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Review of Benthic Invertebrates of Georges Bank in Relation to Gas and Oil Exploration with Emphasis on Management Implications

by

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In view of current needs and activities relating to Georges Bank and in order to increase its availability to concerned individuals, this report, prepared under contract to the Northeast Fisheries Center Director, is being issued as a Laboratory Reference Document.

The report, largely unedited, is issued as submitted to the NEFC. Issurance does not imply that the Center necessarily concurs with all conclusions.

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Abstract

This account was prepared to review data on benthic invertebrates of Georges Bank to provide the base for a position paper on the management of benthos in light of gas and oil exploration. The account which drew heavily from research conducted by the National Marine Fisheries Service and studies supported by the Bureau of Land Management is based on approximately 250 references.

The account starts with a description of the environmental setting of the Bank including geology, physical, and chemical oceanography.

Sections on the benthos include treatment of quantitative samples sieved through 1.0 mm mesh sieves and samples sieved through 0.5 mm mesh together with recent findings of meiofauna featuring Foraminifera. Species composition, density and biomass of benthos are featured. In addition, qualitative data from dredge hauls involving species composition, relative abundance and relative biomass together with distribution maps are also presented. The Nantucket and Martha's Vineyard areas together with the area south and southeast of the Vineyard termed the Mud Patch received special attention. The latter area is of considerable recent interest as a possible depositional sink which could be related to potential accumulation of pollutants (hydrocarbons and trace metals).

Research on the role of benthos in seabed respiration and an energy budget for the Bank were described. These roles

together with the benthos as a prominent source of food for demersal finfish emphasizes the functional aspects of Georges Bank benthos. Moreover, the response of benthic invertebrates to pollutants on Georges Bank was also covered. This was accomplished by 1) providing a brief review of the literature on chronic effects of hydrocarbons, trace metals and drilling muds and fluids on behavior, feeding, growth, molting, respiration, assimilation, depuration, reproduction and larval development, and 2) by reviewing bioconcentration of trace metals and hydrocarbons in selected benthos from Georges Bank.

The last major section synthesizes ecological relationships of Georges Bank benthos in terms of primary productivity, meroplankton, larval retention, circulation, disturbance (biological and geological) and interactions with sediment geochemistry. Based on this synthesis some inferences about the response of the benthos to drilling activities were advanced. Finally, these considerations were posed in terms of management implications involving the BLM Field Monitoring proposal and the NMFS Northeast Monotoring Program.

Preface and Acknowledgments

The purpose of this account was to review the data base of benthic invertebrates for Georges Bank to provide the base for a position paper on the management of benthic resources on Georges Bank in light of gas and oil exploration.

Although the author has been careful identifying sources, he is pleased to acknowledge those individuals and institutions upon which he drew heavily and those who provided documents and encouragement. The project was supported by the National Marine Fisheries Service (NMFS), Northeast Fisheries Center, under the aegis of Dr. Robert Edwards, Woods Hole Laboratory.

Dr. Bradford Butman, United States Geological Survey, provided maps and preprints of articles dealing with geological aspects of sediment dynamics. Drs. Redwood Wright and Ronald Schlitz, NMFS, provided several reports and papers in press dealing with the physical oceanography of the Bank. Dr. Kenneth Sherman made available a review article on zooplankton and Mr. Edward Cohen did the same for phytoplankton and recent work on primary production. Dr. Richard Cooper and Mr. Joseph Uzmann brought several articles of canyon biology and geology to the author's attention. Dr. Marvin Grosslein made available some of the Center's work on the Georges Bank energy budget. Dr. Richard Langton and Mr. Ray Bowman apprised the author of the extensive data base in the food habits group. In view of the focus of this project the help of Mr. Roger Theroux, a benthic specialist, was extremely valuable. He served as the

archivist of earlier work, generously spent much time with the author in assessing the value of various sources, and provided a number of his own documents or those co-authored with his predecessor and colleague Dr. Roland Wigley. Dr. James Thomas, Mr. Frank Steimle and Mr. Robert Reid generously shared their recent work on primary production, sea bed respiration and benthic community structure. Frank Steimle, Bob Reed, Roger Theroux, Dr. J.K. McNulty and Dr. M. Grosslein provided constructive criticism of the first draft.

In addition to the above individuals the author benefitted greatly from his experience with the Bureau of Land Managment (BLM) Baseline Study of Georges Bank. During the course of the project the author drew heavily upon the work of the following people: Energy Resources Co. (ERCO), Mr. David Strimaitis - meteorology and physical oceanography, Dr. Paul Boehm - hydrocarbons, Dr. Steven Piotrowicz - trace metals, Dr. Thomas Novitsky - microbiology; NMFS, Dr. Lowell Sick - trace metals and University of Delaware, Mr. Christian Wethe - sediment analysis; Marine Research, Inc., Mr. Richard Toner - zooplankton and megabenthos. The latter was particularly generous in providing raw data of biomass of megabenthos. Mr. Eiji Imamura, BLM, was most supportive in sharing agency documents.

The author is pleased to particularly recognize Dr. Marvin Grosslein and Mr. Roger Theroux who spent considerable time in discussing various aspects of the project and who shared their extensive experience of the Bank with him. Finally, Dr. John Pearce deserves recognition for formulating the project, providing the author with many documents, serving as a sounding board and devil's advocate, and functioning as an esteemed colleague and friend.

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Introduction

Literature Review

Considerable research on taxonomy and ecology of invertebrates has been conducted in the New England area for a long time. This includes the early work of Leidy, Verrill, Smith, Sumner, and Allee to more recent work by Sanders, Parker, Rhoads, and Young which has been reviewed extensively in Pratt (1973), TRIGOM-PARC (1974), and Wigley and Theroux (1976, 1981 a, b). At the same time relatively few quantitative studies have been made on Georges Bank. To a great extent the available work was produced by the National Marine Fisheries Service (NMFS) primarily through the efforts of Wigley and his associates.

Research efforts can be divided broadly into several general categories. Wigley (1956, 1961b, 1965, 1968a) was particularly interested in quantitatively documenting benthic communities on Georges Bank and in correlating these communities to food relationships with groundfish. Research associated with this direction includes seasonal food habits of haddock, by-catch of finfish, the association between post-juvenile red hake and sea scallops, and the deep sea red crab (Wigley and Jensen, 1967; Wigley and Theroux, 1965, 1971; Wigley, Theroux and Murray, 1975).

Another category included benthic gear deployment. This work involved extensive testing of bottom gear with photographic techniques (Emery and Merrill, 1964; Emery, Merrill and Trumbull, 1965; Wigley, 1967; Wigley and Emery, 1967, 1968) and submersibles (Wigley, 1968b; Emery, Ballard and Wigley, 1970; Cooper and Scarratt, 1973; Uzman, Cooper, Theroux and Wigley, 1977).

Still another category included contributions in taxonomy and ecology of isopods (Wigley, 1960a, 1961c), shrimp (Wigley, 1960b; Haynes and Wigley, 1969; Wigley, 1970, 1973), mysids (Wigley, 1963a, 1964a; Wigley and Burns, 1971), cumaceans (Wigley, 1964b), amphipods (Wigley, 1966c; Wigley and Shave, 1966; Dickinson and Wigley, 1981), pogonophorans (Wigley, 1963b), bivalves (Serchuk, Wood, Posgay, Brown, 1979; Theroux and Wigley, 1981), scaphopods (Wigley, 1966a), crabs (Wigley and Messersmith, 1976; Williams and Wigley, 1977), and lobsters (Cooper and Uzman, 1971; Uzmann, Cooper and Pecci, 1977; Cooper and Uzmann, 1980).

Studies dealing with geology included organic content of sediment and sediment distribution of Georges Bank (Wigley, 1959, 1961a), peat deposits (Emery, Wigley and Rubin, 1965; Emery, Wigley, Bartlett, Rubin and Barghoorn, 1967), ancient oyster shells (Merrill, Emery and Rubin, 1965), rare fossils and remains of recent animals with hard parts (Wigley, 1966b; Wigley and Stinton, 1973) and the geology of canyons (Slater, Cooper and Warme, 1978; Valentine, Uzmann, Cooper, 1980).

Sanders, Hessler and Hampson (1965) initiated a study of benthic organisms from Gay Head to Bermuda which included a few stations on the continental shelf. Rowe, Polloni and Haedrich (1975) estimated abundance, biomass and diversity of the macro- and megafauna in the deep basins of the Gulf of Maine. Haedrich, Rowe and Polloni (1975, 1980) reported on zonation and faunal composition of epibenthic populations on the continental slope south of New England. Larsen and Lee (1978) reported on the abundance, distribution, and growth of post-larval sea scallops on Georges Bank. Kinner (1978) identified and analyzed a series of quantitative samples of polychaetes from the continental shelf ranging from Nova Scotia to Cape Hatteras. The ecology of dominant species of polychaetes, polychaete feeding guilds, and the ecology of polychaetous annelids of Georges Bank were described by Maurer and Leathem (1980a, b, 1981a, b). Gammarid amphipods from the Middle Atlantic Bight and Georges Bank were reported on by Dickinson, Wigley, Brodeur and Brown-Leger (1980) and Dickinson and Wigley (1981).

Conceptual Framework

Models can provide a conceptual framework representing a unified description of relationships among various processes. Although this account is primarily concerned with benthic invertebrates of Georges Bank, it is appropriate to recognize the relationship of the benthos to other components of the ecosystem. This is important because it places the benthos in its proper perspective compared to the treatment actually offered which greatly magnifies its importance through review of a voluminous data base. Moreover, a model sets the stage for the synthesis of this data base which is also an important goal of this account.

A conceptual representation of the New York Bight ecosystem was presented by McLaughlin and Elder (1976). Their model was designed for a geographic area influenced by estuarine inflow and human activity. However, their model identified major sources of energy and mass, many of which would be applicable to

Georges Bank. Major differences between the New York Bight and Georges Bank would be the influence of of estuarine inflow and human waste at the former. Accordingly, the generalized diagram of the New York Bight ecosystem provided by McLaughlin and Elder (1976) was modified for Georges Bank by excluding estuarine inflows and dumped and discharged wastes (Figure 1). Based on this model the benthic community is identified as a loop in the Georges Bank ecosystem. The benthos is coupled to the water column serving mainly as a sink for energy and a source of mass. This mass is important in its own right as a harvestable commodity or one that in turn is used by another loop of the ecosystem involving demersal and pelagic nekton. Moreover, another role of the benthos involves its role in nutrient flux either through its own metabolic activities or the effects of burrowing and bioturbation. Some of these products are utilized by phytoplankters in the water column.

In summary, the benthic loop is an integral part of the Georges Bank ecosystem representing significant energy flow and feedback. Elimination of the benthic loop would certainly not have the same effect on the Georges Bank ecosystem as serious disruption of components of the water column. However, perhaps the most effective way to assess the elimination of the benthic loop would be to examine the effect on demersal nekton. Evidence for this role will be provided later.

Ecosystem representation

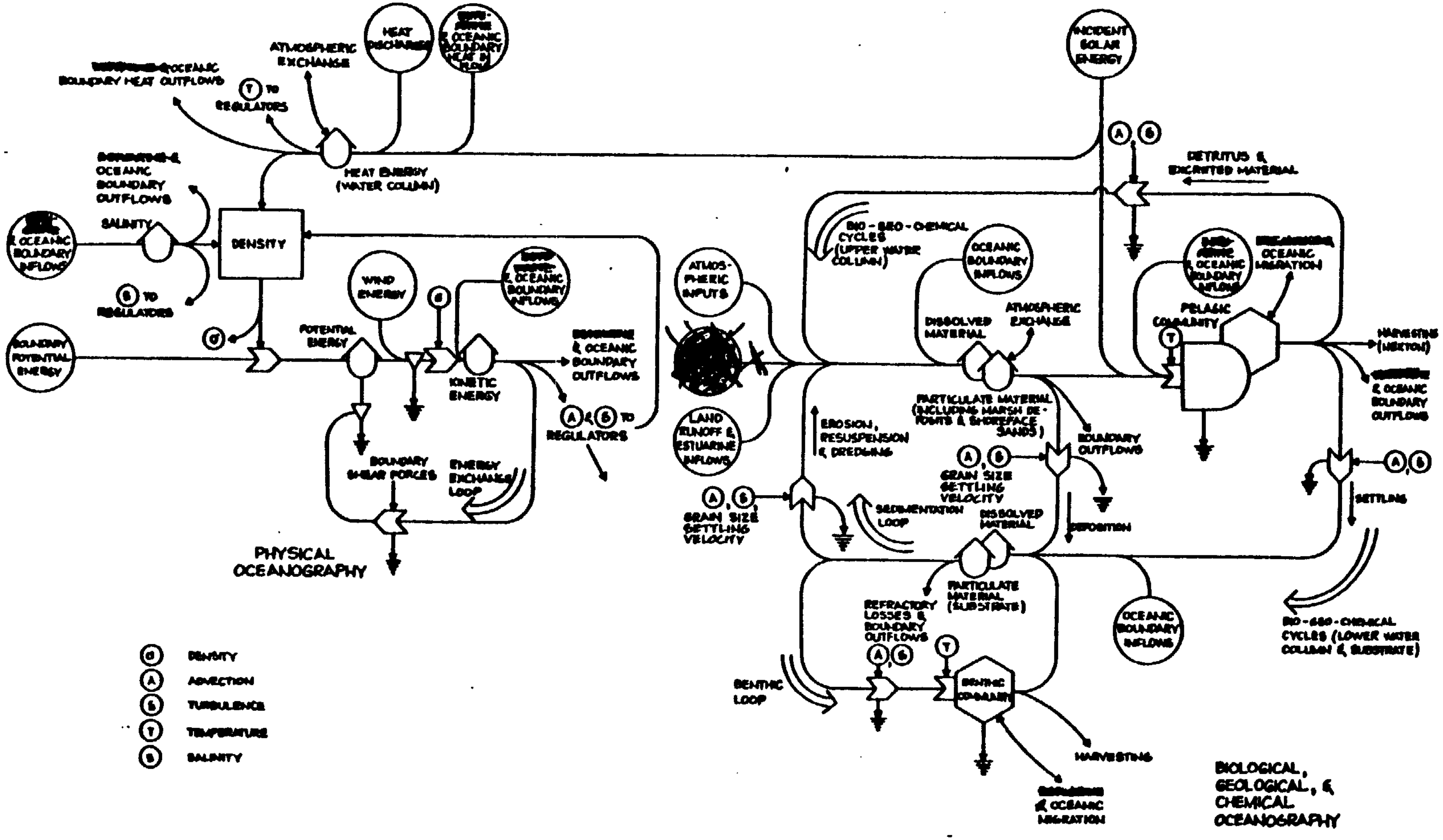


Fig. 1. Generalized diagram of the Georges Bank ecosystem. (taken from McLaughlin and Elder, 1976)

Environmental Setting

Marine Geology

Physiography

The Georges Bank area off New England is a submerged northeast extension of the Atlantic Coastal Plain (Aaron, 1980). The Bank which encompasses approximately 42,000 sq. km. is covered by a few meters to 200 m of water. The Bank is defined by the Gulf of Maine to the northwest, by the northeast channel to the northeast, by the continental slope (200-2,000 m) to the south and by the Great South Channel, which separates the Bank from Nantucket Shoals to the west (Aaron, 1980). The most visually characteristic feature is the abundance of ridge and swales that dominate most of the inner shelf, Nantucket Shoals and Georges Bank (Milliman, 1973). Other important features include the series of canyons dissecting the southern margin and slope of the Bank.

Canyons

The canyons dissecting the southern slope and margin of Georges Bank are quite properly conceived as an integral part of the marine geology of the whole area. However, the biological responses to geologic agents in the canyons and adjacent slopes are different enough from the Bank to warrant separate treatment. To adequately describe the latter and include it in the present synthesis of Georges Bank benthos would greatly expand this account beyond its original scope. A brief description of the canyon habitat is presented to provide some background for later discussion of a few important invertebrates which migrate between the Bank and canyons.

The eight canyons dissecting the southern margin of Georges Bank extending from east to west commonly identified are Corsair, Lydonia, Gilbert, Oceanographer, Welker, Hydrographer, Veatch, and Atlantis. Lydonia, Gilbert and Oceanographer canyons are of particular local significance because of their relative proximity to early announced oil lease tracts. The geology of the canyons, in particular Oceanographer, was recently described (Valentine, et al, 1980). Canyon depths range approximately from 150 to 2,000 m. Shelf sediments are transported from Georges Bank over the eastern rim and into Oceanographer Canyon by the southwest drift and storm currents. Tidal currents and internal waves move the sediment down canyon along the walls and axis. Large erratic boulders and gravel pavements on the eastern rim are ice-rafted glacial debris of probably late Wisconsin age. Modern submarine currents prevent burial of the gravel deposits but thin layers of unconsolidated sediment occur in protected sites. It should be emphasized that the bottom topography and rates of sedimentation and deposition are not all alike from canyon to canyon. Some canyons are actively eroding the slope of Georges Bank while others are more quiescent serving more as basins or depressions of deposition. For example, Lydonia Canyon is probably more in the mode of a sediment sink than Oceanographer Canyon. The degree of activity of geological agents is probably reflected by the relative age of the canyons.

Sediment

General

The topography and sediment from the study area are determined primarily by Pleistocene glaciation and present agents of sediment transport (Schlee, 1973). The sediments of northern Georges Bank are remnants of a glacial moraine whereas the sediment of the southern half are remnants of a glacial outwash plain. Surface sediment has been smoothed and reworked by intermittent transgressions and regressions of sea level since the Pleistocene (Knott and Hoskins, 1968).

Sediment Grain Size

According to Milliman (1973) Continental Shelf sediment including Georges Bank is dominated by sand (62-2,000 microns in diameter). Moreover, sediment with high gravel concentrations occurs on Nantucket Shoals and Georges Bank. This was recently reaffirmed by Bothner, Spiker, Ferrebee and Peeler (1980). Based on the BLM study the mean sediment fraction on Georges Bank would contain 87-89% sand, 2.0-2.7% gravel, 4.7-7.2% silt, 2.4-3.7% clay, would vary in sediment size from 1.9 to 2.2 ϕ and sorting from 0.9 to 1.1 ϕ (Table 1). Since there was no significant seasonal difference in sediment size (mean ϕ), a sediment map was prepared (Figure 2).

Based on Appendix Table (A-1 to A-7), Stations 4-5, 26-27, 36-38 and 40 consistently produced the largest variations in sediment size properties. These variations were almost entirely due to the quantity of gravel present in a sample. Samples tended to be bimodal containing fine to medium sand mixed in varying proportions with gravel-sized material. Stations on the

Table 1. Summary of Georges Bank Sediment Properties, 1977

		Gravel %	Sand %	Silt %	Clay %	Silt-Clay %	Mean ϕ	Sorting ϕ	Carbon mg/g	Nitrogen mg/g	C:N
Winter	$\bar{x}$	2.6	89.9	5.1	2.45	7.46	1.94	0.91	1.98	0.33	5.78
	SD	5.1	17.7	10.0	7.64	17.4	1.32	0.73	2.61	0.39	1.84
	Min.	0.0	2.3	0.6	0.0	0.7	0.4	0.37	0.44	0.09	2.2
	Max.	20.9	99.0	53.0	44.7	97.7	7.7	3.88	13.14	1.66	10.7
	N	41	41	41	41	41	41	41	41	41	41
Spring	$\bar{x}$	2.7	89.2	5.49	2.49	7.99	2.02	0.96	2.53	0.37	6.48
	SD	5.89	18.0	10.5	7.35	17.5	1.28	0.76	2.38	0.32	1.14
	Min.	0.0	2.1	0.5	0.0	0.5	0.52	0.20	0.63	0.13	4.1
	Max.	31.1	99.4	55.2	42.7	97.9	7.6	3.5	12.94	1.63	8.4
	N	42	42	42	42	42	42	42	42	42	42
Summer	$\bar{x}$	2.7	89.3	4.73	2.46	7.19	2.02	1.01	2.86	0.36	7.74
	SD	6.88	19.1	9.9	8.13	17.8	1.31	0.96	2.45	0.27	2.85
	Min.	0.0	3.3	0.3	0.0	0.3	0.01	0.17	0.81	0.16	4.3
	Max.	38.5	99.7	51.7	45.0	96.7	7.8	5.2	13.61	1.63	17.1
	N	35	35	35	35	35	35	35	35	35	35
Fall	$\bar{x}$	2.02	87.1	7.28	3.72	10.7	2.29	1.12	3.45	0.41	7.91
	SD	4.74	20.5	12.5	9.16	20.5	1.48	1.05	3.21	.35	2.78
	Min.	0.0	4.0	0.7	0.0	0.3	0.5	0.30	0.77	0.16	4.6
	Max.	19.1	99.7	57.4	44.6	96.0	7.84	5.06	14.91	1.78	18.5
	N	29	29	29	29	29	29	29	29	29	29

$\bar{x}$ = mean, SD = 1 standard deviation, Min. = minimum value, Max. = maximum value, N = number of stations

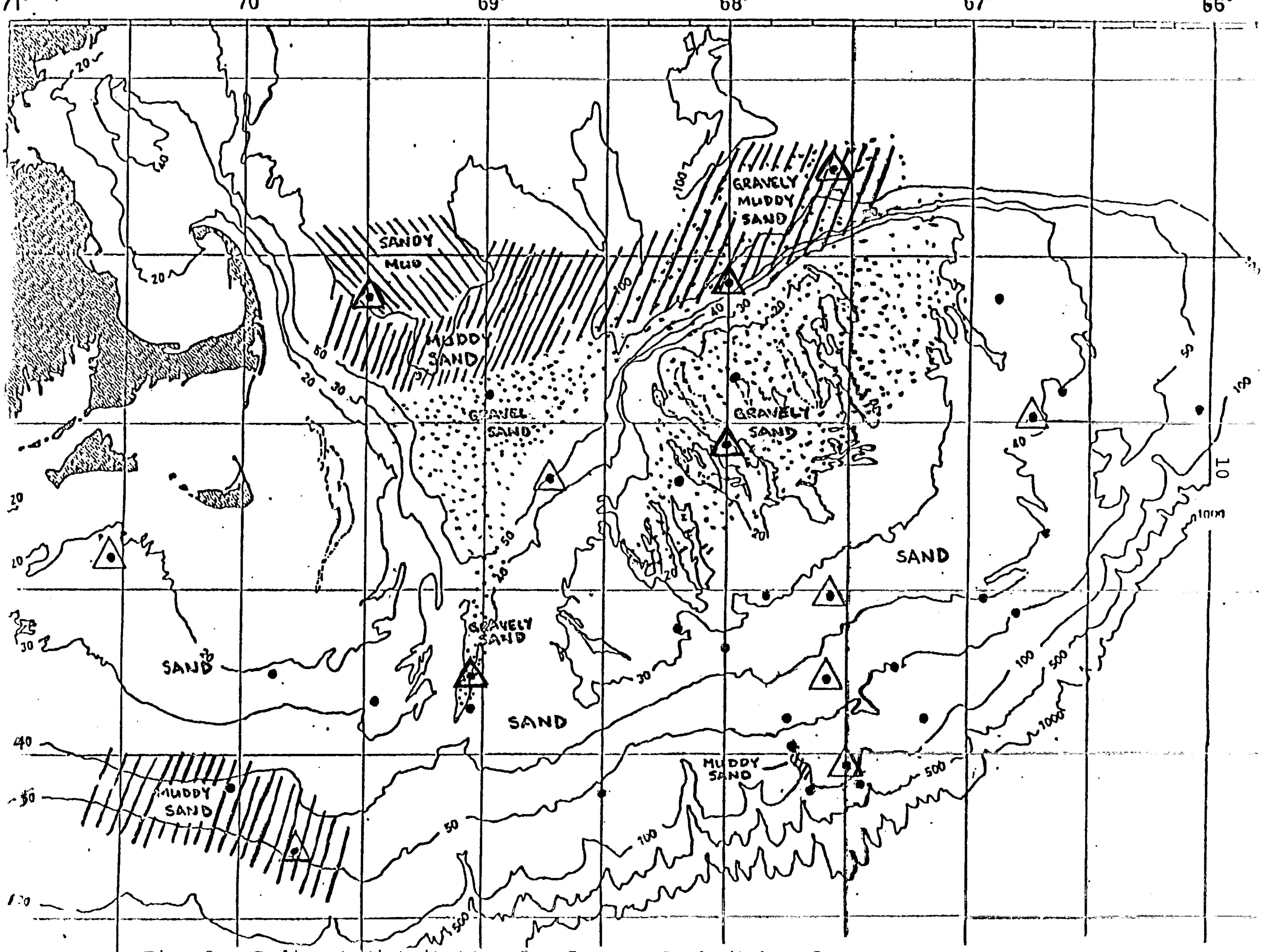


Fig. 2 Sediment distribution for Georges Bank (taken from NEOEB V. 1978)

northern half of the Bank were characterized by gravelly sands. In contrast stations from the southern half of the Bank were mostly fine to medium sand with some coarse to medium gravelly sands found at stations near the edge of the shelf (Stations 26-27). Sediments generally had a single mode with the addition of small amounts of coarser sand or gravel. Samples from the head of Lydonia Canyon (Station 23) varied from silty fine sand to fine sand. The further down the canyon the sample came from, the more silt appeared in the sample.

Sediment from Nantucket Shoals and the Great South Channel were moderately sorted sand with some gravel. Stations 4 and 5 contained varying proportions of gravel. Both stations are located on the edge of the relict glacial terminal moraine. In contrast to coarse-grained sediments stations 6 and 7 represented an entirely different sedimentary regime with some of the highest fraction of fine-grained sediment (30-41% silt-clay). Analysis of the major clay mineral groups indicated that illite was predominant with moderate amounts of chlorite and small concentrations of kaolinite (Bothner, et al, 1980).

Sediment from the Gulf of Maine Stations (41-42) are reworked glacial material. Sediments range from the highest values of clay (17-45%) reported in this study to gravel. The samples commonly contained the highest sorting coefficients.

Sediment Chemistry

Sediment organic matter was described as total organic carbon and organic nitrogen (NEOEB V, 1978). The mean organic matter in sediment contains 1.9-3.4 mg/g carbon, 0.33-0.41 mg/g nitrogen and a C:N ratio of 5.7 to 7.9 (Table 1). However, organic matter varied with sediment size. In predominantly sandy areas (Stations 9-12, 30-33) values of organic carbon generally remained below 2.0 mg/g and the values of organic nitrogen were less than 0.4 mg/g. In the fine-grained sediments in the Gulf of Maine and southwest of Nantucket, values for organic carbon and organic nitrogen rose markedly (southwest of Nantucket - carbon 6.0 to 10 mg/g, nitrogen - 0.8 to 1.2 mg/g, Gulf of Maine - carbon 4.0 to 14.0 mg/g, nitrogen - 0.5 to 1.7 mg/g).

Levels of organic matter in the zone where the shelf/slope front intrudes upon the Bank revealed higher than expected values for the sediment type observed. In addition there was a significant ($\alpha < 0.05$) increase in organic carbon from the winter ($\bar{x}$ = 1.98 mg/g) to summer ($\bar{x}$ = 2.86 mg/g, t = 2.39) and to fall ($\bar{x}$ = 3.45 mg/g, t = 3.57) (Table 1). Organic nitrogen did not increase significantly throughout the year. However, because of the threefold increase in carbon there was a progressive increase in the C:N ration from winter ($\bar{x}$ = 5.78) to fall ($\bar{x}$ = 7.91). Seasonal differences were significant between fall, summer, spring, and winter (t = 5.88, t = 5.62, t = 2.62), fall and spring (t = 3.28) and summer and spring (t = 2.87).

The seasonal addition of organic matter to the sediment was reflected by the slight reduction in % sand and increase in silt-clay for sediment sampled in the fall (Table 1). The high levels of organic carbon observed in the sediments at stations 22, 23, 25, 26, 27 may be attributed to the high productivity in the vicinity of frontal systems. The seasonal incorporation of organic matter in Georges Bank sediment probably represents an important resource to the benthos. Extensive data on hydrocarbon and trace metal composition and concentration in sediments were presented in NEOEB II (1978).

Seston

The following section was based on the work of Milliman, Bothner and Parmenter (1980). Highest concentrations (15,000 µg/L) of seston were measured on the shelf south of Nantucket Shoals during the winter. These concentrations were considered significant because they exceeded estimated levels of suspended matter (3,000-5,000 µg/L) which may cause crude oil to sink. Lowest values of total suspended material (50 µg/L) were generally found in slope waters at the shelf edge.

Sources of suspended matter were predominantly from biological production and to a lesser degree from resuspension of bottom sediment (Milliman et al, 1980). The relative importance of these sources varied seasonally and with the stability of the water column together with major storms which can temporarily override seasonal effects. In contrast rivers and atmospheric input were minimal.

During the winter there was an increase in lithogenic material in surface waters caused by the decrease in stability of the water column and consequent increased mixing. There was a seasonal change in the amount and composition of phytoplankton. Prominent diatoms included *Actinocyclus*, *Coscinodiscus*, and *Thalassiothrix*. *Thalassiosira*, *Chaetoceras*, *Pleurosigma*, *Raphoneis* and *Melosira* were observed in lesser concentrations

(Milliman et al, 1980). Coccoliths decreased gradually from winter to summer on Georges Bank and were replaced by diatoms. Zones of high coccolith concentrations tended to migrate southward off the Bank and resided in greater depths in the water column during warmer months.

Two areas of continuously active sediment resuspension included the southwestern part of the Gulf of Maine north of the Great South Channel and south of Nantucket. Resuspension was also observed on the southeast flank of Georges Bank. The influence of flow through Great South Channel in maintaining or transporting seston was unknown.

The area south and southwest of Nantucket at depths greater than 60 m is covered with silty-clay sediment (Schlee, 1973). According to Milliman et al (1980), this area (Mud Patch) was characterized by increased turbidity in the near bottom water with high concentrations of noncombustible particulates. Preliminary age data of sediment cores suggested that the Mud Patch may be a present-day sink for sediments. If this hypothesis is confirmed, then this area of anomalous fine-grained sediment assumes new significance because it would represent a major depositional site for sediments and sediment-related pollutants introduced by offshore development activity. The large area of Georges Bank and Nantucket Shoals still cannot be discarded as a likely source of the Mud Patch. Finer-grained sediment present in low concentrations of a mainly sand and gravel field may be winnowed from these areas especially during storms, and transported with the net southwestward drift to the area south of Nantucket.

Sediment Transport

Currents and sediment transport in the Georges Bank area have been studied by the USGS since May 1975 (Aaron, Butman, Bothner, and Sylwester, 1980). Data clearly indicated resuspension and transport of bottom sediments. Bottom current speed at 85 m on the south central portion of the Bank ranged from 10 to 30 cm/s. The threshold near-bottom current speed required to transport fine sand is about 25 cm/s. Accordingly, bottom sediment here was frequently in motion.

Sediment was affected by both along-shelf and cross-shelf bottom currents. Winter storms and diurnal tidal currents were also involved. During a single tidal cycle current direction rotated through 360°.

Sand waves, which are large potentially mobile bed forms caused by strong tidal currents and augmented by wind-driven currents, act on loose surficial sand. They are located mainly on Georges Bank and Nantucket Shoals in water 60 m or less. Sand waves on Georges Bank commonly ranged in height from 5 to 15 m and in wave length from 150 to 750 m. The sharp assymetry of many sand waves on Georges Bank indicated that they are active. Sand waves more than 8 m high on northern Georges Bank migrated a maximum net distance of 300 m westward in a 25-28-year period. This migration rate, about 12 m/year, occurred in an area where tidal currents of up to 100 cm/s were measured (Aaron et al, 1980).

U.S.G.S studies showed that tidal currents were sufficient to rework surficial bottom sediments over Georges Bank (Aaron et al, 1980). Near-surface tidal currents (15 m depth) near the crest of the Bank were commonly 75 cm/s and on the north and south flanks of the Bank were about 35 cm/s. Maximum currents measured were 100 cm/s. During storms tidal currents were augmented by wind-driven flow that increased bottom stress causing increased sediment resuspension. It was concluded that the surficial sediments on Georges Bank were frequently reworked and in the shallow water near the top of the Bank, surficial sediments are in constant motion even in normal tidal currents (Aaron et al, 1980).

Physical Oceanography

General Circulation

The major pattern of circulation on Georges Bank was sketched earlier by Bigelow (1927) and Bumpus (1973). Currents on the Bank may be divided into 1) a mean current, 2) low-frequency current fluctuations primarily associated with density effects and storms, 3) diurnal and semidiurnal tidal currents, and 4) other higher-frequency current fluctuations (Butman, Nobel, Beardsley, Vermersch, Limeburner, Magnell, and Schlitz, 1980). This brief review of circulation emphasized mean currents.

According to Butman et al (1980), their data showed a clockwise circulation pattern around the Bank. Flow on the southern flank was consistently toward the southwest. Mean flow was strongest near the surface (15 cm/sec. at 15 m) and weaker at depth (6 cm/sec. at 75 m, 10 m above bottom). On the northern side of the Bank, a strong flow toward the northeast of 30 cm/sec. was measured (Butman et al, 1980). On the northeast peak, this easterly flow weakened, and the mean flow was eastward, southeastward, and then southward around the eastern side of the Bank at 5-10 cm/sec. On the crest of the Bank, flow was weak toward the south and southwest.

On the eastern side of Great South Channel mean flow was consistently toward the north at 5-10 cm/sec. at all depths (Butman et al, 1980). At a station just south of Great South Channel there was a westerly flow similar to that along the southern flank. On the western side of Great South Channel little net flow was measured.

Northeast Channel Flow

Two years of current measurements in Northeast Channel showed three seasonal flow regimes: a steady inflow in summer, large fluctuations with a net inflow in winter, and a period of low transport in the spring (Ramp, Schlitz, and Wright, 1980).

Great South Channel was historically considered a major exit for Gulf of Maine Waters (Schlitz, 1981). However, recent current measurements indicated that mean flow within the channel was mainly directed toward the Gulf of Maine (Butman et al, 1980). Schlitz, Wright and Laughton (1977) showed that a permanent front exists across the channel from Nantucket Shoals toward Georges Bank and this separates the Gulf of Maine from the shelf to the south. According to Schlitz (1981) a small amount of water flows southward through Nantucket Shoals, but this probably does not contribute significant volume. As a result, most water must leave the system either through Northeast Channel or across Georges Bank.

It was concluded that slope water provides a continuous source of nutrient-rich water through Northeast Channel. These nutrients can be made available by at least three processes to the phytoplankton of Georges Bank (Schlitz, 1981). The first would be continuous upwelling of modified water along the northern side of the Bank. The second would involve advection of waters upwelled from the lower seasonal thermocline east of Nantucket Shoals and Cape Cod to Georges Bank where they are mixed onto the Bank. The third process would be deep mixing and transport by direct force of strong northwesterly winds during the winter. Finally, conditions suitable for centrifugal upwelling at the eastern end of Georges Bank were also briefly described.

Environmental Variables

General

Bottom (within 1.0 m) temperature (°C), salinity (°/oo), dissolved oxygen (ml/L), and micronutrients (NO_2, NO_3, S_1O_4, µg-at/L) were measured on Georges Bank for four seasons. Mean values for these variables were 5.1 to 10.4°C, 33.4 to 33.9 °/oo, 5.43 to 6.86 ml/L, 0.08 to 0.26 NO_2, 8.12 to 12.98 NO_3, 6.45 to 9.36 S_1O_4, 0.76 to 0.99 PO_4 µg-at/L and a N/P ration of 9.18 to 12.97 (Table 2). A detailed presentation of bottom and water column hydrographic data was presented in NEOEB II (1978) with graphs and charts in NEOEB IV (1978).

Bottom Temperature

Bottom temperature ranged from 0.5 to 10.6°in the winter with a mean of 5.10, from 4.8 to 11.3° in the spring with a mean of 7.1°, from 5.1 to 17.3° in the summer with a mean of 10.4° and

Table 2. Summary of Georges Bank Environmental Variables, 1977

Near Bottom

		Temp.	Sal.	DO	NO_2	NO_3	S_1O_4	PO_4	N:P
		°C	^{o}/oo	ml/L			µg-at/L		
Winter	$\bar{x}$	5.1	34.0	6.86	.10	12.98	9.36	.99	12.97
	SD	2.1	0.43	0.75	.04	2.49	2.45	.137	2.25
	Min.	0.5	33.4	5.0	.02	0.41	0.3	0.49	0.9
	Max.	10.6	35.4	8.1	.18	16.5	14.3	1.35	16.1
	N	41	41	31	41	41	38	41	41
Spring	$\bar{x}$	7.1	33.9	6.57	.21	6.14	6.45	.76	7.19
	SD	1.61	0.66	0.86	.32	5.02	3.87	.26	4.52
	Min.	4.8	32.9	4.4	0.0	0.0	0.4	0.23	0.0
	Max.	11.3	35.4	7.9	1.91	17.0	19.7	1.40	15.8
	N	41	41	41	41	41	41	41	41
Summer	$\bar{x}$	10.4	33.4	5.68	.08	8.12	7.55	.76	9.18
	SD	2.55	0.93	0.68	.08	5.99	3.96	.29	4.89
	Min.	5.1	32.4	3.68	0.0	0.0	1.0	0.25	0.0
	Max.	17.3	35.3	6.85	0.28	23.24	15.0	1.19	15.5
	N	37	37	37	37	37	37	37	37
Fall	$\bar{x}$	10.2	33.6	5.43	.26	8.82	7.58	.81	9.91
	SD	2.28	0.95	0.87	.37	6.32	4.49	.29	3.93
	Min.	5.6	32.4	3.87	0.0	0.15	0.7	.49	0.6
	Max.	15.6	35.4	6.55	1.83	20.91	14.8	1.36	15.5
	N	28	29	29	29	29	29	29	29

Temp. = temperature, Sal. = Salinity, DO = dissolved oxygen, $\bar{x}$ = mean, SD = standard deviation, Min. = minimum value, Max. = maximum value, N = number of stations.

from 5.6 to 15.6° in the fall with a mean of 10.2° (Table 2). Bottom temperature showed an expected progressive increase from winter to summer with an extended warm period into fall. Gulf of Maine stations (41-42) and those on the northern margin (stations 35-36) consistently contained the coldest bottom temperatures throughout the year. In contrast some shallow-water stations (30-32, 37-38) throughout the central portion of the Bank fluctuated markedly with season, low in the winter and warm in the summer and fall.

Bottom Salinity

Bottom salinity was very stable throughout the year. Bottom salinity ranged from 33.4 to 35.2 °/oo in the winter with a mean of 34 °/oo, from 32.9 to 35.4 °/oo in the spring with a mean of 33.9°/oo, from 32.4 to 35.3 °/oo in the summer with a mean of 33.4 °/oo, and from 32.4 to 35.4 °/oo in the fall with a mean of 33.6 °/oo (Table 2). Stations 7-8 and 22-26 consistently showed the highest salinity. Although the seasonal and annual range of bottom salinity was modest, the seasonal and annual temperature, salinity and density of the overlying water was more dynamic and complex (NEOEB IV, 1978). The high bottom salinity at stations 7-8 and 22-26 was probably associated with frontal systems and the incursion of slope water.

Bottom Oxygen

Bottom oxygen ranged from 5.0 to 8.1 mg/L in the winter with a mean of 6.86 mg/L, from 4.4 to 7.9 mg/L in the spring with a mean of 6.57 mg/L, from 3.68 to 6.85 mg/L in the summer with a mean of 5.68 mg/L, and from 3.87 to 6.55 mg/L with a mean of 5.43 mg/L in the fall (Table 2). Bottom oxygen showed a progressive decrease from winter to summer. Oxygen values were consistently lower at stations 7-8 and 22-26 than elsewhere throughout the year. These relatively low oxygen values were directly associated with the same physical oceanographic processes controlling temperature, salinity and density (NEOEB IV, 1978).

Bottom Nutrients

Particulate Carbon

During the winter, particulate carbon near the bottom was relatively high over Nantucket Shoals (0.06-0.08 μg/l) and the north central portion of the Bank (0.07-0.09 μg/l) and relatively low in the Gulf of Maine (0.03 μg/l), great South Channel (0.04 μg/l) and southern shelf (0.03-0.05 μg/l) (NEOEB V, 1978). In the spring, concentrations of particulate carbon near the bottom increased over winter values everywhere with marked increases for the Great South Channel (0.08-0.1 μg/l) and the Gulf of Maine (0.08-0.12 μg/l). Summer values were similar to spring, only broader areas on Georges Bank were involved. In the fall, values declined rapidly towards the Gulf of Maine (0.06 μg/l) but remained relatively high on Nantucket Shoals (0.1-0.12 μg/l) and the Bank (0.1-0.18 μg/l).

Nitrite

Bottom nitrite ranged from 0.02 to 0.18 μg-at/L in the winter with a mean of 0.10 μg-at/L, from 0.0 to 1.91 μg-at/L in the spring with a mean of 0.21 μg-at/L, from 0.0 to 0.28

µg/at/L in the summer with a mean of 0.08 µg-at/L, and from 0.0 to 1.83 µg-at/L in the fall with a mean of 0.26 µg-at/L (Table 2). These values indicate a pattern containing two low periods (winter and summer) and two highs (spring and fall). During the summer and fall values of bottom nitrite were extremely low at stations 22-28.

Nitrate

Bottom nitrate ranged from 0.41 to 16.5 µg-at/L in the winter with a mean of 12.98 µg-at/L, from 0.0 to 17.0 µg-at/L in the spring with a mean of 6.14 µg-at/L, from 0.0 to 23.2 µg-at/L in the summer with a mean of 8.12 µg-at/L, and from 0.15 to 20.91 µg-at/L in the fall with a mean of 8.82 µg-at/L (Table 2). There was a marked decline in bottom nitrate between winter and spring followed by a moderate increase in summer and fall. Winter values at almost all stations were relatively high (<12 µg-at/L). Bottom nitrate values in the spring, summer and fall generally remained high at the Gulf of Maine stations (41-42) and station 35 and stations 22-27 on the south central portion of the Bank. After the winter bottom nitrate values were generally low on Nantucket Shoals and throughout the Bank.

Silicate

Bottom silicate ranged from 0.3 to 14.3 µg-at/L in the winter with a mean of 9.36 µg-at/L, from 0.4 to 19.7 µg-at/L in the spring with a mean of 6.45 µg-at/L, from 1.0 to 15.0 µg-at/L in the summer with a mean of 7.55 µg-at/L, and from 0.7 to 14.8 µg-at/L in the fall with a mean of 7.58 µg-at/L

(Table 2). The seasonal pattern of bottom silicate was very similar to that of nitrate in that silicate decreased markedly between winter and spring and then increased moderately in summer and fall (Table 2). Winter values at almost all stations were relatively high (<7.0 µg-at/L). Bottom silicate values in the spring, summer and fall generally remained high at the Gulf of Maine stations (41-42) and station 35 and stations 22-27. This geographic pattern was also very similar to that of bottom nitrate.

Phosphate

Bottom phosphate ranged from 0.49 to 1.35 µg-at/L in the winter with a mean of 0.99 mg-at/L, from 0.23 to 1.40 µg-at/L in the spring with a mean of 0.76 µg-at/L, from 0.25 to 1.19 µg-at/L in the summer with a mean of 0.76 µg-at/L, and from 0.49 to 1.36 µg-at/L in the fall with a mean of 0.81 µg-at/L (Table 2). In contrast to bottom nitrate and silicate which decreased markedly and then increased moderately, bottom phosphate peaked in winter and remained relatively stable throughout spring, summer and fall (Table 2). However, the geographic distribution of bottom phosphate essentially agreed with that of nitrate and silicate, high in the Gulf of Maine stations (41-42), station 35, and stations 22-27. Although there were considerable differences in seasonal distribution among these nutrients, their geographic distribution was associated with a sedimentary regime of fine-grained sediment (Tables A-1 to A-4).

N:P Ratio

The N:P ratio ranged from 0.9 to 16.1 in the winter with a mean of 12.97, from 0 to 15.8 in the spring with a mean of 7.1, from 0 to 15.5 in the summer with a mean of 9.1, and from 0.6 to 15.5 in the fall with a mean of 9.9 (Table 2). There was a marked decrease in the N:P ratio between winter and spring with a moderate increase to summer and fall. Both the seasonal and geographic pattern of the N:P ratio were strongly influenced by that of bottom nitrate.

Biology

Meroplankton

General

During the course of the 1977 BLM study, zooplankton samples were generally collected at the 12 water column stations (NEOEB III, 1978). Samples were taken obliquely with Brown-McGowan Bongo net systems fitted with 202 μ mesh and 505 μ Nytex nets. In the laboratory, emphasis was placed on the taxonomic composition of holoplankton, particularly the copepods, with the purpose of examining their relationship with trace metals (NEOEB III, 1978, Sick, 1978).

For purposes of this account, it was deemed appropriate to briefly examine that fraction of the zooplankton data concerned with meroplankton. Presumably, these data would provide information on the recruitment of benthic organisms. As a result, density counts of selected meroplankton were extracted from the data base (NEOEB III, 1978). Analysis was limited to those taxa normally found on soft bottoms, and excluded taxa commonly found on hard bottoms (ectoprocts, barnacles) and pelagic polychaetes (Tomopteridae). Since there was very little specific enumeration of meroplankton these data were divided into major taxa (Gastropoda, Pelecypoda, Polychaeta, Crustacea, Echinodermata) with the insertion of finer taxonomic resolution when available. Notwithstanding the limitation of these broad taxonomic categories some interesting trends emerged.

Seasonal

As it might be expected densities were generally higher in the 202 μ mesh samples than in the 505 μ mesh samples (Table 3). Exceptions to this commonly involved crustacean meroplankton (Table 4). Densities were highest (7.31-251.3$/m^{-3}$) in the summer and lowest (0.025-3.55$/m^{-3}$) in the winter for the major taxa (Table 4). The meroplankton peak in summer contrasted geographically with a spring peak in holoplankton (Sherman and Jones, 1980). The mean density of gastropod larvae was low in the winter (0.025-0.07$/m^{-3}$) and spring (0.26-1.69$/m^{-3}$), increased slightly to a peak in the summer (1.7-7.31$/m^{-3}$) and remained relatively high in the fall (0.10-5.2$/m^{-3}$). Bivalve larvae were also low in the winter (1.24$/m^{-3}$) and spring (0.0019-2.69$/m^{-3}$) and increased enormously to the highest mean densities (1.66-251.3$/m^{-3}$) in summer recorded for any of the taxa (Table 4). There was a marked decline of bivalve larvae in the fall. Mean density of polychaetes increased rapidly from a low in winter (0.40$/m^{-3}$), through spring (7.79-13.3$/m^{-3}$), to a summer peak (1.66-20.1$/m^{-3}$), followed by a marked decline in fall (0.14-0.52$/m^{3}$). The polychaete *Scalibregma inflatum*

Table 3. Mean Densities (No./m^{-3}) of Selected Meroplankton by Station collected with 202μ and 505μ mesh for Georges Bank, 1977

Station		1	4	7	13	18	26	32	35	36	37	39	42
Winter													
202μ	x̄	2.48	—	—		0.46		5.87			0.42		0.005
n= 7	SD	3.91				0.89		11.7			0.61		0.0.3
505μ	x̄	1.46	—	0.024	0.176	0.168		0.085	0.001	0.016	0.05	0.013	
n=10	SD	2.92		0.035	0.253	0.337		0.171	0.001	0.031	0.10	0.02	
Spring													
202μ	x̄	2.68	0.37	5.35	5.48	0.67	4.4	5.92	—	0.53	48.7	—	0.124
n=12	SD	5.99	0.81	8.91	7.70	1.51	9.8	9.03		0.119	67.2		0.202
505μ	x̄	1.12	19.5	0.078	0.57	0.26	0.79	2.66	0.003	0.011	44.5	0.02	0.009
n=12	SD	2.42	38.8	0.17	0.79	0.57	1.34	5.56	0.007	0.015	99.5	0.046	0.02
Summer													
202μ	x̄	33.3	540.7		0.55	4.04	0.183	0.79		0.12	213.6	4.02	0.03
n=10	SD	31.2	796.5		0.66	3.73	0.367	1.59		0.14	380.9	2.34	0.05
505μ	x̄	0.71	0.37		1.64	0.077	0.25	0.99		1.54	479	0.22	0.018
n=10	SD	1.42	0.57		3.25	0.14	0.43	1.99		3.0	924.9	0.442	0.03
Fall													
202μ	x̄	20.1	15.6	1.26	5.15	0.35	0.53	2.03	0.005	0.77	9.72	0.49	0.24
n=12	SD	40.0	17.4	0.89	9.7	0.48	0.60	1.06	0.007	1.55	15.07	0.527	0.49
505μ	x̄	0.26	0.33	0.47	0.63	0.123	0.208	0.83	0.003	0.042	2.87	0.188	0.79
n=12	SD	0.44	0.66	0.63	0.88	0.24	0.33	0.95	0.006	0.038	3.58	0.37	0.13

n = number of stations sampled

— = 0 to little meroplankton sampled.

Table 4. Mean Densities (No./m^{-3}) of Selected Meroplankton by Taxon collected with 202µ and 505µ mesh for Georges Bank, 1977

Taxon	Gastropoda	Pelecypoda	Polychaeta	Crustacea	Echinodermat
Winter					
202µ $\bar{x}$	0.07	1.24	0.40	3.55	
n=7 SD	0.18	3.1	0.71	8.8	
505µ $\bar{x}$	0.025			0.77	
n=10 SD	..05			1.79	
Spring					
202µ $\bar{x}$	1.69	2.69	13.3	12.9	0.029
n=12 SD	4.9	6.4	40.2	28.8	0.09
505µ $\bar{x}$	0.26	0.0019	7.79	20.9	0.025
n=12 SD	0.47	0.006	26.8	63.5	0.08
Summer					
202µ $\bar{x}$	7.31	251.3	20.1	40.1	
n=10 SD	18.7	571.5	42.7	97.9	
505µ $\bar{x}$	1.7	1.66	1.66	188.9	
n=10 SD	5.23	5.24	5.24	589.4	
Fall					
202µ $\bar{x}$	5.2	11.9	0.52	1.1	
n=12 SD	10.4	24.3	0.60	1.93	
505µ $\bar{x}$	0.10	0.5	0.14	1.26	
n=12 SD	0.17	1.0	0.27	2.1	

n = number of stations sampled

was identified among polychaete larvae for the fall (NEOEB III, 1978). Spring was the only period that echinoderm larvae were recorded.

Specific enumeration of meroplankton from the gastropods, pelecypods and polychaetes would be valuable ecologically and economically. Data on bivalve larvae including *Arctica islandica* and *S. solidissima* would provide the basis for testing hypotheses concerning recruitment of these commercially valuable species. Moreover, *A. islandica* comprised a major component of biomass standing crop on the southern half of Georges Bank. For juvenile gastropods and polychaetes, in addition to serving as food source for finfish, the sequence of spawning, larval development and settling of gastropod larvae and their subsequent development has important ecologic and economic ramifications as adults of many gastropods prey on *A. islandica* and *S. solidissima*. In regards to polychaetes the difference between high or low year classes for recruitment must have considerable effect on feeding habits and success of demersal fish.

In contrast to the gastropods, pelecypods and polychaetes taxonomic enumeration with crustaceans was somewhat better, in that order, families and occasionally species were identified (NEOEB III, 1978). Mean densities of crustaceans were highest in the summer (40.1 - 188.9/m^{-3}) and lowest in the fall (1.1 - 1.26/m^{-3}). During the winter, amphipods (gammarids), cumaceans, caridean shrimp (*Crangon septemspinosa*, *Dichelopandalus leptocerus*), anomurans and mysids (*Neomysis americana*) contributed numerically to the crustacean larvae. In the spring, gammarid amphipods, cumaceans, caridean shrimp and mysids were again important but their pooled density was exceeded by crab larvae. In the summer, isopods became more abundant in the plankton samples which were dominated by crab larvae. Larval and juvenile stages of anomuran pagurids were important. Calliopius laeviusculus and Aeginina longicornis contributed to the gammarid and caprellid amphipods respectively. By the fall the densities of crab larvae were similar to or lower than the other taxa of crustaceans (cumaceans, amphipods, isopods, mysids, caridean shrimp) reported for this period. Taxonomic enumeration of crab larvae would also be advisable with the promise of recognizing species of Cancer containing two commercially valuable species (C. borealis and C. irroratus).

Distribution

In general mean densities of meroplankton were relatively high at near-shore stations 1 and 4 and the central Bank station 37 and low at deeper stations (stations 25, 39, 42) (Table 3). During the winter, the peak value at station 32 ($5.87/m^{-3}$) was influenced by Neomysis americana. In the spring, peak values at station 37 were influenced in descending order by larvae of crabs, polychaetes, mysids and gammarid amphipods (NEOEB III, 1978). Peak values were recorded at station 4 ($540.7/m^{-3}$) and station 37 ($213.6 - 479/m^{-3}$) in the summer. A massive ($179.9/m^{-3}$) infusion of bivalve larvae together with polychaetes ($129.7/m^{-3}$) and crab larvae ($313.4/m^{-3}$) influenced density at station 4, whereas larvae of bivalves, crabs and amphipods were dominant at station 37. Finally, during the fall, stations 1, 4 and 37 were dominated by bivalve larvae together with a considerable fraction of gastropod larvae at station 4.

Benthic Invertebrates

Quantitative Grabs - N.M.F.S.

General

This account represents a portion of a larger benthic data base from Georges Bank to the Florida Keys collected by the U.S. Geological Survey and the National Marine Fisheries Service (Wigley and Theroux, 1976, 1981a,b; Theroux and Wigley, 1981). Data from one transect (10 stations) off Martha's Vineyard including a comparison of meiobenthos and macrobenthos were published earlier together with an account from all 64 stations of macroscopic remains of animals with hard parts (Wigley and McIntyre, 1964, Wigley and Stinton, 1972). This presentation was mainly extracted from Maurer and Wigley (1981) and was based on Smith-McIntyre grab samples off Martha's Vineyard. Quantitative samples were sieved through a 1.0 mm mesh screen. Data on station location, physical features (water depth, bottom temperature), sediment size (ϕ, % sand, % silt, % clay) and sediment composition (nitrogen, organic carbon, C/N) were presented in Maurer and Wigley (1981).

Description of the Area

Geology, Physiography and Sediment Composition

Milliman (1973) provided a comprehensive review of the marine geology off southern New England. According to him the most conspicuous feature on the continental shelf is the abundance of ridge and swales (also termed sand ridges and sand shoals). The ridges off southern New England including Nantucket

Shoals probably represent relict features that have been maintained or are altered by tidal currents and major storms.

The study area encompassed about 130 km^2 and extended across the continental shelf to the upper portion of the continental slope (Figure 3). Bottom topography was moderately smooth. Water depths increased gradually and rather uniformly from shore outward to the shelf break approximately 120 m. The most distinguishing feature on the shelf break was the number of gullies and canyons that transect the slope (Figure 3).

Six major sediment types occurred in the study area (Figure 4). Terminology follows the Wentworth particle size classification. Sand, silty sand and sandy silt occurred over a large area whereas gravel-sand, sand-silt-clay and silt comprised a limited areal distribution. Sand covered more than half the area mainly in shallow water (0 to 60-80 m) except in the eastern sector and a narrow (6 km) band parallel to and just below the outer periphery of the continental shelf. In shallow water the sands were silt-free and occasionally mixed with large quantities of shell (mollusks and echinoderm plates). Admixtures of silt occurred with the sand over most of the remaining area.

A large (80 x 100 km) area of fine grained sediment occurred in the southwestern sector. This area has been referred to as the Mud Patch. A relatively circular area of sand-silt-clay near its center was surrounded by an inner band of sandy silt which grades to an outer band of silty sand. Illite was normally the most important clay mineral, and organic content is higher here than in the surrounding sand. Sediments on the continental slope were dominated by silt and clay.

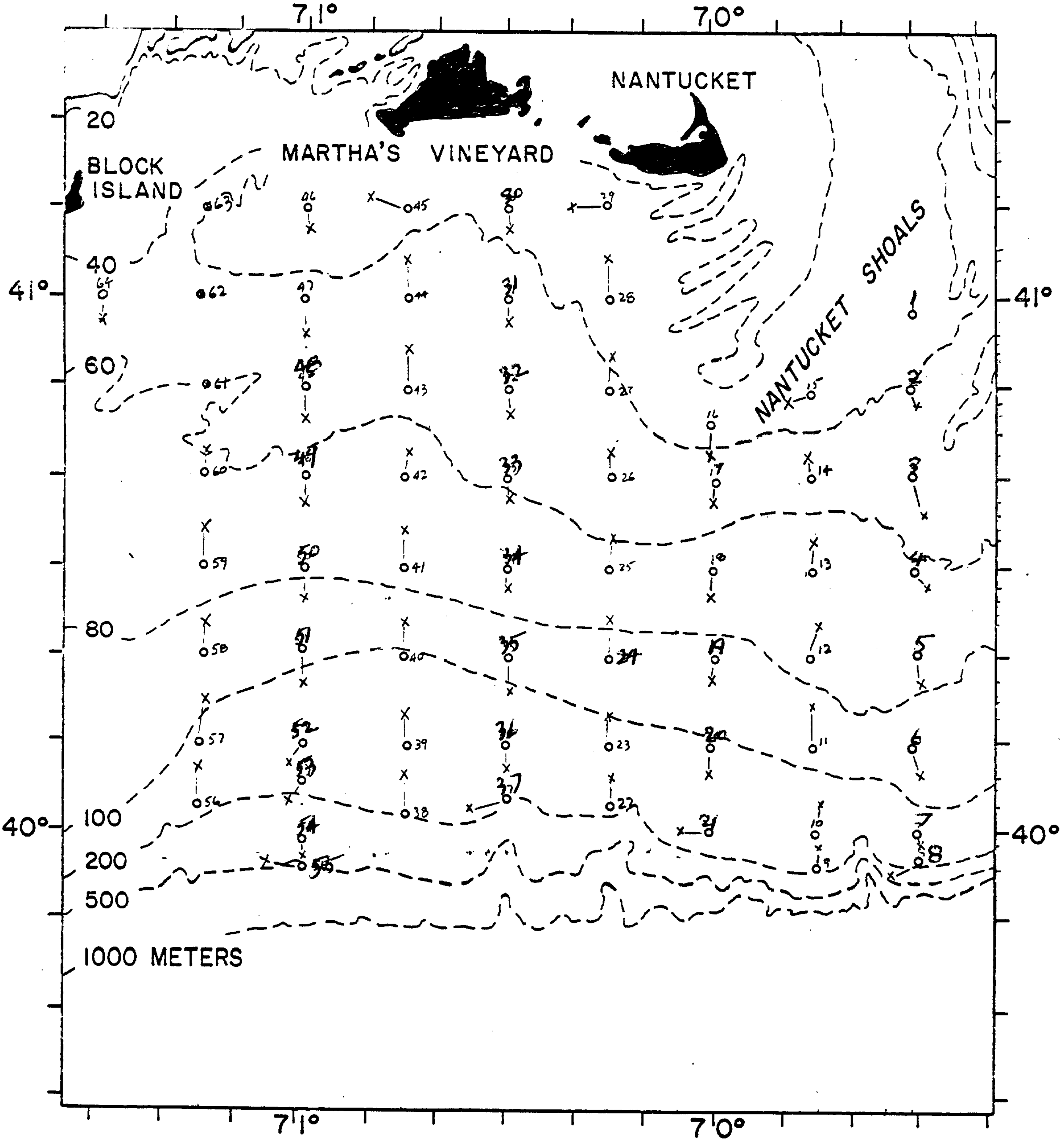


Figure 3. Location of stations of bottom samples for fauna O and sediment X off Martha's Vineyard. (taken from Maurer and Wigley, 1981)

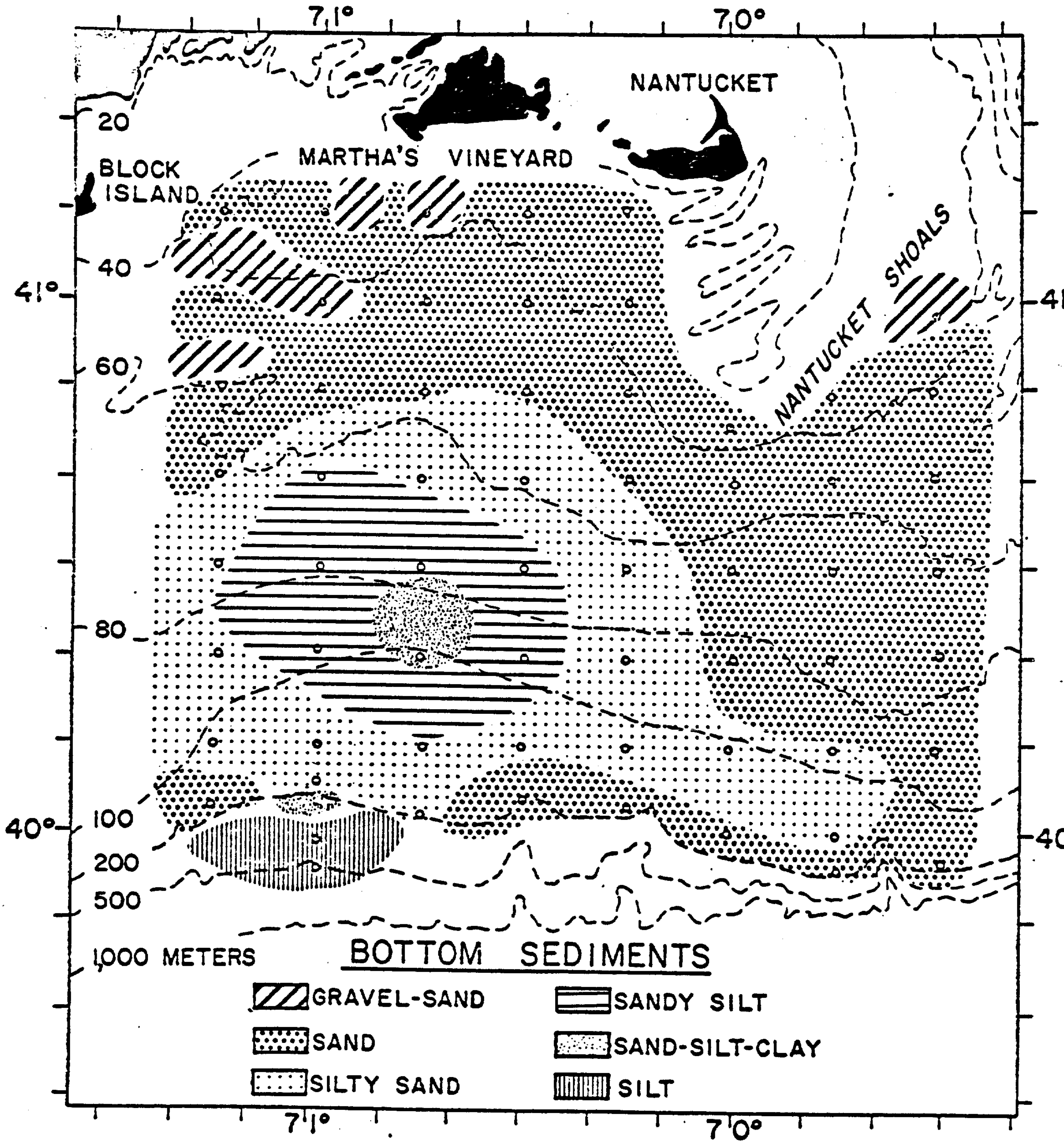


Figure 4. Distribution of various types of bottom sediments. (taken from Wigley and Stinton, 1973)

Hydrography

Within the study area salinity values increased from 32 °/oo or less along the coast to 32 - 33.5 °/oo over the shelf and to 34 - 35 °/oo near the shelf break. Salinity values changed from a winter maximum to a vernal-summer freshening to an autumnal progression culminating again in winter maxima (Colton and Stoddard, 1973). In addition to seasonal runoff from land, salinity may be influenced by local physiography (slopes and shoals).

A cell of cold bottom water (6.1 - 6.9°C) extended in an east-west band from the New York region eastward to longitude 69°30'W (Figure 5). This cell occurred at depths of 40-80 m roughly the mid-shelf region. The cold cell was bounded on the north by higher coastal water temperatures (<12°C) and on the south by values of 10 to 12°C near the shelf break. Long-term (1940-1966) annual maximum and minimum bottom-water temperatures near the shelf break were 16-17°C and 1-2°C respectively (Colton and Stoddard, 1973). However, the annual range here was normally 2°C. Offshore shelf waters, particularly in shallow portions, ranged from 3°C in February-March to 14°C in September-November (Wigley and Stinton, 1973). Non-tidal movements of water masses here were generally westward. Water in the Nantucket Sound area tended to flow turbulently southwesterly across Nantucket Shoals into the Martha's Vineyard area.

Faunal Composition

Two hundred and fourteen genera and/or species together with unidentified groups at higher taxonomic levels were enumerated (Table A-5). For example, Porifera and Nemertea were not

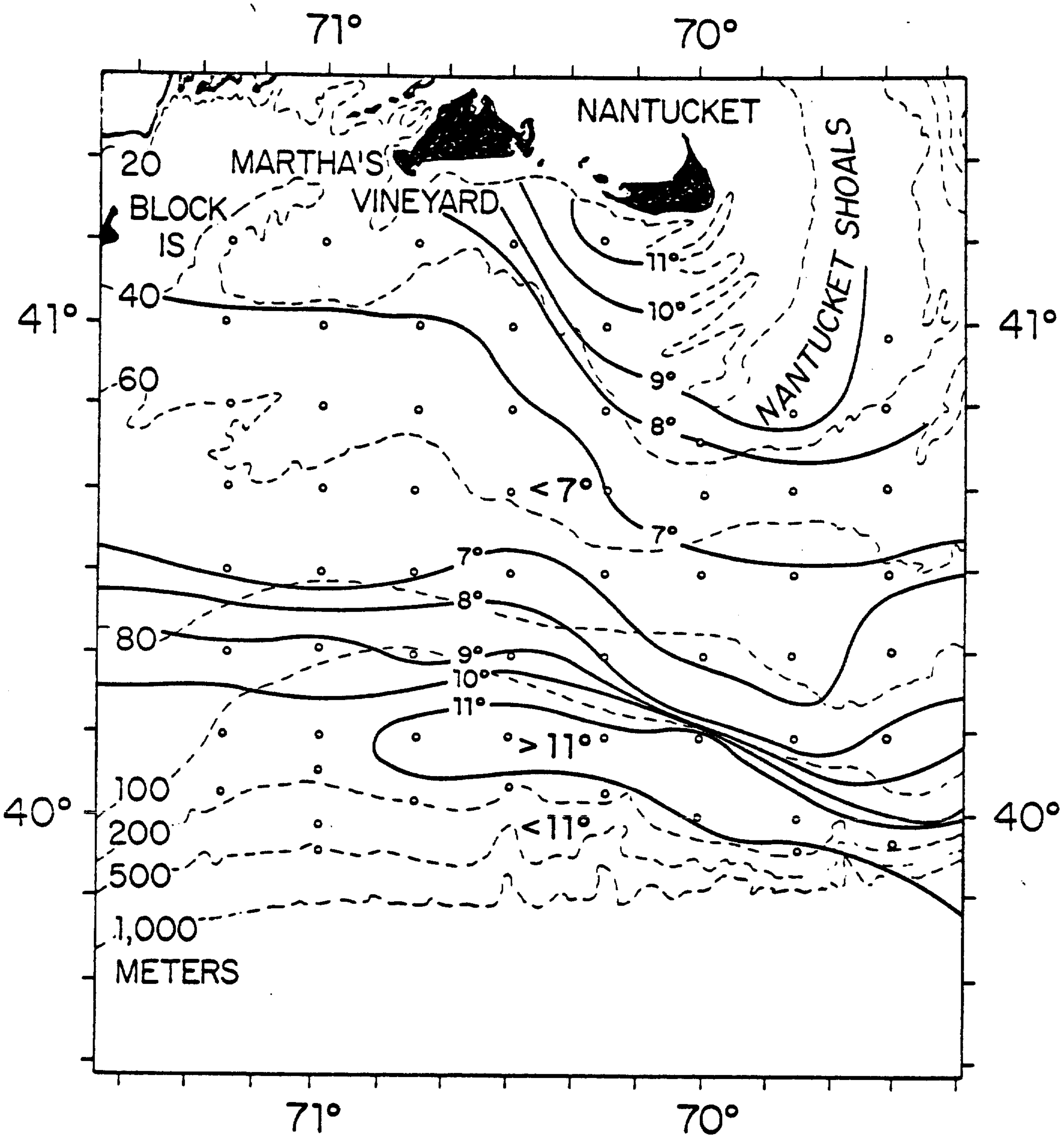


Figure 5. Distribution of bottom water temperature (°C) (taken from Maurer and Wigley, 1981)

identified beyond Phylum. Moreover, some of the identified genera included several species. As a result the number of genera and/or species was definitely conservative. Approximately 24.3% of the fauna were mollusks (pelecypods, gastropods, scaphopods, amphineurans), 27.1% were arthropods (amphipods, decapods, cumaceans, isopods, mysids, cirripeds, tanaidaceans, pycnogonids), polychaetes 24.3%, echinoderms 10.7% (ophiuroids, echinoids, holothurians, asteroids), and miscellaneous taxa 13.6%. Miscellaneous taxa included sipunculids with coelenterates, nemerteans, ectoprocts, ascidiceans, pogonophorans and hemichordates. Descriptive data for taxa and biomass (wet weight g/m^2) and density (No./m^2) of major taxa per station were presented in Maurer and Wigley (1981). Almost 190,000 individuals and 15,500 grams of specimens were quantitatively collected. Average biomass and density were 245.7 g/m^2 and 3008 individuals/m^2 per station respectively. Biomass and density were distributed among the major taxa as follows: Crustacea (4.1% and 62.5%), Mollusca (56.7% and 5.9%), Annelida (10.9% and 20.3%), Echinodermata (21.3% and 7.0%), Miscellaneous (7.0% and 4.3%).

Medium biomass (100-999 g/m^2) occurred in the north central area. This pattern shifted to a low biomass (1-99 g/m^2) area with irregular boundaries (Figure 6). In turn the low biomass area graded to a medium biomass area. A high biomass area (>1000 g/m^2) occurred in the east central section. The medium biomass area shifted to a low biomass area near the 200 m contour. Mollusca, annelids, and shallow-water echinoderms contributed heavily to the high biomass areas.

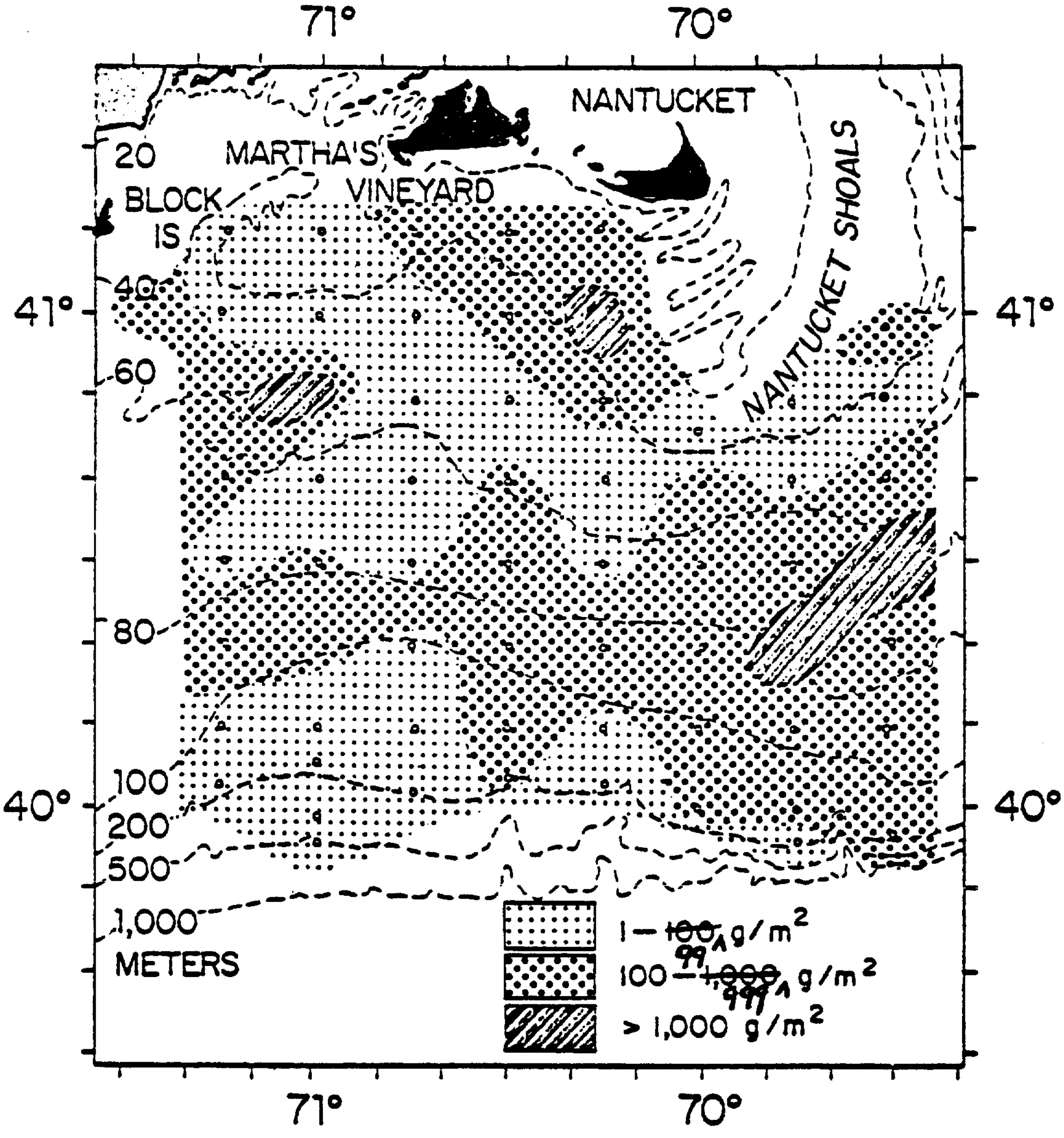


Figure 6. Quantitative distribution of biomass (g/m^2) for all taxonomic groups combined. (taken from Maurer and Wigley, 1981)

In regards to density the pattern was more regular than biomass. High (>3000/m^2) and medium (1000-2999/m^2) densities occurred in the northern shallow portion gradually ranging to medium and low densities (10-999/m^2) in the deeper section (Figure 7). Density on the east side was more complex in that it passed from high to low to medium to high again, to medium and once again to low. Crustacea and Annelida contributed greatly to the high-density areas.

