than at Station 13 (10 mg) or Station 5 (4 mg).

Seasonal variations in flounder food habits were illustrated in the Year 2 Final Report (Battelle and W.H.O.I., 1984, Figure 69). At Station 5 the same prey species dominated the diet in all seasons. In contrast, there was considerable seasonal variation in the diet at Station 10. The diet was dominated by larvae of cusk Brosme brosme in August, by the shrimp Crangon septemspinosa in the fall and winter, and by the amphipods Pontogeneia inermis and Aeginina longicornis in May. At Station 13 the diet was relatively constant except for the epifaunal caprellid A. longicornis which was eaten in great numbers in the winter but much less at other times of the year.

Electivity indices were calculated to determine whether changes in prey composition reflected seasonal changes in benthic community composition. Constant electivity for a given prey species indicates that fish feeding mirrors changes in prey abundance; variable electivity implies that prey suitability or availability change during the year.

Three groups of prey species could be identified based on their occurrence in fish diet and/or in the benthos. For this analysis, "numerous in the benthos" means that a species was among the ten most abundant species at that station, as listed in Table 4. (The only exception is Nephtys incisa, which was the eleventh dominant species at Station 13). "Numerous in the diet" means the species was among the ten most abundant prey species at that station. "Less numerous" means that the species was not within the top ten dominants in the benthos or the diet. Group A consists of species which were numerous in the diet but less numerous in the benthos. Electivity indices are not given for pelagic species because they were under-represented in the grab samples. Group B contains species which were numerous in both diet and benthos. Species numerous in the

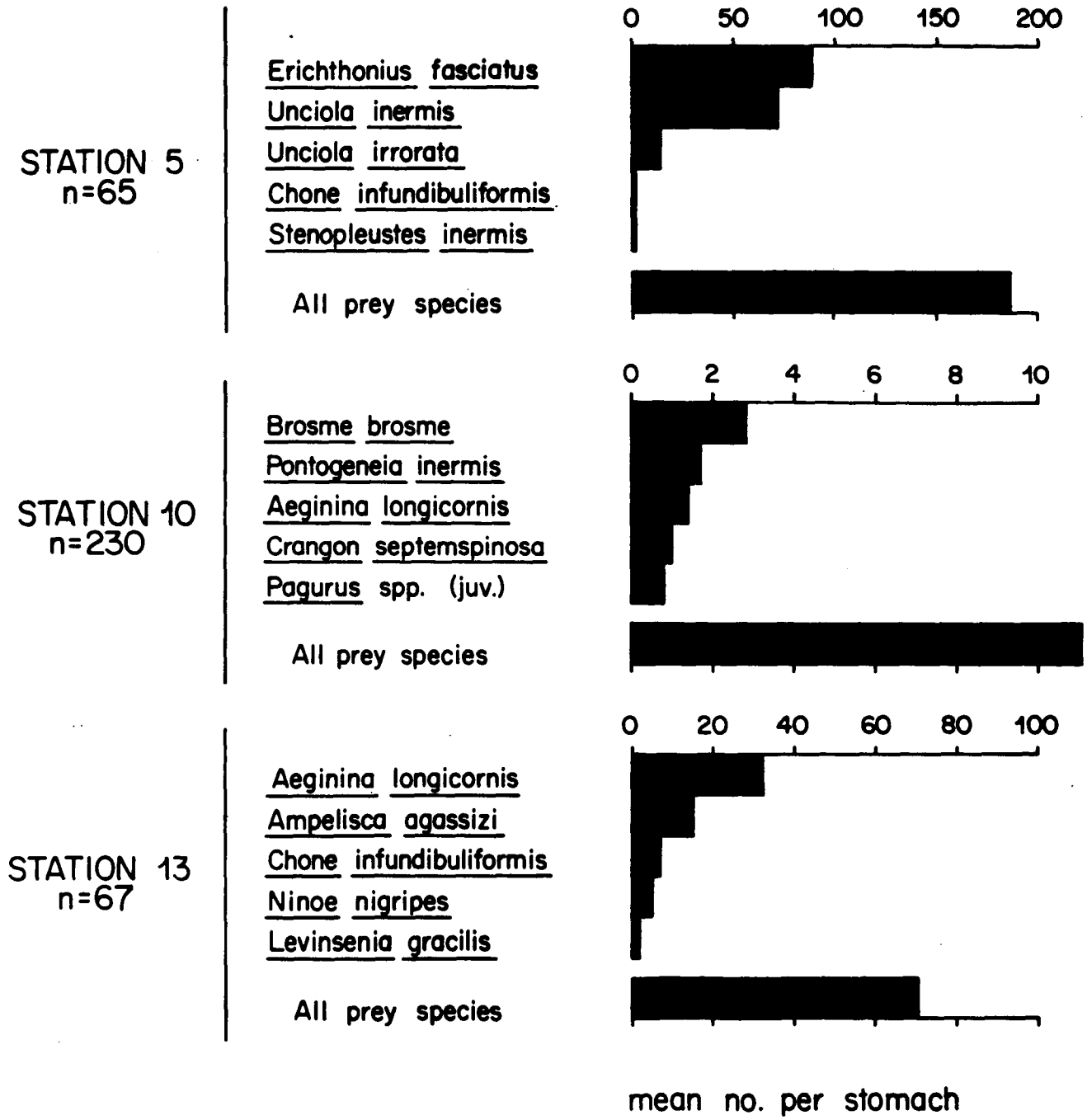


Figure 103. Five most numerous prey species of yellowtail flounder, Limanda ferruginea, at Stations 5, 10 and 13. Data are expressed as mean prey numbers taken over four quarterly collecting cruises.

benthos, yet less numerous in the diet, are in group C. Electivity indices are not given for dominant species which were never eaten.

Seasonal electivity indices for prey species eaten at Stations 5, 10, and 13 are shown in Figures 104, 105, and 106, respectively. As expected, prey species in group A were generally positively selected, group C species were almost always negatively selected and those in group B were either positively or negatively selected. The diet of yellowtail flounder was plastic in that the dominant prey species varied from station to station. On the other hand, the electivity values were consistent between stations. For example, Chone infundibuliformis, C. duneri, and Aeginina longicornis were always positively selected, while Aricidea catherinae was always negatively selected.

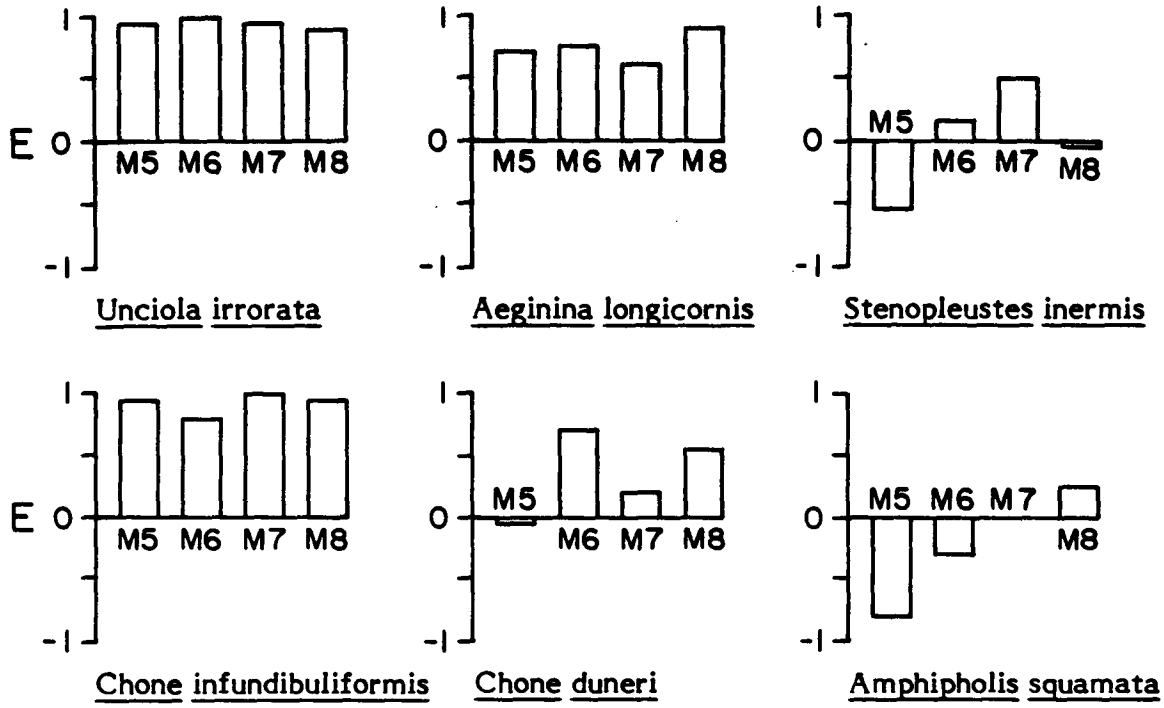
Differences in electivity among prey species and among seasons may, at least partially, be due to size-selective feeding. This was investigated by measuring the sizes of some important prey species found in yellowtail flounder stomachs. The size-frequency distributions generated from the fish stomach contents were compared to those from benthic grab samples, with all frequencies expressed as percentages. Due to small numbers of individuals collected, it was not possible to generate size-frequency distributions for all four seasons for one of the six prey species measured; for three others it was necessary to pool the size data from different seasons.

Length-frequency distributions for Ampelisca agassizi found in flounder stomachs at Station 13 were generated for Cruises M6, M7, and M8 (November 1982, February 1983, and May 1983, respectively). The small number of stomachs collected in July 1982 (Cruise M5) yielded insufficient A. agassizi to measure. Size distributions generated from the grab samples and fish stomachs from May 1983 are compared in Figure 107. Neglecting the small 3-6 mm A. agassizi, the flounder selected the 6-8 mm size range.

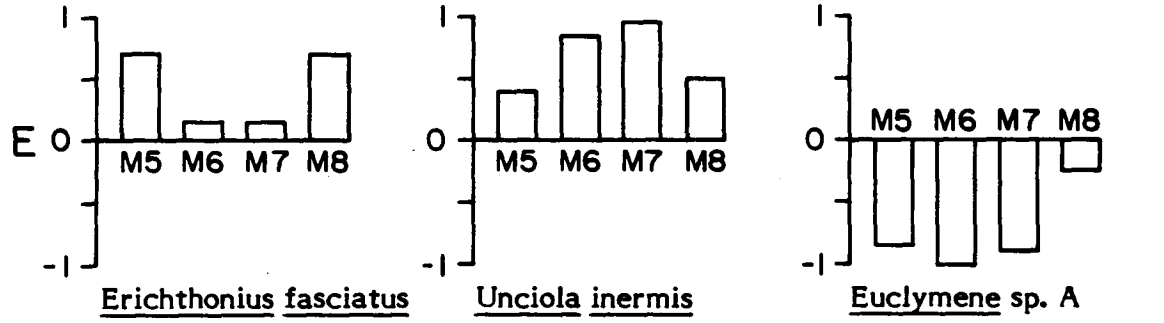
Length frequency distributions were obtained for Unciola inermis and Erichthonius fasciatus found in flounder stomachs at Station 5 in July and November 1982 and February and May 1983 (M5 through M8). The size distributions from grab samples collected at Stations 5-1 and 5-28 were combined by calculating the average percent in each size class, weighted by the densities at each station. The distributions from May 1983 are shown in Figures 108 and 109. For both U. inermis and E. fasciatus, this was a period of recruitment. Again, the flounder selected against the juveniles, feeding most heavily on the adult amphipods.

Although Echinarachnius parma was numerically dominant at Station 10, the small number of sand dollars ingested by flounder made it necessary to pool the length-frequency data from four sampling seasons (M5 - M8). This is justifiable because it can be seen from Figure 102 that the sand dollars grew only slightly during this period.

GROUP A: Numerous in Diet, Less Numerous in Benthos



GROUP B: Numerous in Both Diet and Benthos



GROUP C: Numerous in Benthos, Less Numerous in Diet

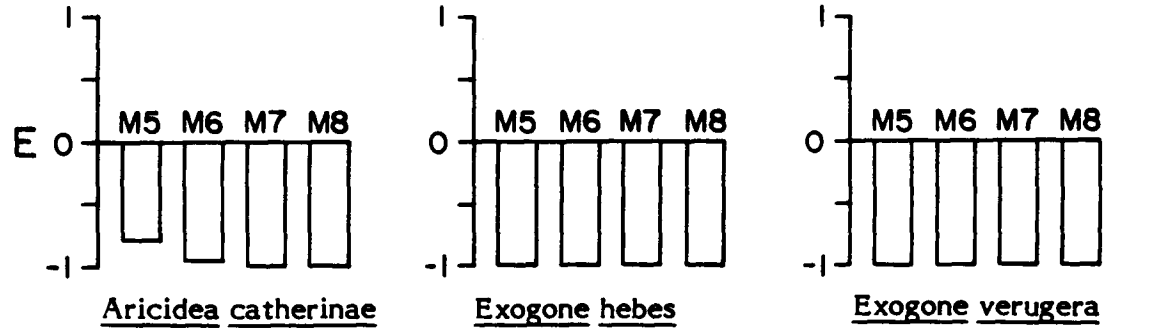
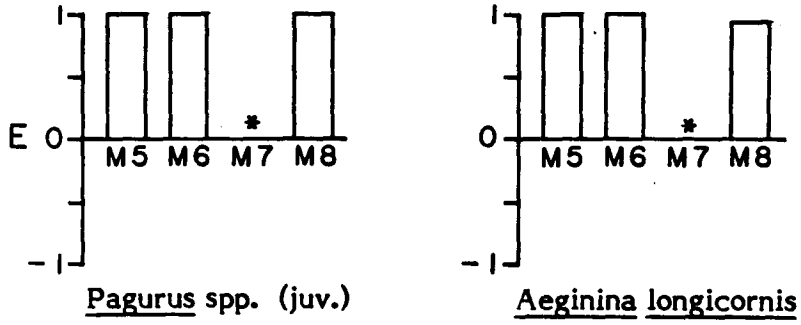
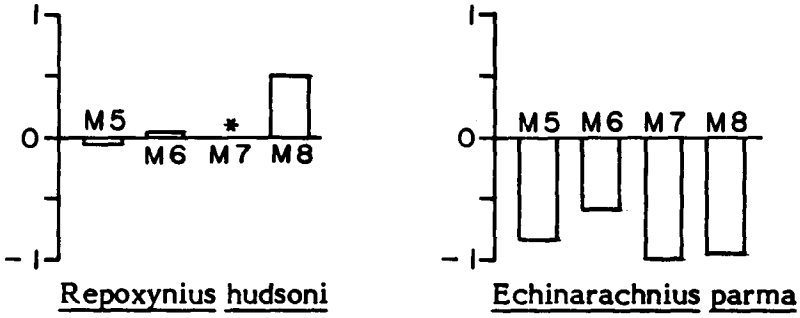


Figure 104. **Yellowtail flounder electivity for benthic prey at Station 5 for Cruises M5-M8 (see Table 3 for corresponding dates).**

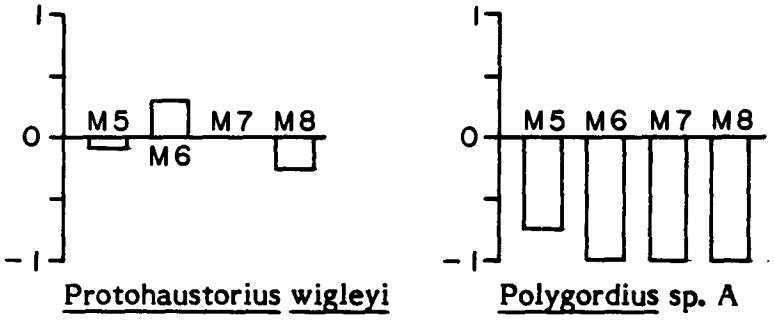
GROUP A: Numerous in Diet, Less Numerous in Benthos



GROUP B: Numerous in Both Diet and Benthos

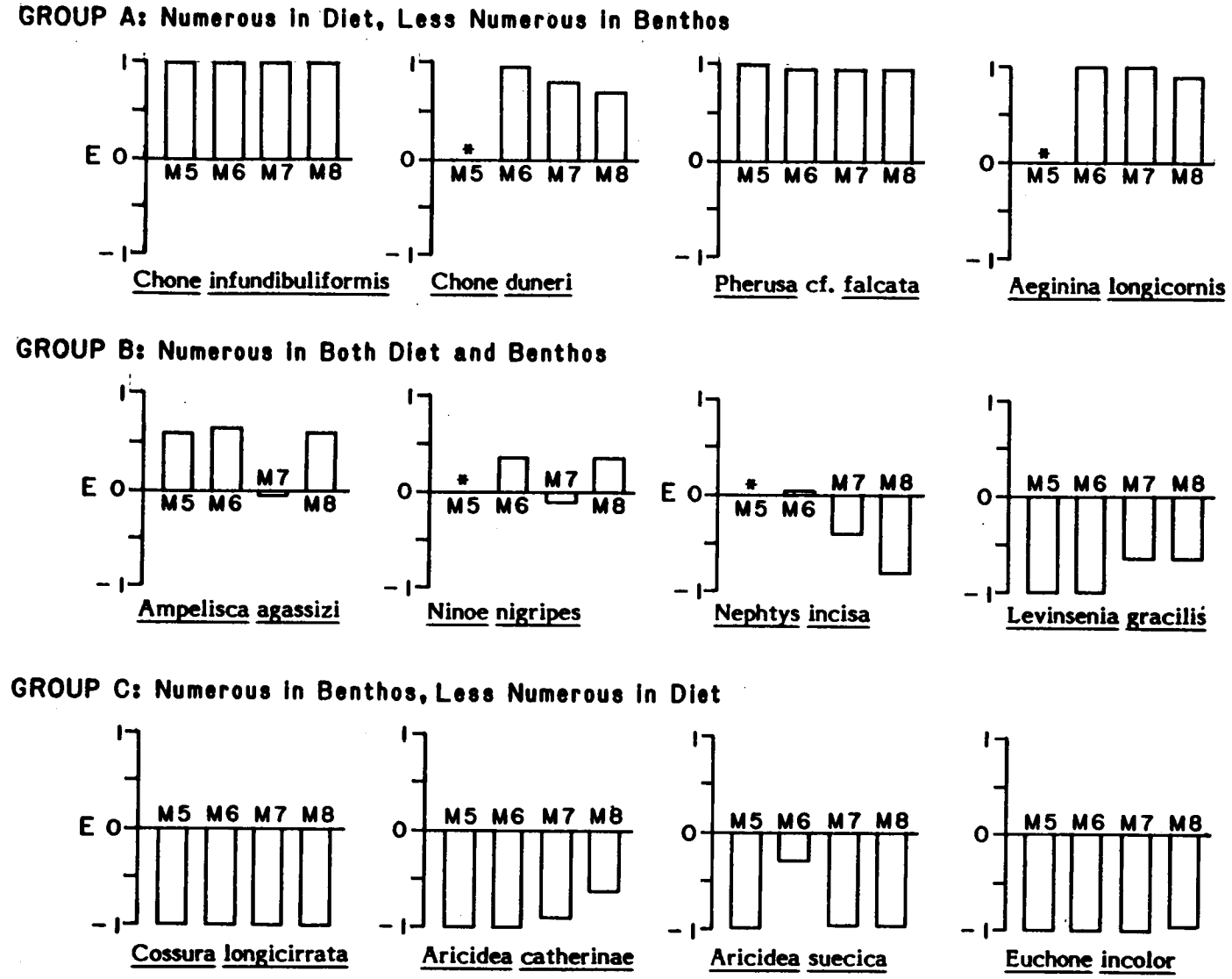


GROUP C: Numerous in Benthos, Less Numerous in Diet



*insufficient sample size

Figure 105. Yellowtail flounder electivity for benthic prey at Station 10 for Cruises M5-M8 (see Table 3 corresponding dates). An * indicates no data.



*Insufficient sample size.

Figure 106. Yellowtail flounder electivity for benthic prey at Station 13 for Cruises M5-M8 (see Table 3 for corresponding dates). An * indicates no data.

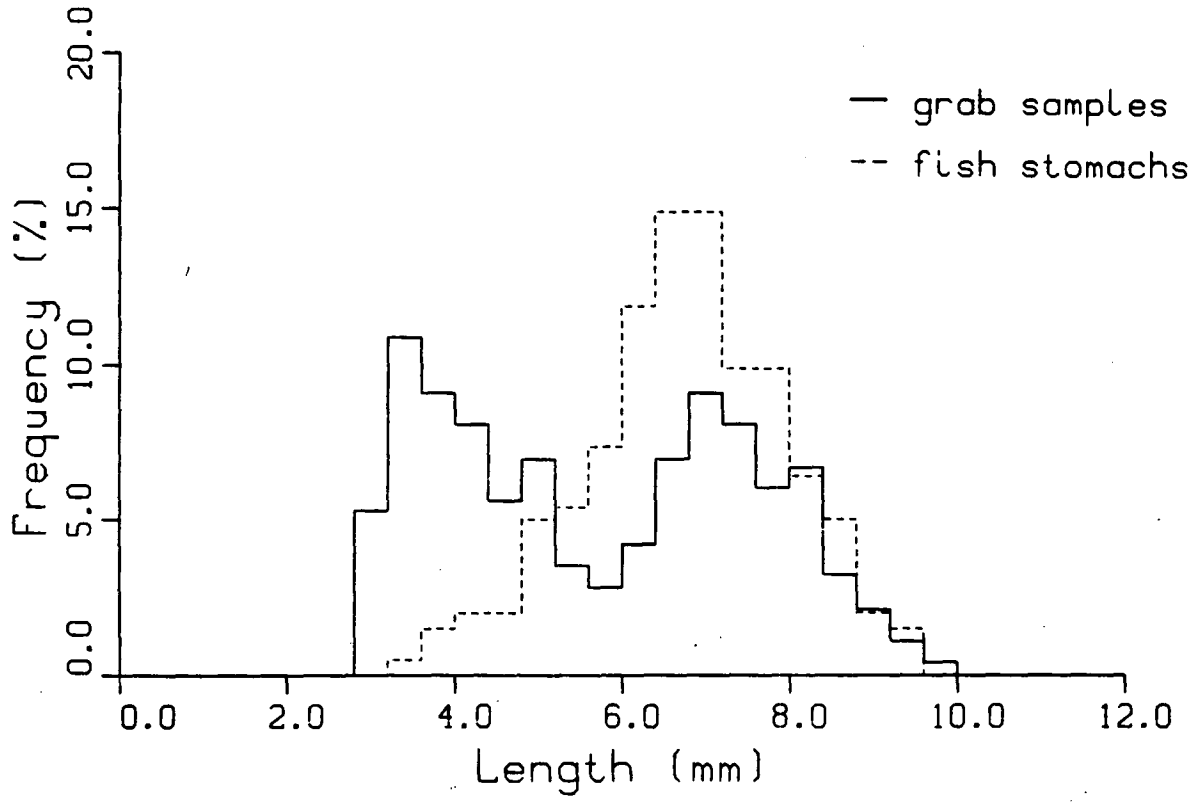


Figure 107. Ampelisca agassizi length-frequency distributions at Station 13 in May 1983. The benthic distribution is based on 285 amphipods measured from three grab samples. The ingested distribution is calculated from 214 amphipods measured from the stomachs of 10 yellowtail flounder 31-35 cm long.

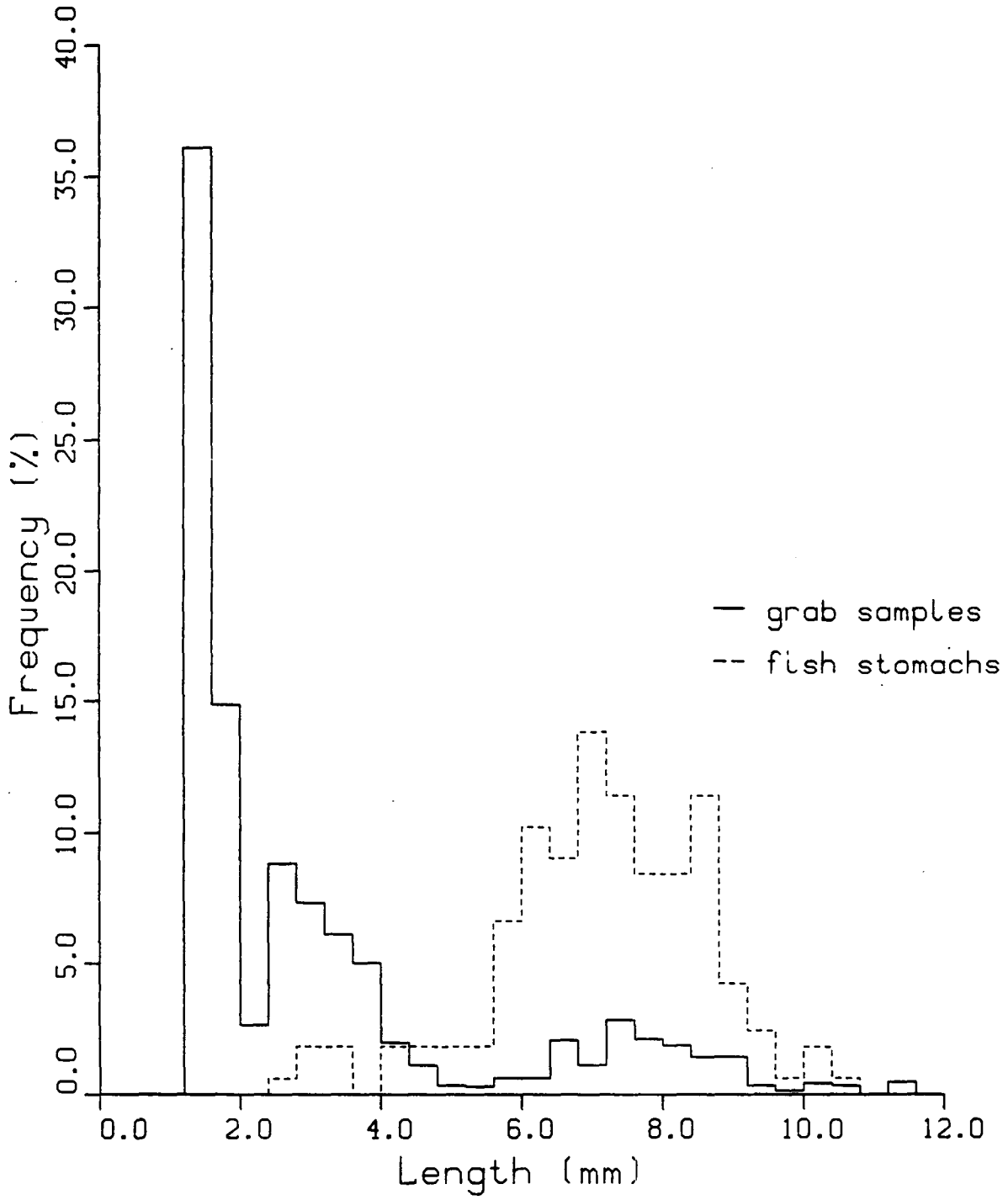


Figure 108. Unciola inermis **length-frequency distributions at Station 5 in May 1983. The benthic size distribution is a weighted mean of 215 amphipods from Station 5-1 and 220 amphipods from Station 5-28. The ingested distribution is based on 167 amphipods measured from the stomachs of 13 yellowtail flounder 30-35 cm long.**

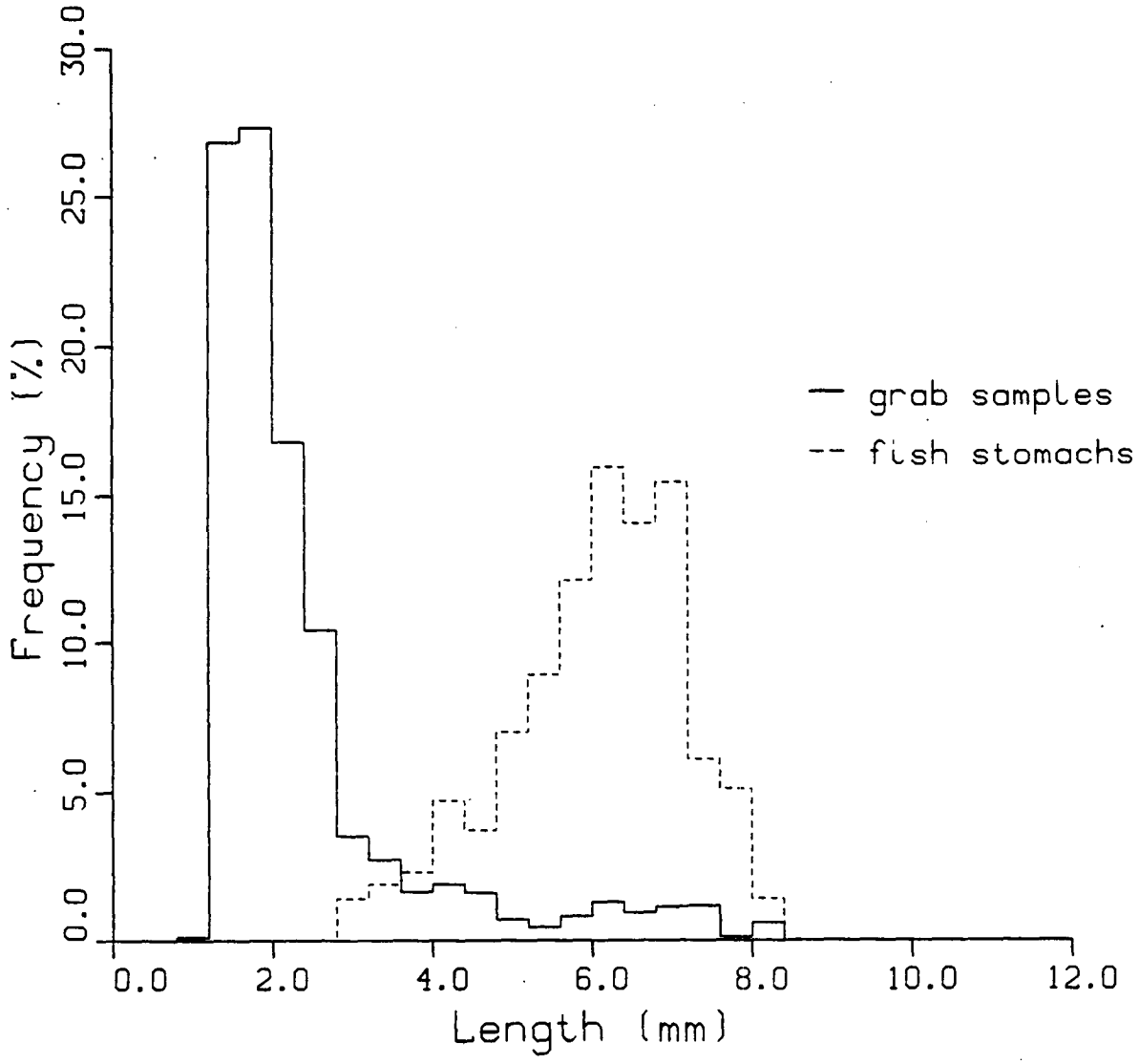


Figure 109. Erichthonius fasciatus **length-frequency distributions at Station 5 in May 1983. The benthic size distribution is a weighted mean of 157 amphipods from Station 5-1 and 203 amphipods from Station 5-28. The ingested distribution is based on 214 amphipods measured from the stomachs of 10 yellowtail flounder 31-35 cm long.**

The resultant length-frequency distributions are plotted in Figure 110. The benthic grab samples contained juveniles in the 0-2 mm size class and larger sand dollars between about 10-25 m long. Yellowtail flounder fed almost entirely on 6-12 mm sand dollars even though these sizes were rare in the benthos.

Chone infundibuliformis, in contrast to E. parma, was strongly selected by flounder despite its low abundance in the benthos at Station 13. Because of the low numbers in the grab samples, and since the size of ingested C. infundibuliformis did not appear to vary with season, the length-frequency data from four seasons (M5 - M8) were pooled and plotted in Figure 111. Making allowance for the difference in sample sizes, the fish stomach and grab-sample length-frequency distributions are very similar.

The best measure of size for Levinsenia gracilis was not length but setiger number as estimated using the regression equation in Table 14. Although L. gracilis was one of the most numerous species in the grab samples from Station 13, it was not found in flounder stomachs collected in July and November 1982. The size-frequency data from February and May 1983 were pooled and plotted in Figure 112. The benthic size-frequency data are skewed towards higher setiger numbers. Flounder fed on the same size range as occurred in the benthos, but the fish stomach size-frequency distribution is more normally distributed and therefore it appears that the fish selected smaller-sized worms.

Table 23 shows how the yellowtail flounder consumption rate was calculated. The flounder population size was divided by the area of Georges Bank to obtain mean yellowtail flounder density. The consumption-to-biomass ratio was multiplied by mean flounder density giving the consumption rate per unit area. This consumption rate must be considered an estimate since it is a mean for all of Georges Bank and because of uncertainty in the numbers used in the calculation.

In Table 24 the yellowtail flounder consumption rate is expressed as a percentage of the production of some of its principle prey species. The production estimates were taken from Table 20 and converted to grams wet weight using the composition data in Table 19. For Unciola inermis and Erichthonius fasciatus the mean of production at Stations 5-1 and 5-28 was used. The contribution of each prey species to the flounder diet at that station was calculated as a percentage of total prey collected in fish stomachs at that station. Finally the consumption rate from Table 23, multiplied by percent of the diet, was divided by the prey species production rate.

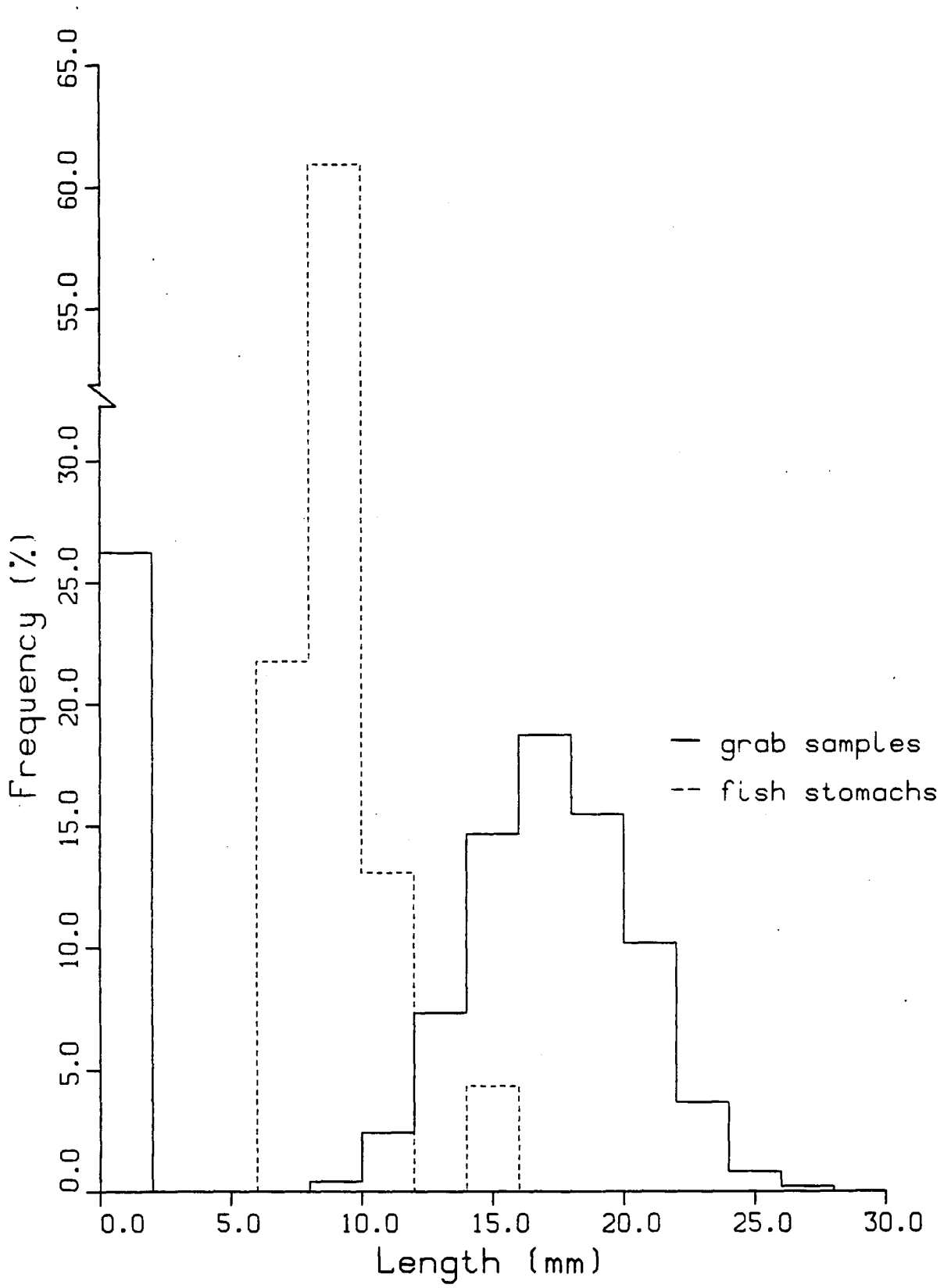


Figure 110. Echinarachnius parma **length-frequency distributions at Station 10 from July 1982 to May 1983. The benthic distribution is calculated from 492 sand dollars measured from Cruises M5 through M8. The ingested size distribution is based on 23 sand dollars found in the stomachs of yellowtail flounder.**

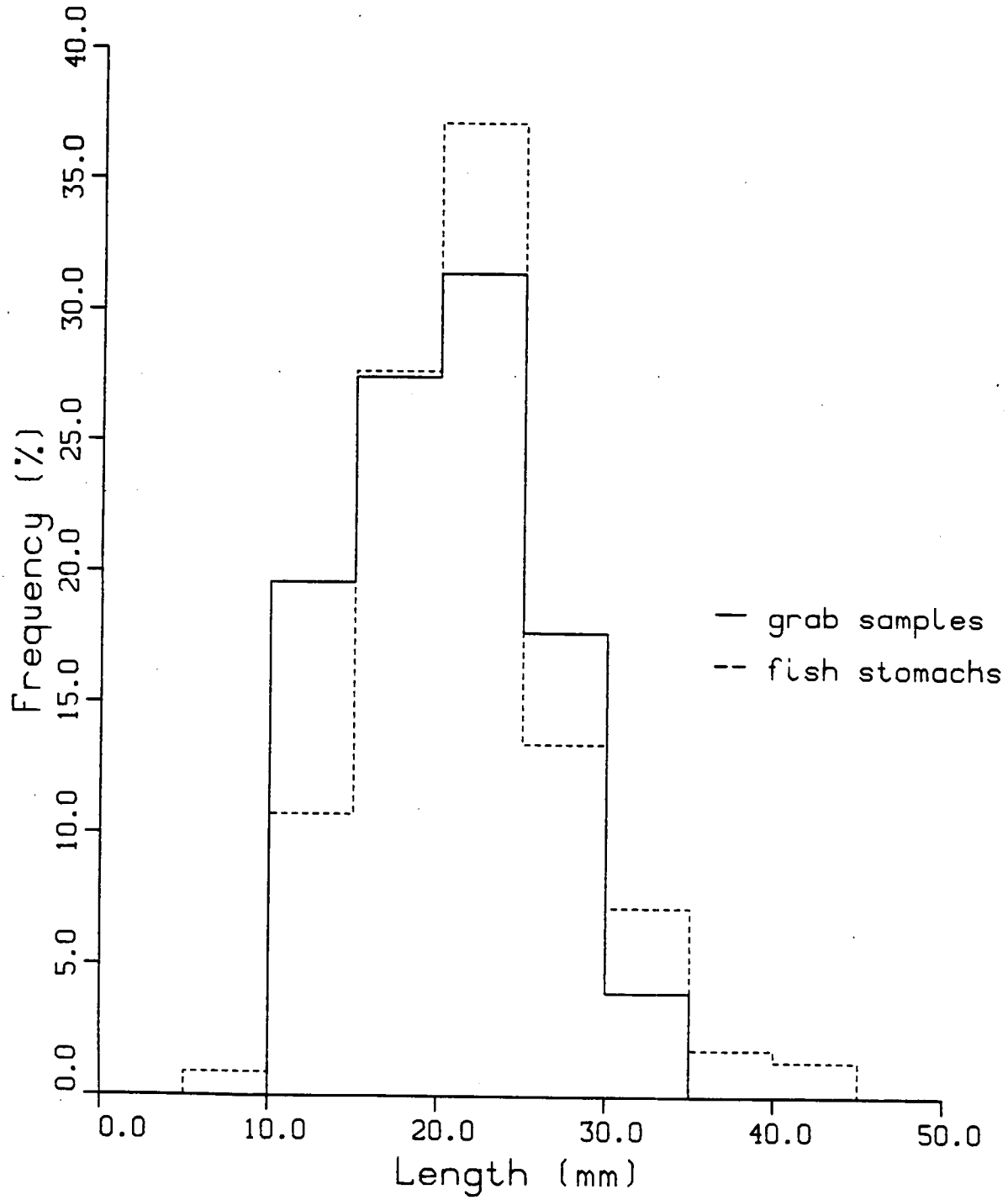


Figure 111. Chone infundibuliformis length-frequency distributions at Station 13 from July 1982 to May 1983. The benthic size distribution is based on 51 worms measured from Cruises M5 through M8. The ingested distribution is generated from 224 worms found in yellowtail flounder stomachs.

