Massachusetts Bay outfall monitoring program: 1996 benthic biology and sedimentology

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MASSACHUSETTS BAY OUTFALL MONITORING PROGRAM: 1996 BENTHIC BIOLOGY AND SEDIMENTOLOGY

submitted to

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EXECUTIVE SUMMARY

This report presents benthic biology and sedimentology data collected in 1996 as part of a monitoring program being performed to assess baseline conditions in Massachusetts Bay prior to discharges from the new sewage outfall now scheduled to begin operations in 1998. Samples have been collected since the summer of 1992 at stations located within 2 km of the new outfall (nearfield), between 2 and 8 km of the outfall (midfield), and at selected distant locations in Massachusetts and Cape Cod Bays (farfield). The data reported here include results of traditional benthic biology in soft-bottom sediments and analyses of photographs taken from a remotely operated vehicle in the hard-bottom areas in the vicinity of the outfall. Sediment grain-size composition analyses, as well as spore counts of *Clostridium perfringens* and analyses of total organic carbon and nitrogen are also presented.

Sedimentology

Sediments at the nearfield stations tend to be coarser-grained than are the sediments found at midfield or farfield stations. In 1996, 5 of the 8 nearfield stations had sediments with greater than 90% sand and gravel. Stations NF22 andNF24, which are located in swales between drumlins, have finer sediments consisting mostly of silt-plus-clay. NF24 in particular appears to be a small mudpatch or depositional area. The sand fraction at the midfield stations tends to be composed of fine-grained rather than coarse-grained sand.

The majority of stations sampled have generally low levels of total organic carbon (TOC) and *Clostridium perfringens* spores. Although some year-to-year changes in levels of both parameters can be attributed to changes in sediment texture, there is no clear relationship between TOC or *Clostridium* and corresponding sediment texture.

Soft-bottom Infaunal Communities

Benthic community parameters observed in 1996 were generally similar to those seen in previous baseline monitoring years, both in the vicinity of the new outfall and throughout Massachusetts and Cape Cod Bays. The distribution of dominant species, as well as similarities among stations as measured by cluster analysis, reflected patterns seen in 1995.

The structure of the benthic communities in the nearfield and midfield was largely determined by sediment grain size, whereas in the farfield water depth and location were of primary importance. Three faunal assemblages have been identified in the nearfield/midfield study area; of these, the *Exogone-Corophium*-oligochaete assemblage found at the coarse-sand nearfield stations is the most consistent. Nearfield stations NF4 and NF17 have been dominated by this fauna for all five years of monitoring. *Prionospio steenstrupi* was the dominant spionid polychaete, as it was in 1995, and together with the capitellid polychaete *Mediomastus californiensis* and the lumbrinerid *Ninoe nigripes* characterized a second, very widespread assemblage that dominated the majority of midfield stations. These basic community structures have been observed in the area since the inception of this program in 1992, with slight annual changes reflecting the shifting of sediments as a result of storms or other sediment transport events.

Species richness (i.e., number of species recorded) was apparently higher in 1996 than in earlier years. This result may be due in part to better identification of juvenile polychaetes and molluscs. It will be of primary importance to maintain similar levels of taxonomic discrimination in the years after the outfall comes on line: any apparent changes in species diversity should be evaluated first by examination of the underlying database.

Calculation of an average species diversity (Shannon-Wiener H′) suggests that diversity at the nearfield stations is slightly higher than average diversity at either midfield or farfield stations. H′ values averaged over the period 1992-1996 were 2.71 ± 0.32 for the nearfield, 2.57 ± 0.35 for the midfield, and 2.62 ± 0.46 for the farfield. These values will be refined after the 1997 samples have been analyzed.

Similar calculations for number of species and numbers of individuals suggest that the farfield stations have the highest numbers of species (76.8 vs. 68.9 for nearfield and 63.2 for midfield) and the midfield has the greatest abundances (45,315 individuals/m^2 vs. 44,159 for the nearfield and 33,505 for the farfield.) For all three parameters, however, the standard deviations are large, thereby suggesting that the differences among study areas are not statistically significant.

High faunal similarities between the faunal community at Station FF1a and the communities found in the midfield suggest that FF1a can serve as a good qualitative reference site for benthic communities in the vicinity of the future outfall. This station is also a farfield monitoring site for an ongoing 301(h) program. Station NF24 may be a good sentinel station for the nearfield because it appears to be a depositional area, acting as a sediment trap. Station FF13 off Hull show high densities of *Ampelisca abdita*, an amphipod becoming increasingly common in the recovering sediments of Boston Harbor; this station may be a good reference station for the Harbor.

Hard-bottom Benthos

The complex topography in the hard-bottom areas in western Massachusetts Bay imposes substantial variability on epibenthic communities. These communities are primarily zoned by depth, with algae dominating the shallower drumlin tops and macroinvertebrates dominating the deeper bottoms. Location on the drumlins, depth, substratum type and habitat relief all appear to play a role in determining the structure of the benthic communities inhabiting hard-bottom areas in the vicinity of the outfall. Some taxa show strong preferences for specific habitats, while others are broadly distributed.

Some areas are homogeneous in terms of substratum type and the fauna inhabiting them, while other areas exhibit more patchiness. Some of the variability observed in the data may be related to difficulties in distinguishing among some of the categories of encrusting organisms that may encompass several species. However, a fair amount of the variability may be due to the inherently patchy nature of hard-bottom habitats and the fauna that inhabit them.

Results obtained in 1996 generally agree with the 1995 findings, even though the areal coverage of the still photographs taken in 1995 was limited and also not as random compared to the 1996 survey. Direct comparisons of abundances and community composition of specific areas are hampered by the inherent within-habitat variability of the drumlins.

Analysis of the still photographs shows finer details of the benthic communities than can be discerned from the video tapes. The two techniques are complimentary in that the video survey provides greater areal coverage and the still photographs provide a more accurate assessment of the taxa inhabiting these areas. Both techniques are valuable for establishing baseline data. The ability to use these data to detect possible future impacts would be enhanced if the still photographs were collected in a manner that permitted quantitative density estimates to be made. As with the soft-bottom benthic community analysis, consistency in taxonomic identifications will be of primary importance in ensuring the ability to make comparison between baseline and post-operational data.

The best potential indicator species for detecting change due to the outfall is the abundant and widely distributed coralline alga *Lithothamnion*. Potential impacts from the outfall might include changes in sediment loading of the sea floor on the drumlins. If materials discharged from the outfall were to accumulate in the vicinity of the drumlins, it is anticipated that this would result in a marked decrease in the coverage of *Lithothamnion* spp. If water clarity were reduced, the lower depth limit of high coralline algal coverage might be reduced. Conversely, if water clarity were increased, then such algal coverage might extend into some of the deeper areas.

The distribution of sea urchins, *Strongylocentrotus droebachiensis,* on drumlin tops is believed to be correlated to availability of *Lithothamnion*, on which the urchins feed. Changes in the abundance of this food source would therefore also be reflected in the abundance of the urchin.

1.0 INTRODUCTION

1.1 Background of the MWRA Monitoring Program

The Massachusetts Water Resources Authority (MWRA) is responsible for the development of secondary sewage treatment facilities serving the greater metropolitan Boston area. A new outfall has been built offshore in Massachusetts Bay at a distance of 15 km from Deer Island and at a depth of 32 m. Secondary-treated effluent will be discharged from the new diffuser array beginning in 1998, but the water and sediment quality of Massachusetts Bay and Cape Cod Bay is not expected to be adversely impacted by the new discharge (EPA, 1988).