Stations were grouped into ranges of depth, temperature, median sediment size and silt-clay. The average biomass and density of major taxa were determined for these grouped stations (Figure 8). A depth range of 40-80 m, temperature 6.0-7.9°C, 2.0-3.99 ϕ, and 0-60% silt-clay encompassed the main distribution of biomass. The principal distribution of density was accounted for by a depth range of 0-100 m, temperature 6.0-9.9°C, 1-3.99 ϕ and 0-40% silt-clay.

Summary of Ecological Analysis

Total average biomass and density were well developed between 1-100 m. Amphipods, pelecypods, polychaetes and echinoderms mainly influenced the distribution of biomass and density (Figure 8). The biomass of Crustacea and Mollusca occurred mostly in shallow to medium depth (0-100 m). Density was similar to biomass but it ranged deeper for Mollusca. The biomass of Echinodermata and Coelenterata was higher in medium to deeper water (80 - >200 m). Their density tended to range from 60 - >200 m. Biomass and density of polychaetes occurred relatively evenly throughout the depth range.

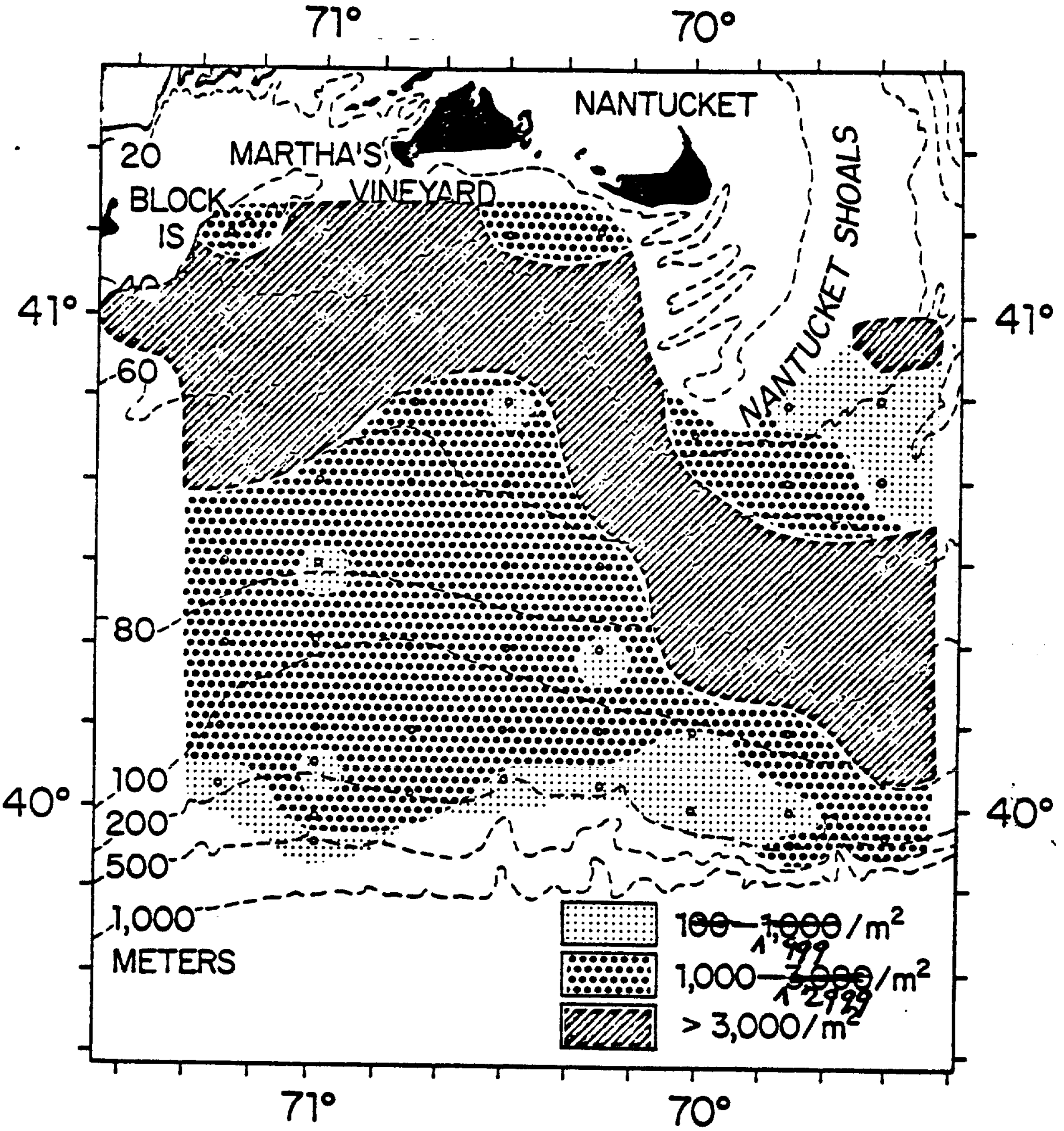
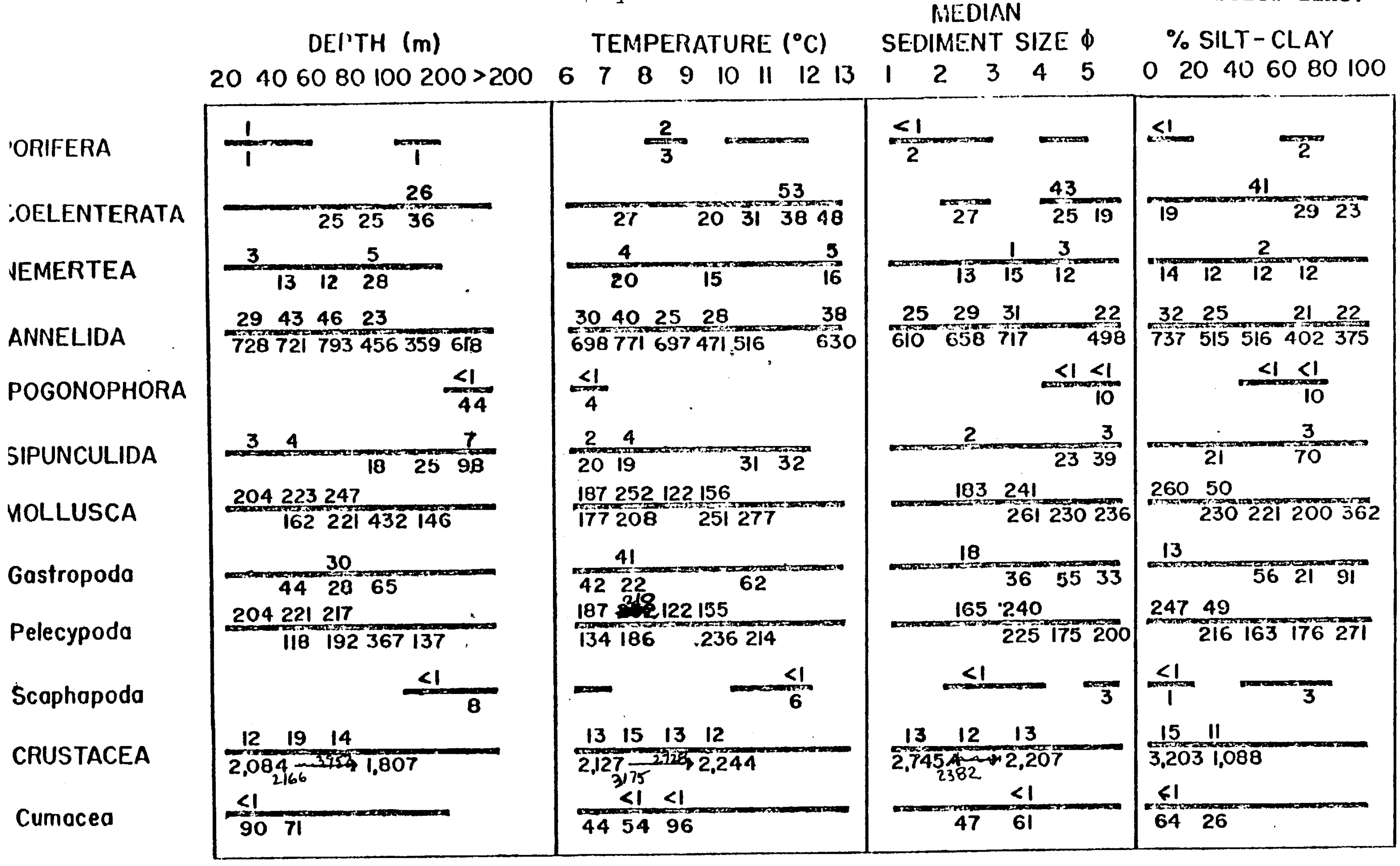


Figure 7. Quantitative distribution of individuals (No/m^2) for all taxonomic groups combined. (taken from Maurer and Wigley, 1981)

Figure 8. Summary of average biomass (g/m^2) and individuals (No./m^2) of major taxa, in relation to depth, temperature, median sediment size and silt-clay.

Biomass above line, density below line.



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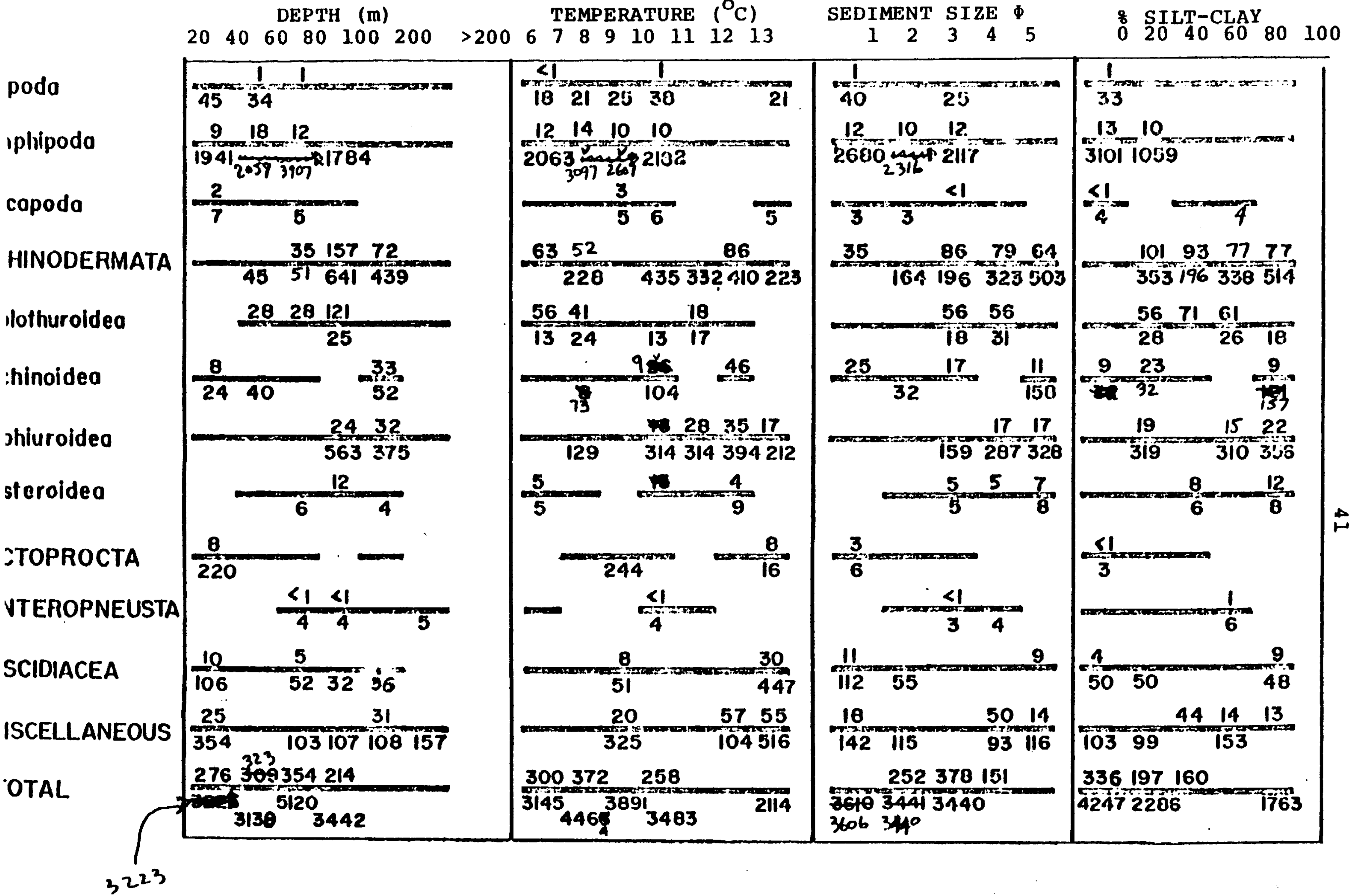


Temperature - $^{\circ}$C

The presence of a cold water cell bounded by warmer water on the north and south (Figure 5) made it difficult to interpret distribution according to temperature. In this case there was a shallow water (0-50 m) and deep water (80-100 m) zone both containing water ranging from 7-12°C. Even though the maximum biomass of certain taxa were associated with shallow water (Bryozoa) and deep water (Ophiuroidea), their maximum biomass according to temperature was similar (11.0-12.9°C). The Coelenterata, another deep water taxon, had its highest biomass in 11.0-11.9°C, a temperature normally associated with depth of approximately 40 m for this time of the year. Thus it is important to bear in mind here the relative position of the cold water cell in relation to depth when comparing distribution according to temperature.

Median Sediment Size - ϕ

Total biomass was well developed between 2.0-5.0 ϕ whereas density peaked between 1.0-4.0 ϕ. Biomass of Crustacea and Mollusca and density of the former occurred mainly between 1.0-4.0 ϕ. Biomass and density of Echinodermata and Coelenterata and density of Mollusca peaked between 3.0-5.99 ϕ. Annelids again ranged in considerable biomass and density throughout the range of median sediment size.

Silt-Clay - %

Total biomass and density were well represented in sediment containing 0-60% silt-clay. Biomass of Crustacea, Mollusca, Echinoidea and Asteroidea was associated with low percent silt-clay while the biomass of Ophiuroidea was associated with greater than 60% silt-clay. The density of Mollusca, Ophiuroidea, Echinoidea and Coelenterata was also associated with sediment containing more than 60% silt-clay.

Meiofauna

Quantitative comparisons of meiofauna and macrofauna were made from some of the samples off Martha's Vineyard (Wigley and McIntyre, 1964). The samples were collected from station 46-55 (Figure 3). These samples were sieved through a 1.00 mm mesh and retained on a 0.7 mm mesh and were analyzed for meiofauna (Table 5). There were three zones or groupings of meiofauna. The inner shelf group (station 46-48) was characterized by a varied and abundant meiofauna represented by 11 major taxa. The number of individuals averaged 662/10 cm^2, with a corresponding wet weight of 3.28 mg (Wigley and McIntyre, 1964).

In the outer shelf group (stations 49-53) the fauna was less varied and except for calcereous Foraminifera, less numerous with an average number of 399/10 cm^2 and a weight of 2.10 mg. At slope stations (stations 54-55) the fauna was relatively sparse in abundance and taxa. The average numbers and weights per 10 cm^2 were 122 and 0.68 mg, respectively.

Gastrotrichs, kinorhynchs and to a lesser extent copepods and ostracods were confined to shallower water, while Foraminifera were most abundant at intermediate depths. Nematoda comprised the major group as they were present in all samples and were the most abundant animals. Nematodes were least

Table 5. Meiofauna wet weight (mg/10 cm^2) and number of individuals (per 10 cm^2) at each station.
(taken from Wigley and McIntyre, 1964)

	STATIONS									
	46	47	48	49	50	51	52	53	54	55
Faunal Groups Number/10 cm^2										
Nematoda	685	50	924	328	507	302	202	438	117	110
Kinorhyncha	19	2	15		2					
Foraminifera	4	4	14	20	7	40	25	32	6	4
Copepoda	122	45	15	2			4	15		1
Ostracoda	2	1	7			1	1	1		
Gastrotricha	7	5								
Halicaridae		1	1	1						
Nauplii	1	9	2							
Polychaeta	30	10	10	6	19	5	3	4	4	1
Amphipoda	3			4						
Isopoda								2		
Cumacea	1					1				
Pelecypoda	1				1	2				1
Echinodermata				1	1					
TOTAL	875	127	988	362	537	351	235	492	127	117
% Nematoda	78	39	94	91	94	86	86	89	92	94
Weight mg/10 cm^2 (Values are equivalent to G/m^2)										
Nematoda	1.016	0.155	2.052	1.066	0.923	0.57	0.349	1.004	0.243	0.359
Kinorhyncha	0.947	0.010	0.074		0.032					
Foraminifera	0.046	0.038	0.163	0.242	0.063	0.526	0.244	0.389	0.053	0.038
Polychaeta	0.958	1.410	2.000	0.810	0.989	1.105	1.116	0.442	0.453	0.105
All Other Groups	0.632	0.074	0.268	0.289	0.105	0.132	0.037	0.060		0.105
TOTAL	3.599	1.687	4.557	2.407	2.112	2.333	1.746	1.895	0.749	0.607

abundant on gravel (39% of the fauna) but ranged between 78 and 94% numerically, of the total fauna in all other sediment types (Wigley and McIntyre, 1964).

Mud Patch Fauna

Earlier the southwest quadrant of the Martha's Vineyard-Nantucket Shoals study area was referred to as the Mud Patch. This area has recently received considerable attention because it has been proposed as a possible depositional sink of fine-grained sediment (Milliman et al, 1980). The significance of this resides in the association of hydrocarbons and trace metals with sedimentation processes controlling deposition of fine-grained sediment. If this hypothesis is accurate, then the benthos within the Mud Patch would be exposed to concentrations of pollutants relatively higher than those on the adjacent shoals. Because of the unique nature of this habitat the general faunal characteristics will be briefly described.

The following stations comprised the Mud Patch: stations 23-25, 33-36, 38-42, 49-53, 57-59. (**Figure** 3). When mean biomass and density were computed for these stations, biomass was 123.7 g/m and density was $1536.2/m^2$. This contrasts markedly with a mean biomass of 245.7 g/m^2 and density of $3008/m^2$ for the entire Martha's Vineyard-Nantucket Shoals area. This comparison indicates that the shallow clean sand bottom contains the highest biomass and density. This relationship might also have been anticipated by examining mean biomass and density in relation to depth and % silt-clay (Figure 8). There was a marked regular reduction in biomass and density with increased

% silt-clay.

The Mud Patch was characterized by anthozoans (Alcyonacea and Pennatulacea), polychaetes (*Onuphis opalina*, *O. quadricuspis*, *Streblosoma* sp., *Tharyx* sp., *Cossura longocirrata*, *Drilonereis* sp.), bivalves (*Bathyarca pectunculoides*, *Nuculana acuta*, *Yoldia* sp., *Nucula* sp.), decapod crustaceans (*Catapagurus* sp., *Hyas* sp., *Euprognatha* sp., *Munida* sp.) and a variety of echinoderms (*Amphilimna olivacea*, *A. macilentus*, *Amphiura otteri*, *Havelockia scabra*, *Schizaster fragilis*). This fauna contains a high proportion of deposit feeders and represents a typical soft bottom community. Echinoderms were particularly important as they contributed greatly to the biomass of this assemblage.

Lease Tract

As a part of a broad-base geological and biological survey ranging from Nova Scotia to the Florida Keys conducted by the U.S.G.S. and the NMFS, quantitative samples were taken from the lease tract area in 1957 and 1963 (Figure 9). These samples were sieved through a 1.0 mm mesh sieve. A list of taxa and wet weight biomass (f/m^2) and density ($No./m^2$) are presented in Table A-6 and Table 6.

Even though the samples were not always completely identified to species, some inferences can be drawn. Comparison of the NMFS data off Martha's Vineyard and Nantucket Shoals (Table A-5) with those from the lease tract (Table A-6) indicates considerable communality of taxa. What is particularly striking is that deep stations off Martha's Vineyard (No. 8, 54, 55) ranging from 183 to 567 m and stations from the lease tract (No. 1116, 1117,

Figure 9. NMFS quantitative grabs (1.0 mm mesh)
1957 and 1963 from the Lease Tract

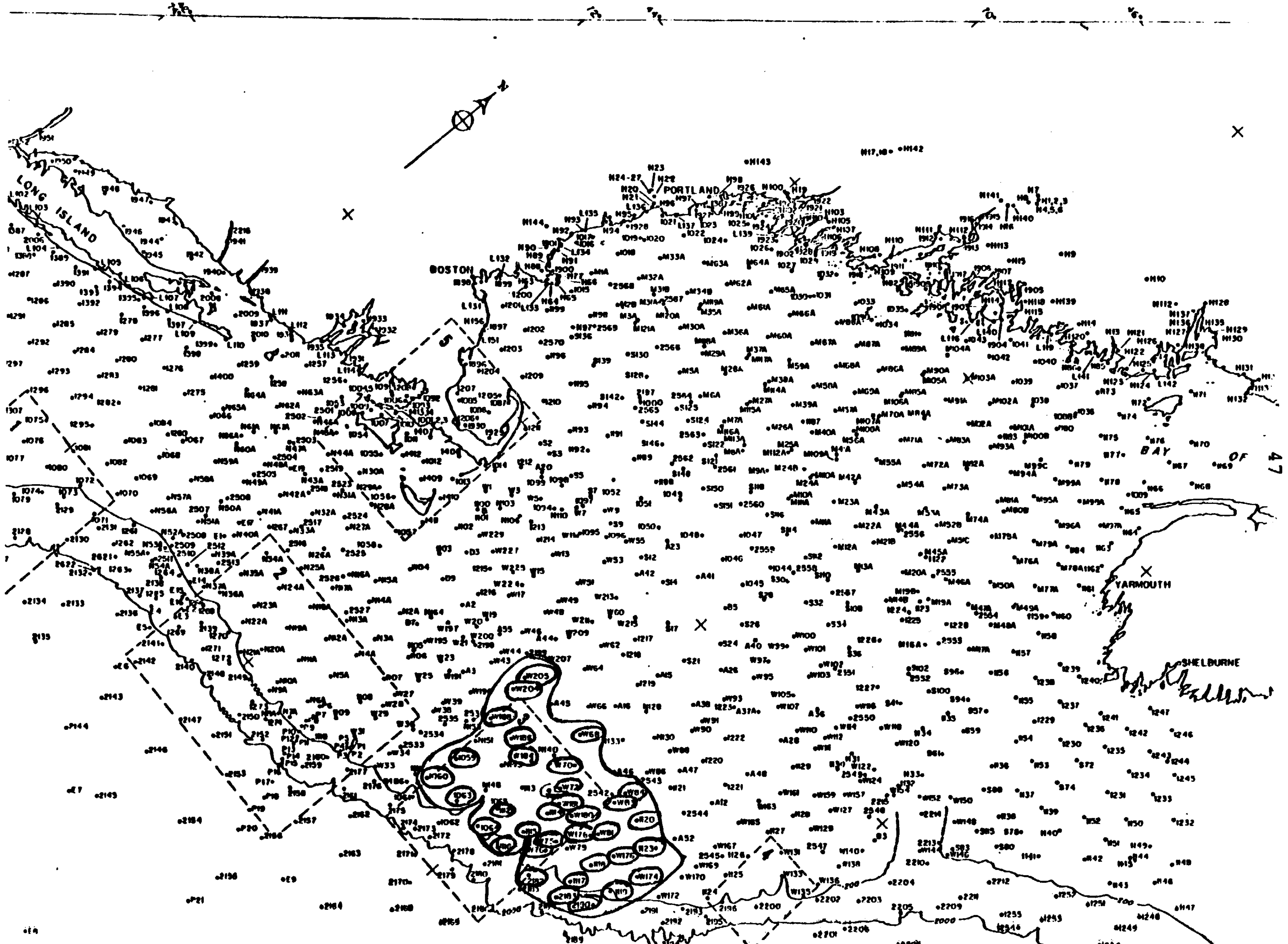


Table 6. Biomass (g/m^2) and Density (No./m^2) of Benthic Invertebrates from NMFS Quantitative Grabs (1.0 mm mesh) from the Lease Tract

Station	Depth (m)	Biomass	Density
1957			
W68	44	1.0	222
W70	51	237.6	920
W72	66	48.9	3230
W75	93	26.2	310
W76	121	1.0	490
W81	81	7.1	1240
W83	68	87.1	1420
W84	60	159.2	2080
W174	103	0.8	50
W176	95	8.7	970
W178	84	17.7	1340
W180	75	105.1	20250
W181	68	83.2	13350
W182	70	10.4	760
W184	66	6.6	470
W186	57	109.5	734
W188	53	1267.9	6100
W204	46	2.5	570
W205	57	25.9	1420
1963			
1059	94	14.9	802
1060	123	10.7	913
1063	144	0.46	86
1064	154	9.1	63
1112	123	2.8	622
1113	86	10.9	233
1114	79	40.4	2380
1115	124	2.7	818
1116	382	6.0	135
1117	235	1.8	266
1118	111	3.9	324
1119	214	15.8	776
1120	74	75.4	308
1123	74	730.0	890
1264	254	7.65	169
1268	316	15.5	915
1270	266	1.57	92
2182	465	16.7	291
2183	1040	0.04	4
2190	1000	7.8	199

1268, 2182) ranging from 235 to 465 m contain a combination of scaphopods (Cadulus pandionis, Dentalium occidentale, pogonophorans (probably Siboglinum atlanticum and S. ekmani), bivalves (Thyasira sp., Bathyarca sp., Phacoides sp., Yoldia sp.), onuphid polychaetes and holothurians (Synapta sp., Thyone sp.). These distributions suggest that there is some bathymetric zonation of soft-bottom infauna extending from off Martha's Vineyard to at least east of the Lydonia Canyon area. Zonation of megabenthic invertebrates and Canyon faunas have been recognized by others (Haedrich, et al, 1975) but zonation of soft-bottom infauna has not been as well documented on the outer shelf and slope. This suggestion remains to be confirmed by a thorough taxonomic analysis of the samples in question.

Some inferences can be drawn in regards to the history of the benthos from this area within the past 25 years. Comparison of the NMFS data from 1957 and 1963 (Table 6) with BLM data (Table A-11)indicates that general bathymetric patterns of biomass distribution have not changed much. Both sets of data show a sharp decline in biomass below 100 m. Peak biomass appears about 70-80 m and is associated with the occurrence of Arctica islandica and E. parma. This mutual association attests to continuity of occurrence throughout this time period.

Dredge Tows - BLM - Georges Bank, 1977

General Taxonomic

During the course of the BLM study (NEOEB III, 1978) approximately 243 species were collected from dredge tows belonging to 10 phyla (Table A-7). Major taxa included polychaetes, amphipods, molluscs, echinoderms and arthropods exclusive of amphipods. The category designated miscellaneous taxa consisted of poriferans, cnidarians, rhynchocoels, sipunculids, brachiopods and urochordates. In terms of number of species, molluscs comprised 29.2% of the fauna, polychaetes 27.6%, echinoderms 13.2%, arthropods exclusive of amphipods 12.8%, amphipods 8.6% and miscellaneous 8.6% (Table 7). The number of species was lowest in the winter (97), increased in the spring (120), peaked in the summer (138), and declined in the fall (116). The percent occurrence of most major taxa fluctuated only slightly throughout the year (Table 7). Thirty-two of 243 species were collected all four seasons and 108 were collected in at least one season.

Number of Species and Relative Abundance

The number of species, relative abundance and diversity of benthic invertebrates from tows for Georges Bank, 1977, were presented in NEOEB III (1978). The mean number of species and mean relative abundance per gear type are presented in Table 8. Based on t-tests with data from the rocking chair dredge, the mean number of species in winter (4.8) was significantly ($\alpha = 0.05$) lower than for the other three seasons (15.5, 13.5, 17.3). The mean number of species in the summer (13.5) was also significantly lower than in the fall (17.3). According to data from the Blake Trawl the mean number of species in the spring (21.4) and fall (18.7) were significantly lower than in the summer (29.9) but the mean number of species in the spring was significantly higher than in the fall.

Table 7. Number and Percent (%) of Invertebrate Species per major taxon from tows for Georges Bank, 1977

	Winter	Spring	Summer	Fall	Total
Polychaetes	20 (20.6)	25 (20.8)	38 (27.5)	32 (27.6)	67 (27.6)
Amphipods	13 (13.5)	3 (2.5)	8 (5.8)	5 (4.3)	21 (8.6)
Arthropods (exclusive of amphipods)	14 (14.4)	18 (15.0)	21 (15.2)	14 (12.2)	31 (12.8)
Molluscs	37 (38.1)	37 (30.8)	42 (30.4)	34 (29.3)	71 (29.2)
Echinoderms	7 (7.2)	23 (19.2)	19 (13.9)	20 (17.2)	32 (13.2)
Miscellaneous (Porifera, Cnidaria, Rhynchocoela, Sipunculoidea, Brachiopoda, Urochordata)	6 (6.2)	14 (11.7)	10 (7.2)	11 (9.4)	21 (8.6)
Total	97	120	138	116	243

Table 8. Mean and standard deviation of relative abundance and number of species from tows for Georges Bank, 1977

	Winter		Spring		Summer		Fall	
	Rel. Abund.	No. of Spp.	Rel. Abund.	No. of Spp.	Rel. Abund.	No. of Spp.	Rel. Abund.	No. of Spp.
Rocking Chair Dredge								
$\bar{x}$	80.2	4.8	720.9	15.5	289	13.5	694.9	17.3
SD	115.7	3.6	1427.9	6.43	397	8.55	1184	7.7
N	8	8	12	12	10	10	12	12
Blake Tow								
$\bar{x}$	-	-	4816	21.4	6042.1	29.9	1578.9	18.7
SD	-	-	8701.6	8.29	9471.2	12.5	1696.7	9.0
N	-	-	12	12	10	10	12	12

$\bar{x}$ = mean, SD = standard deviation, N = number of stations

Based on log transformed ($\log_e (x + 1)$) data from the rocking chair dredge mean relative abundance in spring (720.9/tow) and fall (694.9/tow) were significantly higher than in winter (80.2/tow). When data from the Blake trawl were log transformed, there were no significant differences in mean relative abundances between seasons. However, highest numbers were recorded in the summer (6042.1/tow) with a marked decline in fall (1578.9/tow) (Table 8).

Diversity (Simpson Index) was lowest in the winter ($\bar{x} = 2.4$) but generally very similar the other seasons ($\bar{x} - 3.6$, $\bar{x} = 3.59$, $\bar{x} = 3.7$). There was an indication that diversity was lower at the shallower stations (1, 4, 32, 37, 39) than at the deeper stations (7, 18, 35, 36, 42) but this was not without exceptions. Lower diversity in the central portion of Georges Bank was more marked during the winter than other seasons (NEOEB III, 1978).

The mean number of species and mean relative abundance (log transformed) of samples from the rocking chair dredge and Blake trawl were compared with t-tests. The Blake trawl yielded a significantly higher mean number of species in spring and summer and a significantly higher mean relative abundance in spring, summer and fall then the rocking chair dredge. Thus, one's view of seasonal patterns in the number of species, relative abundance and diversity is strongly influenced by the type of gear employed. Since the rocking chair dredge was used all four seasons, these data provide a more complete annual picture than those from the Blake trawl, which was not used the first cruise (winter). However, the Blake trawl caught more species and higher numbers of organisms than the rocking chair dredge. Data from both pieces of gear were presented to provide a complete and accurate review, but data from the rocking chair dredge considerably underestimated community structure (number of species, relative abundance, relative biomass, diversity) compared to the Blake trawl.

Geographic and seasonal Distribution

General

During the winter, stations on the central portion of Georges Bank contained relatively low mean abundance (Figure 10). The highest value for this period was at station 39 (1753/tow). In the spring high values were recorded at stations 1 (3856/tow) and 36 (8109/tow) with the highest mean relative abundance at station 39 (14698/tow) (Figure 11). In the summer, stations 4 (14605/tow) and 39 (9348/tow) yielded the highest values (Figure 12). Finally, high mean relative abundance in the fall was recorded at stations 42 (2329/tow) and 36 (2657/tow) with the highest value once again at station 39 (2788/tow) (Figure 13). In another study, stations 4-5 and 39-40 produced some of the highest density estimates (14000-18000/m^{-2}) of polychaetes recorded for the Georges Bank area (Maurer and Leathem, 1980a). The association of high mean densities of infauna together with high mean relative abundance of invertebrates from dredge hauls with the Great South Channel area indicates that physical oceanographic processes there make this a very productive area.

Taxonomic

Winter

Based on data presented in NEOEB III (1978), the mean

Figure 10. Mean relative abundance of invertebrate species from tows for Georges Bank, Winter 1977.

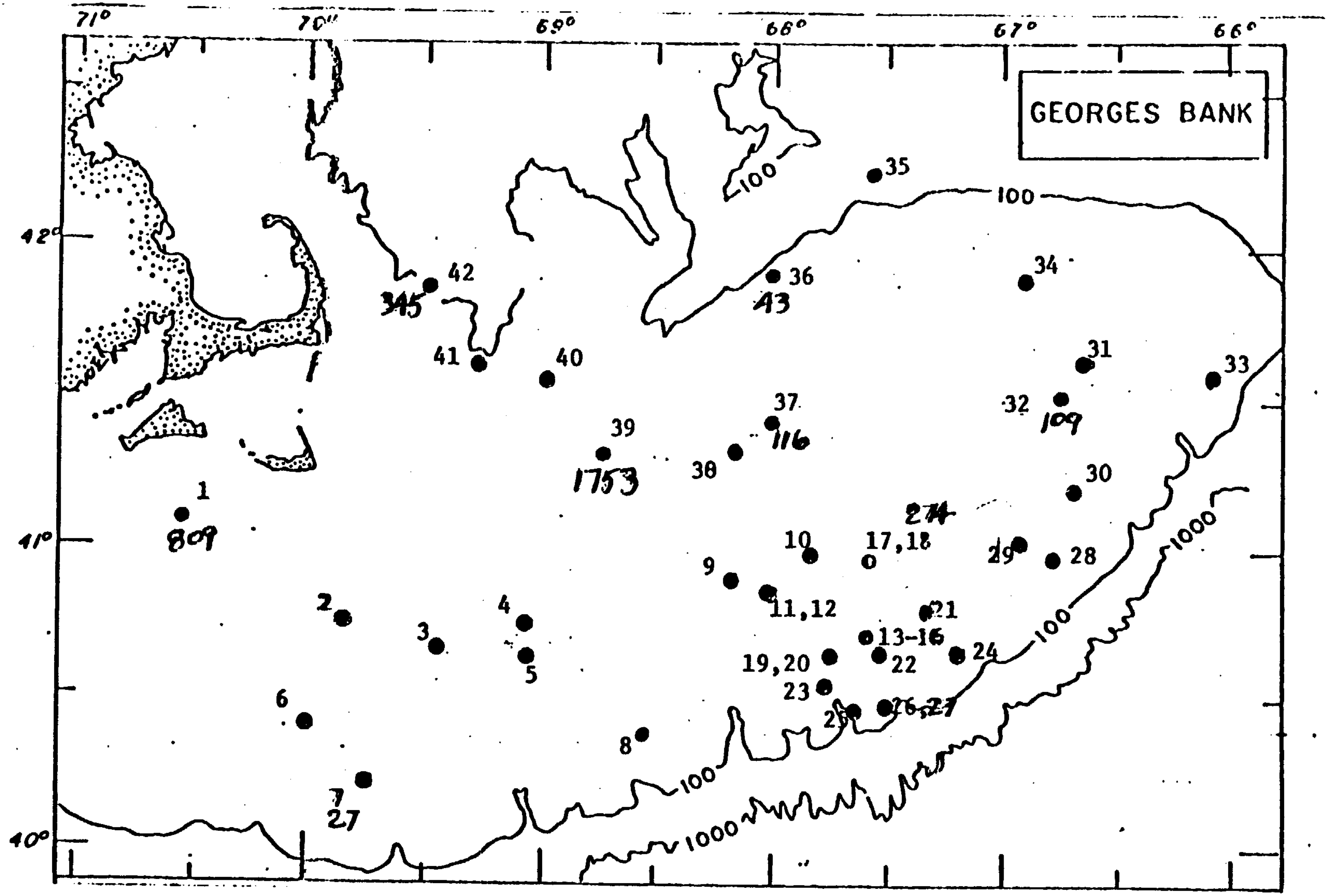


Figure 11. Mean relative abundance of invertebrate species from tows for Georges Bank, Spring 1977.

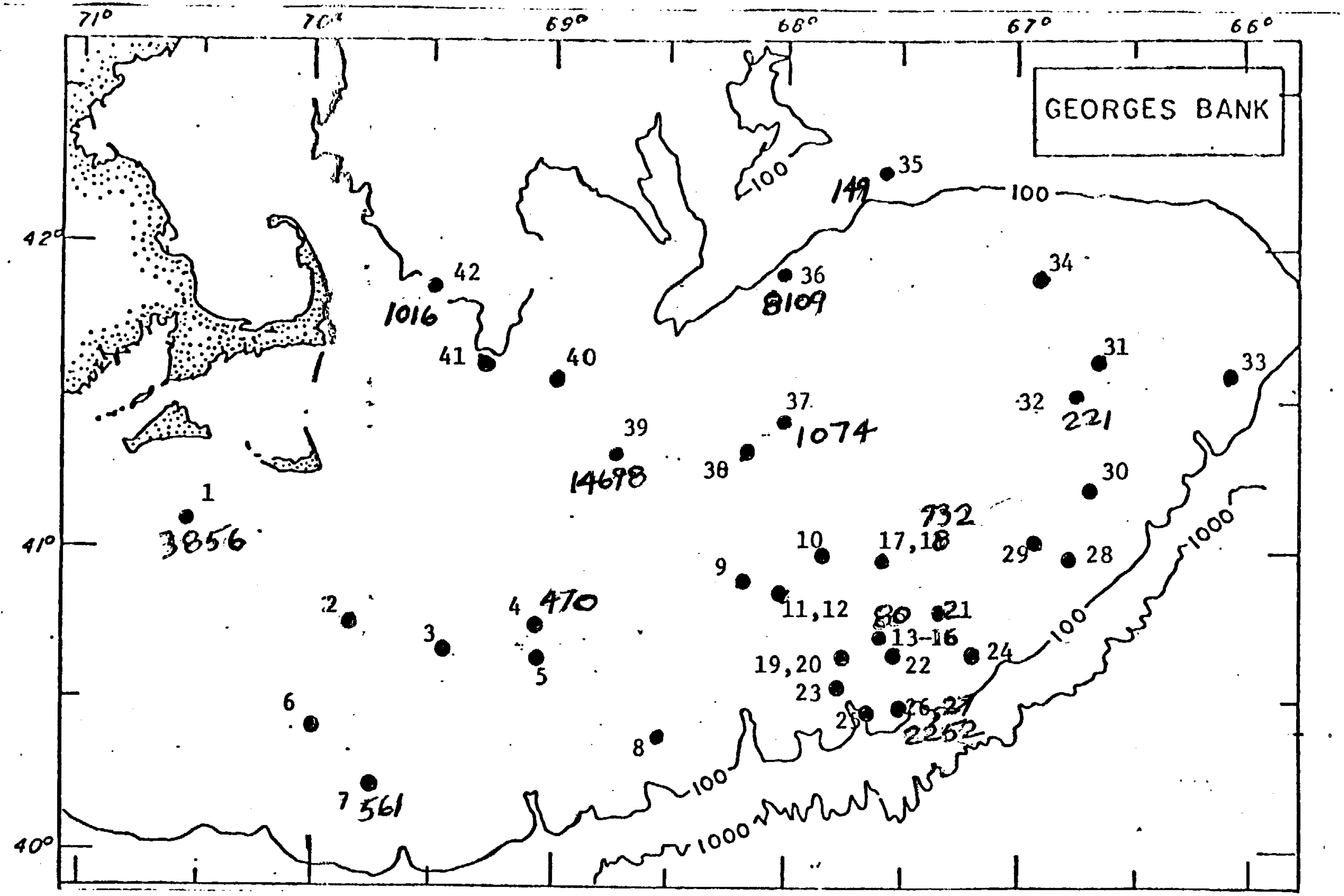


Figure 12. Mean relative abundance of invertebrate species from tows for Georges Bank, Summer 1977.

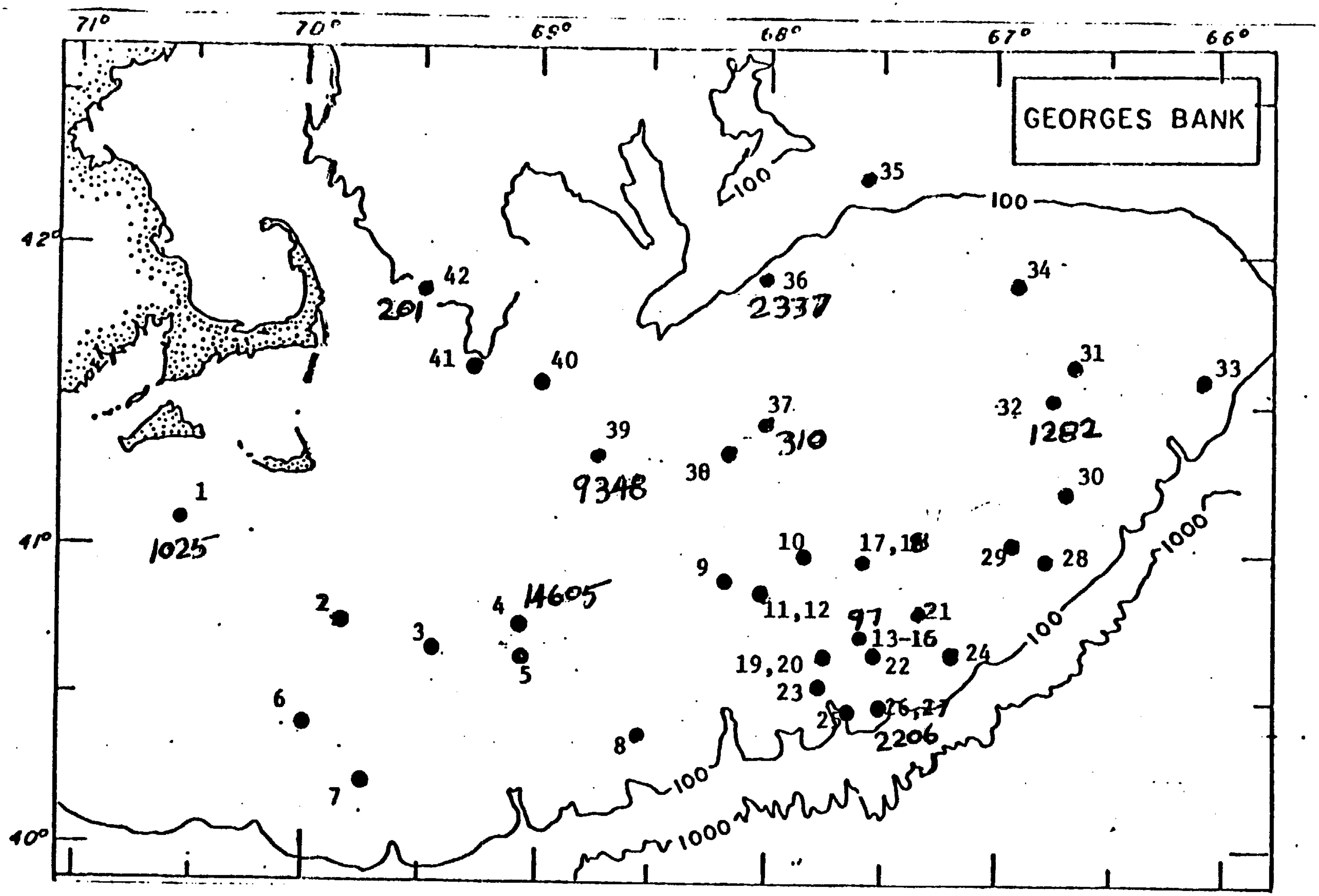
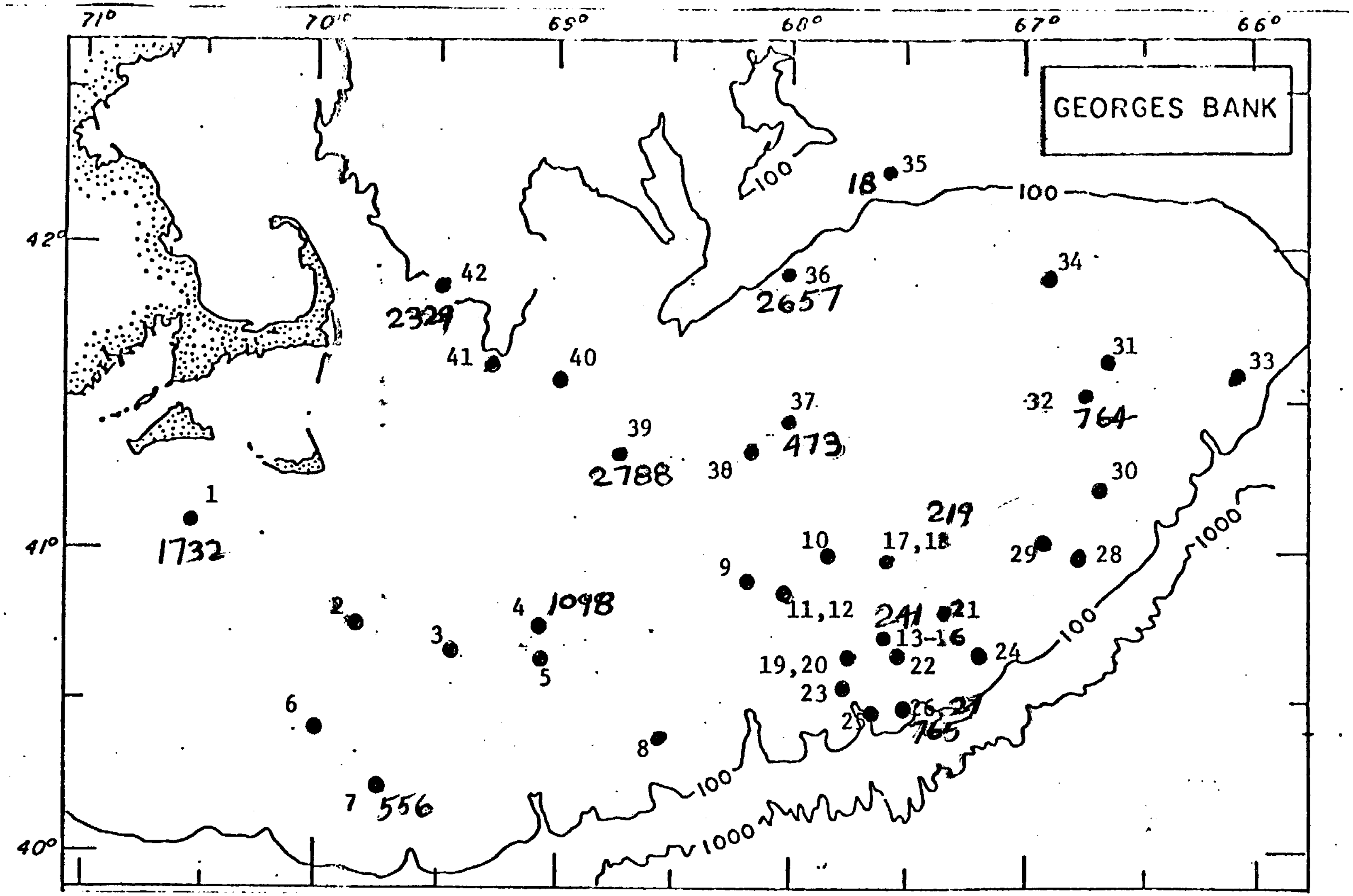


Figure 13. Mean relative abundance of invertebrate species from tows for Georges Bank, Fall 1977.



relative abundance of selected invertebrates per station from tows (all gear) for Georges Bank, 1977, were computed and summarized in Table 9. During the winter the anemone *Epizoanthus americanus* was the most abundant species but it occurred at its lowest levels. *E. americanus* contributed strongly to the abundance at Station 39. The shrimp *Crangon septemspinosa* peaked on Georges Bank (Table 9)and was particularly important at Stations 1, 37 and 18 (Figure 14). In terms of mean relative abundance *C. septemspinosa* was followed by the echinoderm brittle star *Ophiura sarsi* and sand dollar *Echinarchnius parma* which were recorded at their lowest values in the winter. The former occurred exclusively on the northern edge of the area at Stations 42 and 36 (Table 10, Figure 14), while the latter occurred in relatively high numbers on the southern and south central portion at Stations 1, 18 and 32. The ocean quahog *Arctica islandica* and the rock crab *Cancer irroratus* also occurred on the southern portion *A. islandica* occurred at Stations 1, 7, 18 and 32 and *C. irroratus* at 1, 7, 18 and 37 (Table 10). A hermit crab *Pagurus acadianus* occurred widely but in relatively low abundance (Table 10). Mean relative abundance for *P. acadianus* was lowest in the winter (Table 9).

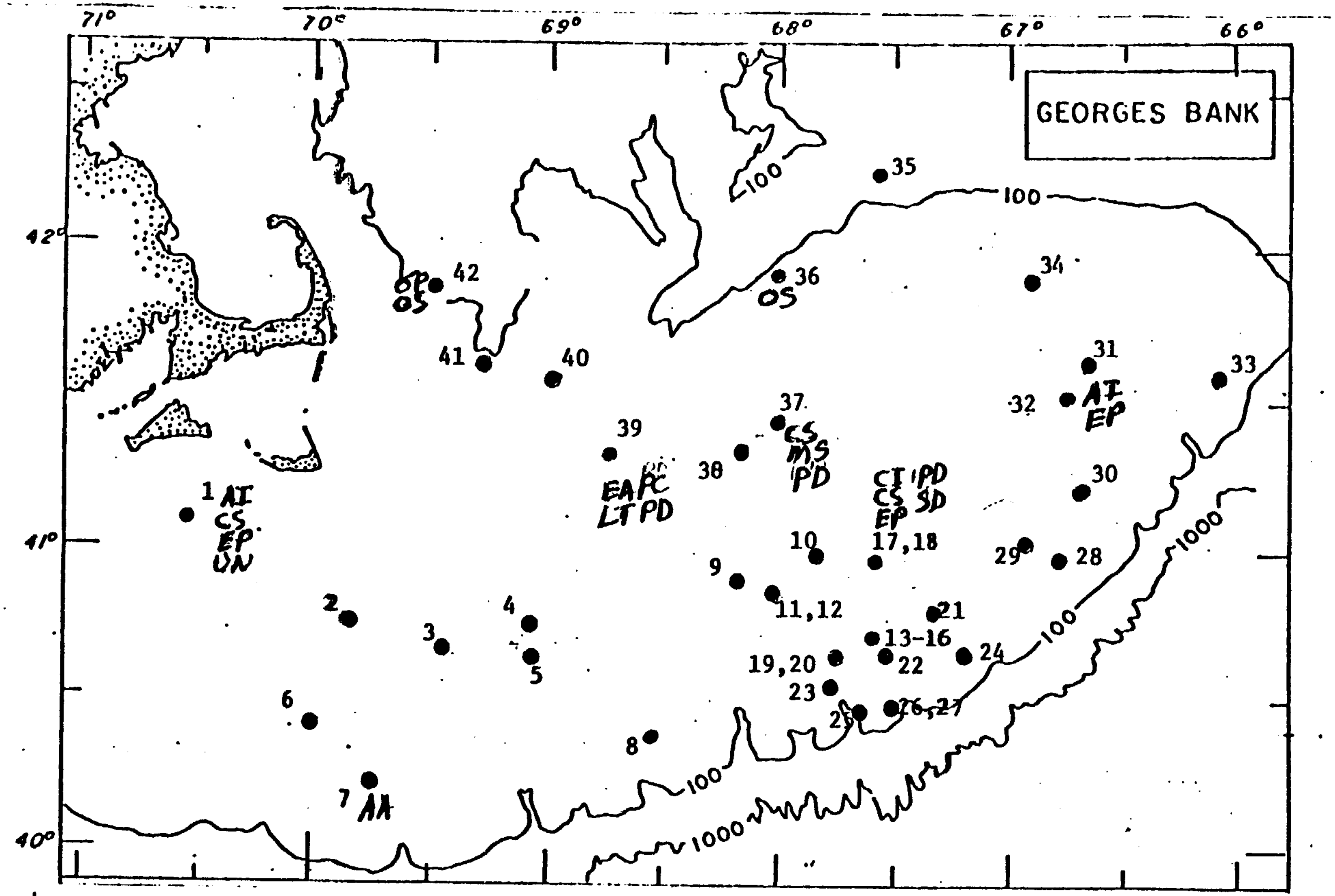
Spring

During the spring mean relative abundance of *Epizoanthus americanus*, *O. sarsi*, *A. islandica* and the hermit crabs *Pagurus arcuatus* and *P. acadianus* peaked on Georges Bank (Table 9). *A. islandica* and *E. parma* contributed greatly to abundance at Station 1 (Table 11) whereas *O. sarsi*, *E. americanus* and *P. arcuatus*

Table 9. Mean relative abundance of selected invertebrates from tows for Georges Bank, 1977

Species	Winter	Spring	Summer	Fall
E. americanus	59.7	535.3	401.6	126.5
M. senile	1.7	9.3	11.7	14.1
A. hastata	0.18	1.29	0.97	0.3
L. fragilis			1.74	0.05
M. sarsi	0.87	1.27	1.22	2.25
N. pelagica	0.05	0.058	0.54	0.03
O. conchylega		79.5	104.4	23.5
O. opalina	8.0	5.75	0.32	6.6
B. undatum	0.62	4.85	4.8	3.1
C. stimpsoni		1.33	0.90	0.85
A. islandica	6.7	104.8	3.06	3.34
P. magellanicus	0.97	0.16	0.49	1.35
S. solidissima	0.5	0.25	0.60	3.0
Unciola spp.	8.37	0.016	0.45	
C. borealis		0.21	0.90	1.18
C. irroratus	2.57	2.18	3.9	3.29
C. septemspinosa	34.4	0.058	6.42	0.76
D. leptocerus	1.5	1.04	4.18	0.88
H. coarctatus	0.025	0.71	0.14	0.26
H. araneus		0.016	0.10	
M. norvegica	1.37	0.12		0.016
P. acadianus	4.0	30.3	26.8	14.1
P. arcuatus		70.7	39.5	16.1
A. americanus	2.62	21.3	0.10	26.5
L. tenera	1.62	9.91	9.6	12.4
B. fragilis	0.37	0.43	0.30	70.5
E. parma	11.46	77.2	118.9	14.1
S. droebachiensis	2.27	7.3	3.2	22.3
O. sarsi	12.5	350.0	124.4	112.7
A. vulgaris		9.05	6.7	16.3

Figure 14. Distribution of key invertebrate species from tows for Georges Bank, Winter 1977.



Legend:

AA	A. americanus				
AI	A. islandica	EA	E. americanus	OQ	O. quadricuspis
AV	A. vulgaris	EP	E. parma	OS	O. sarsi
BF	B. fragilis	LT	L. tanneri	PC	P. arcuatus
BU	B. undatum	MC	M. cristata	PD	P. acadianus
CB	C. borealis	MS	M. senile	SD	S. droebachiensis

Table 10. Mean Relative abundance of selected invertebrates from tows for Georges Bank, Winter 1977

	STATION													
Species	1	4	7	13	18	26	32	35	36	37	39	42	$\bar{x}$	SD	N
E. americanus											478		59.7	168.9	8
M. senile					.6		4			9			1.7	3.25	
A. hastata					1		.5						.18	.37	
L. fragilis															
M. sarsi												7	.87	2.47	
N. pelagica	.2				.2								.05	.09	
O. conchylega															
O. opalina												64	8	22.6	
B. undatum					4		1						.62	1.4	
C. stimpsoni															
A. islandica	73		1		2		13						6.7	18.3	
P. magellanicus	.6				.8		6		.4				0.97	2.05	
S. solidissima	2									2			0.5	.92	
Unciola spp.	67												8.37	23.7	
C. borealis															
C. irroratus	10		.4		10					.2			2.57	4.58	
C. septemspinosa	199		1		42					33		.2	34.4	68.6	
D. leptocerus	12												1.5	4.24	
H. coarctatus	.2												.025	.07	
H. araneus															
M. norvegica												11	1.37	3.88	
P. acadianus	7				11		7			7			4.0	4.47	
P. arcuatus															
A. americanus			21										2.62	7.42	
L. tenera	2				7		1			3			1.62	2.44	
B. fragilis												3	0.37	1.06	
E. parma	32		.6		52		34			2			11.46	20.4	
S. droebachiensis					17		.6			.6			2.27	5.95	
O. sarsi									25			75	12.5	26.7	
A. vulgaris															

Table 11. Mean Relative abundance of selected invertebrates from tows for Georges Bank, Spring 1977

	STATION														
Species	1	4	7	13	18	26	32	35	36	37	39	42	x̄	SD	N
E. americanus		14				7	2	5	55	96	6245		535.3	1798.3	12
M. senile					3	6	.5	.2	.2	63	39		9.3	20.2	
A. hastata	.2				6		.5		2		6	.8	1.29	3.27	
L. fragilis															
M. sarsi												15	1.27	3.38	
N. pelagica		.5			.2								.058	.15	
O. conchylega						954		.5					79.5	275.3	
O. opalina												69	5.75	19.9	
B. undatum		.8			37		5		1	.5	14		4.85	10.9	
C. stimpsoni		.8		.2	2				3		10		1.33	2.89	
A. islandica	1206	15	5	2	6		5		3	2	3	10	104.8	346.8	
P. magellanicus					2								.16	.57	
S. solidissima										3			.25	.86	
Unciola spp.											.2		.016	.05	
C. borealis	2			.2		.2			.2				.21	.56	
C. irroratus	9			2	7				.2	4	4		2.18	3.14	
C. septemspinosa	.5	.2											.058	.15	
D. leptocerus	.2	3	.8	1	.5		.5	.5	3		3		1.04	1.22	
H. coarctatus		.2		.2	2	3		.2			3		.71	1.2	
H. araneus	.2												.016	.05	
M. norvegica								1				.5	.12	.31	
P. acadianus	8	6			39	.8	32	.5	6	146	65		30.3	45.9	
P. arcuatus		1		.2	9				32	7	799		70.7	229.5	
A. americanus			256	.2		.2							21.3	73.8	
L. tenera		52		17	13		2		2	3	30		9.91	16.2	
B. fragilis												5	.43	1.43	
E. parma	680	43			124		51			25	4		77.2	193.3	
S. droebachiensis		7			56		.5	.2	3	20	1		7.3	16.3	
O. sarsi		.2					2	19	3842	.2	47	290	350	1102.7	
A. vulgaris	10	70		1	1	.2	.2		.2	26			9.05	20.6	

provided most of the abundance at peak stations 36 and 39. In addition to *O. sarsi*, the echinoderm *Briaster fragilis* and the brachiopod *Terebratulina septentrionalis* although not abundant were characteristic of the northern stations 42 and 35 respectively (Figure 15). *A. islandica* and *C. irroratus* were characteristic of stations 1, 4, 7, 18, 32 and 42 and 1 and 18 respectively (Figure 15). *E. parma* and *P. arcuatus* increased considerably between winter and spring (Table 9). *E. parma* occurred in the southern and south central portion of the bank (Table 11, Figure 15) and the pagurids (*P. acadianus* and *P. arcuatus*) were widely distributed throughout the central portion of Georges Bank at stations 39, 36, 37, 18, 32. The onuphid polychaete *Onuphis conchylega* was particularly abundant at station 26 near the southern canyon area.

Summer

During the summer mean relative abundance of *O. conchylega*, the shrimp *Dichelopandalus leptocerus* and *E. parma* peaked on Georges Bank (Table 9). *E. parma* contributed greatly to peak abundance at station 4 and *E. americanus* and *P. arcuatus* both which peaked in spring but still were collected in high numbers in summer influenced abundance at Station 39 (Table 12). Other species which peaked in other seasons but were still abundant in summer included the anemone *Metridium senile*, the gastropod *Buccinum undatum*, *C. irroratus*, *P. acadianus*, *P. arcuatus*, *O. sarsi* and *C. septemspinosa*. *O. sarsi* was again characteristic of station 42 and 36 extended its distribution to include stations 39 and 32 (Table 12, Figure 16). The combination of

Figure 15. Distribution of key invertebrate species from tows for Georges Bank, Spring 1977.

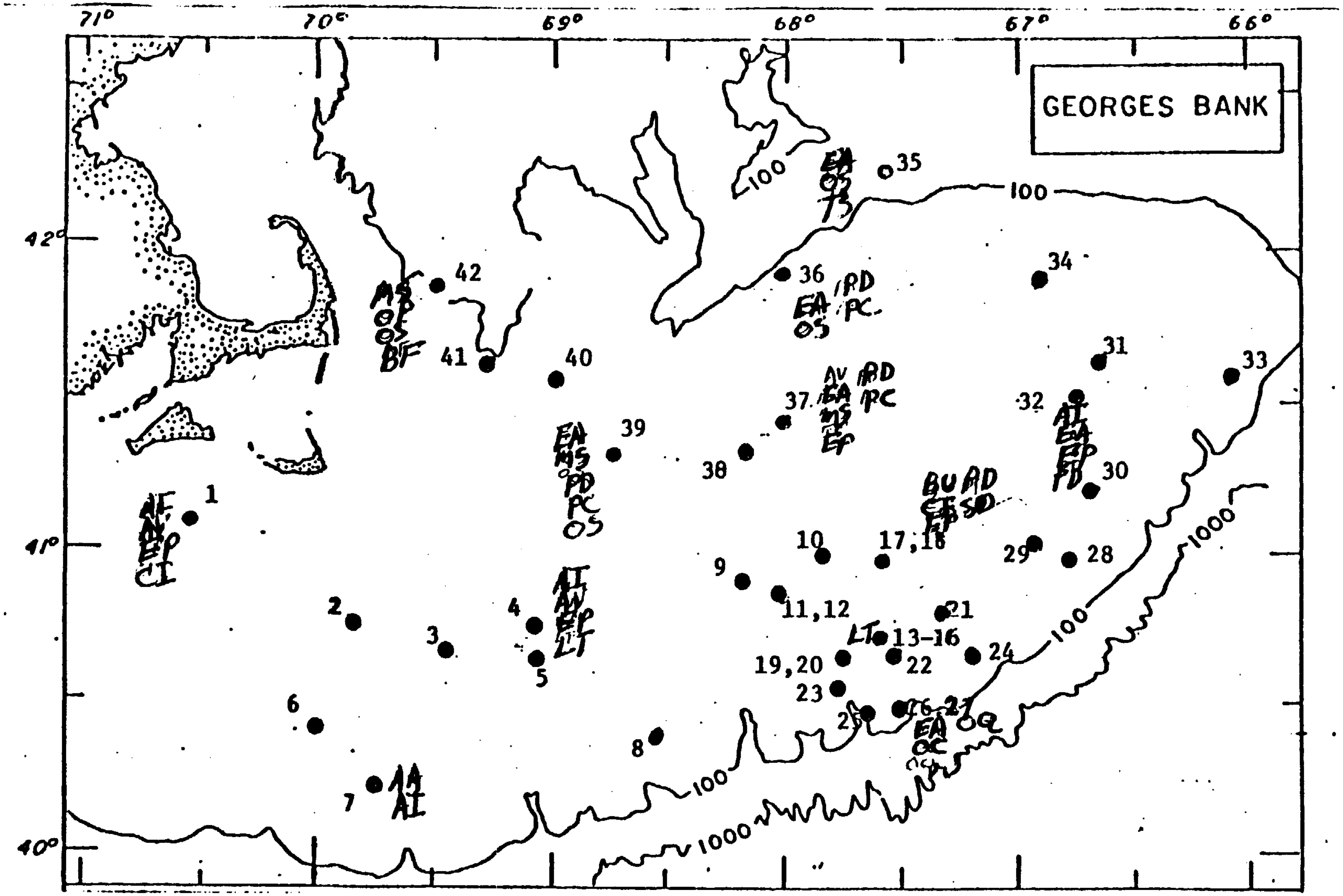


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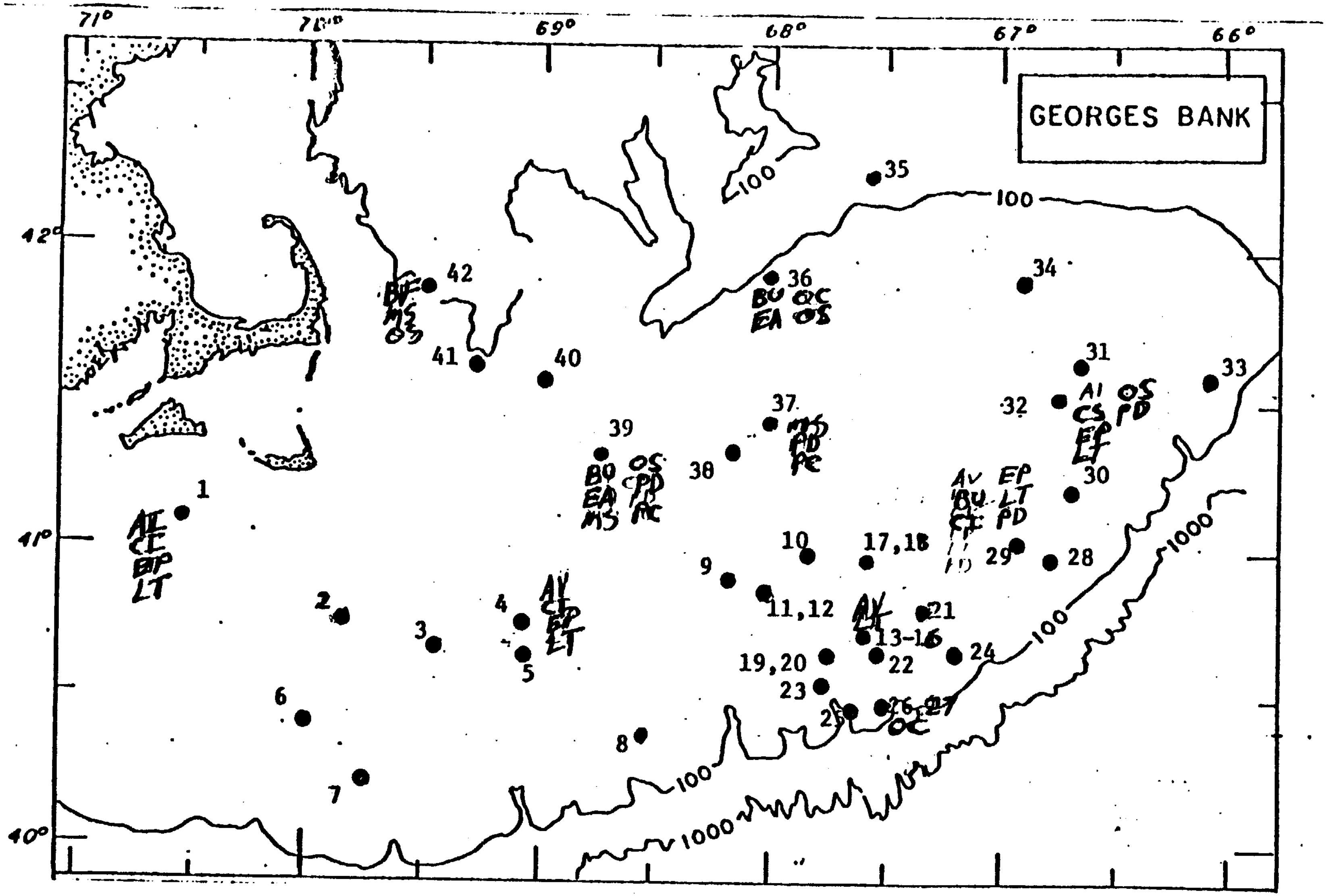
Table 12. Mean Relative abundance of selected invertebrates from tows for Georges Bank, Summer 1977

	STATION														
Species	1	4	7	13	18	26	32	35	36	37	39	42	x̄	SD	N
E. americanus									13		4003		401.6	1265.4	10
M. senile		.8			4		9			37	66		11.7	22.2	
A. hastata	.2	3					.5		1		5		.97	1.69	
L. fragilis	.8	1		.8					10	4		.8	1.74	3.13	
M. sarsi	.2										1	11	1.22	3.45	
N. pelagica	.2	3		2	.2								.54	1.06	
O. conchylega						1034			10				104.4	326.6	
O. opalina											.2	3	.32	.94	
B. undatum		1			6		7		19		15		4.8	7.0	
C. stimpsoni		2					.2		.8		6		.90	1.9	
A. islandica	6	2		.8	3	.8	12		3		2	1	3.06	3.56	
P. magellanicus	1	3					.2		.2		.5		.49	.93	
S. solidissima		3					1			2			.60	1.07	
Unciola spp.	3						.5		.5		.5		.45	.92	
C. borealis		3		3	.8	2					.2		.90	1.27	
C. irroratus	5	8			7		8			9	2		3.9	3.87	
C. septemspinosa	.5	.5					42			21	.2		6.42	14.1	
D. leptocerus	.8	2		.5	.5		7				31		4.18	9.66	
H. coarctatus					.2		.2		.2		.8		.14	.25	
H. araneus		.5									.5		.10	.21	
M. norvegica															
P. acadianus	.8	.5			6		228			8	25		26.8	71.1	
P. arcuatus				.2	4		.8		2	.8	388		39.5	122.4	
A. americanus				.1									.10	.31	
L. tenera	14	23		7	4	2	22		1	4	19		9.6	9.03	
B. fragilis												3	.30	.94	
E. parma	434	522			42		167			19	5		118.9	197	
S. droebachiensis		4			24		2		.8	.2	1		3.2	7.41	
O. sarsi		.5			.5		65		1076		32	70	124.4	335.5	
A. vulgaris		50		9		.5	5			3			6.7	15.4	

Figure 16. Distribution of key invertebrate species from tows for Georges Bank, Summer 1977.



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species including *A. islandica*, *C. irroratus*, *E. parma*, the echinoderm *Leptasterias tenera* were relatively abundant throughout the southern and south central stations (1, 4, 18, 32). Once again *O. conchylega* was collected in high numbers from Station 26. The pagurids were still distributed throughout the central portion of Georges Bank.