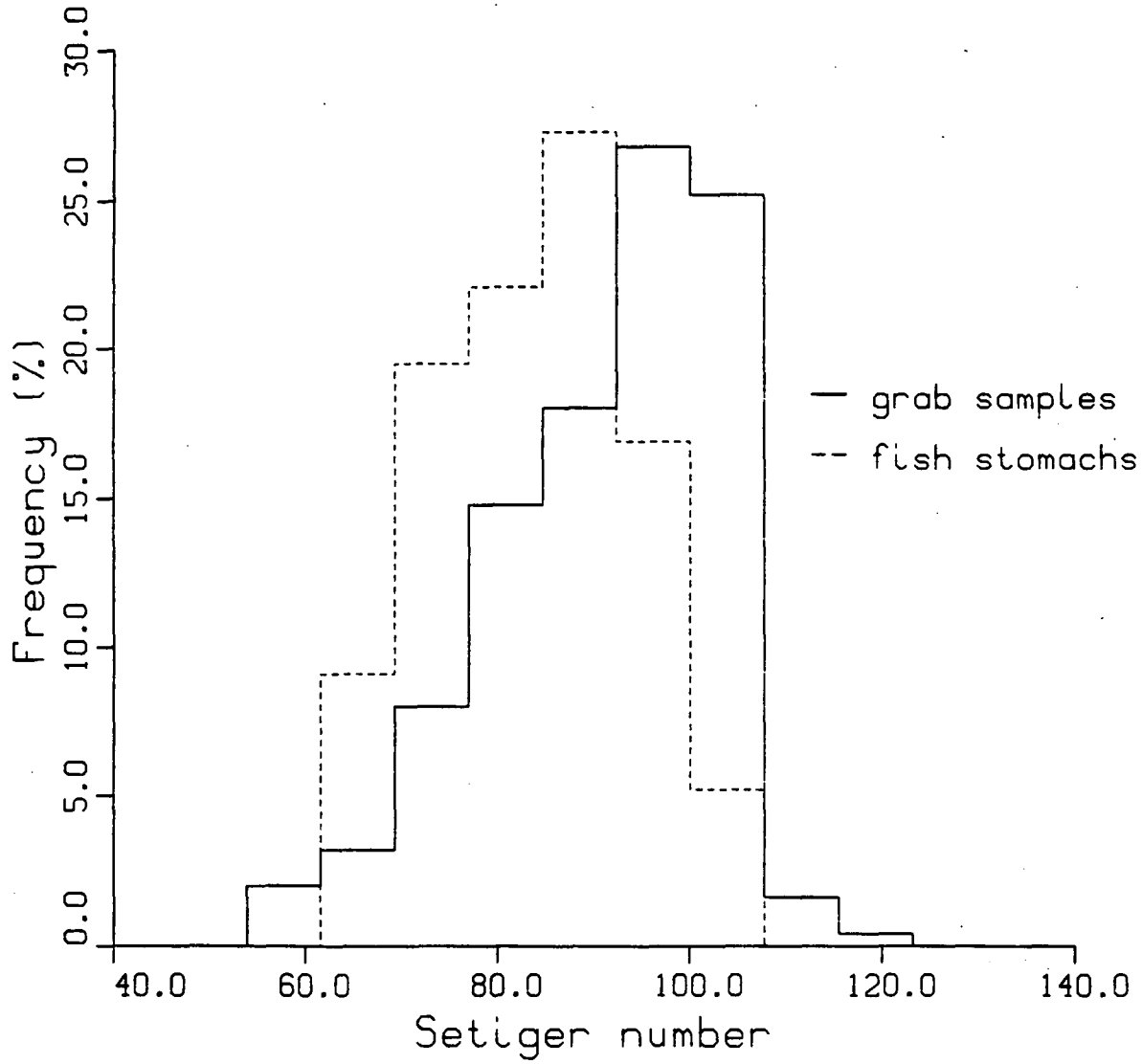


Figure 112. **Levinsenia gracilis size-frequency distributions at Station 13 from February to May 1983. The benthic distribution is based on 250 worms measured from Cruises M7 and M8. The ingested distribution comes from 77 worms eaten by yellowtail flounder.**

TABLE 23. YELLOWTAIL FLOUNDER CONSUMPTION RATE.

Georges Bank population size	$5x10^7$ fish (Collie and Sissenwine 1983)
Area of Georges Bank	$5.3x10^4$ km^2
Yellowtail flounder density	$1x10^{-3}$ 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	$1.4x10^3$ 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 24. 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

DISCUSSION

Life History and Production

The method of length-frequency analysis employed in this task of the monitoring program is critically dependent on the ability to distinguish cohorts and to follow them through time. The three amphipod species studied here lend themselves to this type of analysis because they are relatively short-lived and generations are separable.

Bimodal recruitment has been observed in the following amphipod species: Ampelisca abdita (Mills, 1967), A. tenuicornis (Sheader, 1977) and Corophium volutator (Moller and Rosenberg, 1982); these species are closely related to the three in this study. The most likely explanation for bimodal recruitment is that breeding is synchronous, some females breed twice and the second brood matures later, thus reinforcing the bimodal pattern.

The two years of Echinarachnius parma length-frequency data provide valuable information about this dominant echinoderm species, yet leave some aspects of its life history unanswered. Recruitment of juveniles into the large size groups was not observed during the duration of the study, and therefore it was not possible to age the large sand dollars.

The maximum age of Echinarachnius parma was found to be 21 years by Brykov (1975) in the Sea of Japan using growth ring analysis, a technique used often to age E. parma. Using this technique, Durham (1955) found 48-mm E. parma near Woods Hole to be seven years old, and Graef (1977) found the maximum-sized E. parma (53 mm) to be about six years old in the New York Bight apex area. Comparing the growth of E. parma with other sand dollar species, it took Encope grandis six years and Mellita grantii five years to reach 95 percent of their maximum sizes (Ebert and Dexter, 1975).

Growth rates calculated with Durham's data would be 6.8 mm per year, and that of Graef's would be 8.8 mm per year. Cocanour (1969) found the growth rate of 30-50 mm individuals to be 2.0 to 6.4 mm per year over a 24-30 month period in Maine. The maximum growth rate for Echinarachnius parma determined by the present study was 6.2 mm per year using the mean length of the large sand dollar cohort at the beginning (July 1981, M1) and end (July 1982, M5) of the first year of study for Station 4. Using the above growth rate, the age of the large sand dollars at the end of the study would be 2.8 years at Station 10, 5.8 years at Station 4, and 7.7 years at Station 1. Using the information from the authors cited, the large E. parma at Station 10 could range from 1.9 to 8.5 years old, those of Station 4 from 4.1 to 18.2 years old, and those of Station 1 from 5.4 to 24.0 years old.

The size at maturity for Echinarachnius parma off the coast of Delaware was found by Ruddell (1977) to be 27 mm. The individuals near Maine (Cocanour 1969) reached a length of 40 mm (3 years old) before becoming sexually mature. Several authors (Cocanour and Allen, 1967; Ruddell, 1977) noted fall spawning for E. parma. Fewkes (1886) found larvae in September in Rhode Island, and Maurer et al. (1976) found juveniles (less than 5 mm) in early November off Delaware. However, Costello et al. (1957) noted that new recruits may be available all year but peak in March.

In the present study, juveniles were found nearly every sampling time at each station (e.g. Figure 99), but were most abundant from February through July. The reason for their inability to survive and grow at the three stations from 1981 to 1983 is unknown. Perhaps they were transported to another area. Figure 100 shows the inverse relationship between the number of juveniles and the number of larger sand dollars; juveniles may not be successful if they settle in areas with large numbers of adults. The conditions needed for juvenile survival are not known but physical factors (temperature, current speed), predation, and the number of adults present may affect successful recruitment.

Quarterly sampling is probably adequate for annual species but is not optimal for shorter or longer-lived species. While more frequent sampling would increase the precision of the production estimates, it does not appear that any reproductive events were missed by quarterly sampling. For semi-annual species such as Erichthonius fasciatus, more frequent sampling could help explain events such as the disappearance and recolonization observed at Station 5-1 in 1982. For long-lived species, on the other hand, less frequent sampling over a longer period of time would be desirable. For Echinarachnius parma, twenty years of annual samples would be required to completely describe the life history and to estimate the production of a cohort over its lifespan.

Errors in estimating the number and mean length of animals in each cohort could result from migration, patchiness of species distribution, variation in sampling efficiency (e.g. due to sea state), or from operation of the computer program NORMSEP. Since it is not always possible to distinguish these potential sources of error, the most obvious inconsistencies are discussed.

The total number of Ampelisca agassizi decreased sharply in May 1982 and then increased in July 1982 even though there was no recruitment during this period. Of the four species considered here, A. agassizi is the least patchy and least mobile, suggesting that this is a sampling problem. In May 1982, when the performance of the grab was greatly reduced due to heavy seas, other species in the same grab samples also declined in abundance. One year later in May 1983, A. agassizi was more than five times more abundant at Station 13, implying that the decline seen in 1982 was not a seasonal phenomenon.

On the other hand, the virtual disappearance of Erichthonius fasciatus from Station 5-1 in February 1982 and from Station 5-28 in February 1983 does not seem to be a sampling problem because Unciola inermis persisted in the same grab samples. Reappearance of E. fasciatus at these stations in May was probably due to recolonization by adults from adjacent areas where this species remained abundant in February. In a population open to migration, production is lost to and gained from other areas. Therefore, production as estimated here does not apply to a closed population but instead applies to the area of sea bottom over which the samples were taken.

Inspection of Figure 102 reveals certain inconsistencies in the numbers and mean lengths of the large Echinarachnius parma. Mean size sometimes decreased between cruises and number sometimes increased even though no recruitment to the large cohorts occurred. Since E. parma presumably does not migrate and NORMSEP was not needed to separate cohorts, patchiness and/or sampling inefficiency are the most likely explanations for the numerical inconsistencies. The decreases in mean length could be due either to size-selective mortality or to sampling errors. Cocanour (1969) observed negative growth in winter. Where mean length decreased between cruises, the production estimate was negative. Such negative estimates were included in the summation of total production because a decrease in mean length is theoretically possible and because negative errors ought to be cancelled by positive errors.

Comparing the amphipod length-frequency distributions (Figures 95, 96, and 97) for the same months between years (e.g. July 1981 compared to July 1982 and July 1983), the positions of the modes are quite similar. This is true for all three species and it indicates a strong seasonal influence. On the other hand, numbers of individuals show considerable variation from one year to the next, suggesting that other factors, in addition to the seasonal cycle, affect the distribution and abundance of these amphipods.

Table 20 shows between-year and between-station differences in production, mean biomass, and P/B ratios. Between-year differences could be due to any combination of temperature, food supply, disturbance, and predation. Between-station differences presumably reflect more localized conditions such as current velocity and sediment composition. The difference in amphipod growth rates between Stations 5-1 and 5-28 is somewhat surprising given that these stations are only 6 km apart. The hydrodynamic regime is presumably similar at the two stations as is the sediment composition (Appendix J, Table J-2).

Echinarachnius parma is most abundant in areas of medium and fine sand (Harold and Telford 1982). Stations 1 and 10 are similar with respect to sediment composition; both sites are mostly medium and fine sand (Figure 133). Station 4 differs in that it has a

higher percent fine sand and higher percent organic carbon but it is not clear whether this difference is sufficient to account for the higher growth of E. parma at this location. In the Middle Atlantic Bight, Wigley and Theroux (1981) found the greatest density of echinoids in regions having about 0.5 percent organic carbon in the sediment.

Despite the qualifications mentioned above, these are the first production estimates for the four species studied here and the first direct production estimates for benthic macrofaunal species on Georges Bank. Collie (in press, Table 3) summarized production estimates for other marine amphipod species. Production of the three amphipod species on Georges Bank was within the range of production estimates for related near-shore species.

The production-to-biomass ratios calculated for Echinarachnius parma are comparable to those of other echinoid species. Buchanan and Warwick (1974) found that the heart urchin, Brissopsis lyrifera had a P/B ratio of 0.3, whereas Moore and Lopez (1966) estimated a value of 1.0 for another echinoid, Moira atropes. A P/B ratio of 0.3 means that in one year a population produces 30 percent of its mean biomass. In other words, it would take the population about three years to produce an amount of biomass equivalent to its standing stock. Robertson (1979) found a relationship between the lifespan of a species and its P/B ratio. The relatively low P/B ratio of E. parma is consistent with its long lifespan. However, the production estimates obtained here apply to only two years of sand dollar life and do not account for growth of juveniles. The mean production of E. parma, calculated over the entire lifespan of a cohort, could differ from the values reported here.

Steimle (in press) estimated macrofaunal production on Georges Bank using biomass data from two benthic surveys, and P/B ratios from other areas. It is difficult to compare the biomass data used by Steimle to the biomass data presented in Table 20 because the two benthic surveys differ from the monitoring program in the number and location of stations, season of sampling and type of sampler, as well as in the screen size and preservative used. Furthermore, the biomass data used by Steimle are grouped by major taxa, while the data in Table 20 pertain to individual species.

To estimate production, Steimle used a P/B ratio of 3.5 for Arthropoda and 1.0 for Echinodermata (most of which were Echinarachnius parma). In view of the P/B ratios given in Table 20, 3.5 is a high value for amphipods, except for the fast-growing Erichthonius fasciatus. Similarly, the value of 1.0 used for Echinodermata is higher than the P/B ratios calculated for E. parma. The use of high P/B ratios could result in benthic production being overestimated. Furthermore, the differences in P/B ratios observed between stations, even for the same species, emphasize the danger of using P/B ratios to estimate production.

Comparing the life-history strategies of the four species in Table 21, along with the consumption-rate estimates of Table 24, yields a consistent pattern. Ampelisca agassizi is mainly a deposit feeder on fine sediments in weak currents and its tube extends vertically into the substratum, providing a refuge from fish predation. Of the three amphipod species, A. agassizi has the slowest growth, lowest mortality, and is eaten less frequently by flounder. The low turnover rate and less patchy distribution could be related to the affinity of this species for finer sediments at greater depths where the sediments are presumably disturbed less frequently.

In contrast, Erichthonius fasciatus is an epifaunal tube builder, living in stronger currents, perhaps mainly as a filter feeder. It builds its sandy-mud tubes on rocks, shells and other solid objects (Bousfield, 1973, as E. rubricornis) and is thus more exposed to fish predation. E. fasciatus has the fastest growth, highest mortality, and is eaten more frequently by flounder. The high turnover rate and patchier distribution of this species may be related to its affinity for coarser sediments at shallower depths where sediment resuspension is presumably more frequent. Unciola inermis is also an epifaunal tube-builder in moderate currents but tubes are usually built into the substratum and are thus less exposed to predation. The life history traits of U. inermis are intermediate between those of A. agassizi and E. fasciatus. Echinarachnius parma is slow growing, long-lived, and very patchily distributed. It is eaten less often than the amphipod species by yellowtail flounder but is also preyed on by other fish species (e.g. Bowman and Michaels, 1984).

Fish Feeding and Prey Selection

Results of the fish stomach content analysis agree with published reports of yellowtail flounder food habits (Langton, 1983; Bowman and Michaels, 1984) in that arthropods and polychaetes were the major prey groups. The two studies cited above were based on flounder stomachs collected over wide geographical areas and the stomach contents reflect the diversity of benthic communities on which the fish fed. In this study, the fish were caught in relatively small areas in which the benthic community is relatively uniform. While the flounder diet varied among stations, at each station a few prey species constituted the bulk of the diet.

Yellowtail flounder feed mainly during the daylight hours (Langton, 1983), which implies they are visual predators. The main prey of yellowtail flounder are animals living on or near the sediment surface. Thus, the electivity indices shown in Figures 104, 105, and 106 can be explained on the basis of where the prey species live and how they feed.

The dominant prey species at Station 5, Erichthonius fasciatus, Unciola inermis and Unciola irrorata, are all tubicolous amphipods and were all positively selected (Figure 104). U. irrorata, although much less abundant than U. inermis in the benthos, was more strongly selected by the flounder. U. irrorata usually inhabits tubes constructed by other amphipods or polychaetes, but can build a tube of its own if no others are available (Bousfield, 1973). Smith (1950) observed these amphipods swimming or roaming across the bottom, leaving their tubes for considerable lengths of time. Perhaps U. irrorata is more strongly selected than U. inermis because it is more epifaunal in habit.

The caprellid, Aeginina longicornis, has been collected from sea grass, macroalgae, hydroids, and bryozoans (McCain, 1968). This epibenthic habit explains its positive electivity. The amphipod Stenopleustes inermis is also thought to live on hydroids since other species in this genus have been collected from hydroids (Lincoln, 1979) and alcyonarians (Sars, 1895). S. inermis is not as strongly selected as the other amphipod species, perhaps because of its smaller size (maximum of 6 mm).

The brittle star, Amphipholis squamata, burrows superficially in sandy substrata (Gosner, 1971) and may therefore avoid predation. The sabellids, Chone infundibuliformis and C. duneri, feed with tentacles above the surface (Fauchald and Jumars, 1979); this could explain their positive electivity. The remaining polychaete species are sub-surface burrowers, making them less vulnerable to predation.

At Station 10 (Figure 105) there was less overlap between fish diet and benthos. The main prey species were pelagic except for Aeginina longicornis and Pagurus spp. (juvenile) which were rare in the grab samples. The two most abundant amphipod species, Rhepoxynius hudsoni and Protohaustorius wigleyi, are both burrowers and both were approximately neutrally selected. The sand dollar, Echinarachnius parma, although it lives on the surface, was negatively selected. Polygordius sp. A, the dominant polychaete at Station 10, is a sub-surface burrower and may therefore not be vulnerable to predation.

Station 13 (Figure 106) had the greatest overlap between fish diet and macrobenthos. Pherusa cf. falcata is a surface, deposit-feeding polychaete (Fauchald and Jumars, 1979) and this probably explains its strong positive selection. Ampelisca agassizi, the dominant amphipod species, was also positively selected, except in February 1983. Ninoe nigripes, which feeds on the surface of the mud (Sanders et al., 1962), was approximately neutrally selected. The remaining, numerically dominant polychaetes are all sub-surface burrowers and were all negatively selected.

Figures 107, 108, and 109 show that predation on amphipods was size dependent. Electivity indices calculated for each amphipod size class (not shown) indicated that size selection was consistent among seasons and among prey species. In general, juveniles (less

than 4mm) were selected against, 4-5 mm amphipods were neutrally selected, and adults (greater than 5 mm) were positively selected. Several authors have noted that mature amphipods spend more time than juveniles swimming in the water column (e.g. Mills, 1967; Sheader, 1977). Positive selection for amphipods larger than 5 mm corresponds to the size at maturity for the three amphipod species studied here. Predation on adult amphipods could account for much of the mortality observed on these size classes.

Yellowtail flounder predation on Echinarachnius parma (Figure 110) was strongly size dependent. Sand dollars 6-12 mm long were strongly selected while juveniles and sand dollars larger than 12 mm were rejected. Presumably, there were no 2-6 mm sand dollars available in the benthos. Due to the relatively small mouth gape of yellowtail flounder, they are probably unable to feed on sand dollars larger than 16 mm. This observation could explain the negative electivity values obtained for E. parma in Figure 105. Flounder selected sand dollars within a narrow size range, but most of the sand dollars at Station 10 were either too big or too small. Predation on the intermediate sizes of E. parma by yellowtail flounder and other fish species could explain the absence of these sizes in the benthic grab samples and why the juveniles did not appear to survive and grow.

There was a very close correspondence between available and ingested sizes of Chone infundibuliformis (Figure 111), indicating that size-selective predation was not important for this species. Yellowtail flounder appeared to select the smaller sizes of the polychaete Levinsenia gracilis (Figure 112). This is surprising because L. gracilis is a very small species. Rather than being selected by the flounder, it would seem more probable that L. gracilis was eaten incidentally since it was very numerous at Station 13.

To compare meaningfully size selection among prey species, a common unit of measurement is necessary. If flounder are gape-limited, prey width determines what will fit through the mouth. Wet weight is important because it determines the amount of prey biomass eaten; ash-free dry weight is important because it determines the actual food value obtained. Selection against juvenile amphipods and sand dollars indicates that there is a minimum size of suitable prey. Since sand dollars are hard and approximately round, the width of the sand dollars must be able to pass through the flounder mouth. Therefore the largest sand dollar eaten (16 mm) is probably a good measure of the maximum gape size. Comparing size selection on the basis of prey weight is not possible because length-weight regressions for the worm species are not yet available.

The yellowtail flounder consumption rate, calculated in Table 23, is a first approximation based on published information. The predation rates calculated in Table 24 account for less than 10 percent of prey production, but they are not insignificant.

Yellowtail flounder is a major predator on amphipods but it is only one of many fish and invertebrate predators, such as crabs, that feed on benthic macrofauna. The total predation rates on these four prey species are probably considerably higher than the predation rates given in Table 24. Red hake (Urophycis chuss), little skate (Raja erinacea), and witch flounder (Glyptocephalus cynoglossus), stomachs of which were also collected, are all known to feed on the three species of amphipods (Bowman and Michaels, 1984). American plaice (Hippoglossoids platessoids) and ocean pout (Macrozoarces americanus) feed heavily on sand dollars.

Implications for Biological Monitoring

Results from the life history analyses aid in interpreting seasonal changes in species abundance. During the period of drilling at Block 312, the average number of individuals increased between November 1981 and July 1982 (Figure 4). Table 4 lists the dominant species at Station 5-1 which were primarily responsible for this increase. The summary of reproductive events (Figure 93) indicates that for many of these dominant species, recruitment occurred from May to July; thus the increase in average number of individuals may be accounted for by recruitment.

Life history analysis can similarly be used to explain variation in numbers of individual species. The observation that Unciola inermis is an annual species with some recruitment in May (Figure 20), explains the variation in U. inermis numbers in Figure 28. Peak abundance occurred each May and declined during the rest of the year due to mortality. Similarly, Ampelisca agassizi is a biennial species with recruitment occurring from November to February (Figure 19). This explains the variation in numbers shown in Figure 44. Average number of individuals increased during November 1981 - February 1982 (M2 - M3), and November 1982 - February 1983 (M6 - M7) and November 1983 (M10) due to recruitment and decreased during the rest of the year due to mortality.

Erichthonius fasciatus appears to be a semi-annual species with maximum recruitment during November and May (Figure 21). However, variation in density of E. fasciatus cannot easily be correlated with the timing of recruitment. Lack of correlation may be due to the patchy distribution of this species. In fact, E. fasciatus virtually disappeared from Station 5-1 in February 1982 and from Station 5-28 in February 1983. This disappearance and subsequent recolonization, which appears to be a natural phenomenon, would make it difficult to distinguish potential effects of oil drilling on this species.

Seasonal variation in the mean numbers of Echinarachnius parma is somewhat misleading. Juvenile sand dollars were present during all seasons (Figure 98), yet recruitment to the larger size groups appears to be periodic since it was not observed during the two years of study. During a three-year monitoring program, it would not be possible to distinguish whether lack of recruitment was due to natural causes or to the effects of oil drilling.

The observation that the amphipod P/B ratios varied less among years than did density, biomass, and production suggests that this ratio may have some use in biological monitoring. However, the wide-ranging values obtained for Echinarachnius parma suggest that the P/B ratio ought to be calculated over the entire lifespan of a cohort. The observation for Unciola inermis that the P/B ratio varied even between closely positioned stations means it would be difficult to choose a representative control station. A final drawback is that it is presently not possible to say whether two P/B ratios are statistically different.

The stomach contents analysis confirmed the importance of benthic macrofauna in the diet of yellowtail flounder. Comparing the food habits at Stations 5, 10 and 13 showed that the flounder diet is plastic and that pelagic prey may be eaten in the absence of suitable benthic prey. Electivity indices for many of the prey species did not differ much seasonally (Figures 104, 105, and 106) implying that flounder feeding changed in proportion to variation in benthic abundance. The numerically dominant amphipod species were also dominant prey species at Stations 5 and 13. Production of these amphipod species appears to be as high as production by related near-shore species. A significant proportion of this amphipod production may be consumed by yellowtail flounder and other demersal fish species.

ACKNOWLEDGEMENTS

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CHAPTER 8. ANALYSIS OF EPIFAUNA AND MICROTOPOGRAPHY FROM BOTTOM STILL PHOTOGRAPHS

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INTRODUCTION

Bottom still photographs were taken at regional and site-specific stations for the duration of the three-year program. Analyses of the photographs were performed in order to document the presence of epifauna and demersal fish not observed in infaunal grab samples, to record changes in microtopography, and to detect the possible accumulation of drilling muds and/or cuttings.

METHODS

Bottom still photographs were obtained by deploying an Edgerton Deep Sea Standard Camera (Benthos ®Model 372) and an Edgerton Deep Sea Standard Flash (Benthos®Model 382) instrumentation package. The camera and strobe were mounted on a steel frame which was raised and lowered by hydro-winch. A bottom switch coupled with an auto-advance triggered the camera.

Approximately 20 photographs were taken at each regional and primary site-specific station. Additional frames were exposed if operational difficulties were encountered. Test strips of film were developed on the ship to monitor camera function. The remaining film was developed at W.H.O.I. at the completion of each cruise.

Each frame represented approximately one square meter of area. All frames were analyzed for surficial characteristics as well as the presence and number of visible epifauna and demersal fish. Faunal identifications were made by examining voucher specimens collected from dredge and trawl samples and by consulting taxonomic specialists and the available literature. Faunal densities per square meter were calculated for each taxon in each frame and averaged for the station.

RESULTS

General

The stations for which useable film footage was obtained are shown in Table 25. Equipment malfunctions and severe weather affected the number as well as the quality of photographs obtained during particular cruises.

Due to failure of the bottom contact switch to operate, several regional stations were not photographed in November 1981 (M2). Loss of the camera, although it was later recovered and some stations re-occupied, also reduced the number of site-specific stations filmed in November 1981. Mechanical problems with the strobe and auto-advance in February 1982 resulted in many frames being poorly illuminated and several regional stations not being filmed at all. Rough seas as well as technical difficulties resulted in few stations being photographed in May 1982. Operational problems in July 1982 (M5) and November 1982 (M6) affected the number of stations at which useable film was obtained on those cruises. Severe weather in February 1983 (M7) resulted in only four regional and no site-specific stations being filmed. No useable film was obtained in May 1983 (M8) due to technical problems with the camera system. Successful photo surveys were made in July 1981 (M1) and July 1983 through June 1984 (M9-M12).

Biota

A total of 31 taxa was identified in the photographs from all twelve cruises, including 15 invertebrates and 16 fish. Densities per square meter for each taxon at each station are presented in Appendix H. In some instances, densities could not be calculated due to the abundance of the organisms. Echinarachnius parma, Arctica islandica, Asteroidea, and onuphid polychaetes are represented by a "+" in these cases.

At regional stations, the most commonly occurring organisms were asteroid echinoderms which were present at all but one station. Other frequently occurring taxa were Urophycis sp., Cancer sp., hydroid colonies, and sponges (Porifera). Echinarachnius parma had the greatest densities but appeared at relatively few sites, primarily Stations 1, 4 and 10. This species often occurred in dense patches, as seen in Figure 113.

Site-specific stations were dominated by asteroid echinoderms with individuals belonging to the genera Asterias and Leptasterias being the most common. These species were combined for analysis due to the difficulty in differentiating them in the

TABLE 25. STATIONS FROM WHICH USEABLE FILM FOOTAGE WAS OBTAINED ON GEORGES BANK MONITORING CRUISES.

Sampling Date	REGIONAL STATIONS																						
	1	2	3	4	6	7	7A	8	9	10	11	12	13	13A	14	14A	15	16	17	18			
Jul 1981	x	x		x	x	x	x			x	x	x	x	x	x				x		x	x	x	x
Nov 1981	x	x		x	x		x			x	x	x	x	x	x						x	x	x	x
Feb 1982	x					x	x			x					x							x	x	x
May 1982	x	x		x	x										x							x	x	x
Jul 1982		x		x	x	x			x	x	x	x	x	x								x	x	x
Nov 1982	x	x		x	x	x			x	x	x	x	x	x	x						x	x	x	x
Feb 1983	x	x		x												x								
May 1983																								
Jul 1983	x			x		x			x	x												x	x	x
Nov 1983		x		x	x				x	x	x	x	x									x	x	x
Feb 1984					x	x			x														x	
Jul 1984		x		x	x	x				x	x			x	x							x	x	x

Sampling Date	SITE-SPECIFIC STATIONS																					
	5-1	5-2	5-3	5-4	5-5	5-6	5-7	5-8	5-9	5-10	5-11	5-12	5-14	5-16	5-18	5-19	5-20	5-22	5-25	5-28	5-29	
Jul 1981	x	x					x	x	x	x	x			x	x	x	x	x	x	x	x	
Nov 1981														x	x				x		x	
Feb 1982	x	x		x	x	x		x	x	x	x	x	x	x	x		x	x	x	x	x	
May 1982																						
Jul 1982	x	x	x	x	x	x		x	x	x			x	x	x		x		x		x	
Nov 1982	x	x	x	x	x	x		x	x	x	x	x	x	x	x		x	x	x	x	x	
Feb 1983																						
May 1983																						
Jul 1983	x							x					x	x				x	x	x	x	
Nov 1983	x	x				x		x	x	x	x	x	x	x	x		x	x	x	x	x	
Feb 1984	x	x				x		x	x	x	x	x	x	x	x		x	x	x	x	x	
Jun 1984	x	x	x	x	x	x		x	x	x	x	x	x	x	x		x	x	x	x	x	

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FIGURE 113. REGIONAL STATION 1
A. NOVEMBER 1981 (M2)
B. FEBRUARY 1982 (M3)

photographs. Also frequently occurring at site-specific stations were hydroid colonies, the scallop Placopecten magellanicus, Cancer sp. and Raja sp. A summary of biota by station is presented in Table 26.

Microtopography

As reported for the previous two years, regional stations at similar depths exhibited similar patterns of microtopography and sediment type (Battelle and W.H.O.I., 1983, 1984). Stations 1, 4, and 10 were all at approximately 60 m. The sediment type was a clean, well-sorted sand containing small amounts of shell hash. Little or no detritus or biological material was present. The surface was asymmetrically rippled with some sculpturing. Trails made by motile organisms were also visible (Figure 113).

Stations 2 and 11 were located at 70 to 80 m. They were similar to Stations 1, 4, and 10 except for the presence of greater amounts of detritus and shell fragments. Rippling and sculpturing of the surface were both present during most seasons. At Station 2, the greatest differences during 1982 were observed between July (M5) and November (M6). The July photographs showed regular, asymmetrical ripples and the November photographs showed an irregularly sculptured surface interrupted with deeper troughs. In 1983, there was no useable film from July (M9). The November (M10) frames showed a smooth bottom covered with a large amount of biological material, rather than the higher degree of rippling as seen the previous November. The November 1983 (M10) photographs from Station 2 indicated a bottom that appeared more similar to that seen at Station 5 during the summer months than to the typical rippled surface usually seen at this station. In June 1984 (M12) the photographs showed a sandy, rippled bottom.

Stations 3, 6, and 12 were at approximately 100 m. The sediment was a silty sand containing many large shell fragments of the ocean quahog, Arctica islandica. A uniform layer of silt and fine detritus covered most of the shell fragments. The bottom was smooth and flat with some disturbed areas and animal burrows visible (Figures 114 and 115). Station 7A was similar to Stations 3, 6, and 12 except for the reduced amounts of shell fragments.

Stations 8 and 9 were at 145 m depth. The sediment was a silty sand with small amounts of biological material and shell hash present. The surface was sculptured or smooth with biogenic features apparent. Station 9 appeared more variable than Station 8. Photographs from July 1981 (M1) showed evidence of a smooth bottom, while the remaining cruises for which we have good photographs indicated various degrees of

TABLE 26. SUMMARY OF RESULTS OF BOTTOM PHOTOGRAPH ANALYSIS FROM TWELVE SEASONAL SAMPLES.

Stations	Biota	Microtopography
1	Dominated by Echinarachnius parma. Also present were gastropods, Cancer sp., Pagurus sp., Myxocephalus sp., and Urophycis sp.	Sandy with small amounts of shell hash; no detritus. Ripples frequent and assymetrical.
2	Dominated by Echinarachnius parma and colonial hydroids. Porifera, Placopecten magellanicus, gastropods, and asteroids also common.	Sandy with some detritus and shell hash. Rippling and sculpturing present.
3	Asteroids dominant; also common were Porifera, Placopecten magellanicus and Urophycis sp.	Silty-sand with uniform detritus coverage. Many shell fragments present. Bottom flat with few disturbed areas.
4	Dominated by Echinarachnius parma; colonial hydroids common. Porifera, gastropods, Cancer sp., Pagurus sp., asteroids, Raja sp., and Urophycis sp. also present.	Sandy with some large shell fragments; no detritus. Rippling and sculpturing present.
5	Dominated by asteroids, especially Asterias/ Leptasterias spp. Hydroid colonies also common.	Silty-sand with uniform detritus coverage. Many shell fragments present. Bottom smooth.
6	Asteroids occurred most frequently. Also common were Raja sp., Urophycis sp., and flounder.	Silty-sand with shell fragments and detritus present. Bottom smooth with slight rippling.
7	Porifera, gastropods, asteroids, Ophichthus cruentifer Urophycis sp., and flounder present.	Sandy with some detritus. Bottom smooth with biogenic features.
7A	Colonial hydroids, Cancer sp., Asterias/ Leptasterias spp., Macrozoarces americanus, Ophichthus cruentifer, Urophycis sp., and flounder present.	Sandy with some detritus and shell fragments. Bottom smooth with slight rippling. Biogenic features present.
8	Onuphid polychaetes common. Also present were asteroids, anthozoans, Ulex illecebrosus, Ophichthus cruentifer, flounder and sculpin.	Silty-sand with small amounts of detritus and shell hash. Bottom smooth with biogenic features.
9	Anthozoans, Cancer sp., asteroids and Urophycis sp. present.	Silty-sand with shell fragments and detritus. Ripples present as well as biogenic features.
10	Dominated by Echinarachnius parma. Asterias/ Leptasterias spp. and colonial hydroids also common.	Sandy with some shell hash, little detritus. Ripples present.