In order to monitor any potential effects from the new outfall, the MWRA developed an *Effluent Outfall Monitoring Plan* that describes the physical, chemical and biological monitoring necessary to evaluate the response of the ecosystem to the new outfall (MWRA, 1991). Studies conducted prior to the initiation of discharges from the new outfall are termed Baseline Monitoring and are intended to provide a database against which future changes can be assessed. Baseline Monitoring began in 1992 and has been conducted each year since then. The research and monitoring results to date have provided a reasonable understanding of existing conditions prior to the implementation of discharges from the new outfall. This understanding is crucial to the development of testable predictions for detecting outfall-induced changes once discharge begins.

1.2 Overview of the Present Study

The benthic monitoring program as initiated in 1992 included 10 special stations at farfield locations sampled for biology in May 1992, 20 stations in the nearfield sampled in August 1992, and 12 stations in the farfield also sampled in August 1992. At each of the August 1992 stations, samples were taken to evaluate soft-bottom benthic infaunal communities, microbiology, sedimentary characteristics, and chemical constituents. The benthic biology program for the nearfield was essentially designed as a non-replicated spatial array while the farfield sampling design included three replicates at each station. In addition, the sediment profile camera system was used to evaluate animal/sediment interactions and various physical properties of the sediments.

Between 1992 and 1995, levels of organic and trace metal chemical contaminants were measured in the sediments (Coats, 1995; Hilbig *et al.*, 1997). Coats (1995) reviewed data collected from 1992-1994, concluding that the baseline mean for 10 trace metals and 7 organic contaminants were well below published guidelines for biological effects. Hilbig *et al.* (1997) presented data collected in 1995, finding levels similar to those measured in previous years. After reviewing the 1992-1995 data, the OTMF concluded that the baseline collection of chemical contaminant data was adequate; therefore no additional samples were taken in 1996.

Achieving a good monitoring design for the nearfield area has been difficult due to the heterogeneity of habitats, and the sampling protocol has been modified several times to find the best approach. In 1993, the design for the nearfield was changed to include nine stations, with three replicates each, and one of the farfield stations was dropped. In 1994, the non-replicated design was reinstated with retention of three replicated stations; that design was repeated in 1995 and 1996. The shift in station design presents some problems in comparing year-to-year trends because the 1993 nearfield design departs significantly from that of 1992 and 1994-96. Nevertheless, the five-year baseline database thus accumulated and the continuance in 1997 should permit a full assessment of natural biological processes in the nearfield prior to the initiation of effluent discharge in 1998.

Benthic community structure in soft-bottom areas of western Massachusetts Bay has been shown to be strongly associated with sediment type, and is also apparently influenced by recent sediment transport events. Highly depositional muds tend to support a diverse fauna, often with more than 50 species present in a 0.04-m^2 grab sample. This mud assemblage is characterized by high abundances of the capitellid polychaete *Mediomastus californiensis*, accompanied by abundant spionid polychaetes and/or the paraonid polychaete *Aricidea catherinae*. The faunal assemblage in transitional sediments is relatively similar, but tends to show high dominance of one or more spionid polychaetes. The sandy assemblage is characterized by fewer species and lower abundances, and tends to be dominated by the amphipod *Corophium crassicorne* and syllid polychaetes (Blake *et al.*, 1993; Coats, 1995).

Benthic data from the farfield stations provide the first long-term integrated survey throughout the larger Massachusetts Bay and Cape Cod Bay ecosystem. All farfield stations in relatively deep water (>50 m) east of Cape Ann and throughout Stellwagen Basin show a diverse benthic assemblage, characterized by moderate dominance of spionid and paraonid polychaetes. This deep-water assemblage is so consistent and widespread that, after the first two years of monitoring, station FF1 was abandoned and the effort transferred to a new site (station FF1A) off Cape Ann at a depth similar to the nearfield, but so distant from the future outfall that no conceivable impact could be expected to occur. The two farfield monitoring stations in Cape Cod Bay are in moderately deep water (about 35 m) and contain a distinct fauna, similar to communities observed in the late 1960s (Rhoads and Young, 1971; Young and Rhoads, 1971; Blake *et al.*, 1993; Coats, 1995). In addition to the spionids, these stations are characterized by moderate abundances of the polychaetes *Cossura longocirrata*, *Tharyx acutus*, and *Euchone incolor*.

The high proportion of non-depositional hard-bottom substrate in the area near the diffuser led the OTMF to add a hard-bottom component to the monitoring program in 1994. A video camera was used to provide near-continuous photographic coverage of four transects (Coats *et al.*, 1995a). This design was modified in 1995 and 1996 to cover six transects with emphasis on topographically selected waypoints that include representative drumlin top and flank locations. Both video and still photographs are taken.

The data collected from 1992 to the present allow comparison with earlier historical results to evaluate the consistency of benthic communities from year to year and to predict which components of the fauna might be most affected by sewage discharge. The studies also allow further refinement of the sampling requirements for a long-term monitoring program. Based upon data collected through 1994, Coats (1995) developed a framework for quantifying testable hypotheses for detecting changes in sediment contaminant concentrations and benthic communities in the nearfield, a 2-km zone around the outfall in which changes are most likely to occur once the outfall goes on line. A multivariate analysis based on PCA-H of Trueblood *et al.* (1994) is recommended to detect changes in benthic community structure. By "normalizing" PCA-H scores from baseline samples collected in the nearfield for the apparent effects of sediment grain size and organic carbon concentration, Coats developed a "detrended" (DPCA-H) space against which similarly transformed data from post-discharge samples in the nearfield could be tested for significant departure from baseline faunal composition (Coats, 1995).

Results from the present study, conducted during baseline year 1996, are intended to add to the definition of the baseline variability and enhance our understanding of the benthic environment under pre-disposal conditions. The study included the following elements: (1) physical and chemical analyses of sediments, including total organic carbon and nitrogen concentrations, sediment grain-size composition, and analysis of *Clostridium perfringens* spores as a marker of sewage; (2) traditional soft-bottom benthic infaunal analysis; and (3) semi-quantitative characterization of the epifaunal and epiphytic organisms colonizing the widespread rocky-bottom environments in the immediate vicinity of the outfall, based on examination of 35-mm color photographs and video tapes.

2.0 METHODS

This section provides a brief account of the field, laboratory, and data management methods used during the study. A more detailed account can be found in the Combined Work/Quality Assurance Project Plan (CW/QAPP) (Blake and Hilbig, 1995).

2.1 Field Operations

2.1.1 Sampling Design and Location of Stations

The benthic monitoring program originally used a definition of the nearfield as a rectangle with sides 5 km (3 mi) from the outfall, with farfield stations lying outside the rectangle. Greater sophistication in spatial analyses has allowed discrimination among three subareas of the study area: the nearfield is 0-2 km, the midfield is 2-8 km, and the farfield is greater than 8 km from the new outfall. The nearfield coincides with the area that is most likely to be impacted according to the SEIS. The midfield and farfield are farther from the outfall and should not show impacts. Three stations, approximately 8 km from the nearshore end of the diffuser, were originally designated as farfield stations but are now considered to lie within the midfield area. The original designations for these stations (FF10, FF12, FF13) have been retained because there already are midfield stations MF10, MF12, and MF13. The reassignment of these three farfield stations was implemented in the 1996 program. The sampling design in the nearfield and midfield, established in 1994, represents a compromise between broad areal coverage and comparability of the data with previous studies in the same area. The apparent concentration of stations in the western portion of the nearfield is a result of the lack of soft substrate that can be sampled by benthic grabs in the eastern portion; however, this asymmetry does not introduce a bias because the prevailing currents in the area are not strongly dimensional. Table 1 shows the station designations in detail.

Table 1. Station designations and groupings.