Fall

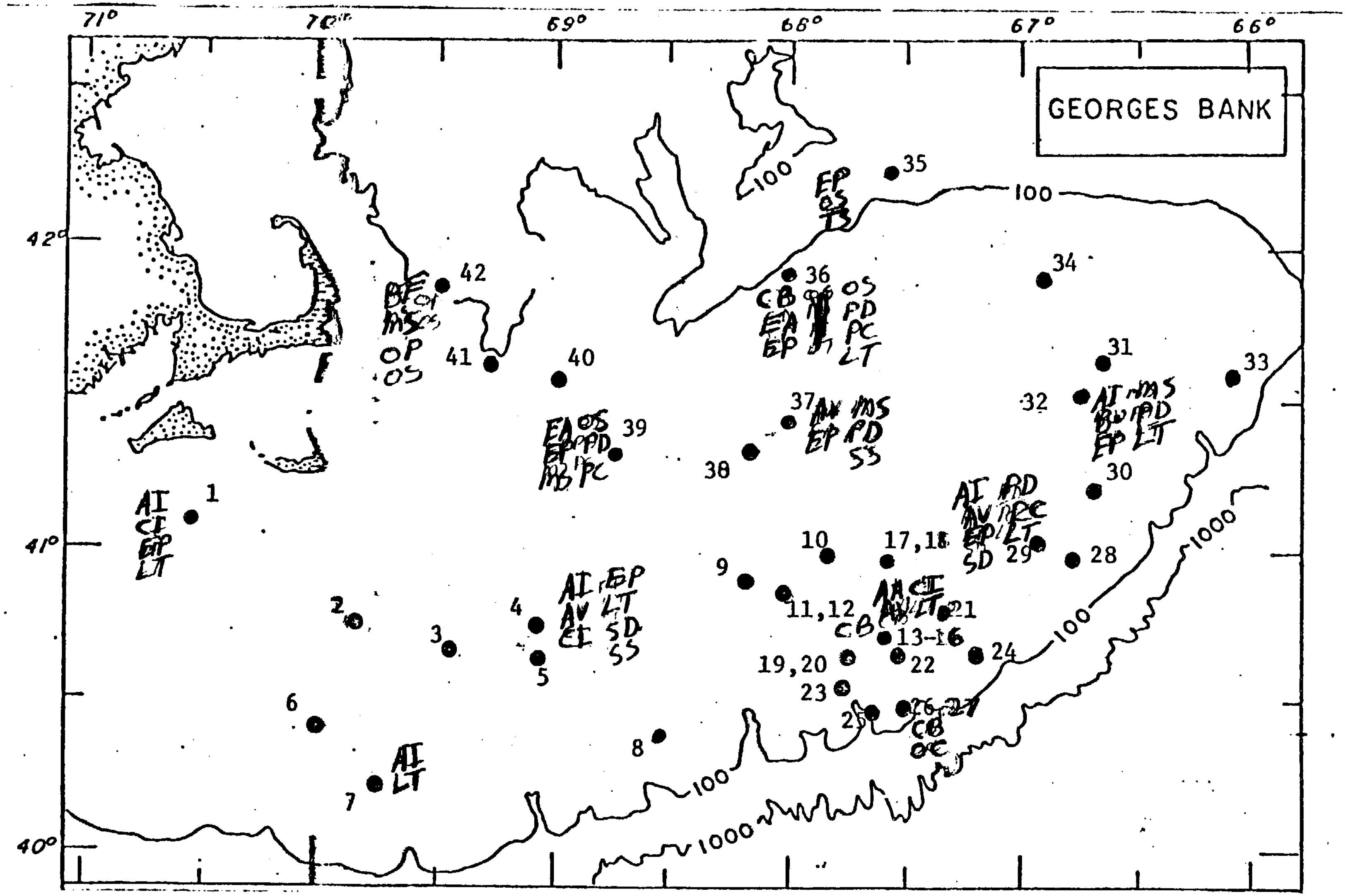
During the fall mean relative abundance of four echinoderms, *Astropecten americanus*, *Asterias vulgaris*, *B. fragilis* and *L. tenera* peaked on Georges Bank (Table 9). *E. americanus*, *O. sarsi* and *P. arcuatus* contributed considerably to the high mean relative abundance recorded at stations 36 and 39 and *O. sarsi* and the polychaete annelid *Onuphis opalina* influenced abundance at station 42 (Table 13, Figure 17). The combination of species including once again *A. islandica*, *C. irroratus*, *E. parma*, *L. tenera* were important in the southern and south central protion of Georges Bank. The pagurids were also still widely distributed throughout the central portion. *O. sarsi* and *B. fragilis* together with *T. septentrionalis* were characteristic of stations 42 and 35 on the northern flank.

In summary, mean relative abundance and diversity was generally lowest during the winter. There were definite seasonal peaks provided by different reproductive cycles of a variety of species throughout the year. Seasonal peaks were superimposed over three general clusters of species. The southern cluster comprised *A. islandica*, *C. irroratus*, *E. parma*, *L. tenera*. This pattern was modified at times by *A. vulgaris*, *A. americanus* and *O. conchylega* which occurred at stations 7, 18

Table 13. Mean Relative abundance of selected invertebrates from tows for Georges Bank, Fall 1977

	STATION													
Species	1	4	7	13	18	26	32	35	36	37	39	42	$\bar{x}$	SD	N
E. americanus						.5			413		1105		126.5	330	12
M. senile		2	.2	.5	12	5	16		1	95	38		14.1	27.7	
A. hastata	.2						3				.5		.3	.86	
L. fragilis		.2										.5	.05	.15	
M. sarsi												27	2.25	7.79	
N. pelagica				.2	.2								.03	.07	
O. conchylega						282	.2						23.5	81.4	
O. opalina												80	6.6	23.1	
B. undatum		.2			.8		18		9		3		3.1	5.94	
C. stimpsoni		.2			1		3		1		5		.85	1.57	
A. islandica	3	22	16	2	7		12				2	6	3.34	5.72	
P. magellanicus	1	7		.8	1		.5		5		.8	.2	1.35	2.24	
S. solidissima		10					4			22			3.0	6.68	
Unciola spp.															
C. borealis	.2	2	.5	7	1	2			1		.5		1.18	1.97	
C. irroratus	6	8		3	11		4		.5	7			3.29	3.87	
C. septemspinosa						.2					2	7	.76	2.04	
D. leptocerus	1				.2		.2		4	.2	5		.88	1.72	
H. coarctatus					.8		.2		2		.2		.26	.59	
H. araneus															
M. norvegica												.2	.016	.05	
P. acadianus	1	7	.2	.8	13		98		5	20	24		14.1	27.7	
P. arcuatus	.2			.2	6	.8	6		49		131		16.1	38.7	
A. americanus			245	72		1							26.5	71.8	
L. tenera	12	63	8	3	7	.2	25		6	1	24		12.4	18.1	
B. fragilis	828											18	70.5	238.6	
E. parma		11			18		118			6	17		14.1	33.4	
S. droebachiensis		218	1		8		2		35	3	1		22.3	62.4	
O. sarsi									472	.2	13	866	112.7	273.6	
A. vulgaris		167		11	1		6			6	4		16.3	47.6	

Figure 17. Distribution of key invertebrate species from tows for Georges Bank, Fall 1977.



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and 26 and by the pagurids, the gastropod *Buccinum undatum* from more northern stations. The central cluster comprised *P. acadianus*, *P. arcuatus*, *Buccinum undatum*, *Colus stimpsoni* with occasional occurrences of *E. parma* and *A. islandica* from the southern cluster and of *Metridium senile*, *E. americanus* and *O. sarsi* from the northern cluster. The northern cluster consisted primarily of *O. sarsi*, *B. fragilis*, *M. senile*, *E. americanus* with occasional occurrences of the widely distributed pagurids *C. borealis* and *E. parma* at station 36 in the fall.

Relative Biomass

Although data on relative biomass of invertebrates from tows were recorded from BLM cruises in 1977, data were never reported. Raw data were kindly made available by Dr. Richard Toner, Marine Research, Inc.

The mean relative biomass (g/tow) per station of invertebrates from tows of BLM cruises in 1977 are presented in Table 14. Based on data from the rocking chair dredge mean relative biomass increased sharply from winter (78.7 g/tow) to spring (1271.1 g/tow), peaked in summer (2305.4 g/tow), and declined somewhat in fall (1521.2 g/tow) (Table 15). The sharp increase between winter and spring is misleading because biomass data were not recorded for Pelecypoda and Gastropoda during the winter cruise. Since pelecypods and gastropods were major contributors to total biomass their omission from the winter data made the increase in biomass between winter and spring appear much larger than it was. However, even when pelecypod and gastropod

Table 14. Mean relative biomass (g) of invertebrates per station from tows for Georges Bank, 1977

	Winter			Spring		Summer		Fall	
Gear	1	2	5	1	6	1	6	1	6
Stations									
1	48.5	93.4	216.1	1351.6	24280	13387.2	9960.2	870.8	2493
4				6503.5	1299.1	2469.1	4664.3	3629.2	11243.4
7	250.6			1710.8	3457.5			2882.4	2239.3
13				106.8	80.2	81.1	632.4	1541.5	1493.5
18	10.6	1.1	900	1822.1	10608	1752.5	1865.8	1579	1541.05
26				200.4	417.9	200.5	424.9	423.1	1710.6
32	251.6	1533.4		1079.4	2174.7	4350.3	1290.2	4303.4	3776.3
35				148.3	66.1				
36		2.9		1589.9	1700.5	348.7	10708.05	1399.5	4095.2
37	9.8	72.1	5339.1	541.3	3573.3	465.1	696.6	616.9	972.1
39	5.2	409		122.3	2551.8		2096.1	944.2	2124.4
42	54.0	98.5	218.1	76.9	687.6		235.4	64.4	2170.1

Gear 1 = Rocking Chair Dredge, 2 = Crab Dredge, 5 = Epibenthic Sled, 6 = Blake Trawl

Table 15. Mean and standard deviation of relative biomass (g) of invertebrates per season from tows for Georges Bank, 1977

		Winter	Spring	Summer	Fall
Rocking Chair Dredge	$\bar{x}$	78.7	1271.1	2305.5	1521.2
	SD	108.1	1785.3	4143.7	1390.6
	N	8	12	10	12
Blake Dredge	$\bar{x}$	-	4241.3	3257.3	2821.5
	SD	-	6924.1	3946.5	2873.6
	N	-	12	10	12

$\bar{x}$ = mean, SD = standard deviation, N = number of stations data were deleted from all seasons, the mean relative biomass for winter through fall was 78.7 g, 374.6 g, 1412 g and 268.3 g/tow, respectively, leaving the same seasonal pattern.

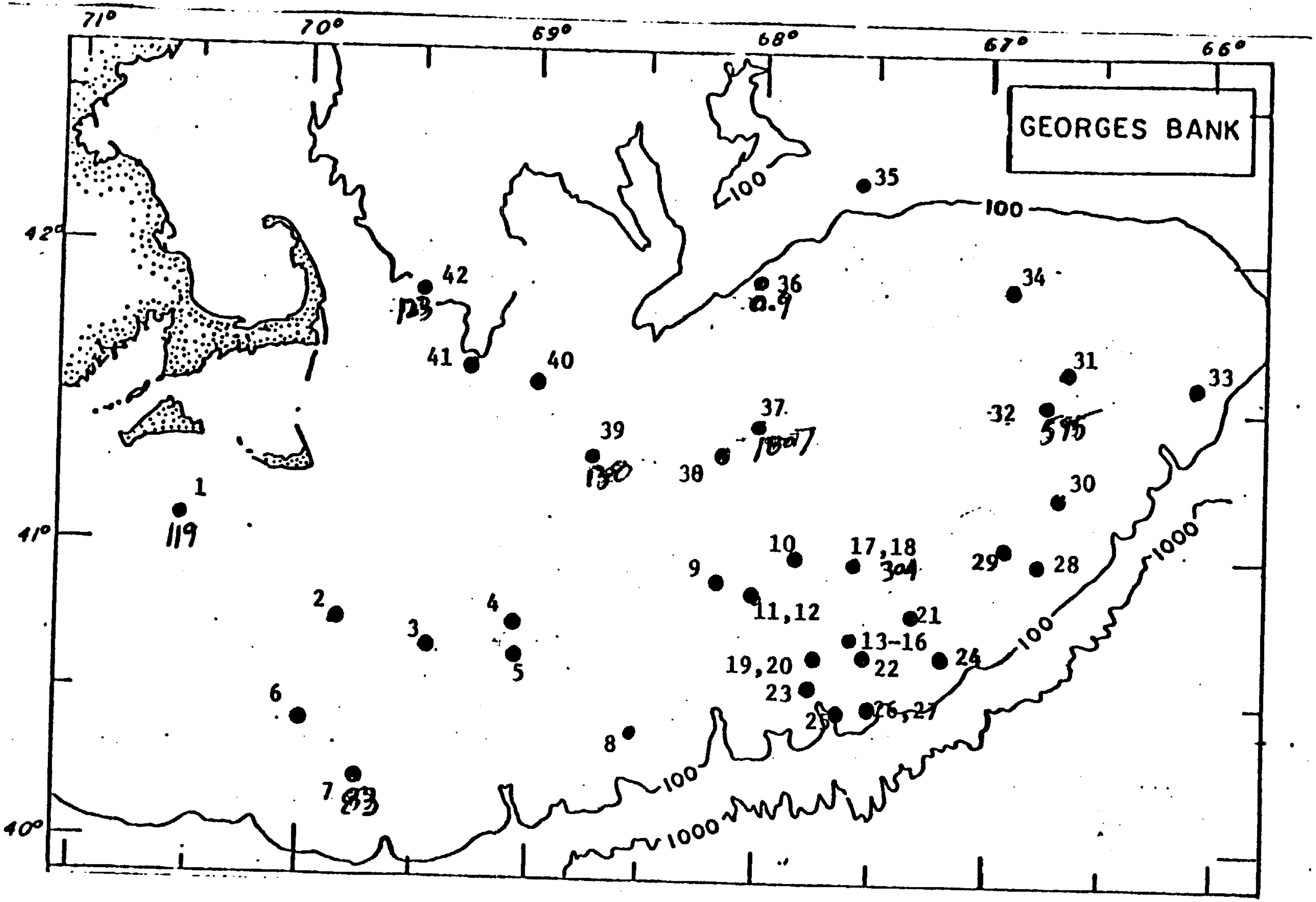
Since the Blake dredge was first used in the spring cruise, there were no winter data from this trawl. Mean relative biomass peaked in the spring (4241.3 g/tow and declined progressively through summer (3257.3 g/tow) and fall (2821.5 g/tow) (Table 15). However, one station (#1) provided 42% of the total biomass estimate for the spring. The station was dominated by a sponge (21,000 G) which comprised 88% of the sample. When this sponge was deleted from the spring calculations, mean relative biomass was 2454 G/tow, leaving summer again as the peak period.

Geographic and Seasonal Distribution of Relative Biomass

General

During the winter the highest mean relative biomass (1807 g/tow) was recorded for station 37 (Figure 18). In the spring the highest value was recorded at station 1 (12,815 g/tow) with other high estimates at stations 18, 4, 36, 7 and 37 (6215 g, 3901 g, 3290 g, 2584 g and 2057 g/tow). (Figure 19). During the summer the highest value was again reported at station 1 (11,674 g/tow) with high estimates at station 36 (5528 g/tow) and station 4 (3567 g/tow) (Figure 20). Finally in the fall station 4 contained the highest mean relative biomass (7436 g/tow) with high values at station 32 (4040 g/tow) and station 36 (2747 g/tow) (Figure 21).

Figure 18. Mean relative biomass (g) of invertebrate species from tows for Georges Bank, Winter 1977.



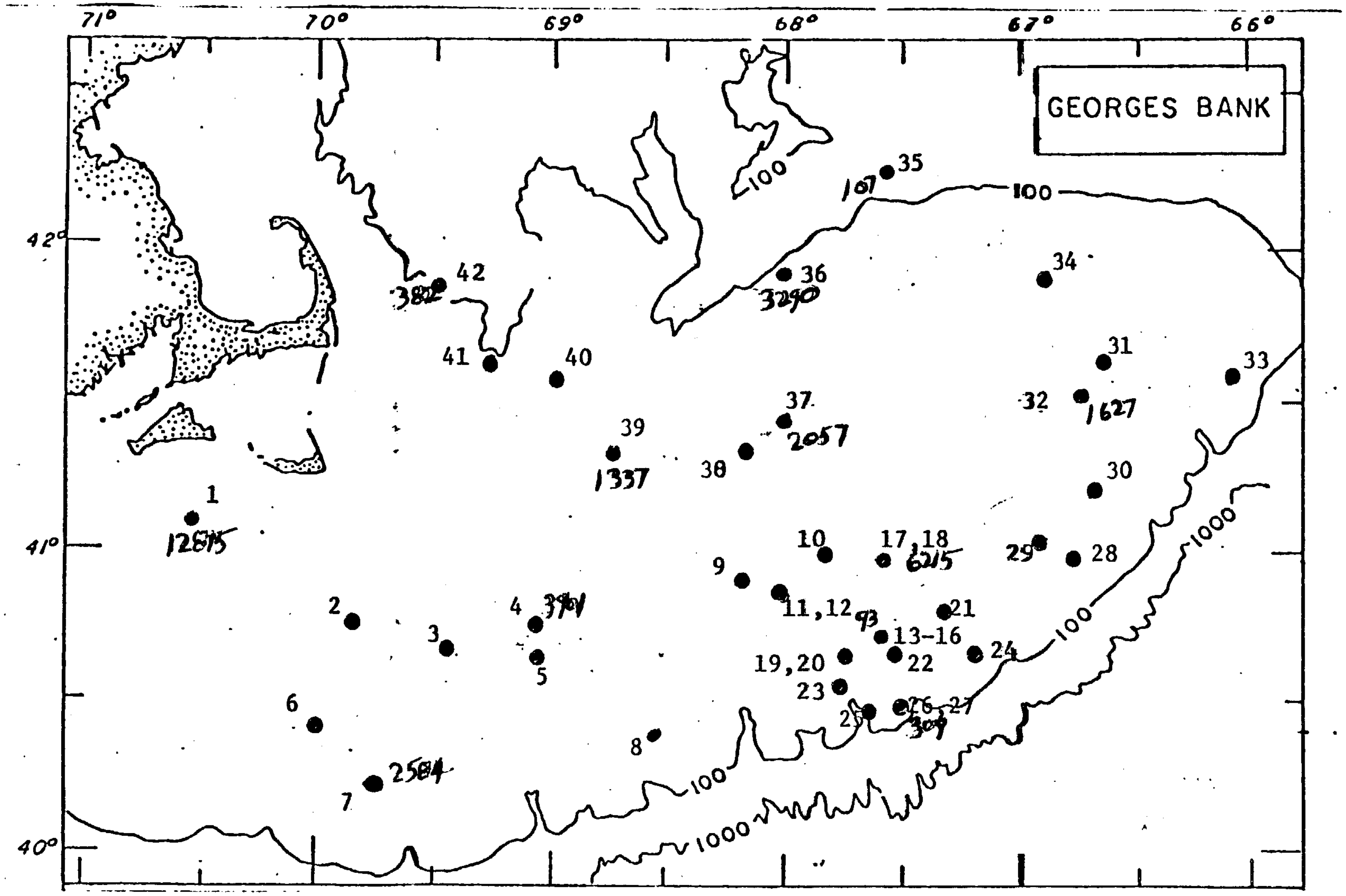


Figure 19. Mean relative biomass (g) of invertebrate species from tows for Georges Bank, Spring 1977.

Figure 20. Mean relative biomass (g) of invertebrate species from tows for Georges Bank, Summer 1977.

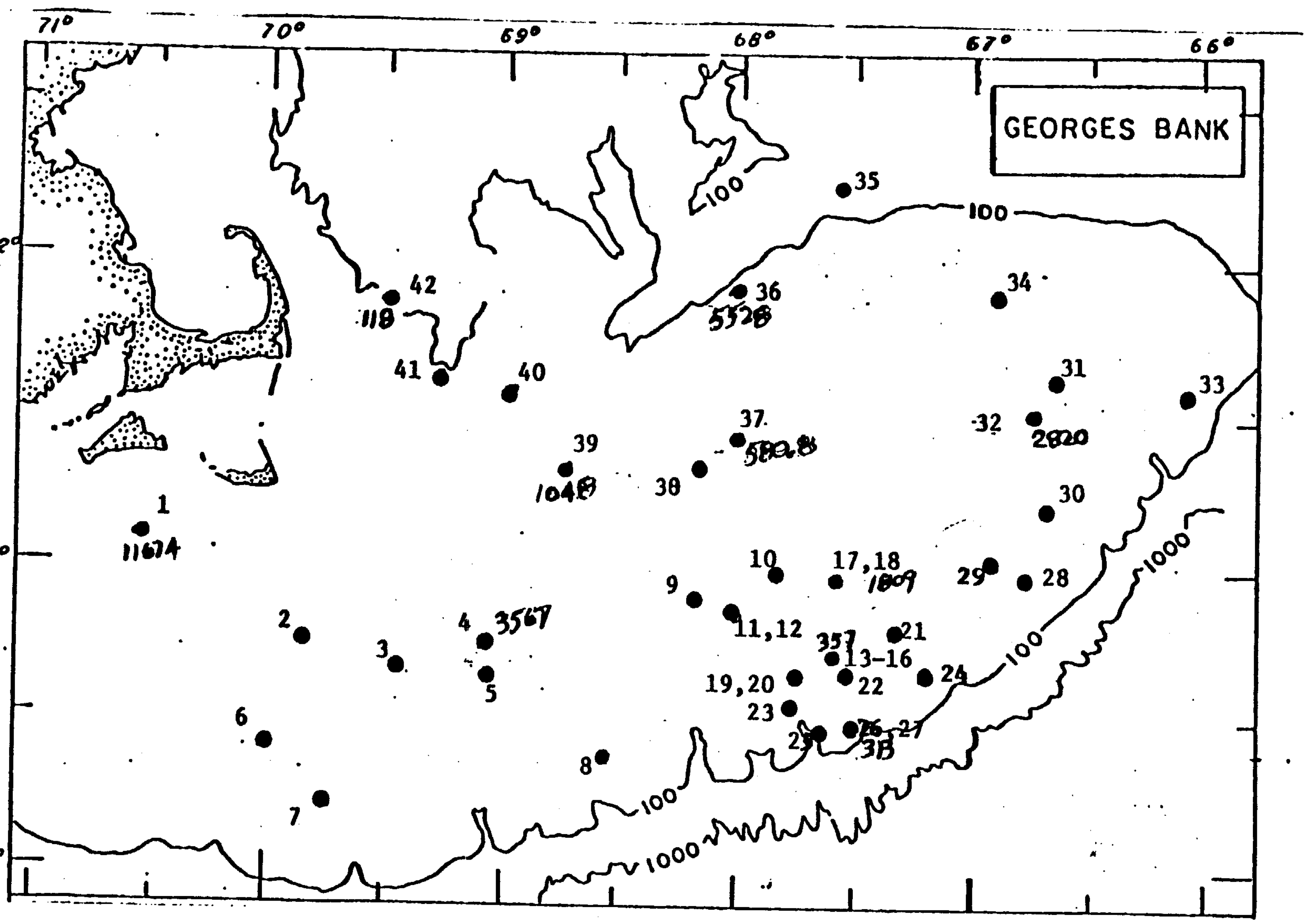
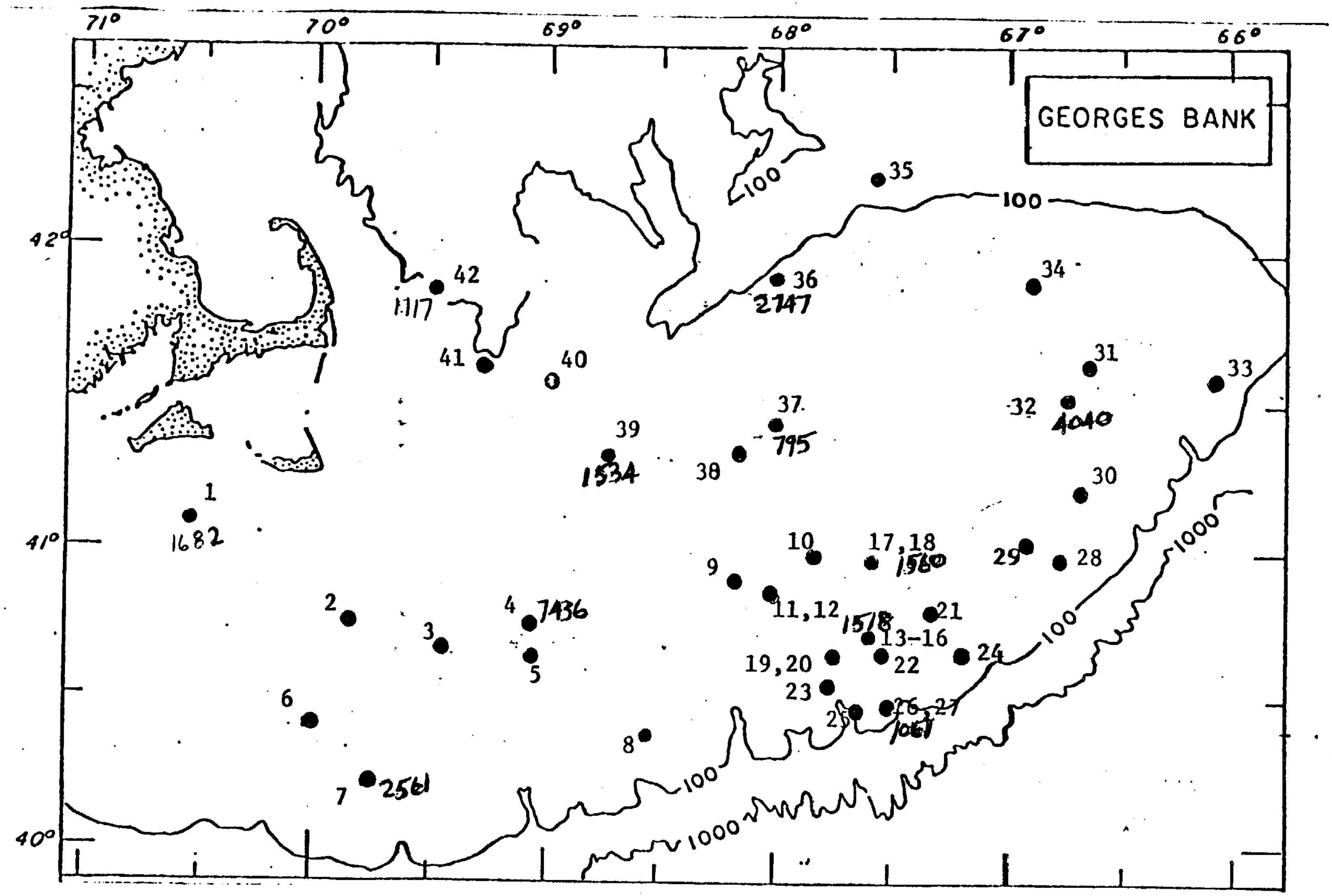


Figure 21. Mean relative biomass (g) of invertebrate species from tows for Georges Bank, Fall 1977.



Taxonomic

Winter

During the winter cnidarians comprised about 57.4% of the mean relative biomass followed by echinoderms with 31.3% (Table 16). In terms of biomass *Epizoanthus americanus* and *Metridium senile* were the biggest contributors among the cnidarians and *Echinarchnius parma*, *Leptasterias tenera* and *Ophiura sarsi* among the echinoderms. *M. senile*, *O. sarsi* and *E. americanus* were more commonly collected from stations 37, 39 and 42 while *E. parma* and *L. tenera* were more commonly sampled at stations 1, 18 and 32.

Spring

During the spring, miscellaneous taxa comprised 34.1% of mean relative biomass, echinoderms 24.1%, pelecypods 16.9%, gastropods 13.1% and decapods 8.5% (Table 16). Miscellaneous taxa included a massive collection of sponge at station 1. Four samples yielded 1317.1 g, 586.5 g, 7054.5 g and 35831.7 g, respectively of sponge (*Suberites ficus*). Important echinoderms included: *E. parma*, *L. tenera* and *Stronglyocentrotus droebachiensis*. *Arctica islandica* and *Placopecten magellanicus* comprised the dominant pelecypods together with *Spisula solidissima*, *Astarte* spp. and *Venericardia borealis*. Gastropods were characterized by *Buccinum undatum*, *Colus stimpsoni*, *Neptunea decemcostata*, *Lunatia heros*, *Crucibulum striatum* and *Crepidula* spp. Decapods were represented by *Cancer irroratus*, *Cancer borealis*, *Pagurus acadianus*, *Pagurus arcuatus* and *Hyas* spp. This list of species comprises many of the largest invertebrates

Table 16. Mean relative biomass (g) of major taxa of invertebrates per season from tows for Georges Bank, 1977.

	Winter %	Spring %	Summer %	Fall %
Cnidaria	57.4	1.2	1.7	2.1
Annelida	.8	1.9	0.5	0.9
Pelecypoda	<.01	16.9	22.0	37.9
Gastropoda	<.01	13.1	4.7	11.1
Decapoda	5.9	8.5	3.9	14.0
Caridea	3.5	0.2	<.1	<.1
Amphipoda	.08		<.1	<.1
Isopoda	<.01			
Echinodermata	31.3	24.1	25.5	30.8
Miscellaneous	.9	34.1	41.6	3.1
Total				

on Georges Bank and as such they individually and collectively contribute major portions of biomass to the area. Their distribution was discussed earlier in the section on relative abundance.

Summer

During the summer, mean relative biomass was generally the highest for many species. Once again miscellaneous taxa represented by *Suberites ficus* at station 1 comprised about 41.6% of the mean relative biomass, followed in turn by echinoderms 25.5%, pelecypods 22%, gastropods 4.7% and decapods 3.9% (Table 16). The extreme values of sponge biomass at only 1 station again masked the importance (frequency of occurrence, abundance, size) of the contribution of molluscs and echinoderms to the biomass of Georges Bank.

Fall

During the fall, pelecypods comprised 37.9% of the mean relative biomass, followed by echinoderms with 30.8%, decapods, 14%, and gastropods with 11.1% (Table 16). Mean relative biomass of *Astropecten americanus*, *Asterias vulgaris* and *L. tenera* peaked on Georges Bank in the fall. The same suite of species that emerged as important contributors to biomass in the spring persisted into the fall.

In summary, mean relative biomass was generally lowest in the winter and highest in the summer. Geographic patterns of biomass did not always reflect abundance patterns. Abundance patterns were commonly controlled by smaller species (*E. americanus*, *C. septemspinosa*, *D. leptocerus*, *Astarte* spp., *V. borealis*, *P. acadianus*, *E. parma*, *P. arctuatus*, *O. sarsi*) and biomass patterns by larger species (*A. islandica*, *P. magellanicus*, *A. americanus*, *A. vulgaris*, *L. tenera*, *S. droebachiensis*, *C. irroratus*, *C. borealis*, *B. undatum*, *C. stimpsoni*, *N. decemcostata*, *A. hastata*). Approximately 25 species comprised 70-90% of the relative abundance and biomass from dredge hauls.

Quantitative Grabs - BLM, Georges Bank, 1977

General

During the course of the 1977 BLM study approximately 602 macrobenthic invertebrates were identified from the Georges Bank area (Table A-8). This is a conservative estimate because some of the taxa were identified at ordinal and familial levels and include additional species. These samples were sieved through a 0.5 mm mesh sieve. Although four seasonal collections were made, initial resources were insufficient to identify all taxa from all seasons. For example, polychaetes were only identified from winter and spring collections (Maurer and Leathem, 1980a). Resources were subsequently provided by BLM to examine representative stations for summer and fall. The most complete taxonomic list was compiled for the winter of 1977. Based on Table A-8 for the winter, annelids comprised the largest group containing 50% (266 spp.) of the number of species, arthropods 24.8% (132 spp.), molluscs 15.6% (83 spp.), echinoderms 3.6% (19 spp.), cnidarians 2.2% (12 spp.), miscellaneous taxa 2.1% (11 spp.) and ectoprocts 1.7% (9 spp.). Annelids consisted mainly of polychaete species 98.8% (263 spp.) and arthropods were dominated by amphipods 67.4% (89 spp.).

Miscellaneous taxa included Porifera, Sipunculoidea, Phoronida, Hemichordata and Urochordata.

Winter

Total Infauna

During the winter the mean number of species, density (No./m^{-2}) and wet weight (g/m^2) biomass of total infauna ranged from 15 to 68.2 species, from 431.7 to 22,503.3/m^{-2}, and from 6.63 to 2556.4 g/m^2 (Table A-9 to A-11) respectively. The mean value per station was 42.9 species, 6152.8/m^{-2} and 305.3 g/m^{-2}.

The mean number of species per station was lower in shallow water than in deeper water (Figure 22). There was a significant (0.05) positive association between the mean number of infaunal species and depth (R = 0.42). Moreover, the mean number of species was negatively associated with dissolved oxygen (R = -0.40) and median sediment size (R = -0.39). The number of species was highly influenced by polychaetes and amphipods.

The mean density per station showed no particular pattern with high and low estimates recorded throughout various depths (Figure 23). There was a significant negative association between mean density and median sediment size (R = -0.34). Density was highly influenced by polychaetes and amphipods.

The mean biomass per station was higher in shallow water than deeper water (Figure 24). There was a significant negative association between biomass and depth (R = -0.43)and percent silt-clay (R = -0.32) and a positive association with dissolved oxygen (R = 0.45), percent sand (R = 0.36) and percent nitrogen in the sediment (R = 0.31). Biomass was highly influenced by

Figure 22. Mean number of macrobenthic species for Georges Bank, Winter 1977.

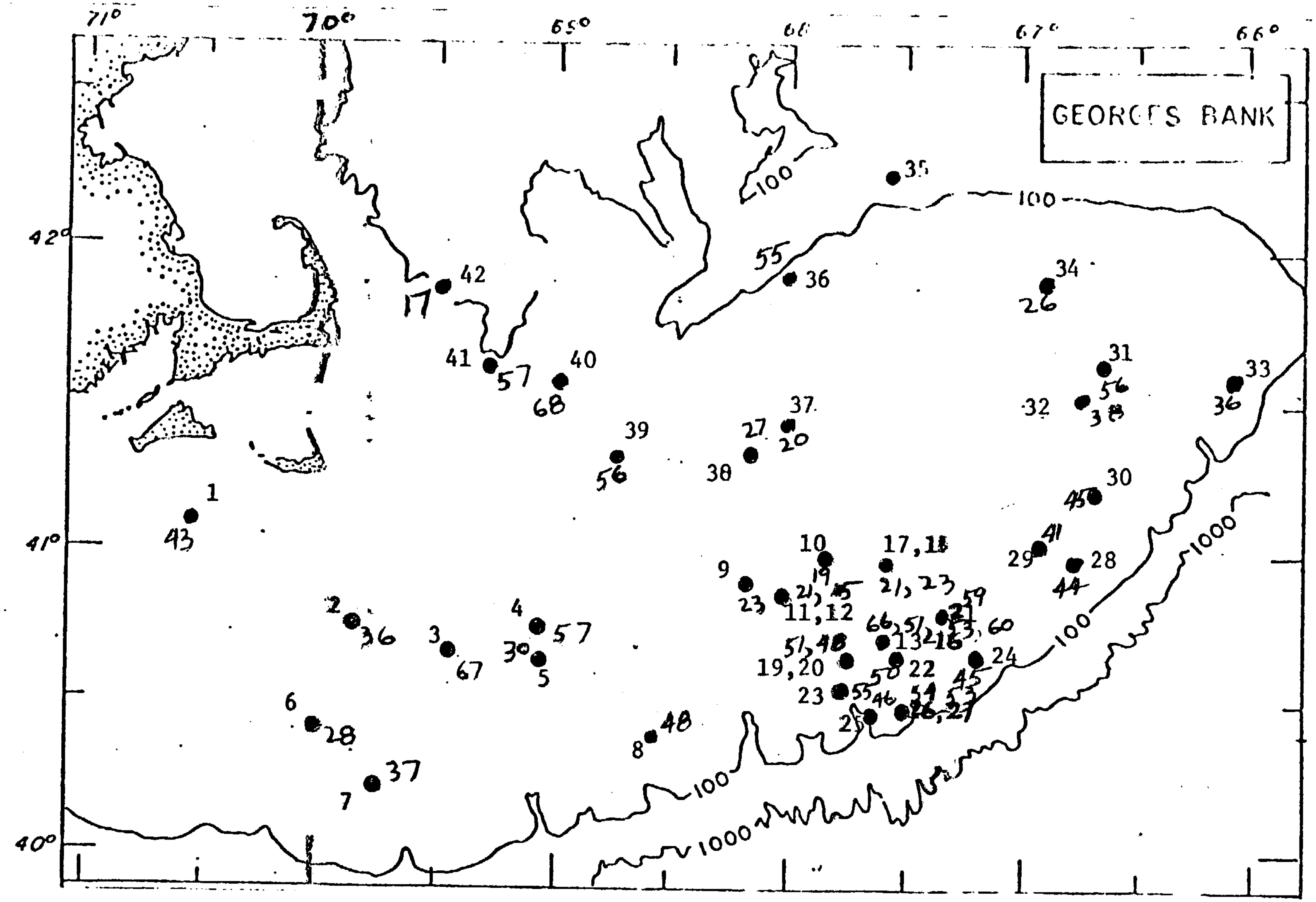
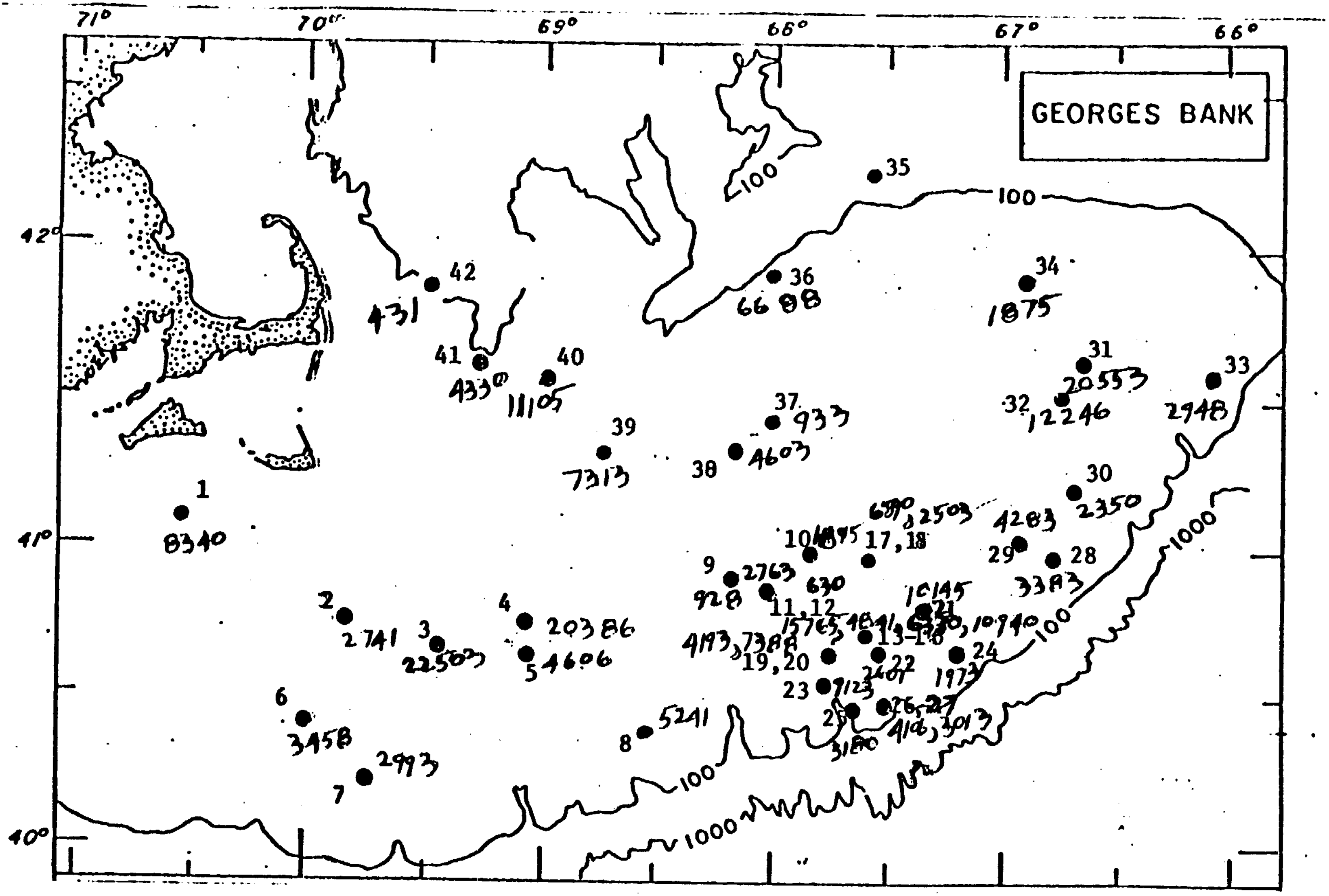


Figure 23. Mean density (No./m^2) of macrobenthic species for Georges Bank, Winter 1977.



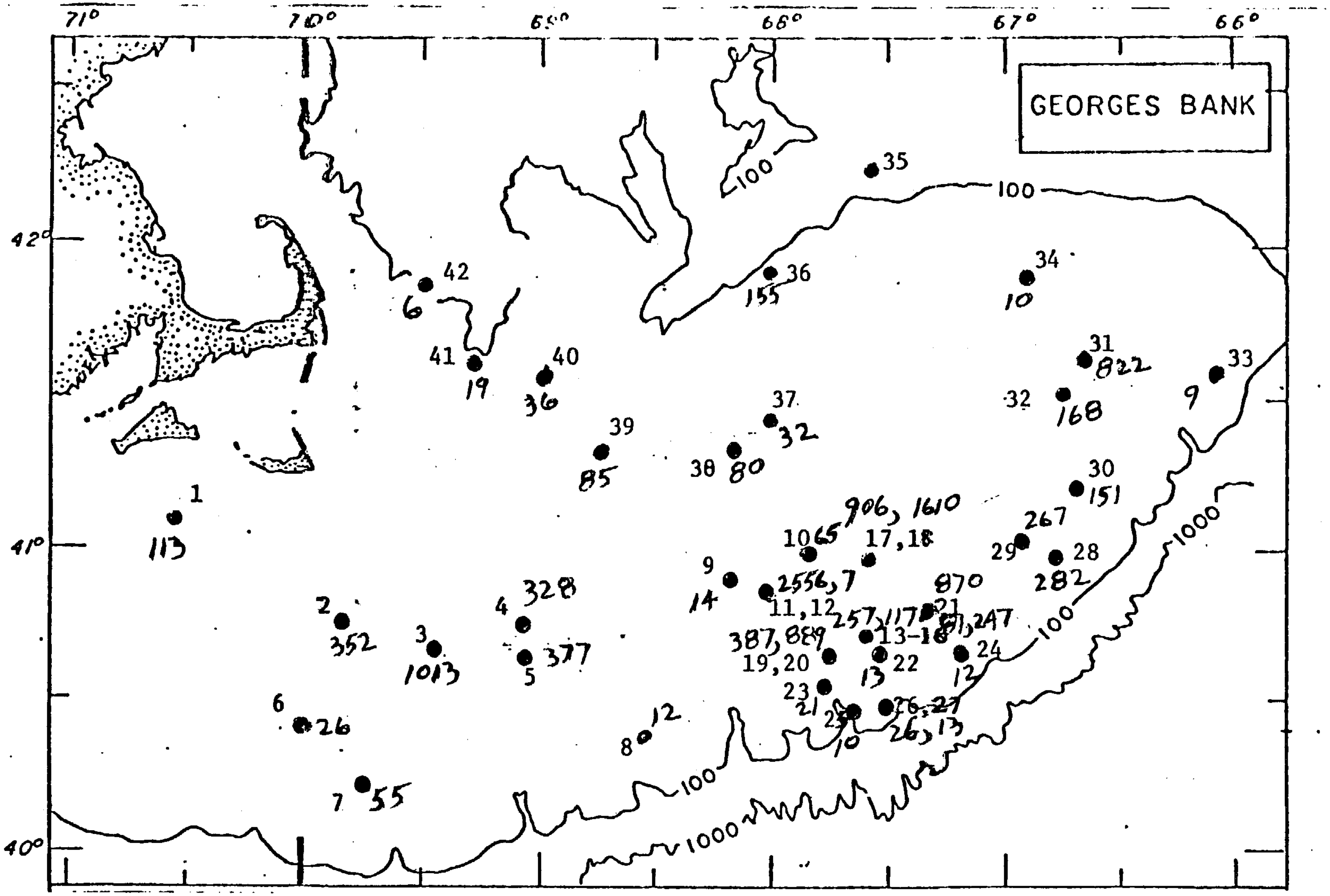


Figure 24. Mean biomass (g/m²) of macrobenthic species for Georges Bank, Winter 1977.

molluscs which contributed about 90% and echinoderms about 6% (Michael, 1977). He stated that the overwhelming effect of molluscs strongly affected the pattern of benthic biomass on Georges Bank. According to him there is solid justification for considering benthic biomass with and without molluscs.

Polychaetous Annelids

General

A detailed account of the ecological distribution of polychaetous annelids from Georges Bank, 1977, was presented elsewhere (Maurer and Leathem, 1980a). The following summary is based on that work.

During the winter, the mean number of species, density and biomass of polychaetous annelids ranged from 3.0 to 43.2 species, from 110 to 18,936.7/m^{-2}, and from 1.5 to 74.3 g/m^{-2}, respectively. The mean value per station was 23.1 species, 3250.9/m^{-2}, and 14.3 g/m^{-2}. In spring the same measures ranged from 7.5 to 49.5 species, from 480 to 17,360/m^{-2}, and from 2.7 to 69.5 g/m^2. The mean value per station was 27.2 species, 3755/m^2 and 15.6 g/M^2. The mean number of species, density and biomass were higher in the spring than the summer but the differences were only significant ($\alpha < 0.05$) for the number of species ($t = 5.75$) and density ($t = 36.3$).

Number of Species

In winter the mean number of species was higher in deeper water than shallow water. Some of the highest numbers occurred at stations 3-4 and 40-41. There was a significant positive association between the number of species and depth ($R = 0.54$)

and percent gravel (R = 0.38) and a negative association with dissolved oxygen (R = -0.47). The general pattern of distribution of number of species was similar in the spring. High numbers were recorded at stations 3-4 and 40-41. Again, there was a positive association between the number of species in the spring with depth (R = 0.51) and negative association with dissolved oxygen (R = -0.31).

Density

In winter there was not a well-defined pattern between density and depth. Stations 3-4, 39-40 and 31 contained high estimates of density. There was a positive association between density and depth (R = 0.29) and percent gravel (R = 0.39) and a negative association with median sediment size (R =-0.40). The general pattern of distribution of density was similar in the spring. High estimates of density were recorded at Stations 4-5, 31-32 and 40. In the spring there was a negative association between density and median sediment size (R = -0.36).

Biomass

In the winter there was no apparent pattern of biomass distribution with depth. Estimates of biomass tended to reflect density estimates. Stations 3-4, 31-32 and 39 contained high estimates of biomass. The pattern of biomass distribution in the spring was generally similar to that in the winter. Stations 3-4, 31-32 and 39 again contained high estimates of biomass. In the spring there was a positive association between biomass and dissolved oxygen (R = 0.39).

Dominant Taxa

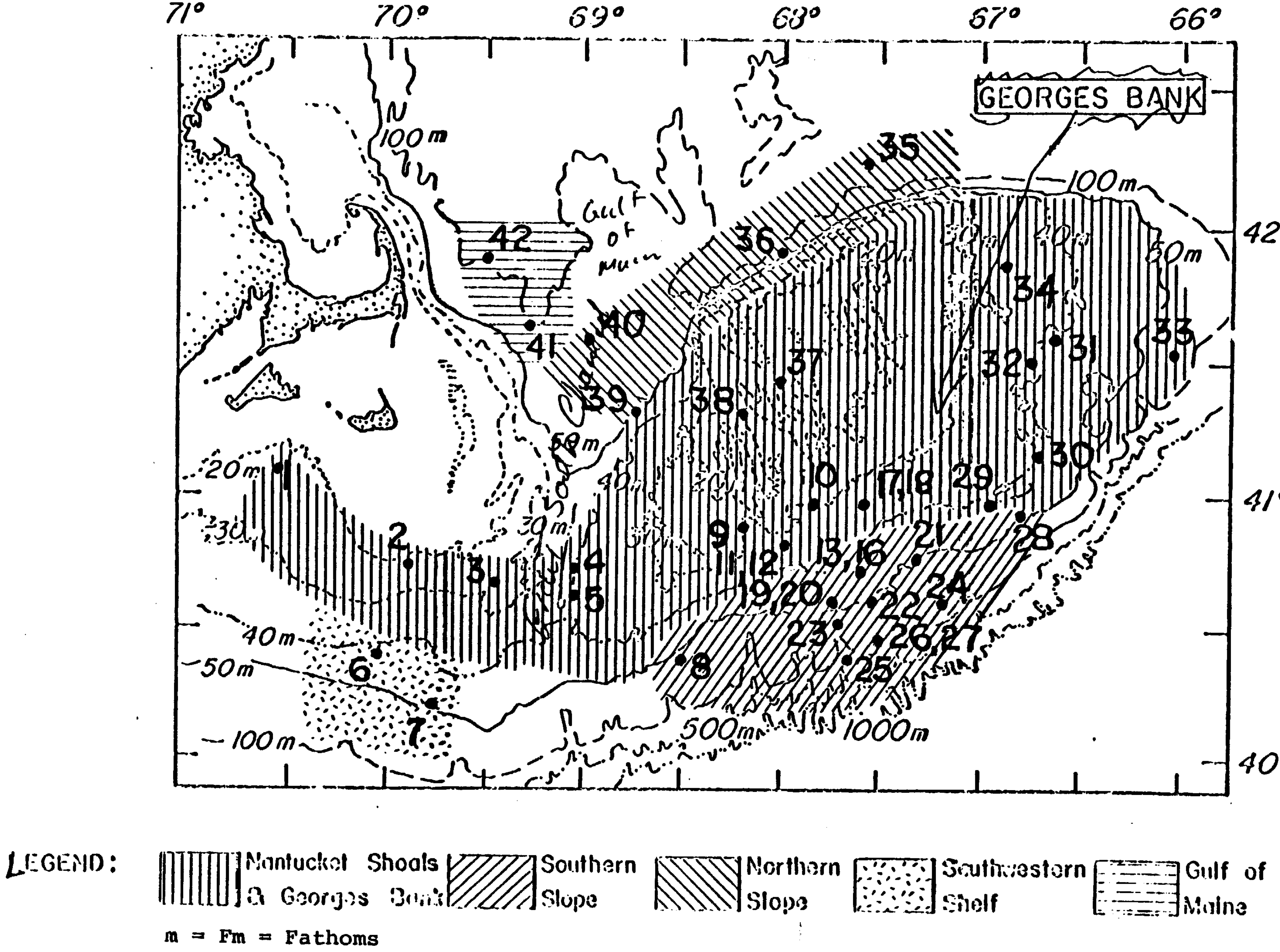
The ecological distribution of dominant polychaete species was presented elsewhere (Maurer and Leathem, 1980a,b). The top 15 taxa in terms of abundance accounted for a mean of 88% (winter) and 89.8% (spring) of the number of polychaetes per station. Accordingly, the biological index value (BIV) of the top 15 taxa per station for winter and spring was computed (Maurer and Leathem, 1980a,b). The top taxa for winter were *Spiophanes bombyx*, *Exogone hebes*, *Euclymene collaris*, *Exogone verugera*, *Aricidea catherinae*, *Phyllodoce mucosa*, Cirratulidae spp., *Parapionosyllis longicirrata*, *Schistomeringos caeca*, *Spiophanes kroyeri*, *Sphaerosyllis erinaceus*, *Tharyx* sp. *B.*, *Goniadella gracilis*, Sabellidae spp., and *Jasmineira filiformis*. In the spring the top 15 taxa were *S. bombyx*, *E. hebes*, *E. verugera*, *Chone infundibuliformis*, Maldanidae spp., Nephtyidae spp., *P. longicirrata*, *A. catherinae*, *S. kroyeri*, *Notomastus latericeus*, Cirratulidae spp., *Tharyx* sp. B., *P. mucosa*, *Euchone incolor*, and *S. caeca*. Among the top 15 taxa from both seasons ten were in common. The same families which dominated the winter were again represented in the spring. In addition, the Nephtyidae and Capitellidae became more important in the spring. The significant increase in density of polychaetes between winter and spring was primarily due to recruitment of *S. bombyx*, *C. infundibuliformis*, Maldanidae spp., and Nephtyidae spp. Seasonal fluctuations among many of the dominant species occurred but not markedly so.

Polychaete Site Groups

Based primarily on numerical classification (normal) together with consideration of the distribution of dominant species and environmental variables (Maurer and Leathem, 1980a) five geographic areas or polychaete site groups were established (Figure 25). The largest area included the greater part of Georges Bank and Nantucket Shoals. This area was characterized by relatively shallow water, sand, considerable gravel (stations 37-38), and bottom topography marked with ridges and swales. The Great South Channel provides a significant physiographic feature which separates Nantucket Shoals on the west from the remainder of Georges Bank to the east. Although these areas might be considered separately, the physical and chemical processes associated with the Great South Channel influence both the shoals and the Bank alike.

A second site group included the southern margin and slope extending at least to the heads of some of the canyons (Figure 25). A third site group is located south of Nantucket Shoals and involved the southwestern shelf characterized by deeper water and sediment with high amounts of silt-clay (Mud Patch). A fourth site group involved the northern margin and slope which was not heavily sampled. Although sediment at stations 35-36 and 40 contained considerable gravel (Table A-1 to A-4) which was comparable to sediment at station 37-38 in site group 1, dominant species in stations 35-36 and 40 were different (Maurer and Leathem, 1980a) and so these stations were included in their own site group. The fifth and final polychaete site group included stations 41 and 42. Both stations

Figure 25. Polychaete site groups for Georges Bank, 1977.



were in deep water with sediment that contained the highest amounts of silt-clay in the study area. Moreover, both stations contained species that were restricted or uncommon throughout Georges Bank (Maurer and Leathem, 1980a). The fifth site group most accurately belonged to the Gulf of Maine system.

Amphipoda

During the winter the mean number of species, density, and biomass of amphipoda ranged from 2 to 15 species, from 20 to $6740/m^2$, and from 0.1 to 25.6 g/m^2, respectively (Tables A-9 to A-11). The mean values per station were 6.5 species, $1533.6/m^{-2}$, and 4.3 g/m^2.

The mean number of amphipod species per station was not clearly related to depth (Figure 26). There was a negative association between the number of species and depth (R = -0.41) and a positive one with dissolved oxygen (R = 0.50). In terms of sediment the number of amphipod species was positively associated with percent sand (R = 0.61) and negatively associated with percent gravel(R = -0.35), percent silt (R = -0.42), percent silt-clay (R = -0.49), percent carbon (R = -0.37, and percent nitrogen (R = -0.40).

Mean density per station showed no particular pattern with depth as high and low density estimates were scattered throughout the Bank (Figure 27). High densities were recorded at station 10-23. Mean density was positively associated with percent sand (R = 0.46).

The mean biomass per station was higher in shallow water

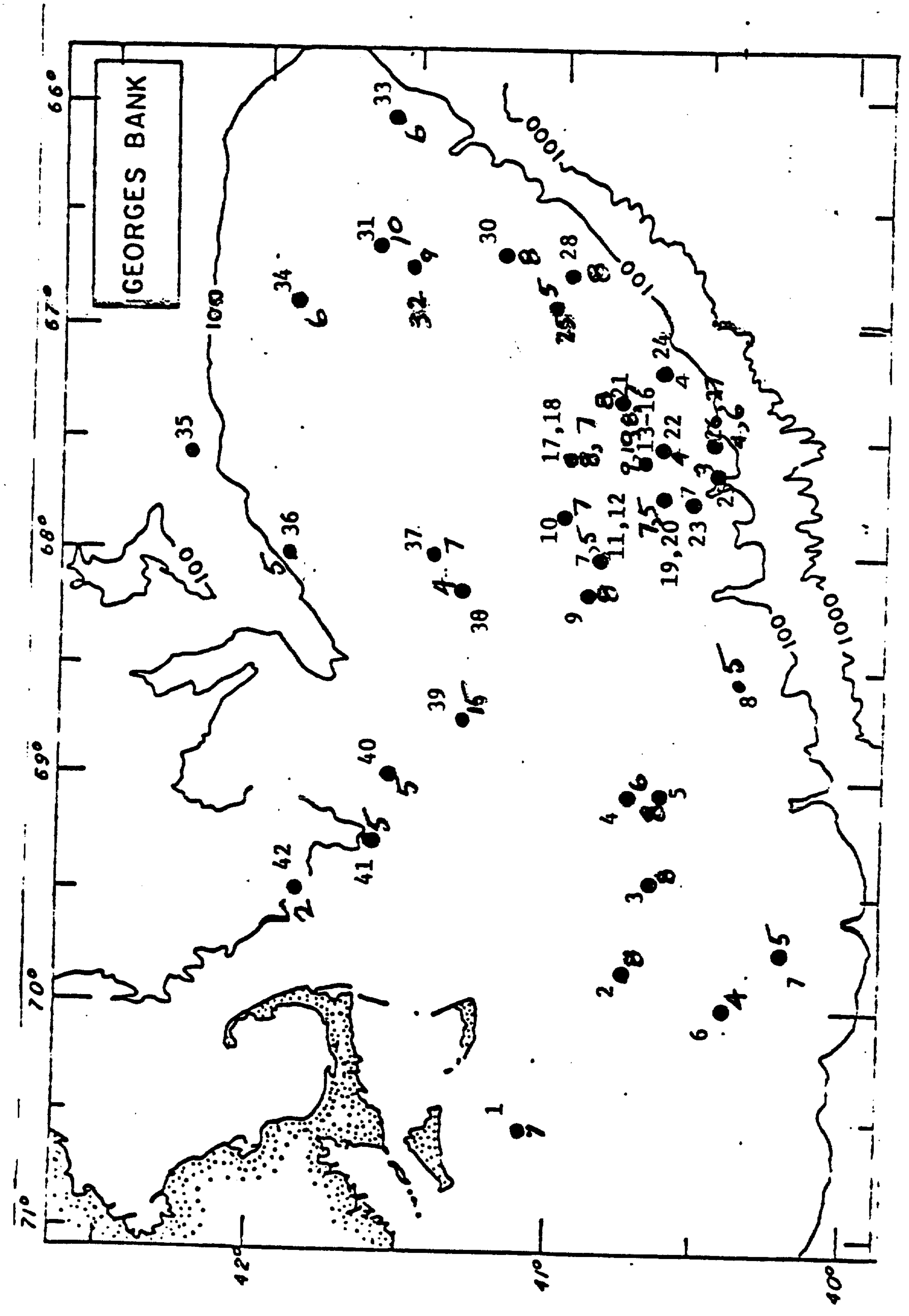
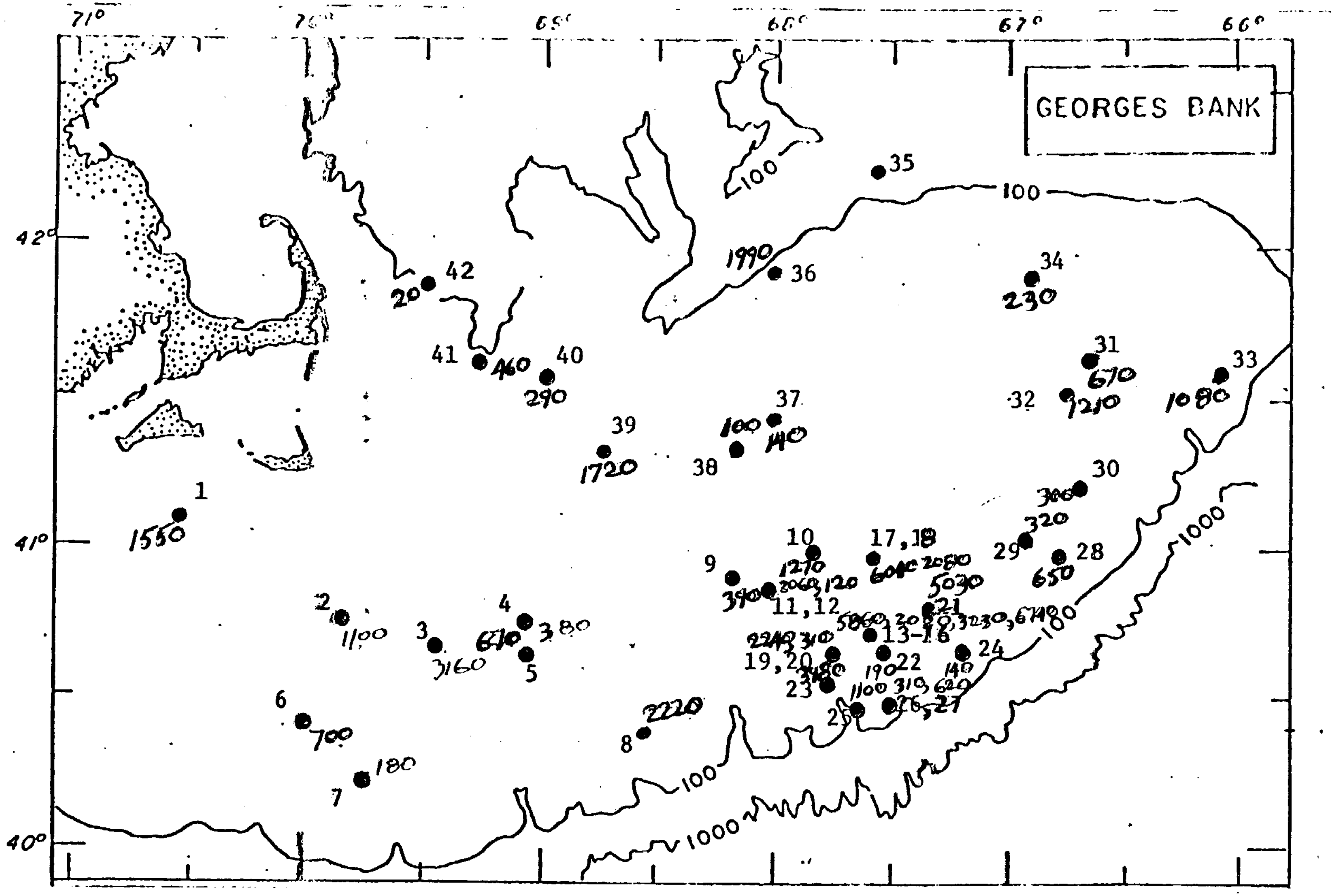


Figure 26. Mean number of amphipod species for Georges Bank, Winter 1977.

Figure 27. Mean density (No./m^{-2}) of amphipods for Georges Bank, Winter 1977.



than in deeper water (Figure 28). There was a negative association between mean biomass and depth ($R = -0.41$). Biomass increased with percent sand ($R = 0.37$) and declined with percent gravel ($R = -0.29$). Stations 1, 3, 15, 17, 36 and 39 contained high estimates of biomass.

When large numbers of amphipods occurred it was often due to the ampeliscids *Ampelisca agassizi* or *Byblis serrata* which generally did not occur together (Michael, 1977). Stations that contained mainly *A. agassizi* had sediment with a mean silt-clay content of 6.9%, over 6 times greater than the mean silt-clay (1.1%) of the stations dominated by *Byblis*. This difference was tested with the Mann-Whitney U-test and found to be highly significant ($0.00 < P < 0.01$). For the winter the numerically important amphipod *Byblis serrata* apparently dominated those sediments where the silt-clay fraction was generally below 2% and *A. agassizi* occupied sediment with a silt-clay fraction greater than 2% (Michael, 1977). However, for the present analyses the mean number of species of total amphipods, density, and biomass were strongly associated with percent sand.

Four distinct amphipod assemblages were tentatively proposed based on winter collections (Michael and Watling, 1977). These assemblages were dominated by *Ampelisca agassizi*, *Byblis serrata*, *Haploops tubicola* and various Haustoriids, respectively (Table 17). The *Ampelisca* assemblage was further divided into four groupings according to sub-dominant species. The *Haploops* assemblage may be influenced by depth while the others may be determined by sediment type.

Figure 28. Mean biomass (g/m²) of amphipods for Georges Bank, Winter 1977.

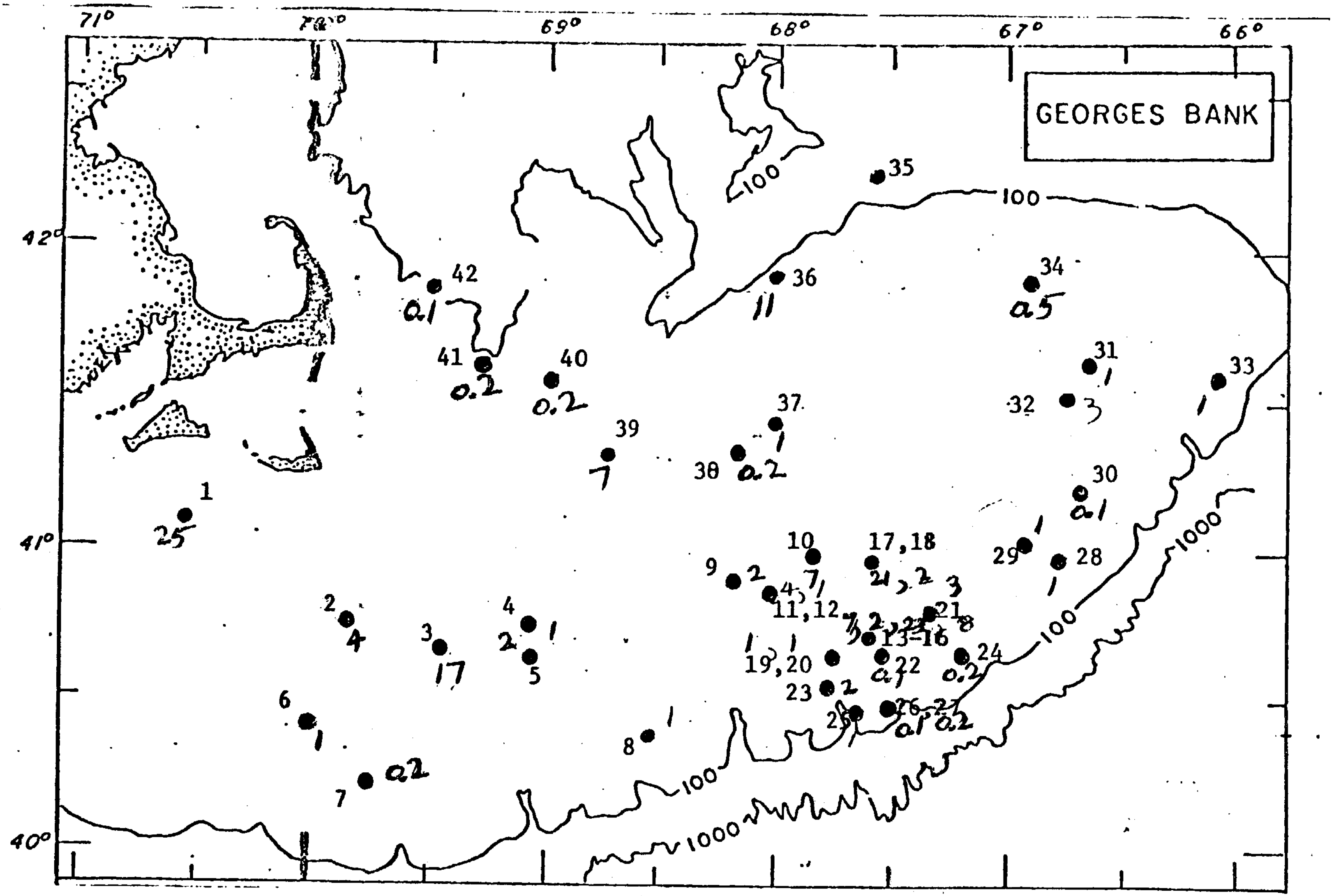


Table 17. Amphipod Assemblages for Georges Bank, Winter 1977
(taken from Michael and Watling, 1977)

Station No.	6-8, 13, 15-16, 21, 25, 28	5, 10, 17	2, 9, 11-12, 33 37-38	39-41
Dominant Amphipoda	*Ampelisca agassizi*	*Byblis serrata*	Haustoriidae	*Haploops tubicola*
	Harpinia N. sp. (sta. 6-7)			
		Pseudunciola obliquua		
Sub-dominant Amphipoda	*Erichthonius rubricornis* (sta. 15-16, 21, 28)			
				Photis reinhardi
		Trichophoxus epistomus	Phoxocephalidae	
	Unciola irrorata (sta. 8, 25)			
		Protohaustorius wigleyi		
	None (sta. 13)			

Mollusca

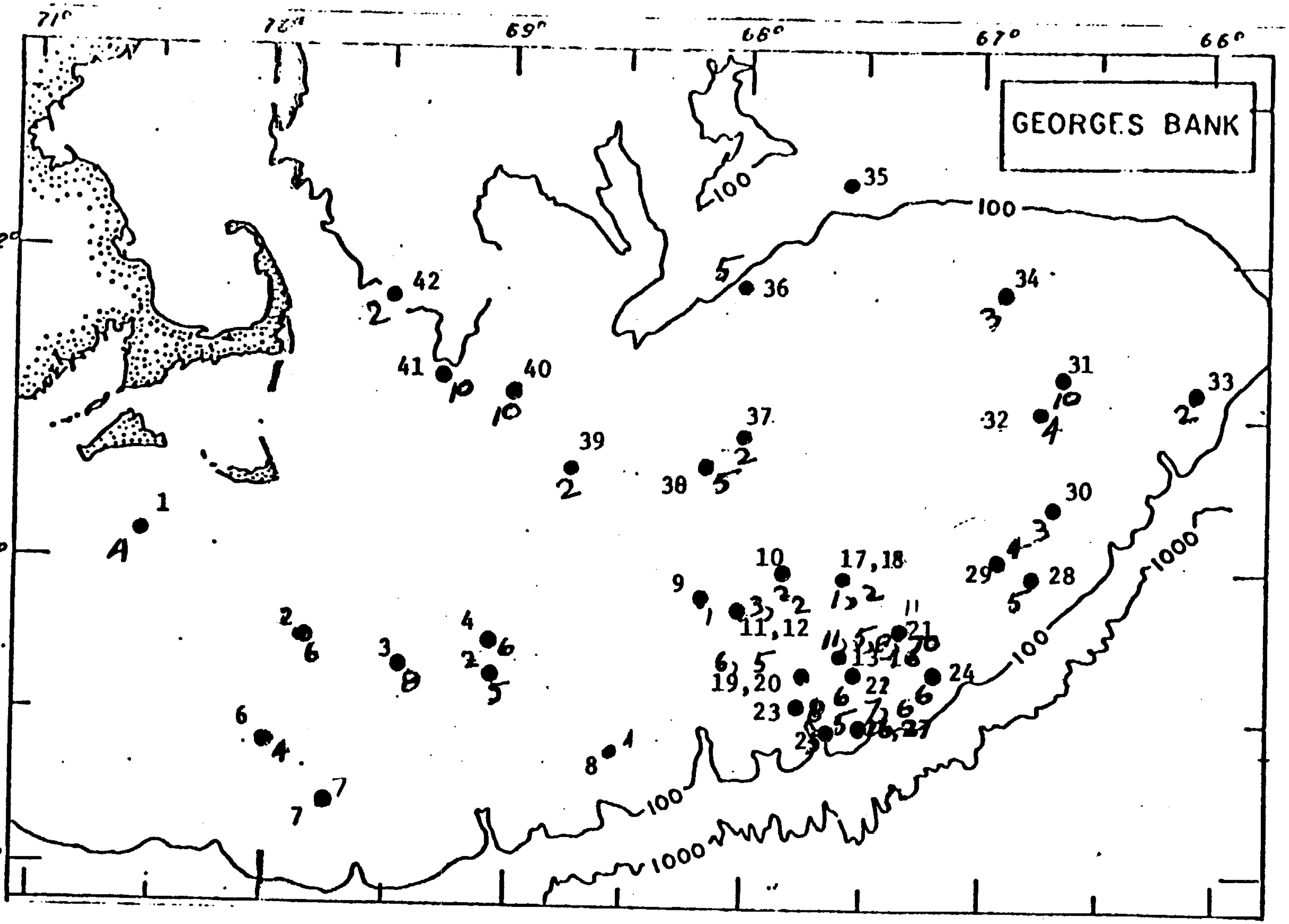
During the winter the mean number of species, density, and biomass of molluscs ranged from 1 to 11 species, from 20 to 6640/ m^{-2}, and from 0.1 to 2535.9 g/m^2, respectively (Tables A-9 to A-11). The mean values per station were 5.2 species, 458.7/m^{-2}, and 264.1 g/m^2.

The mean number of molluscan species per station was generally lower in shallow water than in deeper water particularly in the central portion of Georges Bank (Figure 29). There was a positive association between the mean number of molluscan species and depth (R = 0.29). Stations 13, 16, 31, 40-41 contained relatively high number of species. The mean number of molluscan species increased with percent gravel (R = 0.31) and decreased with lower oxygen (R = -0.35).

There was also a trend of higher density of molluscs with deeper water (Figure 30). There was a positive association between mean density and depth (R = 0.31). Stations 7, 13, 15-16, 23 and 40 contained relatively high density of molluscs. Mean density of molluscs increased with percent carbon (R = 0.31) in the sediment.