TABLE 26. (Continued).

Stations	Biota	Microtopography
11	Dominated by asteroids. Also present were colonial hydroids, Porifera, gastropods, Arctica islandica, Cancer sp., Pagurus sp., Echinarachnius parma, Ophichthus cruentifer and flounder.	Sandy with shell fragments; little or no detritus. Ripples present.
12	Dominated by asteroids. Porifera also common.	Silty-sand with detritus and shell fragments. Bottom flat with biogenic features.
13	Asteroids and colonial hydroids present.	Sandy with shell fragments and detritus. Shallow ripples present.
13A	No useable film available.	
14	Asteroids present.	Sandy with little shell hash or detritus. Bottom sculptured.
14A	No useable film available.	
15	Porifera, asteroids, and Raja sp. present.	Sandy with little shell hash or detritus. Bottom sculptured.
16	Dominated by asteroids and onuphid polychaetes.	Silty-sand with uniform detritus coverage. Shell hash present. Bottom smooth and undisturbed.
17	Dominated by asteroids and onuphid polychaetes Urophycis sp. and Ophichthus cruentifer also common.	Silty-sand with detritus and shell hash. Bottom flat with biogenic features present.
18	Asteroids occurred most frequently. Also present were hydroid colonies, Cancer sp., Macrozoarces americanus, Urophycis sp., and flounder.	Silty-sand with shell hash and detritus present. Bottom flat with biogenic features.

PAGE 236
FIGURE 114. REGIONAL STATION 3
A. MAY 1984 (M12)
B. JULY 1982 (M5)

PAGE 237
FIGURE 115. REGIONAL STATION 3
A. NOVEMBER 1983 (M10)
B. FEBRUARY 1983 (M7)

rippling in both summer (July 1982, M5; June 1984, M12) and autumn (November 1981, M2; November 1982, M6; November 1983, M10) months. The photographs taken in November 1983 show some variation within the station with some areas appearing smooth and others slightly rippled.

Stations 16, 17, and 18 were located in close proximity to one another and 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 biogenic features (Figures 116-120).

Site-specific stations were located around the drill site (Station 5-1) in Block 312 at an average depth of about 80 m. With the exception of Station 5-29, all had similar microtopographical features. The sediment appeared to be sand covered by a fairly uniform layer of coarse detritus and/or biological material. Scattered shell fragments were also present. The topography was flat with many biogenic features (Figures 121-124). Station 5-29 was similar to Regional Stations 3, 6, and 12.

Consistent seasonal changes were evident at nearly all site-specific stations. Smooth, unsculptured surfaces with fairly uniform detritus coverage were representative of spring and summer (Figures 121-124). Photographs taken during fall and winter revealed rippling and sculpturing of the bottom and clumped, patchy detritus coverage (Figures 121-124). Station 5-29 was the only site-specific station not to show seasonal variation, although Station 5-25 showed only slight variation between seasons.

No accumulation of drilling muds and/or cuttings was detected at either regional or site-specific stations. A summary of microtopography by station is presented in Table 26.

DISCUSSION

Analysis of bottom still photographs revealed depth-related and seasonal patterns of microtopography that formed as a result of the presence and strength of water currents. In addition, film analysis indicated the presence of specific faunal assemblages as a function of sediment type.

Photographs of the 60 m stations (1, 4, and 10) revealed a high energy environment characterized by well-sorted sandy sediment containing little detritus or biological

PAGE 239
FIGURE 116. REGIONAL STATION 16
A. JULY 1981 (M1)
B. NOVEMBER 1981 (M2)

PAGE 240
FIGURE 117. REGIONAL STATION 16
A. FEBRUARY 1982 (M3)
B. JULY 1982 (M5)

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FIGURE 118. REGIONAL STATION 16 A. AND B. MAY 1982 (M4)

PAGE 242

FIGURE 119. REGIONAL STATION 16

A. NOVEMBER 1982 (M6)

B. NOVEMBER 1983 (M10)

PAGE 243
FIGURE 120. REGIONAL STATION 16
A. JULY 1983 (M9)
B. MAY 1984 (M12)

PAGE 244
FIGURE 121. SITE-SPECIFIC
STATION 5-1
A. JULY 1981 (M1)
B. FEBRUARY 1982 (M3)

PAGE 245
FIGURE 122. SITE-SPECIFIC
STATION 5-1
A. JULY 1982 (M5)
B. NOVEMBER 1982 (M6)

PAGE 246
FIGURE 123. SITE-SPECIFIC
STATION 5-1
A. JULY 1983 (M9)
B. NOVEMBER 1983 (M10)

PAGE 247
FIGURE 124. SITE-SPECIFIC
STATION 5-1
A. FEBRUARU 1984 (M11)
B. MAY 1984 (M12)

material. The presence of well-defined ripples and sculpturing throughout the year indicated strong wave action and tidal currents not affected by seasonality. Epifaunal diversity was relatively low at these shallow water stations. The sand dollar, Echinarachnius parma, was present in the greatest numbers, often appearing in dense masses. The patchiness of distribution of this species, as indicated by the results of the infaunal grab analyses, was confirmed by the photographs (Figure 113). Other common taxa at these stations were gastropods, hydroid colonies, the crabs Cancer sp. and Pagurus sp., and asteroid echinoderms. These results agree with Wigley's (1968) description of the sand fauna he found inhabiting the shallow waters of the New England fishing banks. The results also agree with those reported by Wigley and Theroux (1970) of a photographic survey on the continental shelf off Massachusetts. The Georges Bank stations located at 64, 66, and 82 m in Wigley's survey had microtopography and fauna similar to that seen at our Regional Stations 1, 4, and 10.

Regional Stations 2 and 11 and all of the site-specific stations centered around Station 5 were located between 70 and 80 m. Topographically, Stations 2 and 11 appeared to be more similar to Stations 1, 4, and 10 than to Station 5. The sediment was sandy with small amounts of shell hash present. Ripples and sculpturing indicated strong wave action, and there was no evidence of seasonality. At the site-specific stations, smooth, flat topography covered by a uniform layer of biological material was generally indicative of spring and summer while patchy detritus distribution and surficial sculpturing were characteristic of the fall and winter. Stations 2 and 11 were also more similar to one another in terms of epifaunal species composition than to the site-specific stations. Echinarachnius parma was the dominant organism, but appeared in fewer numbers than at Stations 1, 4, and 10. Hydroid colonies, asteroid echinoderms, and the scallop Placopecten magellanicus were also common. Site-specific stations were dominated by asteroid echinoderms and no E. parma were present.

Photographs from Stations 3, 6, and 12 (100 m) indicated a low energy environment which showed little seasonality. The sediment was a silty sand containing many large shell fragments. The topography was smooth and flat except for many disturbed areas which appeared to be the result of the numerous demersal fish species present at these stations.

Stations 8 and 9 (145 m) appeared to be low energy environments characterized by smooth, flat topography and silty-sand sediment. Some photographs revealed ripples and sculpturing, but no seasonal pattern emerged. Both stations had relatively low faunal

densities. Station 8 was dominated by onuphid polychaetes and asteroid echinoderms; Station 9 by Cancer sp., Urophycis sp., and asteroid echinoderms. Both stations had many biogenic features present, including tubes, trails, and depressions. The Block 410 stations (16, 17, and 18) also at 140-145 m showed consistent seasonal patterns. Seasonal topographical patterns were previously reported for nearly all regional stations, especially Block 410 (Stations 16, 17, and 18) and Station 2. Although there were inherent variations within stations (Figure 118), smooth flat topography was generally indicative of spring and summer while rippled and sculptured surfaces were characteristic of fall and winter. Less seasonal variability was evident during the third year, mainly because of the lack of useable film from winter cruises (February 1983, M7 and February 1984, M11). Despite this problem, indications of seasonality were evident in the available fall and winter photographs from Block 410 stations. The dominant taxa were asteroid echinoderms, and numerous species of fish were also present. The deeper regional stations which were characterized by flat, smooth, silty topography and by fauna dominated by asteroid echinoderms resembled the silty sand fauna reported by Wigley (1968). However, some species reported during his multi-instrument survey, such as the northern starfish as well as many burrowing or tube-dwelling organisms, were not seen in our photographic analysis.

ACKNOWLEDGEMENTS

Special thanks to John Porteous (W.H.O.I.) for developing and printing the film and to Sandy Freitas, Phillip Nimeskern, and Chris Werme for their assistance in species identifications.

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CHAPTER 9. ANALYSIS OF CARBON, HYDROGEN, AND NITROGEN IN SEDIMENTS

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INTRODUCTION

Sediment concentrations of carbon and nitrogen are important to the understanding of sediment dynamics and may be related to the food supply for benthic animals that filter particles from the water or ingest sediment. Organic matter in sediments originates from both terrestrial and oceanic sources and may precipitate directly out of the water column as organic detritus or as dissolved matter adsorbed to suspended mineral particles. The distribution of organic matter in sediments is influenced by sources in the water column and sediment transport processes.

Measurement of carbon, hydrogen and nitrogen (CHN) was a component of the Georges Bank Monitoring Program beginning with Cruise M2 in November 1981 and continuing through Cruise M12 in June 1984. Modifications in sample handling procedures during Years 2 and 3 have precluded direct comparison of these data to data from Year 1 and results are discussed separately.

METHODS

Field Collection

Samples for CHN analysis were taken as a subsample from each replicate 0.04-m^2 biology grab. A 15-cm^3 core was removed from an undisturbed area of the surface of the grab sample using a syringe and stainless steel spoon. Each subsample was placed in a pre-labelled Whirlpak®and frozen on board ship. All samples were stored frozen until ready for analysis.

Laboratory Analysis

The procedure for the preparation of CHN samples prior to analysis was revised at the end of Year 1. During Year 1, no attempt was made to remove inorganic carbon

primarily in the form of $CaCO_3$, shells, and other skeletal elements from the samples. Concern over the usefulness of the total carbon values being measured led to modification of the preparation procedure for Years 2 and 3. Due to this change in methodology, Year 1 data (organic plus inorganic carbon) are not directly comparable to Year 2 and Year 3 data (organic carbon only). Selected replicates of Year 1 samples were reanalyzed by USGS in Reston, Virginia. Total carbon concentrations were remeasured and partitioned into their organic and inorganic components providing an indication of the percent contribution of inorganic carbon at those stations reanalyzed as well as a quality control check on the total carbon values as determined by W.H.O.I.

Year 1 sediment samples frozen for CHN analysis were thawed at room temperature and any large animals were removed. The sediment was subsequently dried in an aluminum tare dish at 60°C for 12 hr and the dried sediment was then ground into a fine homogeneous powder. An aliquot of this ground sample was placed in a properly labelled, clean, dry 1-dram vial. Remaining portions of all Year 1 samples were archived at Battelle.

Year 2 and Year 3 CHN samples were thawed at room temperature, homogenized, and approximately 5 g from each replicate set aside for analysis. Any large animals were removed or avoided during the subsampling. The remaining portion of each replicate was refrozen and archived at Battelle. Each sample was dried at 70°C for 24 hr and subsequently ground by mortar and pestal to a fine homogeneous powder. All glassware used was fired at 550°C for 24 hr to remove traces of organic carbon. Carbonates were eliminated with the addition of 5 ml of 6 percent sulfurous acid (Gibbs, 1977). Due to the relatively low $CaCO_3$ content of most Georges Bank samples, effervescence caused by the evolution of CO_2 was minimal and the visual end point of the reaction (i.e., discontinued effervescence) could not always be observed. Optimal acid exposure time for complete dissolution of carbonates and retention of organic carbon was determined by exposing 10 replicate samples to the acid for periods ranging from 0 - 36 hr. Sediment used for this test was taken from archived portions of samples collected at Station 16 in May 1982 (M4). The results of this test (Table 27) indicated no relationship between measured percent carbon and length of acid treatment. Therefore, if effervescence was not observed, the sample was exposed to acid for a minimal period of time, usually less than 30 minutes. Following acid treatment, each sample was washed to eliminate acid salts using a Millipore® apparatus fitted with a glass fiber filter. Organic carbon-free water used in the washing process was prepared by filtering tap water through a particle filter, seven in-line deionizing and water softening filters, and into a Milli-Q Reagent Grade

TABLE 27. EFFECTS OF EXPOSURE TO SULFUROUS ACID ON SEDIMENT ORGANIC CONCENTRATIONS.

Replicate Number	Time (Hrs) Exposed to Acid Treatment	%C	%H	%N
1	0*	0.05	0.01	0.00
2	4	0.03	0.01	0.00
3	8	0.05	0.01	0.00
4	12	0.04	0.01	0.00
5	16	0.02	0.01	0.00
6	20	0.05	0.02	0.00
7	24	0.04	0.01	0.00
8	28	0.05	0.01	0.00
9	32	0.04	0.01	0.00
10	36	0.05	0.02	0.00

*Indicates that the sample was swirled briefly in acid and immediately washed.

water system. This system consisted of a Super-C carbon filter, two ion exchange cartridges, and an Organex-Q filter, which produced water with a resistivity of 18 megohm-cm^{-1}. Washed samples were subsequently redried at 70°C for 24 hr.

All samples were sent to W.H.O.I. for analysis. A Perkin-Elmer Model 240 Elemental Analyzer®, which determines the carbon, hydrogen and nitrogen content of organic compounds by analyzing their combustion products, CO_2, H_2O, and N_2, was used. Combustion occurs in pure oxygen under static conditions at 1000°C. Helium is used as the carrier gas. Combustion products are then analyzed automatically in a self-integrating, steady state, thermal conductivity analyzer. An on-line computer provides immediate conversion of the digital display into weight percentages of carbon, hydrogen, and nitrogen present in the sample.

Analytical precision and accuracy were verified by several methods. Replicate carbon-containing reference samples prepared by the National Bureau of Standards (NBS) were sent by Battelle for analysis at W.H.O.I. Fifteen Georges Bank samples previously analyzed at W.H.O.I. were reanalyzed by USGS in Reston, Virginia. To assure that analyses were quantitative, test blanks and replicates of labelled samples were analyzed daily at W.H.O.I. and test standards were run routinely.

Data Analysis

Mean percentages of carbon, hydrogen, and nitrogen were calculated for each station and each sampling period. Total organic carbon (TOC) data were compared to sediment grain-size data by Pearson product-moment correlation coefficients (Sokal and Rohlf, 1969) calculated using the PEARSON CORR of the SPSS-X statistical package. Correlation coefficients were calculated for all variables, all stations combined, and for all variables, each station separate.

RESULTS

Verification of Analytical Precision and Accuracy

Data from five replicate samples of NBS Reference Material analyzed by W.H.O.I. were compared for accuracy using a two-tailed Student's t-test. No significant differences were noted between NBS TOC values and W.H.O.I. measurements.

Fifteen Year 1 samples previously analyzed at W.H.O.I. were verified by the USGS laboratory in Reston, Virginia. No significant differences between total carbon values as measured by the two laboratories were reported (Table 28).

Inorganic Carbon Measurements

Data on samples reanalyzed by USGS showed that inorganic carbon contributed from 4.2 to 84 percent of the total carbon measured (Table 28). Of those samples chosen for reanalysis, percent carbonate was lowest at Stations 13 and 13A (4.2-4.5 and 4.5 percent, respectively), and highest at Station 7 (53 - 84 percent) and Station 3 (24-84 percent). Stations 8, 9, and 12 were also relatively high in inorganic carbon at 62, 52, and 70 percent respectively.

CHN Analyses

The raw data developed as a result of CHN analyses of samples from regional and primary site-specific stations for Years 1-3, sampling Cruises M2 (November 1981) through M12 (June 1984), are given in Appendix I. No CHN samples were taken in July 1981 on Cruise M1. As a result of the acid leaching procedure used on all samples from Years 2 and 3, the carbon data presented for Cruises M5 (July 1982) through M12 (June 1984) are total organic carbon values rather than the total carbon (organic plus inorganic) values presented for Year 1. Although acid leaching can result in systematically low carbon values due to loss of acid-soluble organic carbon during carbonate dissolution (Heath et al, 1977; Roberts et al, 1973), the fraction of organic carbon soluble in acid is dependent on the percent $CaCO_3$, and in samples containing less than 10 percent $CaCO_3$, the ratio of percent soluble organic carbon to percent organic carbon is less than 0.1 (Froelich, 1980). Because Georges Bank sediments are far less than 10 percent $CaCO_3$ (total carbon measurements during Year 1 were 1-2 orders of magnitude less than this), no compensation for soluble organic carbon was made in acid treated samples.

Year 1 Data. Data for November 1981 (M2) through May 1982 (M4) represent total carbon (organic plus inorganic) measurements. Mean percent carbon is given on a station by station, cruise by cruise basis in Figures 125 through 130.

Highest percent carbon was recorded at Station 13 ($\bar{x} = 1.10 \pm 0.03$), where inorganic carbon was determined by USGS to account for 4.2-4.5 percent of the total carbon measurement. Recorded carbon was consistently high at this station during Year 1.

TABLE 28. RESULTS OF USGS ANALYSIS OF SEDIMENT SAMPLES FOR ORGANIC, INORGANIC, AND TOTAL CARBON.[1]

Sample			WHOI	USGS			Percent
Cruise	Sta.	Rep.	Total Carbon	Total Carbon	Organic Carbon	Carbonate Carbon	Carbonate Carbon/TC
2	1	4	0.05	0.05	0.04	0.01	20
2	4	5	0.10	0.11	0.11	<0.01	<9
2	6	3	0.32	0.36	0.24	0.12	33
2	8	3	0.42	0.43	0.16	0.27	63
2	9	2	0.21	0.25	0.12	0.13	52
2	12	4	0.58	0.86	0.26	0.60	70
2	15	4	0.04	0.03	0.02	0.01	33
3	13	6	1.01	1.10	1.05	0.05	4
4	3	1	2.20	2.50	0.40	2.10	84
4	3	6	0.73	0.75	0.57	0.18	24
4	7	4	2.50	2.50	0.40	2.10	84
4	7	5	0.55	0.56	0.26	0.30	54
4	13A	1	2.20	2.20	2.10	0.10	4
4	13	6	0.91	0.95	0.91	0.04	4
4	5-21	4	0.05	0.07	0.06	0.01	14

[1]Data are reported as percentages of sample weight.

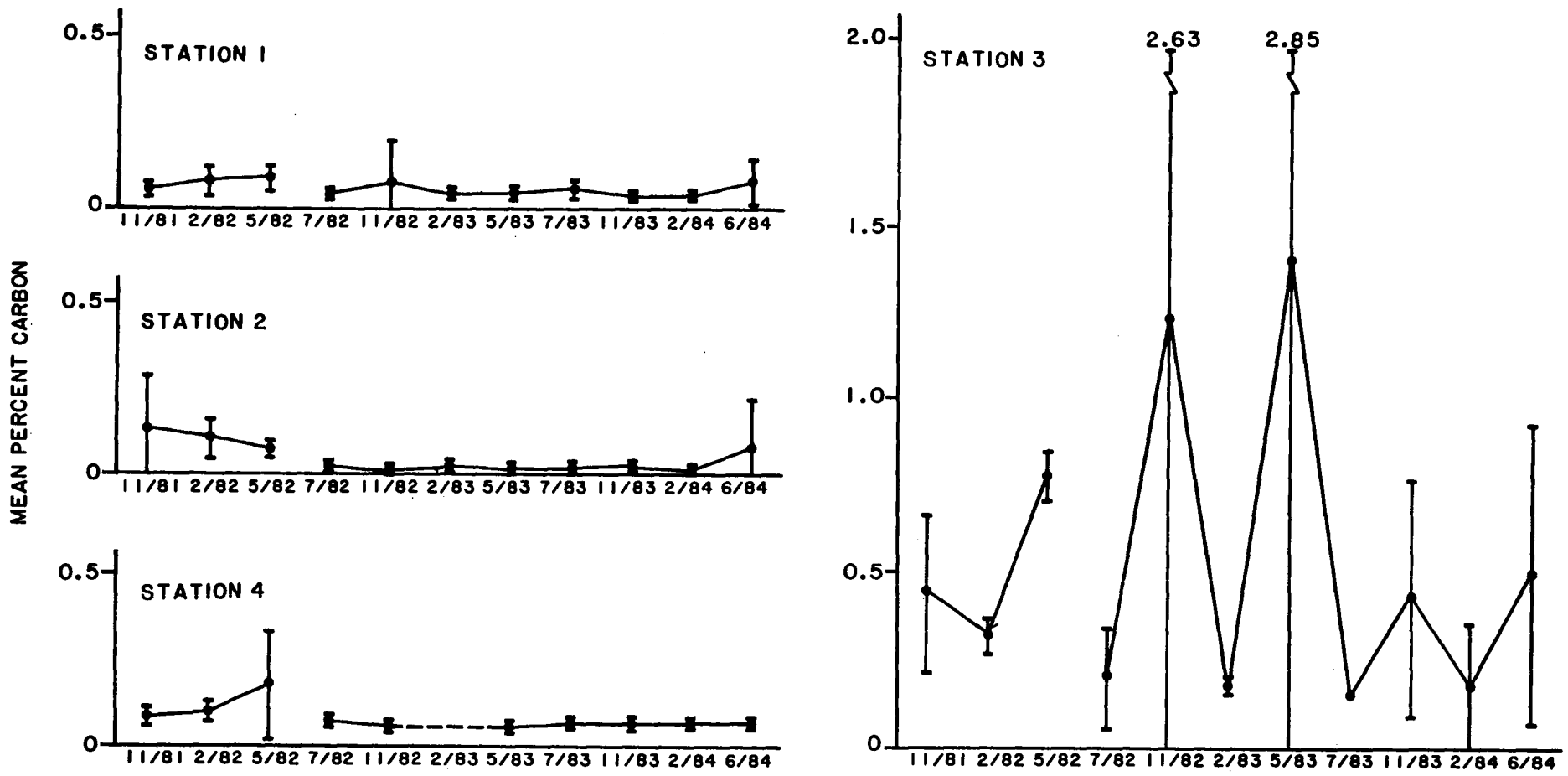

Figure 125. Mean percent carbon ± one standard deviation by sampling cruise from Georges Bank Regional Stations 1, 2, 3 and 4. Data from November 1981 to May 1982 represent total carbon (organic and inorganic) measurements and are not directly comparable to data from July 1982 to June 1984 which represent total organic carbon measurements. A broken line indicates no data.

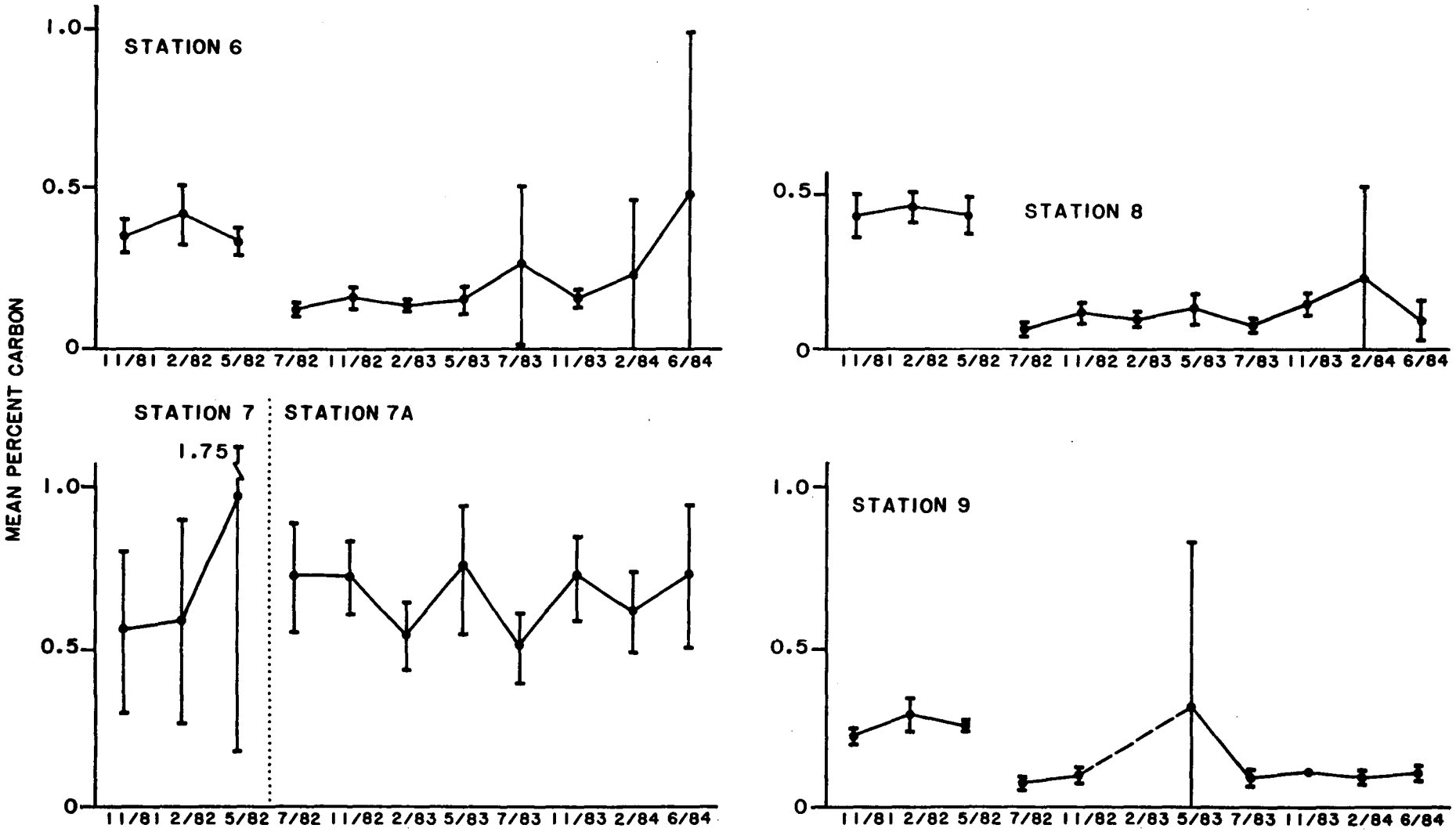

Figure 126. Mean percent carbon ± one standard deviation by sampling cruise from Georges Bank Regional Stations 6, 7, 7A, 8 and 9. Data from November 1981 to May 1982 represent total carbon (organic and inorganic) measurements and are not directly comparable to data from July 1982 to June 1984 which represent total organic carbon measurements. A broken line indicates no data. Station 7 was repositioned in July 1982 and redesignated Station 7A.

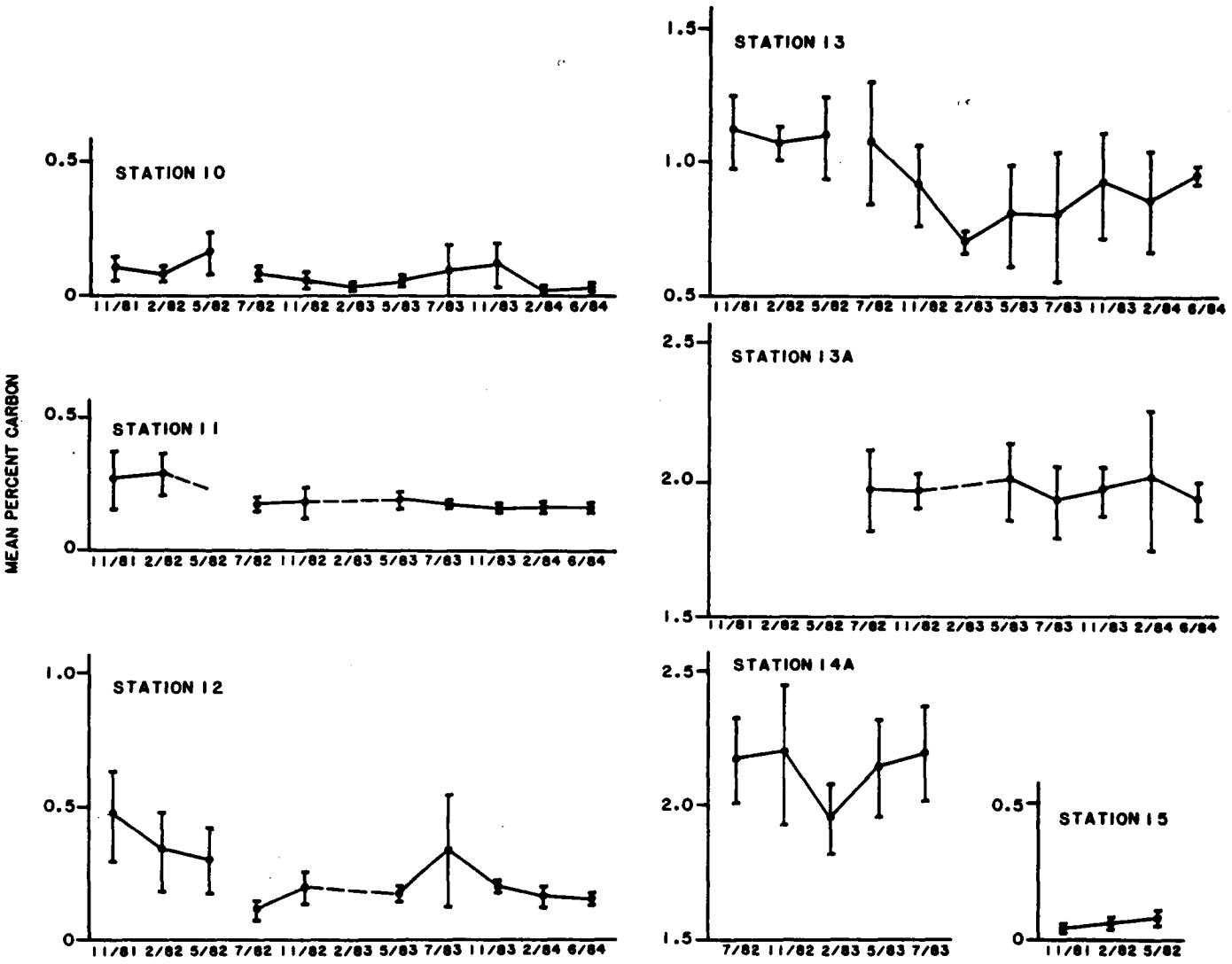

Figure 127. Mean percent carbon ± one standard deviation by sampling cruise from Georges Bank Regional Stations 10, 11, 12, 13, 13A, 14A and 15. Data from November 1981 to May 1982 represent total carbon (organic and inorganic) measurements and are not directly comparable to data from July 1982 to June 1984 which represent total organic carbon measurements. A broken line indicates no data. Station 13A was established in July 1982; Station 14A was sampled only from July 1982 to July 1983; Station 15 was eliminated after May 1982.

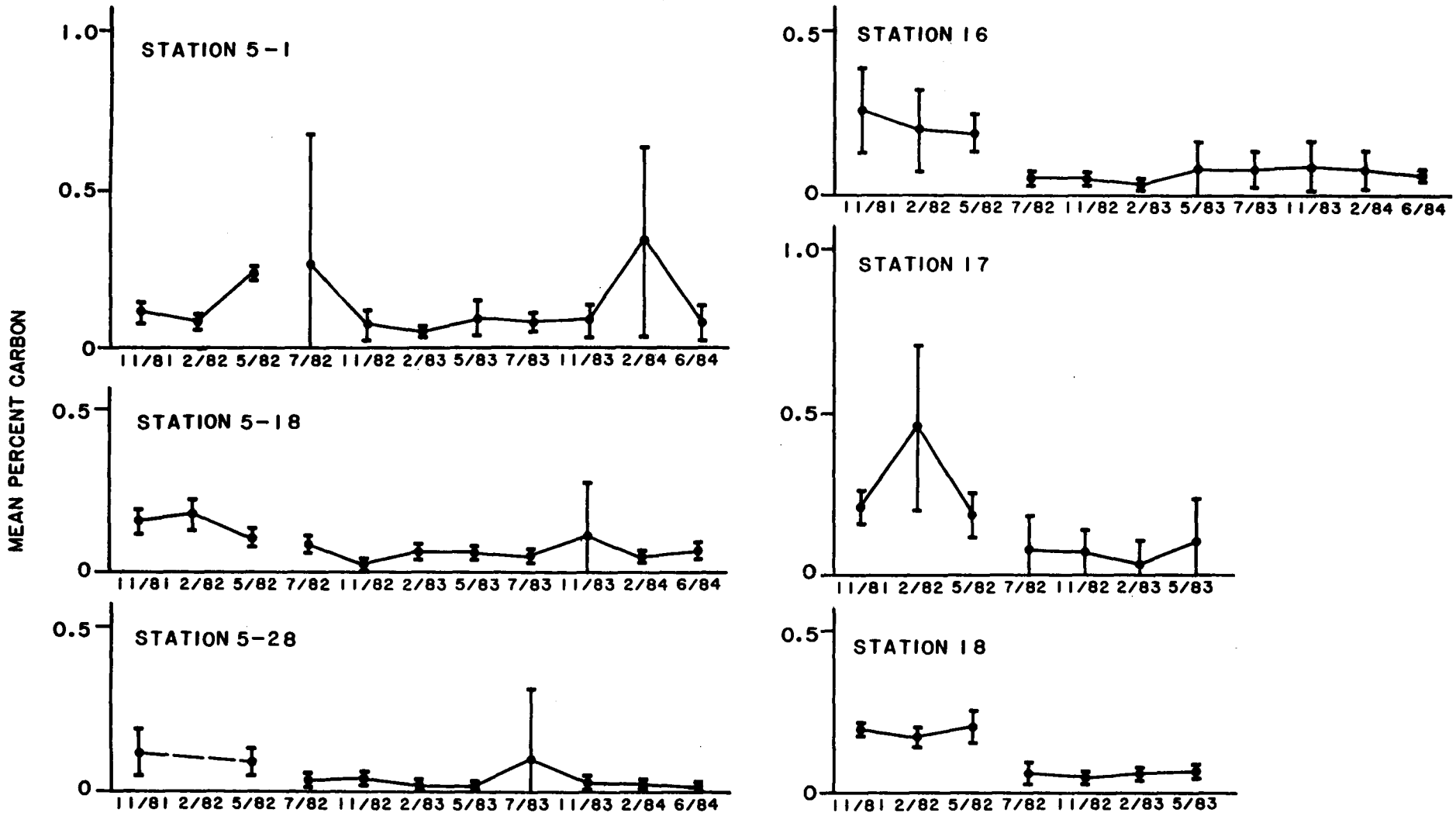

Figure 128. Mean percent carbon ± one standard deviation by sampling cruise from Georges Bank Stations 5-1, 5-18, 5-28, 16, 17 and 18. Data from November 1981 to May 1982 represent total carbon (organic and inorganic) measurements and are not directly comparable to data from July 1982 to June 1984 which represent total organic carbon measurements. A broken line indicates no data. Sampling at Stations 17 and 18 was discontinued after May 1983.

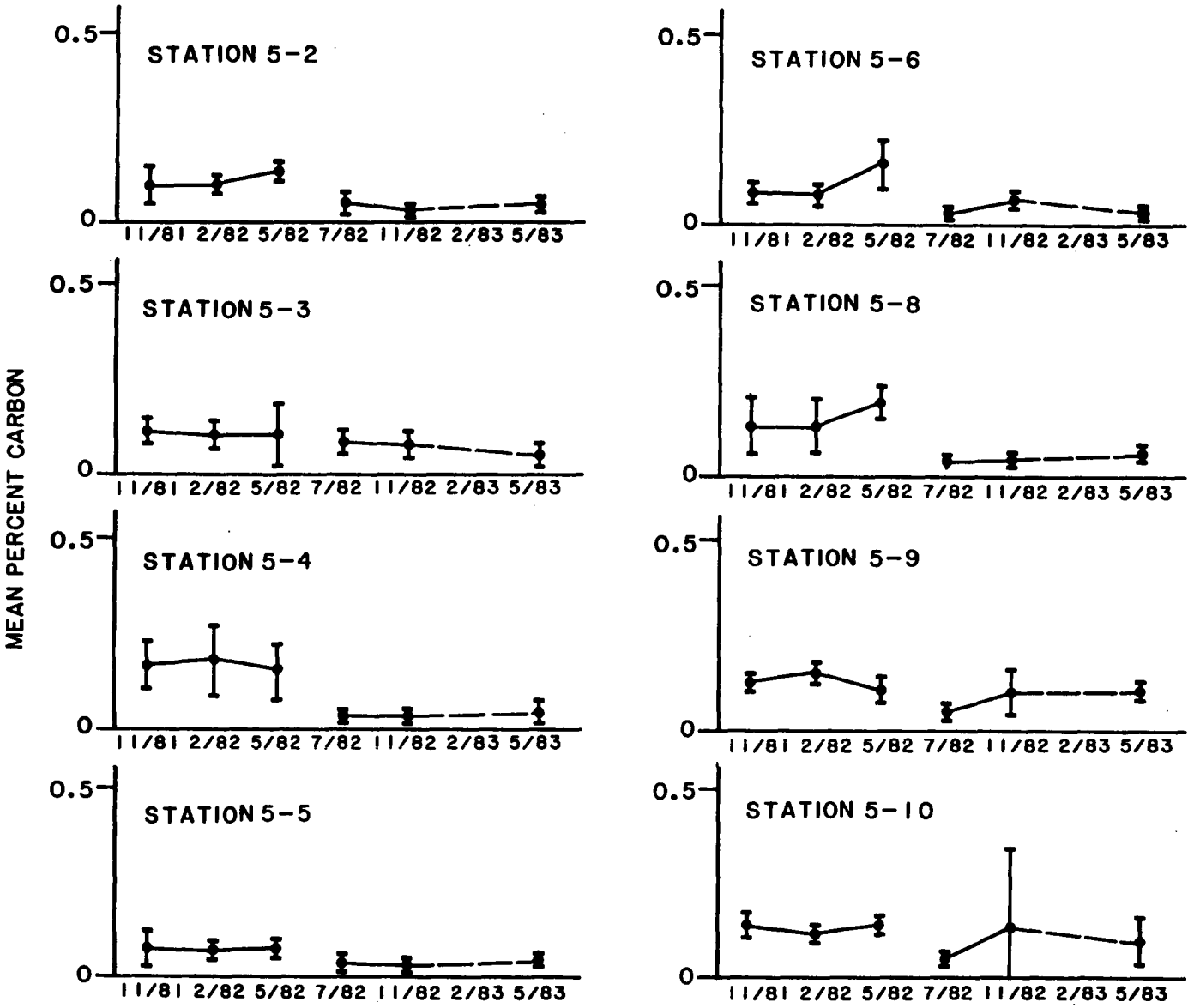

Figure 129. Mean percent carbon ± one standard deviation by sampling cruise from Georges Bank Site-Specific Stations 5-2, 5-3, 5-4, 5-5, 5-6, 5-8, 5-9 and 5-10. Data from November 1981 to May 1982 represent total carbon (organic and inorganic) measurements and are not directly comparable to data from July 1982 to June 1984 which represent total organic carbon measurements. A broken line indicates no data. Sampling at these stations was discontinued after May 1983.