Station Grouping	Distance from Outfall	Stations
nearfield (moderate diffuser-induced changes are expected)	0-2 km	NF13, NF14, NF15, NF17, NF18, NF19, NF23, NF24
midfield (diffuser-induced changes are less likely)	2-8 km	MF2, MF4, MF5, MF7, MF8, MF9, MF10, MF12, MF16, MF20, MF21, MF22, FF10, FF12, FF13
farfield (diffuser-induced changes are highly unlikely)	>8 km	FF1A, FF4, FF5, FF6, FF7, FF9, FF11, FF14

Benthic grab samples for the analysis of macroinfauna and sedimentary characteristics were collected in August 1996 at 23 stations in close proximity to the diffuser (near- and midfield sites, Figure 1, Appendix A1) and 8 stations throughout Massachusetts and Cape Cod Bays (farfield sites, Figure 2, Appendix A1). To ensure good areal coverage, only single grab samples (one biology and one

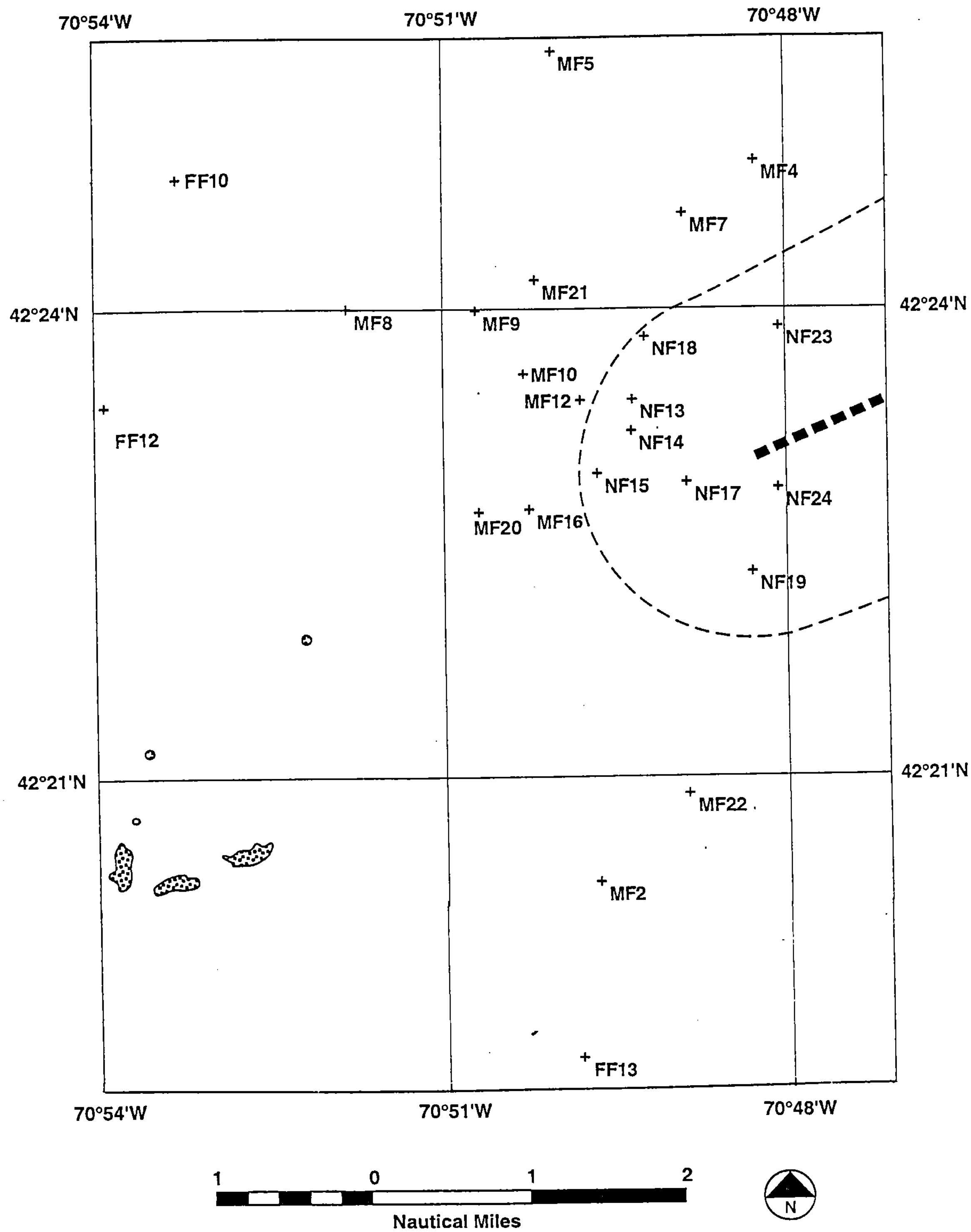


Figure 1. Station locations for grab samples in the nearfield and midfield. Western (soft-bottom) part of nearfield area is indicated by thin curved dashed line; western end of diffuser is indicated by thick dashed line.

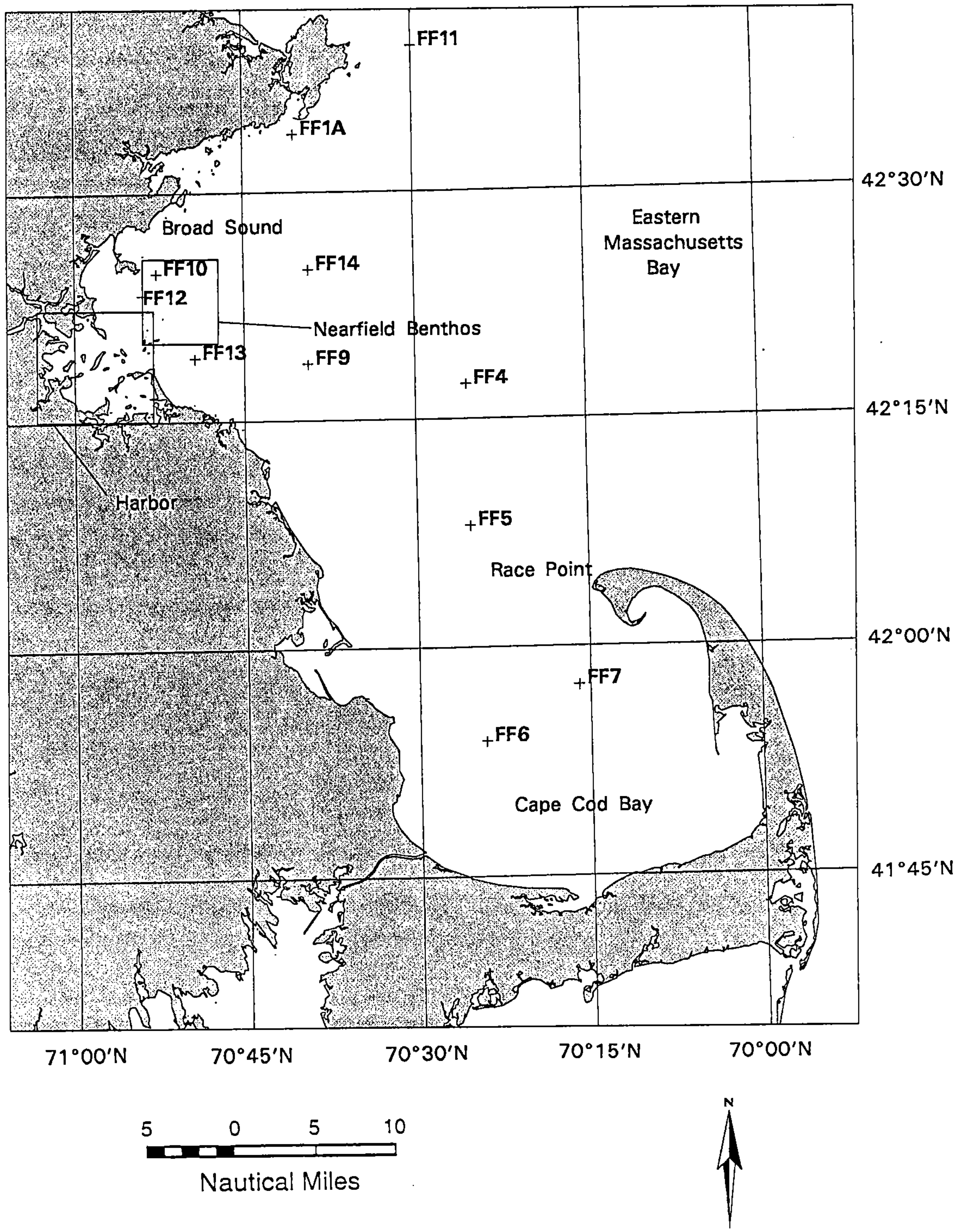


Figure 2. Station locations for farfield grab samples. Boxes indicate Boston Harbor and nearfield survey areas.