There was no particular pattern of molluscan biomass distribution with depth (Figure 31). High and low estimates of molluscan biomass were scattered throughout Georges Bank (stations 2-3, 11-12, 31-32). This high variability was directly attributable to the presence or absence of large bivalves, usually *Arctica islandica*, at some stations (Michael, 1977). Large gastropods such as *Buccinum undatum* and *Colus stimpsoni* also contributed to this high but variable biomass. However,

Figure 29. Mean number of molluscan species for Georges Bank, Winter 1977.



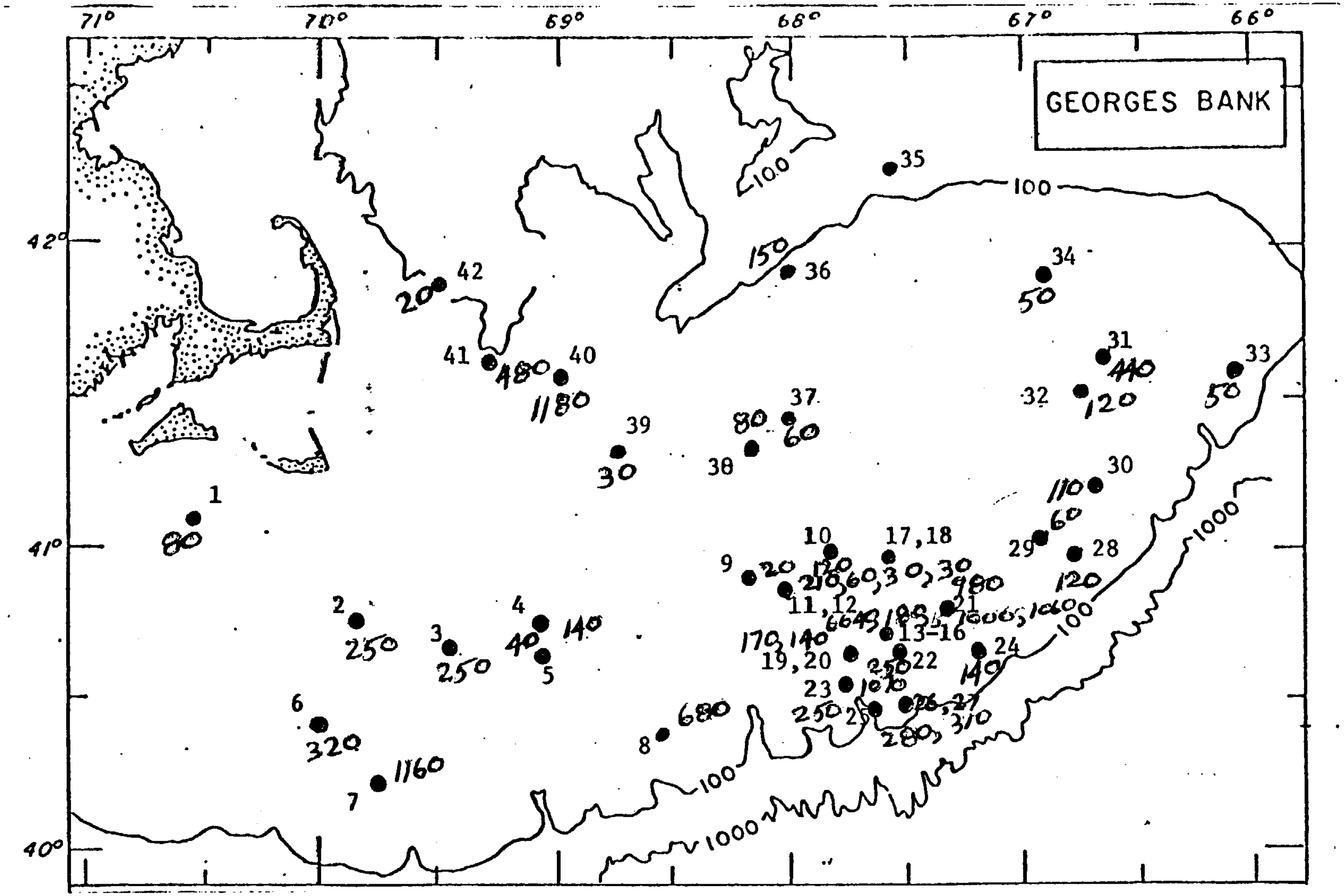
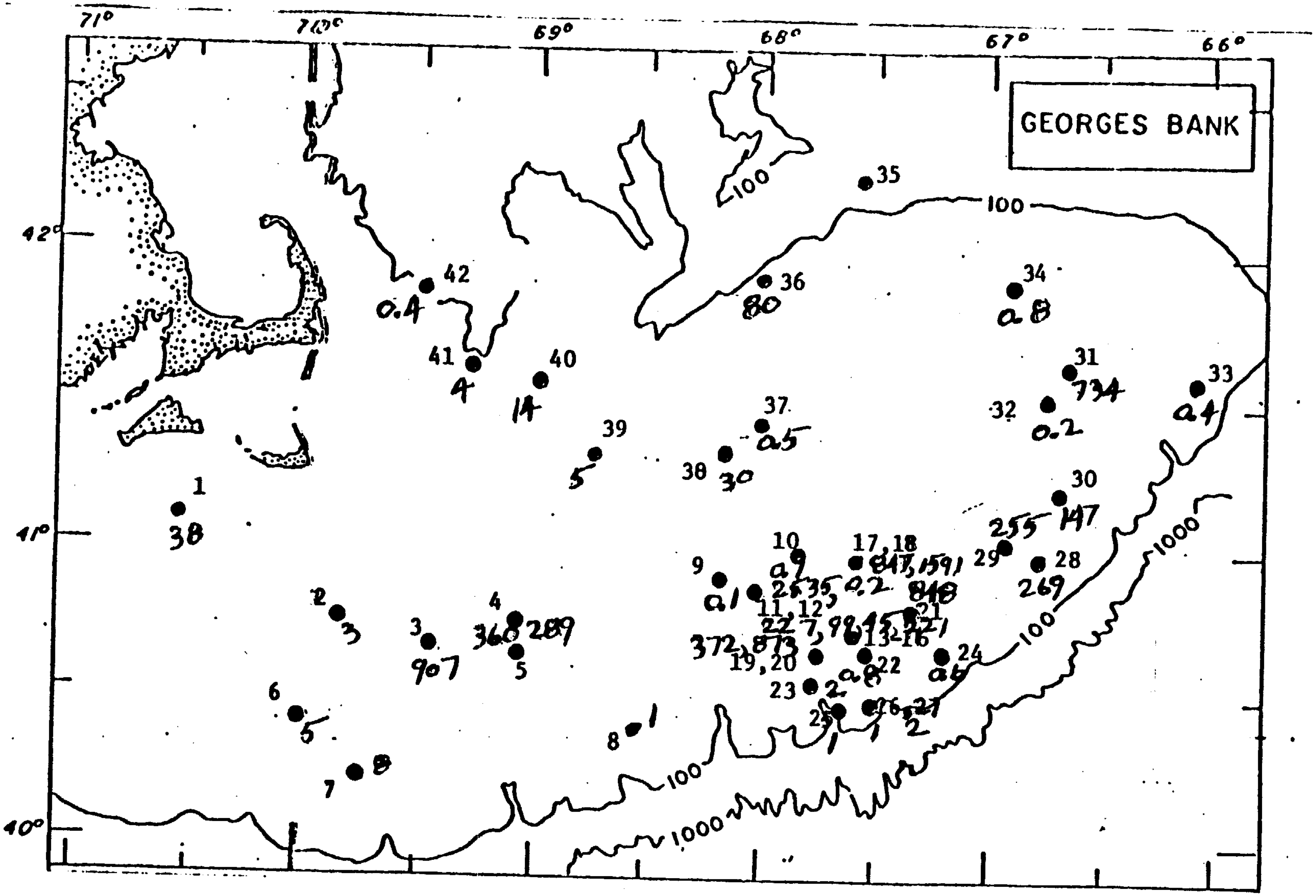


Figure 30. Mean density (No./m^{-2}) of molluscan species for Georges Bank, Winter 1977.

Figure 31. Mean biomass (g/m^2) of Molluscan species for Georges Bank, Winter 1977.



station 3-5, 11, 17-18, 28-30 contained relatively high numbers of *A. islandica*. This alignment suggests some relationship to a particular bathymetric range or set of hydrographic processes that might concentrate bivalve larvae or control nutrient concentrations. There was a positive association between mean biomass of molluscs and dissolved oxygen (R = 0.36).

Larsen and Lee (1978) reported that population densities of the sea scallop *Placopecten magellanicus* ranged up to $122.8/m^{-2}$ in the winter and $62.5/m^{-2}$ in the spring. High densities were recorded at stations 13, 15-16, and 21-22 in the winter and stations 16 and 19 in the spring. Correlation analyses of post-larval scallop density and sand grain size, water depth, salinity and temperature revealed no significant relationships.

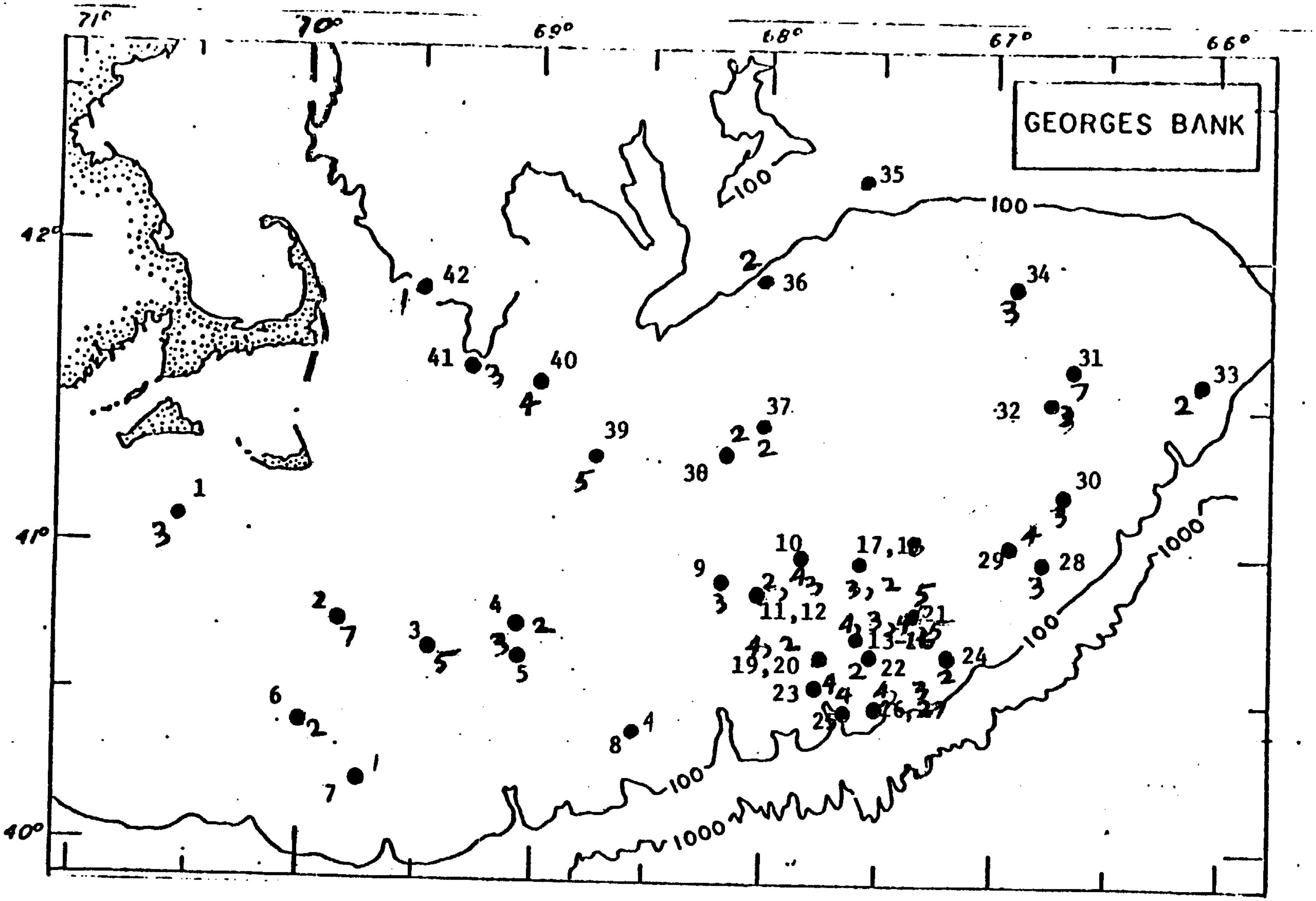
Arthropods (exclusive of amphipods)

During the winter the mean number of arthropod species (exclusive of amphipods) which consisted almost entirely of crustaceans, mean density and biomass ranged from 1 to 7 species, from 10 to $520/m^2$, and from 0.1 to 16.4 g/m^2, respectively (Tables A-9 to A-11). Mean values per station were 3.3 species, $151.9/m^2$, and 1.7 g/m^2.

There was no relationship between mean number of arthropod species and depth (Figure 32). There was a positive association between the mean number of species and percent sand (R = 0.43) and a negative association with silt (R = -0.36) and silt-clay (R = -0.37).

Mean density of arthropods was apparently not related to

Figure 32. Mean number of arthropod species (exclusive of amphipods) for Georges Bank, Winter 1977.



depth (Figure 33). In terms of sediment relations mean density increased with percent sand (R = 0.43) and decreased with fine-grained sediment (silt R = -0.39), silt-clay (R = -0.42), carbon (R = -0.35), nitrogen (R = -0.42), and bacterial biomass (R = -0.57).

Mean biomass of arthropods was not related to depth (Figure 34). Mean biomass of this taxonomic group was negatively associated with percent silt-clay (R = -0.30).

In addition to the four amphipod assemblages tentatively proposed by Michael and Watling (1977), several other crustacean assemblages were recognized. One assemblage was dominated by the tanaid *Leptochelia savignyi* with the isopods *Edotea triloba* and *Chiridotea tuftsi* present as subdominants (Table 18). Large numbers of ostracodes may also be involved. This assemblage occurred at those stations where either a *Byblis serrata* or a haustoriid dominated amphipod assemblage occurred.

The second crustacean assemblage was dominated by the cumacean *Diastylis quadrispinosa* with other cumaceans *Eudorella emarginata* and *Diastylis sculpta* as sub-dominants. At times *D. quadrispinosa* was replaced by *D. sculpta* as the dominant species. This assemblage occurred at stations dominated by *A. agassizi* and the various sub-dominant species mentioned previously (Table 17).

Echinodermata

During the winter the mean number of species, density, and biomass of echinoderms ranged from 0 to 2 species, from 0 to $360/m^{-2}$, and from 0 to 333.9 g/m^2, respectively (Table A-9 to A-11). Mean values per station were 1.1 species, $59.2/m^2$, and 17.4 g/m^2.

Figure 33. Mean density (No./m^{-2}) of arthropod species (exclusive of amphipods) for Georges Bank, Winter 1977.

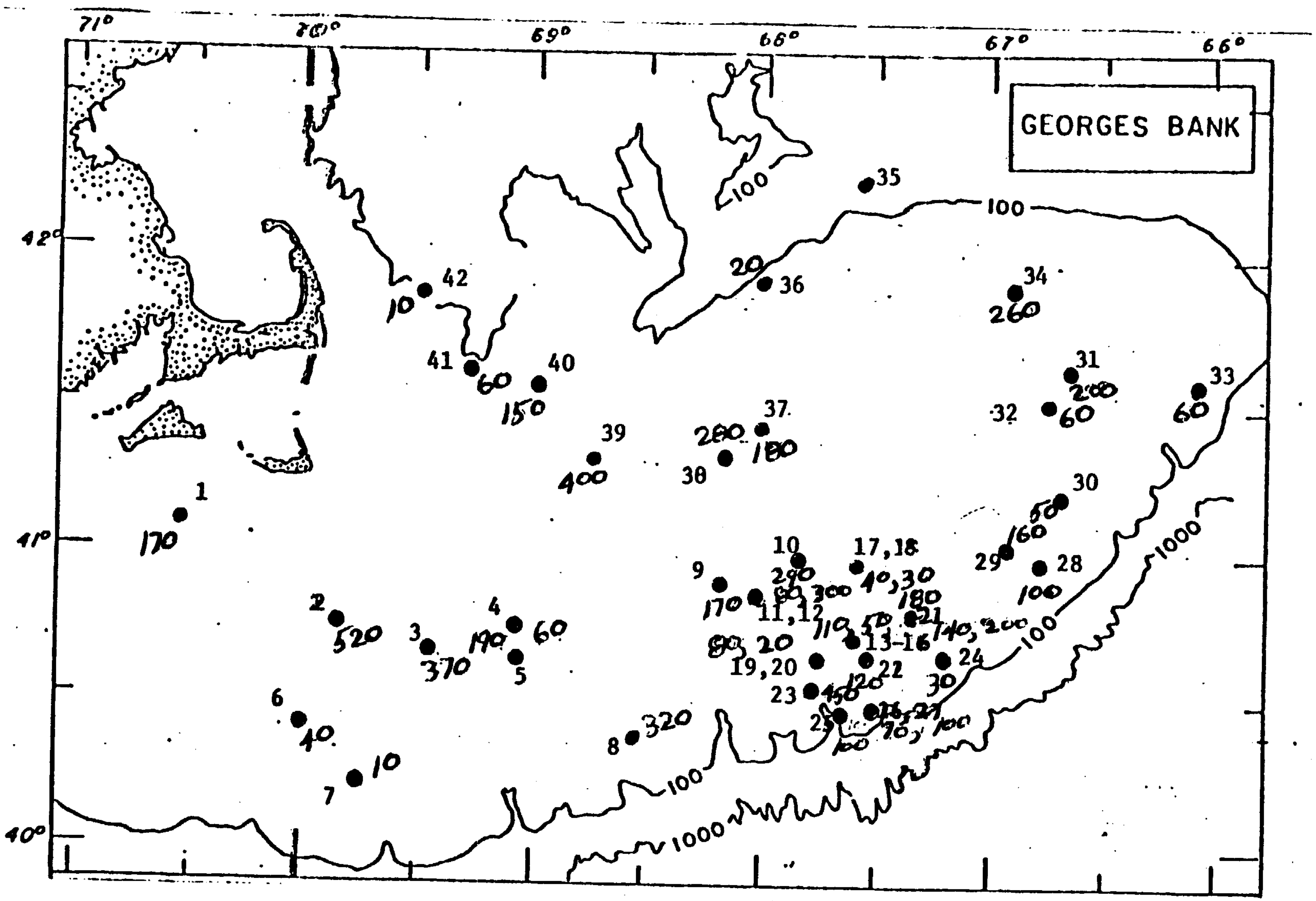


Figure 34. Mean biomass (g/m^2) of arthropod species (exclusive of amphipods) for Georges Bank, Winter 1977.

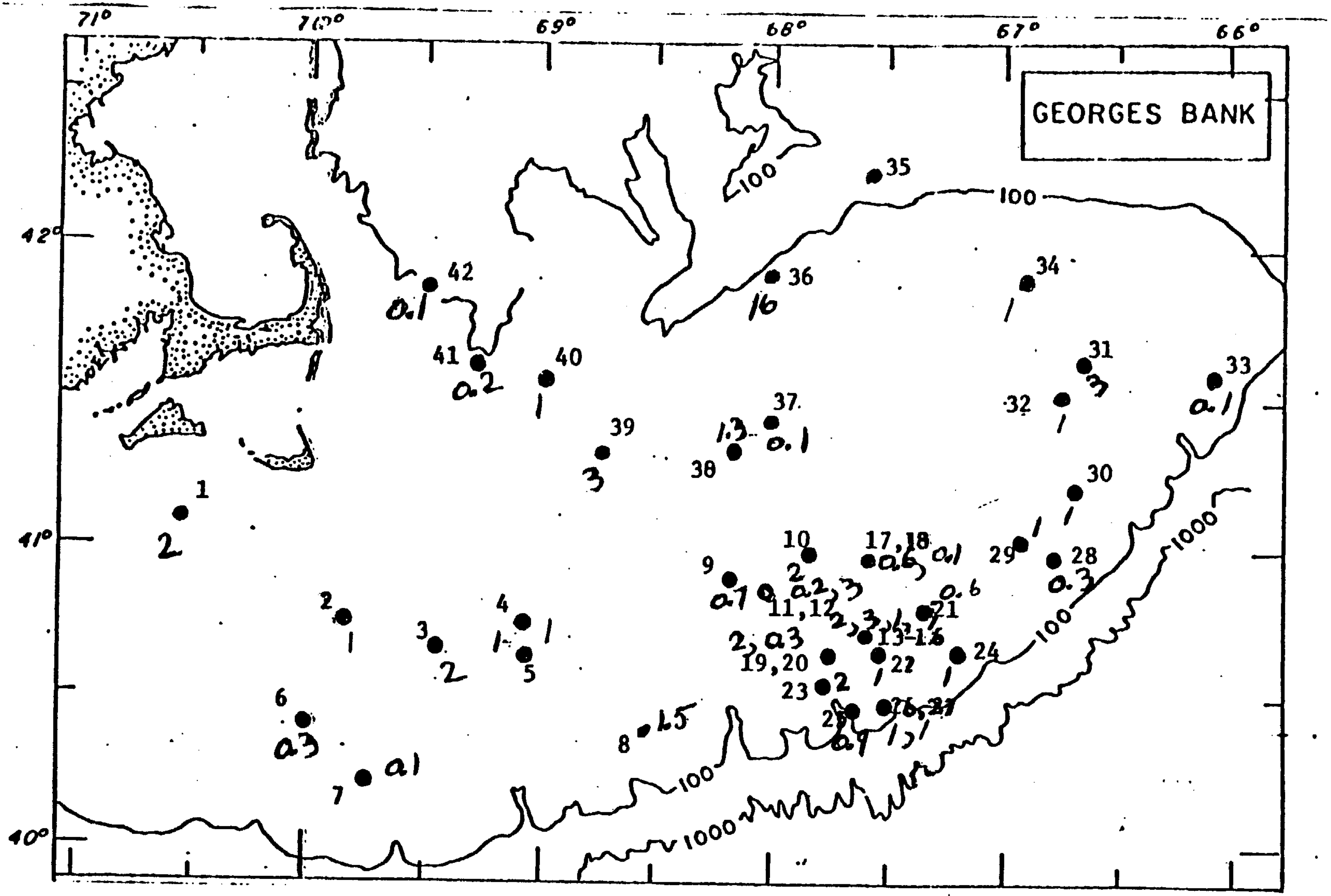


Table 18. Crustacean Assemblages for Georges Bank, Winter 1977
(taken from Michael and Watling, 1977)

Station No.	6-8, 13, 15-16, 21, 25, 28	5, 10, 17	2, 9, 11-12, 33 37-38	39-41
Dominant Crustacea	*Diastylis quadrispinosa*	*Leptochelia savignyi*	*Leptochelia savignyi*	None
Sub-dominant Crustacea	*Eudorella emarginata*	*Edotea triloba*	*Edotea triloba*	———
	Diastylis sculpta	*Chiridotea tuftsi*	*Chiridotea tuftsi*	

There was no apparent relationship between the number of species and depth (Figure 35). The sea stars *Asterias forbesi*, *Astropecten americanus*, *Leptasterias tenera*, the echinoids *Echinarachnius parma* and *Strongylocentrotus droebachiensis*, and ophiuroid brittle stars were important taxa.

Mean density of echinoderms showed no significant relationship with depth (Figure 36). Mean density was negatively associated with dissolved oxygen (R = -0.39). In contrast mean biomass of echinoderms was higher in shallow water than in deeper water (Figure 37). There was a negative association between mean biomass and depth (R = -0.45) and a positive one with dissolved oxygen (R = 0.34). These relationships reflected the fact that although density was relatively regular throughout the depth range, large species (sea stars and echinoids) occurred in relatively shallow water with smaller species (brittle stars) in deeper water.

Meiofauna (Foraminifera)

General

The only members of the meiofauna purposefully collected and analysed from Georges Bank in 1977 were the Foraminifera. Although both live and dead Foraminifera from sediment depths of 1.0, 2.0 and 3.0 cm were analysed together with counts of planktonic forams, Foraminifera distributions were based on counts of live animals from a depth of 1.0 cm (NEOEB III, 1978). During the course of the study 107 species were recognized consisting of 85 calcareous forams and 22 arenaceous forams (Table A-12). Forty-nine species were recorded for winter,

Figure 35. Mean number of echinoderm species for Georges Bank, Winter 1977.

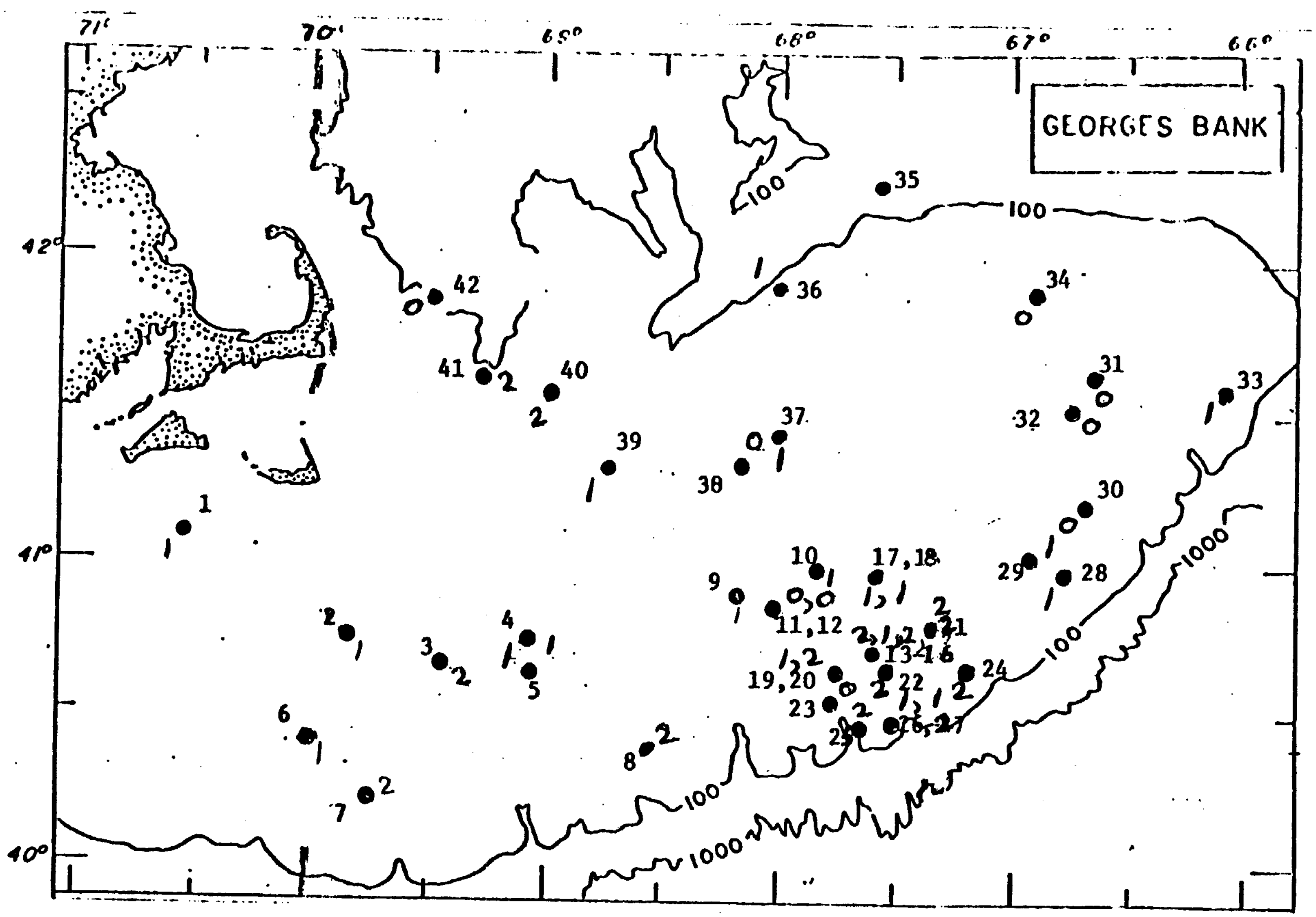


Figure 36. Mean density (No./m^{-2}) of echinoderms for Georges Bank, Winter 1977.

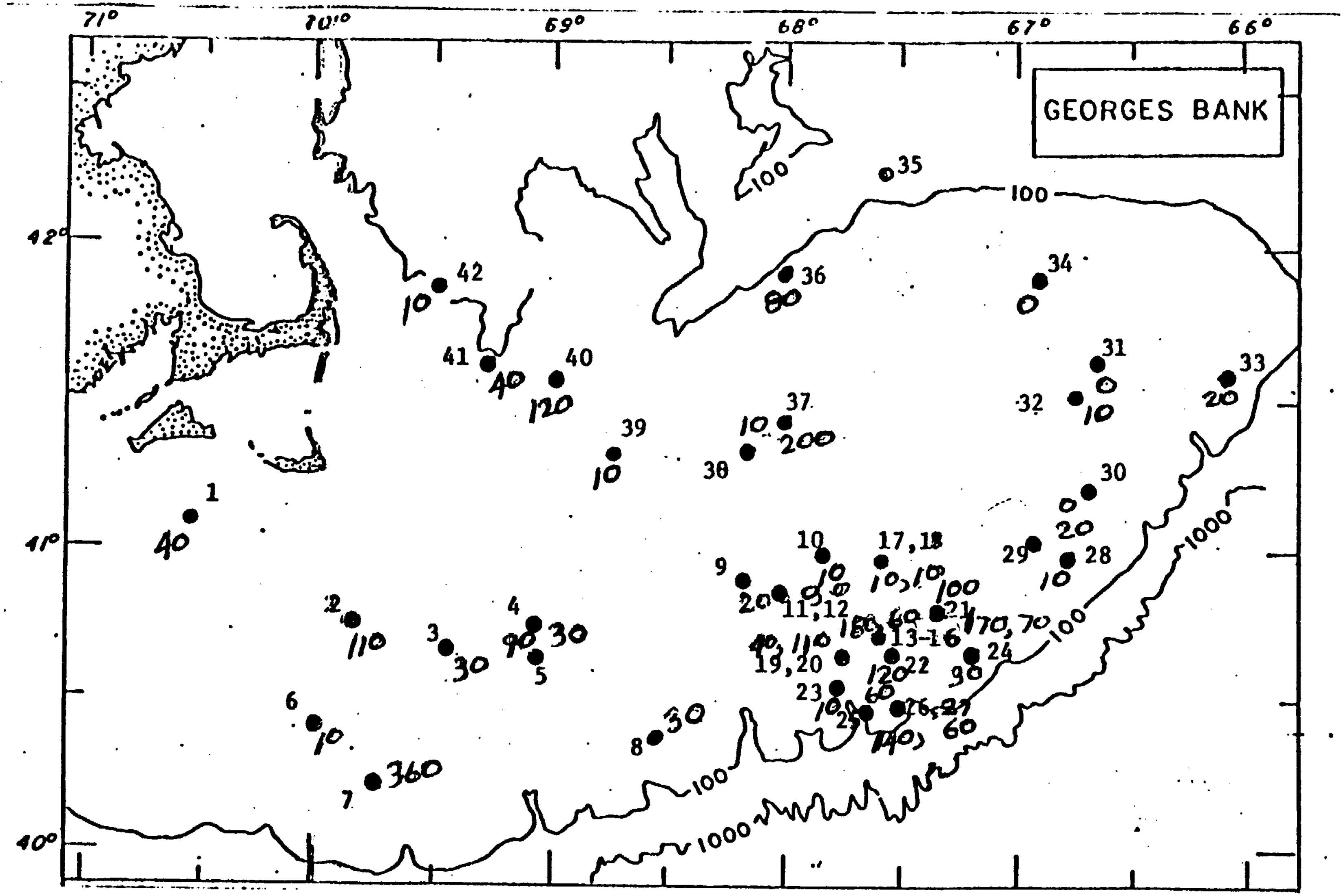
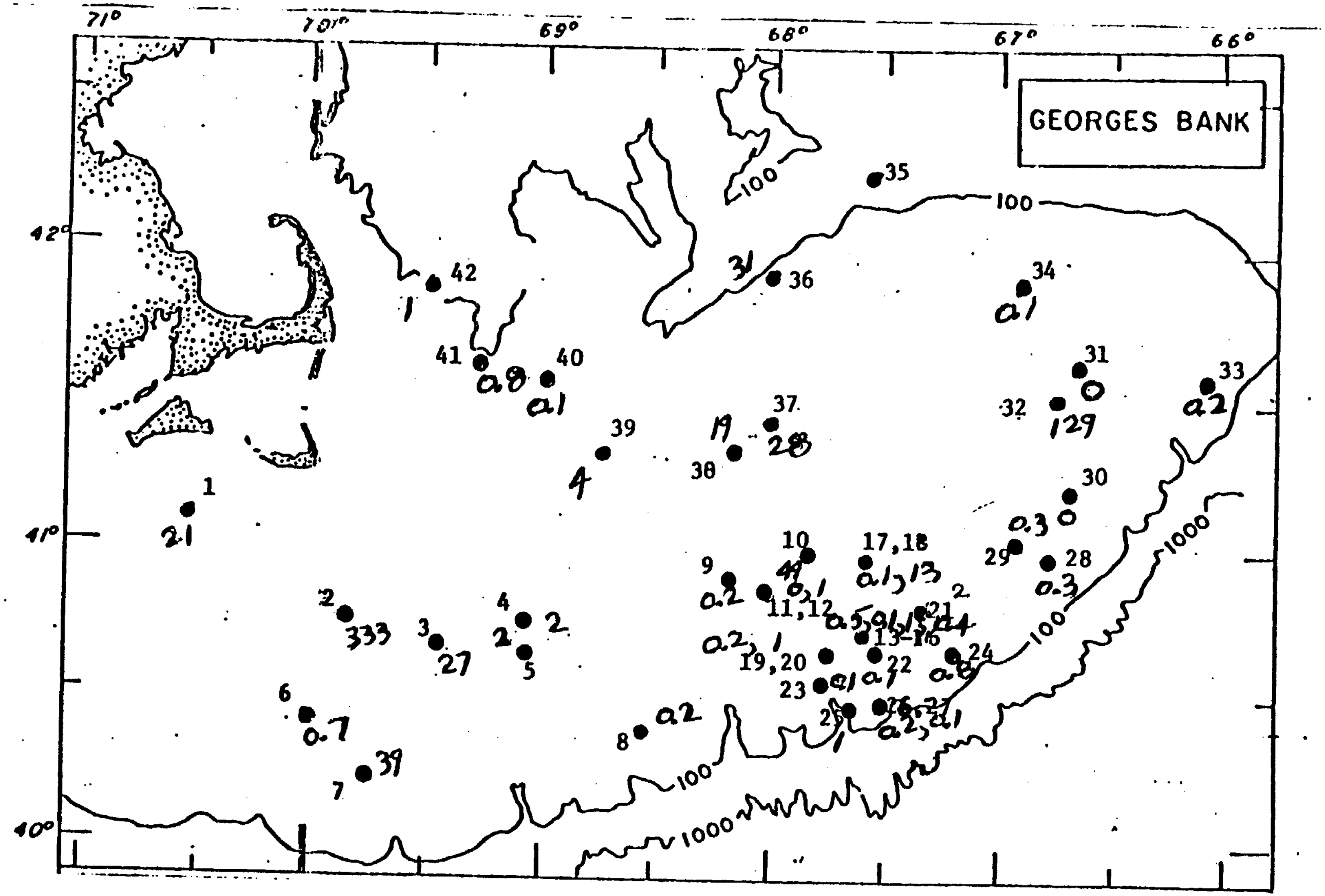


Figure 37. Mean biomass (g/m^2) of echinoderms for Georges Bank, Winter 1977.



spring and summer and 38 for one season alone.

The number of calcareous and arenaceous species was relatively stable between seasons. For calcareous forams in winter, spring and summer there were 63, 56 and 58 species, respectively. For the same seasons the number of arenaceous forams was 19, 15 and 15.

Seasonal

Winter

The mean number of species and density (No.10 cm ^{3}) of live Foraminifera in the winter ranged from 1 to 25 species and from 1 to 355/10 cm ^{3} (NEOEB III, 1978). Mean number and density per station in the winter was 12.4 and 111.8/10 cm ^{3} respectively. During the winter the number of species and density of forams was lower in the central portion of Georges Bank compared to the peripheral deeper water areas (Figure 38-39). There was a positive significant (α 0.05) association between the number of species (R = 0.54) and density (R = 0.34) with increasing depth. In addition there was a negative significant association between the number of species and density with dissolved oxygen (R = -0.51, -0.37) and percent sand (R = -0.31, -0.31). The number of species also increased with percent carbon (R = .36) in the sediment.

Diversity as measured by Simpson's Index, Shannon-Weaver Index and species richness reflected patterns of density and number of species (NEOEB III, 1978).

Cibicides lobatulus, Elphidium clavatum, Elphidium subarcticum and Trifarina angulosa occurred frequently and

Figure 38. Number of species of live Foraminifera (1.0 cm) for Georges Bank, Winter 1977.

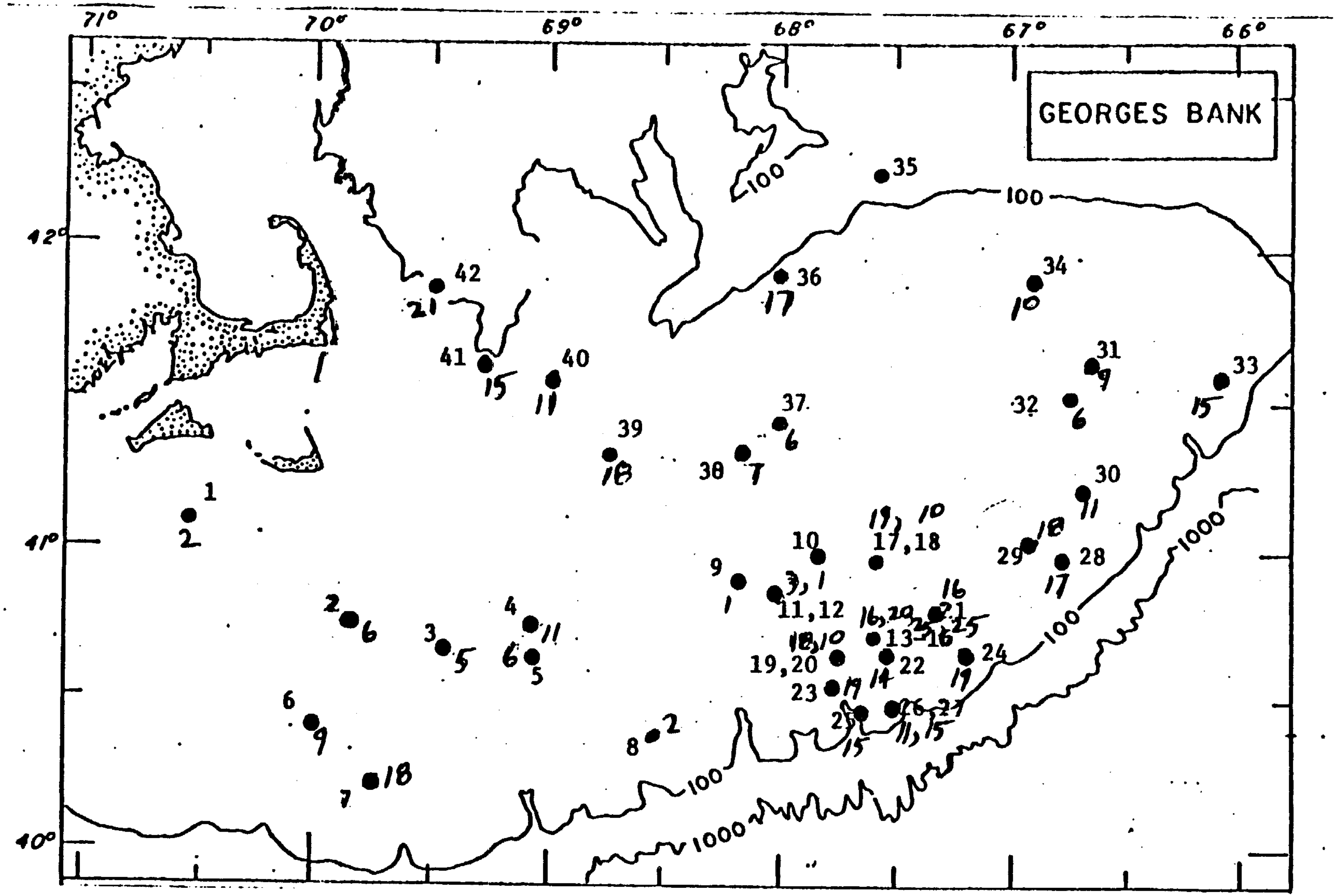
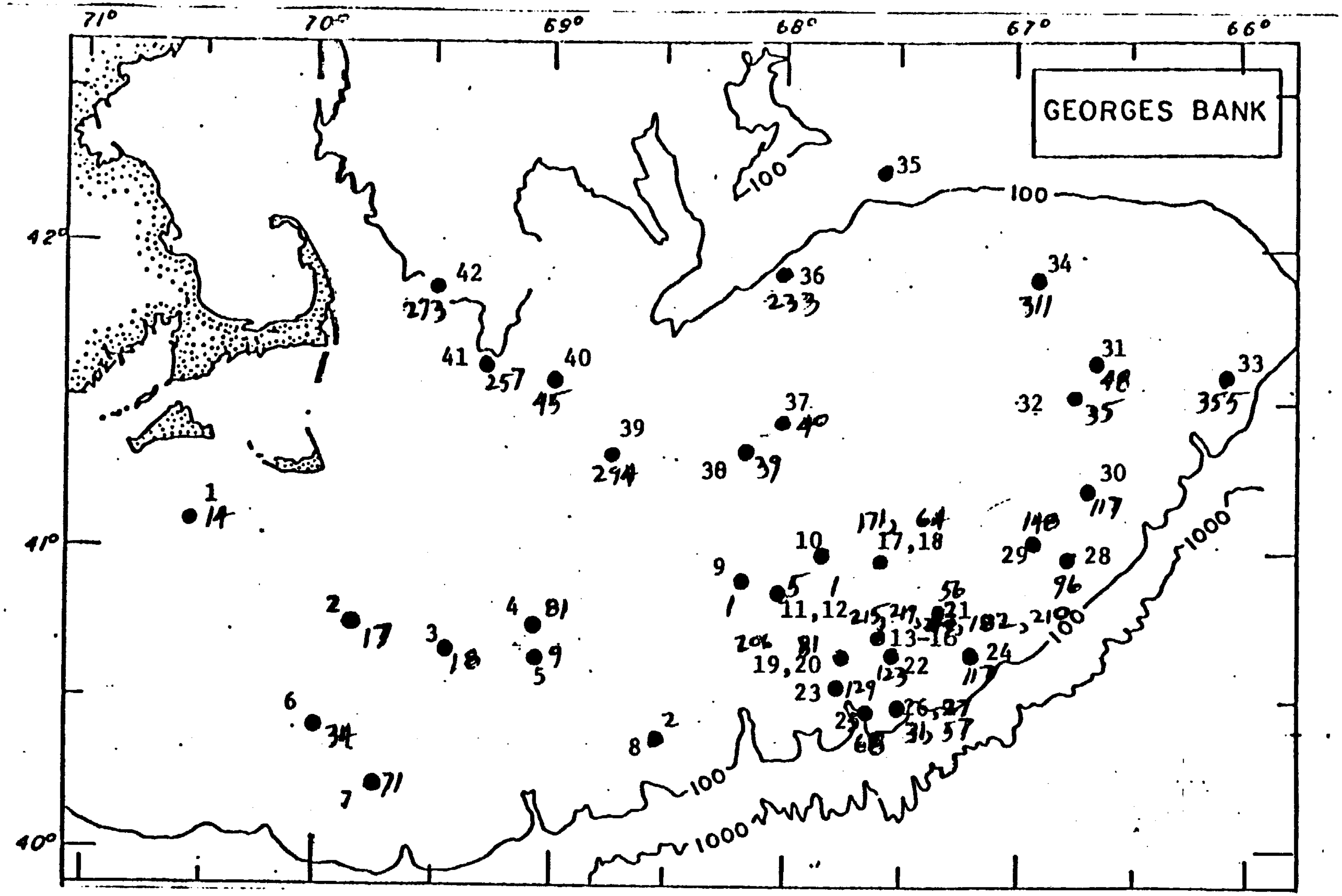


Figure 39. Density (No./10 cm^{-3}) of live Foraminifera (1.0 cm) for Georges Bank, Winter 1977.



abundantly along the southern edge of the bank. At deeper stations (7 and 8) on the southern slope Bulimina marginata was dominant. The central portion of Georges Bank was characterized by arenaceous forams comprising Eggerella advena, Saccammina atlantica and Adercothyma glomeratum. The area around stations 41 and 42 contained many Bulimina aculeata and S. atlantica and Station 1 supported the latter species together with populations of E. clavatum (NEOEB III, 1978).

Spring

The mean number and density of live Foraminifera in the spring ranged from 2 to 21 species and from 2 to 195/10 cm^{-3}. Mean number and density per station in the spring was 12.6 and 87.2/10 km^{-3}, respectively. During the spring the number of species and density of forams in the central portion of the bank appeared to be lower compared to the peripheral deeper water areas (Figure 40-41). There was a significant positive association between the number of species ($R = 0.43$) with increasing depth. Moreover, there was a significant increase in the number of live foram species with percent silt-clay ($R = 0.31$), silt ($R = 0.31$), carbon ($R = 0.37$), nitrogen ($R = 0.32$) and bacterial biomass ($R = 0.46$).

Foraminifera distributions for spring were generally similar to patterns recorded for winter in particular the southern margin. This area, including Stations 2 through 21, was characterized by C. lobatulus, E. clavatum and S. atlantica. The far eastern portion of the bank station 28-34 was dominated by E. subarcticum, C. lobatulus and T. angulosa. The central

Figure 40. Number of species of live Foraminifera (1.0 cm) for Georges Bank, Spring 1977.

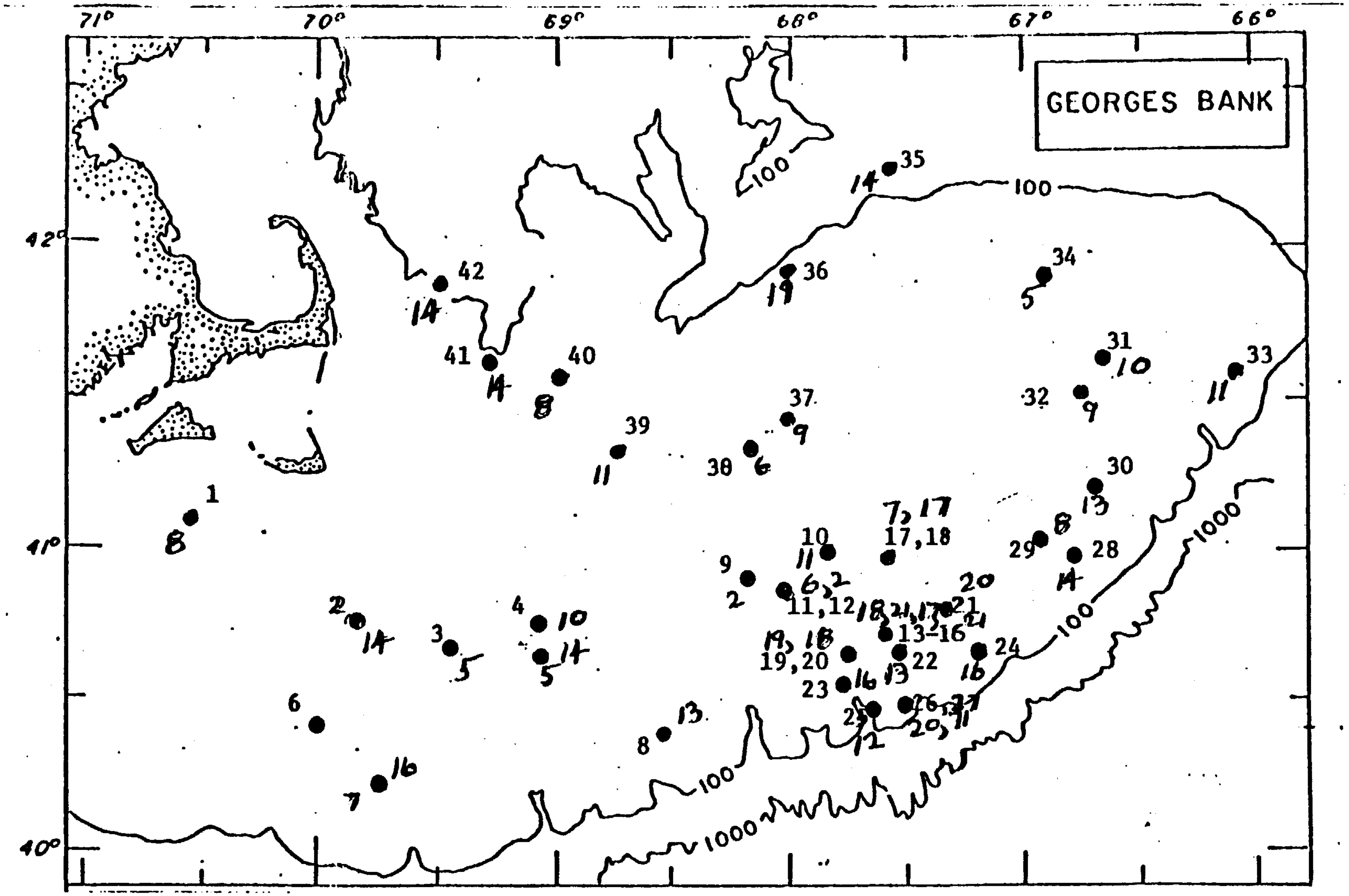
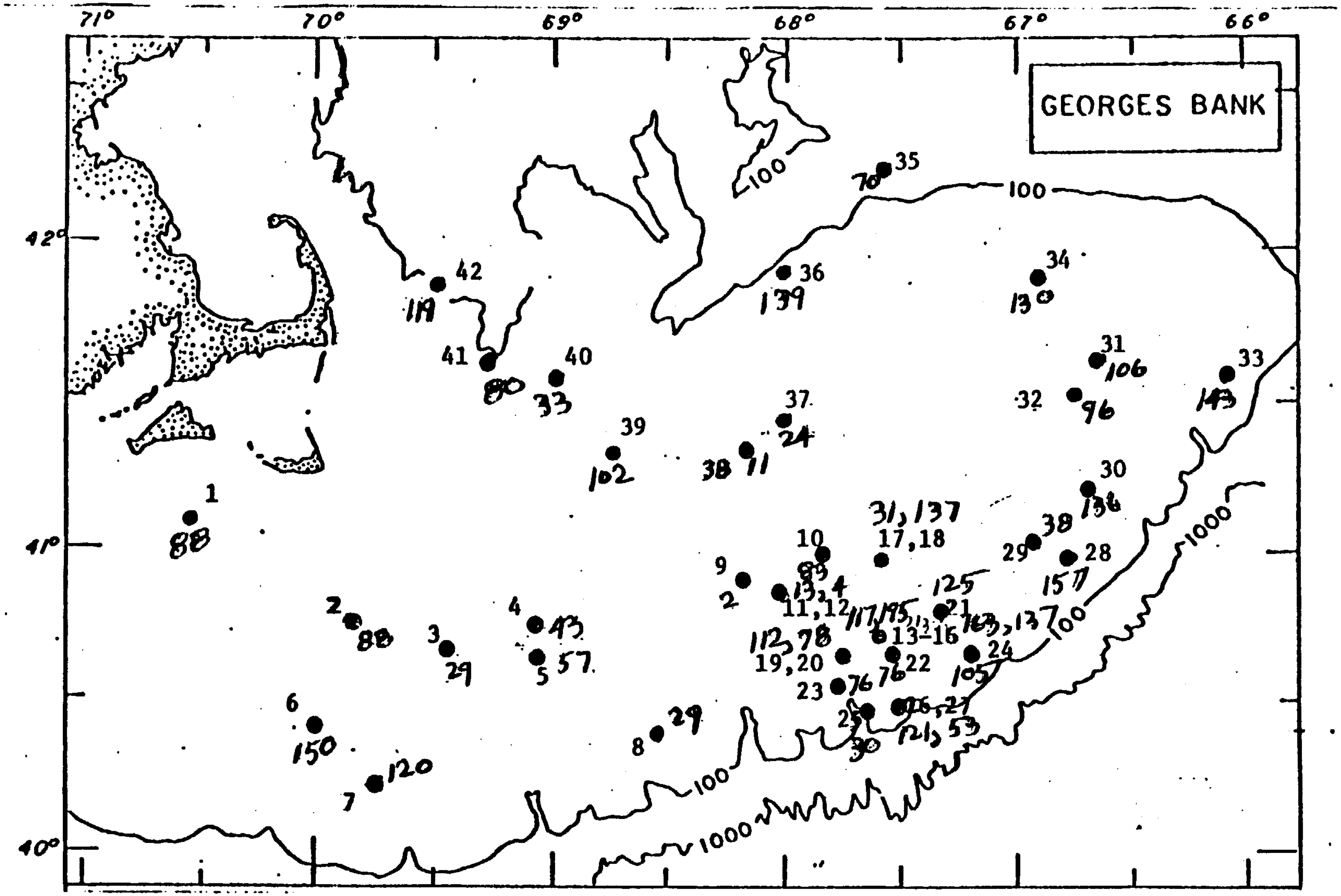


Figure 41. Density (No./10 cm^{-3}) of live Foraminifera (1.0 cm) for Georges Bank, Spring 1977.



Bank contained Rosalina columbiensis and the northern area (stations 35, 40, 41, 42) contained a mixture of those previously mentioned together with Bolivina subaenariensis, Globulimina auriculata, and Cassidulina norcrossi (NEOEB III, 1978).

Summer

The mean number and density of live Foraminifera in the summer ranged from 2 to 27 species and from 2 to 340/cm^{-3}. Mean number and density of live Foraminifera per station in the summer was 14.3 and 113.9/10 cm^{-3}, respectively. The mean number of species and density were compared between seasons. The mean number of species was significantly higher in summer than in winter ($t = 3.22$, $\alpha < 0.05$) and in spring ($t = 3.17$). The mean density in summer was significantly higher than in spring ($t = 15.2$) which was significantly lower than in winter ($t = 12.9$).

During the summer the number of species and density of forams showed no particular relationship with depth (Figure 42-43). However, there was a significant negative association between the number of species and dissolved oxygen ($R = -0.41$) and a positive association with median sediment size ($R = 0.36$). Both the number of species and density were significantly associated with microbial biomass ($R = 0.48$, 0.37) and bacterial biomass ($R = 0.59$, 0.50). The pattern of diversity was generally consistent throughout the three sampling periods (NEOEB III, 1978).

Figure 42. Number of species of live Foraminifera (1.0 cm) for Georges Bank, Summer 1977.

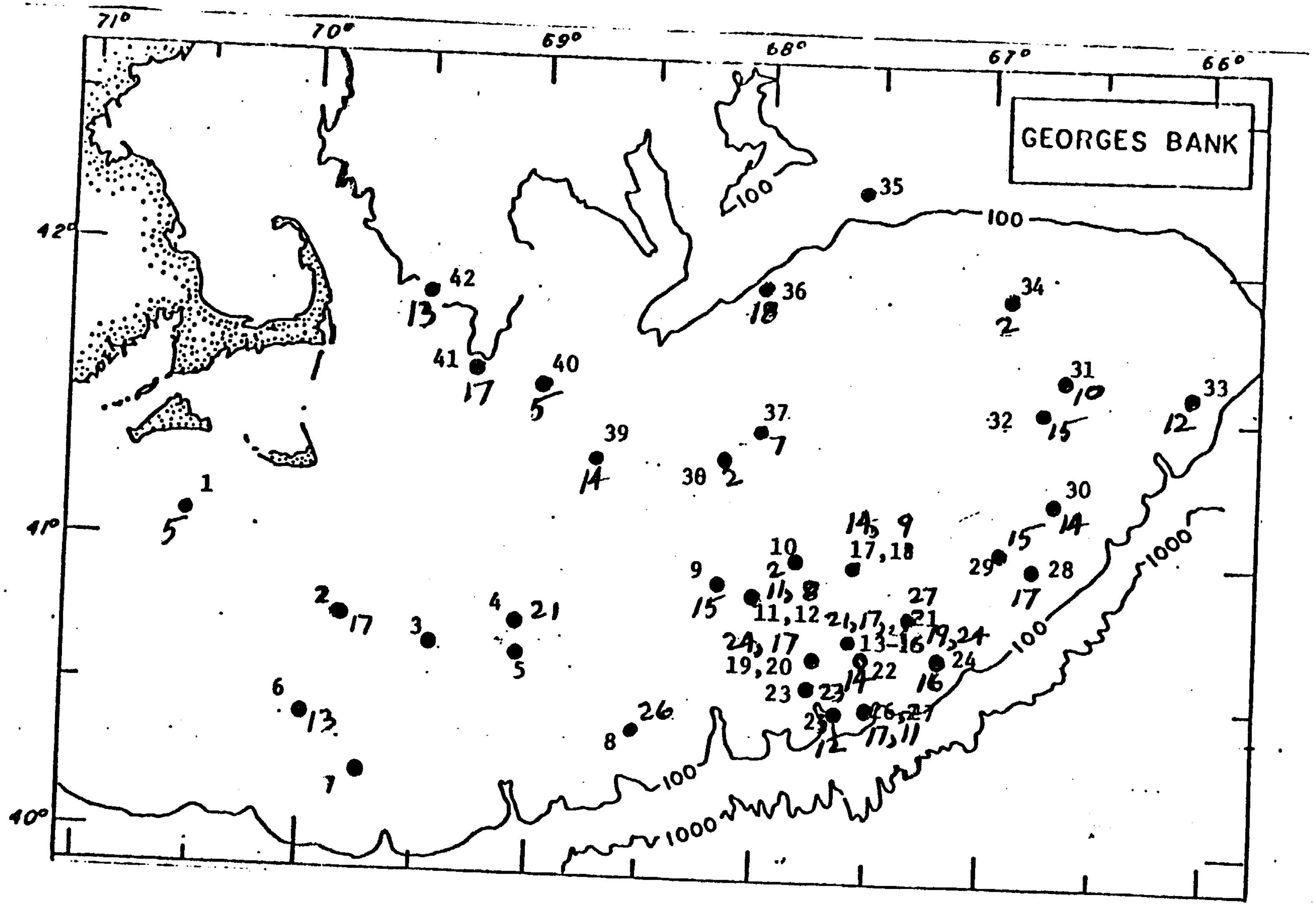
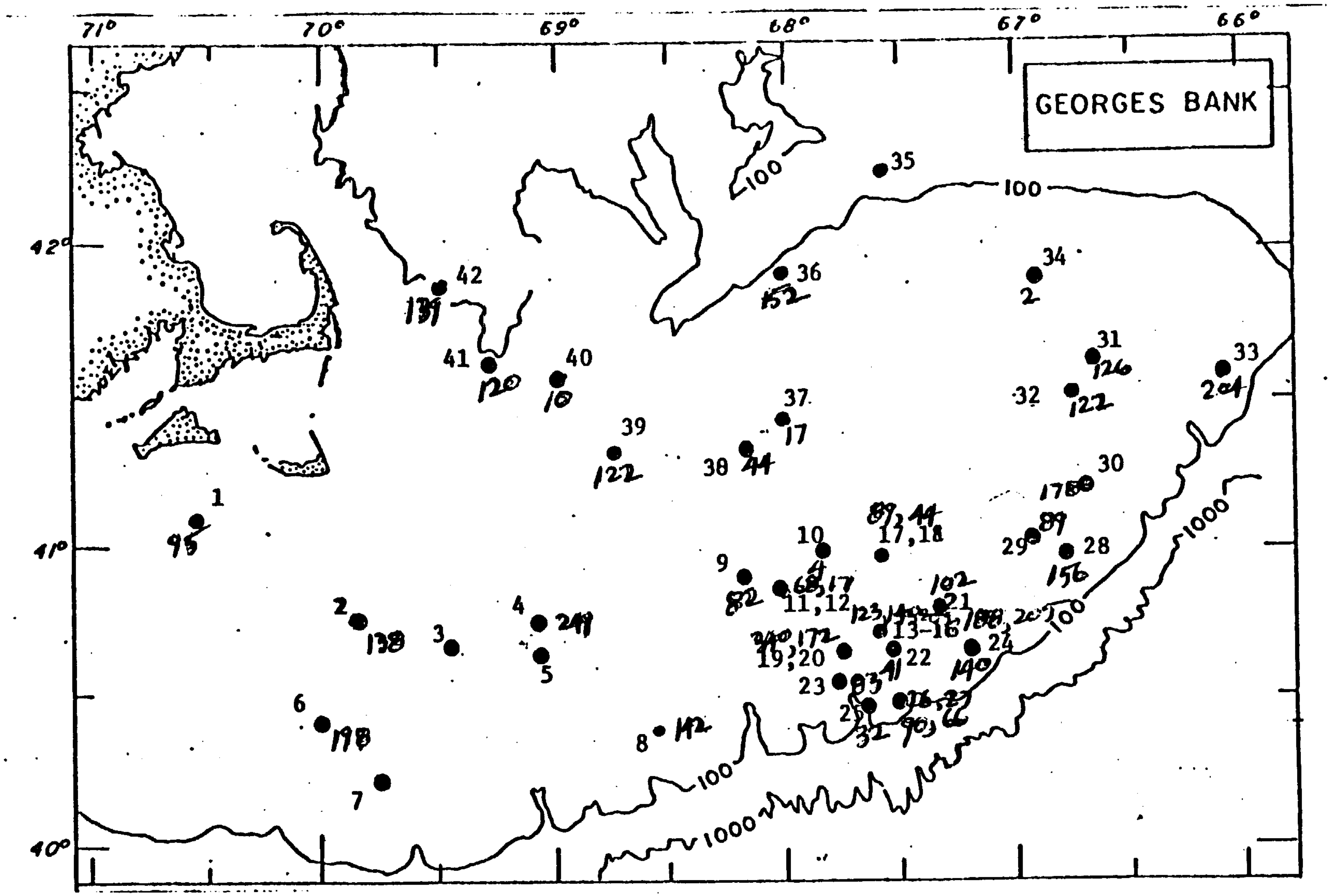


Figure 43. Density (No./10 cm^{-3}) of live Foraminifera (1.0 cm) for Georges Bank, Summer 1977



The distribution of summer Foraminifera was generally similar to previous periods. Station 1 contained abundant S. atlantica and E. advena. The southern margin was characterized by E. clavatum, S. atlantica, C. lobatulus and T. angulosa. The central area was again dominated by R. columbiensis and the north again by S. atlantica and G. auriculata.

According to these data (NEOEB III, 1978) the number of species and density of live Foraminifera in the top 1.0 cm of sediment was highest in the summer. However, seasonal fluctuations of forams were modest and not marked by extreme maxima or minima. In fact dominant species occurred in the same areas and were persistent throughout winter, spring and summer.

Seabed Respiration

General

During March and July 1977 cruises were made to Georges Bank to measure seabed respiration, rates of primary production and total plankton (Thomas, O'Reilly, Robertson and Phoel, 1978). Oxygen consumption rates principally included the respiration of micro- and meiofauna and flora and rarely macrofauna. Seabed respiration rates ranged from 0.04 to 0.11 $gCm^{-2}d^{-1}$ in March and 0.02 to 0.32 $gCm^{-2}d^{-1}$ in July. Data for March were sparse but data for July were more complete (Figure 44). During March the highest rates were recorded on the southern margin of the Bank. In July the highest rates were centered over the Bank and in the Great South Channel.

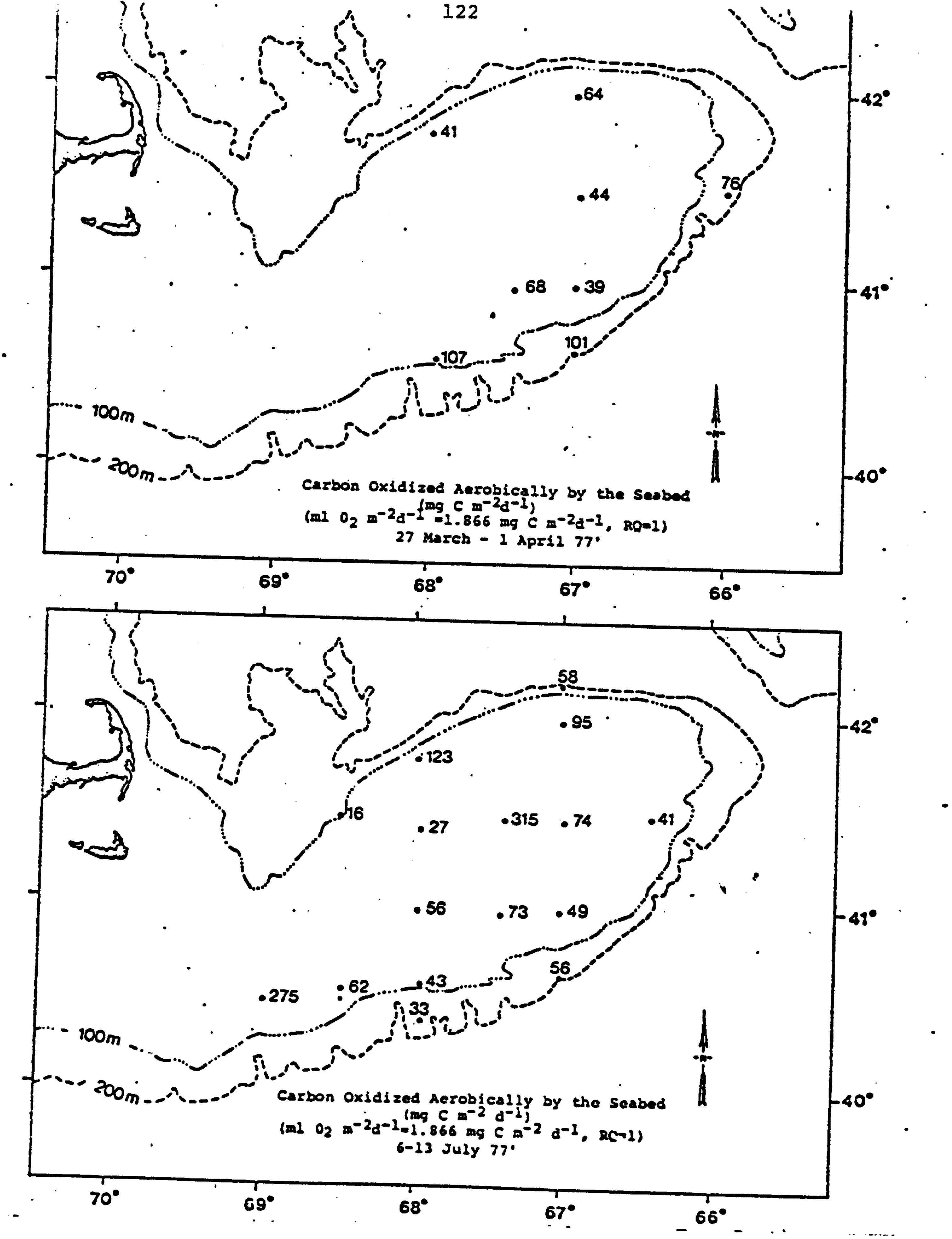


Figure 44. Seabed oxygen consumption rates (expressed as equilavent carbon) for Georges Bank, March 27-April 1, 1977 and July 6-13, 1977.

Total Respiration - Seabed and Total Plankton Components

At stations where concurrent measurements of total plankton and seabed respiration were made the two were added together to provide a total respiration value for the entire water column including the seabed (Thomas et al., 1978). Between 82% and 99% of the total respiration at individual stations was attributable to total plankton respiration. In March, the seabed contribution was highly variable (0.7 to 17.5%) and averaged 6.9% (Figure 45). In July the seabed contribution was less variable (0.7 to 6.5%) and averaged 2.5%. It was concluded that in most cases that the seabed made a relatively minor contribution to the total aerobic respiration of an entire water column including the seabed.

Total phytoplankton primary productivity to total respiration ratios (P/R) were calculated (Thomas et al, 1978). P/R ratios were considerably higher in March ($\overline{x}$ = 1.1) than in July ($\overline{x}$ = 0.6). In addition, P/R ratios over the Bank were higher than those measured on the periphery (>100 m) in both March and June (Figure 46). It was suggested that the Bank functions autotrophically in the spring, producing excess organic matter which is available to higher trophic levels of both grazing and detrital food webs of pelagic and benthic communities. In contrast the Bank functions heterotrophically in the summer, consuming and oxidizing more organic matter than it produces by way of primary productivity.