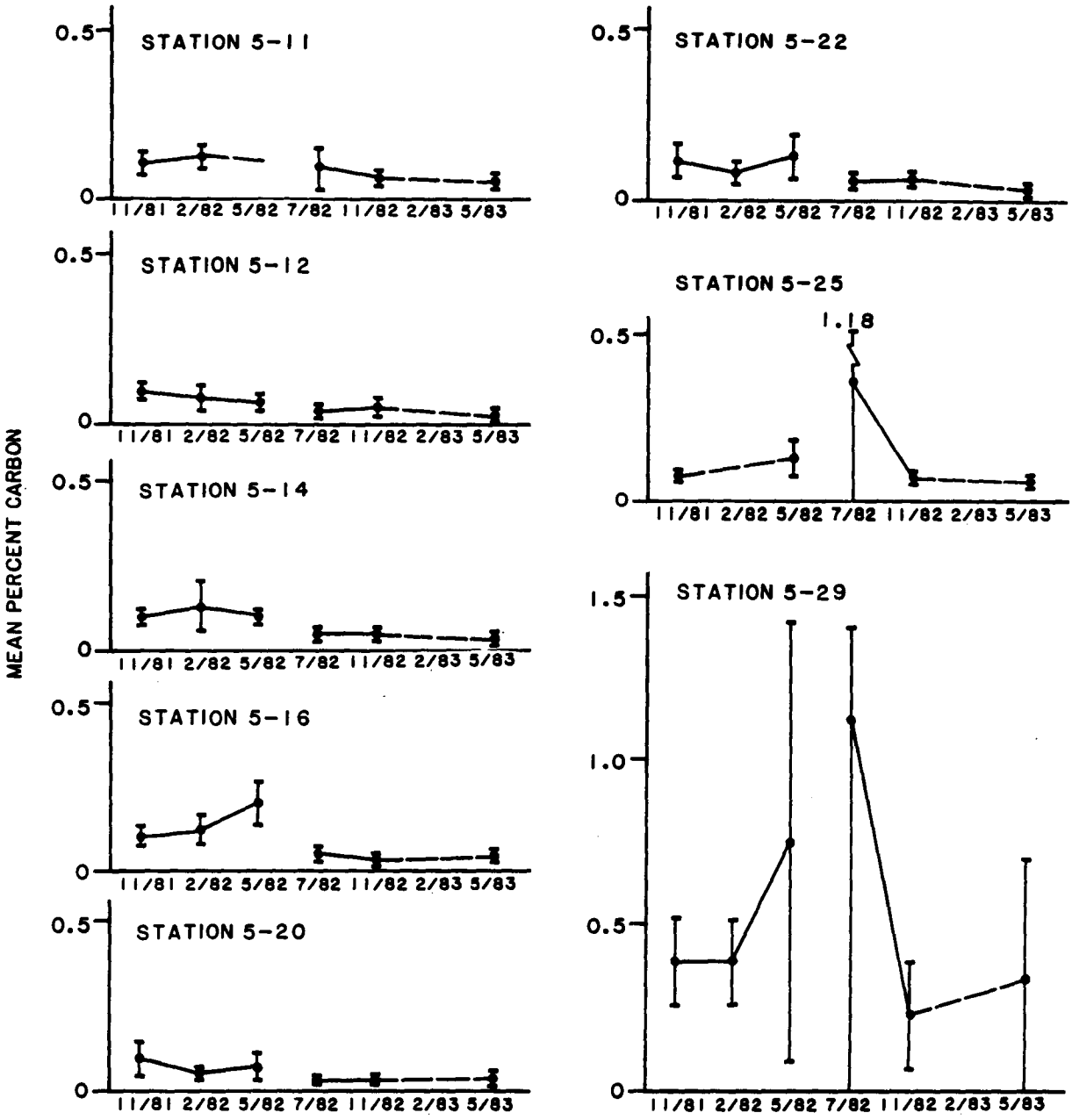

Figure 130. Mean percent carbon ± one standard deviation by sampling cruise from Georges Bank Site-Specific Stations 5-11, 5-12, 5-14, 5-16, 5-20, 5-22, 5-25 and 5-29. Data from November 1981 to May 1982 represent total carbon (organic and inorganic) measurements and are not directly comparable to data from July 1982 to May 1983 which represent total organic carbon measurements. A broken line indicates no data. Sampling at these stations was discontinued after May 1983.

Stations 7 and 3 were second and third highest in total carbon during Year 1 with values of 0.70 ± 0.23 percent and 0.52 + 0.24 percent respectively. However, inorganic carbon may account for a significant percentage of the total carbon measured. Sediments at Station 7 were found to be as much as 53-84 percent inorganic carbon, and at Station 3, 24-84 percent of the total carbon may be accounted for by the inorganic component. Station 7 was characterized by coarse-medium sand while sediments at Station 3 were medium-fine sand. Data at both stations showed considerable variability (high standard deviations).

Site-Specific Station 5-29, also high in mean percent carbon ($\bar{x}$ = 0.52 ± 0.20), was as highly variable as Stations 7 and 3. Measured percent carbon increased by 83 percent between February 1982 ($\bar{x}$ = 0.41 ± 0.13) and May 1982 ($\bar{x}$ = 0.75 ± 0.70) with exceptionally high standard deviations recorded in samples from the latter cruise. Percent silt-clay at Station 5-29 increased by 0.25 percent during the same period.

Stations 8 and 12 were also relatively high in average total carbon at 0.43 ± 0.13 percent and 0.38 ± 0.09 percent respectively. Both stations were again found to be high in inorganic carbon at 62 and 70 percent of total carbon respectively, and both stations were characterized by medium-coarse sediments.

Station 15, the shallowest station at 38 m on the top of the Bank, was characterized by medium-fine sand and the lowest carbon values ($\bar{x}$ = 0.06 ± 0.02). Other stations low in total carbon included Stations 1, 4, and 10 along the 60 m isobath at the edge of the Bank, and Stations 2 and 5 on the shelf at 80 m depth.

Excluding Station 5-29, the site specific stations ranged from 0.08 ± 0.02 mean percent carbon at Station 5-20 to 0.18 ± 0.01 at Station 5-4. Stations 5-4, 5-8, 5-18, 5-16, and 5-10 to the north and west of and closest to Station 5-1 were highest in average carbon readings ($\bar{x}$ = 0.18 ± 0.01; $\bar{x}$ = 0.16 ± 0.04; $\bar{x}$ = 0.15 ± 0.04; $\bar{x}$ = 0.14 ± 0.06; $\bar{x}$ = 0.13 ± 0.01 respectively).

Years 2 and 3 Data. Data for July 1982 (M5) through June 1984 (M12) represent TOC measurements. Mean percent carbon is given for each station and each cruise in Figures 125 through 130. Seasonal patterns in TOC concentrations in Georges Bank sediments are given in Figure 131.

The highest values of percent carbon for all cruises were recorded at Regional Stations 13A in the area known as the Mud Patch ($\bar{x}$ = 1.97 ± 0.05) and 14A in the Gulf of

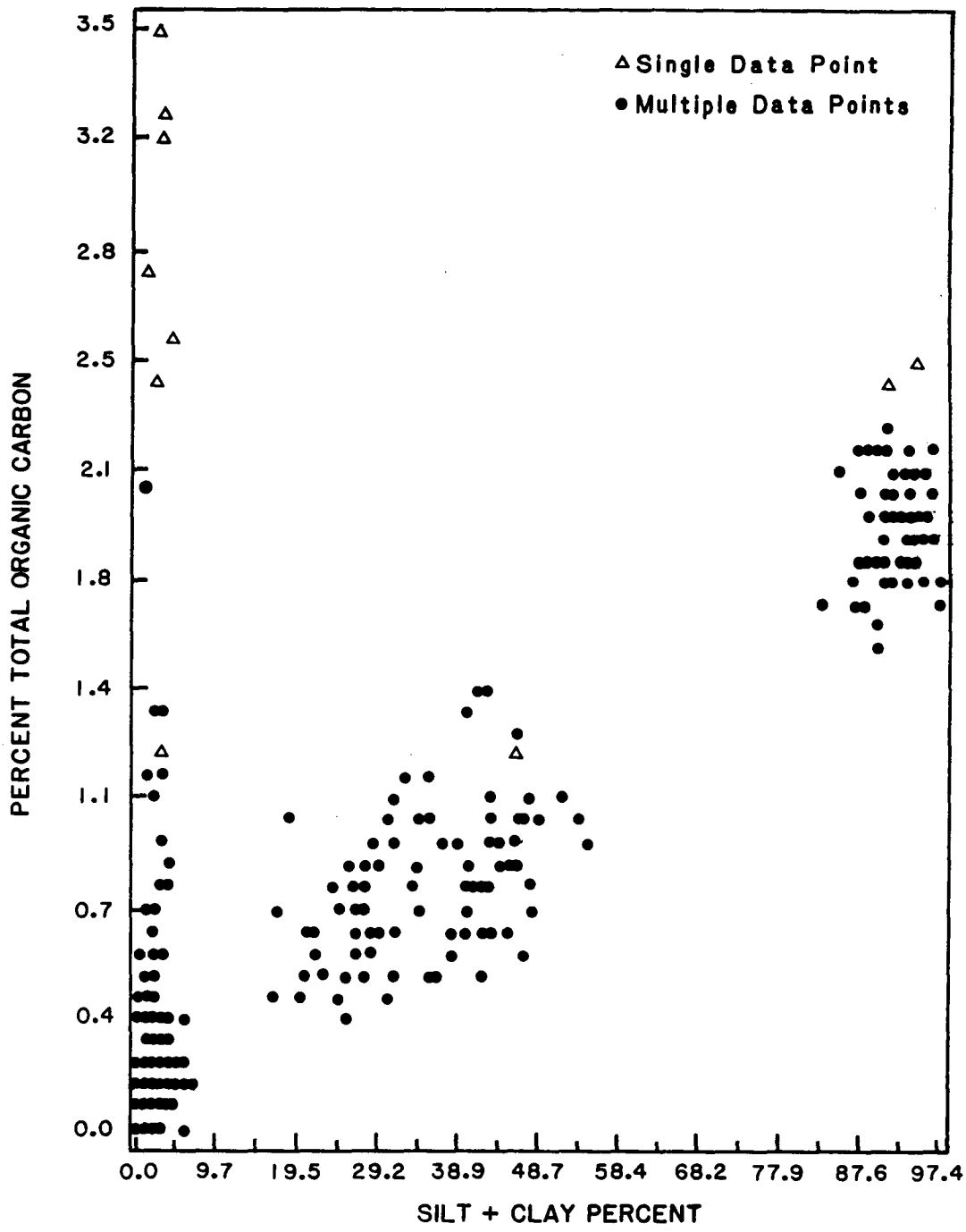

Figure 131. Relationship between total organic carbon and sediment silt + clay fraction.

Maine ($\bar{x}$ = 1.94 ± 0.10). Mean carbon values at these two stations were considerably higher than those of all other stations for all cruises. Sediments in these areas were characterized by 82-96 percent silt-clay. Although data are limited for Stations 13A and 14A, fluctuations in TOC were minimal during those seasons sampled. The lowest organic carbon values at Station 14A were recorded during February 1983, Cruise M7. Other stations also exhibited marked decreases in TOC during this time.

Additional stations at which a relatively high percent carbon was found include Regional Stations 13, also in the Mud Patch ($\bar{x}$ = 0.88 ± 0.11), and 7A at the head of Lydonia Canyon ($\bar{x}$ = 0.67 ± 0.10). These stations showed some similarity in carbon fluctuations, however, without any apparent seasonal patterns. Lows were again noted in TOC measurements for samples from February 1983.

Regional Station 3, northeast of the Bank on the 100 m contour, also exhibited a relatively high mean percent carbon value ($\bar{x}$ = 0.56 ± 0.47); however, this is due to abnormally high mean carbon values for Cruises M6 (November 1982, $\bar{x}$ = 1.22 ± 1.41) and M8 (May 1983, $\bar{x}$ = 1.39 ± 1.48). No other station exhibited a similar pattern. Extreme variability between individual samples at Station 3 is evident in the exceptionally high standard deviations.

Site-Specific Station 5-29, six km west of Station 5-1, also exhibited relatively extreme fluctuations in percent carbon and high standard deviations. Mean percent carbon for M5 (July 1982) was 1.12 ± 1.37 and dropped by 78 percent to 0.25 ± 0.17 for M6 (November 1982) when abnormally high carbon was recorded at Station 3. Sediment texture at this station was finer than at any other site-specific station.

Station 2, on the shelf at 80 m depth, with medium-coarse sandy sediments, exhibited the lowest TOC values of all regional stations sampled ($\bar{x}$ = 0.03 ± 0.02). Carbon values remained stable throughout Years 2 and 3 with a slight increase to 0.08 ± 0.16 percent occurring during June 1984 (Cruise M12). Station 5-1, with similar depth and sediment conditions, exhibited routinely higher carbon values ($\bar{x}$ = 0.13 ± 0.11) and was also subject to more variation in measured TOC. Peak values occurred in July 1982 ($\bar{x}$ = 0.27 ± 0.42) and February 1984 ($\bar{x}$ = 0.33 ± 0.31).

Of the site-specific stations surrounding Station 5, only Stations 5-18 and 5-28 were sampled during Year 3, and Year 2 data is missing for February 1983 (M7) for all stations except these two. Both stations were lower in carbon than Station 5-1 and both were relatively stable with the exception of small increases during November 1983 at Station

5-18 and during July 1983 at Station 5-28. At the remaining site-specific stations, excluding Station 5-29 previously discussed, TOC ranged from 0.03 to 0.13 percent.

Station 11, at 86 m depth only slightly deeper than Stations 2 and 5, had a much higher percentage of fine-very fine sand and a higher concentration of TOC ($\bar{x}$ = 0.18 ± 0.01). Data from Station 11 showed negligible fluctuations during Years 2 and 3 of the sampling period.

Stations 1, 4, and 10 along the 60-m isobath had similar fine-medium sandy sediments and some of the lowest carbon values recorded ($\bar{x}$ = 0.53 ± 0.02; $\bar{x}$ = 0.08 ± 0.01; and $\bar{x}$ = 0.06 ± 0.04 respectively). Only slight fluctuations in TOC were noted with Station 4 being particularly stable. Seasonal patterns were not evident at any of these stations.

Although changes in TOC at Stations 6 and 12 (100 m depth) followed each other over most of the sampling period, values diverged during February and June 1984 when Station 6 exhibited increased carbon concentrations. Sediments at Station 6 were largely fine sand, while Station 12 was characterized by medium-coarse sand. Average TOC was 0.22 ± 0.12 percent at Station 6 and 0.20 ± 0.07 percent at Station 12.

TOC at Stations 8 and 9 (145 m depth) also appeared to vary similarly, with average station values being 0.12 ± 0.05 percent and 0.13 ± 0.09 percent respectively.

Of the Block 410 stations, only samples from Station 16 were analyzed during Year 3. For comparable sampling periods, these stations all exhibited consistently low carbon readings with Station 16 being low during Year 3 as well. Sediments of Stations 16 and 17 were coarse-medium sand while those of Station 18 were fine-medium sand.

Average percent nitrogen was, in general, an order of magnitude lower than recorded carbon, and was unmeasurable in many cases. The highest recorded nitrogen values occurred at Stations 13A ($\bar{x}$ = 0.24 ± 0.01) and 14A ($\bar{x}$ = 0.25 ± 0.02), which were also highest in organic carbon. The C/N ratios at these stations, $\bar{x}$ = 7.73 ± 0.24 for Station 14A and $\bar{x}$ =8.11 ± 0.11 for Station 13A, were among the lowest measured within the sampling array. Seasonal variation in nitrogen was minimal at both stations.

Relatively high nitrogen also occurred at Stations 13 ($\bar{x}$ = 0.12 ± 0.02) and 7A ($\bar{x}$ = 0.07 ± 0.01), and again these stations were high in organic carbon. C/N ratios were also relatively low at these two stations ($\bar{x}$ = 7.91 ± 0.31 and $\bar{x}$ 9.19 ± 0.97 respectively).

Station 15, lowest in carbon during Year 1, was characterized by the lowest nitrogen values ($\bar{x}$ = 0.0006 ± 0.001) and lowest C/N ratio ($\bar{x}$ = 5.00 ± 0.00, Year 1 data only). At Station 2, where the lowest average carbon was recorded during Years 2 and 3, nitrogen

concentrations were virtually undetectable. Station 5, southwest of Station 2 but with similar depth and sediment characteristics, exhibited higher nitrogen values by an order of magnitude ($\bar{x}$ = 0.006 ± 0.004) and a higher C/N ratio ($\bar{x}$ = 21.68 ± 19.95).

C/N ratios were highest at Stations 3, 17, 7, 5-29, 8, and 9 ($\bar{x}$ = 47.05 ± 38.40; $\bar{x}$ = 43.00 ± 0.00; $\bar{x}$ = 36.54 ± 5.47; $\bar{x}$ = 40.03 ± 19.68; $\bar{x}$ = 12.63 ± 8.32; $\bar{x}$ = 13.51 ± 8.88, respectively). It should be noted that data for Station 17 is from May 1983 (M8) only.

Hydrogen concentrations were highest at those stations where carbon and nitrogen were highest: Stations 14A ($\bar{x}$= 0.58 ± 0.03) and 13A ($\bar{x}$ = 0.52 ± 0.02) followed by Stations 13 ($\bar{x}$ = 0.25 ± 0.05) and 7A ($\bar{x}$ = 0.21 ± 0.03).

DISCUSSION

Total organic carbon was found to be correlated with sediment grain size (Figure 131). In particular, a very significant positive correlation was noted between TOC and silt, clay, and silt + clay fractions (r=0.8736, r=0.8015, r=0.8784 respectively; n=1138 all cases; P=<0.001 all cases). Thus, 64-74 percent (r^2) of the measured variability in organic carbon in Georges Bank sediments can be explained by variability in silt and/or clay content. Sandy areas exhibited characteristically low carbon values, usually below 0.2 percent, as well as nitrogen values of less than 0.02 percent. In the finer, predominantly silt-clay sediments (Stations 7, 7A, 13, 13A and 14A), organic carbon and nitrogen values increased markedly, indicative of a net depositional environment. This is consistent with the reviews by Kuenan (1950) and Bordovsky (1965) who suggested that the concentration of organic matter increases with decreased sediment particle size. In low energy depositional environments, fine-grained sediments accumulate and organics readily settle out of the water column. These fine-grained sediments provide a larger total surface area than do coarse sediments for the sorption of organics. Also, in areas of low turbulence, sediment organics are less subject to oxidation.

Associated with the systematic increase in silt + clay from ≤ 1 percent to ≥ 95 percent weight from northeast to southwest along the 70-80 m isobath (Stations 2, 5, 11, 13, 13A respectively), was a similar gradient in TOC from 0.03 percent at Station 2 to 1.97 percent at the Mud Patch Station 13A. A net increase in TOC over the sampling period was evident at Station 13 but not at Station 13A.

Carbon concentrations were lowest in the area of the shelf-bank interface along the 60 m isobath (Stations 1, 4, 10) and were generally found to increase with depth, most noticeably along the transect through the head of Lydonia Canyon (Stations 5, 6, and 7A; Appendix I). A similar depth related gradient was observed in sediment grain size, with

slight increases in very fine sand and silt + clay occurring with increased depth. Although seasonal patterns were not apparent (Figure 132), lower carbon values were recorded at many stations during February 1983 (Cruise M7). Following the severe winter storms of that year, reduced carbon concentrations are likely due to selective winnowing of finer grain sizes rich in organics.

Variability in percent carbon within stations was particularly evident at Stations 3 and 5-29. At Station 5-29 TOC was observed to vary similarly with very fine sand, silt and clay ($r=0.5571$, $n=18$, $P-0.008$; $r=0.4956$, $n=18$, $P=0.018$; $r=0.6691$, $n=18$, $p=0.001$ respectively), indicative of a patchy distribution of organics and sediment types in this area. Twenty four to forty-five percent of the variation in TOC at this station may be accounted for by variability in these sediment types. Carbon concentrations at Station 3, however, did not show the typical correlation to finer sediment grain sizes, and , in fact, exhibited a slightly negative correlation with clay and significantly positive covariances with clay and with gravel ($r=0.0994$, $n=46$, $p=0.255$ for silt; $r=0.3761$, $n=46$, $p=0.005$ for gravel). It is possible that this anomalous variability observed in samples from Station 3 could be due to bias caused by small organisms present in the samples.

The removal of inorganic carbon from Year 2 and 3 samples did, as was expected, lower the carbon values at most of those stations for which comparable data are available. Station 13 exhibited a 20 percent reduction in measured carbon; Station 8, a 27 percent reduction; Station 9, 50 percent; and Station 12, 52 percent. Station 3 actually exhibited an overall increase in mean percent carbon during Years 2 and 3, although the extreme variability among samples from this station may account for this observation.

Carbon data developed during the Monitoring Program are consistent with that reported for the New England OCS Environmental Benchmark Study (Energy Resources Company, Inc., 1978). In that study, the highest carbon values were recorded at Station 42 (1.29 - 1.49 percent) which was located west of our Station 14A, and at Station 6 (0.85 - 1.06 percent) which corresponds to our Station 13. Lowest carbon values as reported in the Benchmark study were found at Station 37 (0.04 - 0.11 percent) which corresponds to our Station 15. Values at Station 20, near our Station 5, ranged from 0.06 - 0.14 percent carbon, comparable to the Year 2 and 3 average of 0.13 percent $\pm$ 0.11 at our Station 5.

The C/N ratio is suggested by Emery (1960) to be an indicator of the origin of sediment organics. Organic C/N ratios greater than 10:1 are considered to be representative of terrestrial sources while ratios less than 5:1 are characteristic of marine origins. The distribution of sediment organics on Georges Bank appears more

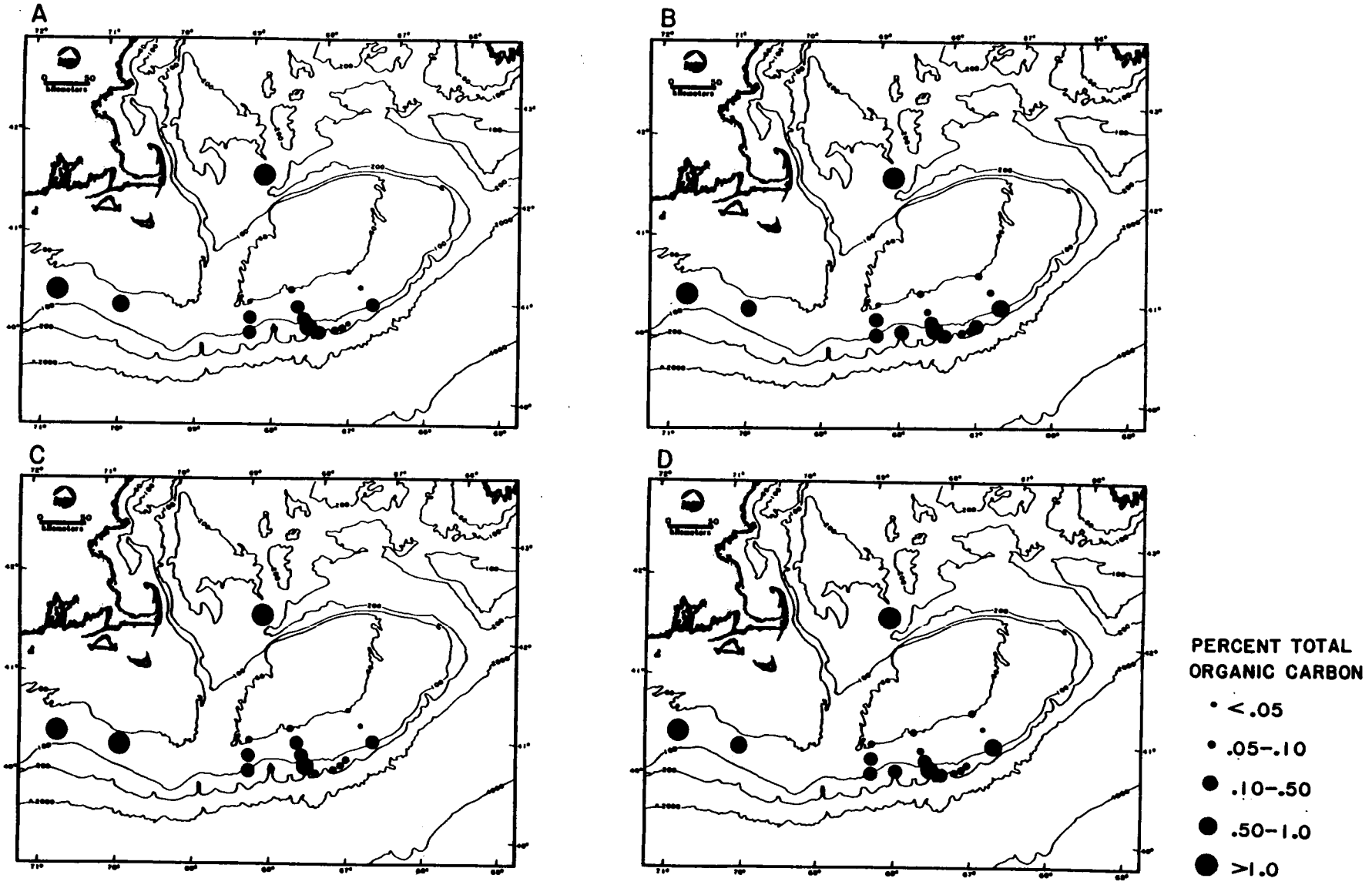

Figure 132. Seasonal variations in total organic carbon concentrations in sediments from Geoges Bank. A. Winter, B. Spring, C. Summer, D. Fall. Year 2 and 3 data only.

complex than this. All C/N ratios were greater than 5:1. Twenty-five stations exhibited C/N ratios greater than 10:1. Those stations closest to the shelf/slope break were found to have the highest C/N ratios, some well over 10:1.

Organic nitrogen was highest in the depositional areas (Stations 14A, 13A, 13 and 7A), possibly due to contributions from microbial carbon which is enriched in nitrogen, but was proportionally higher with respect to carbon at the shelf/slope break. It is doubtful that these high C/N ratios can be explained exclusively by terrestrial sources of organic matter, and they are more likely attributable to an admixture of organic matter from both marine and terrestrial sources.

ACKNOWLEDGEMENTS

I would like to thank the following: Janet Kennedy, Steven Mellenthien, Claudia O'Brien, and John Schlueter from Battelle New England Marine Research Laboratory for the contribution of their talents in processing the samples; John Clarner and Bonnie Woodward from Woods Hole Oceanographic Institution for their cooperation and skill in analyzing the samples; and Michael Bothner from U.S. Geological Survey and Adolfo Requejo of Battelle for their advice and guidance in establishing sample handling protocol and for reviewing this chapter.

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CHAPTER 10. SEDIMENTS OF GEORGES BANK 1981-1984

by

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INTRODUCTION

This section briefly discusses the methodology, associated problems and errors, and interpretation of sediment size data from Georges Bank collected over the three years of the program. Only sedimentation patterns extending over the entire region and/or Monitoring Program lifetime are discussed.

METHODS AND MATERIALS

Analysis

A plug of sediment, approximately 20 cm^3 (10-54 g dry weight), was taken from each of six replicate Van Veen surface grabs per station beginning with the second sampling cruise in November 1981. These samples were frozen for up to two months. Frozen samples were thawed and soaked in a Calgon® solution overnight to enhance deflocculation of fine material (see discussion below on use of Calgon® solution dispersant). Sediments were wet sieved through a 63-μm (4 ϕ) screen with a Calgon® solution; coarse fractions were oven-dried overnight at 70-90°C, sieved through a 2-mm (1 ϕ) screen to split sand and gravel classes, and weighed. Sands were analyzed for percent weight in 1 ϕ intervals in a rapid sediment analyzer (RSA) (Schlee, 1966; Gibbs, 1974). Fines were analyzed for percent dry weight of silt and clay fractions by standard pipette analysis (Folk, 1974); a 5.0 percent Calgon® solution (0.5 percent for June 1984 samples, see discussion below) and filtration apparatus were used in this method.

Procedures were identical to those used by the U.S. Geological Survey in their analyses of Georges Bank sediments, except our omission of Coulter counter measurement of fines and a recent change (June 1984 only) in dispersant concentration (from 5.0 percent to 0.5 percent weight Calgon®). All analyses were performed at the Woods Hole Oceanographic Institution.

Sources of Error

Length and type of pretreatment of samples with high silt + clay content (Nelson, 1983), dispersant concentration in pipette analysis (Rolfe et al, 1960), and inherent lack of resolution in size analysis techniques (Schlee, 1966; Folk, 1974) appear to be major sources of inconsistencies within and between different granulometric methods. The following discussion examines these problems as they relate to Georges Bank sediment analyses.

Pretreatment. Nelson (1983) found statistically significant differences in mean grain size of sediments subjected to different types and lengths of pretreatment (soaking alone from 15 min to 90 hr versus soaking plus ultrasonification up to 15 min). "Best results" in subsequent analyses (maximum clay content and therefore optimal deflocculation) were found with ultrasonification pretreatments. Nelson also recognized a shifting grain-size distribution with length of soak alone. In sediments from Station 13A, chosen for its high silt + clay content, no such trend of clay content increase was apparent over soaking times of 12, 20, and 36 hr in 5.0 percent Calgon® solutions. However, in deep-sea sediment collected from 3000 m off North Carolina (MMS cruise SA-2, Station 5), clay content increased by roughly 6-10 percent weight due to differences in pretreatment (overnight soak versus overnight soak + ultrasonification, Table 29). The simple soaking pretreatment used in analyses of Georges Bank sediments may have resulted in a similar 6-10 percent underestimate of clay content, particularly in stations of high silt + clay content (7A, 13, 13A, 14A, see Appendix J, Table J-1).

Dispersant concentration. Hexametaphosphate, commercially sold as Calgon®, acts as a dispersant, neutralizing cations that would otherwise bind and neutralize the negative surface charge of clay particles. Sustained surface polarity of clays keeps the fine particles from forming secondary, larger grain groups or 'flocs'. However, so-called dispersant solutions that are over-concentrated act as weak electrolytes and enhance flocculation much like seawater (Rolfe et al, 1960). From M2 through M11 we used an approximate 5.0 percent (50 g/l H_2O) Calgon® solution to parallel USGS methods of Coulter counter analyses which actually require a weak electrolyte Calgon® solution. To document effects of dispersant concentrations in the Georges Bank study, 10-15 g samples of silt + clay mud (Station 13A) were subjected to overnight soaking and pipette analysis in serial dispersant solutions (50 g/l, 25 g/l, 10 g/l, 5 g/l, 2.5 g/l, 1 g/l, H_2O). Maximum clay content indicates optimal dispersant concentration (i.e., minimization of flocculation effects and loss of clay particles to silt range). This optimal concentration is 5 g/l, 10 percent of the concentration used in sediment analyses for the first ten sets of samples analyzed (M2-M11). Comparisons of clay content for each Calgon® concentration to that

TABLE 29. EFFECTS OF PRETREATMENT ON OBSERVED CLAY CONTENT IN PIPETTE ANALYSIS OF DEEP-SEA SEDIMENT FROM MMS SOUTH ATLANTIC PHASE 1 STATION 5.

	Clay Content (percent dry weight of material >8 ϕ)	
Pretreatment:	Overnight Calgon® Soak	Overnight Calgon® Soak + Ultrasonification
Replicate		
1	38.7	44.2
2	35.7	45.6

of 5 g Calgon® /l H_2O of the form

$$\frac{\text{percent dry weight clay (Calgon® conc.)}}{\text{percent dry weight clay (5 g/l)}} \quad \text{(column 6, Table 30),}$$

suggest that clay content has been underestimated by a factor of 3 in the Georges Bank study. A single correction factor has not been applied to data from M2 - M11, because sample weights and dispersant concentrations were not uniform. It must be pointed out that total fines (silt + clay) is not affected by this problem. Clay is "lost" only to silt fractions through flocculation.

Silt + clay content is so low (≤5 percent) for most stations on Georges Bank, however, that this complication is negligible. Gross inaccuracies are present only for stations with high fines content (25-95 percent silt + clay from Regional Stations 7A, 13, 13A, 14A, November 1981 - February 1984 (M2 - M11), Appendix J, Table J-1) in which clay content is roughly three times greater than that stated. Analyses of Georges Bank sediments performed independently at W.H.O.I. (this report) and the U.S. Geological Survey (Bothner et al, 1982, 1983, 1984) compare more favorably on the basis of silt + clay for these stations.

Sediment analyses for June 1984 (M12) employed a 5 g/l Calgon® dispersant solution and thus reflect accurate grain-size distributions. Sediment size data for samples from Cruises M2 -M11 (November 1981 - February 1984) are most informative as percent silt + clay.

Replicates and resolution. Replicates from two-way split samples (beach sand, lab "standard" for RSA) and three-way split samples (Station 13A for pipette) yield a range of size distributions varying by ≤5 percent dry weight across all size classes (Table 31). This analytical variability provides a comparative value for single station replicates.

RESULTS

Georges Bank Sediments

Overall description. A summary of sediment size analyses performed over the course of this study appears in Appendix J, Tables J-1 and J-2. Given values are means and standard deviations of percent dry weight for each size class, derived from six replicates per station per cruise.

Surficial sediments of Georges Bank are predominantly (>95 percent) quartz sand with minor amounts of gravel, pelecypod shell and echinoderm test fragments, silt, and

TABLE 30. EFFECTS OF DISPERSANT CONCENTRATIONS ON OBSERVED CLAY CONTENT OF MUD FROM STATION 13A.

Dispersant Concentration (g Calgon®/liter H_2O)	Clay Content (percent dry weight of material >8 ϕ) Replicate 1	2	3	$\dot{x}$	$\frac{\dot{x}}{\dot{x}\ 5g/l}$
50.0	5.69	5.63	5.31	5.63	0.33
25.0	12.26	14.39	14.99	14.39	0.85
10.0	15.70	16.03	14.12	15.70	0.93
5.0	15.86	17.77	16.96	16.96	1.00
2.5	15.56	17.16	15.50	15.56	0.92
1.0	19.11	15.63	14.88	15.63	0.92
0.0 (H_2)	14.01	10.86	11.50	11.50	0.68

TABLE 31. RANGE OF ESTIMATES OF PERCENT WEIGHT OF SEDIMENT SIZE CLASSES FROM REPLICATE SEDIMENT SIZE ANALYSES USING RSA (SAND FRACTION) AND PIPETTE METHOD (SILT + CLAY). (VCS - VERY COARSE SAND: CS - COARSE SAND; MS - MEDIUM SAND; FS - FINE SAND; VFS - VERY FINE SAND).

Sample	Rep	Size Class VCS	CS	MS	FS	VFS	Silt	Clay
"Beach Sand"								
A	1	19.2	48.6	27.1	4.2	0.9	--	--
	2	23.0	45.1	27.8	3.7	0.4	--	--
B	1	12.3	44.1	32.7	9.6	1.3	--	--
	2	17.2	43.7	29.5	8.0	1.6	--	--
Mud Patch								
13A								
	1	--	--	--	--	6.2	73.0	20.8
A	2	--	--	--	--	6.9	72.8	20.3
	3	--	--	--	--	7.1	73.4	19.5
	1	--	--	--	--	4.2	77.8	18.0
B	2	--	--	--	--	5.5	76.6	17.9
	3	--	--	--	--	4.1	81.3	14.6

clay. Sands are noncohesive, medium- to fine-grained, rounded to subangular in shape, and transluscent (clean) to light brown (iron-oxide coated) in color. Areas of exceptionally high (25-90 percent) silt + clay content included the head of Lydonia Canyon (Station 7A), a region west of Georges Bank known locally as the Mud Patch (Stations 13 and 13A), and the Gulf of Maine (Station 14A).