chemistry) were taken at each of 17 near- and midfield stations, and three replicate samples (both biology and chemistry) were taken at the remaining 14 stations (2 nearfield, 4 midfield and 8 farfield).

Camera surveys, including both video and still photographs, were made in hard-bottom areas where sampling with benthic grabs was not possible. A total of 20 waypoints along six transects were surveyed from July 17 to 19, 1996 (Appendix A2, Figure 3). Four transects (T1, T2, T4 and T6) were located on drumlins on either side of the outfall diffuser and two transects (T7 and T8) were located on drumlins further away (reference sites). The survey design was modified slightly from the one used in 1995: Waypoint 3 on Transect 6 was dropped because the area was depauperate and did not provide much information; also, a second waypoint was added at each of the reference sites.

2.1.2 Navigation

Navigational positioning was accomplished with a Northstar 41X Differential GPS system with an accuracy of 5 to 15 m. If the vessel drifted more than 0.01 nmi (ca. 18 m) away from the reference coordinates, it was repositioned between replicate samples. The ship's position was logged every minute while underway and marked at the time of each touchdown of the grab or camera with the Maptech software.

2.1.3 Grab Sampling

A Kynar-coated 0.04-m^2 Ted Young grab was used for collection of all samples. The protocol for processing the biology samples was similar to that followed for the 1995 Harbor survey (see Hilbig *et al.*, 1996). From each chemistry grab, a subsample of the top 2 cm of sediment was collected, homogenized in a stainless steel bowl, and split into subsamples for *Clostridium perfringens*, total organic carbon (TOC) and sediment grain size analyses. All samples were kept cool on ice.

2.1.4 Video and 35-mm Still Photography

A Benthos MiniRover Mk II Remotely Operated Vehicle (ROV) was used to collect bottom photographs. The survey ship M/V *Christopher Andrew* was anchored at each waypoint and the ROV was lowered to the sea floor. Once on the sea floor, the ROV traveled in a northwesterly direction away from the ship. Depending on the relief of the sea floor, the ROV traveled 30 to 70 m away from the vessel before it ran out of tether.

The ROV was equipped with a color video camera, a 35-mm still camera and a strobe. The still camera and strobe were mounted on brackets on the outside of the ROV on either side of the video window. The camera was pointed forward and down, with its field-of-view overlapping slightly with the video image. Approximately 20 minutes of video tape and one 36-exposure roll of color slides were collected at each waypoint. The still photographs were taken at random intervals during this transit.

Table 2 shows the photographic coverage obtained during the survey. Video coverage ranging from 15 to 31 minutes was collected at each of the 20 waypoints. Still photographs were obtained at 18 of these waypoints and ranged from 22 to 35 slides. The stills collected at two of the waypoints (T4-WP1 and T8-WP1) were of such poor quality that they were totally unusable. It appears that condensation on the inside surface of the camera housing lens may have been responsible for this problem. It was decided that in order to monitor potential problems, selected films would be developed on board the ship during subsequent surveys.

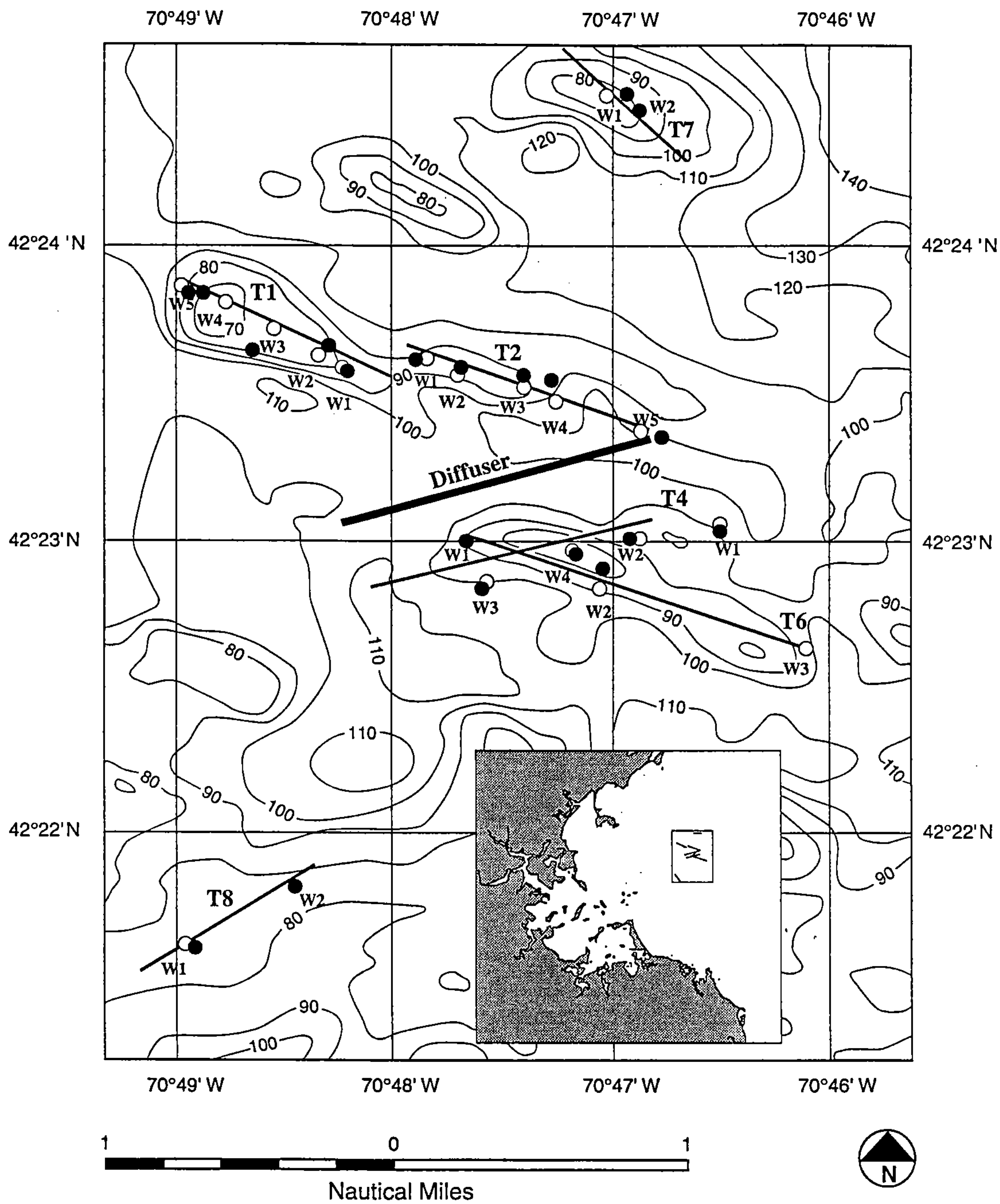


Figure 3. Transects and waypoints surveyed for hard-bottom benthos. Inset shows survey area relative to Boston Harbor. Open circles: stations visited in 1995; filled circles: stations visited in 1996.