These seabed measurements were the very first for Georges Bank and as such represent an important portion of the analysis in assessing the quantity of organic matter that is available to

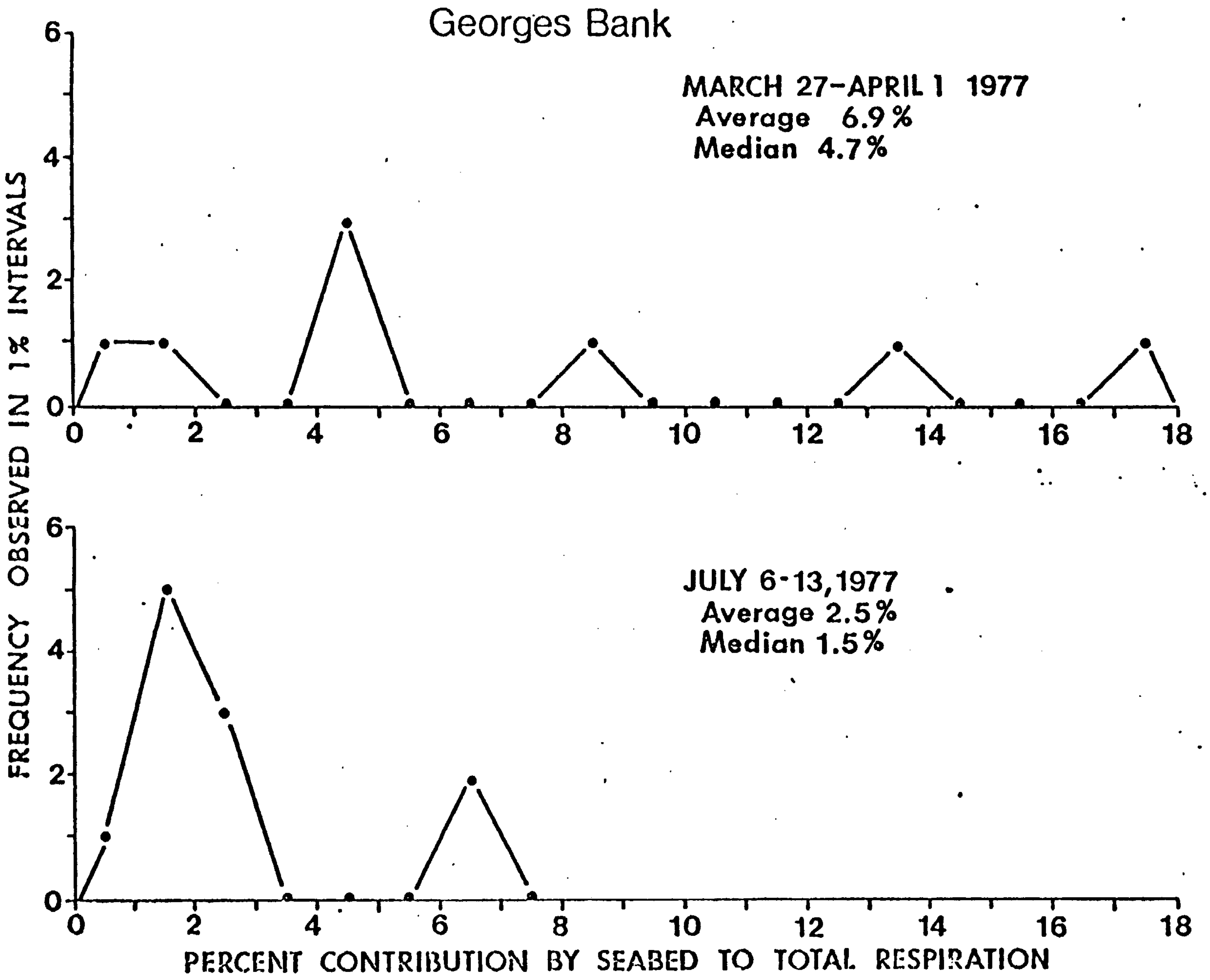


Figure 45. The frequency of occurrence in 1% intervals of the percent contribution made by the seabed to total respiration. (taken from Thomas et al., 1978)

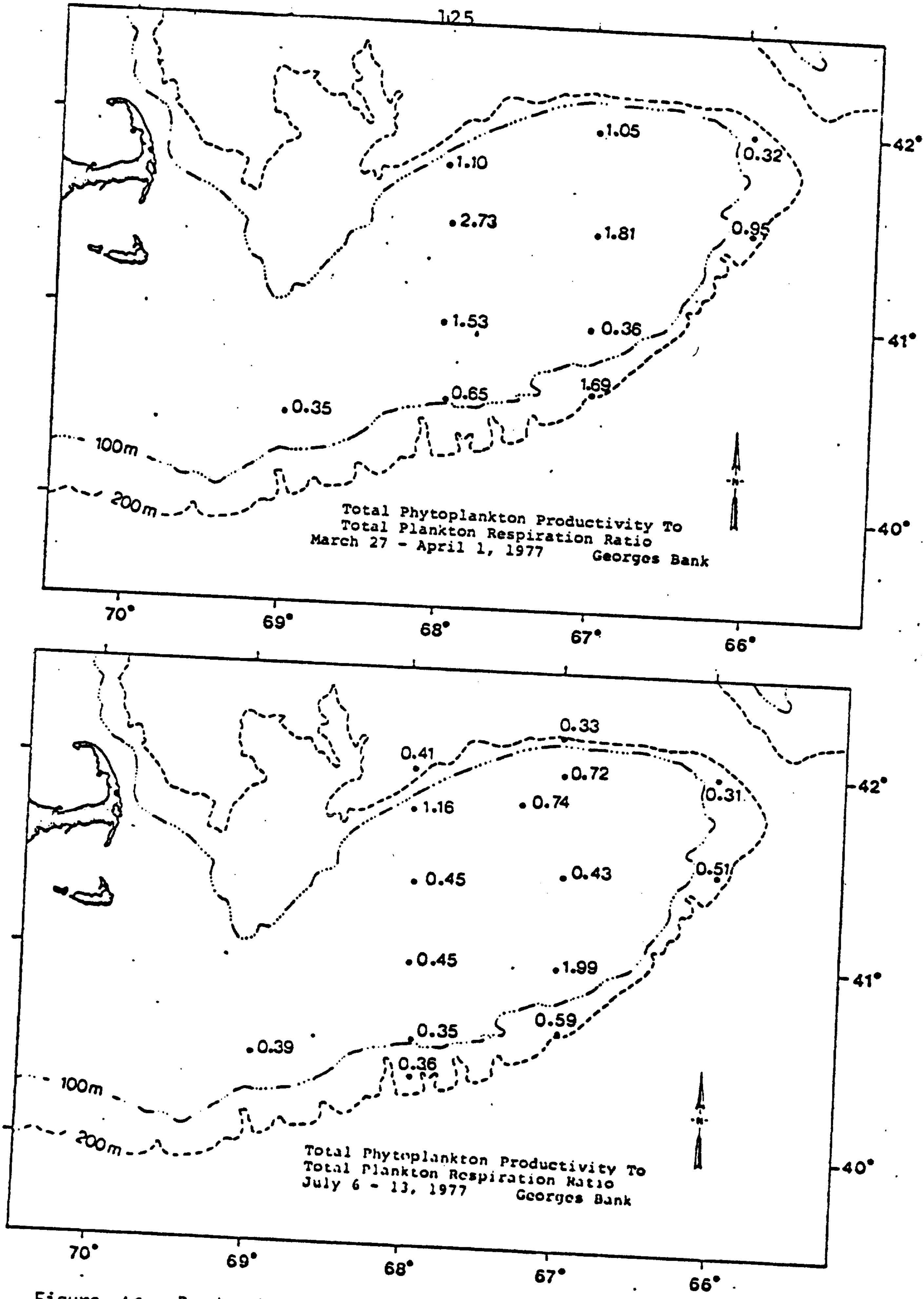


Figure 46. Productivity/respiration ratios (P/R) for Georges Bank March 27-April 1, 1977 and July 6-13, 1977.

higher trophic levels. These measurements should be continued seasonally and should include selected habitats with known dominant macrofauna populations.

Energy Budget

Benthic

An energy budget of Georges Bank biota was prepared by Cohen, Grosslein, Sissenwine and Steimle (1979). Although the budget identified major components and values of energy flow (Figure 47), emphasis here will be placed on the benthic component. Data on estimated productivity of north-western Atlantic invertebrates are so negligible that estimates of secondary production were based on production-biomass (P/B) rations. An estimate of benthic macrofaunal biomass on Georges Bank (240 g wet weight/m^2) was provided by Wigley (personal communication). This value is very close to one computed by Maurer and Wigley (1981) yielding 245 g/m^2 off Martha's Vineyard and Nantucket Shoals. This value (240 g/m^2) was converted into k cal/m^2. The result was 120 k cal/m^2/yr. P/B ratios from the literature were then used to calculate yearly productivity from biomass data. Assuming dominance of relatively low production molluscs and echinoderms on Georges Bank a P/B ration of 1.5 was used (Cohen et al, 1979). An estimate of macrobenthic productivity of 180 k cal/m^2/yr was calculated. Values of 35 K cal/m^2/yr. were computed for the Scotian shelf (Mills, 1980) and values of 20-50 k cal/m^2/yr for the North Sea (Steele, 1974) to provide some basis for comparison with Georges Bank. These values indicate considerable differences in secondary production between Georges Bank and the other two areas but some differences may be

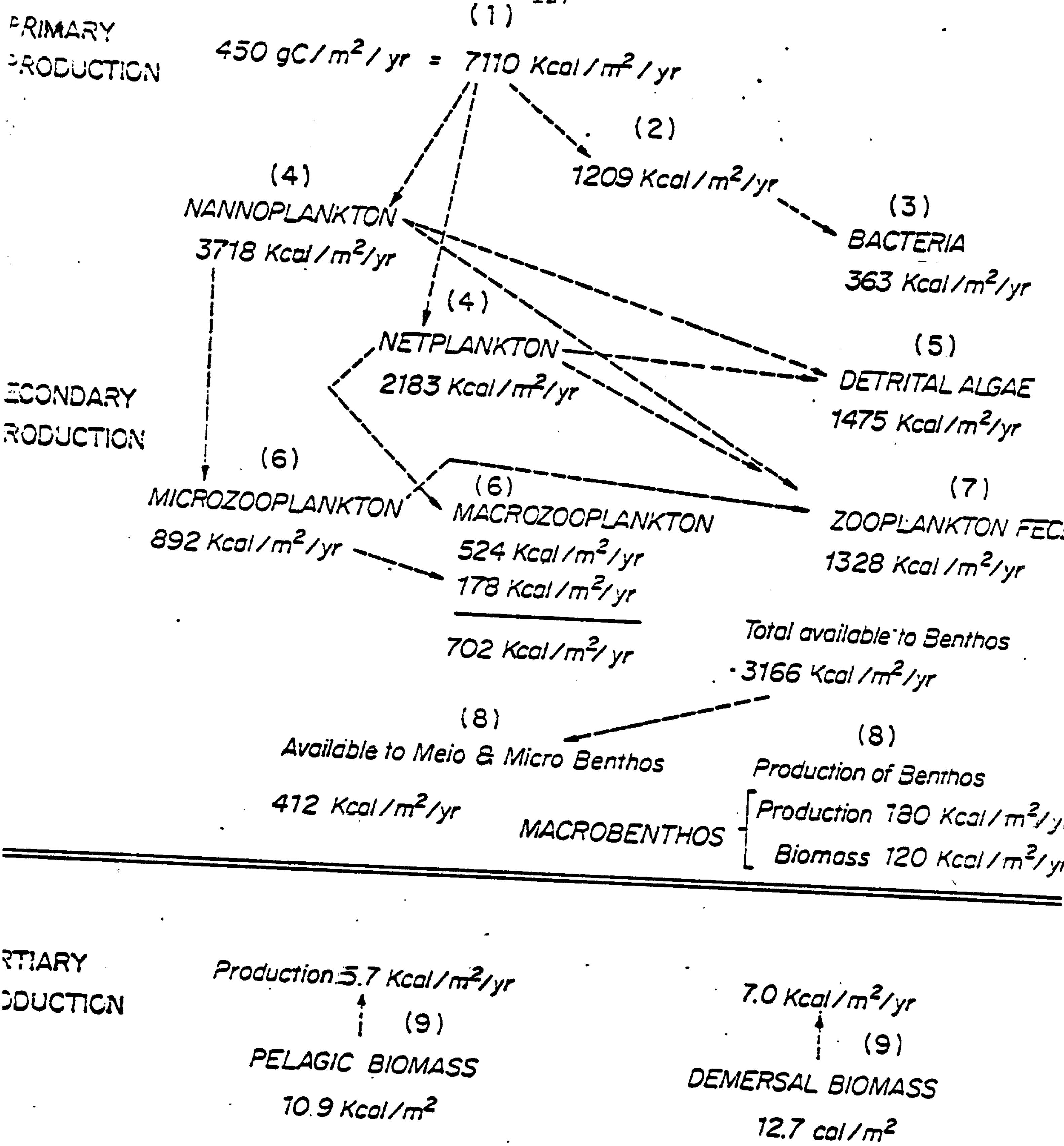


Figure 47. Energy budget for Georges Bank. Energy flow between trophic levels is linked by arrows, but the direction of the arrow represents the logical derivation of the values given, not the direction of energy flow which is always downward. (taken from Cohen et al., 1979).

partly explained by different assumptions for P/B ratios.

A similar procedure was used to estimate meiofaunal productivity. Meiofaunal biomass averaged 2.5 g/m^2 off Martha's Vineyard and Nantucket Shoals (Wigley and McIntyre, 1964). This was converted and an estimate of 1.25 k cal/m^2 was calculated (Cohen et al, 1979). Based on meiofaunal P/B ratios between 5:1 to 12:1, estimates of annual production ranged between 6.25 to 15 k cal/m^2/yr. According to these calculations meiofauna contributed only about 10% of the total benthic productivity on Georges Bank. This was much less than the reported contribution of meiofauna elsewhere in the North Atlantic (Cohen et al., 1979). The dominance of molluscs and echinoderms in terms of biomass on Georges Bank may reduce the energy available to meiobenthos as compared to the North Sea (Steele, 1974) and Scotian Shelf (Mills, 1980), but even so estimates of Georges Bank meiofauna biomass seemed low.

Since the above energy budget was computed, analysis of additional benthic samples has revealed that new data should probably be considered for inclusion in future estimates of the budget. Assuming that the P/B ratio method is applied, using production figures from molluscs and echinoderms (P/B = 1.5), then a mean value of 305 g wet weight/m^2 should be used rather than 240 g/m^2 value. The higher value was obtained from 42 winter stations throughout the Bank (Michael, 1977). Even if the higher value is used to compute secondary production of benthos, it would probably yield conservative estimates because there is evidence to believe that mean biomass is significantly higher in summer and early fall than in winter.

Regardless, the 305 g/m^2 estimate is probably a more accurate estimate than the 240 g/m^2 and this figure is recommended for future estimates until summer and fall values are obtained.

It deserves mentioning that recent study with smaller sieve sizes showed that smaller taxa (polychaetes and amphipods) were extremely diverse, ubiquitous and abundant on the Bank (Michael, 1977; Maurer and Leathem, 1980a). Although these taxa provide relatively small amounts of standing crop compared to molluscs and echinoderms on the Bank, their densities, turnover rates, frequency of occurrence, and caloric values are higher than those of molluscs and echinoderms. Future research investigations involving energy budgets should probably include studies of selected suites of dominant invertebrates involving polychaetes, amphipods and smaller molluscs and echinoderms rather than relying solely on P/B ratios highly influenced by lower production rates of large molluscs and echinoderms. Emphasis on secondary production of amphipods and polychaetes may significantly change our perception of benthic production on the bank.

Based on earlier work by Wigley (1956, 1961b) and more recent work (Michael, 1977; Dickinson and Wigley, 1981; Maurer and Leathem, 1980a), density and standing crop on the bank were not evenly distributed throughout the area. There were definite portions that contained high and low population estimates. The recognition of these areal patterns should probably be considered in future generations of benthic energy budgets. These areal patterns of benthic production also assume additional importance in light of management implications.

There is solid evidence to support the contention that benthic production on Georges Bank exceeds that on the Scotian Shelf (Mills and Fournier, 1979; Mills, 1980) and the North Sea (Steele, 1974).

Relationship between Benthic Invertebrates and Demersal Fish

General

For over 300 years, fishing has been a major industry off the coastal New England states (Wigley, 1961b). The base of this industry is the demersal or bottom-dwelling group of fishes termed groundfish which includes such species as cod, haddock, several hakes and flounders. Investigations on the feeding of groundfish have been a major topic of research since the beginning of fishery research as a scientific discipline (Clepper, 1979; Langton and Bowman, 1980a). The food habits group of the National Marine Fisheries Service, Northeast Fisheries Center, together with participating nations from the International Commission for the Northwest Atlantic Fisheries (ICNAF) have played the major role in these investigations. According to these studies, benthic invertebrates are the principal prey of Middle-Atlantic groundfish, including those on Georges Bank (Edwards, 1976). The purpose of this section is to briefly review these studies to establish the ecological significance of the relationship between benthic invertebrates and demersal fish.

Review

Bigelow and Schroeder (1953) cited early studies on food habits of fish from the Gulf of Maine and surrounding area. However, food studies of Georges Bank fish received direction and scope with Wigley's (1956) study of haddock. In this study, Wigley identified index organisms which defined three food-type areas: Georges Basin, Northeast Peak and the Southeast part. Research on haddock continued with the work of Wigley and Theroux (1965) which featured monthly collections. This research demonstrated distinct seasonal changes in diet composition for haddock. Coincidental with this effort Wigley (1961b) defined certain benthic faunal types for Georges Bank and outlined (Wigley, 1965) the relationship between groundfish and benthic invertebrate density and biomass.

Considerable recent effort has gone into the annunciation and quantitative enumeration of fish prey through thousands of collections and analyses of stomach contents (Bowman, 1977; Maurer and Bowman, 1975; Meyer, Cooper and Langton, 1979; Langton and Bowman, 1980a,b). These studies, together with Wigley's earlier work, provide the bulk of the descriptive data demonstrating the relationship between Georges Bank demersal fish and the benthos as prey. In addition, more recent studies have been concerned with prey selection, estimation of daily rations, and variability of stomach contents of fish (Durbin, Durbin, Langton, Bowman and Grosslein, 1980; Hahm and Langton, 1980; Pennington, Bowman and Langton, 1980). Many of these studies were summarized in terms of management implications for continental shelf fishes (Edwards and Bowman, 1979; Grosslein, Brown and Hennemuth, 1979).

Case Studies

Pleuronectiform fishes

Although there is an extensive data base documenting benthos as prey, several examples of these studies are offered to provide some impression of the type and scope of data. Langton and Bowman (1980b) presented a detailed account of food habits of eight species of pleuronectiform fishes from five geographic areas of the northwest Atlantic. Their data were modified, collated and summarized for Georges Bank only (Table 19). Data dealing with % of unidentified animal remains, sand and rock, and pisces, were excluded from the present discussion.

In general, polychaetous annelids and crustaceans were the most important invertebrate prey for these pleuronectiforms (Table 19). Amphipods, mysidaceans, pandalids and crangonids were the dominant foods among crustaceans for *Psuedopleuronectes americanus* and *Limanda ferruginea*. Cnidarians comprised a considerable portion of their diet, as did squid for *Paralichthys oblongus* and echinoids and ophiuroids for *Hippoglossoides platessoides*.

Polychaetes and Crustaceans in Demersal Fish Food Webs

To emphasize the role of benthic invertebrates in general and polychaetes and crustaceans in particular in fish food webs, a few representative studies from the New England-Middle Atlantic Bight area were reviewed. These studies contained data on polychaetes and crustaceans taken from stomach analyses of fish (Table A-13). Approximately 87 genera/species of polychaetes and 126 genera/species of crustaceans were identified from these

Table 19. Stomach contents of seven species of pleuronectiform fishes from Georges Bank. Data are expressed as a percentage weight for fish collected. + indicates present but < 0.1%. (taken and modified from Langton and Bowman, 1980b).

	Citharichtys arctifrons	Paralichthys oblongus	Scopthalmus aquosus	Glyptocephalus cynoglossus	Hippoglossoides platessoides	Limanda ferruginea	Pseudopleuronectes americanus
idaria	-	-	-	-	+	10.3	30.4
nelida	25.7	+	0.1	87.3	0.4	47.2	15.1
ephtyidae	2.7	-	-	1.8	-	+	+
ldanidae	8.6	-	-	0.1	-	0.9	0.1
mbrineridae	1.9	-	-	5.0	-	1.4	0.1
pharetidae	2.2	-	-	2.0	-	-	1.0
rebellidae	-	-	-	1.0	-	-	1.4
bellidae	+	-	-	-	0.2	0.3	0.6
er Annelida	10.3	+	0.1	77.9	0.2	44.6	11.9
hropoda	68.5	46.4	77.0	6.2	7.0	32.3	3.9
macea	0.4	-	-	+	-	0.1	-
phipoda	41.4	+	0.8	3.5	0.2	28.0	2.0
sidacea	3.1	0.2	20.4	-	0.1	+	-
phausiacea	1.2	-	0.4	0.1	+	-	-
ndalidae	12.3	26.3	6.7	1.3	2.8	0.1	0.1
angonidae	1.2	13.1	45.9	1.0	0.9	1.4	0.1
iidae	-	-	-	+	-	-	-
guridae	0.1	-	0.2	0.2	2.6	0.7	0.1
jidae	-	-	-	-	-	-	0.1
ncridae	-	-	0.4	-	-	+	0.2
er Decapoda	-	4.5	1.7	-	0.2	0.7	0.1
er Arthropoda	8.8	2.3	0.5	0.1	0.2	1.3	1.2
lusca	0.1	10.3	-	0.2	0.3	1.5	20.4
stropoda	-	-	-	-	0.1	0.2	0.1
alvia	-	-	-	0.2	+	1.2	20.3
halopoda	0.1	10.3	-	-	0.1	-	-
r Mollusca	-	-	-	-	0.1	0.1	+
nodermata	0.1	-	3.3	0.2	90.7	2.3	0.5
othuroidea	-	-	-	0.2	-	0.3	0.3
inoidea	-	-	3.3	-	72.2	2.0	0.1
uroidea	0.1	-	-	-	18.5	+	0.1
r Echinodermata	-	-	-	-	-	+	+

studies.

The diet of *Raja erinacea* tended to reflect an epifaunal habit (McEachran, Boesch and Musick, 1976). Decapod crustaceans and amphipods had the highest indices of relative importance. For four seasons, decapods composed 55% of the volume consumed and 31% of the number of prey. *Crangon septemspinosa* was the most frequently eaten decapod over the whole area. This species was less important than *Pagurus pubescens* in Nova Scotia which was replaced by *P. acadianus* in the Middle Atlantic Bight and Georges Bank. Amphipods comprised 51% of the number of prey and occurred in 78% of the stomachs. *Leptocheirus pinguis* was the dominant amphipod species consumed overall. This species was less abundant than *Pleustes panopla* in Nova Scotia and haustoriids were abundant only in Georges Bank samples. Polychaetes comprised the second largest volume of prey and occurred in 55% of the samples. *Eunice pennata* and *Nereis* spp. were the most numerous polychaetes. *Nereis* spp. and *Aphrodita hastata* were abundant in the Middle Atlantic Bight and Georges Bank area, whereas *E. pennata* was abundant in Nova Scotia samples. Consumption of polychaetes was independent of predator size.

The diet of *R. ocellata* tended to reflect an infaunal habit (McEachran et al, 1976). Amphipods and polychaetes were the most important prey. Amphipods comprised 64% of the number of prey, 7% volume, and occurred in 70% of the stomachs. Amphipods consisted primarily of haustoriids and *L. pinguis*. *C. septemspinosa* was the only decapod consumed in large numbers. Polychaetes comprised 13% of the number of prey, 22% volume, and occurred in 70% of the stomachs. The volume of polychaetes gradually increased and the volume of amphipods gradually decreased with increase in skate size. *Nephtys* spp. and *Nereis* spp. were the most frequently consumed polychaetes. Maldanids were abundant in the Middle Atlantic Bight and Georges Bank and *Pectinaria* were abundant on the Scotian Shelf. The highest diversity (H') for the stomach contents of *R. erinacea* and *R. ocellata* were obtained from Georges Bank samples.

The prey of *R. radiata* was size-dependent. Those skates greater than 40 cm long fed chiefly on polychaetes and decapods. Polychaetes comprised 31% of the number of prey, 23% volume, and occurred in 82% of the stomachs. Decapods contained 19% by number, 21% volume and occurred in 40% of the stomachs. *Hyas* spp. and *Eualus pusiolus* were the dominant prey on Georges Bank and Nova Scotia. For *R. senta*, decapods and euphausids were the most important prey with 13% by number, 50% volume, and 67% occurrence. Polychaetes contributed little to their diet.

For the haddock *Melanogrammus aeglefinus*, 173 species of prey were observed (Wigley, 1956). Among these species, 72 were crustaceans and 32 were polychaetes. The crustaceans *B. gaimardii*, *M. edwardsi*, *U. irrorata*, *C. irroratus* and *H. coarctatus*, together with the polychaetes *C. torquata*, *E. pennata*, and *N. pelegica* were among the top 11 species. In another study of haddock, there was a marked seasonal variation in the quantity of prey composition in fish stomachs (Wigley and Theroux, 1965). The top two taxa of prey were crustaceans and annelids. Crustacea varied substantially throughout the year, whereas the proportion of annelids as fish prey was quite uniform. *L. pinguis*, *U. irrorata*, *U. inermis*, *C. borealis*, *C. irroratus*, *D. leptocerus*, *H. coarctatus*, *D. quadrispinosa*, *E. hispida*, *P. declivis*, *A. hastata*, *Nephtys* spp., *Glycera* sp., *L. fragilis*, *G. maculata* and *S. scutata* were important species.

In terms of summer flounder *Pseudopleuronectes americanus*, Richards (1963) reported 25 species of Crustaceans and 40 species of polychaetes from fish obtained in Long Island Sound (Table A-13). Although this review of fish-benthic prey relationships represents a very small portion of the literature, based on this there is solid evidence to infer the ecological significance of invertebrate populations as important prey of Georges Bank demersal fish. Even though considerable time has elapsed between serious benthic studies (Wigley, 1956; Michael, 1977; Maurer and Leathem 1980a) and a variety of collecting gear has been employed (Maurer and Wigley, 1981, Dickinson and Wigley, 1981), the correspondence between resident benthos and fish stomach contents strongly demonstrates this relationship. Many of the dominant (abundance, biomass, size, frequency of occurrence) invertebrate taxa identified earlier (Wigley, 1956, 1961b; Maurer and Wigley, 1981) are still among dominant species today (Michael, 1977; NEOEB III, 1978; Maurer and Leathem, 1980a). Moreover, evidence for the continuity of predator-prey relationships between demersal fish and benthos can be seen from the early work of Wigley (1956, 1961b) through the recent studies of Bowman (1977), Maurer and Bowman (1975) and Langton and Bowman (1980a,b). At least within the past 25 years, benthic invertebrates have been and continue to be of paramount importance as prime prey candidates of Georges Bank demersal fish. This relationship has not always been easy to establish in other geographic areas, such as the Bering and the Western Baltic (Alton, 1974 and Arntz, 1980).

Although the focus of this section was on benthos as prey for demersal fish, another implication of this relationship is the biological effect of predation on benthic communities and therefore their structure and function. In addition to demersal fish playing an important role in cropping benthic organisms, dramatically affecting density, diversity and production, recent studies in estuaries (Virnstein, 1979; Holland, Mountford, Hiegel, Kaumeyer and Mihursky, 1980) and coastal waters (Arntz, 1977) indicate that invertebrates also influence structure and function of soft-bottom assemblages. Candidates for invertebrate predators collected from Georges Bank (Michael, 1977; NEOEB III, 1978) might include the gastropods *Buccinum undatum*, *Colus stimpsoni*, *Lunatia heros*, *Neptunea decemcostata*; the decapods *Cancer borealis*, *C. irroratus*, *Homarus americanus*, *Munida iris*, *Hyas coarctatus*, *Ovalipes ocellatus*, *Pagurus* spp., the asteroids *Asterias vulgaris*, *Astropecten americanus*, *Leptastarias tenera* and the ophiuroids *Amphioplus abdita*, *A. squamata*, *Ophiura sarsi*. However, the latter group are probably not obligate carnivores, as they show considerable flexibility in feeding behavior. Since physical processes can be so dominant seasonally on shallow portions of Georges Bank and biologic interactions by fish predation are so heavy, the effects on invertebrate-invertebrate interactions tend to be obscured.

Because of their commercial importance, there has been considerable research on *Cancer borealis*, *C. irroratus*, *H. americanus* and *G. quinquedens* (Lewis, 1970; Wigley, Theroux and Murray, 1975; Haefner, 1977; Bigford, 1979; Elner and Jamieson, 1979). The biology of the lobster *H. americanus* provides some insight as to the effects of invertebrate predators on invertebrate prey. Inshore lobsters typically move from shoal water (5-20 m) to deep water (30-60 m) when strong winds generate heavy seas and considerable vertical turbulence at the water-substratum interface (Cooper and Uzmann, 1980). These movements are commonly associated with storms. The extent of daily or weekly movement of the home range of inshore lobsters is established during night when foraging for food occurs. Night-time excursions are more frequent and extensive during the summer and fall than in the winter and spring. Mixing of onshore lobsters and migrants from offshore occur from May to September from southern New York to Cape Cod Bay.

Migratory behavior of offshore lobsters is well documented (Cooper and Uzmann, 1971; Uzmann, Cooper and Pecci, 1977). This behavior is probably elicited by temperature, since the seasonal distribution of tagged lobsters is positively associated with bottom temperature (Cooper and Uzmann, 1980). Migration toward shoal water is not a total, well-coordinated population response.

Information on the feeding of offshore lobsters is not available, but data on onshore populations is probably applicable. The american lobster is an omnivorous feeder and predator. The majority of its natural food comprises a variety of bottom invertebrates, including mainly crabs, polychaetes, mussels, periwinkles, sea urchins, and sea stars (Cooper and Uzmann, 1980). Fish, plants, hydroids, ascidians, and ectoprocts comprise a relatively minor part of the diet. Based on stomach contents the lobster appears to be a generalist or opportunist in feeding habit, as its diet generally reflects the relative abundance of prey species in the habitat. Stomach fullness also reflects seasonal changes in feeding activity. Stomach fullness is generally lowest during January, February, and March, and highest during July through November.

In view of the size, density, distribution, locomotion and feeding behavior of the lobster, the effect of grazing pressure on benthos by this single invertebrate predator must be considerable. In addition, other large commercial decapods and smaller crabs, together with a whole host of gastropods, echinoderms, some polychaetes and amphipods, provide many opportunities for significant biological interactions. These latter relationships remain to be accurately assessed on Georges Bank.

Response of Benthic Invertebrates to Pollutants on Georges Bank

Introduction

Recent research on the response of aquatic and marine organisms to pollutants can be assessed through massive documentation provided by a variety of workers and symposia (Vernberg and Vernberg, 1974; Baker, 1976; Lockwood, 1976; Giam, 1977; Malins, 1977; Wolfe, 1977; Vernberg, Thurberg, Calabrese and Vernberg, 1979; Neff, 1979; Kinne and Bulnheim, 1980; Samson, Vandermeulen, Wells, and Moyse, 1980). It is the response of the biota on Georges Bank to petroleum exploration that makes this of paramount interest.

To provide some assessment of the problem, this section will examine data primarily related to benthic invertebrates, hydrocarbons, trace metals and drilling muds and cutting. This will be accomplished two ways. First, the literature will be briefly reviewed emphasizing polychaetes, crustaceans, molluscs and echinoderms since these taxa comprise the dominant benthic invertebrates on Georges Bank. Research dealing with chronic or sublethal effects on functional processes will be emphasized, rather than acute toxicity effects. The preference to examine sublethal effects and functional processes resides in the assumption that pollution levels on Georges Bank would probably not attain acute toxicity levels, and if they did, these conditions would not remain at acute levels for prolonged periods. However, it is more likely (another assumption) that pollution levels in sediment over a period of time could attain chronic levels under particular hydrographic conditions. Consideration of chronic levels then would seem more pertinent for Georges Bank rather than acute ones.

Second, the relationship between Georges Bank benthos and animal tissue hydrocarbons and trace metals acquired in the 1977 BLM study will also be reviewed. In summary, then, this section will examine 1) what is generally known about trace metals, hydrocarbons, drilling fluids and cuttings in selected marine benthos, and 2) what are the actual trace metal and hydrocarbon loads of Georges Bank benthos prior to extensive drilling activities.

Hydrocarbons

Behavior

One of the more immediate responses of biota to disturbance can be seen in behavior. Any significant disruption of natural behavior can have crucial survival implications for the target populations. When exposed to Prudhoe Bay crude oil for 180 days the bivalve *Macoma balthica* showed a decreased burrowing rate at a high concentration of oil in seawater (3.0 mg/l) (Stekoll, Clement and Shaw, 1980). Sluggishness and disorientation of clams appeared after a week of exposure.

Field and laboratory experiments examined how oiled sediment influenced predation on littleneck clams *Protothaca staminea* by Dungeness crabs *Cancer magister* (Pearson, Woodruff, Sugarman and Olla, 1981). Shallow burial and slow reburrowing in oiled sand promoted increased predation through increased accessibility of clams to crabs.

Treated (south Louisiana crude oil) and untreated plates were suspended in seawater to test settling behavior of in situ meroplankton (Ho and Karim, 1978). Freshly coated plates received an average of 0.6/6.5 cm^2 oyster spat of *Crassostrea Virginica*, in contrast to 19.0/6.5 cm^2 for control plates. After treated plates were weathered for two weeks, the spat set was still half that of controls.

Larvae of *Cancer irroratus* cultured in No. 2 fuel oil showed significant behavior differences (Bigford, 1977). Geonegative upward movements in the water column were typically depressed in early-stage larvae and enhanced in late-stage larvae after exposure to oil, showing gravity responses to be greatly affected. Phototactic behavior was significantly changed by the oil and pressure responses were slightly affected. Williams and Duke (1979) cited behavior studies with Pachygrapus crassipes exposed to water-soluble extracts of two crude oils. The feeding response and mating response of males was inhibited when exposed to the female's sex hormone. Inhibition persisted below 10^{-8} concentration. Monoaromatic hydrocarbons were effective as inhibitors of chemoreception for relatively short periods of time (30-60 min.) and polynuclear hydrocarbons inhibited crabs from 8-13 days. The threshold concentrations at which the blue crab Callinectes sapidus detected the petroleum hydrocarbon was found to be 10^{-7} mg/L (Pearson and Olla, 1980). Oriented locomotor activity and defensive displaying began at 2 mg/L of napthalene. These crabs were very sensitive through chemoreception to minute concentrations of aromatic hydrocarbons in sea water.

The locomotive activity of the arctic amphipod Onisimus affinis was significantly impaired by exposure to dispersions of fresh crude oil (Percy and Mullen, 1977). Reduction in activity occurred at the lowest concentration tested (15-20 ppm). Concentrations of dispersed oil comparable to that at which activity is impaired have been found in oil slicks and over considerable areas following a major oil spill.

Studies of the effects of crude oil on the righting behavior of the sea urchin Paracentrotus lividus were made (Axiak and Saliba, 1981). Prolongation of the righting response was recorded in animals exposed to contact with surface or sunken fresh crude oil, or to their water-soluble fractions.

No such effect was recorded on exposure to weathered oils.

Feeding, Growth and Molting

Inhibition of feeding, growth and molting can have important repercussions for any biotic populations. Exposure of hatchlings of the oyster drill *Urosalpinx cinera* to 1 mg/L dosages of Nigerian crude oil and greater caused a significant reduction in growth rates after 8 days when compared to control snails (Edwards, 1980). Growth of older juvenile snails was reduced significantly at 2 mg/L and greater after 6 weeks. Snails at 1 mg/L oil and greater fed at about the same rate as control snails after 5 weeks, although they did not grow nearly as much. Edwards (1980) suggested that this may be due to increased respiratory demands resulting from exposure to oil. When exposed to Prudhoe Bay crude oil for 180 days the growth of the bivalve *Macoma balthica* was even inhibited at the lowest concentration (0.03 mg/L) (Stekoll et al, 1980).

When free amino acids in muscle and mantle of the bivalve *Macoma inquinata* in oil contaminated sediments and control plots were examined, there were significant differences (Roesijadi and Anderson, 1979). Exposed bivalves had reduced levels of free amino acids, primarily glycine, with concomitant elevations in the taurine: glycine ratio. Decreases in some of the free amino acids may represent nutritional effects whereas increase in the taurine: glycine ratio may represent physiologic changes to polluted or natural stresses.

When chronically exposed to fresh and weathered Norman Wells crude oils, juveniles of the arctic isopod *Mesidotea entomon* showed a significant increase in the duration of the intermolt period only at the highest oil concentrations (Percy, 1978). Fresh Norman Wells crude depressed growth slightly and weathered Norman Wells severely inhibited growth at the highest concentration. Larvae of the american lobster Homarus americanus in 0.01 ml/L of Venezuelan crude oil were unable to moult to fourth stage, whereas larvae in 0.001 ml/L and 0.0001 ml/L developed to fourth stage in a manner similar to control larvae. Larvae of the rock crab Cancer irroratus reared in treated conditions (No. 2 fuel oil) exhibited significant reductions in food consumption and growth rate at 0.1 ppm (Johns and Pechenik, 1980).

Respiration

Since respiration is an important measure of energy flow in a population, the effect of hydrocarbons on respiration is a critical area of research. When the bivalves Brachiodontes variablis and Donax trunculus were exposed to concentrations of arabian light crude oil ranging from 1 ml to 100 ml/L, each concentration of oil caused depression of the respiratory rate (Avolizi and Nuwayhid, 1974). Macoma balthica exposed to Prudhoe Bay crude oil for 180 days showed increased respiration rate at a high concentration (3.0 mg/L) (Stekoll et al, 1980). A negative energy balance was observed by 60 days. The authors concluded that chronic exposure of M. balthica to oil-in-seawater concentrations even as low as 0.03 mg/L will, in time, lead to population decreases.

Rates of respiration, assimilation and filtration were determined for two populations of the bivalve Mya arenaria from Casco Bay, Maine, one of which was heavily oiled by a spill of No. 6 fuel oil (Gilfillan, Mayo, Hanson, Donovan and Jiang, 1976). The oiled population gained carbon at only 50% of the rate seen in the unoiled population. This difference resulted from the uptake of hydrocarbons by the oiled population. Stainken (1978) reported that the respiratory rates of all groups of oil-exposed M. arenaria remained altered above the controls. He suggested that a dose-response narcosis may have been evident during this period. Johns and Pechenik (1980) reported that the metabolic cost of maintenance increased for Cancer irroratus larvae exposed to 0/1 ppm No. 2 fuel oil.

Assimilation, Accumulation, Depuration and Degradation

The biologic processes of assimilation, accumulation and depuration commonly involve responses at the cellular and molecular level. As such, measures of these processes represent very critical and subtle responses of the biota to their environment, in this case hydrocarbons. Neff (1979) reported that there are large interspecific differences in ability to absorb and assimilate polycyclic aromatic hydrocarbons (PAH) from food. Moreover, he stated that the potential for food-chain biomagnification of PAH was limited. Mackie, Whittle and Hardy (1974) reported that there was no evidence for concentration of hydrocarbons along a food chain involving Buccinum undatum, Asterias rubens and Nephrops norvegicus as prey and the hake, dogfish, plaice and cod as predators.

In contrast to this point of view, Vandermeulen and Penrose (1978) reported that the bivalve Mya arenaria, Mytilus edulis and Ostrea edulis provided an opportunity for transfer of unaltered hydrocarbons into the food chain. None of the bivalves showed any basal or petroleum-hydrocarbon-induced aryl hydrocarbon hydroxylase (AHH) or N-demethylene activity as shown by their inability to metabolize benzopyrene or imipramine. Dobroski and Epifanio (1980) showed that the diatom Thalassiosira pseudonana accumulated benzo[a]pyrene and that larval hard clams (Mercenaria mercenaria) fed exclusively on the diatom accumulated the hydrocarbon. They concluded that uptake both from water and trophic transfer was important in accumulation of polycyclic aromatic hydrocarbons by filter-feeding bivalves. In a long-term (180 days) experiment, the bivalve Macoma balthica extensively modified characteristics of Prudhoe Bay crude oil (Clement, Stekoll and Shaw, 1980). Aliphatic compounds were handled quite differently by the clams than aromatics. The authors suggested selective metabolism as one of the possible causes of fractionation of petroleum by M. balthica and stressed the importance of conducting accumulation and depuration studies over longer periods of testing than previously conducted.

The bivalves Macoma inquinata and Protothaca staminea were exposed to marine sediments contaminated with Prudhoe crude oil (Roesijadi, Anderson, and Blaylock, 1978). The deposit feeder M. inquinata generally accumulated more aliphatics and diaromatics than the suspension feeder P. staminea. Heavier molecular weight aromatic compounds tended to be more concentrated in tissue and retained for longer periods of time than the lighter compounds.

Elimination of aliphatic hydrocarbon in the tissue of the mussel Mytilus galloprovincialis was followed by Fossato (1975). Hydrocarbon elimination was quite rapid in the first 10-15 days but then slow and incomplete: 12% of the initial content persisted in the tissues for 8 weeks. The biological half-life of hydrocarbons in the mussels was calculated to be a little over 3½ days, but this related only to the initial rapid phase of elimination. It has been suggested that depuration of chronically accumulated hydrocarbons is a two-phase process (Neff, 1979). One is characterized by an initial rapid release of hydrocarbons followed by a second phase of very gradual release of remaining hydrocarbons. Oil ingested by M. galloprovincialis appeared in feces and pseudofeces but differed in composition from the oil to which animals were exposed (Mironov and Shchekaturina, 1979). It contained more heavy fractions and larger aromatics and there was a shift of aliphatics towards heavier alkanes and isoprenoids. They attributed these changes to metabolic processes in the mussels.

When the polychaetous annelid Neanthes arenaceodentata was returned to hydrocarbon-free seawater after 24 hours in a sublethal concentration of No. 2 fuel oil seawater extract, male worms slowly released naphthalenes down to undetectable levels in 17 days (Rossi and Anderson, 1977). Gravid females retained essentially all of the originally accumulated naphthalenes for 3 weeks. At this time, they released their eggs during fertilization with subsequent dramatic decreases in naphthalenes content. Zygotes and trochophore larvae from treated females accounted for a majority of the naphthalenes initially present in parent females. As trochophore larvae developed into 18-segment juveniles (21 days) naphthalene concentrations dropped to near-undetectable levels.

The polychaetes *Nereis virens* and *Capitella capitata* have a mixed-function oxygenase (MFO) system which acts to detoxify aromatic hydrocarbons (Lee, Singer, Tenore, Gardner and Philpot, 1979). MFO was associated with the intestine of *N. virens* but was only detected in *C. capitata* after exposure to petroleum or its components. MFO activity in *C. capitata* was higher in third-generation worms than first or second after exposure to oil. Lee et al. (1979) cited Rossi and Anderson (in press) that third-generation worms of *N. arenaceodentata* were significantly more resistant to fuel oil than the first generation. Lee et al. (1979) suggested that possibly increased resistance of polychaetes to oil was due to an increase to the MFO system. Anderson (1979) alluded to the importance of induction in interpreting findings of chronic effects studies.

Rates of degredation of polycyclic aromatic hydrocarbons (PAH) by the polychaete *Capitella capitata* were examined (Gardner, Lee, Tenore, and Smith, 1979). *C. capitata* increased PAH degradation in sediment. The authors suggested that the worms metabolically degraded the PAH compounds or they improved conditions in the sediment for microbial activity by distributing nutrients to subsurface layers. Degradation by *C. capitata* may have been a factor, since other studies by Lee et al. (1977, 1979) have demonstrated that polychaete worms possess enzyme systems which metabolize hydrocarbons. Lee (1981) stated that in polluted areas there may be a selection for strains with higher MFO activity similar to the higher MFO activity reported for pesticide-resistant strains of certain insects.

According to Gordon, Dale and Keizer (1978) populations of the polychaete *Arenicola marina* which had spent their entire lives in oil-polluted sediment did not have markedly elevated hydrocarbon concentrations and behaved no differently in experiments than worms collected from a clean environment. Calculations suggested that *A. marina* were capable of removing the oil present in a square meter of sediment in 2-4 years. It was concluded that after any oil spill, when concentrations reached tolerable levels, activities of deposit-feeding animals such as *A. marina* can apparently accelerate the weathering rate of sediment-bound oil. Turnover of oil-contaminated sediment by *A. marina* was confirmed by Lyes (1979). However, he did not subscribe to the same rapid rate of turnover described by Gordon et al. (1978).

Reproduction and Larval Development

Certainly a keystone response of biota to natural or human processes involves reproduction and larval development. Research on the effect of petroleum on reproduction and larval development has been conducted on a variety of major benthic invertebrate taxa. A significant suppression in reproduction at 2.2 ppm and 1.3 ppm fuel oil was reported for the polychaetes *Ctenodrilus serratus* and *Ophryotrocha* sp., respectively, and at 9.9 ppm of South Louisiana crude oil for both species (Carr and Reish, 1977).

A significant reproductive stimulation, however, was reported for Ophryotrocha sp. exposed to 1.9 ppm of South Louisiana crude oil. For the amphipods Gammarus mucronatus and Amphithoe valida few or no young were produced in 0.8 ppm (fuel oil) and 2.4 ppm (southern Louisiana crude oil) (Lee, Welch, and Nicol, 1977b). The authors also concluded that amphipods were more sensitive to aqueous extracts of these oils than benthic polychaetes or shrimp.

Research with water-soluble extracts of 16 crude and refined oil products showed harmful effects on developing sea urchin eggs (Strongylocentrotus purpuratus) (Allen, 1971). After 2-hour exposure, eleven of the sixteen oils at 6.25% concentration showed effects significantly different from controls. In some cases cleavage was totally arrested. Four hours after fertilization, fourteen of sixteen oils at 6.25% showed significant differences. Crude and bunker oils had the most inhibiting effect on developing sea urchin eggs (Stronglyocentrotus droebachiensis and S. pallidus) (Falk-Petersen, 1979). Ekofisk crude oil extract had a moderate effect during early development, but affected embryos strongly at the late gastrula and early pluteus stages. Ekofisk residue extract affected development in a similar way but at lower total hydrocarbon concentrations. For gas and oil and kerosene extracts embryos usually cleft irregularly after the two-cell stage. BP fuel oil extract affected larvae at very low total hydrocarbon concentrations and BP gasoline extract affected them at much higher concentrations. Effects from the latter extract occurred at an early stage (Falk-Petersen, 1979).

One year after an oil spill of Iranian crude, the gastropod Littorina littorea was collected from the oil-polluted shore and spawned in the laboratory (Staveland, 1979). Oil contamination had no detectable effects on fertilization. However, hatching success of veliger larvae was significantly less in the oil-polluted population. Some highly abnormal eggs were also observed in this population (Staveland, 1979). A comparison was made between the development of the eggs of the scaphopod Dentalium vulgare, spawned by animals collected before and after the Amoco Cadiz oil spill (Koster and Van den Biggelaar, 1980). Development of eggs from animals collected before the oil spill was significantly better than those collected after the oil spill. It was suggested that development was affected by oil hydrocarbons, accumulated during oogenesis in the lipid-rich phases of the oocytes. When exposed to Prudhoe Bay crude oil for 180 days, the bivalve Macoma balthica reabsorbed gametes even at the lowest concentration (0.03 mg/L) (Stekoll et al, 1980). After a coastal spill of No. 2 fuel oil and jet fuel, the histopathology of the bivalve Mya arenaria was followed (Barry and Yevich, 1975). A high incidence of gonadal tumors was reported in clams contaminated by oil. The highest percent of tumors was associated with the area of highest oil impact. The tumors were considered malignant neoplasms.

Water-soluble extracts of Kuwait, Nigerian and Prudhoe Bay crude oil were tested on the sperm and eggs of two pelecypods Crassostrea virginica and Mulinia lateralis (Renzoni, 1975). Fertilization was depressed and developmental abnormalities appeared after exposure and these were directly related to concentration. Largest effects occurred between 0.1 and 1.0 ml/L concentration. Spermatozoa were more sensitive to the oils than were eggs. After testing the larvae of the bivalves Crassostrea angulata, C. gigas and Mytilus galloprovincialis with a variety of crude oils and fuel oils, Renzoni (1973) reported that these products were harmful to larvae but high concentrations (1000 ppm) were needed. He concluded that such high concentrations were unlikely to be reached in the open sea. The fact that spermatozoa were particularly sensitive to these compounds may have important consequences for the breeding success of contaminated bivalve populations.

Field Mortality and Recruitment

Mortalities from oil spills in the field must be considered extremely relevant to this type of intrusion. Recruitment which is very dependent on reproduction represents still another biologic response to natural and human disturbances. The survival of various species of infauna of 15 beaches from the Amoco Cadiz oil spill was investigated by Chasse (1978). A wide range of susceptibilities was seen. Polychaetes were very resistant. Arenicola marina was apparently unaffected, as were many other species of burrowing worms. Opheliidae spp. and Lanice conchylegia were only slightly hit. In contrast, some bivalves were seriously depleted. For Solen ensis and Pharus, there was almost total kill with a few survivors for Cardium edule. Tellina spp. survived very well, and Mya arenaria seemingly had no mortalities. The amphipods Talitrus saltator and Ampelisca brevicornis experienced heavy mortality with much less mortality for *Haustorius arenarius*, *Bathyporeia* spp. and *Eyrydice pulchra*. Among echinoderms, *Echinocardium cordatum* nearly all perished, a few *Acrocnida brachiata* survived, and good survival was reported for *Leptosynapta gallieni*. Chasse (1978) concluded that the most serious aspect of the spill was the accumulation of petroleum hydrocarbons in sediment and interstitial water. The same serious impregnation of hydrocarbons in sediment together with massive mortalities of benthos were reported also for the West Falmouth oil spill (Sanders, 1978).

In a related Amoco Cadiz study sub-littoral communities were examined (Cabioch, Dauvin, Gentil, 1978). *Ampelisca* spp., an important constituent of the diet of fish, was represented by 6 species which accounted for 90% of the density and 40% of the biomass under summer conditions. The penetration at depth by hydrocarbons from the oil spill resulted in massive mortality of the amphipod population. Within 14 days of the spill, the amphipod population was reduced to a single species (*A. sarsi*). This species declined from 2157/m to 350/m in the same time period. A dramatic reduction in the density of ampelescid amphipod was reported for the West Falmouth oil spill (Sanders, Grassle, Hampson, Morse, Garner-Price and Jones, 1980). In addition to the enormous susceptibility of ampelescids to the Amoco Cadiz spill, Cabioch et al (1978) reported that the presence of oil in different types of sediment suggested a tendency towards its dynamic accumulation in areas of fine sediment.

Two populations (oiled lagoon and a non-oiled lagoon) of the bivalve Mya arenaria near Chedabucto Bay, Nova Scotia, were compared (Gilfillan and Vandermeulen, 1978). The oiled population of clams contained lower total numbers with fewer mature adults, a 1-2 year lag in tissue growth, a lower shell growth rate, and a reduced carbon flux with a lower assimilation rate. The authors concluded that the recovery potential of M. arenaria in these oiled sediments was low and that these oiled populations remained under continued stress 6 years after the Arrow oil spill.

Oyster drills (Urosalpinx cinera) were collected from a recolonizing population at Wild Harbor (scene of the West Falmouth oil spill) and from a long-standing population at Nobska Point (Cole, 1978). Analysis of population dynamics indicated that a reasonably functioning population has been reestablished at Wild Harbor. However, genetic structure (as revealed by genotypic distributions) of Wild Harbor drills exhibited generally greater year-to-year variations than did Nobska organisms. The long-term ecological significance of these genetic changes presumably related to the spill remains to be assessed.

Recolonization studies of benthic invertebrates were conducted in treated (Prudhoe crude) and control trays (Atlas, Horowitz and Busdosh, 1978). Amphipod species were found much less frequently in oil-contaminated than control sediments in contrast to isopods which were found frequently in both trays. Some polychaetes may be attracted while oil may be toxic to other species. Overall, oil-treated sediment was recolonized by invertebrates within 2 months of contamination. However, benthic community structure was markedly different in oil-contaminated sediment than controls. The ecological significance of these structural differences in Arctic benthic ecosystems remains to be assessed. In another set of recolonization studies in clean and oiled sediment in Sequim Bay, Washington, no substantial inhibition of recruitment by benthic organisms was observed (Anderson, Riley, and Bean, 1978).

In a set of 25-week experiments in large microcosms exposed to semicontinuous additions of an oil-water dispersion of No. 2 fuel oil, each of the most common species, *Mediomastus ambiseta*, *Nucula annulata* and *Yoldia limatula*, showed significant differences in population density between oiled and control tanks (Grassle, Elmgren and Grassle, 1981). Larger macrofaunal animals most particularly suspension feeders in oiled tanks showed highly significant differences. A drastic reduction in metazoan meiofauna occurred after five months. After less than two months without oil additions, the harpacticoid copepods and other meiofaunal groups also showed signs of recovery. The macrofauna showed no signs of recovery in the oil tanks during these two months (Grassle et al, 1981).

Trace Metals

General

Reviews of the effects of trace metals on polychaetes, brachyuran decapods, amphipods and molluscs can be found in Hart and Fuller (1979). Cunningham's (1979) review of the use of bivalve molluscs in heavy metal pollution research is very informative. Her account contained sections on acute toxicity and chronic effects related to behavior, feeding, growth, accumulation and depuration, reproduction and larval development together with discussion of extreme factors involving temperature, salinity, chemical form of the metal, heavy metal interactions, season and position in the water column. In addition concentrations in various body tissues, intracellular distribution and a discussion of five specific trace metals were presented.

Behavior

For bivalves (Tellina tenuis) greater than 10 mm in length, the effect of Cu on burrowing was more marked than for small animals, and the effect increased as the period of exposure to the pollutant solution increased (Stirling, 1975). All levels of Cu $\geq$ 250 µg/L had an adverse effect on burrowing for both size groups of T. tenuis. The effect was more marked at higher Cu concentrations, and in some cases the effect increased with duration of the experiment. The burrowing of another bivalve (Macoma balthica) was inhibited in all contaminated (Cu, Pb, Zn, Cr, Ag, Fe, Hg, Cd) sediments compared to the control (McGreer, 1979). The time required for 50% of the population to burrow (ET_{50}) ranged from 0.17 hr. in the control to 4.8 hr. in the most contaminated substratum. A comparison of the concentrations of individual metals in the sediments in relation to burrowing response times showed that Hg and Cd were significant. An active threshold avoidance response by borrowed M. balthica was also demonstrated as clams showed a significant avoidance of sediment containing highest metal levels. Behavior effects to trace metals were also reported in mud snails (Ilyanassa obsoleta) exposed to sublethal levels of Ar, Cd, Cu, Ag and Zn (MacInnes and Thurberg, 1973). Snails exhibited deviations from normal behavior involving movement of the foot and body extension which dramatically impeded locomotion.

The influence of Zn upon the pattern and success of settlement of oyster larvae (Crassostrea gigas) was examined (Boyden, Watling, and Thornton, 1975). Late larvae were more tolerant of Zn than embryos. Delayed settlement was recorded in concentrations as low as 125 µg/L Zn, and numbers of larvae settling were reduced in the presence of Zn. Larvae subjected to Zn immediately prior to settlement showed evidence of slowing in behavioral development. Spat set in the presence of Zn, however, when grown out in clean water, were as viable as controls. Zn at 250 and 500 µg/L suppressed spat growth, but recovery was rapid upon subsequent grow out in clean water conditions (Boyden et al, 1975).

Behavioral and electrophysiological studies have emphasized both the acuity and importance of chemical senses in feeding and social interactions of crustaceans (Bodammer, 1979). Bodammer cited studies showing that the blue crab Callinectes sapidus will respond to solutions of clam extract in concentrations as low as 10^{-15} g/L. These responses are not just restricted to crustaceans as predator-prey relations between asteroid echinoderms and bivalves, gastropods and bivalves, and mating behavior of gastropods may be activated at extremely low concentrations. McLeese (1975) reported behavioral modifications in lobsters (Homarus americanus) exposed to Cu. The lobsters exhibited avoidance behavior and experienced impaired or blocked feeding responses. However, normal feeding responses were regained by exposed animals after their return to clean water. Using McLeese's results as a guide, Bodammer (1979) showed that Cu may have a cytopathological effect on *Callinectes sapidus* chemoreceptors.

Feeding, Growth, Molting and Regeneration

Growth of oyster (*Crassostrea virginica* and clam (*Mercenaria mercenaria*) larvae in Hg, Ag, Cu, Ni, and Zn was markedly reduced at LC_{50} values (Calabrese, MacInnes, Nelson and Miller, 1977). These authors concluded that growth of fully developed larvae may be retarded at concentrations of metal too low to cause significant mortality. This retardation prolongs pelagic existence with added risks of predation, disease and dispersal. After 47 days, shell growth of juvenile oysters (*C. virginica*) was reduced by 77% for the 100 ppb Hg group and by 33% for the 10 ppb group compared to controls (Cunningham, 1976). Oysters in seawater for a 162-day depuration period demonstrated shell growth rates comparable to controls within 34 days (100 ppb) and 20 days (10 ppb).

The relationship between Cd concentration and mussel (*Mytilus edulis*)body weight was investigated in the field (Cossa, Bourget and Piuze, 1979). Their data showed that regression coefficients became considerably more variable when animals entered adulthood. Thus, variations were probably related to biochemical changes occurring during the sexual cycle. The authors recommended using only immature animals which should reduce the influence of metabolism on metal content of mussels, thereby permitting a more precise indication of ambient pollution levels.

For both zinc and iron, the food chain was the major source of metal in the tissues of the dogwhelk (Nucella lapillus) (Young, 1977). The input from food was approximately two orders of magnitude greater than that from sea water.

After multiple autotomy on the fiddler crabs Uca pugilator, U. pugnax and U. minax, both methyl mercury and cadmium retarded limb regeneration and ecdysis (Weis, 1978). When crabs in sea water were exposed to a mixture of both metals, the effect was increased, indicating that the two were interacting in an additive way. In 50% sea water (15 $^{o}/oo$), effects of cadmium were greatly intensified with extremely slow growth of limbs, if any at all. Under the same conditions, the severe effects of Cd were somewhat ameliorated by methylmercury, indicating an antagonistic interaction of the two metals. Addition of calcium to 50% sea water also decreased the severity of the cadmium effect, suggesting calcium-cadmium competition. Weis's (1978) research showed how difficult it is to interpret multifactorial experiments and to anticipate synergistic effects. In other work with methylmercury and U. pugilator, Weis and Weis (1979) showed severe inhibition of limb regeneration at 0.5 mg/L and inhibition of melanogenesis in regenerates at 0.1 mg/L. According to them, a prolonged period of regeneration makes an animal more subject to predation because of impaired locomotion.

Effects of Hg on grass shrimp (Palaemonetes vulgaris) delayed molting (Shealy and Sandifer, 1975). In contrast, after 60 days of chronic exposure of postlarval shrimp (Penaeus setiferus), molting rate was unaffected at 0.5 and 1.0 ppb (Green, Anderson, Petrocelli, Presley and Sims, 1976).

Respiration

Copper caused significant increases in the rate of oxygen consumption by the oyster (Crassostrea virginica) only in the 100 ppb exposure group and 600 ppb cadmium group (Engel and Fowler, 1979). Gill tissue from oysters exposed to 100 ppb Cu showed intracellular alterations. Exposure to 100 ppb Cd, however, caused the induction of cadmium-binding, low-molecular weight protein. Zinc (500 ppm) exerted no effect upon gill (Mytilus edulis) or digestive gland respiration, and neither Zn nor Cu affected respiration of homogenates of gill, digestive gland or gonad (Brown and Newell, 1972). Direct observation of gill tissues during exposure to the metals revealed that 500 ppm Cu caused inhibition of ciliary activity. Exposure of tissues to 2 ppm Cu for 24 hr. resulted in only partial inhibition of the cilia. The authors suggested that metabolic suppression in whole animals and gill tissues was due to the inhibition of an energy-consuming process such as ciliary activity rather than interference with respiratory enzyme systems.

The oxygen uptake of distressed and retracted snails (Ilyanassa obsoleta) was found to be lower than that of controls after exposure to all individual metals (Ar, Cd, Cu, Ag, and Zn) except Cd, which resulted in an elevation of oxygen consumption

(MacInnes and Thurberg, 1973). The combination of Cu and Cd resulted in a lower rate than either metal alone. In contrast, there was no effect of chronic exposure of Hg on the respiration rate of post-larval shrimp (Penaeus setiferus) after 60 days at 0.5 and 1.0 ppb (Green et al, 1976).

Accumulation, Depuration and Adaptation

The uptake and loss of Zn and Pb from Mytilus edulis was studied in the field and under laboratory conditions (Simpson, 1979). Uptake and loss were greatly affected by changing body weights. Simpson's work suggested that phase of reproductive cycle (for animals in the environment) and condition (for animals in tanks) have to be closely considered when reporting on levels of metals in mussels, especially in terms of concentration. Cossa et al (1979) reported similar findings with Cd and M. edulis.

A progressive reduction in the glycolytic rate in limpet tissue (Patella vulgata) was demonstrated as one moved up the Bristol Channel (Shore, Carney and Stygall, 1975). This reduction was associated with a tissue cadmium gradient which also existed along the channel. Shore et al (1975) emphasized that their results could not be taken as conclusive proof of metabolic interference by cadmium, but their study indicated the direction for future experiments.

The uptake, storage and excretion of Cd by Mytilus edulis was studied at sub-lethal concentrations (George and Coombs, 1977). They reported that mussels concentrate and detoxify potentially harmful heavy metals. Stimulation of heavy metal accumulation can occur with both naturally occurring and synthetic organic metal chelating agents present in the aquatic environment. Their work indicated that a potential hazard may exist when an unforseen admixture of metal and complexing agent occurs.

The bloodworm Glycera dibranchiata accumulates cadmium through the general body surface and the intestine (Rice and Chien, 1979). Absorption through the gut accounts for cadmium which rapidly binds to coelomic proteins. Since proteins such as the hemoglobin of G. dibranchiata have higher turnover rates in the presence of Cd, the authors suggested that inhibition of growth and development by heavy metals may involve protein synthesis directed towards its rapid turnover, a clearance function, rather than towards synthesis for growth and development. Absorption of glycine from seawater across the body surface of Nereis diversicolor was most drastically reduced in the presence of Hg and Cd (Siebers and Ehlers, 1979). Mercury exhibited much stronger effects at lower concentrations than Cd. Ocean concentrations of heavy metals were roughly 1000-fold below those concentrations applied for obtaining significant decreases in glycine influx. They amounted to about 0.8 ppb for Cu and 0.07 ppb for Cd in open ocean waters.

Bryan and Hummerstone (1971, 1973) examined concentrations of Cu, Zn and Cd in sediments and the polychaete Nereis diversicolor. They reported that the concentration of Cu and Cd in N. diversicolor were roughly related to the total concentration in the sediment. Their results suggested that Zn uptake was regulated by the polychaete, whereas Cu and Cd were not. An important conclusion from their work was that high-copper animals survived in polluted areas because they had developed a tolerance to toxic effects of copper, which was neither readily lost nor readily gained by nontolerant animals. In toxicity experiments, polychaete populations from high-zinc sediments were better at regulating zinc than normal populations (Bryan and Hummerstone, 1973).

Reproduction and Development

Bifurcated abnormal polychaetes Capitella capitata were produced in the presence of sublethal amounts of copper and zinc (Reish, Piltz, Martin and Word, 1974). Two generations were required to produce abnormal larvae with zinc with the exception of two larvae produced in the first generation. Only one generation was required to produce abnormal larvae in the presence of sublethal amounts of copper.

Oshida, Mearns, Reish and Word (1976) studied the effects of hexavalent chromium on the reproduction of the polychaete Neanthes arenaceodentata. They reported reproductive cessation at 0.1 mg/L and reproductive suppression at 0.0125 mg/L. Further research with the same species showed successful reproduction of three generations at levels between 12.5 and 50 μg/L (about 85 to 360 times ambient). Results ancillary to the reproduction experiments showed an inhibition of mucus production by N. arenaceodentata at levels of 200 μg/L. Young from parents exposed to low levels of chromium did not appear to acquire increased tolerance to acutely toxic levels (Mearns and Young, 1977). Reish and Carr (1978) reported that suppression of reproduction in the polychaete Ctenodrilus serratus by chromium occurred at one order of magnitude less than the concentration of the metal in some local effluents.

Effects of Hg on development of larval grass shrimp (Palaemonetes vulgaris) extended development time, increased the number of larval instars, and increased morphological deformities (Shealy and Sandifer, 1975).

Drilling Fluids and Cuttings

General

Oil exploration and exploitation requires major drilling activity. Drilling activities involve drilling fluids which, in addition to bringing rock cuttings to the surface, serve many other functions (coolant, lubricant, pressure control, filtration). Since considerable volumes of drilling fluids can be expended per well bore, the chemical and physical composition of drilling muds have been considered as targets of potential pollutants associated with drilling. Because of concern about the environmental effect of drilling fluids and cuttings, it was deemed appropriate to include them in the review for Georges Bank. In 1980, a symposium on the environmental fate and effects of drilling fluids and cuttings was held in Lake Buena Vista, Florida. The following discussion is primarily based on the proceedings of that symposium (Proceedings, 1980).

Four products comprise about 90% of total volume of all additives used in drilling mud (Perricone, 1980). These products are barite, bentonite, lignite and lignosulfonate. In addition to variations in chemical composition of the four major constituents which may contain a variety of impurities (trace metals and organics), the remaining 10% of additives may contain a whole host of complex chemicals ranging from innocuous to toxic. During the symposium, it was repeatedly emphasized that all drilling muds are not alike, and that generalizations about the environmental effects of drilling muds should be tailored to particular drilling muds.

Laboratory Studies

A 96-hour static bioassay was used to determine the relative toxicity of five used drilling fluids, collected from offshore drilling rigs, and various components of these fluids, to cold-water animals (Gerber, Gilfillan, Page, Page and Hotham, 1980). The animals included the bivalves *Mytilus edulis*, *Placopecten magellanicus*, and *Macoma balthica*; the gastropods *Thais lapillus* and *Littorina littorea*; the crustaceans *Homarus americanus*, *Pandalus borealis*, *Carcinus maenas*, *Crangon septemspinosa* and *Gammarus locusta*; and the echinoderm *Strongylocentrotus droebachienses*. This suite of species is particularly relevant for Georges Bank. Organisms which survived the toxicity tests were then assayed for levels of cellular enzyme activities or changes in the rates of respiration, excretion and ingestion. Most organisms exposed to various concentrations of the mud fractions had cellular enzyme activities different from the controls. Differences in enzyme activities rates were apparent for different drilling fluids or components. Long-term effects were demonstrated by reduced growth rates in mussels.

When exposed to media containing barite or used drilling mud, the grass shrimp *Palaemonetes pugio* ingested settled barite and drilling mud particles (Conklin, Doughtie and Rao, 1980). Ultrastructural studies on the midgut of shrimp exposed for a 30-day period to 100 or 500 ppm barite-containing media showed that prolonged ingestion of barite causes marked perturbations in the posterior midgut epithelium. Conklin et al (1980) concluded that the long-held view that drilling muds were virtually non-toxic to aquatic organisms was not applicable to some of the muds used in drilling operations.

Exposure of the walking legs of the American lobster *Homarus americanus* for 3-5 minutes to 10 mg/L drilling mud suspended in seawater altered responses to food odors of 29% of the chemoreceptors (Derby and Atema, 1981). Similar exposure to 100 mg/L drilling mud resulted in interference with 44% of all receptors. Interference of the chemoreceptive systems by drilling muds may have consequences on fitness of animals during competition for resources.

The toxicity of four types of used chrome, lignosulfonate, drilling mud-seawater mixtures to different life stages of the opossum shrimp *Mysidopsis almyra* was evaluated (Carr, Reitsema and Neff, 1980). Results indicated that drilling mud exposure reduced biomass production and net growth efficiency of mysids at sublethal concentrations. Carr et al (1980) speculated that other metabolic processes concerned with energy transfer such as gamete production were likely to be affected by similar exposures. The acute toxicity of a used seawater chrome lignosulphonate drilling mud to several species of marine annelids, crustaceans and molluscs was evaluated

(Neff, Carr and McCulloch, 1981). The growth rate and reproduction of the archiannelid Dinophilus sp. were depressed by exposure to sublethal concentrations of the unfiltered mud aqueous fraction (MAF). In contrast, the polychaete Ophryotrocha labronica was able to reproduce successfully even in 100% MAF.

A long-term (100 days) multispecies toxicity test was conducted to elucidate biological effects of drilling fluids on representative estuarine organisms and developing communities (Rubinstein, Rigby and D'Asaro, 1980). Oyster (Crassostrea virginica) growth was significantly inhibited at concentrations of 30 and 100 ppm. Exclusion of colonizing polychaetes was observed in aquaria containing 100 ppm drilling fluids.

The effects of drilling mud on development of estuarine macrobenthic communities which result from settling planktonic larvae, were assessed by comparing number and species of animals that grew in uncontaminated and contaminated aquaria for at least 7 weeks (Tagatz, Ivey, Lehman, Tobia and Oglesby, 1980). Annelids were most sensitive to drilling mud and barite, and significantly fewer occurred in all contaminated aquaria than in control aquaria. For all phyla (Mollusca, Annelida, Chordata, Arthropoda), the average number of species per aquarium was significantly less in treatments with a cover of mud or barite than in the controls. The authors concluded that adverse effects of drilling mud on marine benthos could result from toxic constituents or from those that physically alter the substratum.

Field Studies

The benthic community in the vicinity of a drilling site at lower Cook Inlet, Alaska, was sampled before, during and after the drilling operation (Lees and Houghton, 1980). Some changes in benthic communities were seen near the drill site during the course of the study. However, no statistically significant differences could be attributed to the effects of drilling operations because of patchiness in faunal distributions probably due to differences in successional stages between areas sampled. Rates of accumulation of drilling muds and cuttings on the bottom in a dynamic environment such as found at the well were not great enough to measurably affect benthic populations.

Crippen, Hood and Greene (1980) examined the significance of increased metal concentrations in surficial sediment and benthic fauna resulting from drilling fluid disposal in the Beaufort Sea, Canada. No correlation was found between metal levels in the sediment and levels in infaunal organisms. Density and biomass values for benthic fauna were reduced within 300 m of the drilling platform and equivalent to background levels at distances of 300 m and beyond. Crippen et al (1980) concluded that smothering and modification of the natural marine sediments by the borrow material during construction and subsequent erosion of the platform probably had a greater impact to the marine environment than the disposal of drilling fluids.

Long-term effects of drilling mud exposure on the fouling community of a semi-submersible drilling platform were examined under actual discharge conditions (Benech, Bowker and Pimentel, 1980). The pontoon directly beneath the mud discharge displayed the greatest community differences. The two pontoons unaffected by mud displayed a continuity of community structure in marked contrast to the two mud-affected pontoons. Structural disruption in the latter two was linked to presence of mud particulates on the substratum. Mud substratum accounted for greater community structural disruption than did light or exposure. Long-term community composition was primarily affected by sedimentation within 10 m of the discharge.

Exploratory drilling at the shelf break off Atlantic City, New Jersey had several different effects on benthic invertebrates (Menzie, Maurer and Leathem, 1980). The crab Cancer borealis increased substantially between pre- and post-drilling surveys in the immediate vicinity and to the south of the well site. Moreover, the cuttings did not affect the abundance of the sea star Astropecten americanus, which was the most abundant megabenthic species. The sea star was probably attracted to mussels (M. edulis) that had fallen from the drilling rig and associated anchor chains. In contrast, sessile megabenthos (pennatulids) and macrobenthos were subjected to burial by drill cuttings within 150 m of the well site. Significant reductions in abundance of macrobenthos beyond the immediate vicinity of the well site were attributed in part to increased predation by fish and crabs and in part to increased clay content of the sediments from drilling mud. The affected areas extended predominantly to the southwest of the well site and, based on observed increase in clay, could be detected at least 800 m. Effects on macrobenthos probably extended beyond 800 m. Even though there was significant reduction in benthic densities between pre- and post-drilling operations, there was no significant change in trophic structure among polychaete feeding guilds (Maurer, Leathem, Menzie, 1981).

Macrofaunal Hydrocarbons

General

Hydrocarbon distributions in macrofauna showed some similarities and many differences in individual hydrocarbon components (NEOEB II, 1978). Species sampled included filter feeders (*A. islandica*, *P. magellanicus*), surface detritus feeders (*E. parma*, *S. droebachiensis*, *Ophiura* sp.), carnivores (*A. vulgaris*, *A. americanus*, *A. hastata*) and omnivores (*P. acadianus*). Species analyzed for hydrocarbons at each station over seasons, together with totals of aliphatic (f_1), aromatic (f_2) hydrocarbons, f_1 unresolved complex mixture (f_1UCM), and pristane concentrations for all macrobenthos analyzed, were presented in NEOEB II, 1978.

Strongylocentrotus droebachiensis

Surface detritovores and filter feeders were greatly influenced by hydrocarbons in zooplankton assemblages (NEOEB II, 1978). The sea urchin *S. droebachiensis* was typical of such a distribution. Zooplankton influence (pristane) was 2 orders of magnitude greater in the spring sample and 1 order higher in the fall. These surface-feeding benthic animals, together with other detritovores, directly reflected the biogenic components in the water column and were quite sensitive to variations in planktonic chemistry.

Pagurus acadianus

Results from analyses of the hermit crab *P. acadianus* collected during the fall indicated the complexity encountered in interpreting hydrocarbon data (NEOEB II, 1978). Since P. acadianus is an omnivore, its diet should be reflected in the hydrocarbon composition of the crab. The first and most obvious hydrocarbon was pristane, whose source was zooplankton. There was a dramatic increase in pristane levels of many P. acadianus collected during spring. This increase provided a chemical market of spring zooplankton bloom that occurred on the Bank. However, the levels of pristane were not constant throughout the Bank.

In addition to pristane hydrocarbon fractions of f_1 and f_2 were also measured in P. acadianus. A group of f_1 compounds, recognized as breakdown products of chlorophyll, also reached the ocean bottom and P. acadianus from a zooplankton source. These were present in most extracts of P. acadianus (NEOEB II, 1978). The n-alkane components, together with an accompanying UCM, were present in several extracts of P. acadianus at stations 32 and 39. The most likely source was small tar balls. Moreover, hydrocarbons associated with terrestrial plants and marsh grasses were also identified from P. acadianus. Finally, aromatic/olefinic (f_2) hydrocarbons were also present in the pagurids. It was concluded that f_2 hydrocarbon concentrations generally reflected various amounts of biogenic material and not anthropogenic contaminations.

Placopecten magellanicus

Placopecten magellanicus, a prominent commercially valuable bivalve on Georges Bank, was unfortunately not always sampled in numbers large enough to be useful for hydrocarbon determination. Two samples collected in spring and fall at station 4 had the same distribution of n-alkanes and biogenic hydrocarbons. Scallops collected in the fall had a larger percentage of biogenic hydrocarbons in the f_1 fraction.

The scallop analyses presented a problem that can only be solved by more sampling and analyses (NEOEB II, 1978). Scallops at station 4 (near the Argo Merchant wreck) in the spring and fall were definitely contaminated with petroleum hydrocarbons. The total concentration of the n-alkanes n-C_{14} to n-C_{34} in the spring were 2.2 μg dry weight, high values for any marketable species. The impact of the oil spill on the food habits of various species of groundfish was assessed by surveying stomach contents (Grose and Matson, 1977). Of the 305 fish stomachs examined, three samples representing stomach contents of 2 species of fish contained an oil-like material. Oiled caprellid and gammarid amphipods were found in a few stomachs.