Also of interest were dark gray, calcareous (effervesces in 10 percent HCl), angular rock fragments. This material, presumably exploratory well drill cuttings, was observed in both sand (0.063-2.00 mm) and gravel (>2.00 mm) fractions from Site-Specific Station 5-1 and Regional Station 16 since Year 1. These sampling locations were typically within 200 m of the Block 312 and Block 410 drill sites, respectively. Bothner et al (1983) reported drill cuttings from Station 17, 2 km east of the Block 410 drill site. This material was not observed at other stations.

Station location control. Every effort was made to keep sampling locations within 0.2 km of the designated station coordinates; exceptions may have occurred only in the most difficult of sea conditions. As an additional control, sediment size data may be regarded as a locational signature for replicates taken at a station. Examination of the sediment size data revealed that, in general, standard deviations among six station replicates were of the same order of magnitude as ranges among two-way and three-way split sample replicates ($\leq$5 percent weight). In several cases, standard deviations among six station replicates of a size class approached 10-15 percent weight. This variation may reflect natural variation over distances of 0.2 km in a given sedimentological environment. Selected cases of local gradients at Stations 7A, 13 and 13A will be discussed below. If ecological significance of differences on the order of 10-15 percent is suspected upon analysis of infaunal data, further examination of individual replicates would be warranted. In general, station replicates represented samples taken from the same environmental setting. Mean percent weight values of respective size classes derived from station replicates served as accurate measures of station sediment size distribution.

Spatial patterns. Examination of sediment grain size composition in the vicinity of southeastern Georges Bank revealed a slight increase in material finer than 0.125 mm with depth (very fine sand, silt + clay); particularly high concentrations of these finer size classes occurred at the heads and on the flanks of Lydonia and Oceanographer Canyons (Figure 133). Also revealed in our observations was a well-developed gradient in which silt + clay increased systematically from $\leq$1 percent to $\geq$95 percent weight from northeast to southwest along 70- to 80-m depth contours (Stations 2, 5-1, 11, 13, 13A, respectively; Figures 133 and 134).

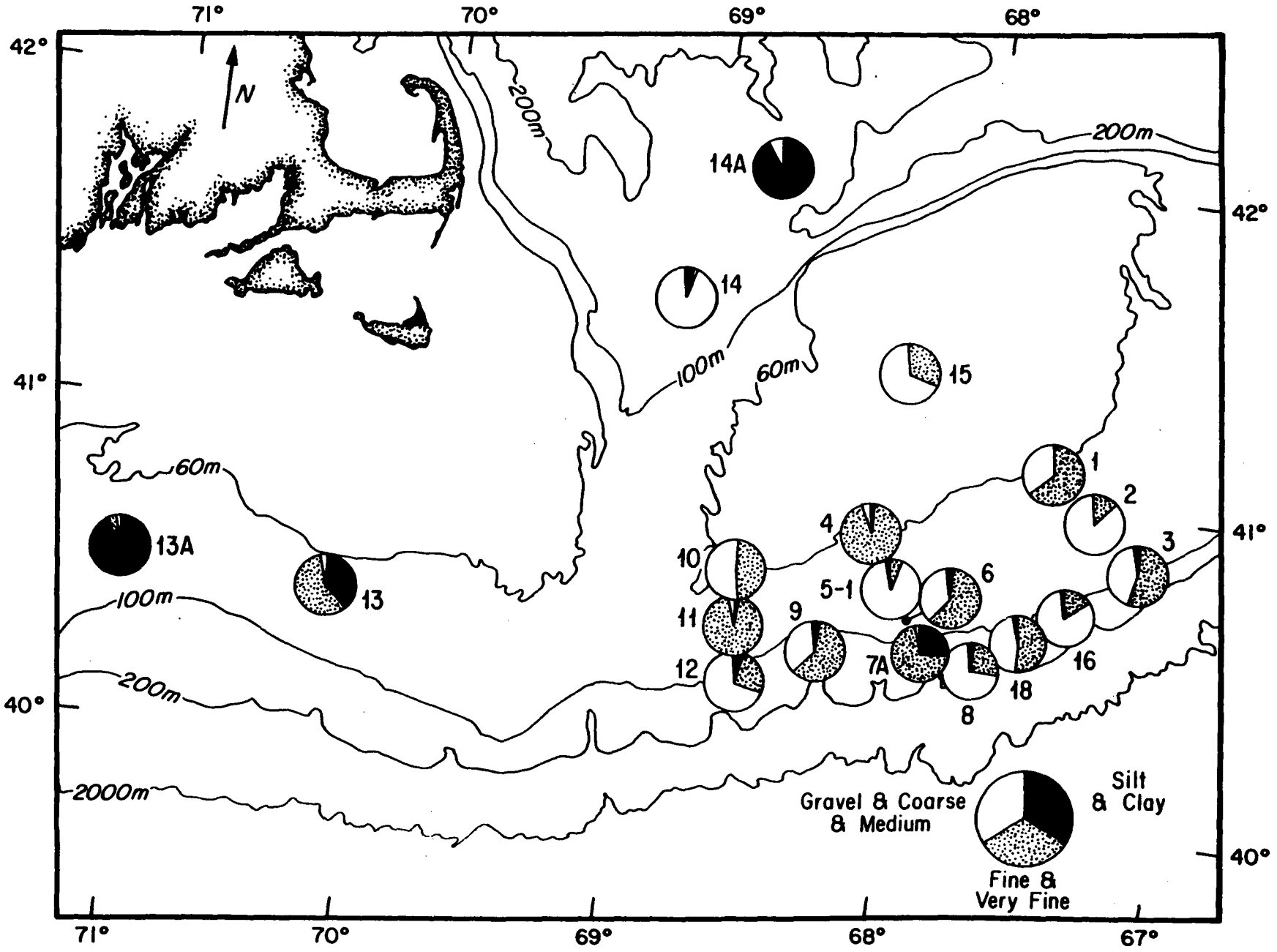

Figure 133. Sediment grain-size composition at Georges Bank regional stations.

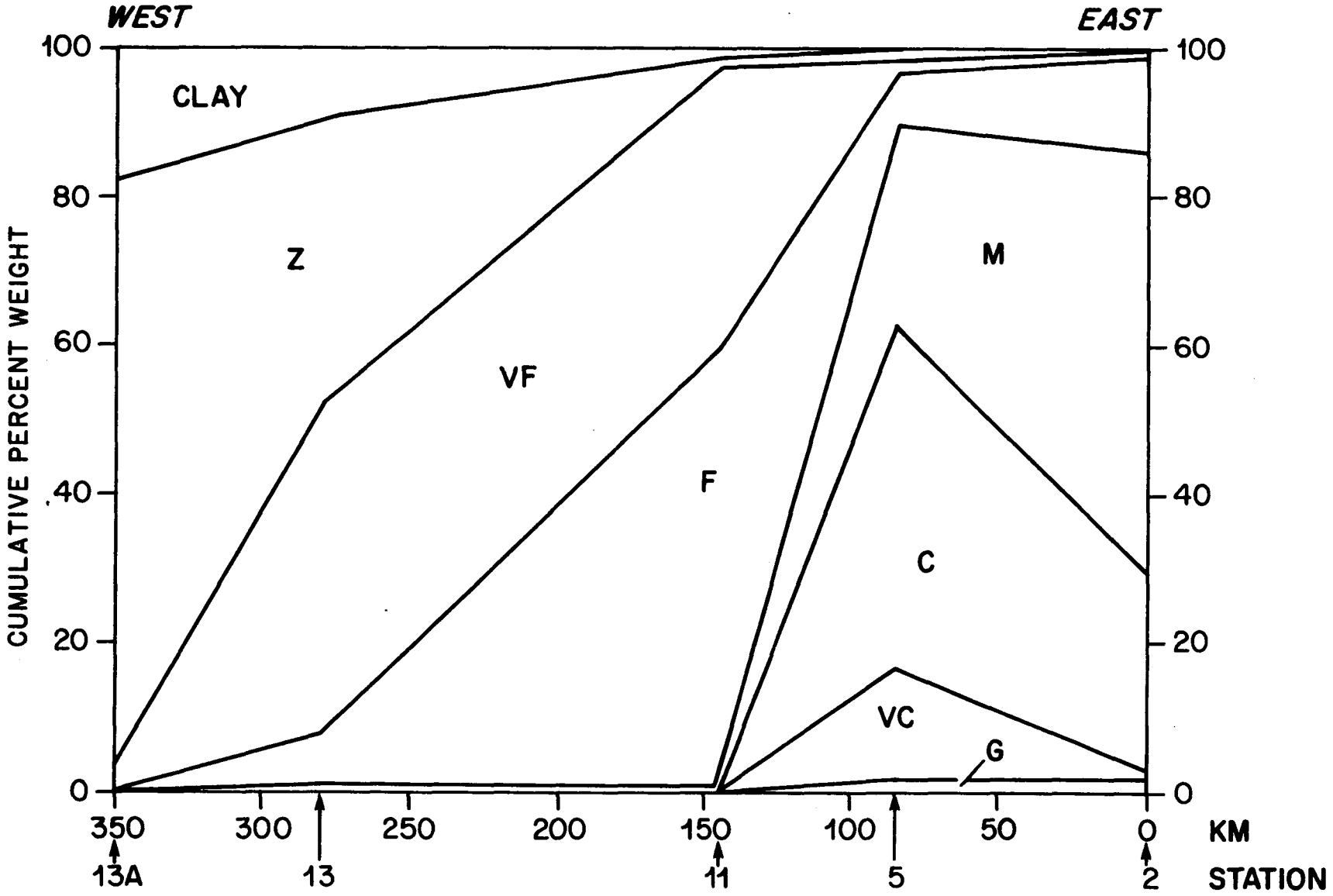

Figure 134. Sediment texture (plotted as cumulative percent weight) along 70-80m isobaths, southeastern flank and west of Georges Bank, June 1984 (M12). G=gravel, VC=very coarse sand, C=coarse sand, M=medium sand, F=fine sand, VF-very fine sand, Z=silt.

Changes over time. At Site-Specific Station 5-1, material coarser than 0.5 mm (coarse, very coarse sand, and gravel) increased by 10-20 percent total weight during the months of November, February, and May over the three year monitoring program (Figure 135). These seasonal changes were demonstrated very well at Station 5-1 as well as at other site-specific stations, and to some extent at other regional stations representative of most depths sampled (Stations 1 and 18, showing fluctuations in fine sand; Station 3, medium sand; and Stations 6 and 11, very fine sand).

Long-term changes in sediment characteristics occurred over the course of this study. Presumed drill cuttings were observed in gravel and sand fractions of Stations 5-1 and 16 since Year 1 (July 1981 to July 1982). A sediment history of Station 5-1 (within 100 m of the Block 312 drill site; drilling initiated December 1981 and ended June 1982) revealed a slight, statistically significant increase (2-5 percent) in material finer than 0.125 mm (very fine sand and silt + clay) since July 1982 (Spearman rank correlation analysis of a trend over time: $r_S = 0.78$, $p = 0.01$; Figure 135). This change may or may not be related to drilling operations; other site specific stations (including Station 5-28, 6 km east or upstream from Station 5-1) showed the same fining trend, as did Station 12 ($r_S = 0.73$, $p = 0.05$; Appendix Table J-1). A sediment history of Station 16 (within 200 m of the Block 410 drill site; drilling initiated August 1981 and ended March 1982), however, showed a decrease (5-10 percent) in very coarse sand (2.0 - 1.0 mm) with complimentary increase in material finer than 0.5 mm (medium + fine + very fine sand) since July 1981 ($r_S = 0.63$, $p = 0.05$; Figure 136). Note also that sediment size composition may be returning to pre-drilling conditions. No such trends exist for near-vicinity Stations 17 and 18 over the course of this study.

Patches of fine sediment around the heads of Lydonia and Oceanographer Canyons (Stations 7A and 9, respectively) and west of Georges Bank (Stations 13 and 13A, locally known as the Mud Patch) have undergone net increases in finer size classes of their respective size compositions (Figures 137 to 140). Station 7A has shown a roughly 12 percent increase in silt + clay (<0.063 mm) and an attendant decrease in medium and fine sands (0.500 - 0.125 mm) over the period July 1982 - May 1984 ($r_S = 0.79$, $p = 0.05$). Station 9 has undergone a systematic increase totalling roughly 13 percent in very fine sand and silt + clay (material $\leq$0.125 mm) over the period July 1981 - May 1984 ($r_S = 0.89$, $p = 0.01$). Stations 13 and 13A both have shown a decrease in sand size classes (>0.063 mm) and complimentary increase (totalling to 20 percent weight) in silt + clay since July 1982 (Station 13: $r_S = 0.76$, $p = 0.01$; Station 13A: $r_S = 0.81$, $p = 0.05$).

Average and replicate sediment size data of Stations 7A, 13 and 13A revealed possible effects of fortuitous sampling over time in areas of locally patchy sediments.

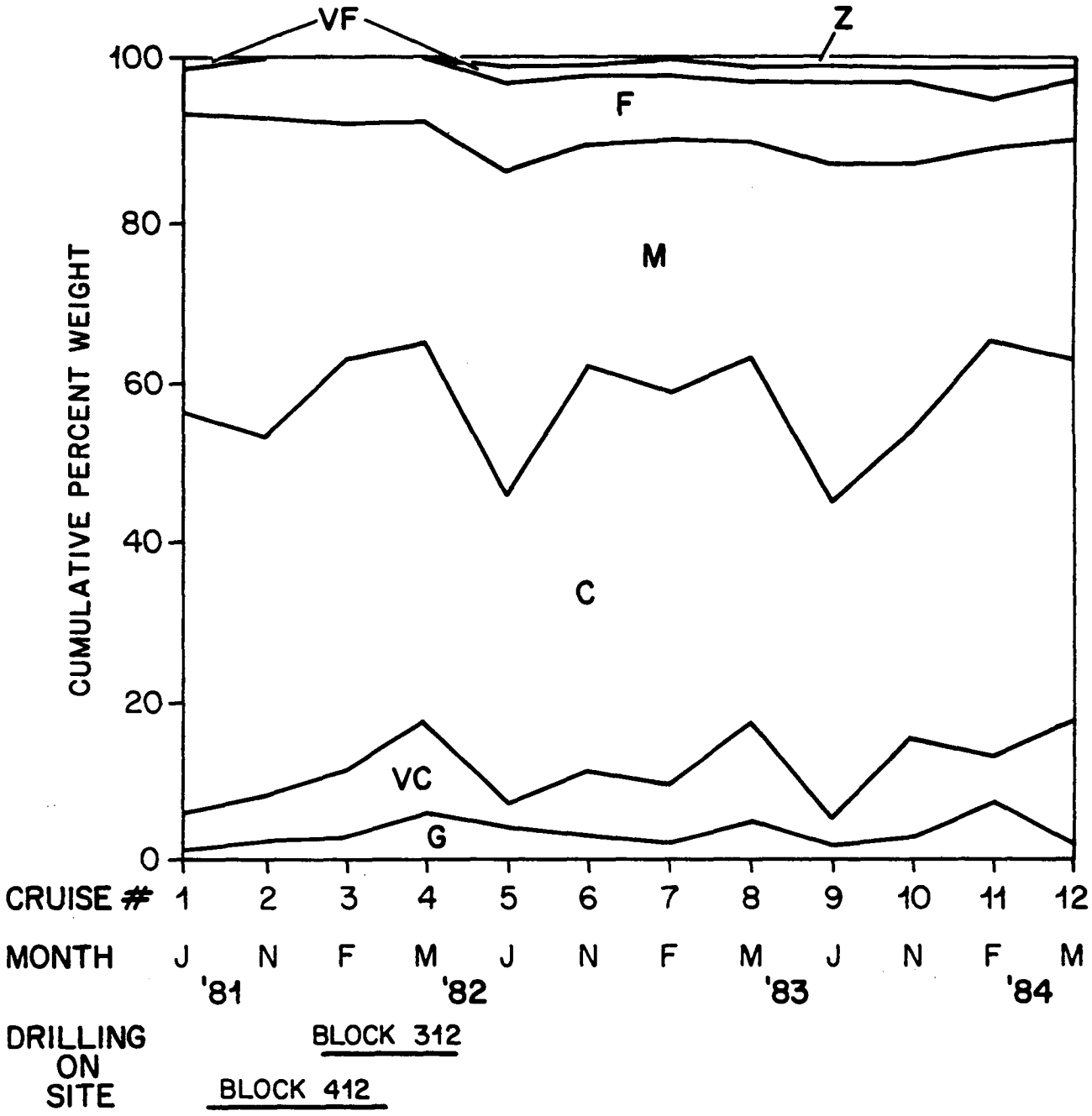

Figure 135. Site-Specific Station 5-1. Sediment texture over all sampling occasions, expressed as cumulative percent weight for each size class. Size classes: G=gravel, VC=very coarse sand, C=coarse sand, M=medium sand, F=fine sand, VF=very fine sand, Z=silt + clay. Months: J=July, N=November, F=February, M=May.

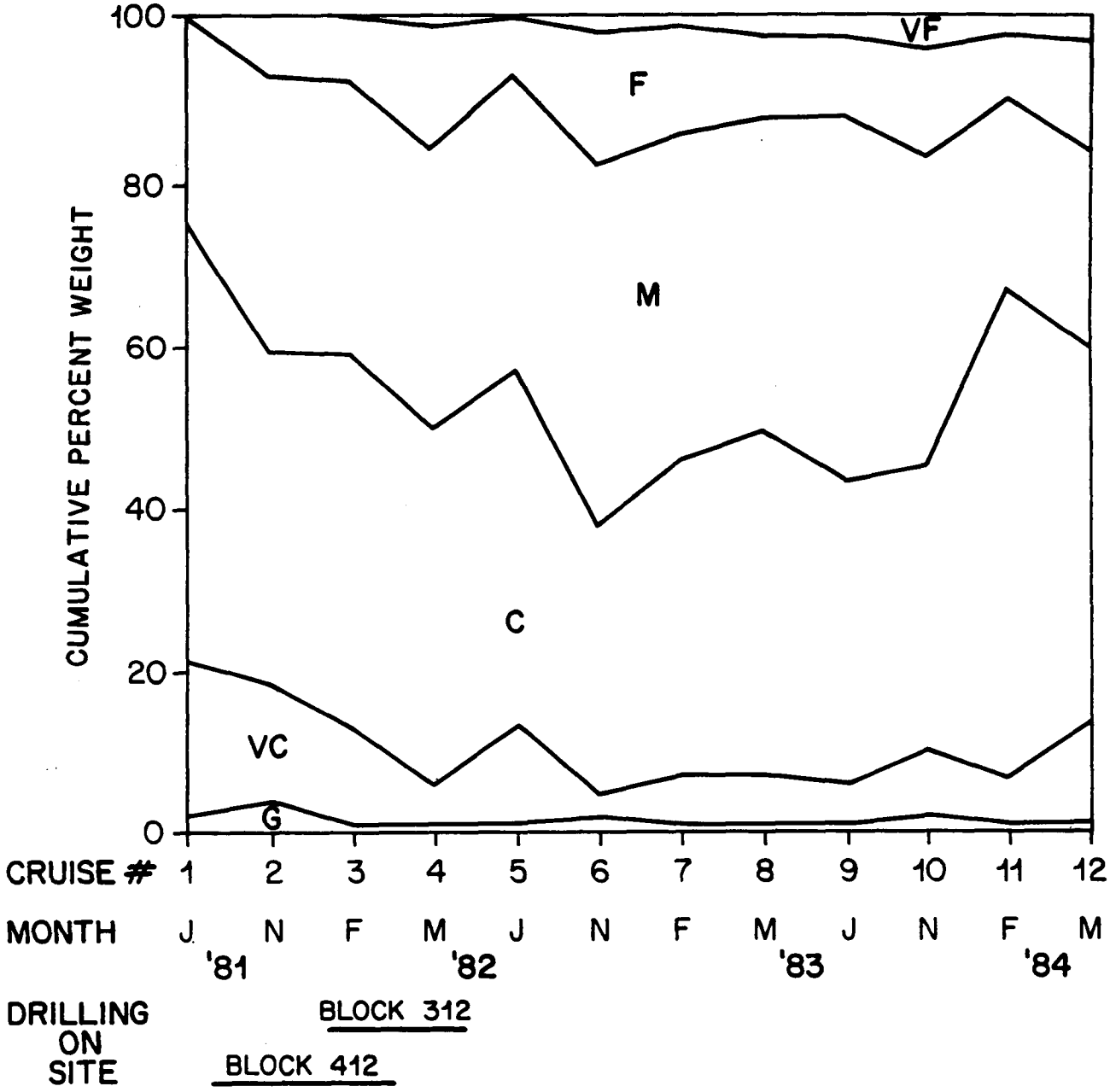

Figure 136. Regional Station 16. Sediment texture over all sampling occasions, expressed as cumulative percent weight for each size class. Size classes: G=gravel, VC=very coarse sand, C=coarse sand, M=medium sand, F=fine sand, VF=very fine sand, Z=silt + clay. Months: J=July, N=November, F=February, M=May.

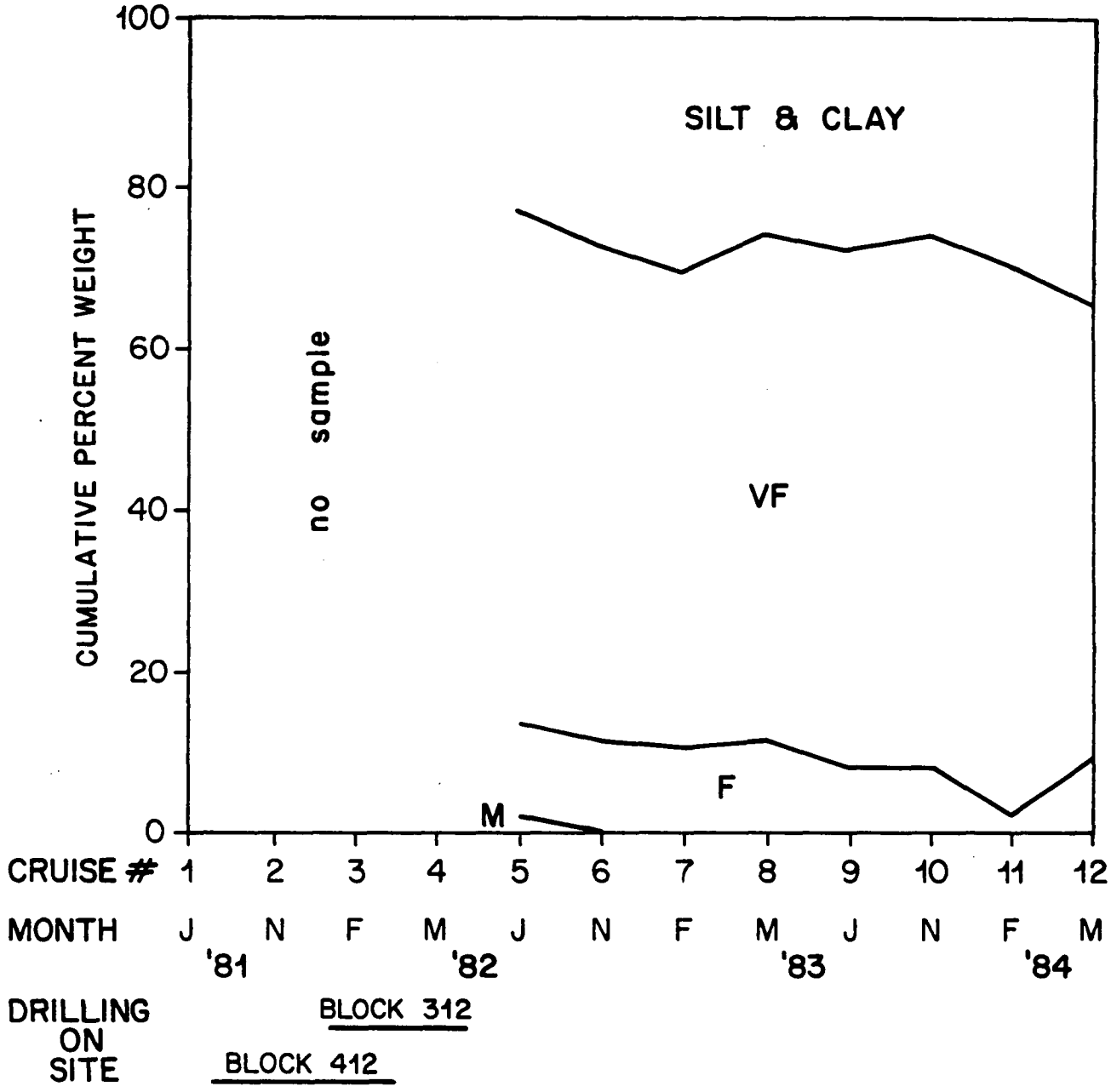

Figure 137. Regional Station 7A. Sediment texture over all sampling occasions, expressed as cumulative percent weight for each size class. Size classes: G=gravel, VC=very coarse sand, C=coarse sand, M=medium sand, F=fine sand, VF=very fine sand, Z=silt + clay. Months: J=July, N=November, F=February, M=May.

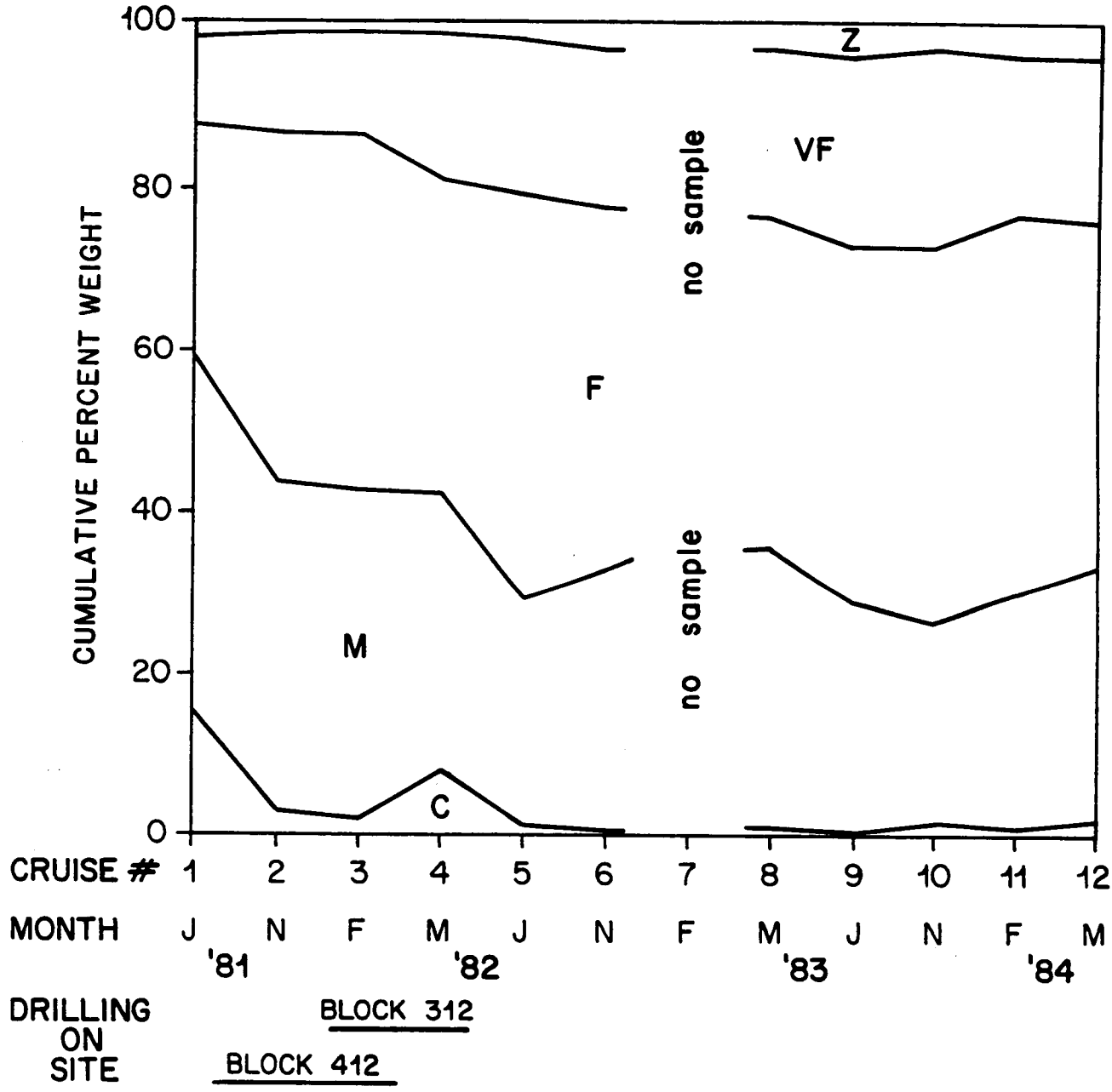

Figure 138. Regional Station 9. Sediment texture over all sampling occasions, expressed as cumulative percent weight for each size class. Size classes: G=gravel, VC=very coarse sand, C=coarse sand, M=medium sand, F=fine sand, VF=very fine sand, Z=silt + clay. Months: J=July, N=November, F=February, M=May.

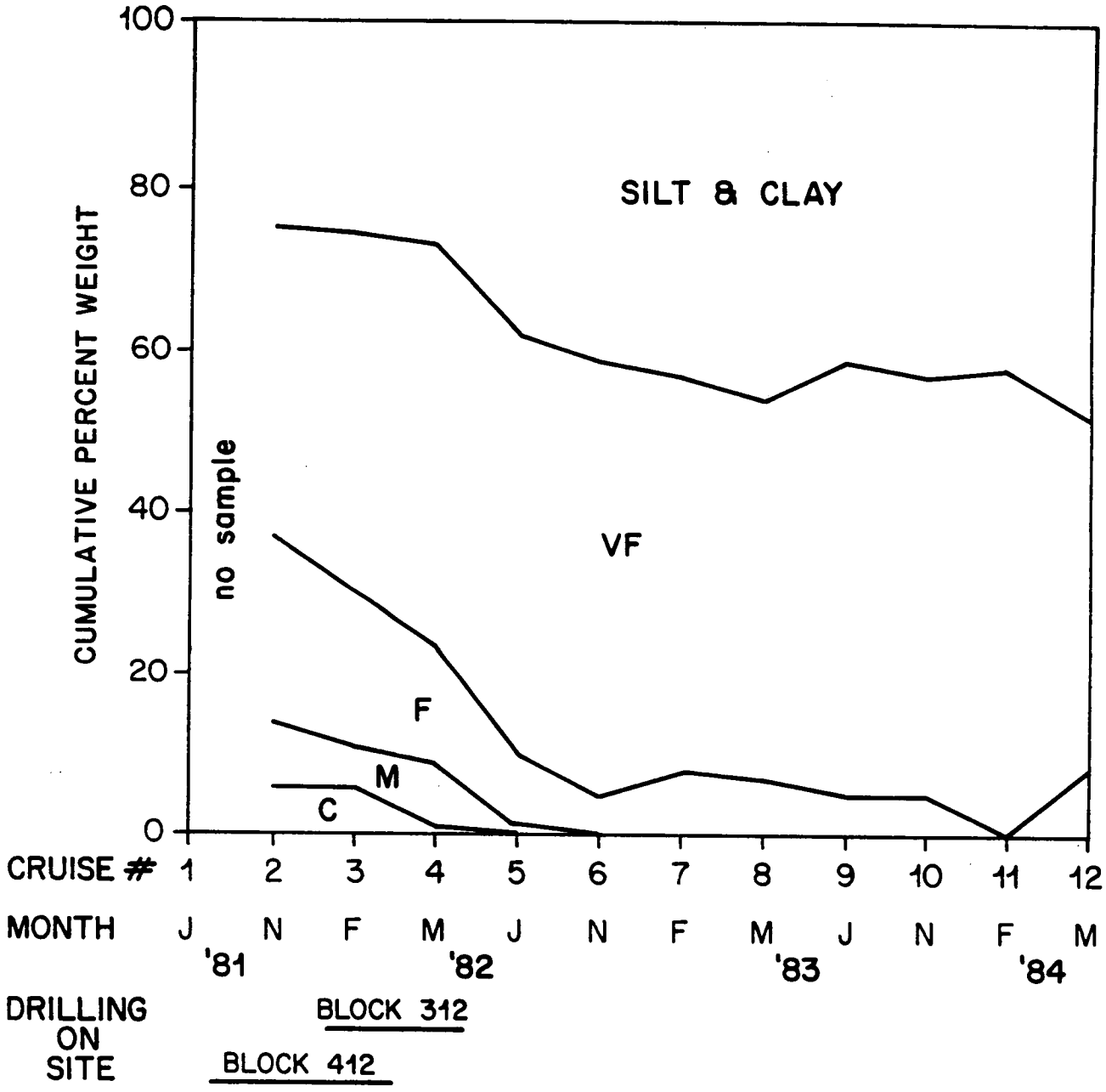

Figure 139. Regional Station 13. Sediment texture over all sampling occasions, expressed as cumulative percent weight for each size class. Size classes: C=coarse sand, M=medium sand, F=fine sand, VF=very fine sand. Months: J=July, N=November, F=February, M=May.

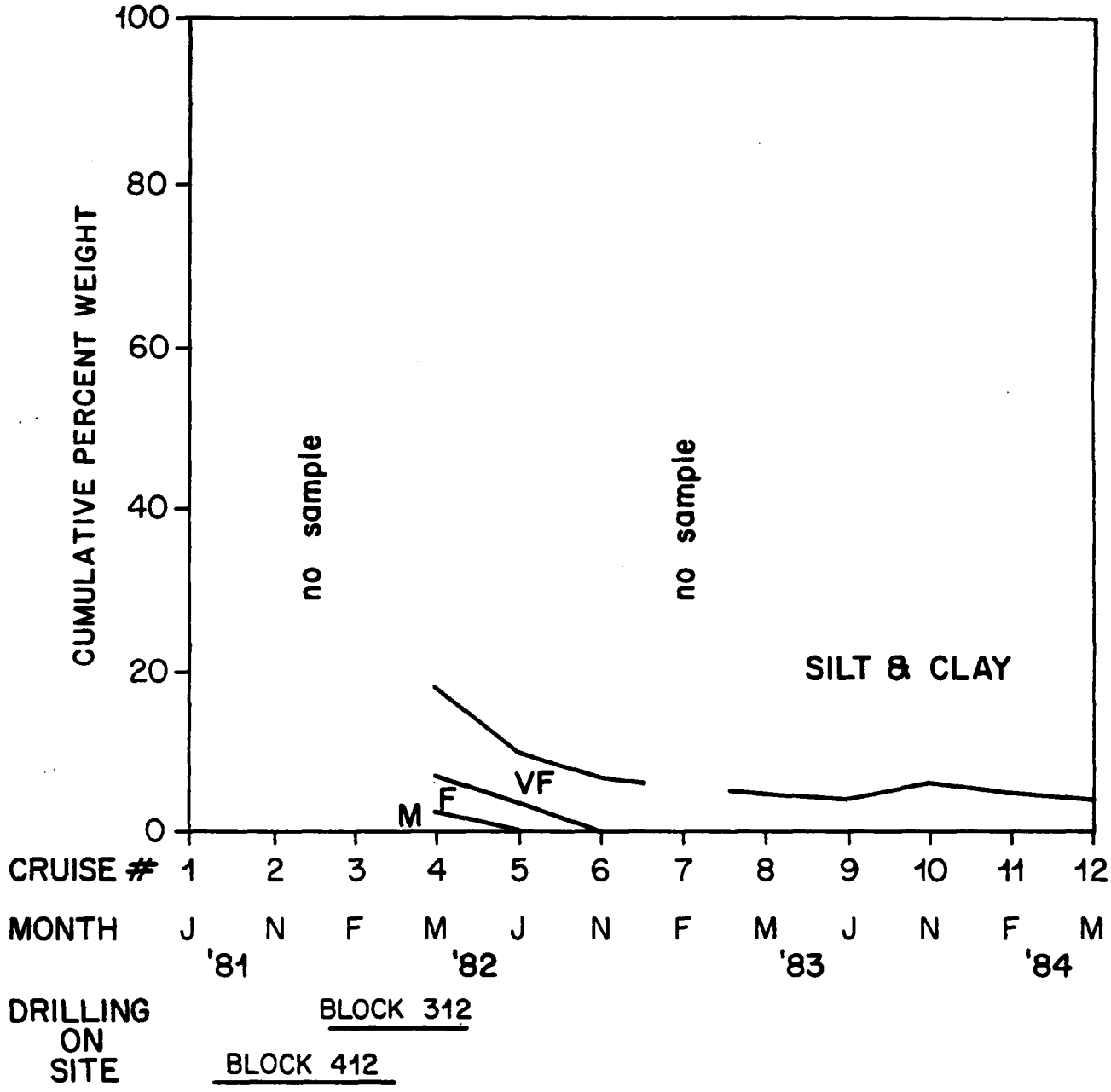

Figure 140. Regional Station 13A. Sediment texture over all sampling occasions, expressed as cumulative percent weight for each size class. Size classes: M=medium sand, F=fine sand, VF=very fine sand. Months: J=July, N=November, F=February, M=May.