Table 2. Photographic coverage at hard-bottom locations surveyed in 1996.

Transect	Waypoint	Location on drumlin	Depth (feet)	Video (min)	Stills (usable) (# frames)
1	1	TF-edge	75-81	26	32 (29)
	2	Top	65-70	22	29 (24)
	3	Top	73-75	22	33 (33)
	4	Top	71-73	31	30 (23)
	5	Flank	84-87	22	32 (23)
2	1	Flank	94-96	20	34 (32)
	2	Flank	102-108	25	33 (32)
	3	Top	92-95	22	26 (25)
	4	Flank	106	22	35 (35)
	5	Low/diffuser	116-117	20	33 (28)
4	1	Flank	105-107	15	0
	2	Flank	102-103	20	34 (32)
	3	Flank	94-95	25	31 (31)
4&6	4	Top	63-65	22	33 (31)
6	1	Flank	101-103	24	33 (33)
	2	Top	72-74	23	31 (31)
7	1	Top	75-78	21	33 (33)
	2	Top	79-86	21	31 (29)
8	1	Top	79-80	17	0
	2	Top	86-90	21	22 (21)

2.1.5 Sample Documentation, Custody, and Quality Assurance/Quality Control

Standard ENSR procedures for sample tracking and custody were followed. Prior to each field survey, preprinted labels were produced that were linked to ENSR's MWRA Harbor/Outfall Monitoring (HOM) database. All sample containers were labeled on the outside, and the macrofauna containers were also labeled on the inside. Information on the labels included the survey number, date, station and replicate number, sample type, and the laboratory to which the sample was to be delivered for analysis.

All pertinent information on field activities and sampling efforts was recorded into a bound, numbered logbook. The number of the logbook was entered into the MWRA HOM database. Entries were recorded in indelible ink and included at a minimum:

- Date and time of starting work
- Names of ship's crew and scientific party
- Sampling sites and activities and references to ship's navigation system
- Deviations, if any, from the survey plan
- Field observations such as weather and sea state

Chain-of-custody forms were created either electronically or by hand when samples left the ship or the custody of the scientist responsible for shipping. All coolers and boxes used for shipping were sealed with numbered chain-of-custody tape; the number on the tape was recorded on the chain-of-custody form.

2.2 Laboratory Methods: Sample Processing and Analysis

2.2.1 Benthic Infauna

About 48 h after the samples had been fixed in formalin, they were resieved on a 300-μm screen with fresh water and transferred to 70% alcohol for preservation. Before sorting, the samples were stained with a saturated alcoholic solution of Rose Bengal, a stain for proteins that enhances the visibility of organisms in the sediment. All animals, including fragments, were then removed from the sediment and sorted into major taxa, such as polychaetes, oligochaetes, mollusks, crustaceans, and echinoderms. Taxonomists then identified each taxon to the lowest practical level (usually to species) and enumerated each species.

2.2.2 Sediment Grain Size

Grain size was determined with a combination of wet and dry sieve and pipette analyses (NOAA, 1993a). The sediment was sieved through a sieve series based on the Wentworth grade scale, including mesh sizes of 2 mm (-1 phi), 1 mm (0 phi), 0.5 mm (1 phi), 0.25 mm (2 phi), 0.125 mm (3 phi), and 0.063 mm (4 phi). The sediment fraction retained on each sieve was weighed and reported as percent gravel (grain size >2 mm) and percent sand (grain size 2 mm to 0.063 mm). Sediment passing through the 0.063-mm sieve was further analyzed by pipette analysis to obtain percent silt (grain size 0.063 mm to 0.004 mm) and percent clay (grain size <0.004 mm). For the sand fraction, the weight percent for each phi size was also recorded.

2.2.3 Total Organic Carbon (TOC)

Analysis of TOC followed NOAA's procedures developed for the Mussel Watch Program (NOAA, 1993a). The sediment samples were dried to constant mass, exposed to HCl fumes to eliminate inorganic carbon, and TOC was measured with a CHN analyzer. Data on Total Organic Nitrogen (TON) and the C/N ratio were also provided.

2.2.4 Clostridium Spores

The enumeration of *Clostridium perfringens* spores was performed using methods developed by Emerson and Cabelli (1982) and modified by Saad (personal communication). The data were recorded as units of spores per gram dry weight of sediment.

2.2.5 Video and 35-mm Still Photography

Each 35-mm slide was projected and analyzed for sea-floor characteristics (i.e., substratum type and size class, and amount of sediment cover) and organisms. Most recognizable taxa were recorded and counted. Encrusting coralline algae were assessed as rough estimates of percent cover of available substratum. Several other taxa, including filamentous red algae, colonial hydroids, and small barnacles and/or spirorbid polychaetes, that were frequently too abundant to count reliably were assessed in terms of relative abundance. The following categories were used to assess abundances of taxa that were not counted on the still photographs:

Category	Percent cover	Numerical value assigned for analysis
rare	1-5	1
few	6-10	2
common	11-50	5
abundant	51-90	15
very abundant	>90	20

Organisms were identified to the lowest possible taxonomic level, about half of them to species, with the aid of pictorial keys and diver handbooks of the local fauna and algal flora (Martinez and Harlow, 1994; Weiss, 1995). Many of the encrusting organisms could not be identified to species, but were recognizable. These organisms were assigned to descriptive categories (e.g., "orange-tan encrusting"); however, each of these categories possibly includes several species. Due to the high relief of many of the habitats surveyed, all reported abundances should be considered to be extremely conservative. In many of the areas with large boulders, only about one-third of the available rock surfaces were visible; thus, actual biotic abundances in these areas are probably 2 to 3 times higher than the counts indicate.

Slides that were taken from a high altitude or only partially filled a frame were examined, but were omitted from further analysis. Of the total 565 still photographs taken during the survey, 525 were retained for subsequent analysis.

The video tapes were viewed to provide additional information about the uniformity of the environment. Notes on substratum size classes, bottom relief and relative degree of sediment drape were recorded. Large, clearly identifiable organisms (such as echinoderms, fish, mussels and single non-encrusting sponges) were enumerated. Counts of encrusting forms were not attempted due to the general lack of resolution of the video footage.

2.3 Data Management and Analysis

2.3.1 Benthic Infauna

The raw data were entered directly into a QuattroPro spreadsheet or imported electronically. NODC codes and ENSR's alphanumeric codes were added and the data were converted into a database format suitable for statistical analyses. Juvenile and indeterminable organisms were included in calculations of density but were excluded from similarity and diversity measures.

Diversity was calculated as Shannon-Wiener index H′ and the associated evenness value J′ and with the rarefaction method (Sanders, 1968) as modified by Hurlbert (1971). The rarefaction technique is more sensitive to rare species than is the Shannon-Wiener index. The Shannon-Wiener index was calculated using the base $\log_e$; for the rarefaction analyses, the number of individuals was set at defined points between 100 and 8000.

Similarity among samples was determined by two clustering techniques, including the Bray-Curtis similarity coefficient (Boesch, 1977) and Gallagher's CNESS, and also by principal components analysis (PCA-H) (Trueblood *et al.*, 1994). Group average sorting was the clustering strategy for both techniques; m was set at 18 for CNESS. Principal components analysis of metrically scaled CNESS distances (PCA-H) was employed to further examine the community structure of the infauna.