Petroleum Contamination in Georges Bank Macrofauna

Tar Specks

Hydrocarbon analysis of benthic macrofauna on Georges Bank showed that petroleum hydrocarbons were present in a wide range of samples in significant concentrations over most areas of the Bank (NEOEB II, 1978; Boehm, Steinhauer, Fiest, Mosesman, Barak and Perry, 1979). Tar specks (miniature tar balls) were the major agents of this contamination. The source of the highly paraffinic tar balls was probably crude oil sludge which is cleaned from tanks during ballast pumping operations. Sea lanes to New York, Boston, and Portland pass to the north of the

Bank and through Great South Channel. Tripp, Farrington and Teal (1981) suggested that unburned coal could provide a quantitatively substantial input to total hydrocarbon levels in sand areas of the Bank. The circular current and tidal movement over the Bank tend to evenly distribute this sestonic material over the area (Table 20). *A. islandica* (summer - station 1) was the most contaminated of all samples analyzed, with a total concentration of n-alkanes of 12.8 μg/g dry weight. This bivalve exhibited sizeable concentrations related to petroleum at several stations throughout the year. *Asterias vulgaris* (winter - station 37) presented an example more typical of contamination with tar specks, whereas *Astropecten americanus* (spring - station 37) was unusual in that it had a slight bimodal distribution of n-alkanes. Oil was observed in the guts of interstitial harpacticoids and the polychaete *Ophyrotrocha* and adhering to the appendages of a burrowing amphipod following the aftermath of the *Argo Merchant* (Pratt, 1978).

Aromatics

The aromatic fraction of a sample (summer - station 26) was analyzed by mass spectrometry. Mass spectra results for various species are listed in Table 21. Sizeable concentrations of methyl naphthalene, phenanthrene, and M/E 252 (benzopyrene) were observed. This was a significant finding (NEOEB II, 1978). Organisms in the region have received inputs of aromatic hydrocarbons probably from shipping operations prior to offshore development. However, all samples did not contain aromatic hydrocarbons. Further study of the areal distribution of potential

Table 20.

MACROBENTHIC HYDROCARBON SAMPLES WITH TAR SPECKS CONTAMINATION
(taken from NEOEB II, 1978)

CRUISE	SPECIES	STATION	TOTAL HYDROCARBONS (µg/g)
Winter	Arctica islandica	1	132.8
	Asterias vulgaris	37	2.4
Spring	Pagurus acadianus	1	284.0
	Placopecten magellanicus	4	54.8
	Aphrodita hastata	18	
	Echinarachnius parma	18	10.2
	Strongylocentrotus droebachiensis	18	37.2
	Astropecten americanus	7	9.3
	Neptunea decemcosta	39	16.0
Summer	Arctica islandica	1	62.4
	Pagurus acadianus	4	31.2
	Leptasterias tenera	4	9.1
	Ophiura sarsi	42	48.5
Fall	Arctica islandica	1	83.4
	Leptasterias tenera	1	2.4
	Asterias vulgaris	4	4.0
	Placopecten magellanicus	4	15.3
	Astropecten americanus	13	4.5
	Asterias vulgaris	13	3.3
	Sclerasterias tanneri	26	2.8
	Placopecten magellanicus	32	97.3
	Arctica islandica	32	24.9
	Pagurus acadianus	32	13.4
	Buccinum undatum	32	88.4
	Asterias vulgaris	37	18.3
	Leptasterias tenera	39	3.5
	Pagurus acadianus	39	10.4

Table 21.

GC/MS DATA, AROMATIC HYDROCARBONS, MACROBENTHOS SUMMER CRUISE 1977 (ng/g dry weight)[a] (taken from NEOEB II, 1978)

STATION	SPECIES	NPH	MN	DMN	PHN	MPH	DMP	PYR	CRY	252
1	*Astarte castanea*	-	-	-	214	-	36	231	0.3	71
1	*Arctica islandica*	-	-	-	55	39		47	-	-
4	*Leptasterias tenera*	-	5.4	5.4	20	7.2	18.1	36.2	3.6	-
4	*E. parma*	-	-	-	6.1		10.6	9.1	-	-
26	*Sclerasterias tanneri*	-	-	-	-	-	-	27.4	-	-
26	*Cancer borealis*	-	136		39	-	-	-	-	36
32	*Pagurus acadianus*	-	-	-	-	-	-	-	-	-

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[a] NPH = naphthalene; MN = methylnaphthalene; DMN = dimethylnaphthalene; PHN = phenanthrene; MPH = methylphenanthrene; DMP = dimethylphenanthrene; PYR = pyrene + fluoranthene; CRY = crysene + triphenylene; 252 = benzofluorenes, benzopyrenes.

carcinogens in both commercially and ecologically important species would be of great interest.

UCM (f_1)

The unresolved complex mixture (UCM - f_1) was used as an indicator of anthropogenic input. Most specimens exhibited UCM to some extent. The quantitative amount of UCM did not correlate well with species, feeding type, station or season.

Ratios of UCM to total f_1 are shown in Figure 48 for the three species collected in most abundance. The ratio of f_1 UCM to total f_1 was fairly constant for A. islandica across stations and seasons. The ratio was more variable for E. parma and P. acadianus. The source of the UCM ultimately can be traced to the water column particulate matter which contained significant amounts of UCM (NEOEB II, 1978).

Conclusions

Hydrocarbon distributions in macrofauna did not show well-defined trends in the distribution of either biogenic compounds or petroleum-related hydrocarbons (NEOEB II, 1978). For example, even the same species (P. acadianus) collected during a given season showed marked qualitative and quantitative differences over the study region. Biogenic inputs from the water column were evident in filter feeders and detritovores during the spring and summer. However, transport processes coupling the water column and the benthos were not demonstrated with the present data base.

No geographic trends as far as hydrocarbon "hot spots" were identified. Evaluation of aromatic hydrocarbon levels in

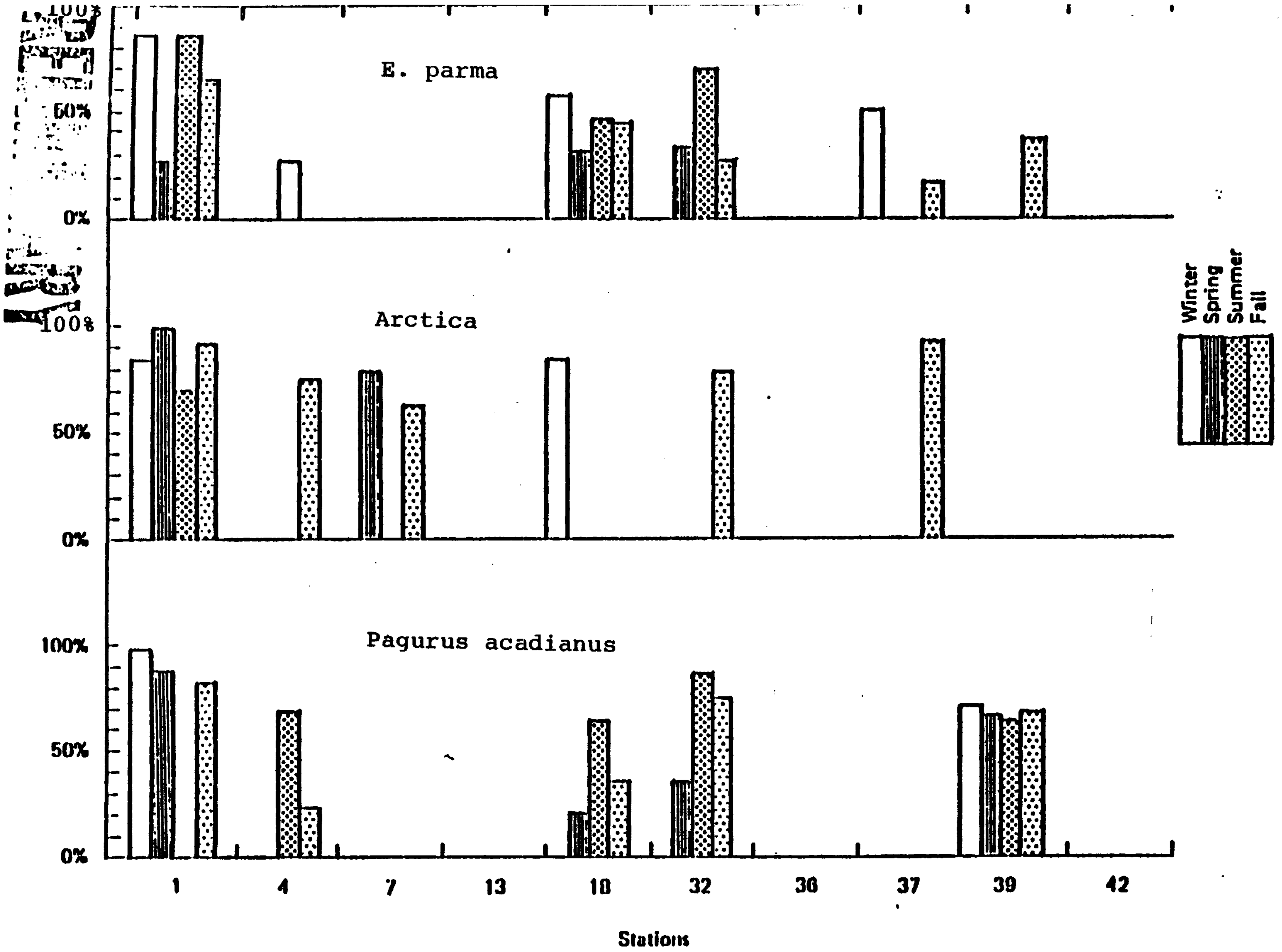


Figure 48. Macrobenthos hydrocarbons, f_1 (ucm)/total f_1 per selected species. (taken from NEOEB II, 1978)

macrofauna was difficult due to the small number of GC/MS analyses performed. However, polynuclear aromatics (PAH) were present in macrofauna and were found in commercially important species (A. islandica). Further evaluation of PAH distribution in segregated tissues (gut, muscle, gonad, etc.) will be required. Petroleum hydrocarbons were distributed over the Bank, probably in the form of tar specks, and did become incorporated into the food web of macrofauna.

Geographic Comparison

Considerable research on the effect of hydrocarbons and trace metals on marine organisms has been conducted (Malins, 1977; Neff, 1979; Vernberg et al, 1979). Further, body burdens of these contaminants are mainly problems in estuaries and coastal waters (Caspers, 1975). However, very little information on hydrocarbon body burdens is available for open-ocean species, particularly those on Georges Bank. To provide some expression of comparison of hydrocarbon body burdens on other areas, it is necessary to extrapolate findings from species that are as taxonomically or ecologically similar to Georges Bank fauna as possible. Moreover, modes of chemical analysis and units of measure are not always compatible with those used on Georges Bank biota, which also makes direct comparison difficult.

On Georges Bank, the following pristane values were obtained from analyses of the sea star Asterias vulgaris: Winter - 0.03 μg/g dry weight, spring - 0.0 to 0.33, summer - 0.18, and fall - 0.02 to 0.13. Hydrocarbon content (pristane) for Asterias rubens was reported at 35 (parts/10^8) in the Firth of

Clyde (Mackie, Whittle and Hardy, 1974). On Georges Bank pristane levels for the gastropod Buccinum undatum were 0.07-0.09 µg/g dry weight in the spring, 0.06-0.56 in the summer and 0.01-0.14 in the fall, while a pristane level of 21 (parts/10^8) was recorded for the same species in the Firth of Clyde (Mackie et al, 1974). Based on the spill of Bunker C oil in Chedabucto Bay, Nova Scotia, values of 21-94 µg/g wet weight were recorded for the sea urchin Strongylocentrotus droebachiensis (Scarratt and Zitko, 1972). On Georges Bank, values of aromatic (f_2) for S. droebachiensis were recorded as follows: winter - 1.3 µg/g dry weight, spring - 3.1-48.0, summer - 47.0 and fall 3.4-18.8.

Levels of polynuclear aromatic hydrocarbons taken from a variety of sources are presented in Table 22. Table 22 indicates much higher levels of benzopyrene in relatively polluted waters compared to relatively unpolluted waters. Values of PAHS from Georges Bank biota generally fall into levels associated with relatively unpolluted conditions. Mean levels of benzopyrene (µg/kg wet weight) recorded from Mytilus edulis and Mytilus californianus mainly from near-shore areas were as follows: Redondo Beach M. californianus 0.6, M. edulis 0.8; Royal Palms M. californianus 0.5, M. edulis 1.0-1.1; Seal Beach M. californianus 2.3, M. edulis 1.9-3.0 (Dunn and Young, 1976). Highest values recorded for M. californianus and M. edulis were 2.3 and 8.2, respectively. Although attention to larger (more tissue to work with) and commercially (edible) important species is justified in analyses of PAHS, some of the smaller and more numerous soft-bodied organisms should be

Table 22.

Levels of polynuclear aromatic hydrocarbons (μg/kg wet weight)
(taken from IMCO et al., 1977)

	Relatively Unpolluted		Relatively Polluted	
	Benzopyrene	Benzoanthrene	Benzopyrene	Benzoanthrene
Mytilus	ND - 28(55*)	3.8 - 4.3	(11 - 750)	-
Mercenaria	0.38 - 1.1	4.4	8.2- 16	-
Ostrea	ND - 4.0	5.8	ND - 6.0	-
Crassostrea	ND - 1.4	8.7	26.0	<10
Cardium	ND - 5.0	<2.0	ND -(25-780) 11.7 (tainted)	6 ND
Pecten	4 - 6.7	5.3	-	-
Chlamys	(90)	-	40	-
Solen	ND - (12.5)	-	-	-
Tapes	ND	-	(100 - 550)	-
Crangon	ND - 0.5	0.7	ND - (90)	-

*Figures in brackets = dry weight

ND = not detectable

analysed in view of opportunities for biomagnification.

Values of total hydrocarbons (μg/g dry weight) from the hard clam Mercenaria mercenaria were reported from Narragansett Bay (Farrington and Quinn, 1973). Values ranged from 26 μg/g near the entrance to the sound and 160-163 μg/g in the Providence River. They concluded that sediments and clams near sewage effluents were contaminated by petroleum hydrocarbons. In general, levels of total hydrocarbons (μg/g dry weight) of a variety of taxa, including bivalves, on Georges Bank were lower than the highest values recorded by Farrington and Quinn (1973). There were some exceptions as a few values in Astarte sp., P. acadianus, O. sarsi, S. droebachiensis occasionally exceeded values reported in the Providence River (NEOEB II, 1978).

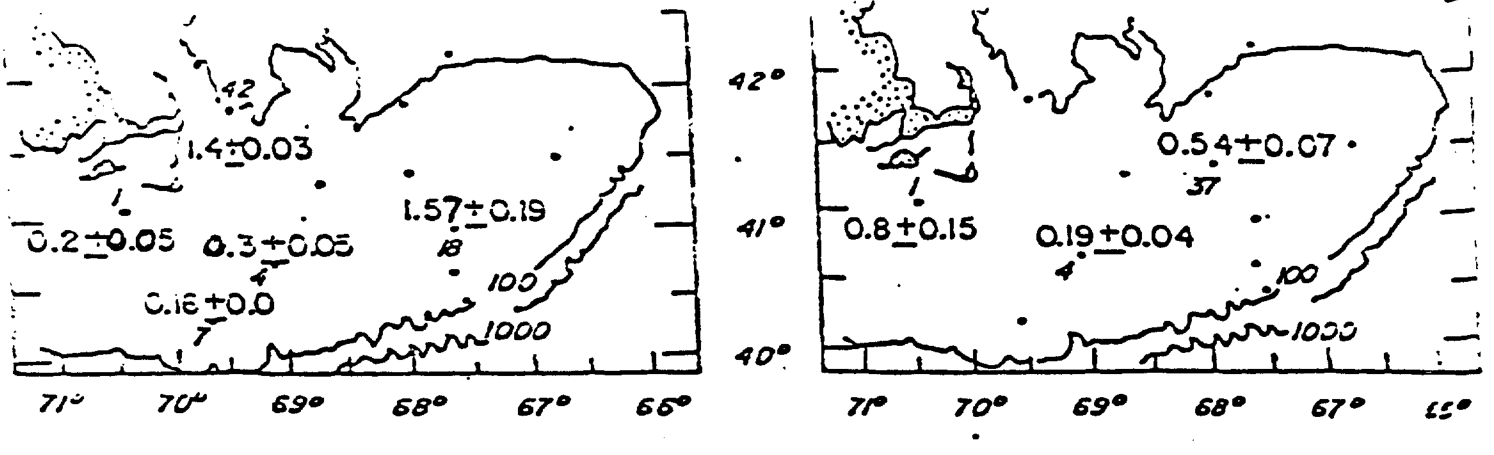
Geographic Distribution in Trace Metal Composition in Selected Macrofauna

General

Geographic distributions of trace metals (ppm dry weight) found among selected members of the macrobenthic community in May 1977 were selected for description as indications of trends during the year (Sick, 1978). Species selected as representative of most macrobenthic assemblages throughout the year were A. islandica, E. parma, S. droebachiensis, P. acadianus, A. vulgaris and O. sarsi (Figures 49-55).

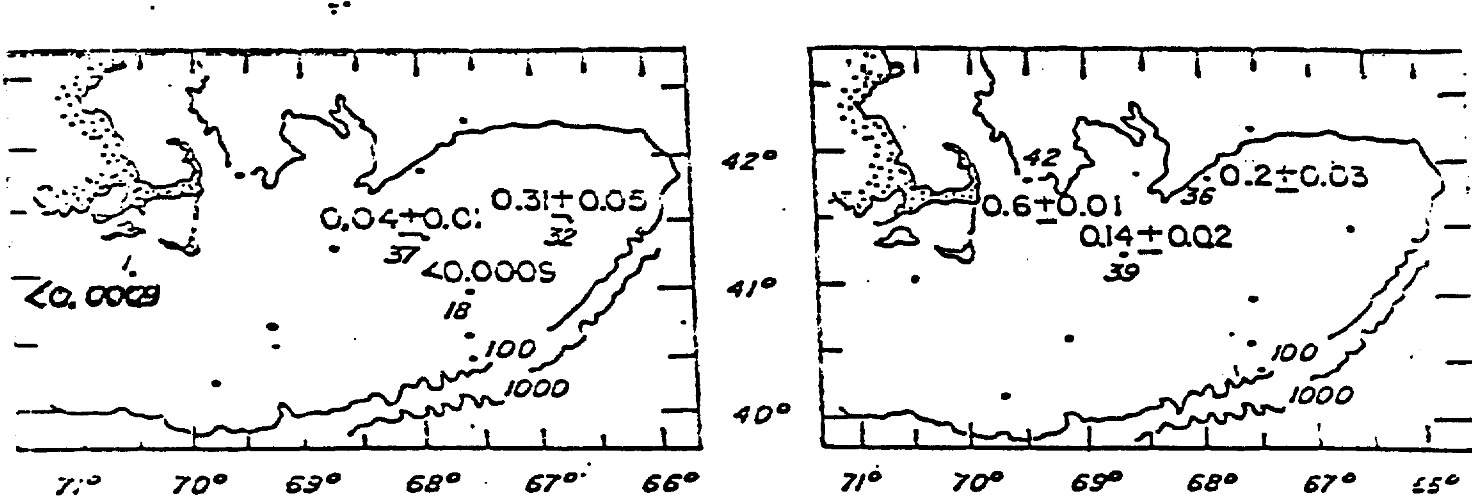
Cadmium

Cadmium concentrations among the six representative species were indicative of geographic trends found during the year (Figure 49). Concentrations of Cd were distinctly higher among populations at nearshore station 1 and stations on the northwest



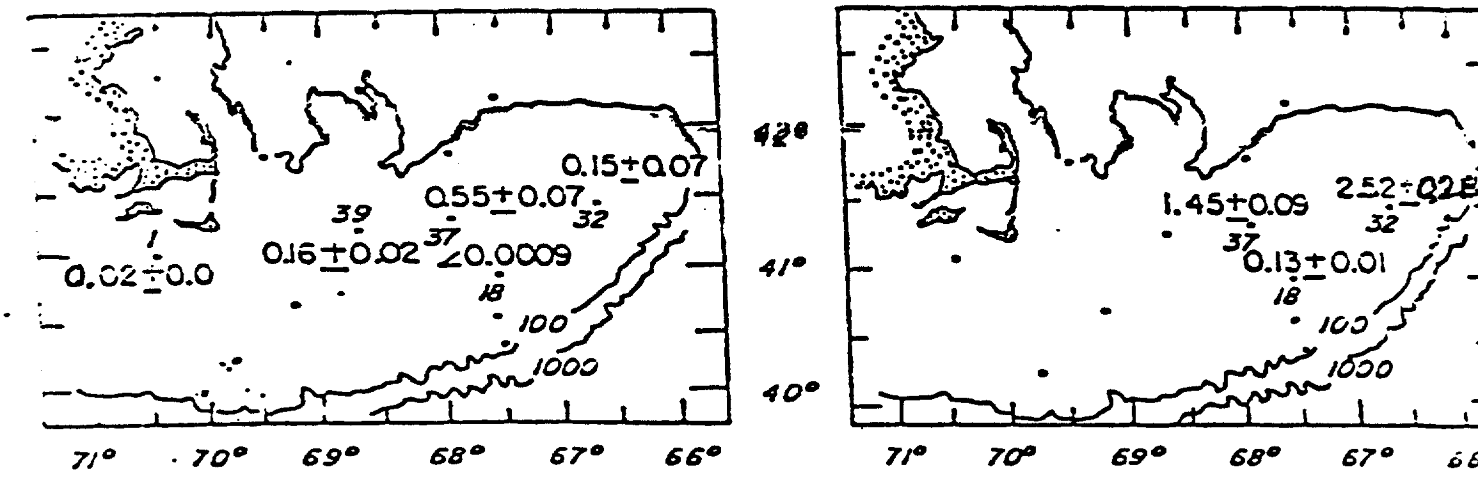
Arctica islandica

Asterias vulgaris



Echinarachnius parma

Ophiura sarsi



Pagurus acadianus

Strongylocentrotus droebachiensis

Figure 49. Concentrations and geographic distributuions of cadmium among selected macrobenthic invertebrates collected during May, 1977. Concentrations are expressed as means and standard deviations from five determinations. (taken from Sick, 1978).

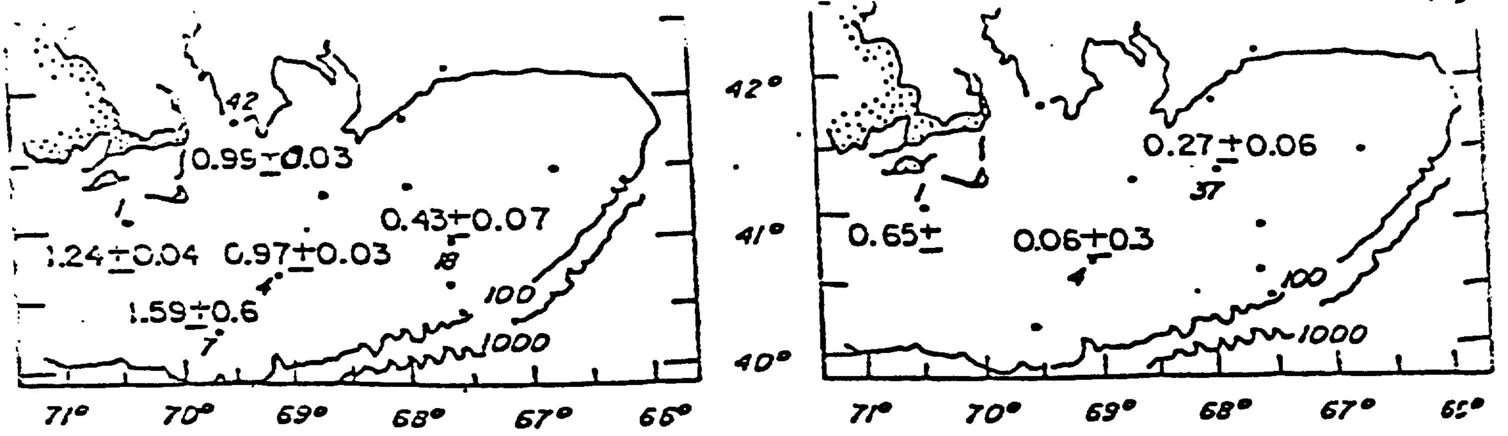
part of Georges Bank (stations 36, 39 and 42). Highest values were found in *A. islandica* (adductor muscle) and *S. droebachiensis* (1.57 and 2.52 ppm, respectively) and lowest values in *E. parma* (0.04 and <0.0009 ppm) (Sick, 1978).

Chromium

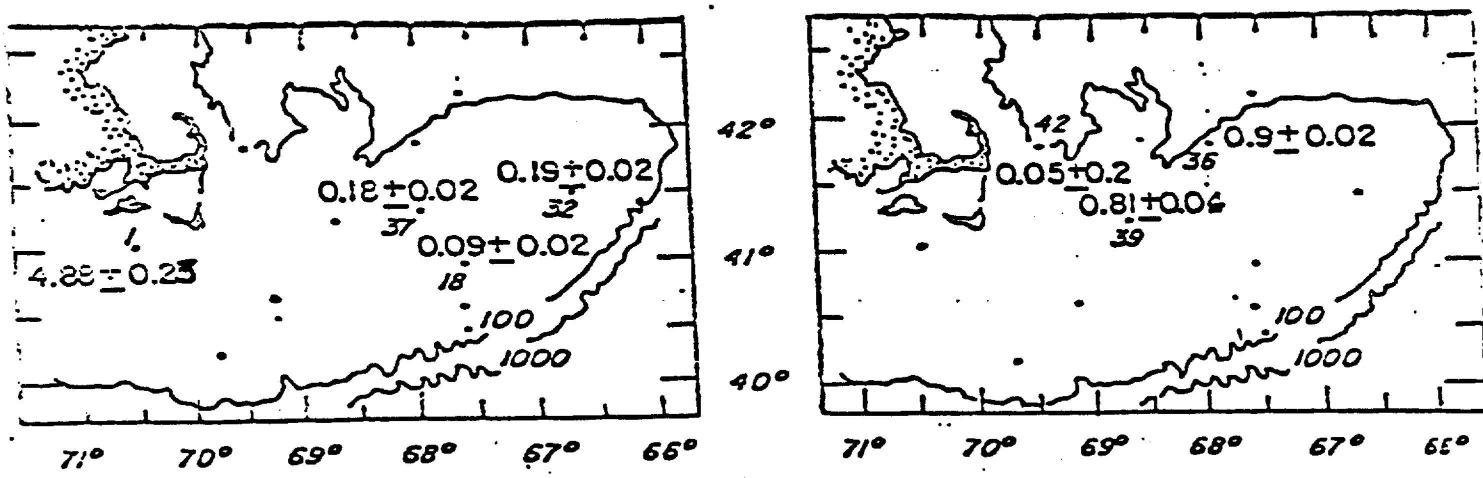
Chromium concentrations were generally higher in macrobenthos at station 1 and stations along the northwestern portion of the Bank than offshore stations or ones situated on the southeastern portion of the Bank (Figure 50). For example, concentrations of Cr in the adductor muscle of *A. islandica* were 1.24, 1.59, and 0.99 ppm at nearshore stations 1, 7, and 42, respectively. In comparison, specimens from station 18 (center of Georges Bank) had an average Cr concentration of 0.43 ppm. *E. parma* and *S. droebachiensis* had the highest average concentrations of Cr (1.34 and 4.46 ppm, respectively) while *A. vulgaris* and *O. sarsi* had the lowest average values (0.11 and 0.001 ppm, respectively) (Sick, 1978).

Copper

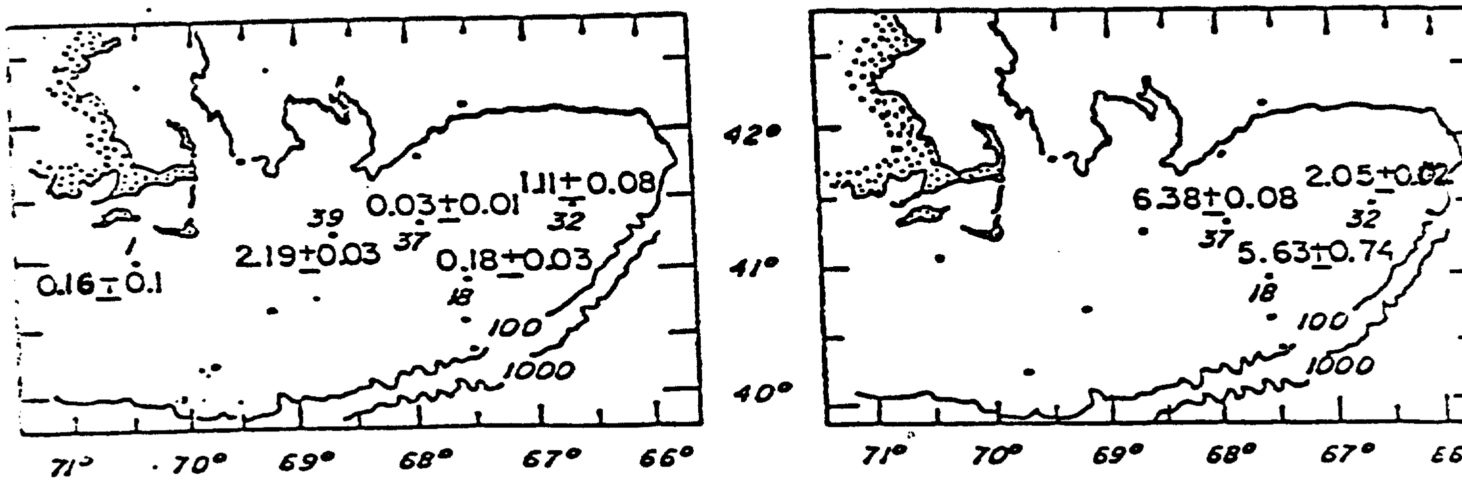
Macrobenthos analyzed for copper from inshore stations (1, 4, 7, 42) had consistently higher copper values relative to other stations (Figure 51). Moreover, organisms obtained from northern stations (36) and stations located in the center of the Bank (32, 37, and 39) consistently had copper values higher than organisms obtained from more southerly stations (18). Average Cu concentrations in *A. islandica*, *E. parma*, and *S. droebachiensis* were similar (ca 5 to 20 ppm). Highest Cu concentrations were measured in individuals of *P. acadianus*,



Arctica islandica *Asterias vulgaris*

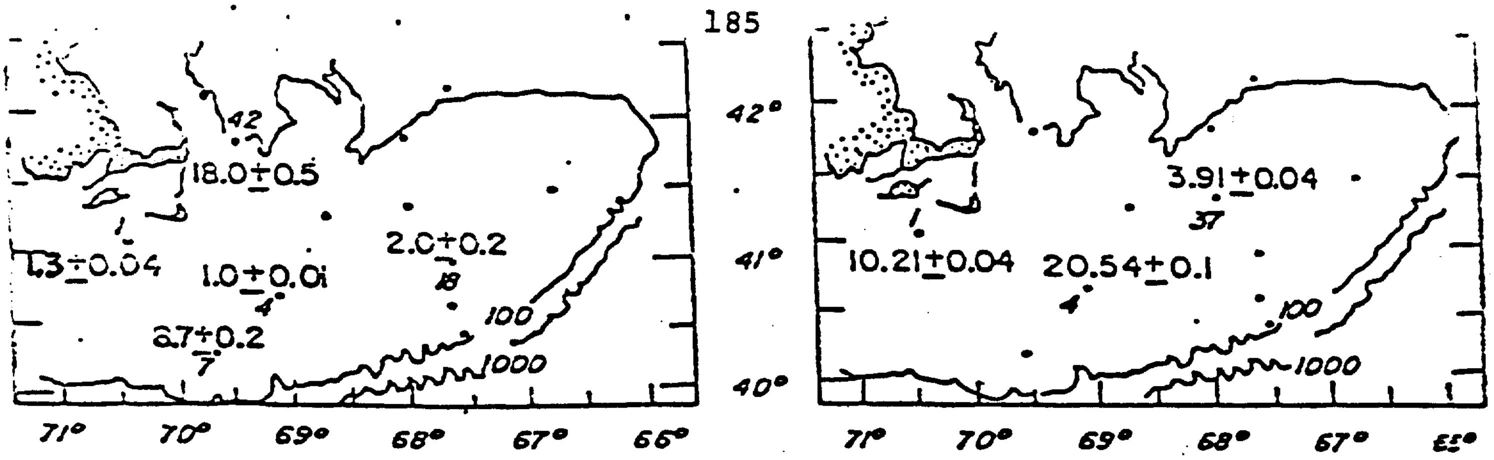


Echinarachnius parma *Ophiura sarsi*

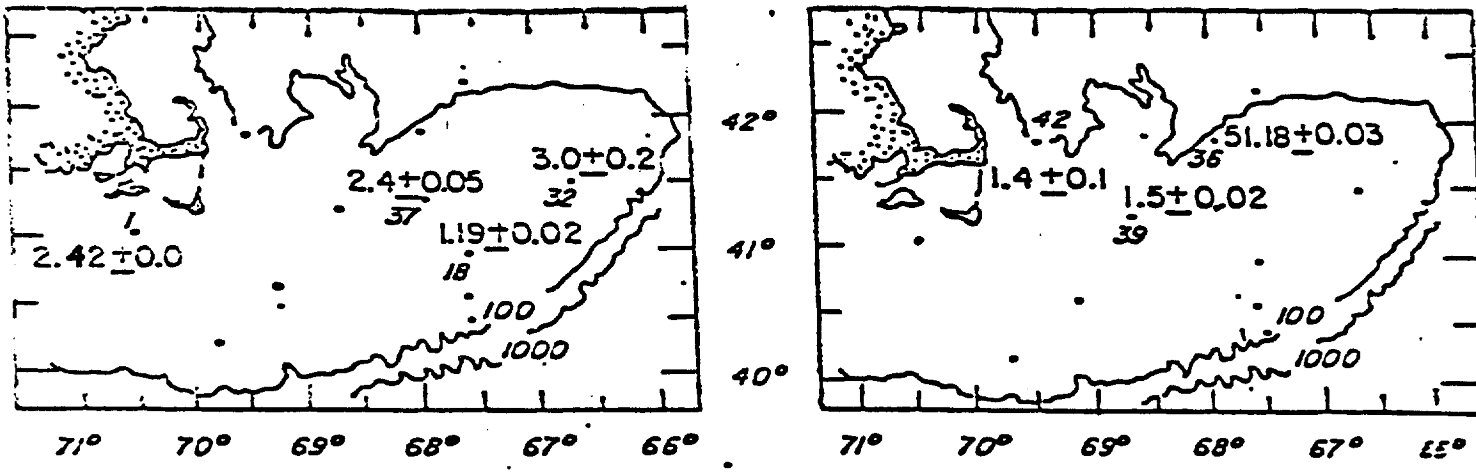


Pagurus acadianus *Strongylocentrotus droebachiensis*

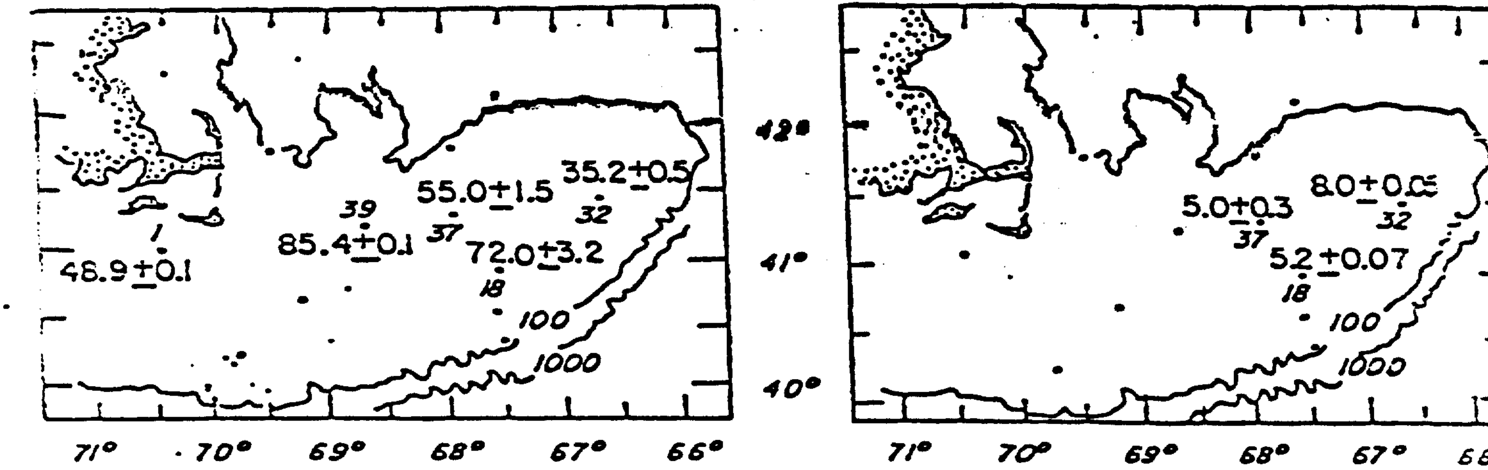
Figure 50. Concentrations and geographic distributions of chromium among selected macrobenthic invertebrates collected during May, 1977. Concentrations are expressed as means and standard deviations from five determinations. (taken from Sick, 1978).



Arctica islandica *Asterias vulgaris*



Echinarachnius parma *Ophiura sarsi*



Pagurus acadianus *Strongylocentrotus droebachiensis*

Figure 51. Concentrations and geographic distributions of copper among selected macrobenthic invertebrates collected during May, 1977. Concentrations are expressed as means and standard deviations from five determinations. (taken from Sick, 1978).

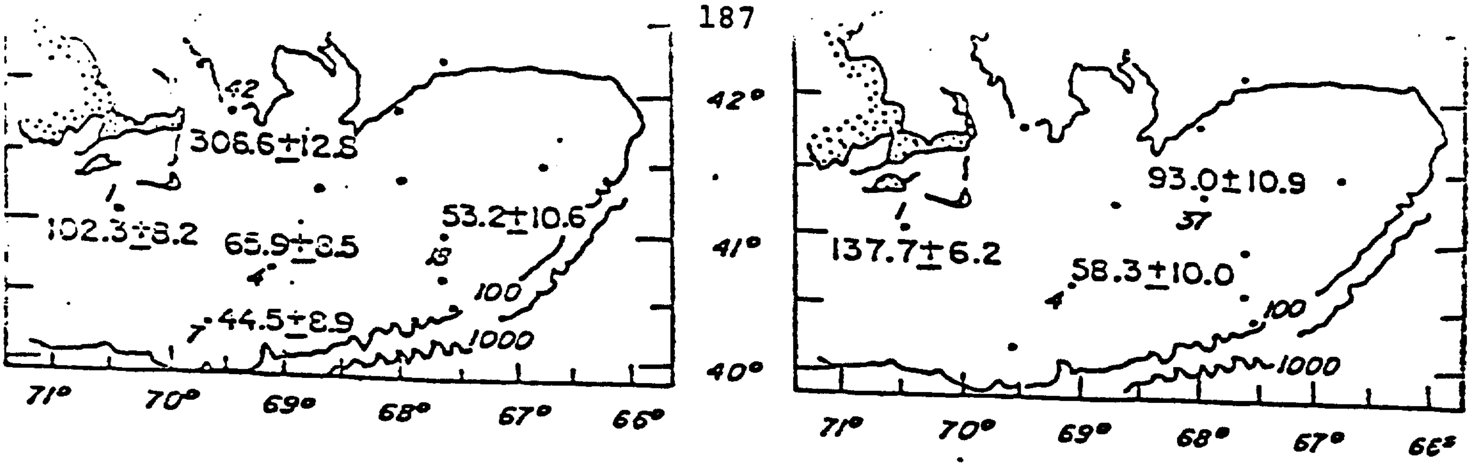
O. sarsi and *A. vulgaris* (Ca 20 to 90 ppm).

Iron

A. islandica had significantly higher concentrations of iron in nearshore populations station 1, 102.3 ppm and 42, 306.6 ppm relative to stations on Georges Bank (station 18, 53.2 ppm) (Figure 52). *A. vulgaris* showed a similar trend. In contrast, *E. parma* and *P. acadianus* both had significantly higher concentrations of Fe at stations on the northern and central portions of Georges Bank. Most of the species analyzed had similar concentrations of Fe. Exceptions included *E. parma* and *S. droebachinesis*, which both had significantly higher concentrations (4114 ppm at station 37 and 4380 ppm at station 18, respectively).

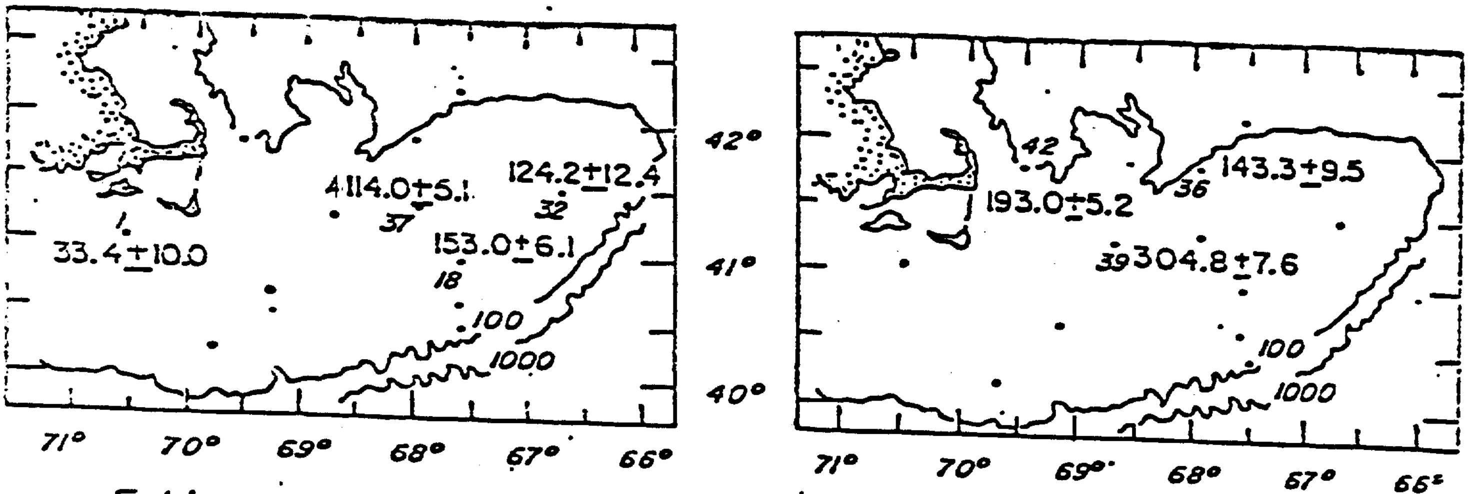
Nickel

Concentrations of nickel were distinctly higher in organisms collected nearshore and at the northwestern margin of Georges Bank (Figure 53). For example, specimens of *A. islandica* from stations 1 and 42 contained average Ni concentrations of 22.8 and 54.1 ppm, respectively, in contrast to concentrations of 6.5 and 3.6 ppm at stations 4 and 18, respectively. Similar trends were found for *A. vulgaris* and *E. parma*. Although no specimens of *O. sarsi* and *S. droebachiensis* were found inshore for these analyses, higher concentrations of Ni were measured in these species at stations 36 and 37 in comparison to more southeasterly station 18. Populations of *P. acadianus* contained lower concentrations of Ni from stations on the northern side of the Bank (Figure 53). As was the case for most metals, *S.*



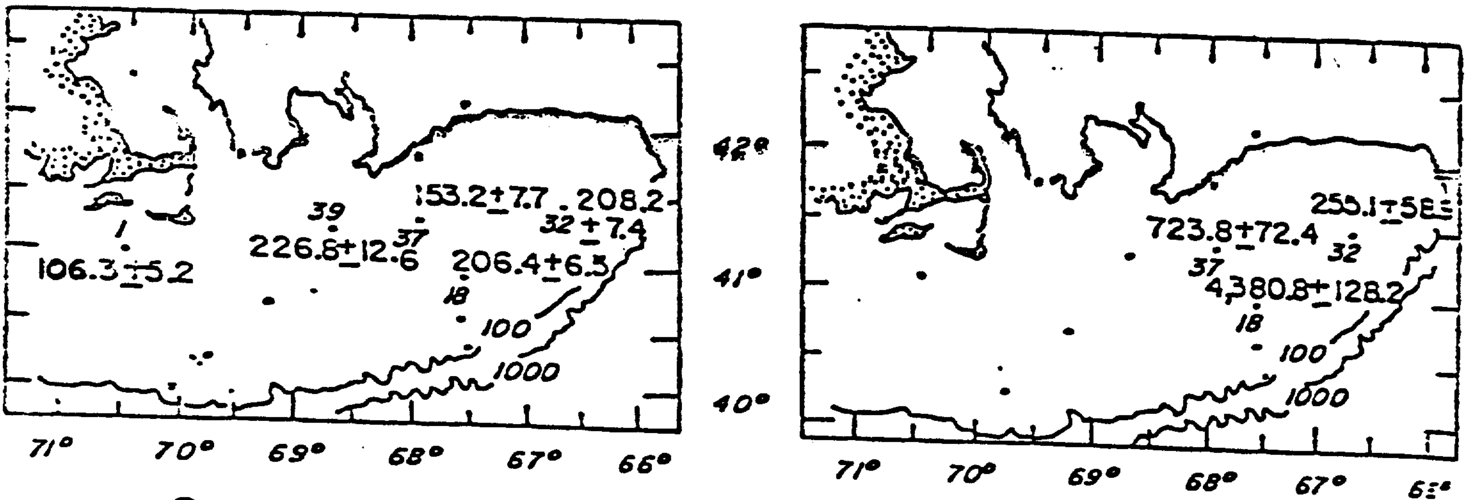
Arctica islandica

Asterias vulgaris



Echinarachnius parma

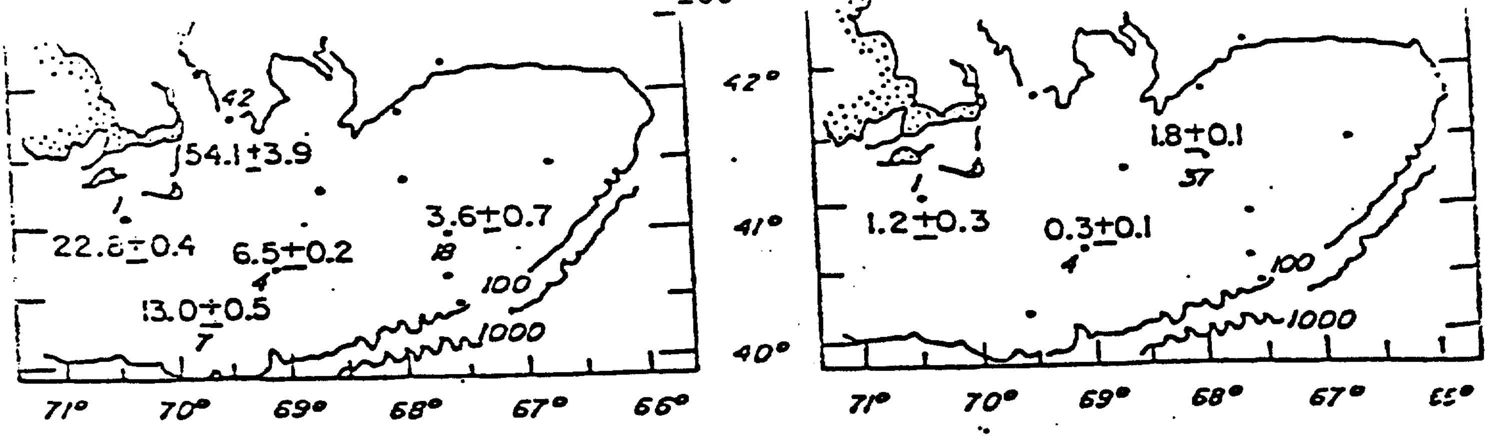
Ophiura sarsi



Pagurus acadianus

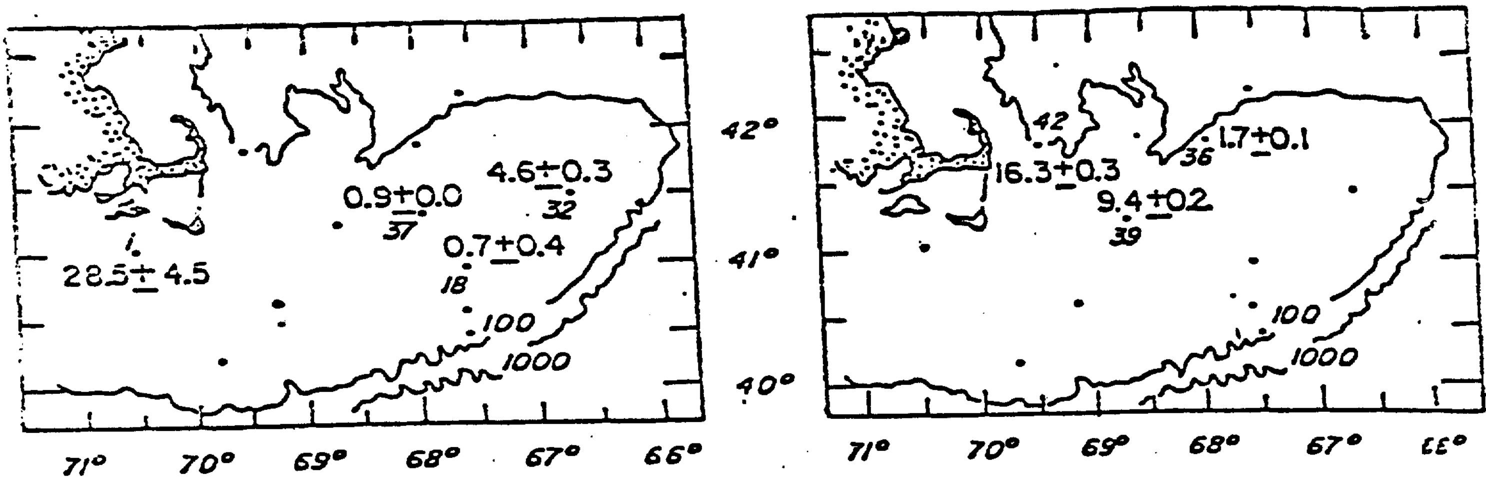
Strongylocentrotus droebachiensis

Figure 52. Concentrations and geographic distributions of iron among selected macrobenthic invertebrates collected during May, 1977. Concentrations are expressed as means and standard deviations from five determinations. (taken from Sick, 1978).



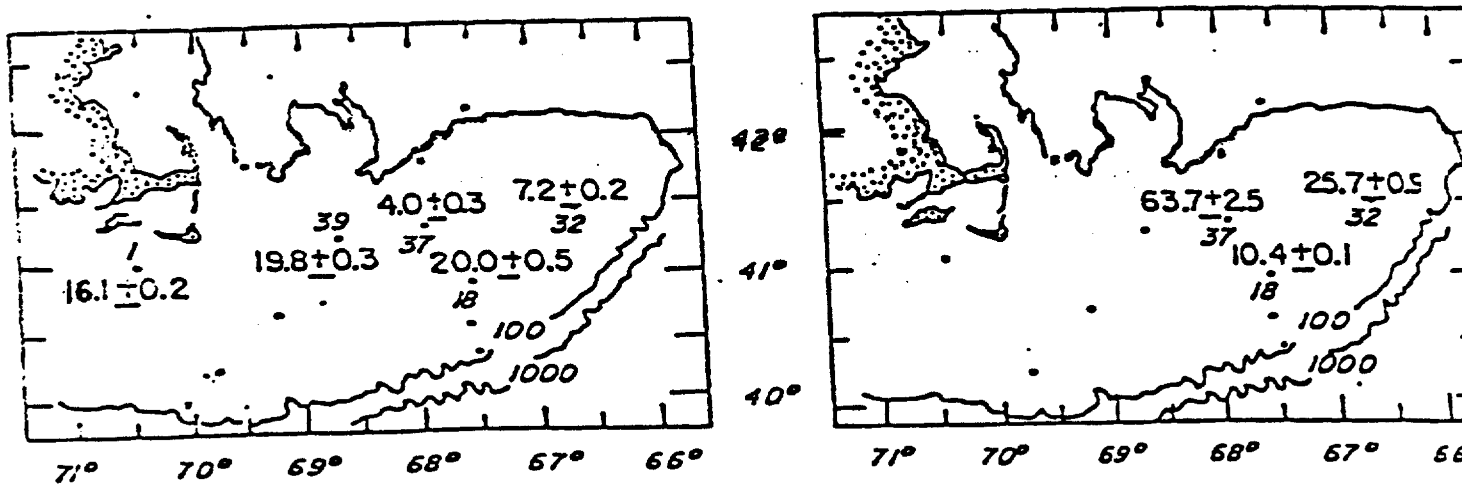
Arctica islandica

Asterias vulgaris



Echinarachnius parma

Ophiura sarsi



Pagurus acadianus

Strongylocentrotus droebachiensis

Figure 53. Concentrations and geographic distributions of nickel among selected macrobenthic invertebrates collected during May, 1977. Concentrations are expressed as means and standard deviations from five determinations. (taken from Sick, 1978).

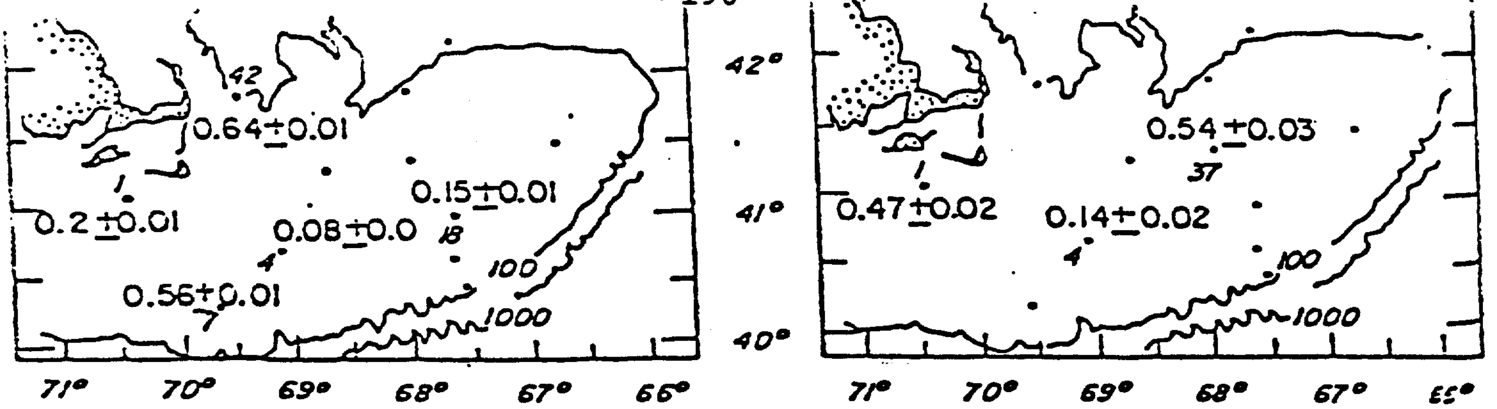
droebachiensis tended to have highest concentrations of Ni (63 ppm). In addition, relatively high concentrations (54 ppm) were also measured in adductor muscle tissue of A. islandica.

Lead

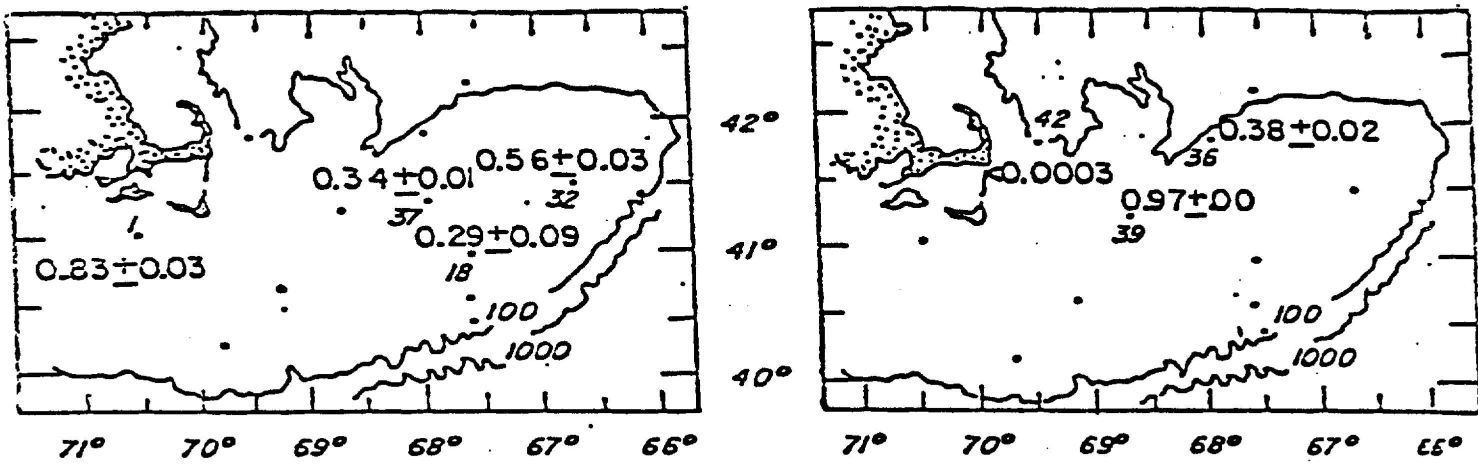
Distribution of lead in macrobenthos followed a gradient in concentrations from high inshore values and those along the northwestern slope of the bank to lower values along the most seaward and southeastern stations (Figure 54). As an illustration of this pattern, A. islandica showed relatively high values of 0.20, 0.64 and 0.56 ppm at stations 1, 42 and 7, respectively relative to 0.08 and 0.15 at stations 4 and 18, respectively. A similar trend was determined for A. vulgaris, E. parma and S. droebachiensis. In contrast, specimens of O. sarsi and P. acadianus contained relatively high values on Georges Bank. Compared to other metals analyzed, concentrations of lead were extremely low in most macrobenthos. Many stations and species had specimens with Pb concentrations below AAS detection limits. Consistent with other metals, S. droebachiensis had highest Pb concentrations (3.58 ppm).

Zinc

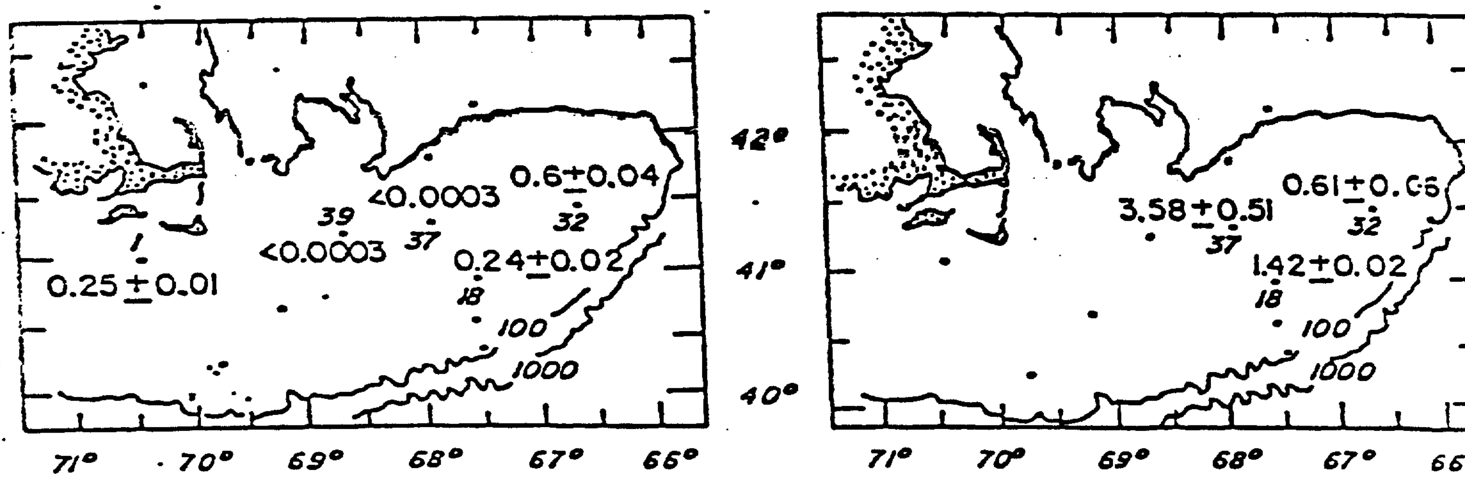
Relative to other stations, zinc concentrations in most macrobenthos were at least twice as concentrated in inshore stations or stations in the northwestern margin of the Bank (Figure 55) (Sick, 1978). For example, concentrations of Zn in A. vulgaris were 254.0 and 252.4 ppm at stations 1 and 37, respectively, compared to 67.5 at station 4. Tissues of P. acadianus contained concentrations of 175.0, 120.6, and 213.3



Arctica islandica *Asterias vulgaris*

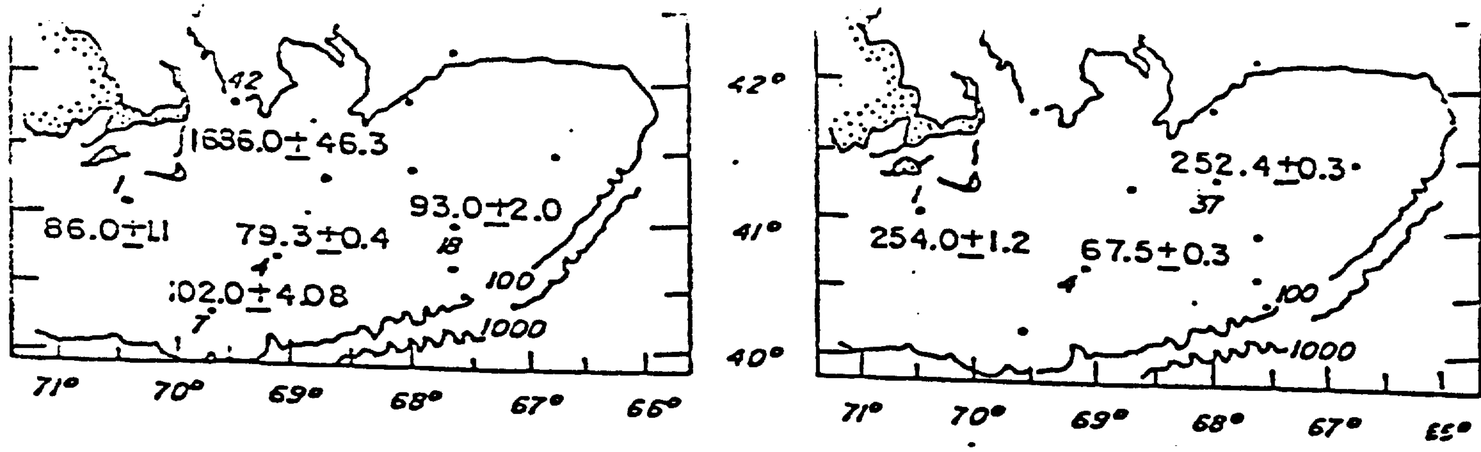


Echinarachnius parma *Ophiura sarsi*



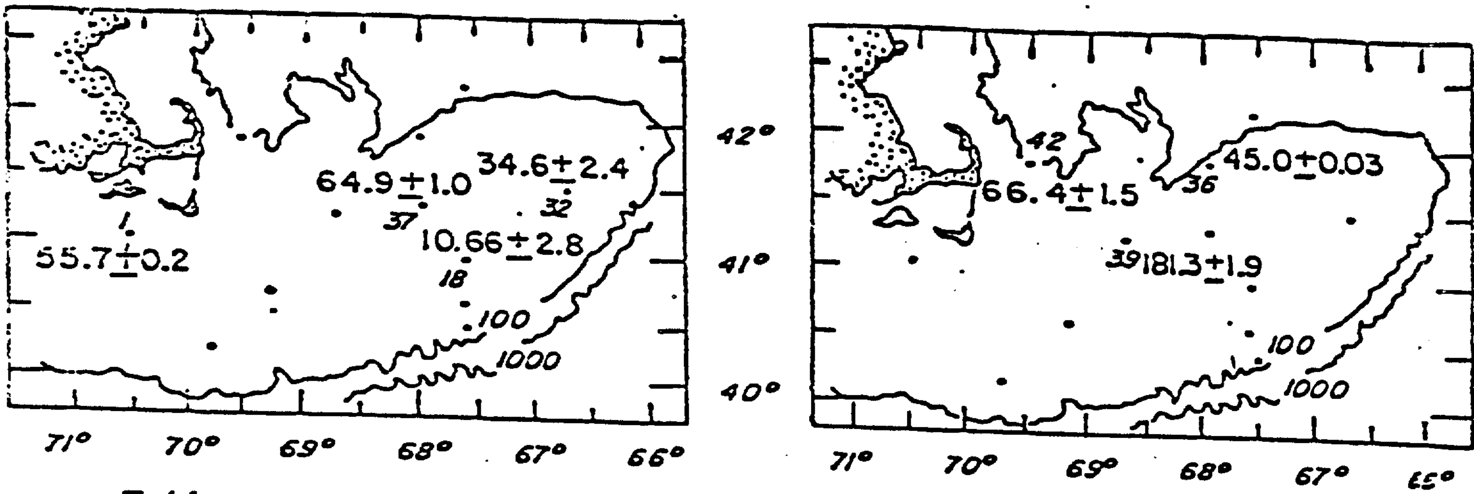
Pagurus acadianus *Strongylocentrotus droebachiensis*

Figure 54. Concentrations and geographic distributions of lead among selected macrobenthic invertebrates collected during May, 1977. Concentrations are expressed as means and standard deviations from five determinations. (taken from Sick, 1978).



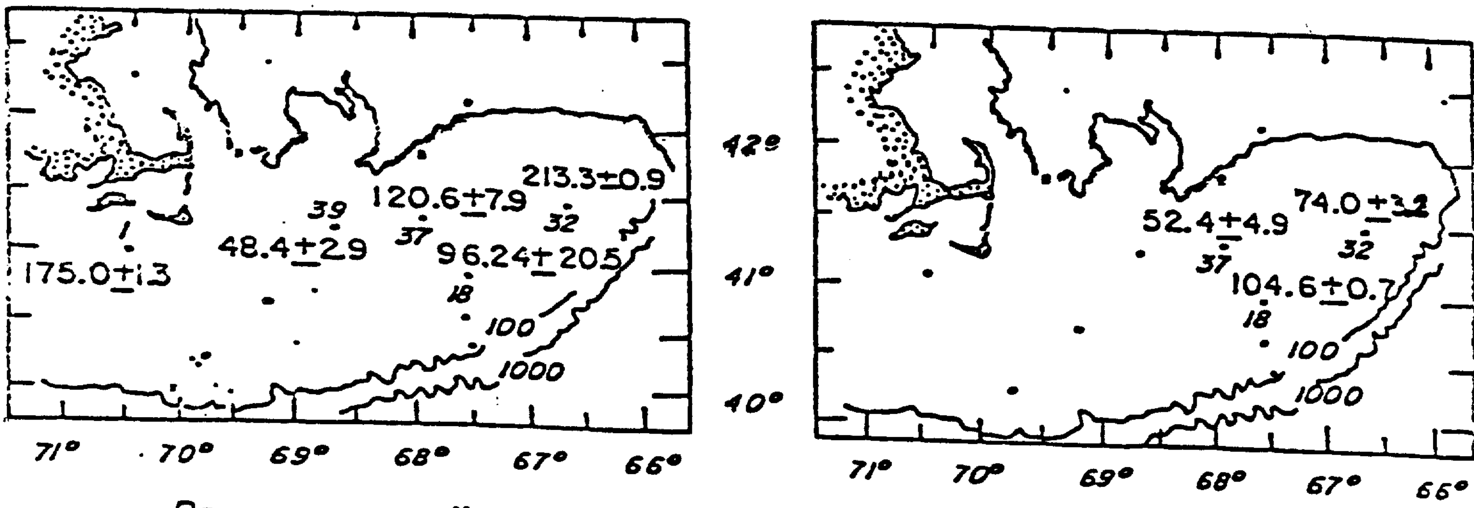
Arctica islandica

Asterias vulgaris



Echinarachnius parma

Ophiura sarsi



Pagurus acadianus

Strongylocentrotus droebachiensis

Figure 55. Concentrations and geographic distributions of zinc among selected macrobenthic invertebrates collected during May, 1977. Concentrations are expressed as means and standard deviations from five determinations. (taken from Sick. 1978).

ppm at stations 1, 37 and 32, respectively. More southerly station 18 had a concentration of 96.2 ppm. Zn concentrations in E. parma showed a similar trend. In contrast, Zn concentrations in O. sarsi and S. droebachiensis did not display distinct inshore-offshore or north-south gradient patterns (Figure 55). The highest concentration of Zn was 1686 ppm, measured in adductor muscle of A. islandica at station 42.

Seasonal Variation in Geographic Distribution of Trace Metals in Selected Macrofauna

Seasonal and geographic comparisons among macrobenthos were extremely difficult to meaningfully assess (Sick, 1978). In addition to sporadic occurrence of some species, seasonal variation limited making generalizations for even individual species and stations. To facilitate some comparison, several stations representing relatively uniform conditions (sediment regime, bottom topography, and hydrography) were conveniently grouped (Sick, 1978).

In terms of seasonal trends, trace metal concentrations were usually highest during fall and winter, intermediate in value during the spring, and significantly low during the summer. Trace metal concentrations obtained during the summer were close to or below analytical detection limits for all of the metals analyzed. In the nearshore zone, represented primarily by analyses of macrobenthos from station 1, highest trace metal concentrations were generally measured during the autumn. For example, among populations of E. parma, highest Cu concentrations (578.2 ppm) were found in November samples, while lowest concentrations (<0.0009 ppm) occurred among August samples.

A similar pattern in *E. parma* was recorded for Cd, Cr, Fe, Ni and Pb.

Geographically, there was a distinct seasonal reversal in trace metal concentrations between nearshore macrobenthos compared to Georges Bank stations (Sick, 1978). For instance, *E. parma* collected at nearshore station 1 in February 1977 had significantly higher concentrations of Cr, Cu, Fe, Ni and Pb than the same species obtained offshore (station 37). In contrast, concentrations of the same metals were generally higher among Georges Bank populations of *E. parma* during the summer. In fall, specimens from station 1 again contained higher trace metal concentrations. Although the geographic and seasonal continuity was much less continuous for other macrobenthic species, a similar trend was apparent among all of the benthos analyzed.

Seasonal Variation in Geographic Distribution of Trace Metals in Tissues of Selected Macrofauna

Much of the variation in trace metal composition among macrobenthos was specific to the type of metal and organ analyzed (Sick, 1978). For example, gill tissue dissected from *P. magellanicus* contained distinct maxima in trace metal concentrations during late summer and fall. Concentrations of Cr were 0.43, 7.82, and 2.75 ppm for gill tissues sampled in spring, summer, and fall, respectively. Concentrations of other trace metals in gill tissue showed identical seasonal patterns.

The digestive gland was found to have a predominantly summer minimum trace metal pattern. For instance, Cr concentrations of 6.45, 1.92 and 3.61 ppm were measured in tissues of *P. magellanicus* for spring, summer, and fall, respectively.

A similar pattern occurred for other metals except for Pb, which peaked in summer gill tissue.

Both mantle and muscle tissues were conservative, with only small seasonal fluctuations and no seasonal patterns (Sick, 1978). Exceptions included seasonal variation in Cd and Fe concentrations among mantle tissue. In the mantle of P. magellanicus, Cd concentrations were 2.72, 6.96 and 16.8 ppm during spring, summer, and fall, respectively. Fe concentrations for these seasons were 283.9, 28.2, and 273.9 ppm. Fe concentrations in mantle tissue of other macrobenthos also were found to be the only concentrations having seasonal variation. Spring, summer and fall values of Fe were 119.7, 8.03 and 47.5 ppm for B. undatum and 110.7, 86.2, and 102.8 ppm for A. islandica, respectively. In general, seasonal trends and variations were small in muscle tissues. Muscle tissue from B. undatum contained high trace metal concentrations. Fe concentrations during the spring were 66.4, 95.6 and 25.6 ppm for muscle tissue of A. islandica, B. undatum and P. magellanicus. Although other metals had this same trend among these three species, concentrations of Cu showed the greatest magnification being 3.25, 52.1, and 2.4 ppm in respective species.

Geographic Comparison

There is a much larger data base for trace metal analyses than hydrocarbons. The reason for this is that serious environmental concern was raised earlier about trace metals than hydrocarbons, and the latter are more expensive to analyze than the former. However, the variety of taxa covered by trace metal values is still primarily limited to large and commercial species, although the range of taxa is generally broader than those analyzed for hydrocarbons. Moreover, there seems to be a greater mode of conformity in trace metal analyses than with hydrocarbon analyses, which makes comparison of findings on Georges Bank with other areas relatively easier than with hydrocarbon analyses.