Average positions of Station 7A on successive cruises between July 1982 and June 1984 (M5-M12) suggest a possible trend over time to sample downslope over a distance of less than 0.1 km in which silt + clay may increase from 22 to 35 percent of sediment weight (Appendices A and J). A review of average positons of Station 13A revealed a clustering of samples taken during Cruises M4-M6 (May 1982 - November 1982) approximately 0.15 km east of samples taken during Cruises M8-M12 (May 1983 - June 1984) (Appendix A), possibly producing the observed trend over time depicted in Figure 140.

Station 13 is examined in more detail here due to the ecologically significant relationship of sediment grain size and faunal change described in Chapters 3 and 5. Average positions and silt + clay values for Station 13 on successive cruises suggest a gradient of increasingly fine sediments from southeast to northwest over a distance of 0.4 km (Appendices A and J). Unfortunately, average station positions of successive cruises drifted along this gradient. A scatterplot of M2-M12 Station 13 replicate values of silt + clay vs. position along a SE-NW line ($\sqrt{(\text{Longitude})^2 + (\text{Latitude})^2}$) revealed a statistically significant correlation between sediment size and location independent of time of sampling ($r = 0.44$, $n = 66$, $p = 0.01$; Figure 141). However, time-independence of this gradient is in question. Samples from Year 1 (November 1981 - May 1982) occurred over most of the locational gradient yet were uniformly low in silt + clay (17-37 percent; Figure 141). Samples collected in Years 2 and 3 (July 1982 - June 1984) occurred over most of the locational gradient and were uniformly high in silt + clay (31-55 percent; Figure 141). Percent silt + clay contoured on position (Figure 142) shows the spatial gradient of increasing silt + clay to the northwest. This figure shows, too, that low values ($\leq$30 percent silt + clay) of the southwest and anomalous patch in the northwest are all Year 1 replicates; higher values ($\geq$40 percent silt + clay of the northwest and anomalous patch of the southeast are all Year 3 replicates. Data of Year 2 are intermediate in position and silt + clay content. Although the range of silt + clay values is greater than that attributable to analytical error, we cannot separate the changes in sediment characteristics in time and space.

DISCUSSION

Regional distribution of Georges Bank sediment types reflects both historical and present environmental conditions (Schlee, 1973; Bothner et al, 1979; Bothner et al, 1981; Twichell et al, 1981; Butman, 1982; Butman and Moody, 1983; Butman et al, 1983; Twitchell, 1983). Surficial sediments are relict deposits of glacial activity ending approximately 10,000 years ago. As post-glacial sea level rose, material has been

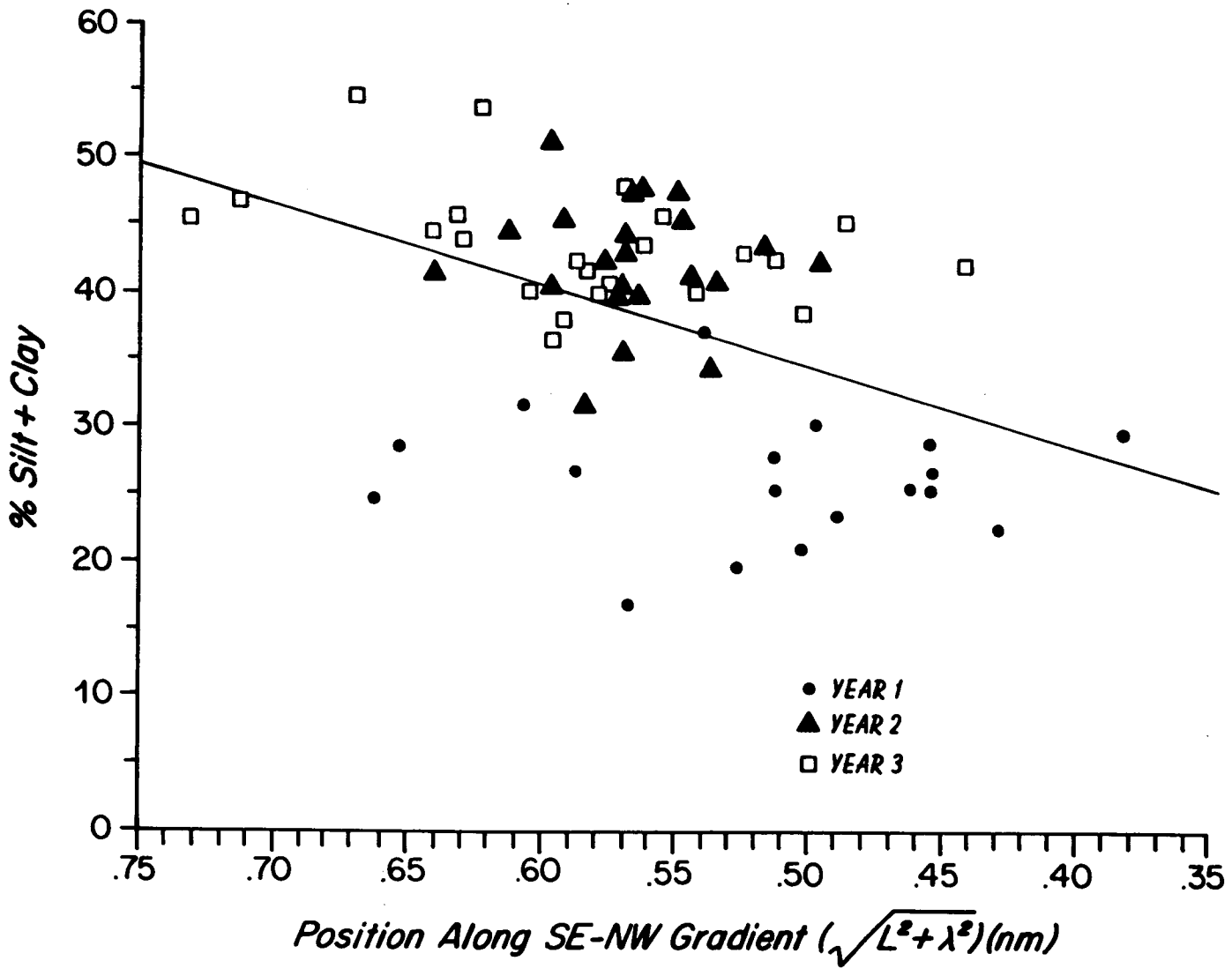

Figure 141. Station 13. Scatterplot of silt + clay versus position along a SE-NW trending line ($\sqrt{(\text{Latitude})^2 + (\text{Longitude})^2}$) in nautical miles for all replicates November 1981 to June 1984 (M2-M12).

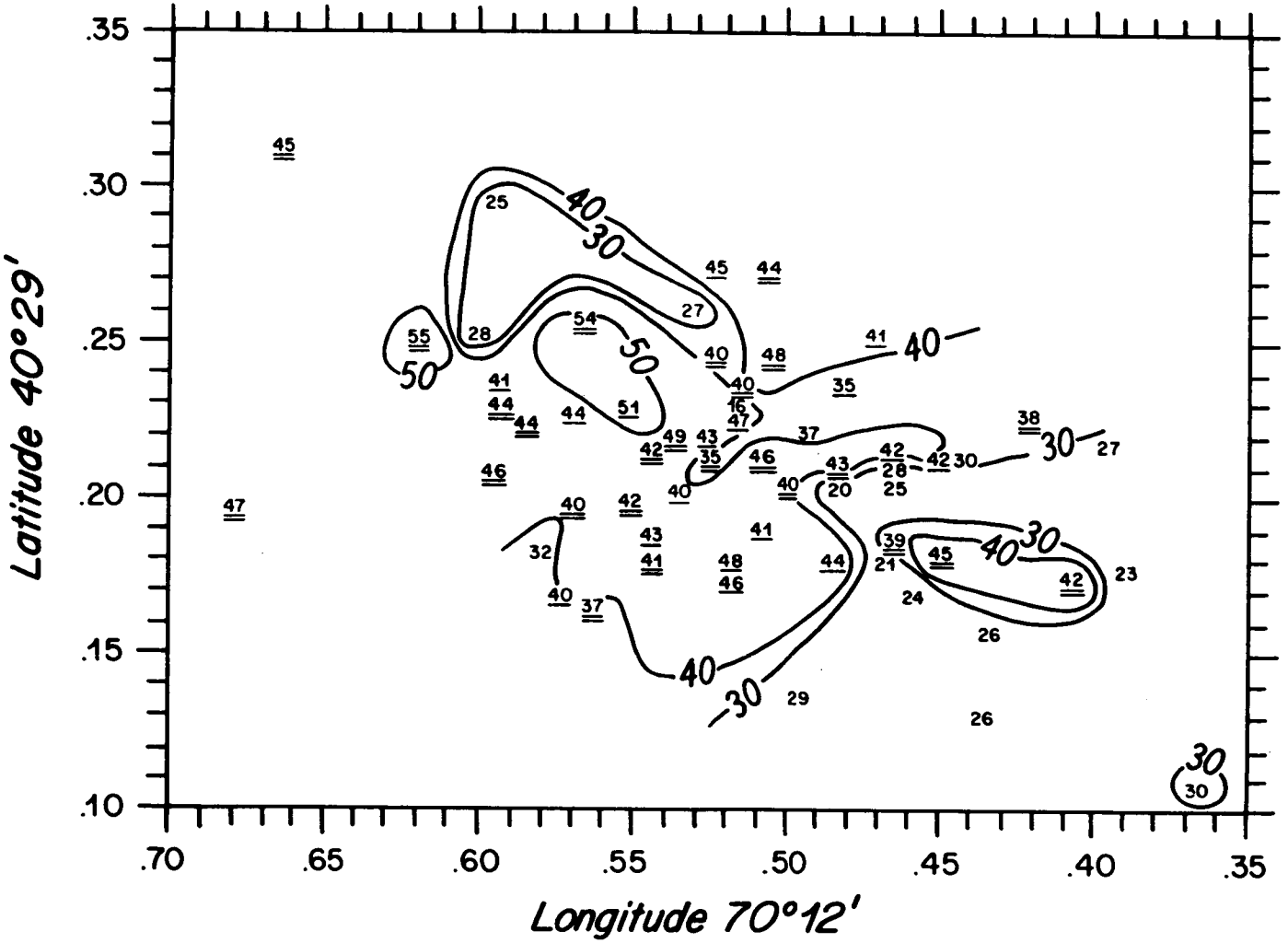

Figure 142. Station 13. Silt + clay content contoured in 10 percent intervals on geographical position for all replicates November 1981 to June 1984 (M2-M12). A silt + clay value with no underline indicates replicates of Year 1 (November 1981 to May 1982), one underline indicates replicates of Year 2 (July 1982 to May 1983) and two underlines indicates replicates of Year 3 (July 1983 to June 1984).

reworked continuously by tidal and mean net southwestward flows and periodically during storm events. Attenuation of transport mechanisms with depth on the southern flank of and distance downstream from Georges Bank has resulted in localized, modern-day accumulation of fine material "winnowed" from upslope/upstream bank deposits. The resulting regional sediment distribution includes:

1) A complex planar sediment distribution across shelf characterized by a) a slight increase in fine material with depth, b) present-day accumulation of material finer than 0.125 mm at the heads and on the flanks of Lydonia and Oceanographer Canyons, and c) regions of coarse material (>0.250 mm) on shelf areas not immediately adjacent to canyons (Butman et al, 1983; note particularly Figures 8-10). This regional pattern is apparent in our own observations.

2) A net increase in present-day accumulation of fine grained material along shelf (NE to SW) to the region south of Cape Cod known locally as the Mud Patch; the gradient exists along depth contours in a downstream direction relative to net southwestward currents observed to depths of 100 m (Bothner et al, 1981; Twichell et al, 1981). This regional pattern is particularly well-demonstrated in our observations at depths of 70-80 m. Along this gradient, silt + clay increases from ≤ 1 to ≥ 95 percent weight.

Measurements of bottom current regime and suspended sediment load and observations in bottom photographs document the importance of continuous tidal and seasonal storm processes in reworking Georges Bank sediments (Battelle and W.H.O.I., 1983, 1984; Butman and Folger, 1979; Butman and Moody, 1983; Butman, in prep.). These processes effect not only the regional distribution of sediments as described above, but periodic changes in their magnitude and frequency also result in temporal fluctuations of surface sediments at a site. Seasonal changes in the type and extent of biological activity observed in bottom photographs also result in sediment variation over time on Georges Bank (Butman, 1982).

Observations during the winters of 1977 (Butman, 1982) and 1978 (Butman and Moody, 1983) at a site on the southern flank of Georges Bank (Station A, 85 m depth) reveal mean bottom currents of 20-30 cm/sec increased by ≥ 10 cm/sec for extended periods of time (≥ 10 hr) during storm events. Under such conditions, material less than 0.125 mm (very fine sand, silt, and clay) is easily resuspended while larger material is transported as bedload (Butman and Moody, 1983). At our Site-Specific Station 5-1 (85 m depth, approximately 35 km west of Station A studied by Butman and others) from July 1981 to May 1984, sediment size fluctuations reflect this seasonality particularly well. Increases in coarse fractions at Station 5-1, as well as at Stations 1, 2, 6, 11, and 18

during periods of heightened storm activity (November, February, May) are presumably the result of winnowing of finer fractions during storm events. While temporal fluctuations are present at other stations, their ecological significance must be examined case by case. Seasonal sedimentation patterns may be confounded by other periodic events of intense sediment reworking, such as internal waves particularly important in the stratified water column of summer months (Butman and Moody, 1983; Butman, in prep.).

The occurrence of drill cutting rock fragments at Blocks 312 and 410 drill sites has not appreciably changed the grain size distribution at those sites; only particle composition has changed.

The sedimentation patterns described above are corroborated by independent analyses performed at the U.S. Geological Survey (Bothner et al, 1982; 1983; 1985). Those described for Stations 13 and 13A are exceptions, however, USGS data revealed little or no change in sediment size characteristics of these locations over the course of the study. Increases in fine sediments at these stations as well as at Stations 7A and 9 observed over time may be partialy explained by 1) successive samplings along a local size gradient within an area of locally patchy sediments, 2) a real trend over time, or 3) some combination of the two. A fourth possibility is that of experimental artifact: three independent technicians performed the W.H.O.I. analyses of samples from Cruises M2-M4, M5-M9, M10-M12, respectively. It is hard to choose among these possible explanations with the given data. At Station 13 in particular, at least, sediment texture changed over Years 1-3 of the monitoring program. The activities of increasingly dominant surface deposit feeders could result in a net increase in fine sediments at the surface as observed at Station 13 (see Chapters 3 and 5).

Sedimentation patterns of a smaller scale than those presented here (e.g., changes over two cruises, or paired comparisons of stations) have not been discussed. Such comparisons are best made in conjunction with a specific ecological question or known physical event. Analysis of smaller scale patterns should take advantage of the independent analyses of similar samples performed at the U.S. Geological Survey. Only trends apparent in both sets of sediment data can be treated with complete confidence.

SUMMARY

- Despite procedural errors in some of our analyses (which have been resolved), we were able to determine a 5 percent weight or greater difference in size class comparisons between replicates, stations, or cruises.

- With respect to sediment data, most station replicates are homogeneous. These station replicates thus represent true replicates of similar environmental settings.
- The distribution of sediment texture determined in this program agrees with observations reported in earlier studies. There is a slight increase in fine material with depth, most noticeably around the head of Lydonia Canyon (Station 7A), and to the west of Georges Bank alongshelf (a well-defined gradient exists along 70-80 m depth contours, Stations 2, 5, 11, 13, 13A).
- Several stations (1, 2, 5, 6, 11, 18), representative of most depths sampled, exhibit seasonal changes in sediment size characteristics: finer size classes show an increase of 5 to 20 percent total weight in July of each year as a result of reduced winnowing action of storms.
- Long term changes observed in the study include:
  1. occurrence of calcareous drill cuttings in sand and gravel fractions of Station 5-1 (at drill site of Block 312) and Station 16 (at drill site of Block 410) since Year 1;
  2. an increase of roughly 10-20 percent weight in respective finer size classes at Station 7A (160 m depth, head of Lydonia Canyon), Station 9 (140 m depth, head of Oceanographer Canyon), Stations 13 and 13A (75 m depth, Mud Patch west of Georges Bank), and Station 16 (140 m depth, southeastern flank of Georges Bank, Block 410 drill site) since Year 1;
  3. an increase of roughly 2-5 percent total weight in very fine sand and/or silt + clay at all site-specific stations (5-1 through 5-28, approximately 85 m depth) of Block 312, and Station 12 (104 m depth) since Year 1;
  4. observed increases in fine sediments at these stations is attributed to some combination of real trends over time, successive samplings along local gradients or in areas of patchy sediments, and/or technician error associated with personnel changes.

- Other fluctuations in sediment size characteristics do exist and should be examined in the context of specific ecological relationships or physical events.

ACKNOWLEDGEMENTS

Deborah Wiebe, Diane Eskansy, and Melinda Sweeney performed much of the laboratory analysis of sediments described here. Our gratitude is extended to Dr. M. Bothner, Dr. B. Butman, L. Poppe and R. Rendigs of USGS and Dr. J. Milliman of W.H.O.I. for advice and use of facilities.

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CHAPTER 11. HYDROGRAPHY

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INTRODUCTION

An important premise underlying the regional station design of the Georges Bank Benthic Infauna Monitoring Program was that dominant factors controlling benthic infaunal community structure on the southern flank of the Bank are water depth and sediment texture or granularity. However, it is well known that hydrographic factors such as water temperature, salinity, and dissolved oxygen concentration can contribute to small-scale or regional variations in distribution or abundance of different benthic infaunal populations. Therefore, in comparing benthic infaunal communities in the region of exploratory drilling with those upcurrent and downcurrent of it for evidence of possible drilling-related impacts, it is important to examine and compare the hydrographic regimes of the three regional transects and other stations in nearby depositional areas. In this chapter, we present the results of the hydrographic investigations and examine these data in relation to station, water depth, and season.

METHODS

The hydrographic parameters of temperature, dissolved oxygen concentration, and salinity were measured at all regional stations and at one site-specific station on all cruises. In a few cases some of these data were not collected due to bad weather or other problems. Surface water samples were taken by lowering a bucket over the side while bottom water samples were taken with a Niskin water sampling bottle attached to the winch wire of the grab sampler.

Temperature data were obtained with expendable bathythermographs (XBTs). A deck-mounted launcher was used to deploy the XBT and a strip chart recorder was used to produce the temperature-depth profile.

Salinity at each station was measured for one surface water sample and one bottom water sample. Samples from the first, second, and fifth through twelfth cruises were analyzed on an AUTOSAL 8400® at W.H.O.I., while the samples from the third and fourth cruises were analyzed with either a Hydrolab® Model IIB conductivity probe or an American Optical® refractometer.

The dissolved oxygen concentrations were determined from three replicates of bottom water from the Niskin bottle sample at each station. When the water sample was received on deck, portions were drawn off into Winkler (BOD) bottles and fixed with manganous sulfate and alkaline iodide solutions. A Winkler titration was performed using an automated burette within three hours of sample collection. On Cruises M7 through M9 an additional measurement of dissolved oxygen was taken using an oxygen electrode coupled to a PH/MV meter.

RESULTS

With some exceptions, water temperature, salinity and dissolved oxygen concentrations were measured at all regional stations on all twelve sampling cruises. These data are summarized in tabular form in Appendix K. Because seasonal patterns of benthic infaunal abundance and distribution can be influenced profoundly by natural fluctuations in temperature, salinity, and dissolved oxygen of near-bottom water, this discussion will focus on these parameters. Values for near-surface salinity and temperature will not be discussed further here.

The distribution of bottom water temperature in the study area showed characteristic seasonal patterns (Figures 143 to 147). The stations below 100 m on the southern slope of Georges Bank had higher bottom water temperatures than did shallower stations in the fall, winter, and spring of 1981/82. In May 1982, an unusually high temperature of 16.8°C was recorded at Station 14 in the Gulf of Maine and at Station 17 in 140 m of water on the southern flank of the Bank (Figure 145). In the summer of 1982, the highest bottom water temperature was recorded at Station 15 on the top of the Bank. Unusually low temperatures, compared to nearby stations, were observed at Stations 2 and 7. The pattern of bottom water temperature distribution was similar in the winter of 1982 (Cruise M3) and 1984 (Cruise M11) (Figures 144 and 147). The seasonal pattern that emerged was that bottom water temperature fluctuated most on a seasonal basis at the shallowest stations and became more stable at deeper stations. Bottom water temperature varied seasonally by more than 10°C at Station 15, but remained near 10°C throughout the three years of the program at deeper stations such as Stations 7, 8, 9, 16,

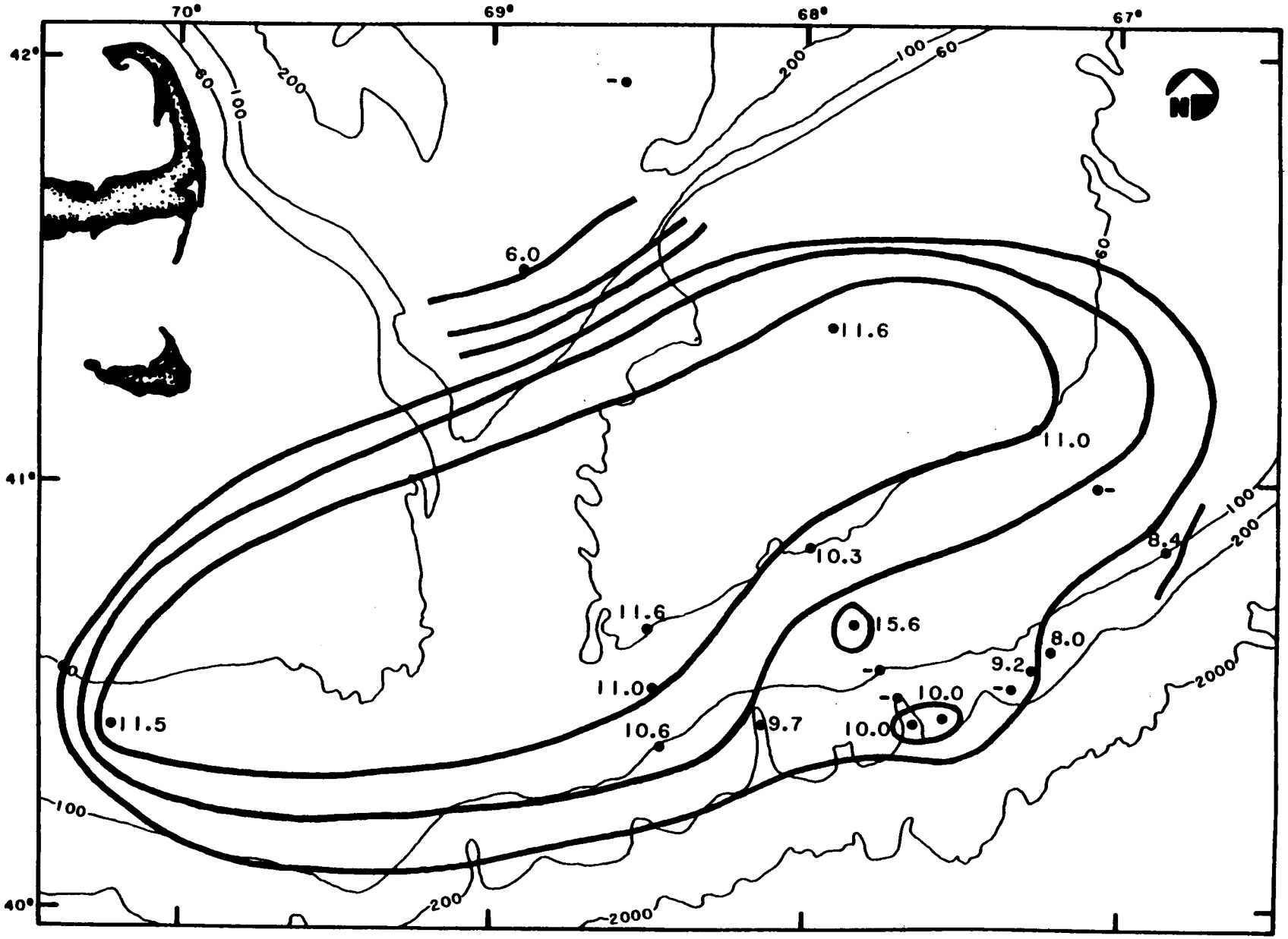

Figure 143. Bottom temperature distribution, Cruise M2, November 1981.

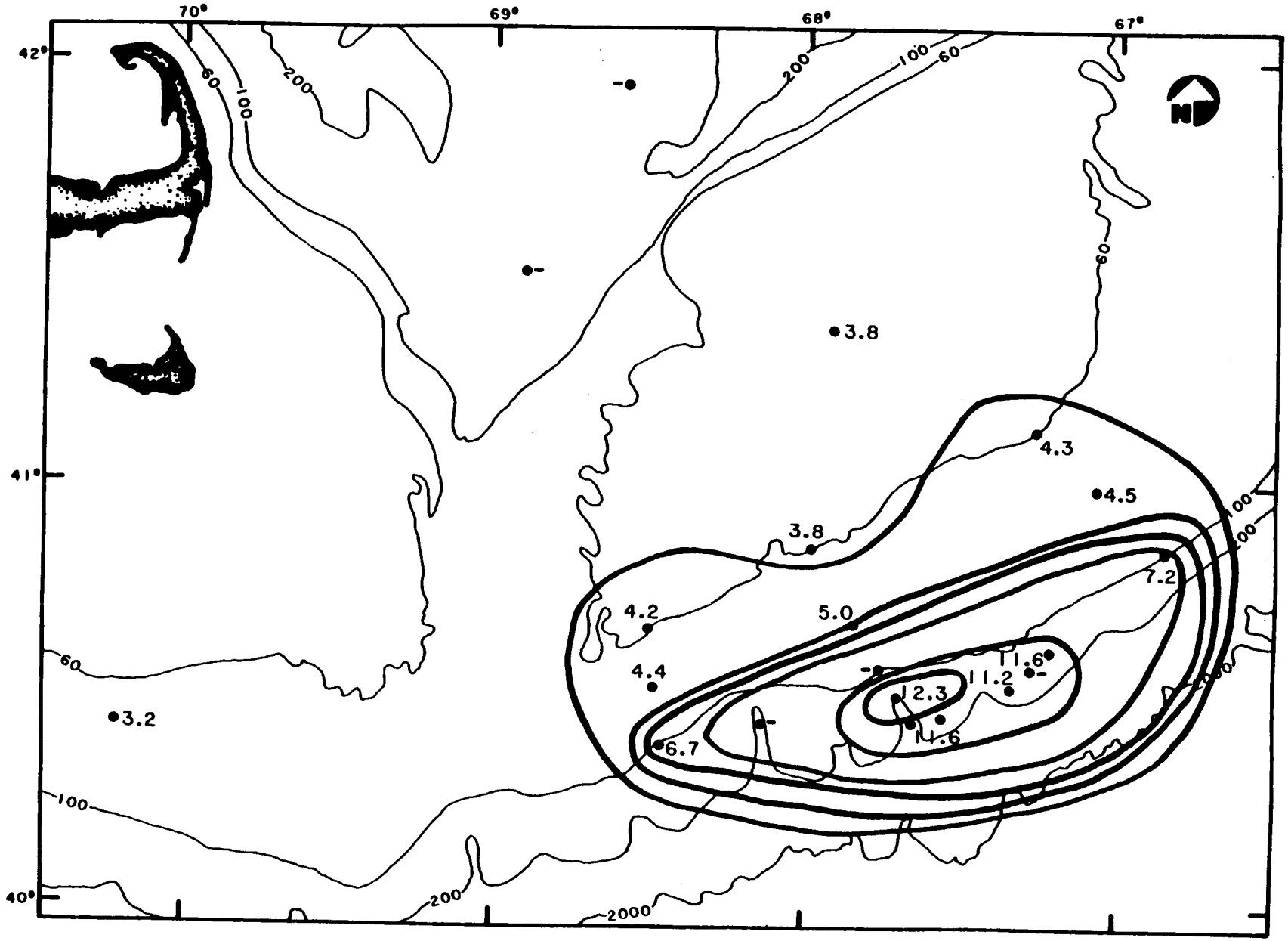

Figure 144. Bottom temperature distribution, Cruise M3, February 1982.

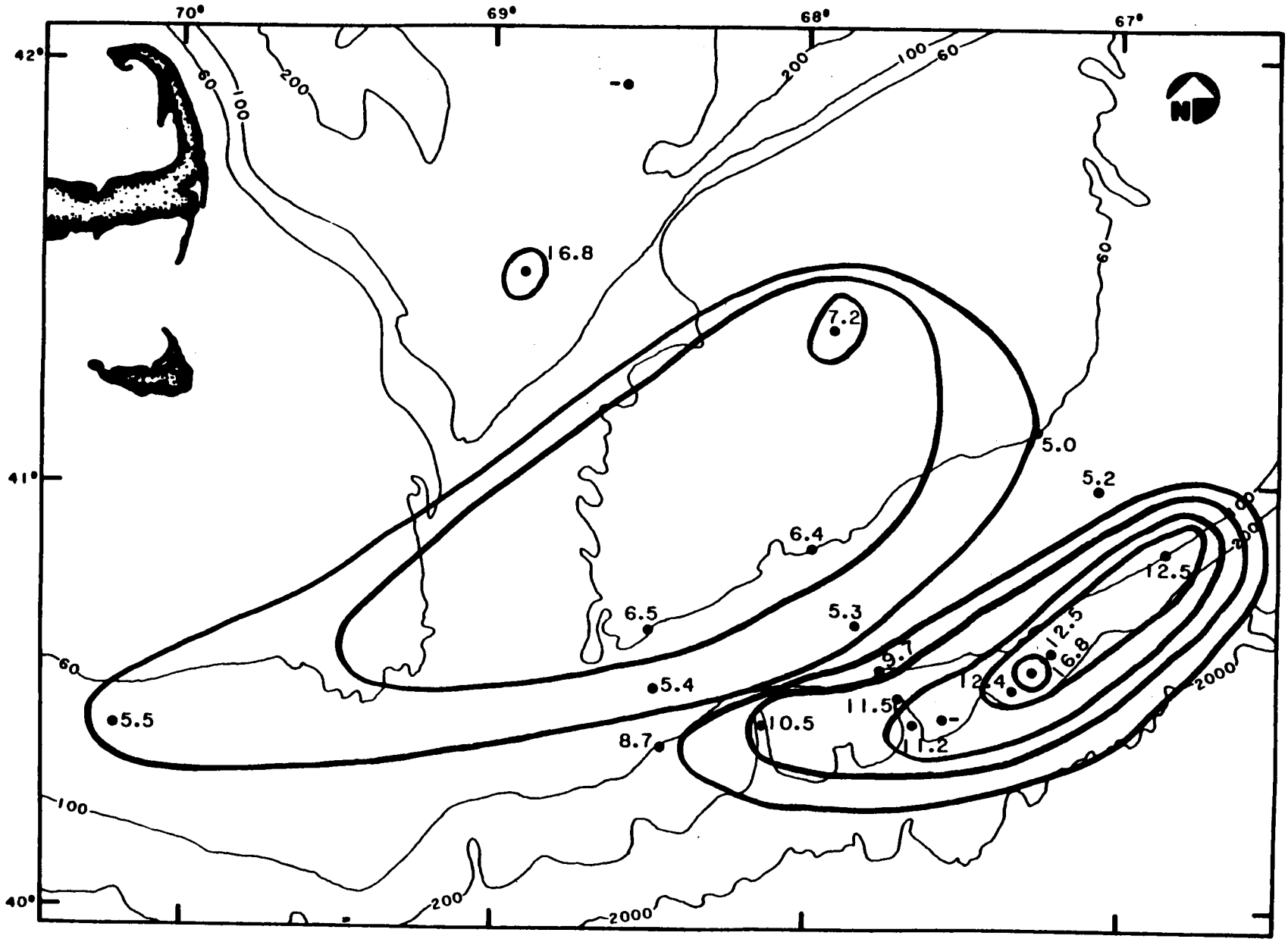

Figure 145. Bottom temperature distribution, Cruise M4, May 1982.

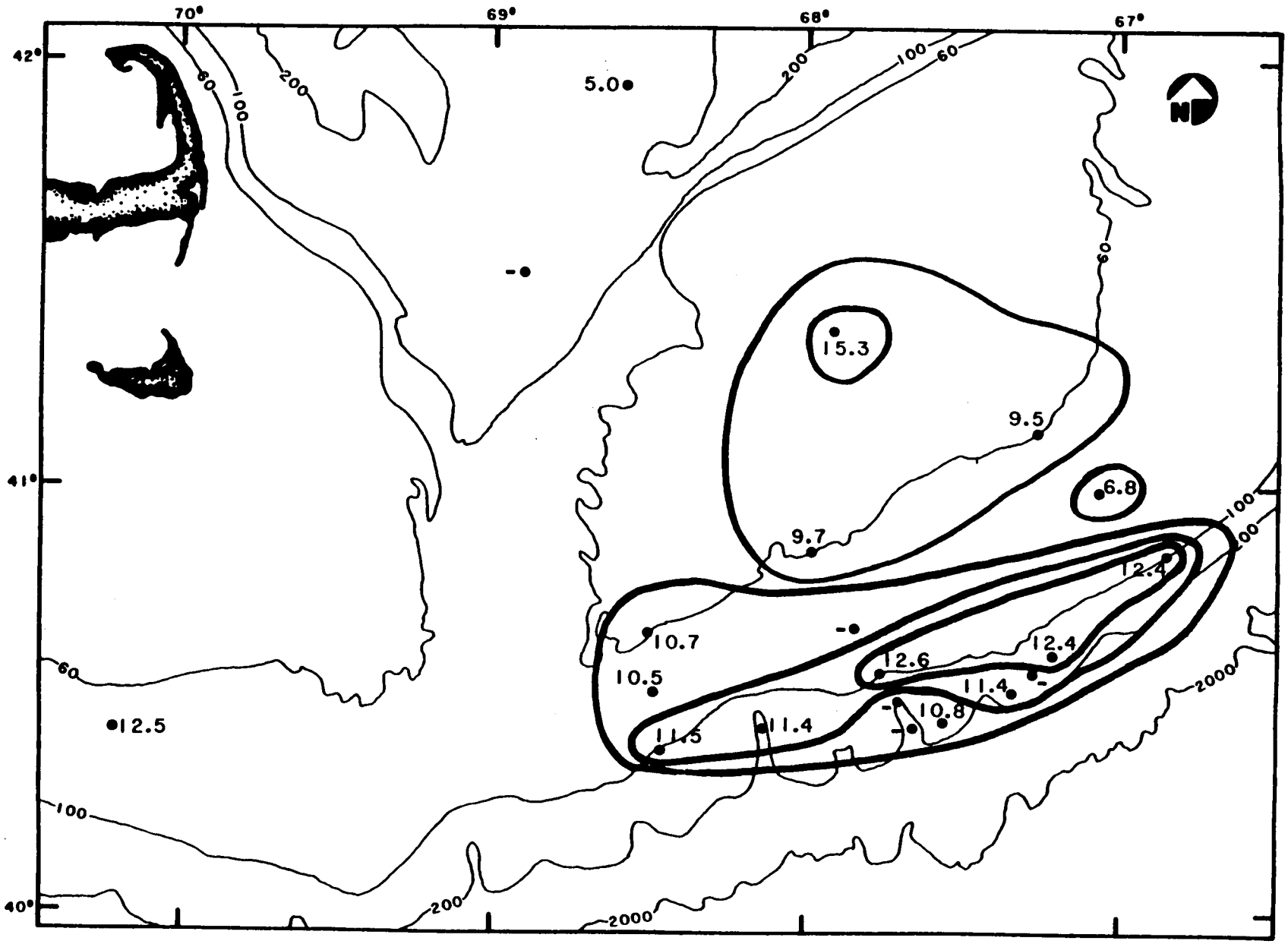

Figure 146. Bottom temperature distribution, Cruise M5, July 1982.