Nearfield and midfield stations were grouped together for analysis and discussion. The three replicated stations (MF12, NF17, and NF24) were included in both the near/midfield and farfield similarity analyses; only one replicate was analyzed along with the other unreplicated near- and midfield stations, and all three replicates were included in the farfield analysis.

2.3.2 Still Photographs

Data were pooled from all slides taken at each waypoint. To facilitate comparisons among waypoints, species counts were normalized to mean number of individuals per slide to account for unequal numbers of slides. Hydroids and small barnacles and/or spirorbids were omitted from the data because they consisted of several species and could not be accurately assessed. Only taxa with abundances of five or more individuals in the entire data set were retained for subsequent analyses. This process resulted in 43 out of the original 78 taxa being retained.

Hierarchial classification was used to examine the data obtained from the still photographs. This analysis consisted of a pairwise comparison of the species composition of all waypoints using the percent similarity coefficient (Whittaker and Fairbanks, 1958). This coefficient was chosen because it relies on the relative proportion that each species contributes to the faunal composition, and is thus least sensitive to differences in sampling effort among locations. Unweighted pair-group clustering was used to group samples with similar species composition (Sokal and Sneath, 1963). This strategy has the advantage of being relatively conservative in clustering intensity, while avoiding excessive chaining (i.e., successive samples joining a group one at a time).

3.1 Benthic Soft-Bottom Communities and Sedimentology, Nearfield and Midfield

3.1.1 Sediment Grain Size

Grain-size composition of sediments collected in August 1996 from the 8 nearfield and 15 midfield stations, as determined by sieving and gravimetric analysis, is given in Appendix B1. Percentages of gravel, sand, silt, and clay are shown in Figure 4. In general, sediments from the nearfield stations were coarser-grained than those from the midfield stations. Nearfield sediments contained greater amounts of gravel, coarser sand particles, less silt, and less clay than did sediments from midfield stations.

Five nearfield stations had sediments with more than 90% sand and gravel (Figure 4); three stations had more than 20% gravel (NF13 with 20%, NF14 with 53%, and NF18 with 71%). Medium and fine sands were the dominant sand fractions in the nearfield, except at NF24 where they were outranked slightly by the very fine sand fraction. Medium sand predominated at NF13, NF14, NF17-2, NF18, and NF23; whereas fine sand was the most common fraction found at stations NF15, NF17-1, and NF19. There were significant amounts of coarse sand at NF13, NF14, and NF17-2. In contrast to this pattern, sediments from NF24 were very high in silt (52%) and clay (16%).

Very little gravel was present at midfield stations: MF20 and MF21 had the highest percentages, with 9.3 and 9.6, respectively. Sands in the midfield were composed, for the most part, of fine or very fine sand. Fine sand predominated at the six stations where percent total sand was greater than 60% (MF2, MF4, MF5, MF7, MF16, and MF20). Very fine sand was most common at the remaining midfield stations, with the exception of one replicate from FF13 that contained almost equal parts of medium, fine, and very fine sands. The two sandiest midfield stations, MF2 and MF4, were low in silt and clay. Sediments from the remaining midfield stations were high in silt, ranging from 18% at MF16 to 61% at MF8, and contained moderate amounts of clay (from 5.5% at FF10 to 19.3% at MF12).

3.1.2 Total Organic Carbon and Carbon/Nitrogen Ratio

Sediments within the nearfield and midfield areas generally had low percentages of total organic carbon (TOC) (Appendix B2, Figure 5). In 1996, slightly more than half of all nearfield and midfield stations (12 of 23) had TOC values less than 1%. All nearfield stations had TOC values less than 1%, except NF24, which had 1.6% TOC. Five nearfield stations (NF13, NF15, NF17, NF19, and NF23) had TOC values less than 0.5%. Of the 15 midfield stations, five (MF2, MF4, MF20, FF10, and FF12) had TOC values less than 1%. The highest TOC values seen in the midfield were at stations FF13 (1.5%), MF10 (1.9%), and MF12 (1.7%).

A clear relationship of increasing TOC with an increase in mean phi (i.e., decreasing grain size, as determined by laboratory analysis) is shown in Figure 6A. Of the eight stations with a mean phi of less than 3 (fine and medium sand), six had less than 0.5% TOC. Of the four stations with a mean phi greater than 5 (medium silt), all had TOC of greater than 1%, and three of these stations had TOC above 1.5%.

Levels of Total Organic Nitrogen (TON) and carbon/nitrogen (C/N) ratios are given in Appendix B2. TON was at or near detection limits at 11 of the 23 stations, and ranged from 0.066 (NF18) to 0.213 (FF13-2) at the remaining 12 stations. C/N ratios ranged from 4.95 at NF17 to 15.70 (MF16) (Figure 7). Fresh algal material has a C/N of around 6; this ratio increases as the material decomposes because nitrogen is recycled faster than carbon. A C/N greater than 15 is indicative of land plants or well-processed marine material.

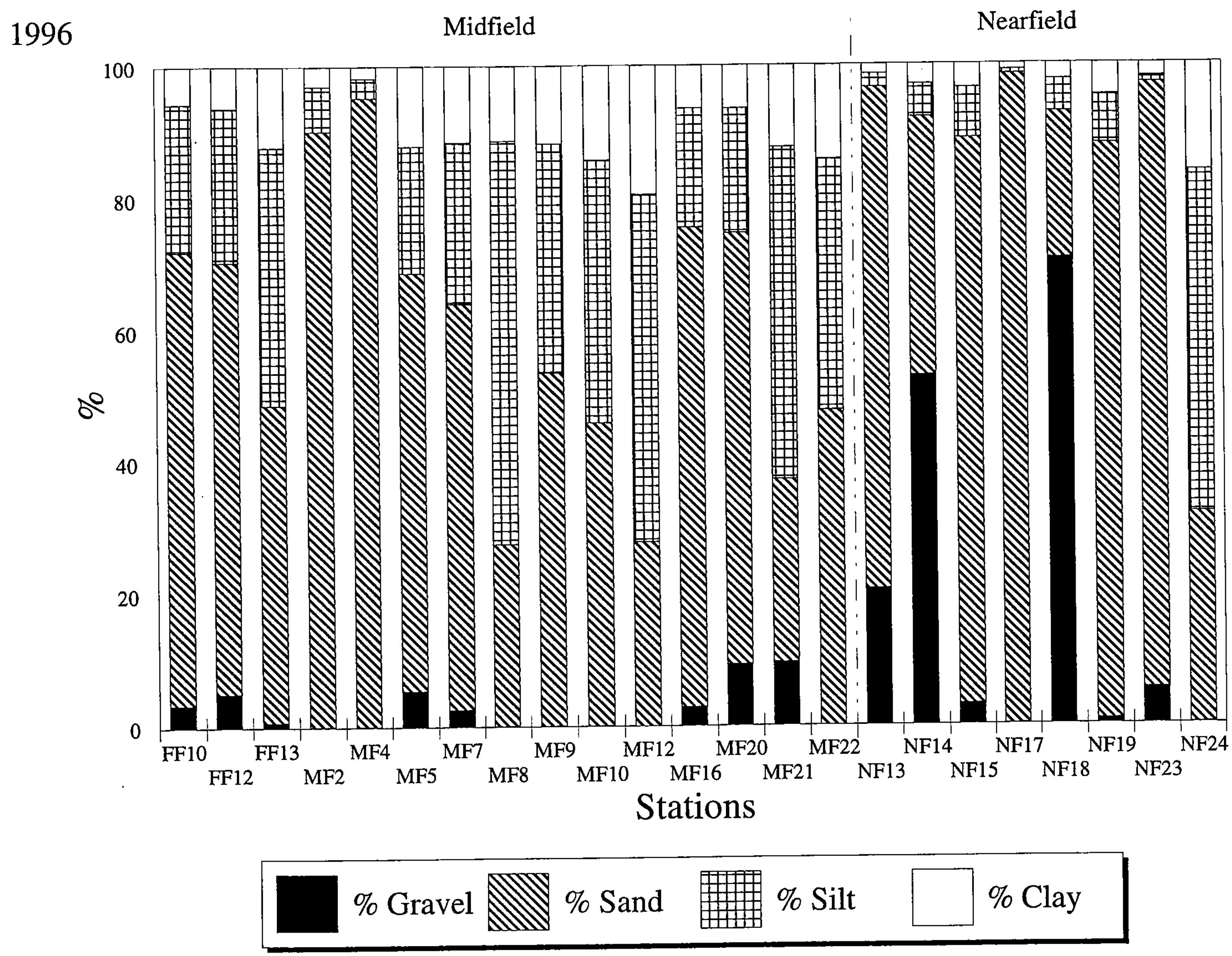


Figure 4. Sediment grain-size composition of the nearfield and midfield stations, August 1996.