Trace metal analyses in the BLM baseline study focused on 6 species: A. islandica, E. parma, S. droebachiensis, P. acadianus, A. vulgaris and O. sarsi (Sick, 1978). Some seasonal data were also provided on B. undatum and P. magellanicus. Concentrations of Cd, Cr, Cu, Ni, Pb, Zn in A. islandica collected from Georges Bank in 1977 were 0.16-1.4 ppm (dry weight) 0.43-1.59 ppm, 1.3-18.0 ppm, 3.6-22.8 ppm, 0.08-0.64 ppm and 79.3-1686.0 ppm, respectively (Sick, 1978). For the same species, Wenzloff, Greig, Merrill and Ropes (1979) reported Cd levels of 0.54 ppm, Cr 1.03 ppm, Cu 7.16 ppm, Ni 0.91 ppm, Pb 1.8 ppm and Zn 12.6 ppm (wet weight) at 41°-40°30' from the Middle Atlantic Bight Continental Shelf. Values at the southern end of their study area (38°30'-36°30') were: Cd 0.39 ppm, Cr <1.1 ppm, Cu 2.84 ppm, Ni <0.59 ppm, Pb <0.9 ppm and Zn 10.4 ppm. Body burdens of trace metals in A. islandica were generally higher on Georges Bank than those reported farther south (Wenzloff et al, 1979). There is a definite pattern of a latitudinal cline in trace metal concentrations in A. islandica for the portion of the shelf ranging from Georges Bank to Chesapeake Bay. This pattern should be confirmed with other taxa. Assuming additional taxa show similar patterns, the processes and mechanisms controlling the patterns should be examined.

Mean metal concentrations (ppm/dry weight) of P. magellanicus whole animal tissue were determined from within and around two ocean disposal sites off the Delmarva Peninsula (Pesch, Reynolds and Rogerson, 1977). Mean values of Cd 20.9 ppm, Cr 3.08 ppm, Cu 7.31 ppm, Fe 803 ppm, Ni 4.41 ppm, Pb 3.59 ppm and Zn 1-5 ppm were recorded. Comparison with trace metal values in P. magellanicus from Georges Bank is difficult because the latter was analyzed for digestive gland, gills, mantle and muscle. Values in the digestive gland of P. magellanicus were commonly the highest. Mean values of Cd in the digestive gland ranged seasonally from 43.09-220.6 ppm, Cr 1.92-6.45 ppm, Cu 11.4-25.5 ppm, Fe 678.7-1124 ppm, Ni 4.23-41.0 ppm, Pb 0.64-1.98 ppm and Zn 175.5-374.3 ppm. The only metal lower on Georges Bank than the disposal sites was Pb.

On Georges Bank, Cd values in the digestive gland of the gastropod Buccinum undatum ranged seasonally from 7.1-206 ppm, Cr 1.1-2.5 ppm, Cu 29.4-83.3 ppm, Fe 168.2-326.4 ppm, Ni 2.4-38.7 ppm, Pb 0.13-1.0 ppm and Zn 221-5583 ppm. In the Firth of Clyde near a sludge dump area, trace metal values (dry weight) in Buccinum undatum were: Cd 5.7 ppm, Cr 25.0 ppm, Cu 78 ppm, Ni 8.5 ppm, Pb 41.0 ppm and Zn 650 ppm (Mackay, Halcrow and Thornton, 1972). Cr and Pb values at the dump site were markedly higher than in B. undatum from Georges Bank. Levels of the other metals were roughly comparable at both sites.

For Pagurus acadianus and Asterias vulgaris on Georges Bank, the following trace metal values were recorded: P. acadianus

Cd <0.0009-0.55 ppm, Cr 0.03-2.19 ppm, Cu 35.2-85.4 ppm, Fe 106.3-226.8 ppm, Ni 4.0-20.0 ppm, Pb <0.0003-2.4 ppm, Zn 48.4-213.3 ppm; A. vulgaris Cd 0.19-0.8 ppm, Cr 0.06-0.65 ppm, Cu 3.91-20.5 ppm, Fe 58.3-137.7 ppm, Ni 0.3-1.8 ppm, Pb 0.14-0.54 ppm, Zn 67.5-254.0 ppm (Sick, 1978). For some related species from coastal waters of Portugal and Spain, levels (dry weight) of 7.4-7.9 ppm Cd, 110-170 ppm Cu, 17 ppm Pb and 135-180 ppm Zn were reported for Eupagurus bernhardus and 0.6-12.0 ppm Cd, 6.0-8.0 ppm Cu, 14.0-22.0 ppm Pb and 70-90 ppm Zn for Asterias rubens (Stenner and Nickles, 1975). Levels of Cd, Cu and Pb were much higher in E. bernhardus than P. acadianus, and levels of Cd and Pb were higher in A. rubens than A. vulgaris.

Although comparisons such as these must consider differences in sampling techniques, chemical analyses, size, reproductive state and tissue of the target species and the season of sampling, our general lack of knowledge of background levels and how natural processes affect seasonal cycling and pulses emphasizes our inability to accurately infer causality at dump sites. Natural processes involving upwelling, frontal systems and storms probably play an important role in nutrient recycling (including trace metals) in the water column and subsequently in the benthos (Sick, 1978); Sick, Johnson and Engel, 1978). These processes are probably capable of seasonally enhancing or depleting the supply of trace metals to the benthos. As a result, the effect of these natural processes may mask the effect of dump sites as sources of contaminants to the water column and benthos. Georges Bank, which does not contain any dump sites, and which is commonly considered a pristine environment, has benthic organisms that contain trace metal concentrations comparable to those recorded at dump sites (Mackay et al, 1972; Pesch et al, 1977). Moreover, Georges Bank may be a part of a gradient system of trace metal dynamics (Wenzloff et al, 1979) ranging from the Gulf of Maine to at least off Chesapeake Bay.

Synthesis of Ecological Relationships

General

To understand how the benthic portion of the Georges Bank ecosystem might respond to oil and gas exploration, it is necessary to examine why the benthos contains a dynamic (seasonal fluctuation), diverse (>600 spp), abundant ($\approx \bar{x}$ $6000/m^2$), widely distributed, highly interactive and persistent (at least the last 25 years) fauna of invertebrates. A variety of complex mechanisms are involved which serve to maintain this benthic fauna at a high degree of integrity. Re-examination of the ecosystem and the interaction between physical oceanography (Figure 1) and the pelagic community provides a plausible starting point.

Phytoplankton

Recent accounts of phytoplankton studies on the Bank show that a winter minimum yields to a heavy spring bloom with a smaller summer bloom, gradually diminishing through early fall (Cohen and Wright, 1978). Primary production was calculated to be on the order of 400 to 500 G cm^{-2} y^{-1}, which makes Georges Bank one of the more productive areas in the ocean. Primary production on the Scotian Shelf is about 127 G cm^{-2} y^{-1} (Mills, 1980) and in the North Sea 90 G cm^{-2} y^{-1} (Steele, 1974). Production on Georges Bank is associated with nutrient supply from the Gulf of Maine and slope water intrusion coupled with extensive mixing over the Bank (Ramp et al., 1980; Schlitz, 1981). Definite seasonal pulses have been recognized.

Zooplankton and Circulation

Zooplankton may be generated by resident populations on the Bank, may be introduced from the Gulf of Maine, Scotian Shelf, slope water intrusion or by slightly more exotic means of warm core rings (Cox and Wiebe, 1979). These sources, together with a transition zone between a major zoogeographic boundary north and south of Cape Cod (Kinner, 1978) provide considerable potential for the diversity of benthos encountered there. Earlier workers reported relatively high zooplankton concentrations along the northwestern region of the Bank (Redfield, 1941). These concentrations were related to a zone demarking the convergence of a clockwise gyre over the Bank and a counterclockwise gyre in the Gulf of Maine. Research on current circulation, zooplankton and ichthyoplankton supports the view that there is strong tidal mixing coupled with a net westerly drift and a clockwise gyre around the Shoal part of Georges at least some of the time (Bumpus, 1976; Sick, 1978; Butman et al, 1980; Dorkins, 1980). Surveys of larval herring indicate that major losses of larvae from Georges Bank are relatively infrequent, since significant numbers of larvae were seldom seen on the perimeters of Georges Bank-Nantucket Shoals area (Grosslein et al, 1979). As they become older and grow, their distribution contracts more and more toward the central portion of Georges Bank well inside the 100 m depth contour.

Data based on recent samples of meroplankton (Tables 3-4) are not inconsistent with patterns observed by others. Relatively high densities were reported south of Martha's Vineyard, in the Great South Channel, and in the north central portion of the Bank with relatively low densities in the Gulf of Maine, the northern margin, near Lydonia Canyon, and on the south western shelf. The agents for concentrating plankton on Georges Bank are seasonal and associated with major patterns of circulation and bottom topography which seem to provide a mechanism to retain larvae on the Bank.

Plankton and Sediment Dynamics - Recruitment

Even assuming reproduction of benthos throughout the late fall and winter, (maximum reproduction is spring through summer and early fall) and some sort of larval retention mechanism, sediment dynamics on the Bank (<80 m) during this period would greatly impede successful settlement and maintenance of many juvenile infauna. Predation by finfish and invertebrates would also be operative at this time. This potential reduction of benthos by sediment dynamics would probably not restrict vagile benthos (shrimp and crabs), larger epibenthos (sea stars and sand dollars), and long-lived infauna (<u>Arctica islandica</u>). Data from BLM dredge hauls showed that the number of species, relative abundance and relative biomass were lowest in winter and highest in the warmer months, primarily summer (Tables 7-8, 15). In contrast, the shrimp Crangon septemspinosa peaked in the winter. Moreover, there was also some indication of an expansion in area on the central portion of the Bank containing higher relative abundance, biomass and diversity with warmer weather and reduced sediment dynamics. This expansion of benthos becomes more apparent with the migration of larger decapods, particularly lobsters, from the southern slope and Canyon heads (Uzmann et al, 1977; Cooper and Uzmann, 1980). Additional evidence for this annual expansion and seasonal occupation of the Bank was seen from quantitative grabs of polychaetes between winter and spring (Maurer and Leathem, 1980a). However, a full seasonal complement of quantitative samples must be analyzed before this assertion of seasonal expansion and contraction of Georges Bank infauna can be accepted.

Groundfish and Benthos Interaction

Although there is evidence to view that the benthos of Georges Bank is extremely responsive to physical factors (sediment dynamics) during the late fall and winter, biological factors are operative throughout this period, eventually becoming extremely important spring through fall. A major biological factor, albeit not the exclusive one, involves predation; predation by finfish and predation by other invertebrates. The effect of grazing pressure on the benthos depends on the seasonal activity of predators and their ability to cope with the physical factors (sediment dynamics) influencing colonization of benthos. That is, as sediment transport seasonally stabilizes on the Bank and bottom temperatures increase, this serves to trigger migration of predators influencing foraging, feeding, mating and spawning. Increased feeding activity exerts enormous pressure on developing benthos mediating between abiotic factors of the environment and the benthic community (Levings, 1975). Experimental studies in shallow water have shown that biologic factors (predation and competition) can control benthic community structure and function (Woodin, 1976; Peterson, 1977; Peterson and Andre, 1980). Extrapolation of these results to the shelf, particularly during periods of relatively low physical energy, provides a plausible hypothesis.

To obtain some impression of the potential scale of finfish predation on benthos or the role of benthos in finfish nutrition, it is appropriate to cite some earlier work by the NMFS. Based on benthic surveys conducted in 1957, an estimate of 156.6 g/m^2 mean weight and $1690/m^2$ mean density was projected for the Bank (Wigley, 1961b). Pronounced differences in quantity and species composition of benthos were associated with geographic location. The fauna was most plentiful on the northeast peak, south central and western sections of Georges Bank.

Based on this scheme, Wigley (1965) presented data to show that groundfish on the New England continental shelf congregate in specific geographic areas (Figure 56). These areas generally coincided with aggregation of macrobenthic invertebrates (Figure 57). Although these relationships were based on descriptive statistics and not experimental studies, inferences drawn from these relationships provided the impetus to explore the mechanisms

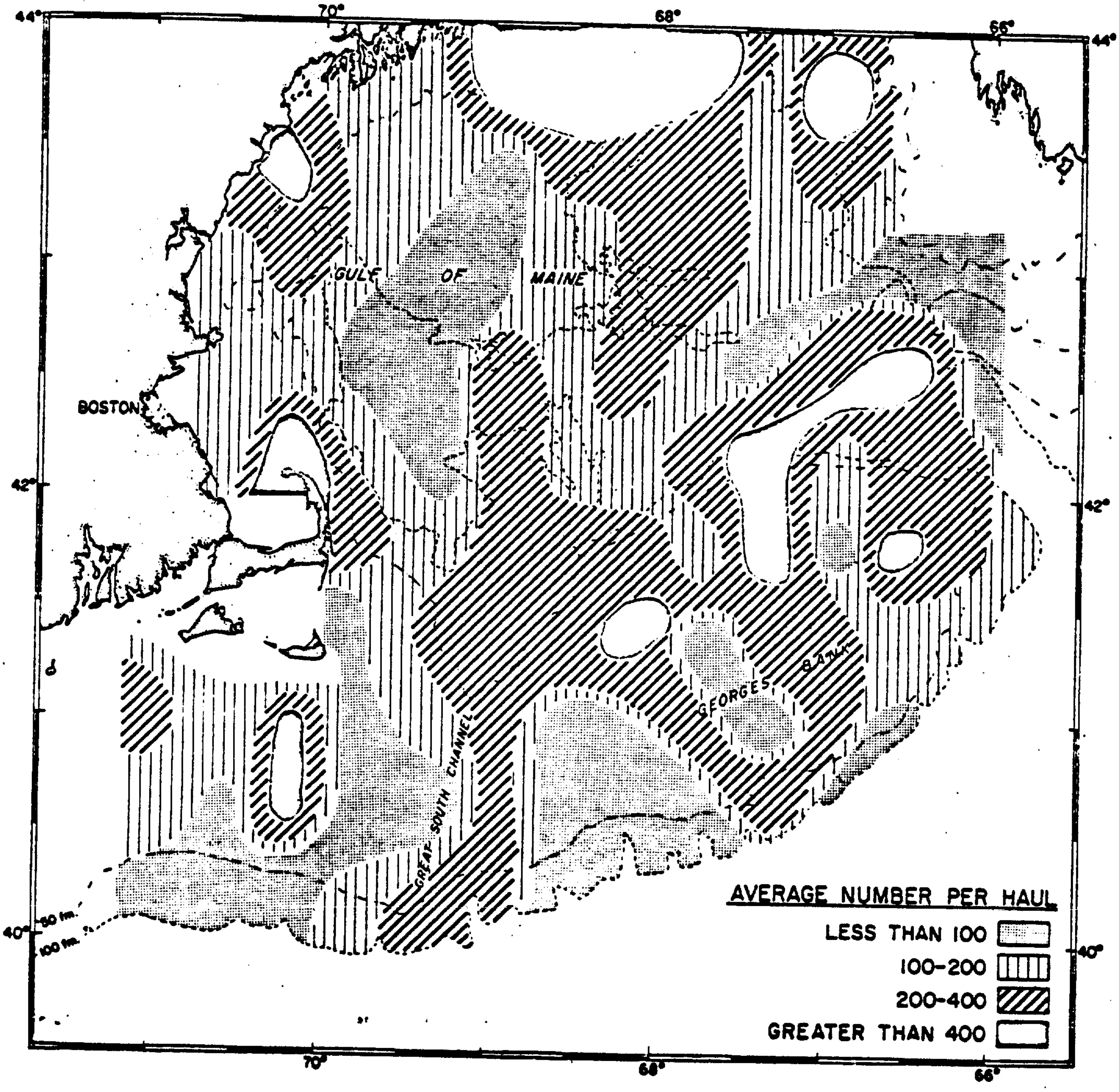


Figure 56. Autumn density-distribution of New England groundfish based on inventories conducted by research vessels Albatross III and Delaware from 1955 through 1961. Values are mean number caught per 30 minute haul in a No. 36 otter trawl, (Wigley, 1965).

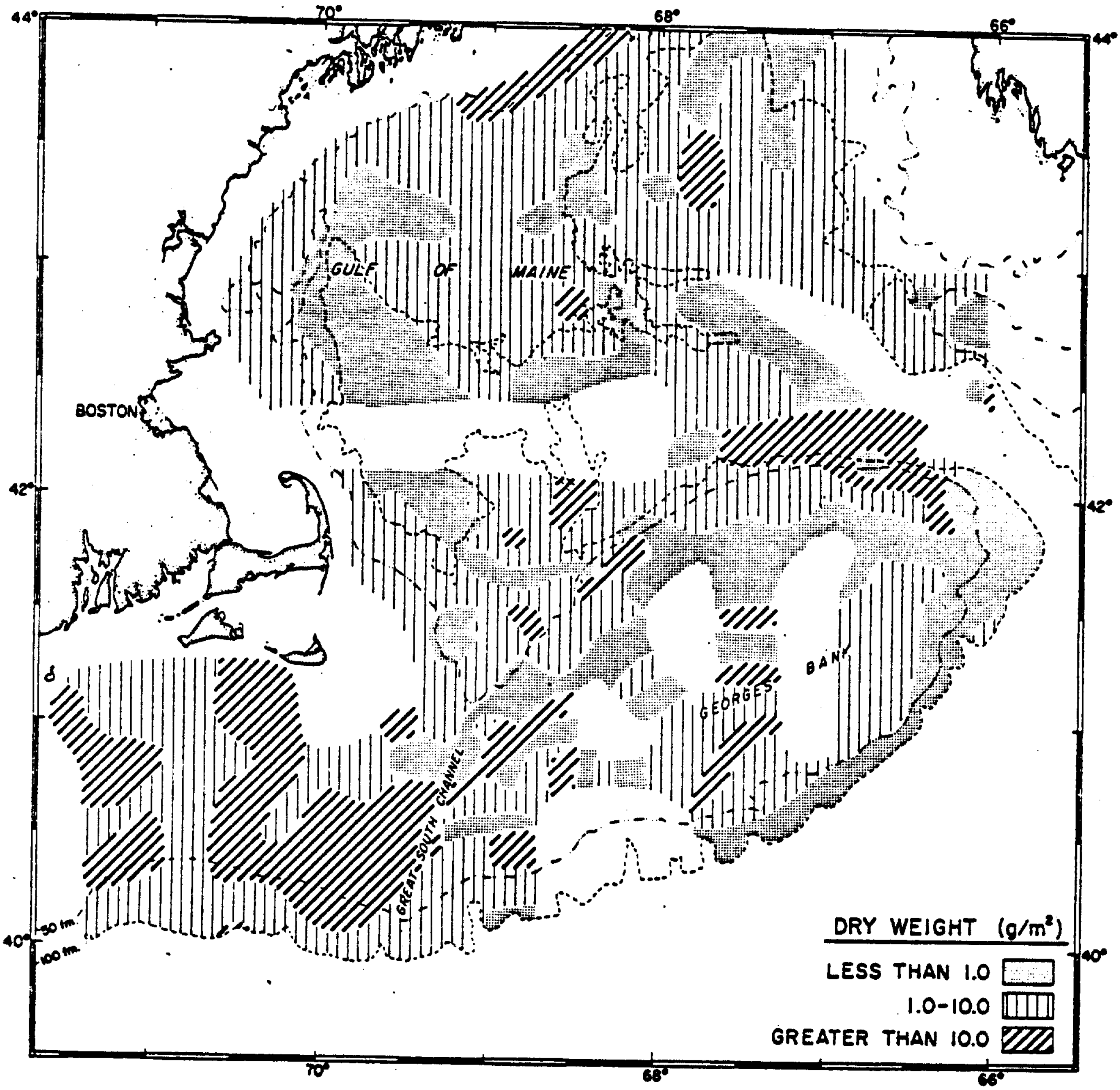


Figure 57. Biomass of the macrobenthic invertebrate fauna collected with a Smith-McIntyre grab sampler. Values are dry weight (grams) per square meter. (Wigley, 1965).

involved. To a large extent recent programs involving food habits of Georges Bank groundfish are a product of these earlier observations (Bowman, 1977, 1981; Maurer and Bowman, 1975; Myer et al, 1979; Langton and Bowman, 1980a,b).

Examination of the distribution and abundance of Georges Bank benthos based on recent surveys compared to earlier surveys shows some interesting patterns. Patterns that are persistent through time and consistent with physical and geologic processes operating on the Bank. The biomass pattern of macrobenthos reported from the BLM study showed relatively low estimates for the northern half of the Bank and relatively high ones for the southern half (Figure 24). Within the southern half the area immediately east and west of the Great South Channel contained mean estimates of 328-1013 g/m^2. Another area directly north of Lydonia Canyon (stations 11, 13, 16-20) comprised relatively high standing crop ranging from mean estimates of 257-1610 g/m^2. Further east at stations 30-33, relatively high densities (2350-20,553/m^2) and biomass (168-822 g/m^2) were reported (Tables A-10 to A-11). These regions of relatively high density and biomass are very similar to those recognized 25 years earlier by Wigley (1961b, 1965). A major exception is the Northeast Peak, which was not sampled in the 1977 BLM study.

Although earlier studies used a 1.0 mm mesh screen for sieving samples which underestimates density and diversity compared to a 0.5 mm mesh screen, estimates of standing crop are relatively unaffected in view of the contribution of molluscs and echinoderms to total estimates of standing crop. Because mesh size has so little effect on estimates of standing crop, comparison of earlier and recent data can be made with some validity. For this reason, it is interesting and reassuring to see that areas identified at least 25 years earlier as important ones containing relatively high estimates of standing crop are still maintaining that production. This observation, coupled with no major shifts in adult fish diets for this same period (Wigley, 1956; Grosslein et al, 1979) argues strongly for the persistence of this quantitative relationship between finfish and benthos. In view of the historical age of this fishery, the inference for an even longer link between the finfish and the benthos can be made.

Thus, this biological process and dependency of Georges Bank groundfish on benthos is an integral part of the ecosystem. The process provides necessary nutrition to the groundfish, which directly exerts control on the benthos. The degree of this biological control varies seasonally and geographically. Even though there is year-round foraging on the Bank by groundfish, winter feeding probably focuses on echinoderms and crustaceans. Seasonal foraging by groundfish and invertebrate predators is strongest in the summer (Wigley and Theroux, 1965; Cooper and Uzmann, 1980) diminishing in intensity towards the periphery of the Bank on the surrounding slope.

Benthos and Biological Disturbance

Based on theoretical considerations, Johnson (1970) suggested that continual occurrence of small-scale disturbances can account for part of the spatial and temporal variations of diversity within benthic marine communities. The role of disturbance (physical/biological) on benthic communities has been recognized for some time (Dayton, 1977; Grassle and Sanders, 1973; Sutherland and Karlson, 1977). The effect of grazing pressure by finfish on Georges Bank benthos represents biological disturbance. However, this disturbance, which is cyclical in nature, has some feedback to the benthos. Heavy selective predation on epifauna and shallow dwelling infauna increases opportunity for colonization and recruitment and reduces competition for food among invertebrates.

Benthos and Physical Disturbance

In addition to biological disturbance, physical disturbance has been invoked as a mechanism to maintain benthic community organization at a pioneer or colonizing level (Rhoads, McCall and Yingst, 1978). Where habitats are disrupted, recolonizing forms consist of species with rapid growth rates, frequent reproduction in large numbers, and relative instability in terms of the resulting community structure. These species result in greater productivity than so-called equilibrium species which, while more stable, through time tend to be less productive. On Georges Bank many amphipods (≃ 90 spp.) and polychaetes (≃ 300 + spp.) comprise annual colonists (pioneer species) while populations of the mollusc A. islandica would be representative of an equilibrium species. Thus, as biological disturbance diminishes in the late fall with decreasing bottom temperature and increasing energy and turbulence across the sediment-water interface, physical disturbance increases, restricting development of many shallow-burrowing infauna.

Off the coast of Northumberland, unstable sands in shallow water affected by wave action contained a fauna impoverished in diversity, biomass and numbers of individuals (Buchanan, 1963). The dominance (frequency of occurrence and relative abundance) of haustoiid amphipods (Bousfield, 1970 and Dickinson and Wigley, 1981) and hermit crabs in sand and gravelly sands of the central and northern portion of the Bank are examples of colonization by organisms adapted through behavior and morphology (burrowing, shell nestlers) to rapidly shifting sand. Some development of burrowing amphipods can be seen on the shifting sand off Nantucket Shoals (Maurer and Wigley, 1981). Regardless, the surface remains disturbed to many and diverse benthos occurring throughout the winter, increasing space for recruitment the ensuing spring and summer.

Georges Bank benthos are seasonally controlled by biological and physical stresses. According to Sanders (1968), all real communities are mixtures of these extremes. This apparent seasonal expansion and contraction of many invertebrates stimulated by biologic and physical disturbance shows how dynamic the system is, and how dependent it is on high primary productivity coupled with regular input of meroplankton and some sort of larval retention mechanism on the Bank. Even though features related to the high production of benthos on Georges Bank remain to be identified and assessed, some of the preceding mechanisms and processes are probably involved.

Sediment Geochemistry

Two basic regimes were identified, one comprising the shallow region of Nantucket Shoals and Georges Bank, and the second comprising the Gulf of Maine region and southern slope (NEOEB II, 1978). The basic geochemical differences were determined by the distribution of fine-grained materials, primarily the clay mineral component of the sediments. Relatively high concentrations of hydrocarbons (total hydrocarbons $f_1 + f_2$; f_1 aliphatic, f_2 aromatic-olefinic, pristane; nonacosane C_{29}-alkane) and trace metals (Cd, Cr, Cu, Fe, Ni, Pb, Zn) were generally associated with fine-grained materials containing relatively high concentrations of clay. Concentrations of hydrocarbons and trace metals were not considered unduly high compared to levels in estuaries and some coastal areas or sites of excessive disposal (New York Bight) (Imco et al, 1977; Farrington and Quinn, 1973; MacKay et al, 1972). It should be emphasized that these concentrations are occurring prior to gas and oil exploration and that atmospheric conditions in the industrialized northeastern United States are probably important sources (NEOEB II, 1978; Boehm et al, 1979; Karinen, 1980).

Sediment geochemistry was the result of a complex, transitory set of dynamic processes. These processes tend to accumulate materials in the Gulf of Maine, canyon heads in the southern and northern slopes, and perhaps the southwestern region (Mud Patch). These sites may serve as reservoirs or sinks. The observation that the Mud Patch serves as a sink remains debatable. Chemical parameters that exhibited a large degree of variability (Pb and pristane) have that variability reflected in all sinks of the system. This may indicate that these, and possibly other parameters, have their distributions controlled by the source of the material. An increase in the source may be reflected in all of the geochemical reservoirs. There was insufficient data to evaluate whether such inputs are reflected in biogeochemical reservoirs. This situation is further complexed in that sinks may occasionally function as sources depending on season or storms causing resuspension of seston.

Most of the remaining chemical parameters appear to have their distributions controlled by the processes maintaining sinks. There appears to be a lag time on the order of months between the introduction of material to the water column and its reflection in sediments. The shelf/slope interfaces were potential regions of massive transport of materials possibly both onto and off the Bank (Sick, 1978). It was suggested that the Gulf of Maine was potentially the source of the material in the sediments in the south and southwest of the sampling region.

The following hypothesis was offered to be tested concerning the mechanism of transport of material (NEOEB II, 1978). During the dynamic winter months, most material contributing to variations in geochemistry (associated with fine-grained sediment and silt) is removed from the Bank and deposited in deep water. As the seasons progress into the high-runoff conditions and slightly stratified water column of the spring, a large influx of fresh water and extensive mixing occur throughout the northern edges of the Bank. This water and the material it contains may be transported across the region and deposited in the southwest. During the summer, intense stratification of the water column, combined with the formation of the double-gyre system between the Bank and Gulf of Maine, forces material to be transported through Great South Channel and/or around the Bank in surface waters. Material deposited on the southern slopes may then be acted upon by dynamic transport processes and redistributed back onto the shelf.

A speculative scenario for a spill or series of spills on Georges Bank might show the following: Physical processes that tend to maintain a geochemical steady state tend to distribute chemically spilled materials that reach the sediments and associate with fine-grained particles resembling the way in which TOC (total organic carbon) and silt/clay are distributed (NEOEB II, 1978). Chronic pollutants deposited in deeper waters of the southern shelf may be redistributed via on-Bank transport associated with oceanic frontal system. Pulsed inputs of pollutants (spills) may tend to behave as do Pb and pristane. Their deposition to the sediments is determined by their association with particles, and there may be a significant delay between spillage and deposition. Pollutants associated with pulsed inputs are short-lived (for only months) in the sediment if texture is not altered. This hypothesis does not address the possibility of biological uptake of pollutants and associated transport processes.

Hydrocarbons and Invertebrates

Hydrocarbon distributions in macrofaunal species did not exhibit clearcut trends in the distributions of either biogenic compounds or petroleum-related hydrocarbons. For example, the hermit crab Pagurus acadianus, collected during a given season, exhibited marked qualitative and quantitative differences over the study region.

Biogenic inputs from the water column were evident in filter feeders and detritovores from the spring and summer. However, limitations of the data base precluded unequivocal coupling of the water column and benthic fauna.

The number and distribution of macrofaunal samples on the Bank was inadequate to provide any statistical meaning for the observed hydrocarbon levels in the samples. No geographical trends as far as hydrocarbon "hot spots" were inferred.

Evaluation of aromatic hydrocarbon levels in benthos was difficult due to the small number of GC/MS analyses performed. However, polynuclear aromatics which have been associated with carcinogens were found in commercially important species (Arctica islandica)(Table 21). Hydrocarbon data obtained so far represented whole animal analyses and not segregated tissues (gut, mussels, gill, etc.). Petroleum hydrocarbons were distributed over the Bank, probably in the form of tar specks, and find their way into the macrobenthic food web.

There was no direct relation between sediment and macrofaunal hydrocarbon compositions or concentrations in the region based on BLM samples. Chronic input of hydrocarbons to the water column and eventually to the macrofauna appeared to be mediated by particulate tar specks in the water column rather than resuspension of sediment.

Trace Metals and Invertebrates

In contrast to hydrocarbons, some relative "hot spots" of trace metal occurrence in invertebrates were observed (Sick, 1978). A comparison of six macrobenthic species having a relatively wide distribution in May 1977 revealed that highest concentrations of most trace metals generally occurred along the northwestern boundary of Georges Bank and at nearshore stations (Figures 49-55). Concentrations of trace metals and their general geographic distribution among benthos were similar among samples collected during other seasons.

Concentrations of trace metals in macroinvertebrates collected on Georges Bank were significantly higher during August than during the rest of the year. At this time, concentrations of most trace metals were as high as concentrations found among nearshore populations throughout the year.

Populations of benthos tended to reflect seasonal and geographical changes in dynamic processes in the associated water column (Sick, 1978).

Trace metals in organisms collected at stations associated with the vertical front correlated with concentrations of particulate metals found in the adjacent water column. This effect was predominant among suspension feeders and only minimally apparent among deposit feeders.

In contrast to hydrocarbons, average concentrations of most trace metals in benthos had significant associations with average trace metal concentrations in ambient sediments. Exceptions were found for Cu and Zn, trace metals associated with metabolic manipulations in most biological systems. This relationship, however, was highly meaningful, since seasonal and geographic differences in trace metal concentrations in sediment were generally insignificant. Gill and digestive gland tissues consistently had higher concentrations of most trace metals than mantle, muscles and gonadal tissues. Gill tissue had selectively relatively high concentrations of Zn.

Benthos on the Bank displayed a potential for readily responding to changes in trace metal concentrations in both the water column and sediment. The ability of benthos to accumulate trace metals from the ambient environment and adjust rapidly to changes in such concentrations has significance to proposed oil development on Georges Bank.

Discussion of Response of Benthic Invertebrates to Pollutants on Georges Bank

General

Based on the literature review and concentrations of trace metals and hydrocarbons in sediments and benthos presented in NEOEB II (1978) and Sick (1978), some inferences can be drawn about the potential response of benthic invertebrates to pollutants on Georges Bank. To insure responses from target species, many of the early bioassay tests used concentrations and experimental time periods that have been challenged as unnaturally high and short, except for some of the most polluted estuarine and coastal habitats (Wolfe, 1977; Vernberg and Vernberg, 1974; Proceedings, 1980). The second wave of bioassay tests has been concerned with sublethal levels and long-term experiments emphasizing biological processes and functions (behavior, feeding, growth, accumulation, depuration, reproduction, recruitment, biomagnification). Testing these processes appears to be more biologically meaningful than acute toxicity alone in assessing the effects of pollutants. Even at relatively high experimental concentrations some bivalves, crustaceans, and polychaetes demonstrated mechanisms for detoxification (Fossato, 1975; George and Coombs, 1977; Rossi and Anderson, 1977; Lee et al, 1979; Lee, 1981). Many target species returned to unpolluted seawater began to depurate and achieve control or pre-testing responses.

Acute/Lethal

In view of the turbulence in the water column and massive sediment transport on Georges Bank, particularly in the winter (Aaron et al, 1980), it seems highly unlikely that concentrations of hydrocarbons and trace metals in sediments would attain widespread levels of toxicity for adult benthos, if ever, and then only for a short period of time. This opinion is supported by studies on the effect of the Argo Merchant oil spill on the benthos off Nantucket Shoals. Hoffman and Quinn (1978) indicated that little oil actually was found in the bottom sediments supporting macrobenthos. They concluded that the high degree of physical activity on the shoals was probably responsible for the areal patchiness and inhomogeneous mixing of hydrocarbons with depth in the sediments.

Sawyer (1978) reported no histopathological findings in molluscs, crustaceans and sea stars that could be attributed solely to exposure to petroleum from the Argo Merchant. Brown and Cooper (1978) also investigated the histopathology of benthos from the vicinity of the wreck. The authors concluded that the effects of Argo oil were, for the most part, within the physiological toleration limits of the macrobenthos, and the overall impact of the oil spill was minor.

Pratt (1978) examined interactions between petroleum and benthic fauna at the Argo Merchant spill site. He stated that there was little evidence of impact in the form of dead or dying animals or of changes in population densities. In terms of gross population mortality, the effects of the Argo Merchant spill on benthos were negligible compared to the Florida and Amoco Cadiz spills (Sanders, 1978); Sanders et al, 1980; Cabioch et al, 1978; Chasse, 1978; Spooner, 1981). Acute effects of the Argo Merchant on plankton and ichthyoplankton were another matter (Polak, Filion, Fortier, Lanier and Cooper, 1978; Bowman and Langton, 1978; Longwell, 1978). An oil spill fishery interaction model for Georges Bank suggested that the largest impacts on hydrocarbon-induced egg and larval mortality would occur for spring and winter spills (Spaulding and Saila, 1981).

Chronic/Sublethal

If no or little short-term disruption of benthic communities can be anticipated from a spill on Georges Bank, can the same pattern of response be projected for long-term sublethal or chronic changes? Because the data base for chronic and sublethal effects of pollutants is commonly grounded on unnaturally high concentrations, there are considerable philosophical problems in extrapolating laboratory toxicology to the field (Epifanio, 1979). However, some biotic responses (behavior) to hydrocarbons and trace metals were detected at extremely low levels, levels that are compatible with concentrations in the open sea. It appears that invertebrate behavior keyed by chemoreceptors is responsive to very low levels (McLeese, 1975; Williams and Duke, 1979; Bodammer, 1979; Pearson and Olla, 1980; Denby and Atema, 1981). Some of this behavior involves locomotion, foraging and mating. Inhibition or interference with any of these activities could be serious to target species and populations. During the Argo Merchant spill, Placopecten magellanicus and Modiolus modiolus from oil-impacted areas had depressed gill-tissue oxygen consumption (Thurberg, Gould, and Dawson, 1978). In addition, malicdehydrogenase activity of scallop muscle, together with lactate oxidation, was also significantly lowered. The latter observations suggested a possible weakening of the ability to shift to anaerobiosis. Although normal values of gill-tissue oxygen consumption were recorded from scallops six weeks later, the ecological significance (predation, susceptibility to disease and parasites, increased physiologic stress) during the interim recovery period remains unknown.

Vessel and Platform Spills

Repeated oil spills from vessels and platform discharges could provide continuous sources of petroleum input for chronic or sublethal levels on Georges Bank. A review of world oil spillages from 1960-1975 was compiled by VanGelder-Ottway and Knight (1976). For those spills recognized as occurring in the marine environment, only a very few represented open ocean habitats. For open ocean habitats, few or no reports of benthic mortalities were cited. Their statement should be tempered by the fact that few open ocean spills receive the same scientific scrutiny as those occurring in estuaries and coastal waters. If one considers the Argo Merchant wreck as an open ocean spill, then it was fortuitous that the spill occurred in the vicinity of a large, sophisticated marine research complex. As such, the wreck represented one of the better known and studied open ocean oil spills and is a notable exception to scientific coverage in such habitats.

Another important source of hydrocarbons could be discharges from offshore platforms. The platforms might be the source of a major spill (Ekofisk and Extoc) or small continuous discharges. The British experience in the North Sea is relevant. During peak production, United Kingdom offshore oil discharges formed a very small (2.4%) addition to much larger inputs arising from long-established activities (Read and Blackman, 1980). Moreover, discharges entered larger bodies of deeper water, with a much greater capacity for dilution and dispersion than the shallow, turbid coastal waters receiving most of these larger inputs. In addition, low molecular weight compounds (highly toxic aromatics) predominate in refinery and certain terminal discharges. On these grounds alone, offshore discharges are less likely to produce acute biological effects when compared to onshore counterparts. Read and Blackman (1980) concluded that if there are any serious biological effects from oil discharges in the United Kingdom, they are more likely to occur in waters receiving coastal discharges than in those around offshore oil platforms.

The marine environment in the Ekofisk area was assayed for the presence of oil components after the blowout on Platform Bravo (Mackie, Hardy, and Whittle, 1978). The presence of oil was detected in the biota and taste panels were able to identify an oil taint in some fish caught near the platform. A second survey 2 months after the spill indicated that little, if any, oil from the blowout remained in the water column. Short-term biological effects were considered negligible, and any long-term effects remain to be determined (Berge, 1977). Sediment samples were collected around a drill site on the Texas shelf before (November) emplacement of an exploratory oil rig, during (January) drilling, and after the rig had been in place for 2 months (Lytle and Lytle, 1979). Changes in sediment geochemistry were slight but more noticeable at stations close (100 m) to the rig. Hydrocarbons in the C_{14} to C_{20} region of the aliphatic chromatograms were in low abundance in all samples. The high molecular weight region contained high concentrations of the odd carbon numbered n-alkanes.

Deep Sea

According to the foregoing studies, substantial spills from offshore platforms are relatively rare. Moreover, if spills occur, their influence is primarily restricted to the vicinity of the well site and damage to the biota is very localized. Such a view deemphasizes concern about input of hydrocarbons to offshore areas. However, this view contrasts markedly with that of Karinen (1980) who reviewed and commented on literature relating to petroleum hydrocarbons in the deep sea and its biological effects. According to Karinen, hydrocarbons of apparent anthropogenic origin are accumulating in bottom sediments of shallow coastal waters and in deeper offshore waters. He stated that large quantities of petroleum hydrocarbons can be rapidly transported to the deep sea floor by several mechanisms (water mass transport, fecal pellets, crustacean exoskeletons, vertical migrators). Further, petroleum hydrocarbons are intimately associated with particulate matter in the sea, behaving much the same as natural biogenic material and having the potential to modify or interrupt natural processes. Finally, Karinen (1980) stated that the unique physiology of deep-water life forms increased the potential for adverse impact of petroleum hydrocarbons on the deep sea environment.

Conditions on Georges Bank seem to conform with some of Karinen's (1980) concerns. That portion of Georges Bank extending to about 80 m will probably not experience serious biotic disruptions from a massive spill or even continuous small discharges. However, hydrocarbons and trace metals are accumulating on Georges Bank prior to any substantial oil exploration and production (NEOEB II, 1978). In many situations the highest levels of hydrocarbons and trace metals were associated with fine-grained sediment high in silt-clay, carbon and nitrogen. In brief, trace metals and hydrocarbons on Georges Bank are strongly influenced by the hydrographic regime controlling sedimentation. Areas of deposition are likely places for the deposition and accumulation of hydrocarbons and trace metals. These areas would include the Gulf of Maine, some of the canyons dissecting the southern margin of the Bank, and perhaps the Mud Patch south of Martha's Vineyard. These areas should provide candidate sites for monitoring these pollutants.

In addition to sediment accumulation of hydrocarbons and trace metals, the benthic biota are accumulating these pollutants (NEOEB II, 1978; Sick, 1978). The concentrations may be low compared to estuaries and coastal waters but the processes are in progress. An important but disconcerting finding was that the benthic biota, including the commercially important *Arctica islandica*, were accumulating polynuclear aromatic hydrocarbons (PAH). PAH's have received serious attention because of their association with potential carcinogens (Neff, 1979).

Barry and Yevich (1975) reported a high incidence of gonadal tumors in the clam *Mya arenaria* contaminated with oil in a near-shore spill. This level of contamination may never be attained in the sedimentary basins of Georges Bank, but the long-term accumulation of hydrocarbons which has already started suggests that the histopathology of some of these benthic populations deserves attention. Histopathology is important per se, but it assumes added importance if it interferes with the reproductive potential of target populations. Studies of histopathology and gonadal development of selected invertebrates were conducted during 1977, but these studies were never completed or reported. Thus, there is some basis for concern about accumulation of trace metals and hydrocarbons by Georges Bank benthos.

Another point of view about hydrocarbons in marine systems involves adaptations. Pequegnat and Jeffrey (1979) examined petroleum in deep benthic ecosystems of the Gulf of Mexico and Caribbean sea. Chemical analyses of sediment samples in depths ranging from 180 to 4557 m showed that tars contained no volatile hydrocarbons in the range of C_{10} to C_{40}, were highly asphaltic, low in paraffins, and unusually high in sulfur, vanadium and nickel. Specimens of the starfish Persephonaster echinulatus were found engulfing and solubilizing tar lumps. A rich and varied bottom fauna was found associated with stations yielding large amounts of plant material and oil. The authors speculated that where petroleum occurred in substantial quantities (natural seeps), in addition to an enriched bottom fauna, some species may well make some use of it as food.

In another example of natural oil seeps with a very different setting, Spies and Davis (1979) studied an infaunal benthic community in fine sand (16 m) near Santa Barbara, California. The seep oil was a complex mixture of alkane, aromatic and polar compounds with large proportions of branched and cyclic components and normal alkanes so well developed in many commercial crude oils. They reported a consistently larger but fluctuating density of organisms at the seep station compared to a reference station. However, several measures of diversity were similar for both stations. Denser populations of oligochaetes and the maldanid polychaete Praxillella affinis pacifica suggested some advantages for deposit feeders at the seep station in sediments containing over 3000 ppm (3 mg/g) of hydrocarbons some of which must be potentially toxic. Spies and Davis (1979) presented hypotheses suggesting trophic enrichment and biochemical adaptation at the oil seep. In a more expansive statement of this work, Spies, Davis and Stuermer (1980) concluded that heterotrophic enrichment, alteration of the sulfur cycle in sediments, and enhanced colonization of oiled sediments are features of the seep area emerging from their study. These features may be widely applicable to marine oil pollution.

Mechanisms for detoxification of hydrocarbons and trace metals were presented earlier (Mironov and Shchekaturina, 1979; Clement et al, 1980; Neff, 1979). Adaptation to trace metals and hydrocarbons have also been described (Bryan and Hummerstone, 1971, 1973; Pequegnat and Jeffray, 1979; Spies and Davis, 1979). Thus, there is evidence that marine benthic biota are capable of adapting to natural oil seeps or mine tailings under certain conditions. However, there are no known natural oil seeps on Georges Bank. As continental seas have transgressed and regressed over the Georges Bank area, the benthic biota have not colonized areas with natural oil seeps, which appears to be the case off California and the Gulf of Mexico. Thus, it would be premature to conclude that Georges Bank benthos in sedimentary basins would necessarily adapt to increasing incursions of hydrocarbons from vessel spills and platform discharges.

Drilling Fluids and Cuttings

Some concerns have been expressed concerning the effect and fate of drilling fluids and cuttings. Laboratory studies cited in Proceedings (1980) showed a range of effects. Some field studies indicated little or no damage to benthic biota. When damage was reported, it was localized. These studies were conducted in relatively high-energy hydrographic regimes. However, the study conducted on the shelf off New Jersey demonstrated significant reduction in the benthic biota (at least 800 m from the rig) that was attributed in part to the mechanical effects (burial, smothering, clogging) of clay from the drilling fluids and cuttings (Menzie et al, 1980). Moreover, trace metals, including barite, were accumulated by bivalves, echinoderms, and polychaetes (Mariani, Sick and Johnson, 1980). Accumulation of these metals might have provided an opportunity for biomagnification. In addition, if the source of the trace metals was continuous with drilling activities for a long period of time, organisms near the rig might not be able to depurate or activate detoxification mechanisms. Although amphipods were not included in the trace metal analyses because they were relatively unimportant at the New Jersey site, their numbers and distribution are quite important on Georges Bank (Dickinson and Wigley, 1981). Their sensitivity to pollutants and vulnerability to trace metals and hydrocarbons is well known. Equally well known is their nutritional value to demersal fish. Acute or chronic effects of pollutants on amphipods might result in an associated fluctuation in demersal fish. This key food web relationship between pollutionally sensitive amphipods and demersal fish predators probably deserves field and laboratory study to confirm or deny how critical this link may be.

The New Jersey site did not have a particularly strong hydrographic regime. A year after the post-operation study

(July, 1979) was conducted, there was still evidence of drill cuttings around the former rig site and barite in bivalves, echinoderms and polychaetes. This study emphasized the importance of the role of physical oceanography and marine geology in assessing the effect of drilling fluids and cuttings on the benthos. Because of the heavy sediment transport on Georges Bank these bottom conditions would seem to preclude serious concern for benthic community disruption or excessive accumulation of cuttings on bottoms shallower than about 80-85 m. However, the same caveat applied to the deposition of hydrocarbons and trace metals applies to drilling fluids and cuttings. Areas of sedimentation should also be monitored for effects and accumulation of drilling fluids and cuttings. It is these deeper areas on the periphery of the bank, with their associated benthic fauna and potential interaction with migrating demersal fish and invertebrates, that should draw our attention.

Management Implications

General

In view of the enormous temporal and spatial variation in physical, chemical, geological and biological processes on Georges Bank, it will be very difficult to correlate significant ecologic changes in the benthos with activities associated with gas and oil exploration. This view might be tempered when larval stages are considered, but even then, effects would probably be ephemeral and short-term, probably occurring under conditions much more expansive than the Argo Merchant spill.

There is no doubt that hydrocarbons and trace metals (and probably other contaminants) are accumulating in ecologically and economically important benthos without any activity associated with gas and oil exploration (NEOEB II, 1978; Boehm et al, 1979). If no significant deleterious effects will be associated with drilling activity (a statement that will assuredly not go unchallenged), other mechanisms are providing measurable input to this system with some predictability. Given accumulation of contaminants by important benthic prey of fish with possible biomagnification through commercial groundfish, accumulation by commercial benthos (clams, lobsters, crabs), and even the slightest possibility of carcinogens in sea food (Table 21), no monitoring program would be a serious lapse in management of this valuable renewable resource (CRC 1976, Dicks, 1976). Regardless of gas and oil, without some sort of organized monitoring program, there would be no direct way to assess pollution conditions associated with human activity. Although it may be presently topical to mount a monitoring program designed to cope with gas and oil exploration, the monitoring program should ultimately be founded on broad-based ecological relationships, facilitating modes of research responses to multivariate sources of pollution. Even though monitoring methods are commonly too coarse to reliably and consistently demonstrate significant cause and effect related to drilling activity, some processes, organisms, and habitats are probably more sensitive measures of change than others.

The Biological Task Force (BTF) for OCS lease sale No. 42 on Georges Bank was established to recommend to the U.S.

Geological Survey (USGS) 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 exploration. The BTF prepared a research program (Research Plan 1980). The Bureau of Land Management developed a request for proposal (AA851-RP1-28) to monitor Georges Bank based on recommendations from the BTF research program. The purpose of this section is to review the research proposal in terms of its applicability to Georges Bank benthic biota and environmental processes.

Bureau of Land Management Research Proposal

The major emphasis of the monitoring program was to link the fate of discharges from oil and gas exploratory operations to effects of benthic components. The proposal recognizes the need for seasonal sampling. There is solid evidence to support the importance of seasonal coverage (Tables 7-8, 14). Two basic categories of sampling stations were identified. The first consists of a series of regional stations designed to monitor broad-scale, long-term changes in benthic epifaunal and infaunal populations, sediment texture, and the chemistry of sediments and benthic organisms. This approach builds on the 1977 BLM baseline study and is further strengthened by the results of a drill rig monitor study off New Jersey (Menzie et al, 1980).

The BLM proposal recognized the importance of physical oceanographic processes in the design of the sampling plan. They identified upcurrent stations as long-term regional control sites and downcurrent stations as sites where effects are more likely to occur. Moreover, control stations are situated such that comparisons with respective downcurrent stations are made along or near the same isobath. This strategy takes into account that geological processes and benthic communities change significantly in a cross-shelf direction from the crest of Georges Bank to the edge of the continental shelf, but change less drastically along a given isobath accordingly. This strategy is supported by the findings of Michael (1977) and Maurer and Leathem (1980a,b).

Additional long-term regional stations were also located in areas identified as active depositional sites (heads of Lydonia and Oceanographer Canyons, shelf/slope break, Mud Patch). These stations represent an effort to test hypotheses concerning deposition of fine-grain sediment containing associated contaminants (hydrocarbons and trace metals) suggested by Milliman et al (1980). If benthos at these sites are found to contain concentrations of trace metals, particularly Ba, considerably above background levels, these data would then support hypotheses indicating transportation of drilling muds,cuttings and leachates from Georges Bank exploration sites to these depositional sites.

An oversampling approach with stations finely spaced in a quasi-radial pattern was suggested by BLM for a sampling strategy for site-specific arrays. This approach was used at the drilling site off Atlantic City, New Jersey (Menzie et al, 1981). This particular sampling design was very sensitive in detecting sediment and faunal changes, at least within 800 m of that drill site. There was evidence to suggest faunal changes extended even beyond 800 m. Thus, there is solid precedent for the site-specific sampling strategy requested by BLM.

The BLM proposal required using two grabs of different size and volume and two sieve sizes. It was pointed out by BLM that the combination of a fine sieve size (0.300 microns) and small grab sampler size ($0.04m^2$) produces greater number of species and individuals and lower inter-sample variance than a combination of a coarser sieve (500 microns) and larger grab site ($0.1m^2$). In studies involving estimates of secondary production and recruitment, smaller sieve sizes would provide more refined data than coarser sieve sizes. Moreover, the 0.300 micron sieve and $0.04m^2$ grab would be the preferred combination in a study of small-scale heterogeneity of benthic dispersion. However, for the present BLM proposal these are not the stated goals. Moreover, even though the smaller sieve size might yield more species and individuals than the 0.500 micron sieve, the mean size of the individuals would be smaller. This translates to increased difficulty in identifying juvenile forms. Thus, the increased diversity expected from collecting more species of smaller size with a finer sieve might be mitigated by losing precision in attempting to identify a greater proportion of juveniles of average-size species. Since polychaetes comprise about 50% of the fauna by number of species and density on the Bank, considerable taxonomic problems might be expected here (Maurer and Leathem, 1980a). Taxonomy of polychaetes is extremely challenging and we simply do not know enough about their juvenile morphology to correctly identify them at these stages with great confidence. Thus, at least for a broad-based survey, it is not feasible to increase the number of organisms which may not really be amenable to accurate and rapid identification.

Another concern involves the prior commitment of BLM programs in general, and the Georges Bank study in particular, to the 0.500 micron sieve and $0.1m^2$ grab. Over 600 quantitative grab samples were collected from Georges Bank in 1977 with a $0.1m^2$ grab and sieved through a 0.500 micron sieve (NEOEB I, 1978). In addition, a large number of quantitative samples were collected in the Middle Atlantic, southeastern U.S., and southern California BLM studies using a $0.1m^2$ grab and a 0.500 micron sieve. This enormous commitment to that combination of grab and sieve size would support its continued use in the monitoring program for purposes of comparison with the 1977 Georges Bank baseline study and BLM studies from other areas. Although the $0.04m^2$ grab may reduce inter-sample variance, it certainly will grossly underestimate larger macrofauna. During the 1977 winter cruise, high densities of ocean quahogs were collected at some stations with the $0.1m^2$ grab. These densities ranged from $40-60/m^2$. A grab smaller in size (area) and weight than the $0.1m^2$ grab would not be as effective in collecting those members of the infauna contributing the largest biomass of any taxa. The BLM is to be commended for using both large and small grabs and fine and coarse sieve sizes and is encouraged to build on the earlier extensive data mass.

The BLM proposal also requires bottom still photographs at the long-term regional stations and site-specific stations.

Bottom photographs provide valuable information to remote collecting methods. These photographs were also taken in the 1977 baseline study. However, the value of underwater television in assessing sediment structures and epifaunal assemblages at a drill site was demonstrated at a rig site off New Jersey (Menzie et al, 1980). Although this method is more expensive than bottom still photographs, it would be a preferred tool for this activity.

National Marine Fisheries Service - Northeast Monitoring Program

The National Marine Fisheries Service (NMFS) could serve a legitimate role in cooperating with the BLM to monitor Georges Bank. In 1977 the NMFS at the Northeast Fisheries Center (NEFC) developed the Ocean Pulse Program. The purpose of the Ocean Pulse program was to provide a monitoring program to assess the health of northeast coastal ecosystems and biological resources from the Gulf of Maine to Cape Hatteras. More recently, the Ocean Pulse Program has been placed under the aegis of the Northeast Monitoring Program (NEMP). NEMP is a program to integrate ongoing and planned NOAA marine pollution monitoring in the northeast. The objectives of NEMP are severalfold: 1) determining levels and trends of specific contaminants in the marine and coastal environment and biota, and how these contaminants affect biological resources, 2) compiling an archive of marine pollution data, fostering interagency cooperation, 3) determining the effects of specific impacts (oil drilling, waste dumping, etc.), 4) detecting critical changes in the environment and ecosystems that may degrade biological resources, and 5) developing standard monitoring methodologies.

As of August 1981, there were 40 work units or contracts in research and development fulfilling the objectives of the NEMP. The work units range from field to laboratory studies, including traditional monitoring studies and the development and application of in-situ monitoring methods and experiments. That portion of the NEMP field monitoring program dealing with Georges Bank has already been incorporated in the BLM research proposal. The area where the NEMP could make a valuable contribution to the BLM monitoring program could involve the application of in-situ monitoring methods and experiments. The work units for the NEMP in-situ methods to assess physiological effects of pollutant stress have been developed. These methods include: respiratory measurements and analyses of blood samples of fish and shellfish, micronuclear testing for chromosome mutation, and measurements of anaerobic bacteriology metabolism. Other in-situ bioassay methods are being developed under the NEMP (Baine, Anderson, Engel, Gilfillan, Hoss,Lloyd and Thurberg, 1980; Thurberg, 1980). Regardless of the particular combination of in-situ bioassays that might be applied to monitoring gas and oil drilling rigs on Georges Bank, the NEMP has the expertise and experience to implement in-situ methods. It is recommended that in-situ methods focusing on ecological processes and functions as developed and practiced by the NEMP should be coupled with the BLM field program to provide a comprehensive approach to monitoring Georges Bank.

Key Species for Protection and/or Research

A conservative estimate of macrobenthic invertebrates on

Georges Bank is 600 + species. The number is probably closer to 700-800 without inclusion of meiobenthos (nematodes, gastrotrichs, harpacticoid copepods, etc.). Given this enormous diversity and the cost of conducting research with any species, is there any rationale upon which to base selection of species for study? Examination of an extensive data base from field studies on the New England shelf and a review of laboratory studies in pollution ecology provides some criteria for selection of species to be protected or considered for research. These criteria include: abundance, distribution, frequency of occurrence, biomass, size, commercial value, fish prey, invertebrate predator, sensitivity to pollutants, biomagnification and bioaccumulation. The following species are based at least on some of the above criteria.

- Cnidaria
  - *Ceriantheopsis americanus*
  - *Epizoanthus americanus*
- Mollusca
  - Gastropoda
    - *Buccinum undatum*
    - *Colus stimpsoni*
- Pelecypoda
  - *Arctica islandica*
  - *Astarte* spp.
  - *Mytilus edulis*
  - *Placopecten magellanicus*
  - *Spisula solidissima*
- Annelida
  - Polychaeta
    - *Aglaophamus circinata*
    - *Aphrodita hastata*
    - *Exogene* spp.
    - *Glycera* spp.
    - *Nephtys* spp.
    - *Onuphis* spp.
    - *Phyllodoce mucosa*
- Annelida (continued)
  - Polychaeta (continued)
    - *Scalibregma inflatum*
    - *Schistomeringos caeca*
    - *Scoloplos armiger*
    - *Spiophanes bombyx*
- Crustacea
  - Amphipods
    - *Ampelisca* spp.
    - Haustoriids
    - *Paraphoxus epistomus*
    - *Unciola inermis*
    - *Unciola irrorata*
  - Decapoda (sensu latu)
    - *Cancer borealis*
    - *Crangon septemspinosa*
    - *Homarus americanus*
    - *Neomysis americana*
    - *Pagurus acadianus*
    - *P. arcuatus*
- Echinodermata
  - *Asterias vulgaris*
  - *Astropecten americanus*

Echinodermata (continued)
    Echinarchnius parma
    Leptasterias tenera
    Ophiura sarsi
    Strongylocentrotus droebachiensis

Several pelecypods are of commercial importance (A. islandica, P. magellanicus, S. solidissima) and this taxon as a whole is very efficient in bioaccumulation. The gastropods and larger species of echinoderms (Asterias vulgaris, Astropecten americanus, Leptasterias tenera) are important invertebrate predators and might be expected to be involved in biomagnification. The polychaetes and amphipods generally occur in the highest densities and frequencies of all the benthos. Both taxa are important constituents of fish diets, particularly the amphipods. Moreover, amphipods have been recognized as particularly sensitive and vulnerable to hydrocarbons and trace metals. Decapods contain some of the largest species and biomass and are also represented by commercial species (Cancer borealis, C. irroratus, Homarus americanus). Some of the decapod shrimp would also be sensitive to hydrocarbons and trace metals (Crangon septemspinosa, Meganyctiphanes norvegica, Neomysis americana).

The list above contains 34 taxa. At first glance this does not appear very selective or cost effective in considering them as candidates for monitoring programs. However, these species represent less than 5% of the total diverse taxa on the Bank. Most important, these taxa comprise about 80% of the density and biomass of benthos from the Bank. As such, these species are prime candidates for protection or special consideration in monitoring studies.

Suggested Research

The most recent comprehensive account of drilling muds in the environment is contained in the proceedings of a 1980 symposium held in Florida. The proceedings were reviewed in an earlier section. Several themes emerged. Considerable concern was expressed about interpreting and comparing results of toxicity and bioassay studies because of differences in drilling muds. This artifact could be reduced by developing or designing several drilling muds as standards for experiments. This approach was used earlier for hydrocarbon testing which served to provide a more solid base for interlaboratory calibration and comparison.

Related to the problem of provenance of drilling muds was the general lack of support chemistry associated with testing. This was due to lack of resources in most cases. Regardless, in many instances the value of some well conceived and innovative approaches to toxicity and bioassay testing were mitigated by ignorance of the chemical nature, disposition and fate of drilling muds throughout the experimental period. In addition, there was confusion about the relative effects of mechanical (cuttings and particles) inhibition of drilling muds and chemical inhibition or some sort of vaguely understood synergism.

Based on field studies, another important feature emerged. At present, drilling muds have not been associated with adverse effects on the benthic biota in relatively high-energy environments (Tanner Bank, California; Cook Inlet, Alaska). The scale of physical and geological processes rapidly assimilate, dilute and diminish the effect of drilling muds at these sites. In contrast, there is evidence to show that in a relatively low-energy site (off New Jersey) that cuttings from drilling muds settled near and around the spud site initially causing some mechanical problems related to burial. Reduction in density of benthos was recorded in this low energy site. Moreover, trace metals associated with drilling muds (Ba) have been measured in significant concentrations in infaunal organisms. Finally, even after almost 18 months, benthic densities were still depressed and trace metal concentrations in the benthos remained high, which was probably caused from leaching of undisturbed cuttings in the low-energy site. What is still unclear is whether Ba causes inhibitions or other trace metals and impurities from the drilling muds affect the benthos. Thus, my inventory of important features associated with drilling muds involves: provenance of the mud, support chemistry for toxicity studies and bioassays, distinction between mechanical and chemical effects, detoxification mechanisms and low-energy sites compared to high-energy sites. These features lend themselves to the following hypotheses:

1) The effects of drilling mud on benthos are attributable to mechanical effects,

2) The effects of drilling mud on benthos are attributable to chemical effects,

3) The effects of drilling mud on benthos are attributable to synergistic mechanical-chemical effects,

4) It is unlikely that detoxification mechanisms provide protection to benthos from drilling muds, and

5) It is likely that response of benthos to drilling muds in low energy sites will be the same as in high energy sites.

These hypotheses have been stated in terms of falsification to provide the opportunity to pursue alternative hypotheses pending the outcome of tests.

To test the above hypotheses, the following experimental design is proposed. The experimental design should include field and laboratory studies. Measures of effects on benthos should focus on body trace metals and hydrocarbon burdens, reproductive condition and larval settling in rig monitoring studies in the field, and rearing, reproduction, larval development and settling in the laboratory. These features should be emphasized because: 1) body burdens provide an objective, tractible means of comparison to other studies and an indication of the gradients involved associated with plumes at rigs, 2) any interference with reproductive processes threatens the survival of local species populations, 3) monitoring of larval settling is an effective means to measure recolonization at drill sites. Similar features should be examined in the laboratory emphasizing sublethal concentrations of drilling muds permitting closer scrutiny of processes including the many landmarks of reproduction (gametogenesis, spawning behavior, fecundity, fertilization, embryonic development, larval behavior) and settling. Settling relates to the colonization process mentioned above. Finally, this approach should also include examination of F_1 and F_2 generations to determine whether there is any remission of the effects of the drilling muds or increased induction of purging. Parallel studies on detoxification mechanisms should be conducted initially featuring adults of selected species and eventually including the F_1 and F_2 generations.

Criteria for selection of species should include geographic range and feeding and reproductive strategy. Since polychaetous annelids commonly comprise 50% of the number of soft bottom species, over 50% of benthic density, occur on a variety of sediment types, and show diverse feeding and reproductive strategies, they provide a representative benthic taxon to focus on. However, several species of bivalves and amphipods, which are next in importance in the marine benthos, should also be included.

These species should exhibit a variety of feeding guilds (surface detritus feeders, subsurface deposit feeders, suspension feeders, carnivores, etc.) and reproductive strategies (monotelic - breed only once; polytelic - several breeding times; semi-continuous - breed repetitively over an extended season) coupled with combinations of external fertilization, internal fertilization, budding. A commitment to studying diverse feeding and reproductive strategies is based on the premise that various pathways of ingestion and assimilation and partitioning of trace metals are related to feeding and mode of reproduction. Thus, drilling muds would be expected to impact suspension feeders differently than surface detritus feeders and sequestering of trace metals in body tissue would differ in species that broadcast their young than species that brood their young. Even though the abundance and diversity of benthos is enormous and therefore prohibitive to include all types in such a study, by identifying and exposing some major feeding and reproductive types to drilling muds one could realize some useful generalizations.

Initial focus would be on species with short life cycles. This permits one to deal with several generations in a relatively short time. This also translates to important savings in research funding. Mechanisms most active in purging or detoxification should be studied. For example, some polychaetes have a mixed function oxygenase (MFO) system which acts to detoxify aromatic hydrocarbons and coelomic proteins have been identified as binding trace metals in polychaetes.

Special attention should be given to designing experiments distinguishing between mechanical and chemical effects of drilling mud. This would require examining settling properties of drilling muds and drilling muds without trace metals. To some extent, this can be garnered from the literature. Once the settling properties of drilling muds and controls are determined tolerance of species in controls to turbidity and burial would be determined. The same tests would be conducted with drilling muds. The difference in biotic response as above between controls and drilling muds would serve to clarify the relative contribution of mechanical and chemical inhibition. The leachate from drilling muds aged for various time periods would also be used in these experiments.

The design, deployment and retrieval of sediment and larval traps is still emerging even though the knowledge obtained from studying larval settling is very promising in monitoring studies. Accordingly, this portion of the program would require research and development prior to full testing and implementation.