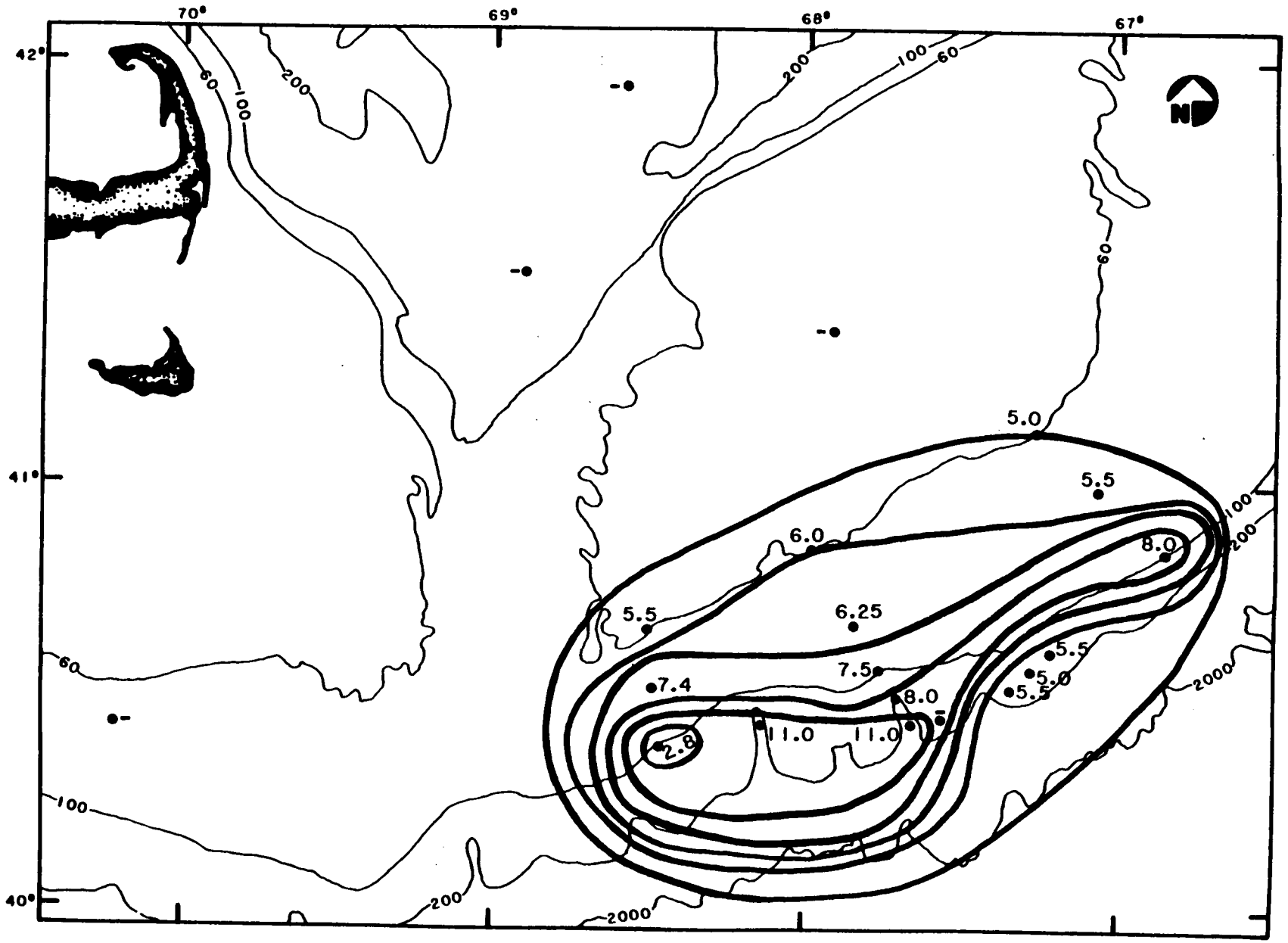

Figure 147. Bottom temperature distribution, Cruise M11, February 1984.

17, and 18 (Table 32). Temperature of bottom water at Stations 8 and 9, at 152 and 144 m water depth, respectively, ranged from 9.5 to 12.5°C during the twelve seasonal cruises.

In designing the sampling program, groups of three stations on parallel transects, Regional Stations 1, 4, and 10; 2, 5, and 11; and 3, 6, and 12, were located at similar water depths so that comparisons could be made of chemical and biological parameters between stations upcurrent (Stations 1-3) and downcurrent (Stations 10-12) of the drilling sites with those through the drill site (Stations 4-6). Bottom water temperatures at each set of three stations at similar depth are summarized in Figures 148 through 150. Bottom water temperatures at Stations 1, 4, and 10 (58-70 m water depth) were quite similar on each cruise (Figure 148). The maximum temperature differential among the three stations on any one cruise was 2°C in November 1983 (Cruise M10).

At Stations 2, 5, and 11 (66-83 m water depth), bottom water temperatures were similar on most cruises. On Cruises M2 (November 1981) and M10 (November 1983), water temperature varied by 4.5 to 6.6°C among the three stations. For the deeper group, Stations 3, 6, and 12 in 90-110 m of water, water temperature never differed by more than 4.8°C on any one cruise. There was no clear seasonal pattern of temperature change over all or in any one year of the three-year monitoring program. The difference between the lowest recorded temperature (6.7°C at Station 12 in February 1982) and the highest temperature (13.0°C at Stations 3 and 12 in November 1982) was only 5.3°C, indicating a relatively stable temperature regime.

The salinity of bottom water on Georges Bank varied seasonally and at different stations from 31.0 to 35.5 parts per thousand (ppt). The lowest salinities were recorded at stations in less than 100 m water depth in the winter. Highest salinities were recorded at stations deeper than 100 m in the summer. At any one station, salinity of bottom water varied seasonally by no more than 2-3 ppt.

The seasonal variation in the concentration of dissolved oxygen in bottom water had a similar pattern at all stations (Figures 151 to 154). Dissolved oxygen concentration was highest in the winter and declined gradually with season from spring to summer to fall. In any season, highest dissolved oxygen concentrations were recorded at the shallowest stations and lowest values were recorded at the deepest stations. Dissolved oxygen concentrations below 5 mg/l were recorded at Stations 7, 8, 12, 13, 16, 17, and 18 in the fall of 1982 and in July 1983 at Station 9 (Table 33). Biologically, the absolute concentration of dissolved oxygen is not as important as the percent saturation of the water with oxygen at the ambient salinity, temperature, and barometric pressure. Calculated values for percent saturation of the bottom water with oxygen are included in Table 33 wherever salinity and temperature values were available. Percent oxygen

TABLE 32. MEAN BOTTOM WATER TEMPERATURE, IN °C, AT REGIONAL STATIONS DEEPER THAN 130 METERS ON THE SOUTHERN FLANK OF GEORGES BANK.

		Station					
		7/7A	8	9	16	17	18
		Depth (M)					
Cruise	Date	130/167	152	144	142	141	152
M1	Jul 1981	-	10.8	11.2	10.4	10.6	10.6
M2	Nov 1981	10.0	10.0	9.7	9.2	8.0	-
M3	Feb 1982	12.3	11.6	-	-	11.2	11.6
M4	May 1982	11.5	11.2	10.5	16.8	12.4	12.5
M5	Jul 1982	8.8	10.8	11.4	12.4	-	11.4
M6	Nov 1982	13.4	11.2	12.5	13.0	12.9	15.9
M7	Feb 1983	-	-	-	-	-	-
M8	May 1983	11.4	11.3	10.1	12.5	12.0	12.0
M9	Jul 1983	11.0	11.5	10.0	11.5	12.0	11.5
M10	Nov 1983	10.5	12.5	11.0	-	13.5	13.0
M11	Feb 1984	8.0	11.0	11.0	8.5	9.0	9.5
M12	June 1984	10.5	12.5	11.5	13.0	13.0	13.0

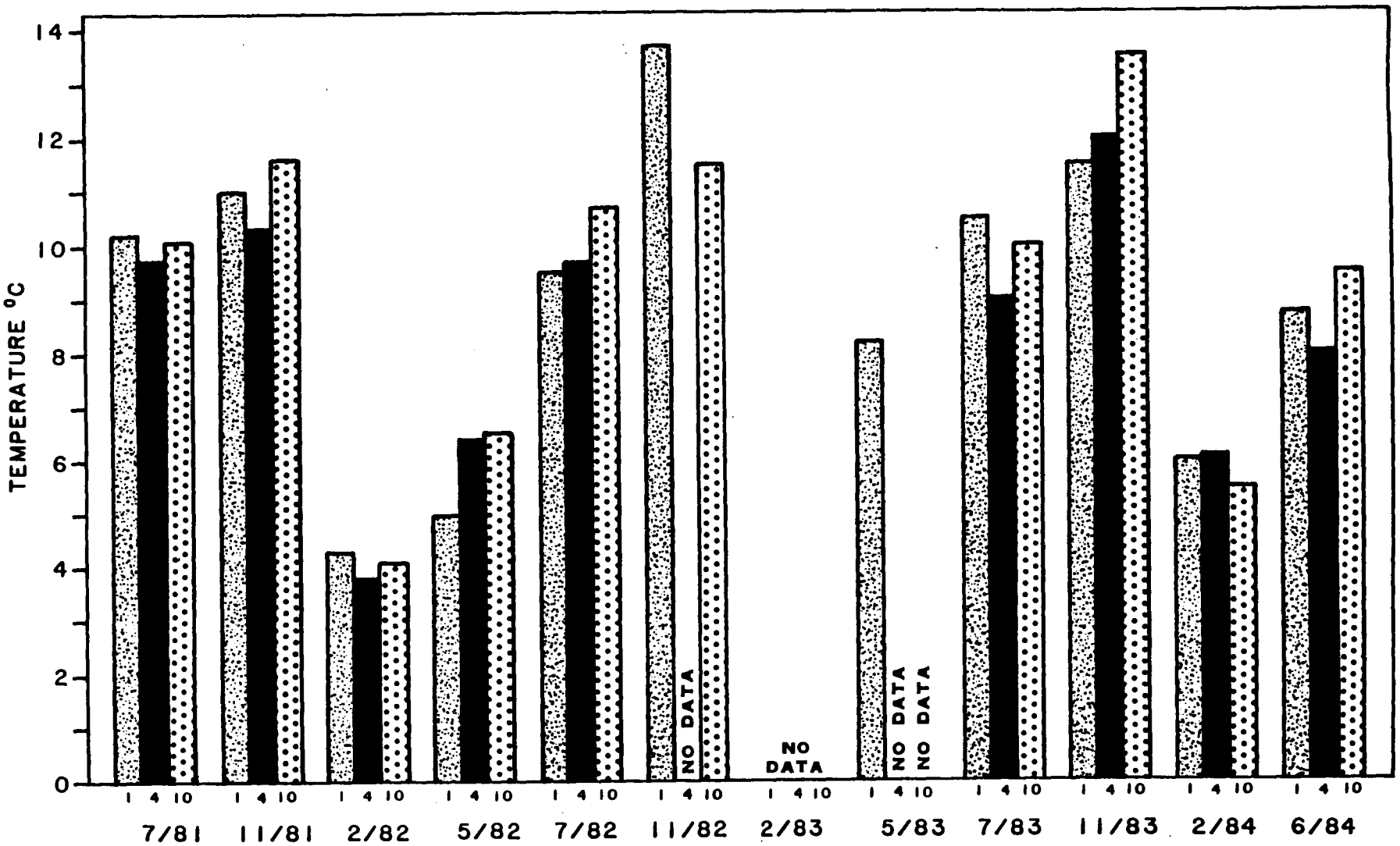

Figure 148. Bottom temperature at Stations 1, 4, and 10.

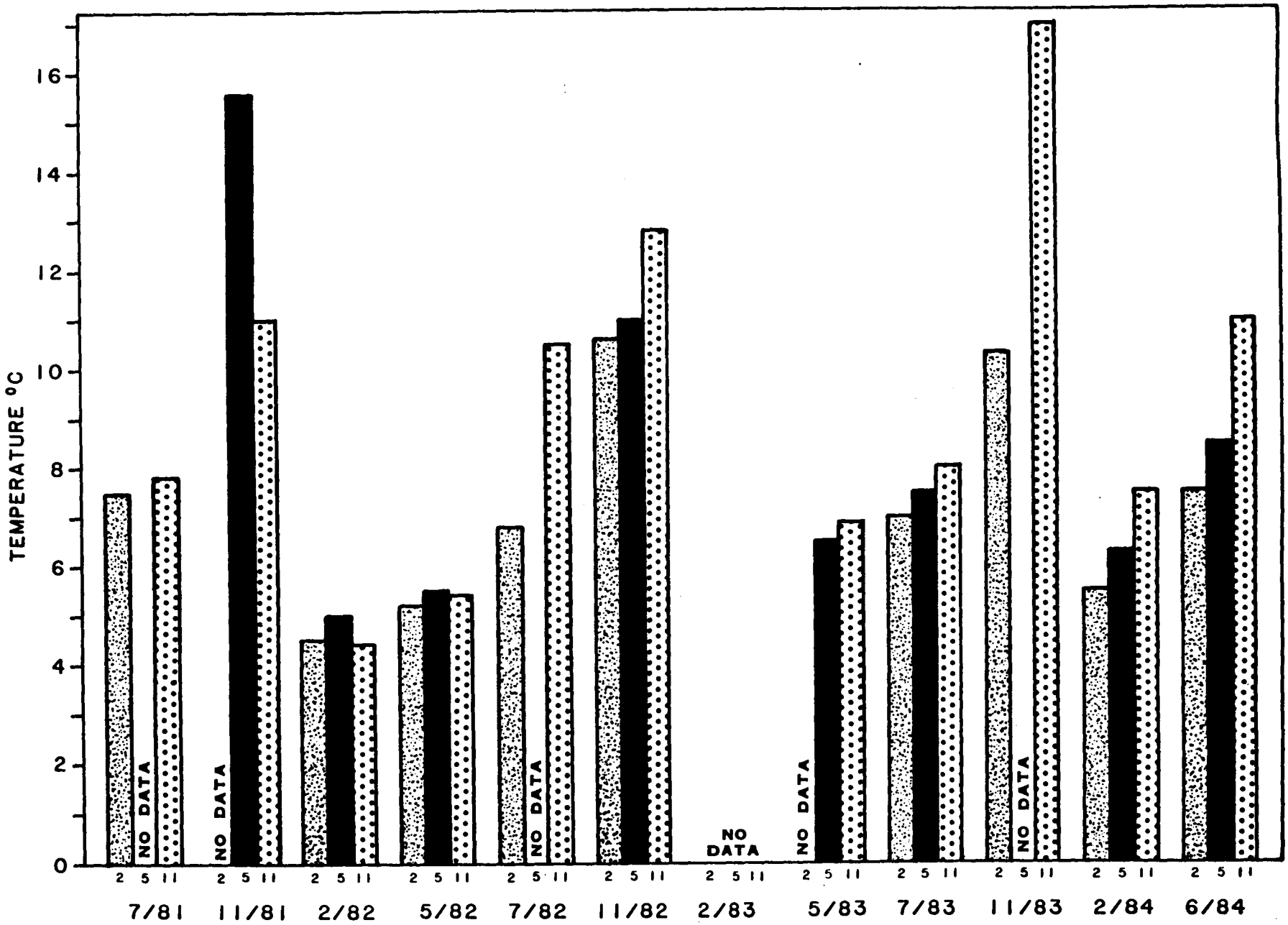

Figure 149. Bottom temperature at Stations 2, 5 and 11.

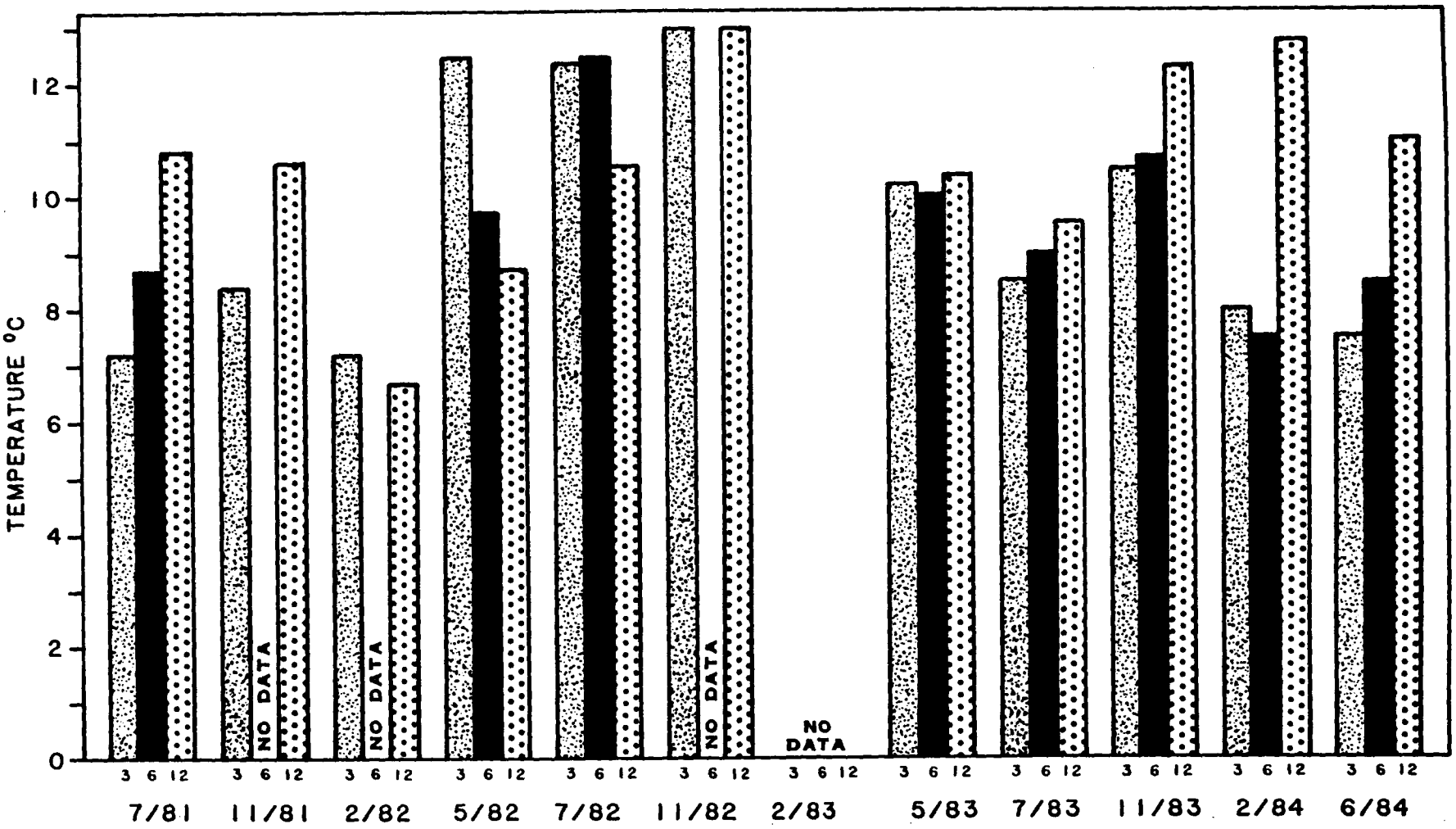

Figure 150. Bottom temperature at Stations 3, 6 and 12.

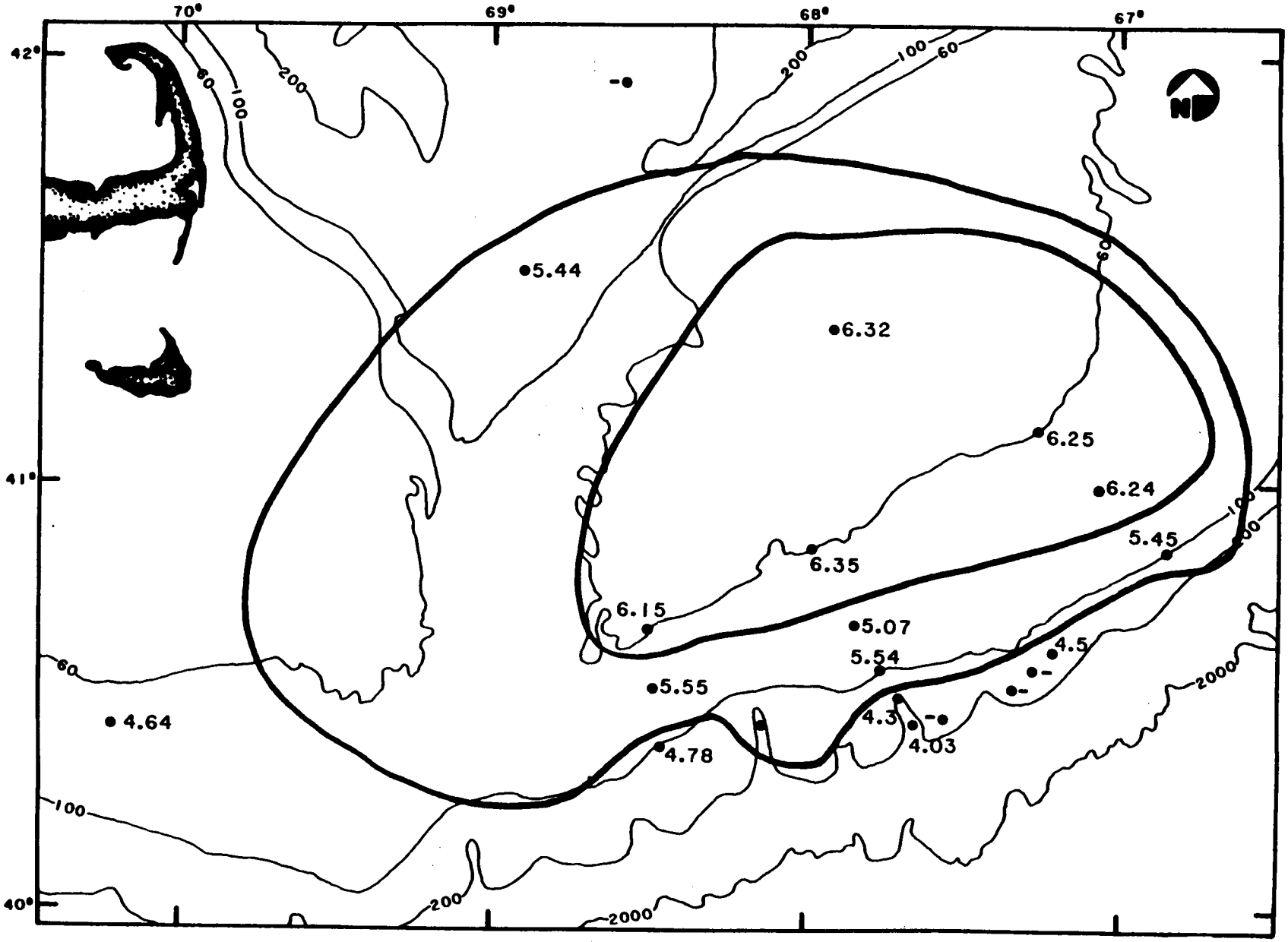

Figure 151. Bottom water dissolved oxygen concentration distribution (mg/l), Cruise M2, November 1981.

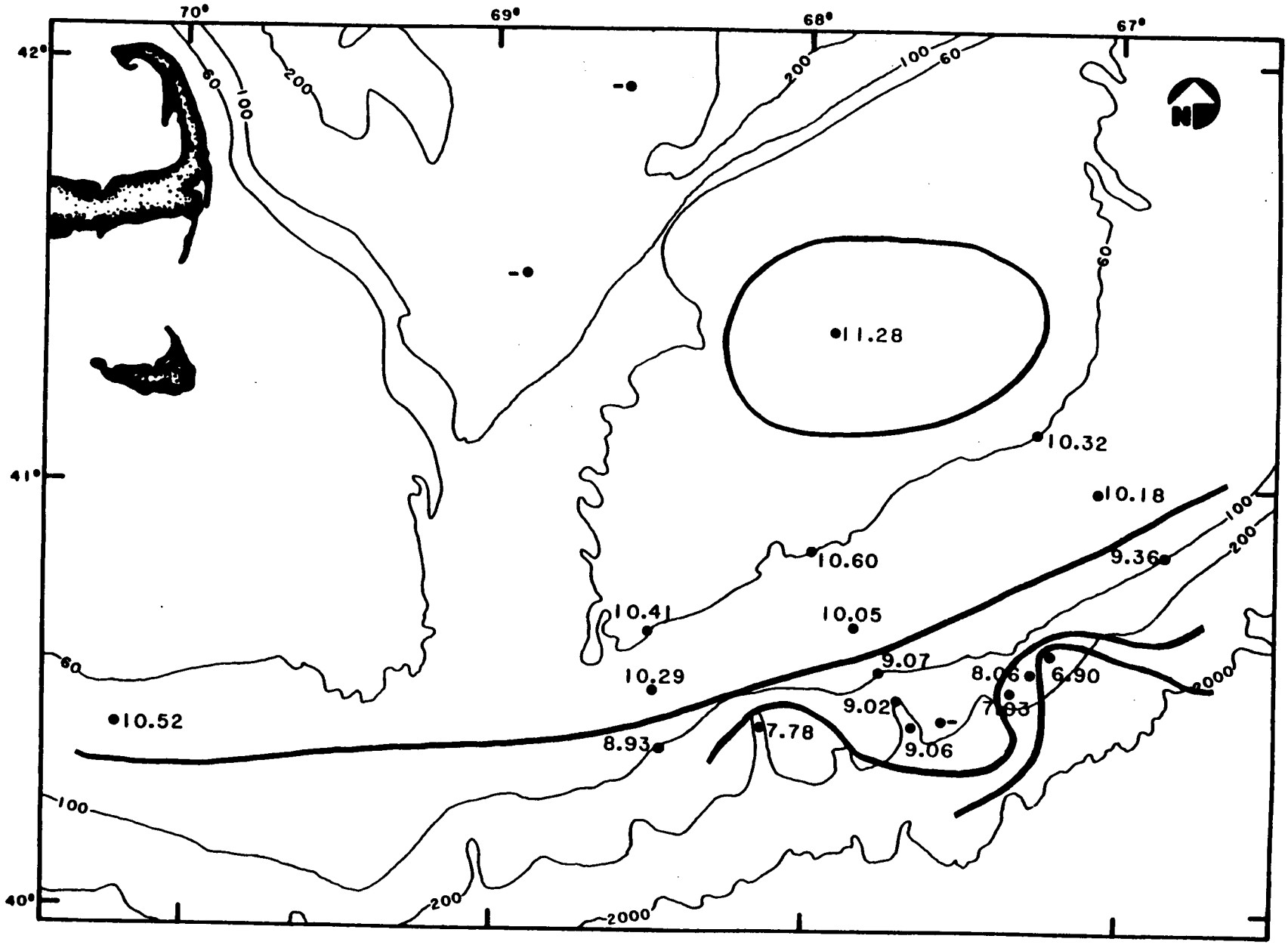

Figure 152. Bottom water dissolved oxygen concentration distribution (mg/l), Cruise M3, Feburary 1982.

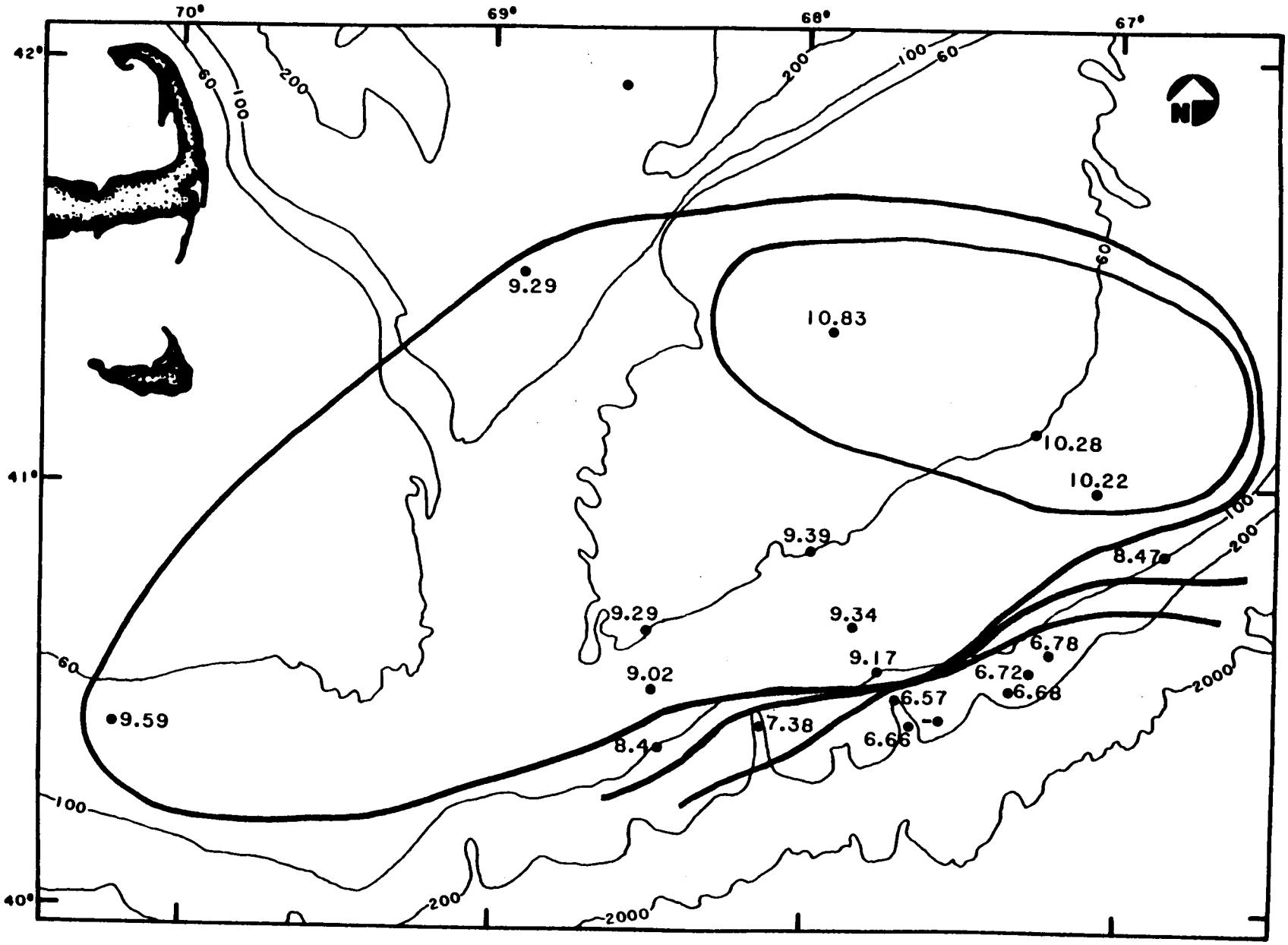

Figure 153. Bottom water dissolved oxygen concentration distribution (mg/l), Cruise M4, May 1982.

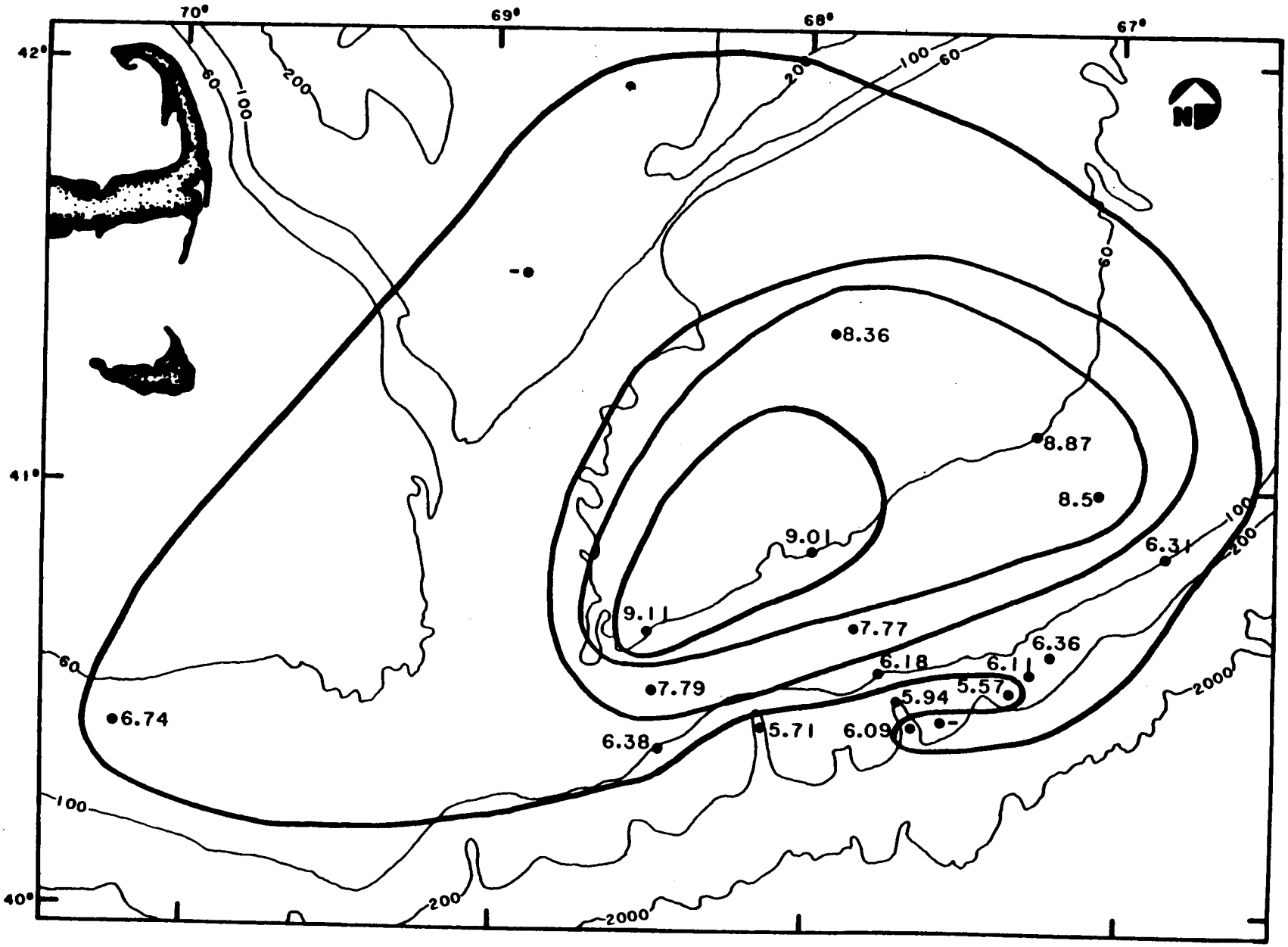

Figure 154. Bottom water dissolved oxygen concentration distribution (mg/l), Cruise M5, July 1982.

TABLE 33. DISSOLVED OXYGEN CONCENTRATIONS (MG/LITER) AND PERCENT OXYGEN SATURATION (IN PARENTHESES)* OF BOTTOM WATER SAMPLES FROM STATIONS DEEPER THAN 130 METERS ON THE SOUTHERN FLANK OF GEORGES BANK.

		Station			
		7/7A	8	9	16
		Depth (M)			
Cruise	Date	130/167	152	144	142
M1	Jul 1981	4.23	-	6.25(71)	4.58(51)
M2	Nov 1981	4.30(48)	4.00(43)	5.40(59)	4.96(54)
M3	Feb 1982	9.02(113)	9.06(98)	7.78	7.06
M4	May 1982	6.57(73)	6.67(76)	7.38(81)	6.72(85)
M5	Jul 1982	5.95(64)	6.36(72)	5.69(65)	6.09(71)
M6	Nov 1982	6.26(75)	6.38(72)	5.79(68)	5.72(68)
M7	Feb 1983	6.18(66)	7.28	-	6.99
M8	May 1983	6.19(70)	5.97(67)	6.80(75)	6.42(73)
M9	Jul 1983	6.46(72)	5.10(57)	4.27(47)	6.46(73)
M10	Nov 1983	5.93(67)	5.79(67)	7.21(81)	5.81(68)
M11	Feb 1984	6.27(67)	6.43(71)	6.22(70)	7.47(79)
M12	June 1984	6.97(78)	6.17(71)	6.79(78)	6.93(82)

*Solubility of oxygen in sample interpolated based on salinity and temperature of sample and assuming barometric pressure of 760 mm Hg.

saturation varied from 43 percent at Station 8 in November 1981 to 113 percent in February 1982. Most values were in the 60-80 percent range, which is sufficiently high to be non-stressful to nearly all benthic and demersal marine animals.

Stations 7 and 7A at the head of Lydonia Canyon, Stations 13 and 13A in the Mud Patch, and Stations 14 and 14A north of Georges Bank in the Gulf of Maine are considered depositional sites. They contain finer-grained sediments higher in organic matter than other stations sampled in this program. Such areas sometimes are characterized by a higher biological and/or chemical oxygen demand than areas with coarser-grained sediments. Therefore, it is somewhat surprising that dissolved oxygen concentration in bottom water at these stations was never recorded below about 4.5 mg/l (Figure 155). Most values were above 6 mg/l with some in excess of 9 mg/l. Highest values each year were recorded in February and May.

Drilling fluids also have a high apparent biological and chemical oxygen demand, especially when they contain hydrocarbon lubricants or starch (Breteler et al., 1984). Therefore, it was of interest to determine if dissolved oxygen concentrations in bottom water dropped following initiation of drilling at Station 5 in December 1981, shortly after Cruise M2. The concentration of dissolved oxygen in bottom water at Station 5 was consistently quite close to concentrations in bottom water at the upcurrent Station 2 and downcurrent Station 11 from February 1982 through May 1984 (Figure 156). The greatest difference among the stations (1.9 mg/l dissolved O_2) occurred in November 1982 (Cruise M6) and here the value for Station 5 was intermediate between those for Stations 2 and 11.

DISCUSSION

The near-bottom waters of Georges Bank are a surprisingly stable environment with respect to the hydrographic parameters: temperature, salinity, and dissolved oxygen concentration. In general, the deeper stations were less variable seasonally than the shallower stations. Below about 100-110 m water depths, seasonal patterns of change in these parameters were small and inconsistent from year to year.

The presence of the drilling rigs or the discharges from them at Stations 5 and 16 had no measurable influence on these physical/chemical environmental parameters. Any discharges from the rigs would be diluted sufficiently rapidly in the high energy environment of Georges Bank so that there would be no measurable change in such parameters as salinity and dissolved oxygen in the water column.