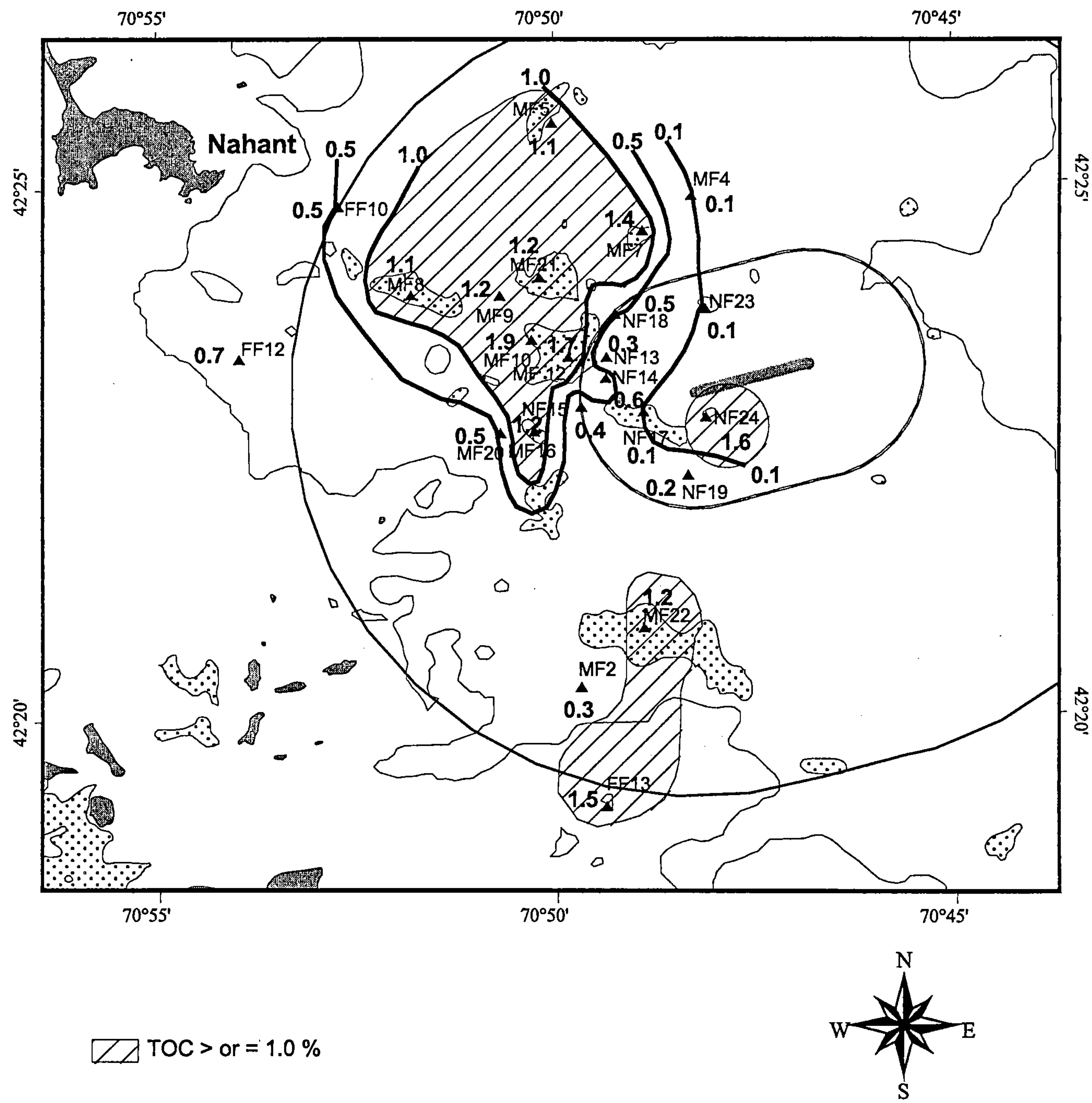
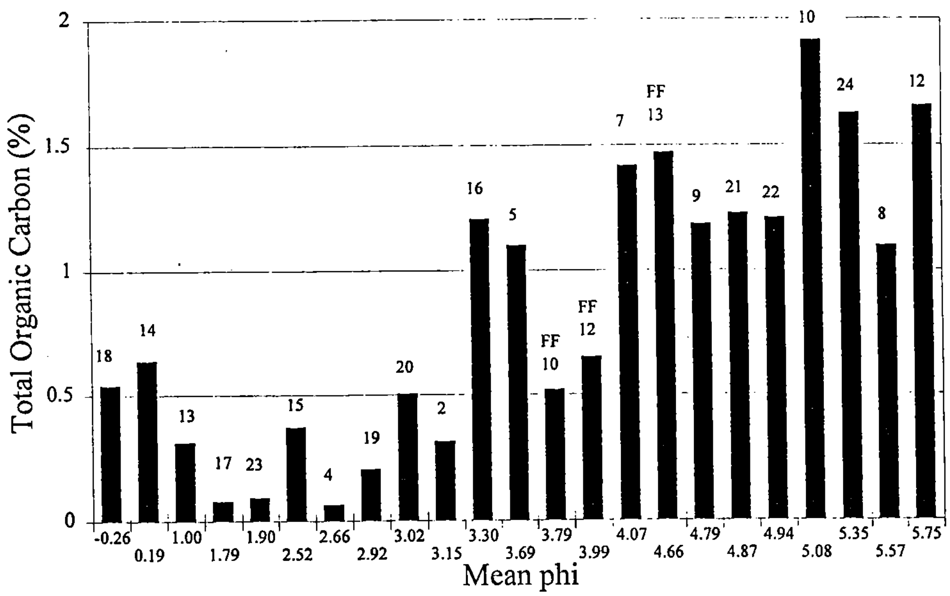


Figure 5. **Areal distribution of total organic carbon (TOC) in sediments of nearfield and midfield in August 1996.**