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APPENDIX TABLES

Table A-1. Georges Bank sediment properties--winter 1977 (taken from NEOEB V, 1978)

Station	Gravel %	Sand %	Silt %	Clay %	Silt-Clay %	Mean ϕ	Sorting ϕ	Carbon mg/g	Nitrogen mg/g	C:N
1	0.0	98.9	1.0	0.0	1.0	1.2	0.50	0.53	0.14	3.9
2	0.0	93.2	5.0	1.8	6.8	2.5	0.59	1.22	0.22	5.6
3	1.3	97.3	1.4	0.0	1.4	1.1	0.66	1.48	0.16	8.7
4	10.8	87.4	1.8	0.0	1.8	0.4	0.95	0.48	0.11	4.4
5	0.0	98.4	1.5	0.0	1.5	1.7	0.61	0.64	0.08	7.8
6	0.0	62.5	28.2	9.3	37.5	4.1	1.88	10.57	1.85	5.7
7	0.0	67.4	24.7	7.9	32.6	3.9	1.54	7.39	1.40	5.3
8	0.0	94.6	4.0	1.4	5.4	2.1	0.64	1.88	0.26	7.3
9	0.0	99.0	0.9	0.0	0.9	2.1	0.38	0.45	0.08	5.4
10	0.0	99.2	0.8	0.0	0.8	2.2	0.20	0.52	0.11	4.8
11	0.0	99.0	1.0	0.0	1.0	2.5	0.18	0.78	0.16	5.0
12	0.0	99.0	1.0	0.0	1.0	2.1	0.36	0.45	0.09	4.8
13	0.2	96.3	3.6	0.0	3.6	2.1	0.80	1.94	0.28	7.0
14	1.6	95.6	2.9	0.0	2.9	1.9	0.80	1.38	0.25	5.6
15	0.7	95.9	2.8	0.6	3.5	2.1	0.69	1.91	0.28	6.9
16	0.2	95.4	2.5	1.9	4.4	2.0	0.81	2.67	0.40	6.7
17	0.0	98.6	1.4	0.0	1.4	2.1	0.45	0.94	0.16	5.8
18	0.0	98.9	1.1	0.0	1.1	2.1	0.36	1.23	0.17	7.5
19	0.2	97.1	18	1.0	2.8	2.0	0.46	1.67	0.38	4.4
20	1.4	97.5	1.1	0.0	1.1	0.7	0.72	0.61	0.11	5.4
21	0.0	97.2	2.8	0.0	2.8	2.4	0.67	2.41	0.44	5.5
22	11.2	86.4	1.8	0.4	2.3	0.53	1.12	1.91	0.33	5.9
23	0.5	89.1	7.3	3.1	10.5	2.42	1.15	2.20	0.61	3.6
24	1.2	97.3	1.5	0.0	1.5	0.85	0.75	0.84	0.38	2.2
25	1.5	96.4	2.1	0.0	2.1	1.46	0.75	0.88	0.12	7.2

Table A-1
(concluded)

Station	Gravel %	Sand %	Silt %	Clay %	Silt-Clay %	Mean φ	Sorting φ	Carbon mg/g	Nitrogen mg/g	C:N
26	9.2	88.2	1.8	0.8	2.6	0.76	1.27	1.10	0.10	10.7
27	3.8	94.7	1.5	0.0	1.5	0.97	0.97	0.97	0.11	8.6
28	0.0	96.9	3.1	0.0	3.1	2.1	0.37	2.05	0.29	7.1
29	1.9	97.1	1.0	0.0	1.0	0.89	0.71	0.44	0.10	4.3
30	0.0	99.0	1.0	0.0	1.0	1.10	0.52	0.20	0.06	3.3
31	0.1	98.7	1.2	0.0	1.2	1.70	0.54	1.02	0.23	4.3
32	0.7	98.8	0.6	0.0	0.6	1.5	0.60	0.56	0.19	3.0
33	1.5	97.6	0.9	0.0	0.9	1.58	0.70	0.51	0.16	3.2
34	2.5	96.5	1.0	0.0	1.0	1.67	0.57	0.56	0.13	4.5
35	-	-	-	-	-	-	-	-	-	-
36	15.2	81.4	2.1	1.3	3.4	0.70	1.53	2.04	0.37	5.5
37	1.2	98.1	0.7	0.0	0.7	1.54	0.52	0.44	0.14	3.1
38	20.9	73.8	3.2	2.0	5.2	0.84	2.05	1.85	0.31	6.0
39	0.4	95.8	2.9	0.9	3.8	2.49	0.55	2.11	0.31	6.8
40	17.2	76.7	2.7	3.3	6.0	0.55	1.75	3.13	0.38	8.2
41	3.1	52.3	24.7	20.0	44.6	4.57	3.88	4.37	0.53	8.2
42	0.0	2.3	53.0	44.7	97.7	7.72	3.04	13.14	1.66	7.9

Table A-2. Georges Bank sediment properties--spring 1977 (taken from NEOEB V, 1978)

Station	Gravel %	Sand %	Silt %	Clay %	Silt-Clay %	Mean ϕ	Sorting ϕ	Carbon mg/g	Nitrogen mg/g	C:N
1	0.4	97.6	1.7	0.2	1.9	1.20	0.71	1.95	0.27	7.3
2	0.6	98.3	1.1	0.0	1.1	2.16	0.43	1.94	0.29	6.7
3	0.0	99.0	1.0	0.0	1.0	2.02	0.26	0.63	0.14	4.5
4	2.9	95.9	1.2	0.0	1.2	1.07	0.71	1.12	0.20	5.6
5	12.9	86.5	0.5	0.0	0.5	0.52	1.14	0.66	0.13	5.0
6	0.0	58.3	30.3	11.5	41.7	4.39	2.04	8.69	1.25	6.9
7	0.0	68.9	24.6	6.5	31.1	3.83	1.27	7.56	1.24	6.1
8	0.0	93.8	4.1	2.1	6.1	1.64	1.03	2.56	0.44	5.9
9	0.0	99.4	0.5	0.0	0.5	2.30	0.26	0.81	0.15	5.3
10	0.0	99.2	0.8	0.0	0.8	2.36	0.28	0.81	0.16	5.1
11	0.0	98.4	0.8	0.3	1.1	2.47	0.20	2.25	0.33	6.8
12	0.0	99.5	0.5	0.0	0.5	2.07	0.32	1.33	0.16	8.2
13	0.0	95.1	4.4	0.4	4.8	2.51	0.73	3.03	0.50	6.1
14	0.7	97.5	1.8	0.0	1.8	1.58	0.85	1.40	0.20	7.1
15	0.2	96.3	2.8	0.6	3.4	2.24	0.71	2.05	0.26	7.8
16	0.0	96.3	3.7	0.0	3.7	2.00	0.74	3.45	0.47	7.3
17	0.0	98.8	1.2	0.0	1.2	2.23	0.50	1.60	0.20	8.1
18	0.0	98.3	1.7	0.0	1.7	2.23	0.45	1.71	0.32	5.4
19	0.0	95.9	3.4	0.7	4.1	2.51	0.44	2.21	0.25	8.8
20	0.3	98.6	1.1	0.0	1.1	0.99	0.57	1.15	0.20	5.8
21	0.0	96.5	3.5	0.0	3.5	2.31	0.66	3.00	0.42	7.1
22	1.0	94.5	4.5	0.0	4.5	1.73	0.75	2.00	0.32	6.3
23	0.0	85.4	12.4	2.2	14.6	2.77	1.28	3.85	0.56	6.9
24	0.7	98.2	1.0	0.0	1.0	1.11	0.67	1.27	0.23	5.6
25	0.3	97.8	1.9	0.0	1.9	1.58	0.73	1.52	0.24	6.4

Table A-2.
(concluded)

Station	Gravel %	Sand %	Silt %	Clay %	Silt-Clay %	Mean ϕ	Sorting ϕ	Carbon mg/g	Nitrogen mg/g	C:N
26	4.5	94.6	0.9	0.0	0.9	1.09	0.71	1.13	0.14	7.8
27	1.9	95.2	2.9	0.0	2.9	1.17	0.92	1.68	0.25	6.8
28	0.0	96.8	2.8	0.4	3.2	2.14	0.40	1.82	0.32	5.7
29	1.5	97.7	0.9	0.0	0.9	0.94	0.62	0.94	0.13	7.2
30	3.9	94.9	0.9	0.0	0.9	1.00	0.86	1.03	0.19	5.5
31	0.2	99.3	0.7	0.0	0.7	1.75	0.44	1.51	0.28	5.4
32	0.2	98.7	1.1	0.0	1.1	1.78	0.52	1.01	0.18	5.5
33	3.4	95.6	1.0	0.0	1.0	1.33	0.82	0.75	0.17	4.4
34	5.4	93.9	0.7	0.0	0.7	1.24	0.68	1.14	0.16	7.3
35	11.9	73.6	7.5	7.0	14.5	1.72	2.59	3.92	0.47	8.4
36	4.5	83.6	8.6	3.2	11.9	2.12	1.56	3.77	0.51	7.3
37	12.6	86.7	0.7	0.0	0.7	1.17	1.13	0.73	0.18	4.1
38	31.1	65.8	1.6	1.5	3.1	0.26	2.09	2.88	0.41	7.1
39	0.0	94.7	4.1	1.2	5.3	2.51	0.81	3.55	0.53	6.7
40	14.1	78.0	3.2	4.7	7.9	0.61	2.02	4.32	0.75	5.7
41	1.3	51.5	27.6	19.6	47.2	4.93	3.50	4.87	0.64	7.6
42	0.0	2.1	55.2	42.7	97.9	7.61	3.29	12.94	1.63	7.9

Table A-3. Georges Bank sediment properties--summer 1977 (taken from NEOEB V, 1978)

Station	Gravel %	Sand %	Silt %	Clay %	Silt-Clay %	Mean φ	Sorting φ	Carbon mg/g	Nitrogen mg/g	C:N
1	1.2	97.3	1.5		1.5	1.2	0.69	1.88	0.30	6.2
2	0.6	99	0.9		0.9	2.4	0.35	1.54	0.25	6.2
3	0.0	98.5	1.5		1.5	1.9	0.17	0.81	0.17	4.7
4	7.1	91.4	1.5		1.5	0.9	1.1	2.25	0.34	6.6
5	9.3	89.6	1.1		1.1	0.8	1.2	1.44	0.31	4.7
6	0.0	61.6	29.1	9.4	38.4	4.2	1.9	8.47	1.01	8.4
7	-	-	-	-	-	-	-	-	-	-
8	0.1	94.8	3.1	2.0	5.1	1.7	1.0	3.09	0.37	8.3
9	0.0	98.9	1.1		1.1	2.3	0.25	1.73	0.20	8.8
10	0.0	99.2	0.8		0.8	2.3	0.23	1.16	0.21	5.6
11	-	-	-	-	-	-	-	-	-	-
12	0.0	99.7	0.3		0.3	2.1	0.3	1.72	0.20	8.7
13	0.3	96.7	2.3	0.7	3.0	2.6	0.63	3.76	0.38	9.9
14	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-
16	0.8	96.6	2.6		2.6	2.2	0.79	2.45	0.36	6.9
17	-	-	-	-	-	-	-	-	-	-
18	0.0	98.7	1.3		1.3	2.3	0.45	1.82	0.35	5.3
19	-	-	-	-	-	-	-	-	-	-
20	0.2	98.6	1.2		1.2	1.2	0.6	1.40	0.25	5.6
21	0.0	95.7	4.3		4.3	2.4	0.66	3.58	0.51	7.1
22	0.1	95.7	4.2		4.2	2.2	0.74	5.19	0.30	17.1
23	0.5	88.5	7.5	3.6	11.0	2.3	1.3	4.13	0.46	8.9
24	2.4	96.1	1.5		1.5	1.1	0.79	1.36	0.20	6.9
25	0.0	98.1	1.8		1.8	1.6	0.75	3.41	0.26	12.9
26	9.5	87.4	3.1		3.1	0.99	1.2	4.28	0.28	15.1
27	1.3	96.7	2.1		2.1	1.3	0.83	3.0	0.24	12.7
28	0.0	97.3	2.7		2.7	2.1	0.51	3.14	0.38	8.3
29	0.8	98.2	1.0		1.0	1.3	0.80	0.71	0.16	4.3
30	0.7	98.3	1.0		1.0	1.3	0.63	1.36	0.21	6.6

Table A-3
(concluded)

Station	Gravel %	Sand %	Silt %	Clay %	Silt-Clay %	Mean ϕ	Sorting ϕ	Carbon mg/g	Nitrogen mg/g	C:N
31	0.0	98.9	1.0		1.0	1.8	0.51	1.65	0.22	7.4
32	0.8	98.6	0.6		0.6	1.9	0.60	1.9	0.28	6.7
33	0.0	99.4	0.6		0.6	1.5	0.60	1.03	0.18	5.8
34	0.2	94.9	1.5	1.0	2.4	1.6	0.59	1.37	0.20	7.0
35	-	-	-	-	-	-	-	-	-	-
36	1.7	90.8	4.2	3.4	7.6	2.2	1.3	3.49	0.53	6.6
37	11.0	65.7	0.8		0.8	1.4	1.23	1.06	0.22	4.9
38	38.5	58.7	1.6	1.1	2.7	0.01	2.1	1.83	0.31	6.0
39	1.5	95.8	2.7		2.7	2.7	0.56	2.23	0.32	7.0
40	3.2	91.9	2.3	2.6	4.8	1.0	1.3	3.06	0.45	6.8
41	4.3	56.8	21.3	17.6	38.9	4.3	3.54	5.34	0.63	8.5
42	0.0	3.3	51.7	45.0	96.7	7.8	5.22	13.61	1.63	8.4

Table A-4. Georges Bank sediment properties--fall 1977 (taken from NEOEB V, 1978)

Station	Gravel %	Sand %	Silt %	Clay %	Silt-Clay %	Mean ϕ	Sorting ϕ	Carbon mg/g	Nitrogen mg/g	C:N
1	0.0	98.6	1.4		1.4	1.5	0.57	1.18	0.20	6.0
2	-	-	-	-	-	-	-	-	-	-
3	0.0	98.8	1.2		1.2	2.1	0.32	1.02	0.17	5.9
4	9.6	89.2	1.2		1.2	0.5	1.1	1.71	0.21	8.0
5	1.9	96.9	1.2		1.2	1.3	0.84	2.02	0.30	6.7
6	0.0	59.2	30.0	10.8	40.8	4.3	2.0	8.94	1.16	7.7
7	0.0	69.8	23.4	6.8	30.2	3.7	1.3	6.09	0.79	7.7
8	0.0	95.1	2.9	1.9	4.9	1.5	0.97	3.41	0.43	8.0
9	0.0	99.0	1.0		1.0	2.2	0.42	1.11	0.18	6.1
10	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-
12	0.0	99.7	0.3		0.3	2.4	0.3	1.03	0.18	5.6
13	0.2	94.9	3.7	1.2	4.9	2.4	0.81	3.93	0.51	7.6
14	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-
18	0.0	99.0	1.0		1.0	2.2	0.41	1.61	0.28	5.8
19	-	-	-	-	-	-	-	-	-	-
20	0.0	97.8	2.2		2.2	1.4	0.8	1.34	0.21	6.4
21	0.0	96.6	3.4		3.4	2.3	0.67	3.02	0.41	7.4
22	0.1	95.3	4.0	0.6	4.6	2.1	0.7	6.89	0.37	18.5
23	0.1	74.6	17.1	8.2	25.3	3.6	1.7	9.21	0.91	10.1
24	-	-	-	-	-	-	-	-	-	-
25	0.0	97.1	2.9		2.9	1.6	0.7	3.7	0.25	14.6

Table A-4
(concluded)

Station	Gravel %	Sand %	Silt %	Clay %	Silt-Clay %	Mean φ	Sorting φ	Carbon mg/g	Nitrogen mg/g	C:N
26	7.8	91.5	0.7		0.7	0.89	1.0	1.67	0.16	10.2
27	-	-	-	-	-	-	-	-	-	-
28	0.0	97.1	2.9		2.9	2.2	0.45	2.32	0.31	7.5
29	0.0	98.3	1.7		1.7	1.4	0.61	1.17	0.19	6.3
30	-	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-
32	0.0	99.0	1.0		1.0	1.63	0.53	0.97	0.17	5.7
33	0.6	98.4	1.0		1.0	1.61	0.68	0.77	0.17	4.6
34	0.1	98.7	1.2		1.2	1.4	0.48	1.44	0.21	6.9
35	2.0	79.8	10.6	7.6	18.2	2.9	2.09	5.62	0.59	9.5
36	0.1	96.3	3.1	0.5	3.6	2.8	0.27	2.65	0.38	7.0
37	19.1	80.0	1.0		1.0	0.87	1.43	1.07	0.16	6.7
38	-	-	-	-	-	-	-	-	-	-
39	0.0	96.7	3.3		3.3	2.5	0.51	3.03	0.38	7.9
40	14.4	76.7	4.5	4.4	8.9	0.70	2.09	3.50	0.45	7.8
41	2.3	50.6	25.9	21.3	47.1	4.82	3.67	4.9	0.56	8.8
42	0.0	4.0	51.4	44.6	96.0	7.84	5.06	14.91	1.78	8.4

Table A-5. Taxonomic List of Species from the Martha's Vineyard-Nantucket Shoals Area

- Porifera

- Cnidaria
  - Hydrozoa
    - *Hydractinia echinata*
  - Anthozoa
    - *Cerianthus* sp.
    - *Edwardsia* sp.
    - *Epizoanthus americanus*
    - *Pennatula aculeata*
    - *Stylatula elegans*

- Nemertea

- Annelida
  - *Aglaophamus circinata*
  - *Ammotrypane aulogaster*
  - *Amphitrite* sp.
  - *Ancistrosyllis* sp.
  - *Aphrodita hastata*
  - *Arabella iricolor*
  - *Aricidea jeffreysii*
  - *Asychis biceps*
  - *Brada* sp.
  - *Capitella* sp.
  - *Ceratocephale loveni*
  - *Chaetozone* sp.
  - *Chone infundibuliformis*
  - *Cossura longocirrata*
  - *Drilonereis longa*
  - *Eunice pennata*
  - *Flabelligera* sp.
  - *Glycera robusta*
  - *Glycera tesselata*
  - *Goniada brunnea*
  - *Goniada maculata*
  - *Harmothoe extenuata*
  - *Hyalinoecia tubicola*
  - *Laonice cirrata*
  - *Leanira* sp.
  - *Lumbrineris fragilis*
  - *Lumbrineris tenuis*
  - *Melinna cristata*
  - *Nephtys bucera*
  - *Nephtys incisa*
  - *Nereis pelagica*
  - *Ninoe nigripes*
  - *Notocirrus* sp.
  - *Onuphis conchylega*
  - *Onuphis opalina*
  - *Onuphis quadricuspis*
  - *Orbinia ornata*

- Annelida (cont'd)
  - *Owenia* sp.
  - *Paradiopatra* sp.
  - *Paramphinome pulchella*
  - *Paraonis neopolitana*
  - *Phyllodoce mucosa*
  - *Prionospio* sp.
  - *Scalibregma inflatum*
  - *Sphaerodorum gracilis*
  - *Spio* sp.
  - *Spiochaetopterus* sp.
  - *Spiophanes bombyx*
  - *Sternaspis scutata*
  - *Sthenelais limicola*
  - *Streblosoma spiralis*
  - *Tharyx* sp.

- Sipunculida
  - *Golfingia catherinae*
  - *Golfingia elongata*
  - *Golfingia minuta*
  - *Golfingia (Phascoloides)* sp.
  - *Onchnesoma steenstrupi*
  - *Phascolion strombi*

- Arthropoda
  - Amphipoda
    - *Aeginina longicornis*
    - *Ampelisca compressa*
    - *Ampelisca macrocephala*
    - *Anonyx* sp.
    - *Byblis serrata*
    - *Caprella* sp.
    - *Casco bigelowi*
    - *Corophium* sp.
    - *Dulichia* sp.
    - *Eriopisa elongata*
    - *Harpinia propinqua*
    - *Haustoriidae*
    - *Hippomedon serratus*
    - *Lembos* sp.
    - *Leptocheirus pinguis*
    - *Orchomenella groenlandica*
    - *Paraphoxus* sp.
    - *Photis macrocoxa*
    - *Phoxocephalus holbolli*
    - *Protomedia fasciata*
    - *Siphonoecetes smithianus*
    - *Stenopleustes gracilis*
    - *Unciola irrorata*
    - *Unciola leucopis*

Table A-5. (continued)

Decapoda
Axius serratus
Cancer borealis
Cancer irroratus
Catapagurus sharreri
Crangon septemspinosa
Bythocaris nana
Dichelopandalus leptocerus
Europrognatha rastellifera
Hyas coarctatus
Munida iris
Pagurus acadianus
Pagurus arcuatus
Pagurus politus
Pontophilus brevirostris
Isopoda
Calathura sp.
Chiridotea tuftsi
Cirolana polita
Edotea triloba
Ptilanthura tenuis
Cumacea
Diastylis polita
Diastylis quadrispinosa
Eudorella emarginata
Eudorellopsis sp.
Leptocuma minor
Leptostylis sp.
Petalosarsia declivis
Mysidacea
Bathymysis renoculata
Erythrops erythropthalma
Hypererythrops caribbaea
Mysis mixta
Neomysis americana
Cirripedia
Balanus sp.
Pycnogonida
Achelia spinosa
Paranymphon spinosum

Mollusca
Amphineura
Chaetoderma nitidulum
Pelecypoda
Anomia sp.
Arctica islandica
Astarte undata
Bathyarca pectunculoides
Cerastoderma pinnulatum
Crenella glandula
Cuspidaria perrostrata
Cuspidaria striata

Pelecypoda (cont'd)
Ensis directus
Hiatella sp.
Lyonsia arenosa
Lyonsia hyalina
Macoma calcarea
Mesodesma arctatum
Mytilidae
Nucula proxima
Nucula tenuis
Nuculana acuta
Pandora gouldiana
Pandora inflata
Periploma papyratium
Phacoides blakeanus
Phacoides filosus
Placopecten magellanicus
Siliqua costata
Spisula solidissima
Tellina agilis
Thracia sp.
Thyasira ferruginosa
Thyasira gouldi
Thyasira ovata
Thyasira trisinuata
Venericardia borealis
Yoldia sapotilla
Scaphapoda
Cadulus pandionis
Cadulus verrilli
Dentalium occidentale
Gastropoda
Alvania carinata
Buccinum undatum
Colus stimpsoni
Crepidula plana
Crucibulum striatum
Cylichna alba
Epitonium dallianum
Lunatia heros
Lunatia triseriata
Nassarius trivitatus
Neptunea sp.
Polinices sp.
Retusa gouldi
Scaphander sp.

Echinodermata
Asteroidea
Asterias vulgaris
Astropecten americanus
Astropecten sp.
Henricia sanguinolenta
Leptasterias tenera
Porania sp.

Table A-5. (concluded)

- Echinoidea
  - *Brisaster fragilis*
  - *Echinarachnius parma*
- Ophiuroidea
  - *Amphilimna olivacea*
  - *Amphioplus abditus*
  - *Amphioplus macilentus*
  - *Amphiura fragilis*
  - *Amphiura otteri*
  - *Axiognathus squamatus*
  - *Ophiura robusta*
  - *Ophiura sarsi*
- Holothuroidea
  - *Caudina arenata*
  - *Chiridota* sp.
  - *Cucumaria frondosa*
  - *Havelockia scabra*
  - *Molpadia oolitica*
  - *Psolus fabricii*
  - *Stereoderma unisemita*

Bryozoa

- *Dendrobeania murrayana*
- *Electra hastingsae*
- *Electra pilosa*
- *Haplota clavata*
- *Hippothoa hyalina*
- *Scruparia chelata*

Ascidiacea

- *Bostrichobranchus pilularis*
- *Ciona intestinalis*
- *Cnemidocarpa mollis*
- *Heterostigma singulare*
- *Molgula citrina*
- *Molgula complanata*
- *Molgula siphonalis*

Pogonophora

- *Siboglinum atlanticum*
- *Siboglinum ekmani*

Hemichordata

- Enteropneusta
  - *Balanoglossus* sp.

Table A-6. Taxonomic List of Genera/Species from Quantitative NMFS Grabs (1.0 mm mesh) from the Lease Tract

- Cnidaria
  - Anthozoa
    - *Cerianthus* sp.
    - *Edwardsia* sp.
    - *Epizoanthus americanus*
- Annelid
  - Polychaeta
    - *Ammotrypane* sp.
    - *Brada* sp.
    - *Glycera* sp.
    - *Goniada* sp.
    - *Lumbrineris* sp.
    - *Maldane* sp.
    - *Nephtys* sp.
    - *Phyllodoce* sp.
    - *Polydora* sp.
    - *Potamilla* sp.
    - *Scalibregma inflatum*
    - *Streblosoma* sp.
- Mollusca
  - Bivalvia
    - *Arctica islandica*
    - *Astarte* sp.
    - *Bathyarca* sp.
    - *Cerastoderma pinnulatum*
    - *Crenella* sp.
    - *Ensis* sp.
    - *Hiatella arctica*
    - *Limopsis* sp.
    - *Lyonsia* sp.
    - *Macoma* sp.
    - *Nucula* sp.
    - *Periploma* sp.
    - *Phacoides* sp.
    - *Siliqua costata*
    - *Spisula* sp.
    - *Thyasira ferruginosa*
    - *Thyasira gouldi*
    - *Venericardia borealis*
    - *Yoldia* sp.
  - Gastropoda
    - *Cyclichna* sp.
    - *Lunatia* sp.
    - *Margarites* sp.
    - *Nassarius trivittatus*
    - *Neptunea* sp.
    - *Scaphander* sp.

Scaphopoda

- *Cadulus* sp.
- *Dentalium* sp.

Arthropoda

Crustacea

Cumacea

- *Diastylis polita*
- *Diastylis quadrispinosa*
- *Diastylis sculpta*
- *Eudorella* sp.
- *Lamprops* sp.
- *Leptocuma* sp.

Isopoda

- *Cirolana impressa*
- *Cirolana polita*
- *Edotea acuta*
- *Edotea triloba*
- *Idotea phosphorea*

Amphipoda

- *Aeginina longicornis*
- *Ampelisca agassizi*
- *Ampelisca compressa*
- *Amphiporeia lawrenciana*
- *Anonyx* sp.
- *Byblis serrata*
- *Caprella* sp.

Amphipoda (continued)

- *Casco bigelowi*
- *Corophium* sp.
- *Dulichia* sp.
- *Harpinia plumosa*
- *Haustorius arenarius*
- *Hippomedon serratus*
- *Ischyrocerus* sp.
- *Leptocheirus pinguis*
- *Monoculodes* sp.
- *Orchomenella* sp.
- *Paraphoxus* sp.
- *Paroediceros* sp.
- *Photis* sp.
- *Phoxocephalus holbolli*
- *Podoceropsis nitida*
- *Pontogeneia inermis*
- *Pleustes panoplus*
- *Unciola inermis*
- *Unciola irrorata*
- *Unciola leucopis*
- *Unciola obliquua*

Decapoda

- *Cancer irroratus*
- *Catapagurus* sp.
- *Crangon septemspinosa*

Table A- 6. (concluded)

Decapoda (continued)

- *Dichelopandalus* sp.
- *Eualus* sp.
- *Meganyctiphanes*
- *Neomysis americana*
- *Pagurus acadianus*
- *Pagurus pubescens*

Echinodermata

- Asteroidea
  - *Asterias vulgaris*
  - *Astropecten americana*
  - *Astropecten cingulatus*
  - *Leptasterias* sp.
- Echinoidea
  - *Echinarachnius parma*
- Ophiuroidea
  - *Amphipholis* sp.

Holothuroidea

- *Molpadia* sp.
- *Synapta* sp.

Pogonophora

Urochordata

- Ascidiacea
  - *Molgula arenata*

Table A- 7. Taxoncmic List of Benthic Species from tows for Georges Bank, 1977 (taken from NEOEB III, 1978)

	W	Sp	S	F
Porifera				
Cliona celata				X
Halichondria spp.		X		
Hymeniacdan heliophila				X
Polymastia robusta			X	X
Porifera		X		
Suberites ficus	X	X	X	X
Tentorium semisuberites				X
Cnidaria				
Anthozoa				
Anthozoa		X		
Ceriantheopsis americanus		X	X	
Epizoanthus americanus	X	X	X	X
Metridium senile	X	X	X	X
Pennatula aculeata		X		
Rhynchocoela				
Nemertea	X		X	X
Annelida				
Polychaeta				
Ampharete arctica			X	
Ampharetidae	X	X		
Amphicteis gunneri				X

Table A- 7.(continued)

	W	Sp	S	F
Amphitrite ornata	X			
Aphrodite hastata	X	X	X	X
Ammotrypane aulogaster			X	
Arabella iricolor	X			
Autolytus emertoni	X			
Capitella capitata			X	
Clymenella torquata			X	X
Drilonereis caulleryi			X	
Drilonereis magna				X
Euclymene sp.				X
Eulalia bilineata			X	
Eunice pennata		X	X	X
Exogene hebes	X			
Flabelligeridae				X
Glycera dibranchiata			X	
Goniada norvegica			X	X
Harmothoe acanellae			X	
Harmothoe extenuata	X	X		X
Harmothoe imbricata				X
Laetmonice filicornis		X	X	X
Leanira hystricus	X			
Lumbrineris fragilis			X	X
Lumbrineris spp.	X			
Maldane sarsi	X	X	X	X

Table A-7.(continued)

	W	Sp	S	F
Maldanidae		X	X	X
Marphysa sanguinea				X
Melinna cristata		X	X	X
Melinna sp. 1		X		
Neanthes virens		X		
Nephtyidae			X	
Nephtys bucera			X	
Nephtys caeca				X
Nephtys incisa	X	X	X	X
Nereis grayi			X	X
Nereis pelagica	X	X	X	X
Nicomache lumbricalis		X	X	X
Onuphis conchylega		X	X	X
Onuphis opalina	X	X	X	X
Onuphis quadricuspis		X		X
Ophioglycera gigantea			X	
Owenia fusiformia	X	X	X	
Pherusa affinis			X	
Phyllodoce maculata		X		
Pista cristata				X
Polydora commensalis			X	
Polydora ligni				X
Polydora socialis		X		

Table A-7. (continued)

	W	Sp	S	F
Polyphysa crassa				X
Potamilla neglecta	X	X	X	
Potamilla reniformis	X	X	X	
Praxillella sp. A	X			
Praxillella sp. B	X			
Praxillella praetermissa		X		
Scalibregma inflatum	X			
Sigalion arenicola			X	
Spionidae			X	
Spiophanes bombyx	X			
Sternaspis scutata		X	X	X
Sthenelais boa		X		X
Sthenelais limicola			X	
Syllis gracilis			X	
Terebella lapidaria			X	X
Terebellidae		X	X	X
Terebellides stroemi			X	X
Mollusca				
Gastropoda				
Acanthodoris pilosa	X		X	
Anachis avara	X			
Aporrhais occidentalis		X	X	
Buccinum undatum	X	X	X	X
Capulus ungaris		X		

Table A-7.(continued)

	W	Sp.	S	F
Colus pygmaeus			X	
Colus stimpsoni	X	X	X	X
Colus ventricosa	X			
Crepidula convexa		X		
Crepidula fornicata		X	X	X
Crepidula plana	X	X	X	X
Crucibulum striatum	X	X	X	X
Cylichna acculata		X		
Diodora tanneri			X	
Epitonium greenlandicum	X		X	
Haminoea solitaria	X			
Lora cancellata	X			
Lunatia heros		X	X	X
Lunatia triseriata	X			X
Margarites helicinus	X	X		
Nassarius trivittatus	X	X		X
Natica clausa		X	X	
Neptunea decemcostata	X	X	X	X
Nudibranchia				X
Pleurobranchaea tarda			X	
Polinices duplicatus	X			
Polinices immaculatus	X			
Solariella obscura	X			

Table A-7.(continued)

	W	Sp	S	F
Scaphopoda				
Dentalium eboreum	X	X		
Dentalium occidentale		X	X	X
Bivalvia				
Anomia aculeata	X	X	X	
Anomia simplex		X	X	X
Arctica islandica	X	X	X	X
Astarte castanea	X	X	X	X
Astarte subaequilatera	X		X	X
Astarte undata	X	X	X	X
Bathyarca glomerula	X			
Bathyarca pectunculoides	X	X		X
Chlamys islandica				X
Cerastoderma pinnatulum	X		X	X
Crenella glandula	X		X	
Cuspidaria glacialis		X		
Ensis directus			X	X
Ensis minor			X	
Lyonsia hyalina			X	
Macoma calcarea		X	X	X
Microcardium peramabile	X	X	X	
Modiolus modiolus		X	X	X
Musculus niger		X	X	X
Mytilus edulis	X			
Nucula spp.	X	X		

Table A-7.(continued)

	W	Sp	S	F
Nuculana caudata	X			
Nuculana tenuisulcata		X	X	X
Pallilolum striatum			X	
Pandora gouldiana	X		X	X
Panomya arctica		X		
Periploma fragile			X	
Placopecten magellanicus	X	X	X	X
Siliqua costata			X	
Solem viridis	X		X	X
Solemya velum				X
Spisula solidissima	X	X	X	X
Thracia septentrionalis	X			
Thyasira flexuosa			X	
Thyasira trisinuata				X
Venericardia borealis	X	X	X	X
Yoldia myalis		X	X	X
Cephalopoda				
Bathypolypus arcticus		X	X	X
Rossia tenera		X		
Stoloteuthis leucoptera		X		
Teuthoidida				X
Arthropoda				
Pycnogonida				
Nymphon macrum	X	X		X
Pycnogonium littorale			X	

Table A- 7 (continued)

	W	Sp	S	F
Cirripedia				
Balanus amphitrite niveus				X
Balanus crenatus	X			
Balanus hameri		X	X	X
Balanus spp.	X	X		
Scalpellum sp.		X		
Isopoda				
Chiridotea tuftsi	X		X	
Cirolana concharum	X			
Idotea metallica			X	
Idotea phosphorea	X			
Amphipoda				
Acanthohaustorius spinosus	X			
Aeginella longicornis		X		X
Ampelisca spp.	X			
Ampelisca vadorum			X	X
Amphipoda			X	
Caprellidae	X		X	
Corophiidae			X	X
Gammarus annulatus		X		
Gammarus sp.				X
Hippomedon serratus	X			
Leptocheirus pinguis	X			

Table A- 7.(continued)

	W	Sp	S	F
Melita dentata	X		X	X
Monoculoides eawardsii	X			
Pleustidae	X			
Podoceropsis nitida			X	
Pontogeneia inermis	X			
Psamonyx nobilis	X			
Stegocephalus inflatus	X			
Unciola dissimilis			X	
Unciola irrorata	X	X	X	
Unciola sp. 1	X			
Decapoda				
Calocaris templemani			X	
Cancer borealis		X	X	X
Cancer irroratus	X	X	X	X
Crangon septemspinosa	X	X	X	X
Dichelopandalus leptocerus	X	X	X	X
Eualus pusiolus	X			X
Euprognatha rastillifera			X	
Homola barbata			X	
Hyas araneus		X	X	
Hyas coarctatus	X	X	X	X
Meganyctiphanes norvegica	X	X	X	X
Munida iris		X	X	X
Ovalipes ocellatus		X	X	

Table A-7. (continued)

	W	Sp	S	F
Pagurus acadianus	X	X	X	X
Pagurus arcuatus	X	X	X	X
Pagurus longicarpus			X	
Pagurus pubescens			X	
Parenthope pourtalesi		X	X	X
Pinnotheres maculatus		X		
Sclerocrangon boreas		X		
Sipunculoidea				
Golfinga sp.			X	X
Golfinga vervilli			X	
Phascolosoma procerum	X	X		
Sipunculida	X	X	X	X
Brachiopoda				
Terebratulina septentrionalis		X	X	
Echinodermata				
Asteroidea				
Asterias vulgaris		X	X	X
Astropecten americanus	X	X	X	X
Briaster fragilis	X	X	X	X
Ceramaster granularis		X		
Ctenodiscus crispatus				X
Henricia sanguinolenta		X	X	X
Hippasteria phrygiana		X		

Table A-7.(continued)

	W	Sp	S	F
Leptasterias tenera	X	X	X	X
Leptychaster arcticus		X		
Odontaster hispidus			X	X
Porania insignis		X	X	X
Poraniomorpha hispida		X		
Pseudarchaster intermedius		X		
Sclerasterias tanneri			X	X
Solaster papposus			X	X
Ophiuroidea				
Amphipholis squamatus			X	
Amphiura otteri		X	X	X
Amphiura spp.	X			
Ophiacantha bidentata		X		
Ophiopholis aculeata		X	X	X
Ophiura sarsi	X	X	X	X
Echinoidea				
Echinarchnius parma	X	X	X	X
Strongylocentrotus droebachiensis	X	X	X	X
Holothuroidea				
Cucumaria frondosa		X		X
Havelockia scabra				X
Holothuroidea		X		
Pentamera calcigera			X	

Table A-7. (concluded)

	W	Sp	S	F
Psolus phantapus		X	X	X
Psolus sp.		X		
Psolus valvatus		X		X
Stereoderma unisemita		X	X	X
Thyanium commune			X	
Urochordata				
Ascidacea				
Ascidacea		X		
Molgula manhattensis		X	X	
Polycarpa fibrosa		X		X

Table A-8. Taxonomic List of Species from Quantitative Grabs (0.5 mm mesh) for Georges Bank, 1977 (taken from Michael, 1977; Maurer and Leathem, 1980a)

W - Winter
Sp- Spring

Porifera

Porifera unidentified
Scypha sp.

Cnidaria

Hydrozoa

Campanularia sp.
Clytia johnstoni
Clytia sp.
Hydractinea echinata
Hydroida unidentified
Thuiaria argentea

Anthozoa

Alcyonaria unidentified
Anthozoa unidentified
Astrangia danea
Cerianthus americanus
Metridium senile
Sagartia modesta

Platyhelmmthes

Turbellaria unidentified

Rhynchocoela

Micrura sp.
Rhynchocoela unidentified

Annelida

Archiannelida unidentified
Hirudinea unidentified
Oligochaeta unidentified

Polychaeta

Aphroditidae

Aphrodita hastata	W, Sp
Aphrodita spp. juvenile	W
Aphroditidae spp.	Sp
Laetmonice filicornis	W, Sp

Polynoidae

Antinoella angusta	W
Arcteobia anticostiensis	W
Austrolaenilla mollis	Sp
Austrolaenilla sp. A	Sp
Enipo gracilis	W, Sp
Gattyana amondseni	W
Harmothoe extenuata	W, Sp
Harmothoe spp.	W, Sp
Harmothoe sp. A	W
Hartmania moorei	W
Polynoidae spp.	Sp

Sigalionidae

Laenira tetragona	Sp
Pholoe minuta	W, Sp
Sigalion arenicola	W, Sp
Sthenelais boa	W, Sp
Sthenelais limicola	W, Sp
Sthenelais spp.	Sp

Amphinomidae

Paramphinome jeffreysii	W, Sp
Pareurythoe borealis	W, Sp

Euphrosinidae

Euphrosine armadillo	W, Sp
Euphrosine ap. A	W

Phyllodocidae

Eteone longa	W, Sp
Eteone spp.	Sp
Eteone spetsbergensis	W, Sp
Eulalia bilineata	W, Sp
Eumida sanguinea	W, Sp
Hesionura sp. A	W, Sp
Mystides borealis	W, Sp
Paranaitis spp.	Sp
Paranaitis speciosa	W, Sp
Phyllodoce mucosa	W, Sp
Phyllodoce spp.	Sp
Phyllodocidae spp.	Sp

Table A- 8.(continued)

Iospilidae

Iospilus phalacroides	Sp

Hesionidae

Microphthalmus sp. A	Sp
Microphthalmus sp. B	Sp
Nereimyra punctata	W, Sp
Podarke obscura	W, Sp

Pilargiidae

Ancistrosyllis groenlandica	W, Sp
Synelmis klatti	W, Sp

Syllidae

Autolytus prolifera	W, Sp
Autolytus sp. A	W, Sp
Braniella pupa	W
Eusyllis blomstrandi	W
Eusyllis lamelligera	W, Sp
Eusyllis spp.	Sp
Eusyllis sp. A	W, Sp
Eusyllis sp. B	Sp
Exogone hebes	W, Sp
Exogone naidina	W, Sp
Exogone sp. A	Sp
Exogone verugera	W, Sp
Odontosyllis longiseta	W
Parapionosyllis longicirrata	W, Sp
Proceraea cornuta	W, Sp
Sphaerosyllis erinaceus	W, Sp
Streptosyllis arenae	W, Sp
Streptosyllis varians	W, Sp
Streptosyllis websteri	W, Sp
Syllidae spp.	Sp
Syllides benedicti	W, Sp
Syllides convoluta	W
Syllides japonica	W
Syllides spp.	Sp
Syllis (Langerhansia) cornuta	W
Syllis spp.	Sp
Syllis (*Typosyllis*) *hyalina*	W, Sp
Syllis (*Typosyllis*) sp. A	W, Sp
Syllis (*Typosyllis*) *tegulum*	W, Sp

Nereidae

Ceratocephale loveni	W, Sp
Nereidae spp. juvenile	Sp
Nereis (*Neanthes*) *accuminata*	W, Sp
Nereis pelagica	W,
Nereis spp.	Sp
Nereis sp. A	W, Sp
Nereis zonata	W, Sp

Nephtyidae

Aglaophamus circinata	W, Sp
Nephtyidae spp.	Sp
Nephtys bucera	W, Sp
Nephtys caeca	W, Sp
Nephtys ciliata	W, Sp
Nephtys discors	Sp
Nephtys incisa	W, Sp
Nephtys longosetosa	Sp
Nephtys sp. juvenile	W, Sp
Nephtys squamosa	W

Sphaerodoridae

Ephesiella minuta	W
Sphaerodoridium sp. A	W, Sp

Glyceridae

Glycera americana	Sp
Glycera capitata	W, Sp
Glycera dibranchiata	W, Sp
Glycera robusta	W, Sp
Glycera sp. A juvenile	W, Sp

Goniadidae

Goniada brunnea	W, Sp
Goniada maculata	W, Sp
Goniada norvegica	W, Sp
Goniada spp.	W, Sp
Goniadella gracilis	W, Sp

Eunicidae

Eunice pennata	W, Sp
Eunice vittata	Sp
Eunicidae sp. juvenile	W
Marphysa belli	W, Sp
Marphysa spp.	Sp
Marphysa sp. A	Sp
Marphysa Sp. B	Sp
Marphysa stylobranchiata	Sp

Table A- 8.(continued)

Onuphidae

Nothria conchylega	W, Sp
Nothria spp. juvenile	Sp
Onuphidae spp. juvenile	W, Sp
Onuphis opalina	W, Sp
Onuphis pallidula	W, Sp

Lumbrineridae

Lumbrineris acuta	W, Sp
Lumbrineris fragilis	W, Sp
Lumbrineris impatiens	W, Sp
Lumbrineris inflata	W
Lumbrineris latreilli	W, Sp
Lumbrineris sp. A	W
Lumbrineris sp. B	Sp
Lumbrineris tenuis	W, Sp
Ninoe brevipes	W
Ninoe nigripes	W, Sp
Ninoe sp. A	W

Arabellidae

Arabella sp. A	Sp
Arabellidae spp.	W, Sp
Drilonereis caulleryi	W
Drilonereis filum	W
Drilonereis longa	W, Sp
Drilonereis magna	W, Sp
Drilonereis spp.	W

Dorvilleidae

Dorvillea sp. A	W
Protodorvillea gaspeensis	W, Sp
Protodorvillea kefersteini	W, Sp
Schistomeringos caeca	W, Sp
Ophryotrocha puerilis	Sp

Orbiniidae

Orbinia michaelsoni	W, Sp
Orbinia ornata	W, Sp
Orbinia spp.	W, Sp
Orbinia swani	W, Sp
Orbiniidae spp.	W, Sp
Scoloplos armiger	W, Sp
Scoloplos fragilis	W
Scoloplos robustus	W, Sp
Scoloplos sp.	Sp

Apistobranchidae

Apistobranchus sp. A	W

Paraonidae

Aedicira sp. A	W
Aedicira sp. C	W, Sp
Aricidea albatrossae	W, Sp
Aricidea catherinae	W, Sp
Aricidea cerruti	W, Sp
Aricidea neosuecica	W, Sp
Aricidea quadrilobata	W, Sp
Aricidea suecica	W, Sp
Aricidea wassi	W, Sp
Cirrophorus lyriformis	W, Sp
Paraonidae spp.	W, Sp
Paraonides sp. A	W, Sp
Paraonides sp. B	W, Sp
Paradoneis lyra	W, Sp
Paraonis fulgens	W, Sp
Paraonis gracilis	W, Sp
Paraonis spp.	W
Paraonis sp. A	W
Paraonis sp. B	W, Sp
Paraonis sp. C	W, Sp
Paraonis sp. D	W, Sp

Questidae

Novaquesta trifurcata	W, Sp

Trochochaetidae

Disoma carica	W, Sp

Spionidae

Aonides oxycephala	Sp
Laonice cirrata	W, Sp
Polydora caulleryi	W, Sp
Polydora colonia	Sp
Polydora concharum	W, Sp
Polydora socialis	W, Sp
Polydorella sp. A	W
Prionospio cirrifera	W, Sp
Prionospio cirrobranchiata	W, Sp
Prionospio steenstrupi	W, Sp
Scolelepis spp.	W
Scolelepis sp. A	W, Sp
Scolelepis sp. B	W

Table A- 8.(continued)

Spionidae (concluded)

Scolelepis squamata	W, Sp
Scolelepis tridentata	W, Sp
Spio filicornis	W, Sp
Spio multioculata	W, Sp
Spio pettiboneae	W, Sp
Spionidae spp.	Sp
Spionidae sp. A	W, Sp
Spionidae sp. C	W
Spiophanes bombyx	W, Sp
Spiophanes kroyeri	W, Sp
Spiophanes wigleyi	W, Sp
Streblospio benedicti	W

Unknown Family, Near Spionidae

Aberranta enigmatica	Sp

Chaetopteridae

Chaetopteridae spp.	W
Spiochaetopterus costarum	W

Psammodrilidae

Psammodrilus balanoglossoides	W, Sp

Cirratulidae

Caulleriella spp.	Sp
Caulleriella sp. A	W, Sp
Caulleriella sp. B	W, Sp
Caulleriella sp. C	W, Sp
Chaetozone setosa	W, Sp
Chaetozone spp.	W, Sp
Chaetozone sp. A	W, Sp
Chaetozone sp. B	W, Sp
Chaetozone sp. juvenile	W
Cirratulidae spp.	W, Sp
Dodecaceria sp. A	W, Sp
Tharyx acutus	W, Sp
Tharyx annulosus	W, Sp
Tharyx sp. A	W, Sp
Tharyx sp. B	W, Sp
Tharyx sp. C	W, Sp

Cossuridae

Cossura longocirrata	W, Sp

Ctenodrilidae

Raphidrilus sp. A	W, Sp

Flabelligeridae

Brada villosa	W, Sp
Flabelligeridae spp.	Sp
Pherusa affinis	W, Sp
Pherusa sp. A	Sp

Scalibregmidae

Asclerochelius beringianus	Sp
Pseudoscalibregma parvum	W, Sp
Scalibregma inflatum	W, Sp
Scalibregmidae spp.	Sp

Opheliidae

Ophelia limacina	W, Sp
Opheliidae spp.	W, Sp
Ophelina acuminata	W, Sp
Ophelina cylindricaudata	W, Sp
Ophelina spp.	W, Sp
Travisia forbesii	W, Sp

Capitellidae

Barantolla sp. A	W, Sp
Barantolla sp. B	Sp
Capitella capitata	W, Sp
Capitellidae spp.	W, Sp
Capitellides sp. A	Sp
Heteromastus filiformis	W, Sp
Mediomastus ambiseta	W, Sp
Notomastus latericeus	W, Sp

Maldanidae

Axiothella sp. A	W
Clymenura borealis	W
Clymenura sp. A	W, Sp
Clymenella torquata	W, Sp
Euclymene collaris	W, Sp
Isocirrus sp. A	W, Sp
Maldane sarsi	W, Sp
Maldanella sp. A	W
Maldanidae spp.	W, Sp
Microclymene tricirrata	W
Nicomache lumbricalis	W, Sp

Table A- 8. (continued)

Maldanidae (concluded)	
Notoproctus oculatus	W
Petaloproctus tenuis borealis	W, Sp
Praxillura longissima	W, Sp
Rhodine gracilior	W, Sp
Oweniidae	
Owenia fusiformis	W, Sp
Myriochele heeri	W
Myriochele oculata	W, Sp
Myriochele sp. A	Sp
Sternaspidae	
Sternaspis scutata	W, Sp
Pectinariidae	
Cistena hyperborea	
Ampharetidae	
Amage tumida	W, Sp
Ampharete arctica	W, Sp
Ampharetidae spp.	W, Sp
Amphicteis gunneri	W, Sp
Anobothrus gracilis	W, Sp
Asabellides oculata	W, Sp
Auchenoplax crinita	Sp
Glyphanostomum spp.	Sp
Glyphanostomum sp. A	Sp
Melinna cristata	W, Sp
Sabellides octocirrata	W, Sp
Samytha sexcirrata	W, Sp
Samythella eliasoni	W, Sp
Samythella elongata	Sp
Samythella spp.	W
Sosanella apalea	W
Sosanella spp.	W
Terebellidae	
Amaena sp. A	W
Amphitrite grayi	W
Eupolymnia nebulosa	W, Sp
Hauchiella tribullata	Sp
Leaena collaris minima	Sp
Lysilla sp. A	W, Sp
Terebellidae (concluded)	
Lysilla sp. B	Sp
Pista cretacea	W
Pista cristata	W, Sp
Pista palmata	W, Sp
Pista spp.	W
Pista unibranchia	Sp
Polycirrus haematodes	W, Sp
Polycirrus medusa	W, Sp
Polycirrus spp.	W, Sp
Polycirrus sp. A	W, Sp
Polycirrus sp. B	W, Sp
Polycirrus sp. C	Sp
Polycirrus sp. D	Sp
Polycirrus sp. E	Sp
Polycirrus tenuisetis	W, Sp
Streblosoma sp. A	W, Sp
Terebellidae spp.	W, Sp
Thelepus cincinnatus	W
Thelepus setosus	W
Thelepus sp. A	W
Trichobranchidae	
Terebellides stroemi	W, Sp
Trichobranchidae spp.	Sp
Trichobranchus glacialis	W, Sp
Sabellariidae	
Sabellaria spinulosa alcocki	W
Sabellidae	
Chone infundibuliformis	W, Sp
Desdemona sp. A	W, Sp
Euchone elegans	W, Sp
Euchone incolor	W, Sp
Euchone rubrocincta	W
Jasmineira filiformis	W, Sp
Laonome kroyeri	W
Megalomma bioculata	W, Sp
Potamethus spp.	W
Potamilla neglecta	W, Sp
Potamilla reniformis	W, Sp
Sabellidae spp.	W, Sp
Serpulidae	
Filograna implexa	W, Sp
Serpula vermicularis	W
Vermiliopsis sp. A	Sp

Table A- 8.(continued)

Mollusca

Gastropoda

*Alvania arenaria**
Alvania areolata
Alvania carinata
Alvania castanea
Buccinum undatum
Cocculina beanii
Colus stimpsoni
Crepidula fornicata
Crucibulum striatum
Cylichna alba
Diaphana minuta
Epitonium angulatum
Epitonium multistriatum
Epitonium pourtalesii
Lunatia heros
Lunatia immaculata
Lunatia triseriata
Melanella distorta
Mitrella dissimilis
Moelleria costulata
Nassarius trivittatus
Neptunea decemcostata
Nudibranchia unidentified
Odostomia bartschi
Odostomia gibbosa
Odostomia sulcosa
Oenopota concinnula
Oenopta harpularia
Oenopta turricula
Philine sinuata
Puncturella noachina
Sayella unifasciata
Scaphander punctostriata
Solariella obscura
Vermicularia spirata

Bivalvia

Anomia simplex
Anomia squamula
Arctica islandica
Astarte borealis
Astarte castanea
Astarte elliptica
Astarte quadrans
Astarte subequilatera
Astarte undata

* Remaining Taxa = W

Bivalvia (concluded)

Bathyarca pectunculoides
Bivalvia unidentified
Cerastoderma sp.
Corbula contracta
Crenella decussata
Crenella glandula
Cuspidaria glacialis
Cyclocardia borealis
Ensis directus
Hiatella arctica
Limatula subauriculata
Lucinoma filosa
Lyonsia granulifera
Macoma calcarea
Modiolus modiolus
Musculus niger
Nucula delphinodonta
Nucula proxima
Nucula tenuis
Nuculana tenuisulcata
Pandora gouldiana
Pandora inornata
Pectinidae sp.
Periploma leanum
Periploma papyratium
Placopecten magellanicus
Poromya granulata
Propeamussium thalassinum
Solemya velum
Spisula solidissima
Tellina agilis
Thyasira elliptica
Thyasira flexuosa
Thyasira trisinuata
Yoldia sapotilla
Yoldia thraciaeformis

Scaphopoda

Cadulus agassizi
Cadulus grandis
Dentalium sp.

Arthropoda

Pycnogonida

Nymphon hirtipes
Nymphon grossipes

Table A- 8.(continued)

Cephalocarida

Hutchinsoniella macracantha

Ostracoda

Ostracoda unidentified

Cirripedia

Balanus crenatus

Crustacea

Cumacea

Brachydiastylis resima
Campylaspis rubicunda
Diastylis bispinosa
Diastylis polita
Diastylis sculpta
Eudorella emarginata
Eudorella pusilla
Eudorella truncatula
Eudorellopsis deformis
Lamprops fuscata
Lamprops quadriplicata
Leptostylis ampullacea
Leptostylis longimana
Leucon nasioides
Petalosarsia declivis
Pseudoleptocuma minor

Tanaidacea

Leptochelia savignyi

Isopoda

Calathura branchiata
Chiridotea tuftsi
Cirolana concharum
Cirolana polita
Edotea triloba
Idotea phosphorea
Ptilanthura tenuis
Isopoda unidentified
Gnathiidea unidentified

Amphipoda

Acanthohaustorius intermedius
Acanthohaustorius millsi
Acanthohaustorius shoemakeri
Acanthohaustorius spinosus

Amphipoda (continued)

Aeginina longicornis
Ampelisca agassizi
Ampelisca macrocephala
Ampelisca vadorum
Amphilochidae sp.
Amphilochus N. sp. M
Anonyx liljeborgi
Argissa hamatipes
Bathyporeia quoddyensis
Byblis serrata
Caprella penantis
Caprella unica
Casco bigelowi
Corophium crassicorne
Dulichia monocantha
Dulichia porrecta
Dulichia sp.
Eophilantidae sp.
Ericthonius brasiliensis
Ericthonius rubricornis
Eriopisa elongata
Gammaropsis nitida
Gammaropsis N. sp.
Gammarus sp.
Haliragoides sp.
Haploops setosa
Haploops tubicola
Harpinia propinqua
Harpinia truncata
Harpinia N. sp. 2
Hippomedon serratus
Hippomedon sp.
Hyalella azteca
Idunella N. sp. P
Ischyrocerus anguipes
Ischyrocerus megacheir
Jassa falcata
Jerbarnia sp.
Lepidepecreum N. sp. C
Leptocheirus pinguis
Leptocheirus plumulosus
Mayerella limicola
Melita dentata
Melphidippa goesi
Metopa sp.
Monoculodes edwardsi
Monoculodes N. sp. T
Oedicerotidae sp.
Orchomenella minuta
Parahaustorius attenuatus
Parahaustorius holmesi

Table A- 8.(continued)

Amphipoda (continued)

Parahaustorius longimerus
Parametopella sp.
Parametopella cypris
Parapleustes sp.
Pardaliscidae sp.
Photis dentata
Photis macrocoxa
Photis reinhardi
Photis sp.
Phoxocephalus holbolli
Platyischnopus sp.
Pleustidae sp.
Podoceropsis sp.
Pontogenia inermis
Protohaustorius wigleyi
Protomedia sp. cf. *fasciata*
Psammonyx nobilis
Pseudohaustorius borealis
Pseudohaustorius caroliniensis
Pseudunciola obliquua
Rhachotropis N. sp. D
Siphonoecetes smithianus
Siphonoecetes sp.
Stenopleustes gracilis
Stenopleustes gracilis var. *inermis*
Stenopleustes inermis
Stenothoidae sp.
Synchelidium americanus
Tmetonyx similis
Trichophoxus epistomus
Unciola inermis
Unciola irrorata
Unciola serrata
Unciola spicata

Decapoda

Cancer borealis
Cancer irroratus
Crangon septemspinosa
Euprognatha rastellifera
Homarus americanus
Ianachinae sp.
Munida iris
Ovalipes ocellatus
Pagurus acadianus
Pagurus arcuatus
Pagurus politus
Pontophilus brevirostris

Sipunculoidea

Phascolion strombi
Sipunculoidea unidentified

Phoronida

Phoronis architecta

Ectoprocta

Bicellariella sp.
Bugula sp.
Cryptosula pallasiana
Ctenostomata unidentified
Ectoprocta unidentified
Electra sp.
Membranipora sp.
Scrupocellaris scabra
Tubulipora sp.

Echinodermata

Asteroidea

Asterias forbesi
Asterias sp.
Astropecten americanus
Goniasteridae sp.
Leptasterias polaris
Leptasterias tenera

Ophiuroidea

Amphioplus abdita
Amphipholus squamata
Amphiura sp.
Ophiacantha bidentata
Ophiura robusta
Ophiura sarsi

Echinoidea

Echinarachnius parma
Strongylocentrotus droebachiensis

Holothuroidea

Chirodota laevis
Chirodota wigleyi
Cucumaria frondosa
Leptosynapta tenuis

Table A-8. (concluded)

Crinoidea

  <u>Hathrometra</u> sp.

Hemichordata

  Enteropneusta

Urochordata

  Ascidiacea

    Ascidiacea unidentified
    Molgulidae sp.

Table A-9. Mean Number of Species of Infauna by Taxonomic Group for Georges Bank, Winter 1977

Station	Amphipods	Polychaetes	Echinoderms	Molluscs	Arthropods	Miscellaneous	Total
1	7	25.7	1	4	3	3	43.7
2	8	11.2	1	6	7	3	36.2
3	8	39.7	2	8	5	5	67.7
4	6	35.0	1	6	2	5	57.0
5	8	14.7	1	2	3	2	30.7
6	4	15.5	1	4	2	2	28.5
7	5	19.0	2	7	1	3	37.0
8	5	31.3	2	4	4	2	48.3
9	8	8.3	1	1	3	2	23.3
10	7	3.0	1	2	4	2	19.0
11	7	6.7	0	3	2	3	21.7
12	5	3.0	0	2	3	2	15.0
13	9	34.2	2	11	4	6	66.2
14	10	28.8	1	5	3	4	51.8
15	8	26.3	2	8	4	5	53.3
16	7	32.7	2	10	5	4	60.7
17	8	6.6	1	1	3	2	21.6
18	7	8.3	1	2	2	3	23.3
19	7	29.2	1	6	4	4	51.2
20	5	30.0	2	5	2	4	48.0
21	8	28.3	2	11	5	5	59.3
22	4	30.8	2	6	2	6	50.8
23	7	32.7	0	8	4	4	55.7
24	4	27.5	2	6	2	4	45.5
25	3	28.8	2	5	4	4	46.8
26	4	33.8	1	7	4	5	54.8
27	6	32.5	1	6	3	5	53.5
28	8	23.3	1	5	3	4	44.3
29	5	24.6	1	4	4	3	41.6
30	8	25.0*	0	3	3	6	45.0
31	10	23.7	0	10	7	6	56.7
32	9	20.1	0	4	3	2	38.1
33	6	22.5	1	2	2	3	36.5
34	6	11.1	0	3	3	3	26.1
35	-	-	-	-	-	-	-
36	5	38.7	1	5	2	4	55.7
37	7	6.2	1	2	2	2	20.2
38	4	11.7	0	5	2	5	27.7
39	15	28.0	1	2	5	5	56.0
40	5	43.2	2	10	4	4	68.2
41	5	33.5	2	10	3	4	57.5
42	2	11.6	0	2	1	1	17.6
$\bar{x}$	6.58	23.09	1.09	5.19	3.26	3.68	42.9
SD	2.31	10.9	0.73	2.88	1.36	1.34	15.2

Mean of five replicates exclusive of polychaetes modified from Michael (1977).
Mean of six replicates of polychaetes from Maurer and Leathem (1980).

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* Only one sample from Station 30

Table A-10. Mean Density (no./m^{-2}) of Infauna by Taxonomic Group for Georges Bank, Winter 1977

Station	Amphipods	Polychaetes	Echinoderms	Molluscs	Arthropods	Miscellaneous	Tota
1	1550	5330	40	80	170	1170	8340
2	1100	421.7	110	250	520	340	2741
3	3160	14453.3	30	250	370	4240	22503
4	380	18936.7	30	140	60	840	20386
5	670	1386.7	90	40	190	2230	4606
6	700	2268.3	10	320	40	120	3458
7	180	1113.3	360	1160	10	170	2993
8	2220	1931.7	30	680	320	60	5241
9	390	258.3	20	20	170	70	928
10	1270	155	10	120	290	50	1895
11	2060	163.3	0	210	80	250	2763
12	120	110	0	60	300	40	630
13	5860	2575	180	6640	110	400	15765
14	2030	1921.7	60	180	50	600	4841
15	3230	1460	70	1000	140	470	6370
16	6740	2480	170	1060	200	290	10940
17	6040	310	10	30	40	160	6590
18	2080	283.3	10	30	30	70	2503
19	2240	1573.3	40	170	80	90	4193.
20	310	6178.3	110	140	20	630	7388.
21	5030	3035	100	980	180	820	10145
22	190	1561.7	120	250	120	360	2601.
23	3980	3153.3	10	1070	450	460	9123.
24	140	1273.3	30	140	30	360	1973.
25	1100	1450	60	250	100	120	3180
26	310	2306.7	140	280	70	500	4106.
27	620	1553.3	60	310	100	370	3013.
28	650	863.3	10	120	100	1640	3383.
29	320	2813.3	20	60	160	910	4283.
30	300	1550*	0	110	50	440	2350
31	670	18663.3	0	440	200	580	20553.
32	1210	6676.7	10	120	60	4180	12246.
33	1080	1268.3	20	50	60	470	2948.
34	230	935	0	50	260	400	1875
35	-	-	-	-	-	-	-
36	1990	3378.3	80	150	20	1070	6688.
37	140	253.3	200	60	180	100	933.
38	100	2243.3	10	80	280	1890	4603.
39	1720	5003.3	10	30	400	150	7313.
40	290	8525	120	1180	150	840	11105
41	460	3120	40	480	60	170	4330
42	20	351.7	10	20	10	20	431.
$\bar{x}$	1533.6	3250.9	59.2	458.7	151.9	686.3	6152.
SD	1756.06	4466	72.5	1050.1	127.6	950.4	5473.

Mean of five replicates exclusive of polychaetes modified from Michael (1977).
Mean of six replicates of polychaetes from Maurer and Leathem (1980).

* Only one sample from Station 30

Table A-11. Mean Biomass (g/m^{-2}) of Infauna by Taxonomic Group for Georges Bank, Winter 1977

Station	Amphipods	Polychaetes	Echinoderms	Molluscs	Arthropods	Miscellaneous	Total
1	25.6	18.35	21.1	38.3	2.0	7.7	113.0
2	4.3	6.93	333.9	3.0	1.1	3.7	352.9
3	17.4	50.98	27.5	907.2	2.1	8.0	1013.1
4	1.4	30.58	2.4	289.6	1.8	2.8	328.5
5	2.2	9.33	2.5	360.1	1.1	1.8	377.0
6	1.4	13.0	0.7	5.6	0.3	5.3	26.3
7	0.2	3.55	39.3	8.0	0.1	4.0	55.1
8	1.6	6.77	0.2	1.0	1.5	1.5	12.5
9	2.3	6.38	0.2	0.1	0.7	5.0	14.6
10	7.6	4.41	49.6	0.1	2.3	1.0	65.0
11	4.6	12.81	0.0	2535.9	0.2	2.9	2556.4
12	1.2	1.15	1.2	0.2	3.2	0.2	7.1
13	7.7	13.83	0.5	227.7	2.4	5.3	257.4
14	2.4	10.31	0.1	99.0	3.3	2.7	117.8
15	23.4	8.53	1.4	45.2	1.4	1.2	81.1
16	8.0	14.28	0.4	221.0	1.0	2.5	247.1
17	21.8	34.9	0.1	847.9	0.6	1.6	906.9
18	2.7	1.87	13.2	1591.4	0.1	1.1	1610.3
19	1.8	8.85	0.2	372.9	2.6	0.8	387.1
20	1.4	11.45	1.0	873.8	0.3	1.9	889.8
21	3.5	13.13	2.7	848.4	0.6	2.1	870.4
22	0.1	10.08	0.1	0.8	1.0	1.6	13.6
23	2.2	12.52	0.1	2.0	2.4	2.1	21.3
24	0.2	6.67	0.8	0.6	1.2	2.8	12.2
25	1.0	5.67	1.0	1.0	0.9	1.3	10.8
26	0.1	13.96	0.2	1.6	1.2	9.9	26.9
27	0.2	7.48	0.1	2.1	1.4	2.0	13.0
28	1.3	9.06	0.3	269.2	0.3	2.0	282.1
29	1.4	8.16	0.3	255.4	1.6	1.1	267.9
30	0.1	1.5*	0.0	147.0	1.0	1.8	151.4
31	1.4	74.38	0.0	734.3	3.9	8.2	822.1
32	3.8	26.96	129.8	0.2	1.5	6.3	168.5
33	1.4	6.55	0.2	0.4	0.1	0.5	9.1
34	0.5	3.07	0.1	0.8	1.2	4.4	10.0
35	-	-	-	-	-	-	-
36	11.1	13.5	31.2	80.9	16.4	2.6	155.7
37	1.7	1.21	28.2	0.5	0.1	0.6	32.3
38	0.2	15.48	19.2	30.8	1.3	13.4	80.3
39	7.9	59.08	4.2	5.4	3.0	6.4	85.9
40	0.2	15.98	0.1	14.4	1.5	4.8	36.9
41	0.2	12.73	0.8	4.4	0.2	2.6	19.9
42	0.1	2.93	1.1	0.4	0.1	2.0	6.6
$\bar{x}$	4.3	14.35	17.4	264.09	1.68	3.4	305.3
SD	6.51	15.4	55.5	507.4	2.55	2.84	507.9

Mean of five replicates exclusive of polychaetes modified from Michael (1977)
Mean of six replicates of polychaetes from Maurer and Leathem (1980).

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* Only one sample from Station 30

Table A-12. Taxonomic List of Live Foraminifera Species from Georges Bank, 1977 (collated from NEOEB III, 1978)

	W	Sp	S
Calcareous			
Ammonia becarii		X	
Asterellina puchella	X		
Bolivina sp.	X		
Bolivina pseudoplicata	X	X	X
Bolivina subaenariensis	X	X	X
Bolivina variablis	X		
Bucella frigida	X	X	X
Bulimina aculeata	X	X	X
Bulimina marginata	X	X	X
Cassidulina sp.	X		
Cassidulina algida	X	X	X
Cassidulina crassa	X	X	X
Cassidulina norcrossi	X	X	X
Cassidulina subglobosa	X	X	X
Cassidulinoides bradyi		X	X
Cibicides sp.	X	X	X
Cibicides floridana	X	X	X
Cibicides lobatulus	X	X	X
Cibicides pseudouvigeriana	X		X
Cristellaria sp.			X
Dentalina sp.			X
Dentalina communis	X	X	
Dentalina mucronata		X	X
Discorbinella berthebti	X		

Table A-12. (continued)

	W	Sp	S
Elphidium clavatum	X	X	X
Elphidium subarcticum	X	X	X
Entosolenia marginata		X	X
Eosyrinx curta	X	X	X
Eponides umbonata			X
Eponides wrighti			X
Epistomina elegans	X	X	X
Fissurina sp.	X	X	X
Fursenkoina compressa	X	X	X
Fursenkoina fusiformis	X	X	X
Globulimina auriculata	X	X	X
Globulimina turgida	X		
Globulina inaequalis	X		
Guttulina lactea	X	X	X
Gyrodina orbicularis	X		
Gyrodina solidani		X	X
Hanzawaia concentricus		X	
Hoglundia elegans			X
Lagena sp.	X	X	
Lagena acuticosta	X	X	
Lagena clavata	X	X	X
Lagena gracillima		X	
Lagena laevis	X		
Lagena meridonalis		X	X
Lagena striata	X		

Table A- 12. (continued)

	W	Sp	S
Lagena substriata	X		
Lagena sulcata			X
Lenticulina sp.	X	X	X
Lenticulina calcar		X	
Lenticulina septrionalis	X	X	X
Marginulina sp.	X	X	X
Marginulina bachii	X	X	X
Melonis pompilaides	X	X	X
Melonis zaadamae	X	X	
Nodosaria sp.	X		
Nodosaria flintii		X	
Nodosaria pyrula	X		
Nodosaria vertebralis	X		
Nonion grateloupi	X	X	X
Nonionella atlantica		X	X
Nonionella labridorica	X		X
Oolina costata		X	
Oolina hexagonia			X
Pateoris hauerinoides	X	X	X
Planulina arminensis	X		X
Planulina foveolata	X	X	X
Planulina mera			X
Pseudopolymorphina novangliae	X	X	X
Pyrgo striatella	X	X	X
Pyrgo subsphaerica	X	X	X

Table A- 12. (continued)

	W	Sp	S
Quinqueloculina lata	X	X	X
Quinqueloculina jugosa	X		
Quinqueloculina seminulum	X	X	X
Rosalina sp.	X		X
Rosalina columbiensis	X	X	X
Rosalina floridana	X	X	X
Sarcenaria latifrons		X	
Trifarina angulosa	X	X	X
Uvigerina sp.	X		
Uvigerina peregrina	X		X
Webbinella hemisphaerica	X	X	X
Arenaceous			
Adercothyma glomeratum	X	X	X
Ammodiscus sp.	X		
Ammodiscus catinus		X	X
Cribrostomoides crassimarga	X	X	X
Cribrostomoides jeffreysii		X	
Eggerella advena	X	X	X
Glomospira gardialis	X		
Hemisphaermina sp.	X	X	X
Karreriella affinis	X	X	X
Miliammina fusca	X	X	X
Psammosphaera fusca	X	X	X
Reophax dentaliniformis	X		
Reophax fusiformis	X	X	X

Table A-12. (concluded)

	W	Sp	S
Reophax scotti	X	X	X
Saccammina atlantica	X	X	X
Textularia sp.	X	X	X
Textularia guesii	X		X
Trochammina compacta			X
Trochammina lobata	X	X	X
Trochammina ochracea	X	X	
Trochammina quadriloba	X		
Trochammina squamata	X		

Table A-13. Representative studies of stomach analyses of demersal fish in the New England area containing polychaetes and crustaceans.

Polychaete Taxa	McEachran, et al.,(1976) Nova Scotia, Georges Bank, Middle Atlantic Bight				Wigley (1956) Georges Bank	Wigley and Theroux (1965) Off Cape Cod	Richards (1963) Long Island Sound
	Raja erinacea	Raja ocellata	Raja radiata	Raja senta	Melanogrammus aeglefinus		Pseudopleuronectes americanus
Ammotrypane aulogaster	x		x	x			x
Ampharete acutifrons					x		
A. arctica							x
Ampharete sp.							x
Amphicora fabricii					x		
Amphitrite sp.					x		
Aphrodita aculeata						x	
A. hastata	x	x	x		x		
Arabella sp.							x
Arabella iricolor							x
Arenicola sp.							x
Autolytus sp.							x
Autolytus cornutus							x
Capitella capitata							x
Cirratulus grandis					x		x
Clymenella torquata	x	x			x		
Drilonereis filum					x		
Ephesia gracilis					x		
Eteone longa					x		
Eualia sp.					x		x
Eumida sanquinea					x		
Eunice pennata	x		x				x
Eupomatus dianthus							x
Flabelligera affinis							x
Glycera americana					x		
G. capitata					x		x
G. dibranchiata	x						

Table A -13 (continued)

	McEachran, et al. (1976) Nova Scotia, Georges Bank, Middle Atalntic Bight				Wigley (1956) Georges Bank	Wigley and Theroux (1965) Off Cape Cod	Richards (1963) Long Island Sound
	Raja erinacea	Raja ocellata	Raja radiata	Raja senta	Melanogrammus aeglefinus		Pseudopleuronectes americanus
G. tesselata	x						
Glycera sp.							x
glycera spp.	x	x	x			x	
Goniada brunnea	x		x				
G. gracilis							x
G. maculata					x	x	
Harmothoe imbricata							x
Laonice cirrata			x				
Leiochone dispar	x	x					
Lepidonotus squamatus	x		x	x			
Lumbrineris acuta					x		
L. fragilis	x	x	x	x	x	x	
L. tenuis							x
Maldane sarsi							x
Maldane sp.							x
Maldanid spp.	x	x	x				
Marphysa sp.					x		
Megalona papillicornis							x
Melinna cristata							x
Neanthes succinea							x
Nephtys bucera		x					
N. caeca	x	x	x				
N. incisa	x	x	x		x	x	x
N. ingens							x
Nephtys sp.				x			
Nephtys spp.	x	x	x			x	
Nereis ciliata							x
N. pelagica	x	x	x		x		x
N. zonata	x		x				

Table A-13 (continued)

	McEachran, et al.,(1976) Nova Scotia, Georges Bank, Middle Atlantic Bight				Wigley (1956) Georges Bank	Wigley and Theroux (1965) Off Cape Cod	Richards (1963) Long Island Sound
	Raja erinacea	Raja ocellata	Raja radiata	Raja senta	Melanogrammus aeglefinus		Psuedopleuronectes americanus
Nereis sp.							x
Nereis spp.	x	x	x				
Nothria conchylega	x						
Odontosyllis sp.					x		
Onuphis opalina			x		x		
Ophelia denticulata	x	x	x				
Ophioglycera gigantea	x						
Owenia fusiformis					x		
Pectinaria gouldii					x		x
Pectinaria sp.	x	x	x				
Pherusa affinis	x						
Phyllodoce fragilis							x
P. mucosa					x		
Polycirrus eximius							x
Polydora sp.					x		
Potamilla neglecta							x
Praxillella praetermissa	x						
Praxillella sp.		x					x
Rhodine loveni					x		
Sabella crassicornis					x		
Sabellaria vulgaris					x		
Sabellid sp.	x		x				
Samythella elongata					x		
Scalibregma inflatum					x		x
Spionidae unidentified							x
Sternaspis scutata						x	
Sthenelais gracilis							x

Table A- 13 (continued)

	McEachran, et al. (1976) Nova Scotia, Georges Bank, Middle Atlantic Bight				Wigley (1956) Georges Bank	Wigley and Theroux (1965) Off Cape Cod	Richards (1963) Long Island Sound
	Raja erinacea	Raja ocellata	Raja radiata	Raja senta	Melanogrammus aeglefinus		Pseudopleuronectes americanus
S. limicola	x						
Stylaroides arenosa					x		
Travisia carnea		x			x		
Travisia sp.							x
Crustacean Taxa							
Acanthohaustorius borealis		x					
Aeginella longicornis					x		x
Aega sp.					x		
Ampelisca eschrichti			x				
Ampelisca spinipes					x		
Ampelisca sp.	x	x	x				x
Amphithoe rubricata					x		
Anonyx mugax					x		
Argissa hamatipes					x		
Axius serratus	x		x		x	x	
Byblis gaimardii					x		
Byblis serrata			x	x			
Calathura branchiata					x		
Calocaris templemani			x				
Calliopius laeviusculus	x	x			x		
Cancer borealis						x	
C. irroratus		x	x		x	x	

Table A- 13 (continued)

	McEachran, et al. (1976) Nova Scotia, Georges Bank, Middle Atlantic Bight				Wigley (1956) Georges Bank	Wigley and Theroux (1965) Off Cape Cod	Richards (1963) Long Island Sound
	Raja erinacea	*Raja ocellata*	*Raja radiata*	*Raja senta*	*Melanogrammus*	*aeglefinus*	*Pseudopleuronectes americanus*
Cancer sp.	x						
Caprella geometrica					x		x
C. linearis							x
Caridion gordoni					x		
Casco bigelowi	x						
Chiridotea tuftsi	x	x	x		x		
Cirolana concharum					x		
C. polita	x	x	x		x		
Corophium crassicorne					x		
C. cylindricum							x
C. volutator					x		
Corophium sp.							x
Crangon septemspinosa	x	x	x	x	x		x
Cyathura carinata					x		
Cyathura polita							x
Cyathura sp.			x				
Diastylis quadrispinosa						x	x
D. sculpta					x		
Diastylis sp.	x	x	x				
Dichelopandalus leptocerus	x	x	x	x	x	x	
Dulichia monacantha	x						
Edotea montosa					x		x
Edotea triloba	x	x					
Edotea sp.			x				x
Erichthonius brasiliensis							x
E. hunteri					x		
E. rubricornis					x		
Erythrops erythropthalma			x	x			

Table A-13 (continued)

	McEachran, et al. (1976) Nova Scotia, Georges Bank, Middle Atlantic Bight				Wigley (1956) Georges Bank	Wigley and Theroux (1965) Off Cape Cod	Richards (1963) Long Island Sound
	Raja erinacea	Raja ocellata	Raja radiata	Raja senta	Melanogrammus aeglefinus		Pseudopleuronectes americanus
Eualus pusiolus	x	x	x	x	x		
Eudorella hispida						x	
Eusirus cuspidatus	x				x		
Gammarellus angulosus					x		
Gammarus locusta					x		
Gammaropsis melanops					x		
Haustorius arenarius					x		
Haustoriid spp.	x						
Hippomedon serratus	x	x	x		x		
Hyperia medusarum					x		
Hyas coarctatus					x	x	
Hyas sp.	x	x	x	x			
Idotea metallica	x						
Idotea sp.							x
Ischyrocerus anguipes					x		
Janira sp.					x		
Lamprops quadriplicata	x				x		
Lebbeus sp.	x		x	x			
Lembos smithi					x		
Leptocuma minor					x		
Leptocheirus pinguis	x	x	x	x	x	x	x
Maera loveni	x						
Meganyctiphanes norvegica	x	x	x	x	x		
Melita dentata	x	x	x		x		
Monoculodes edwardsi					x		x
Monoculodes sp.	x	x	x				
Neomysis americana	x	x	x	x	x		x
Neopleustes pulchellus					x		
Orchomenella minuta	x	x	x		x		
O. pinguis					x		
Ovalipes ocellatus	x	x					

Table A- 13(continued)

	McEachran, et al. (1976) Nova Scotia, Georges Bank, Middle Atlantic Bight				Wigley (1956) Georges Bank	Wigley and Theroux (1965) Off Cape Cod	Richards (1963) Long Island Sound
	Raja erinacea	Raja ocellata	Raja radiata	Raja senta	Melanogrammus aeglefinus		Pseudopleuronectes americanus
Pagurus acadianus	x		x	x			
P. arcuatus	x	x	x	x			
P. bernhardus					x		
P. kroyeri					x		
P. longicarpus							x
P. pollicaris					x		
P. pubescens	x	x	x	x			
Pandalus borealis	x		x	x	x	x	
P. montagui				x	x		
P. propinquus				x			
Parahaustorius attenuatus	x	x					
P. holmesi	x	x					
P. longimerus	x	x					
Parathemisto compressa					x		
Pasiphaea tarda			x				
Pelia mutica	x						
Petalosarsia declivis	x	x					
Photis macrocoxa					x		
P. reinhardi							x
Photis sp.					x		
Phoxocephalus holbolli					x		
Pleustes panopla	x	x	x	x			
Podoceropsis nitida	x		x	x	x		x
Pontharpinia spinosa					x		
Pontogeneia inermis	x				x		
Pontophilus norvegicus					x		
Pontoporeia sp.			x				
Protomedia fasciata					x	x	
Pseudohaustorius borealis	x						
Pseudounciola obliquua		x					
Rocinella americana	x				x		

Table A-13 (concluded)

	McEachran, et al. (1976) Nova Scotia, Georges Bank, Middle Atlantic Bight				Wigley (1956) Georges Bank	Wigley and Theroux (1965) Off Cape Cod	Richards (1963) Long Island Sound
	Raja erinacea	*Raja ocellata*	*Raja radiata*	*Raja senta*	*Melanogrammus aeglefinus*		*Pseudopleuronectes americanus*
Sabinea sarsi							x
Sclerocrangon boreas	x		x	x			
Siphonocoetes smithianus							x
Sphaeroma quadridentatum					x		
Spirontocaris sp.				x			
Stegocephalus inflatus			x		x		
Stenopleustes gracilis					x		
Stenothoe cypris					x		x
S. minuta					x		
Stenothoe sp.							x
Sympleustes glaber					x		
Themisto abyssorum					x		
Tiron acanthurus					x		
Tmetonyx cicada					x		
Tmetonyx sp.	x	x	x				
Trichophoxus epistomus	x	x					
Unciola inermis						x	
U. irrota	x	x	x		x	x	x
Upogebia affinis							x