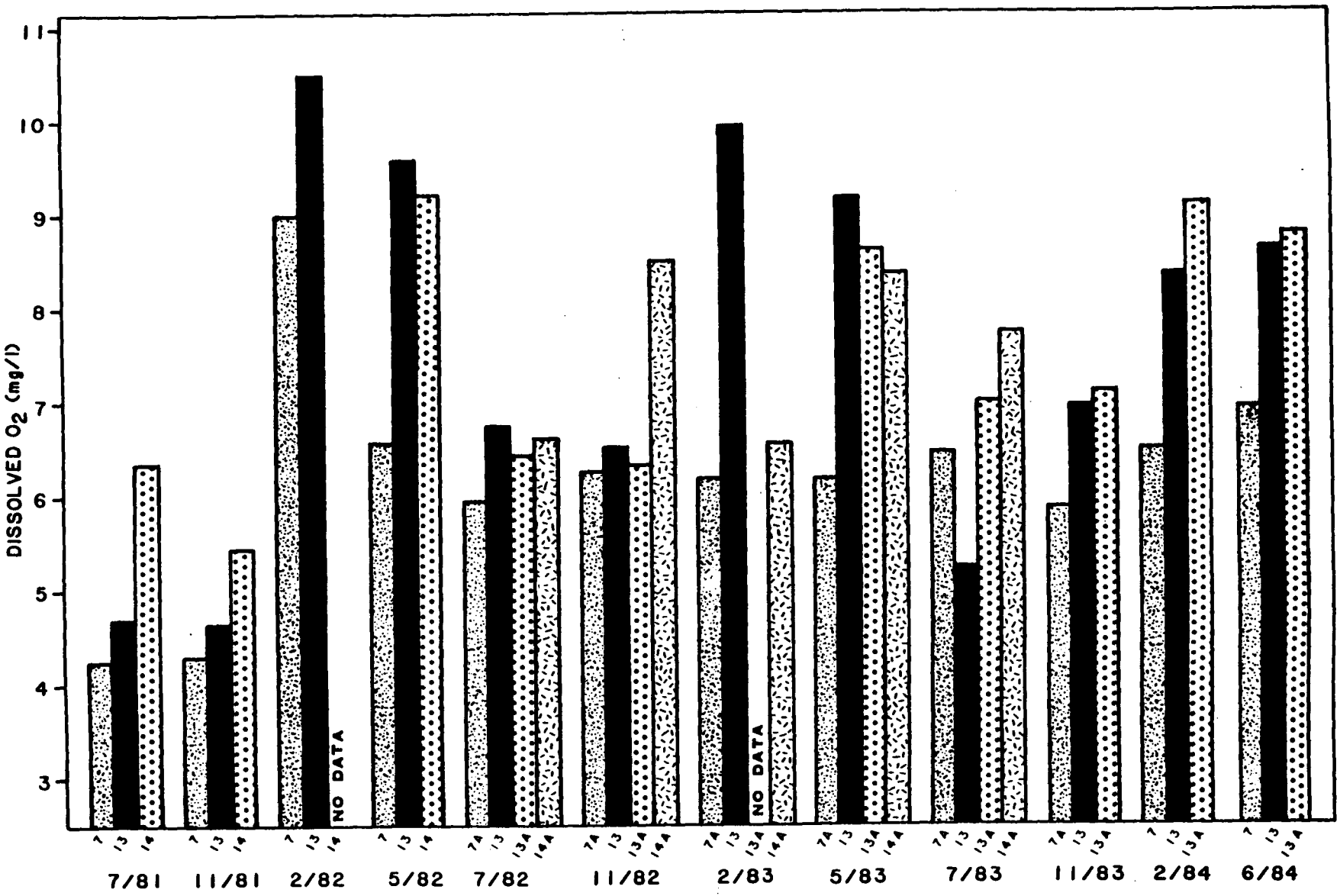

Figure 155. Bottom dissolved oxygen at Stations 7, 7A, 13, 13A, 14 and 14A.

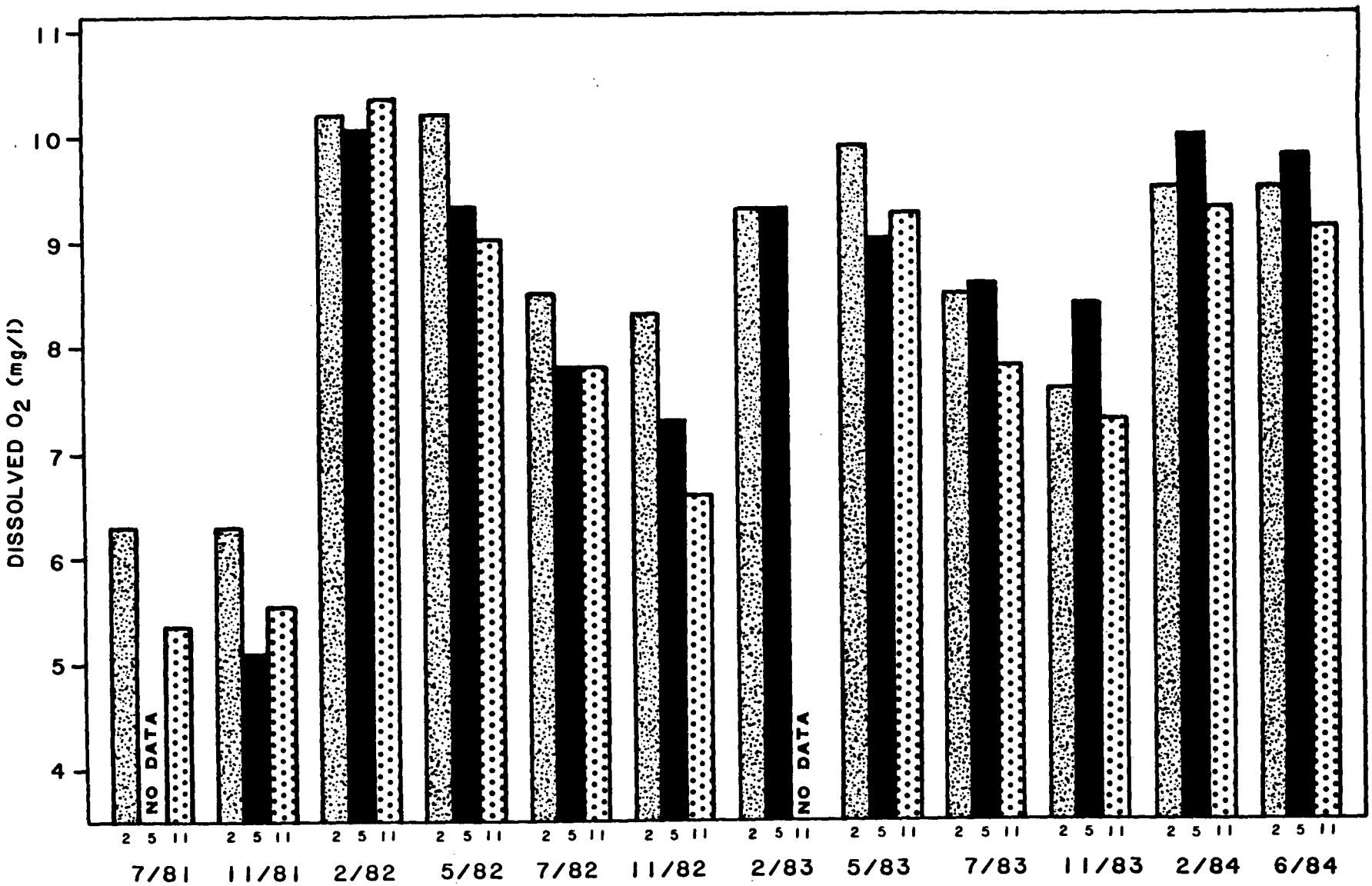

Figure 156. Bottom dissolved oxygen at Stations 2, 5 and 11.

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CHAPTER 12. DISCUSSION

by

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DRILLING DISCHARGES TO GEORGES BANK

Exploratory drilling was initiated on Georges Bank in Block 410 near Regional Station 16 in July 1981, shortly after Cruise M1. Drilling continued there intermittently until March 1982. Exploratory drilling was initiated in Block 312, the location of the site-specific array, on December 8, 1981, shortly after Cruise M2, and continued with several interruptions until June 1982, shortly before Cruise M5. The last of eight exploratory wells was completed on September 27, 1982. All eight wells were reported to be dry holes.

The total amounts of drilling fluid solids used to drill the wells in Blocks 410 and 312 were 1,193.6 and 1,524.0 mt, respectively (E.P. Danenberger, MMS, personal communication). These drilling muds contained 510 and 1,083 mt, respectively, of barium sulfate, and 27.6 and 16.3 mt, respectively of chrome lignosulfonate. In addition, approximately 16,200 l of diesel fuel were added to the drilling fluids in Block 312 to aid lubrication and to free stuck pipe. It is estimated that approximately 50 percent of the drilling mud for each well was either left in the hole at the end of drilling or lost to permeable formations.

Neff (1984) estimated that approximately 600 mt of drilling fluid solids containing 250 mt of barite and 14 mt of chrome lignosulfonate were discharged from the rig in Block 312. Payne et al (1982) estimated that approximately 525 liters of diesel fuel also were discharged with the drilling fluids from the rig in Block 312. Several samples of drilling fluid collected at different times during drilling in Block 312 contained 23 to 1,130 mg/liter (ppm) total hydrocarbons (Payne et al, 1982). Approximately 1,150 mt of drill cuttings also were discharged during drilling of each of these exploratory wells (Neff, 1984).

Neff (1984) estimated that a total of approximately 9,200 mt of drill cuttings and approximately 5,000 mt of drilling fluid solids containing 3,000 t of barite and 100 t of chrome lignosulfonate were discharged to the waters of Georges Bank during the drilling of eight exploratory wells in 1981-1982. By comparison, the rate of deposition of fine-grained sediments in the Mud Patch (in the region of Regional Stations 13 and 13A), which is considered one of the depositional sites for fine-grained sediments swept off of Georges Bank (Twichell et al, 1981; Bothner et al, 1981), could be as high as 84 million mt per year (Neff, 1984).

REGIONAL STATIONS

Bulk concentrations of barium, chromium, other metals, and petroleum hydrocarbons in sediments from the upcurrent regional reference stations (Regional Stations 1-3) did not change significantly during the three years of the monitoring program (Bothner et al, 1985; Payne et al, 1984). Barium is a widely-used tracer of the fate in the ocean of drilling mud solids because it is extremely dense and insoluble and is present in most water-base drilling muds at concentrations many orders of magnitude higher than those in most marine sediments.

By analyzing barium concentration in the fine fraction of surficial sediments, Bothner et al (1985) were able to detect a temporal pattern of net westward transport of barium-rich fine sediment during the monitoring program. Based on increases in barium concentration and barium/aluminum ratio in the fine fraction of sediment, Bothner et al (1985) 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 in February and May 1983 (M7 and M8). 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. Bothner et al (1985) also estimated that the initial half-time (immediately after drilling) for retention of discharged barium in the upper 2 cm of sediments within 2 km of the rig site is 0.34 years.

Concentrations of barium (240-290 ppm) and hydrocarbons (1.0-2.5 ppm) were higher at Regional Stations 7A, 13, and 13A than at other stations (Bothner et al, 1985; Payne et

al, 1984). However, these concentrations did not change significantly during or after drilling. These stations are depositional sites with fine-grained sediments, which typically contain higher concentrations of metal and organic materials than coarse-grained sediments. Bothner et al (1985) provided evidence from sediment trap samples that drilling discharges from the exploratory rigs did reach the vicinity of Station 7A (Lydonia Canyon).

There were no obvious trends in benthic community parameters at these stations. At Station 13, the pattern of increasing mean number of individuals from July 1981 to February 1982 (Cruises M1 to M3), followed by a sharp decline in May 1982 (Cruise M4), was much less marked during the second and third year of the monitoring program. The marked decline of both number of individuals and number of species at Station 13 in May 1982, may have been due to differences in station position in an area where there are sharp gradients in sediment composition or, possibly, migration of animals following an isolated event such as a storm. Overall, there were no changes in benthic community parameters at these stations that could be attributed to exploratory drilling activities.

BLOCK 410

At Station 16, within 200 m of the drilling rig 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 and the sixth cruises (Bothner et al, 1984; this report Figure 157). After drilling, the excess barium in surficial sediments had an extremely patchy distribution as evidenced by large standard deviations for the means of three replicate analyses. Mean concentrations of barium in surficial sediments decreased to the range of 75 to 95 ppm in February 1983 through November 1983, with a second spike of 147 ppm in February 1984 nearly two years after completion of drilling at this site. This undoubtedly reflects the very patchy distribution of drilling mud solids in sediments near the rig site. No increases in the concentration of chromium or other metals were observed in bulk surficial sediments from Station 16.

Since predominant grain size of drilling mud-grade barite is less than 60 μm, barium also was analyzed in the fine sediment fraction of sediments. In the fine fraction of sediments from Station 16, barium concentration rose from approximately 250 ppm before drilling to the region of 8,000 to 10,000 ppm in February 1982 through February 1983 (M3-M7). Smaller increases in barium concentration were observed in the fine fraction of sediments from Stations 17 and 18, 2 km upstream and downstream, respectively from the drill rig. Chromium concentration in the fine fraction of sediment from Station 16 increased a maximum of two-fold during drilling.

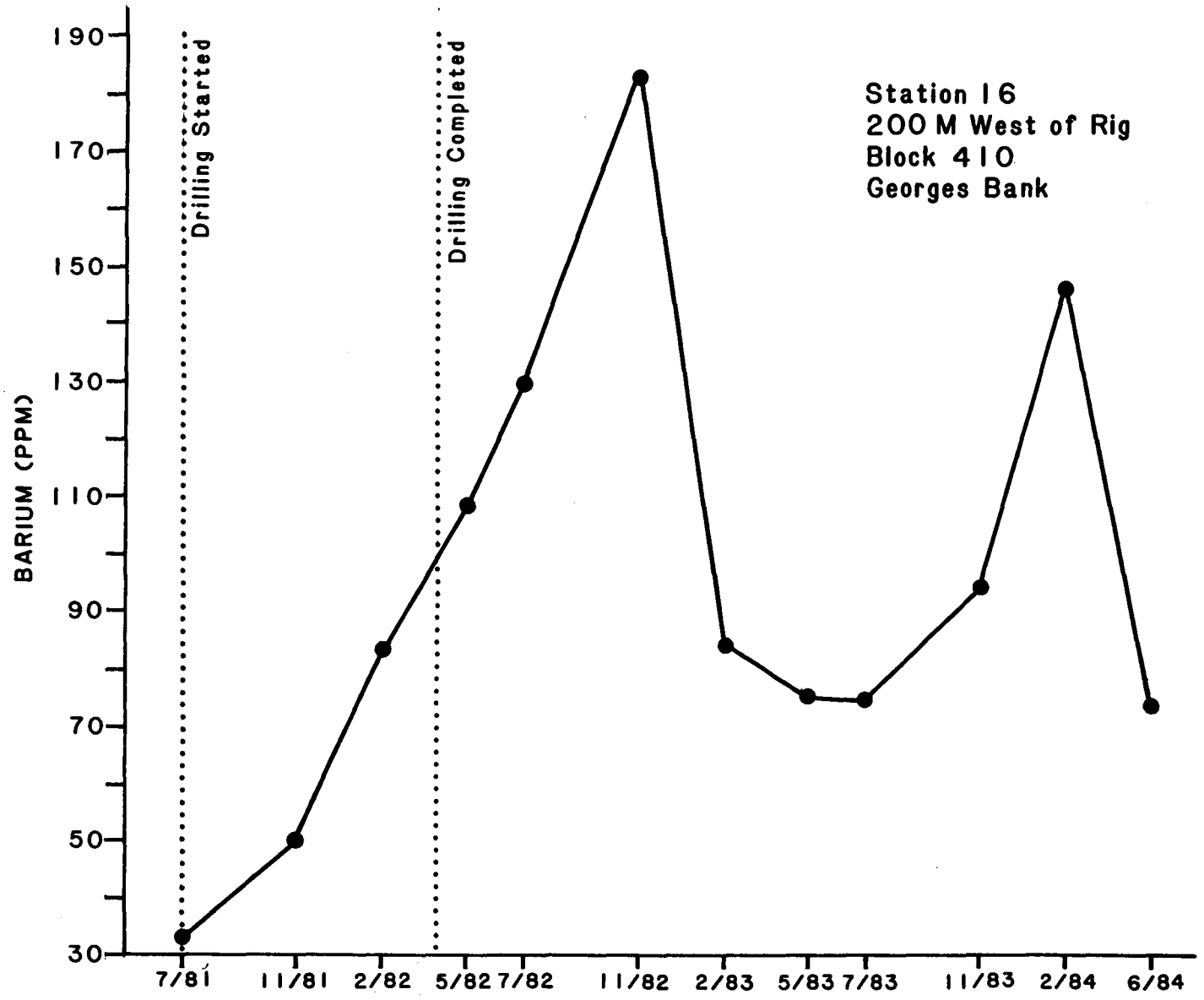

Figure 157. Mean barium concentration in bulk surficial sediments at Regional Station 16 on twelve sampling occasions. Values are in mg/kg dry weight. (Data from Bothner et al, 1984).

Drill cuttings also were detected in surficial sediments from Station 16 (Chapter 10, this report; Bothner et al, 1984). The cuttings were 2 to 8 mm in diameter and were composed of calcite. This represented no more than 1.5 percent of the weight of the sediment samples. Although more than 500 mt of bentonite (montmorillonite) clay were discharged from the eight exploratory rigs, there was no evidence of an increase in clay in surficial sediments near the drill sites.

No biological effects attributable to deposition of discharged drilling mud solids and drill cuttings were observed in the benthos at the Block 410 stations. At Station 16, the average number of individuals per 0.04 m^2 was lowest in July 1981 (before drilling began) and November 1981 (during drilling) (Figure 158). For the remainder of the monitoring program, average number of individuals showed a gradual rising trend. Number of species was lowest during and immediately after drilling (November 1981 through May 1982) and then remained above 110 for the remainder of the monitoring program. Shannon-Wiener diversity index (H') was lowest in February 1982 (during drilling) and November 1983, and remained high for the remainder of the monitoring program. Measures of faunal similarity (i.e., NESS and percent similarity) indicated a consistent high level of similarity of benthic fauna between the rig site (Station 16) and the upcurrent reference station (Station 17). These two stations have the same dominant species. The downcurrent reference station (Station 18) has finer-grained sediments than Stations 16 and 17 and has had a slightly different benthic fauna than these stations throughout the monitoring program. Thus, if the slightly lower number of individuals or number of species of benthic infauna observed during drilling were in any way caused by drilling discharges, recovery was extremely rapid after drilling was completed (within three months).

BLOCK 312

In the site-specific array of stations in Block 312, the concentrations of barium in bulk surficial sediments from several stations around the rig site increased during and immediately after drilling (Bothner et al, 1984). The largest increase was approximately 4.7-fold (from 28 ppm in July 1981 to 131.6 in July 1982) shortly after drilling was completed and occurred at Station 5-1 within 200 m of the rig site (Figure 159). Other site-specific stations where there was a large increase in barium concentration in bulk surficial sediments during drilling included Stations 5-2, 5-4, 5-8, and 5-12. At these stations, there was a trend for mean sediment barium concentrations to decrease to near background levels by November 1982 to May 1983. Slightly greater increases were observed to the west than to the east of the drill site. Small amounts of drill cuttings

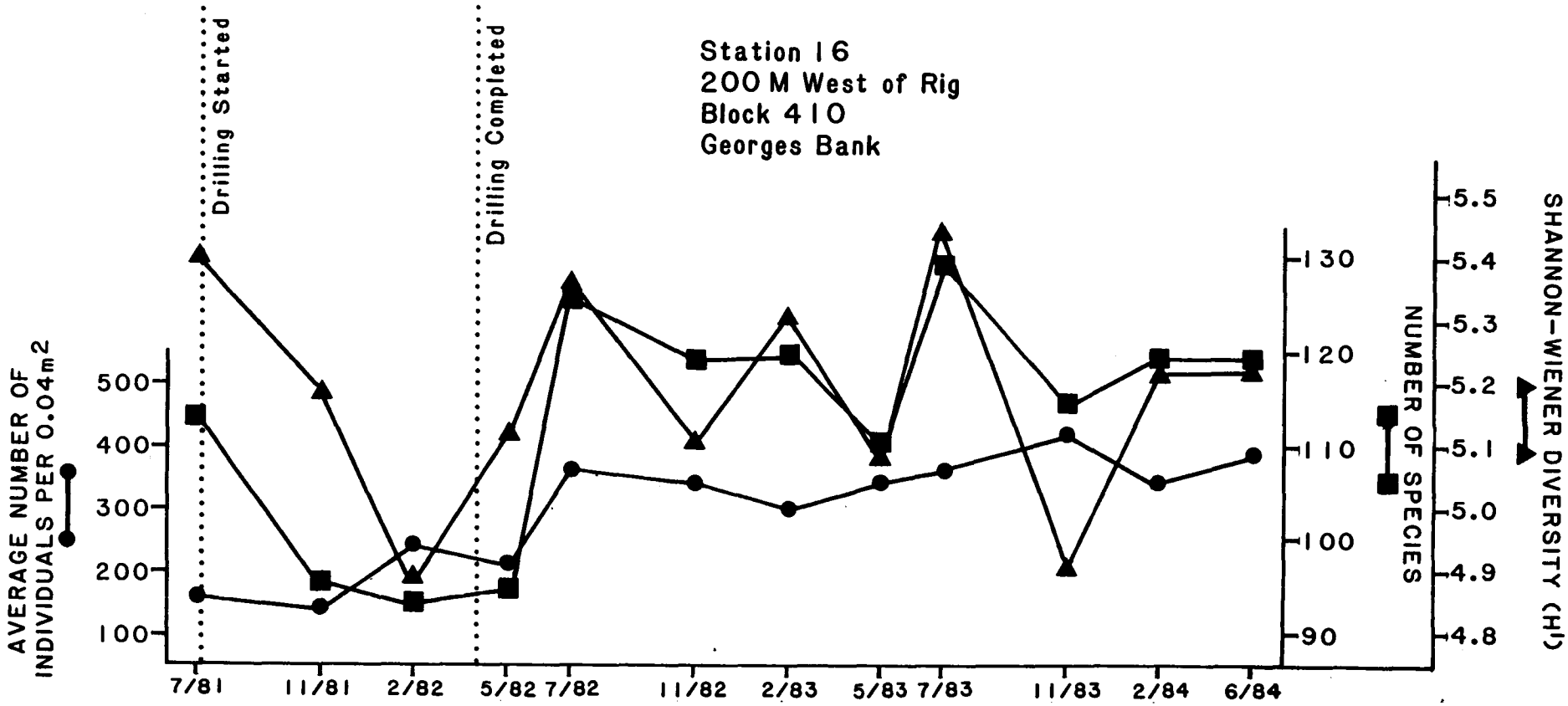

Figure 158. Average number of individuals per 0.04 m^2, total number of species in six replicate grab samples and Shannon-Wiener diversity index (H') at Regional Station 16 on twelve sampling occasions.

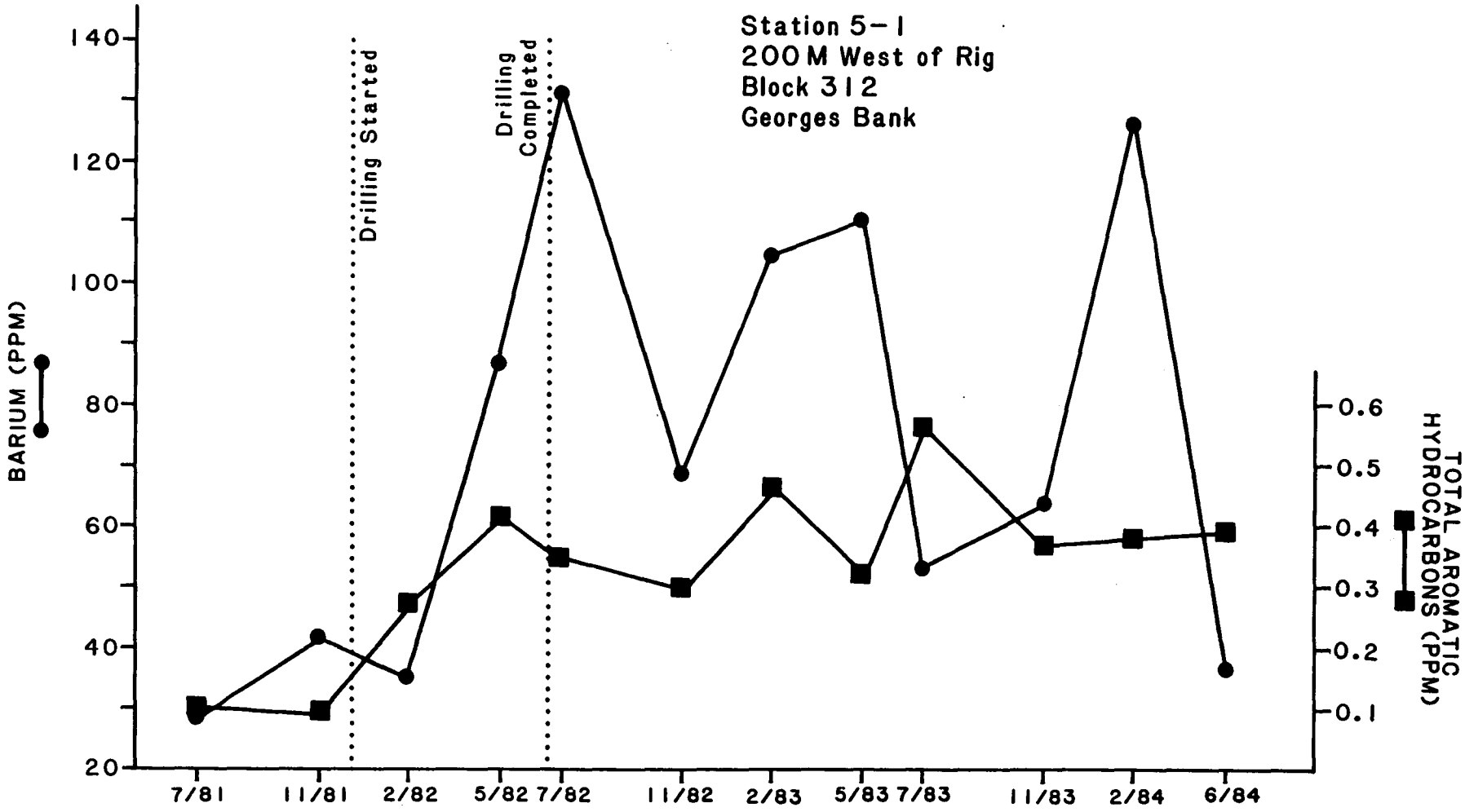

Figure 159. Mean barium and total aromatic hydrocarbon concentrations in bulk surficial sediments at Site-Specific Station 5-1 on twelve sampling occasions. Aromatic hydrocarbon values for the first four cruises (July 1981 to May 1982) are based on a single analysis of a pooled sample of three replicates. Other data points are the means of three replicate samples (barium data from Bothner et al, 1984; hydrocarbon data from Payne et al, 1984).

were observed at all stations within 0.5 km of the drill site (Stations 5-1 to 5-5), but there was no indication of the accumulation of a cuttings pile.

Payne et al (1984) 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 159). Methylnaphthalenes through perylene were detected in quantifiable concentrations by GC/MS in samples taken during drilling, suggesting a petroleum origin of the hydrocarbons, probably from the diesel fuel added to drilling mud from this rig. The increase was small, from a predrilling concentration of 0.007-0.102 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 (July 1982 to June 1984). These concentrations of low-to-medium molecular weight aromatic hydrocarbons in sediments are not considered toxic to benthic organisms (Neff and Anderson, 1981).

At Station 5-18, 2 km west of the rig site, concentrations of total aromatic hydrocarbons in surficial sediments rose from about 0.1 ppm during Year 1 of the Monitoring Program to about 0.34 ppm in June 1984. Small amounts of aromatic hydrocarbons, possibly of drilling mud origin, were also detected in surficial sediments from Station 5-28, located 6 km east of the rig site, in February 1982, but not subsequently.

Ocean clams, Arctica islandica, collected from Station 5-3 were analyzed for petroleum hydrocarbons and metals. These infaunal molluscs showed no indication of a net accumulation of petroleum aromatics, barium, or other metals during the timecourse of the Monitoring Program.

No biological impacts in the benthic infauna attributable to drilling have been detected at the site-specific stations (Figure 160). During drilling, there was an increase in both the average number of individuals per 0.04 m^2 and the total number of species at Station 5-1. The Shannon-Wiener diversity index (H') remained relatively constant. For the period July 1982 to June 1984 (M5-M12), average numbers of individuals and number of species remained high, with a drop in number of species in May 1984 (M11). The fluctuations in these parameters appeared to be annual, with only a small seasonal component. The other primary site-specific stations exhibited a similar pattern.

In most cases, the average number of individuals per 0.04 m^2 was lowest in November 1981 (M2), just before drilling began for stations within 1 km of the drill site, or February 1982 (Cruise M3) for site-specific stations more than 1 km from the drill site. Species abundance also was lowest in most cases in November 1981. There was an increase in the number of individuals and number of species at nearly all primary

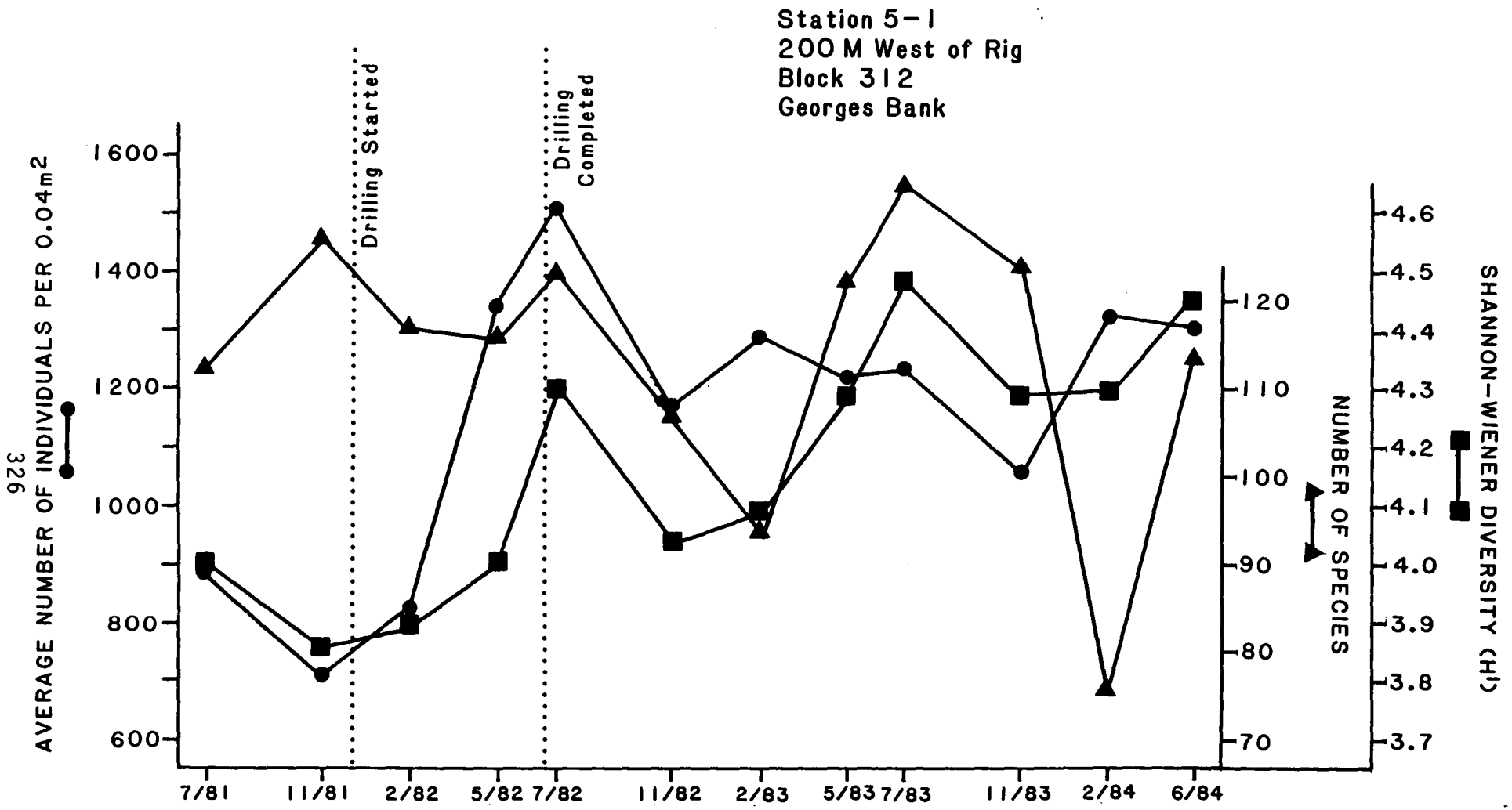

Figure 160. Average number of individuals per 0.04 m^2, total number of species in six replicate grab samples and Shannon-Wiener diversity index (H') at Site-Specific Station 5-1 on twelve sampling occasions.

site-specific stations between February and July 1982, during most of which time drilling was taking place in Block 312. Those species which showed the most marked decline in abundance in November 1981 or February 1982, such as the amphipods Erichthonius fasciatus and Unciola inermis showed substantial recovery by May or July 1982. These seasonal patterns of abundance are related to seasonal changes in sediment texture due to winter storms (see Chapter 10) and seasonal reproductive/recruitment patterns (see Chapter 6), rather than drilling discharges.

CONCLUSIONS

General

- Biological patterns in Year 3 were basically similar to those reported in Years 1 and 2. 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 (i.e., Stations 3, 6, 8, 9, and Block 410), the samples were very homogenous within years and it was possible to resolve subtle differences between years.

- During Year 3, as during Years 1 and 2, the replicate infaunal samples from each station showed an exceptionally high degree of homogeneity. Cluster analysis demonstrated that all of the replicates of any one station were more similar to each other than to replicates from any other station. The benthic community at any particular station was always distinct from that at surrounding stations. When replicates from each sampling date were summed, the samples from each of the twelve sampling periods fused before any separation occurred between stations.

- Biomass varied over time and among stations. At some stations there were significant increases in biomass between the first and second years. When they were present, Arctica islandica and Echinarachnius parma dominated the biomass and when they were absent, polychaetes and arthropods dominated the biomass. Levels of biomass found in this study were comparable to levels found in previous studies.

- Bottom photographs taken during the three-year Monitoring Program revealed depth-related patterns of microtopography. Surficial seasonal patterns were visible at the Blocks 410 and 312 stations, but were not consistently present at the remaining stations. No accumulations of drilling cuttings or muds was seen. 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.

- 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.

Block 312

- Drilling began in Block 312 on December 8, 1981 and continued until June 1982. At site-specific stations where an increase in the concentration of barium (from drilling discharges) in bulk surficial sediments was observed between July 1981 (before drilling) and July 1982 (after drilling), there was no statistical correlation between benthic infaunal community similarity parameters and the increase in barium concentration seen between the same dates, or percent silt-clay in sediments. A highly significant correlation between community similarity 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 benthic infauna in Block 312.

- Patterns of decline in the number of individuals per 0.04 m^2 and abundance of certain dominant species such as the amphipods, Erichthonius fasciatus and Unciola inermis, at stations near the rig site at which barium subsequently accumulated occurred in the fall and winter of each of the three years of sampling. These results indicate that the fluctuations were 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, 1983), 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 has been detected after analysis of

twelve seasonal samples at the rig site itself (Station 16) with the statistical methods used.

Life History Analysis

• Results from the life-history analysis aid in interpreting observed changes in species abundance. For the three amphipod and one echinoderm species studied, much of the variation in abundance can be explained on the basis of recruitment and mortality, although adult migration may be important in explaining population changes in Erichthonius fasciatus. Data on several polychaete species are more difficult to interpret in explaining patterns of abundance. Cossura longocirrata exhibited declines in population abundance along with other species at Station 13 during one seasonal episode which correlated with timing of reproduction in Cossura longocirrata. This episode however, may be due to factors not related to reproduction. For Exogone verugera and Sphaerosyllis cf. brevifrons, there appears to be a good correlation between timing of recruitment and observed increases in density. 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 a winter-spring sequence.

Benthic Production and Fish Feeding

• Yellowtail flounder on Georges Bank feed primarily on macrobenthic species. The dominant prey species varied seasonally and among stations. Predation was strongly species dependant and size dependant. Flounder appear to accommodate changes in the abundance of their preferred prey species.

CHN Analysis

• Total organic carbon (TOC) on Georges Bank was correlated with sediment grain size. Sandy areas exhibited organic carbon values below 0.20 perent. 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. Correlated with net southwestward currents and associated gradients in sediment grain size, TOC increased systematically from northeast to southwest along the 70 to 80-m isobath (Stations 2, 5, 11, 13, and 13A). C/N

ratios indicate that the sediment organics of Georges Bank likely originate from both marine and terrestrial sources.

Sediment Grain Size Analysis

- The sediments at the Monitoring Program stations were predominantly medium to fine sand. There was a slight increase in fine material with depth, most noticeably around the head of Lydonia Canyon and to the west of the Bank along the 70- to 80-m depth contour. Several stations exhibited seasonal changes in sediment grain size characteristics: the finer size classes increased 5 to 20 percent in total weight in July of each year as a result of reduced winnowing action of storms.

Comparison With Historic 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 (Butman, 1982). 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), the benthic populations did not show a sharp decline during the 1980-1982 winter periods.

- The increase in fine sediments at Station 13 was preceded by four common deposit feeders that may be responsible for a graded buildup of fine sediments.

- The longer data set at Station 6 allowed us to see a significant decline in Polygordius sp. A in 1983 and early 1984. A similar trend, though not significant, occurs with Euchone incolor and Ampelisca agassizi.

- 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 species reported in common. The average density of individuals at each of the eleven stations was generally higher in the Monitoring Program samples, even when only the individuals retained on the 0.5-mm screen were compared.

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 monitoring 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 data base already established and to correlate with the recently initiated North Atlantic Slope and Rise study.

- We recommend sampling at seven stations, including the deeper Regional Stations 7A, 8, 9, and 16 and 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.

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