A



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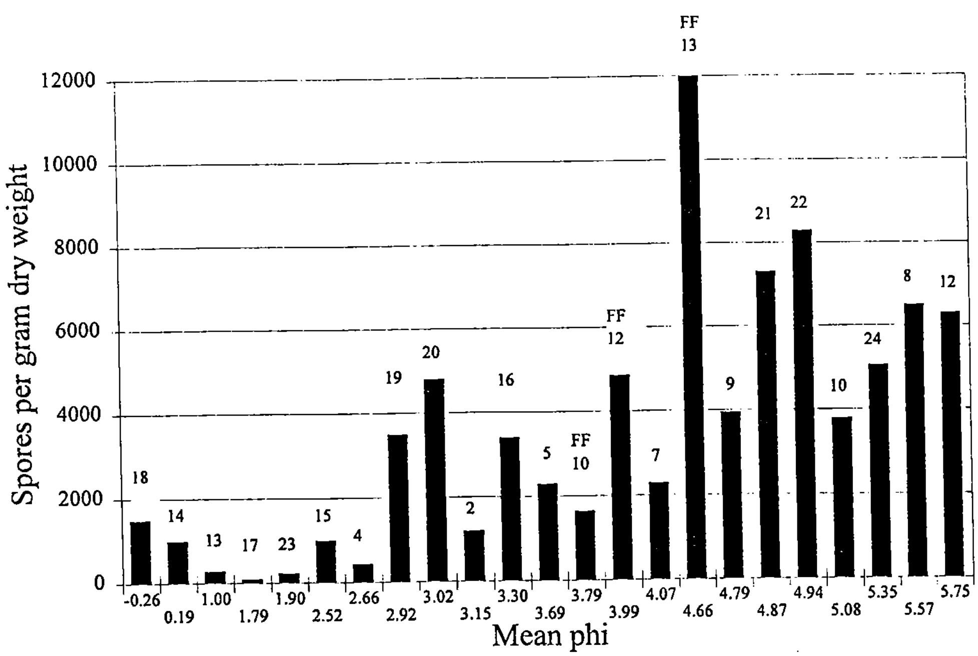

Figure 6. **Total organic carbon concentration (A) and *Clostridium perfringens* spore counts (B) plotted against sediment grain size (mean phi) measured at the nearfield and midfield stations in August 1996. Numbers above the bars are station numbers.**

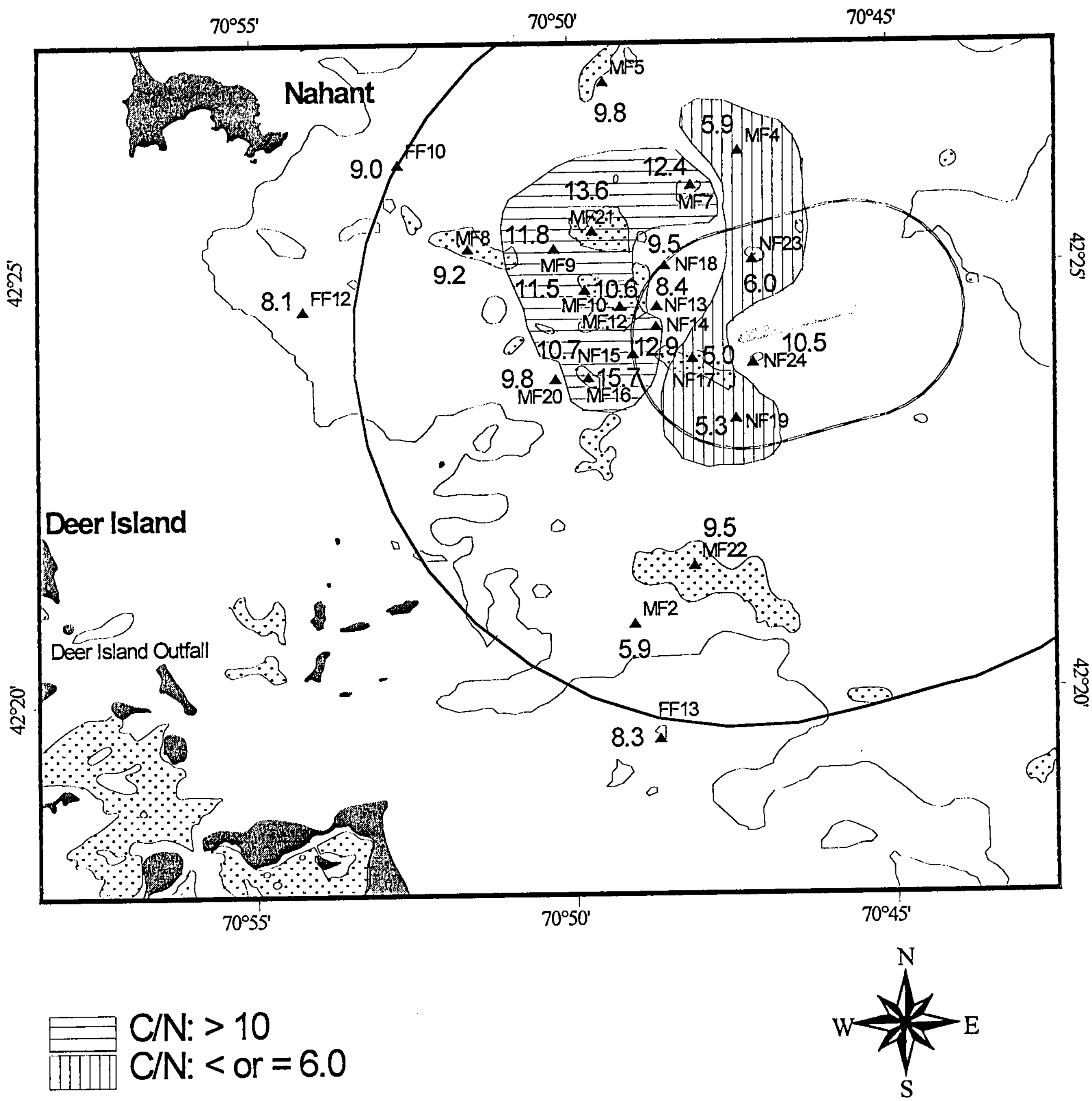

Figure 7. Carbon/nitrogen (C/N) ratio at nearfield and midfield stations in August 1996.

3.1.3 Clostridium Spores

The density of *Clostridium perfringens* spores at nearfield/midfield stations ranged from a low of 94 (station NF 17) to a high of 12000 (station FF13) colony-forming units per gram dry weight of sediment (Figure 8, Appendix B3). In general, the density of *Clostridium* spores increased with increasing mean phi (i.e., towards finer sediments) (Figure 6B). Spore density was higher at stations with finer sediments and higher levels of TOC.

3.1.4 Benthic Infauna

Taxonomic Composition

The benthic infauna of all of the 1996 samples consisted of 234 species. Table 3 summarizes the breakdown of species into major taxonomic groups. As in previous years, annelids comprised about half the taxa, followed by crustaceans and mollusks and some representatives of other groups . The largest polychaete families were the Spionidae (14 species), the Maldanidae (11), and the Cirratulidae and Syllidae (10 each). The largest crustacean groups were the Amphipoda (53 species) and the Cumacea (16 species). A cumulative species list for the 1995 and 1996 samples can be found in Appendix C1.

Table 3. Taxonomic composition of benthic infaunal samples collected in August 1996.

Taxonomic Group	Nearfield/Midfield		Farfield		Entire Study Area	
	Number	Percent	Number	Percent	Number	Percent
Annelida	109	47	114	46	152	47
Crustacea	65	28	67	27	84	26
Mollusca	38	16	44	18	53	16
Other	22	9	24	10	34	10
Total	234	100	249	100	323	100

Figure 9 shows the taxonomic composition of samples taken at the nearfield and midfield stations. Only two stations (MF4 and NF17) had less than 50% polychaetes; at these stations, amphipods were the dominant group. Amphipods were also important at the sandy stations FF13, NF13 and NF23.

Distribution and Density of Dominant Species

As in the previous year, the most common dominant species in the nearfield/midfield area were two spionid polychaetes, *Prionospio steenstrupi* (among the top ten species at 20 of the 23 stations) and *Spio limicola* (14 stations), the capitellid *Mediomastus californiensis* (19 stations), and also the lumbrinerid *Ninoe nigripes* (18 stations). *Ninoe nigripes* has been relatively widespread throughout the duration of

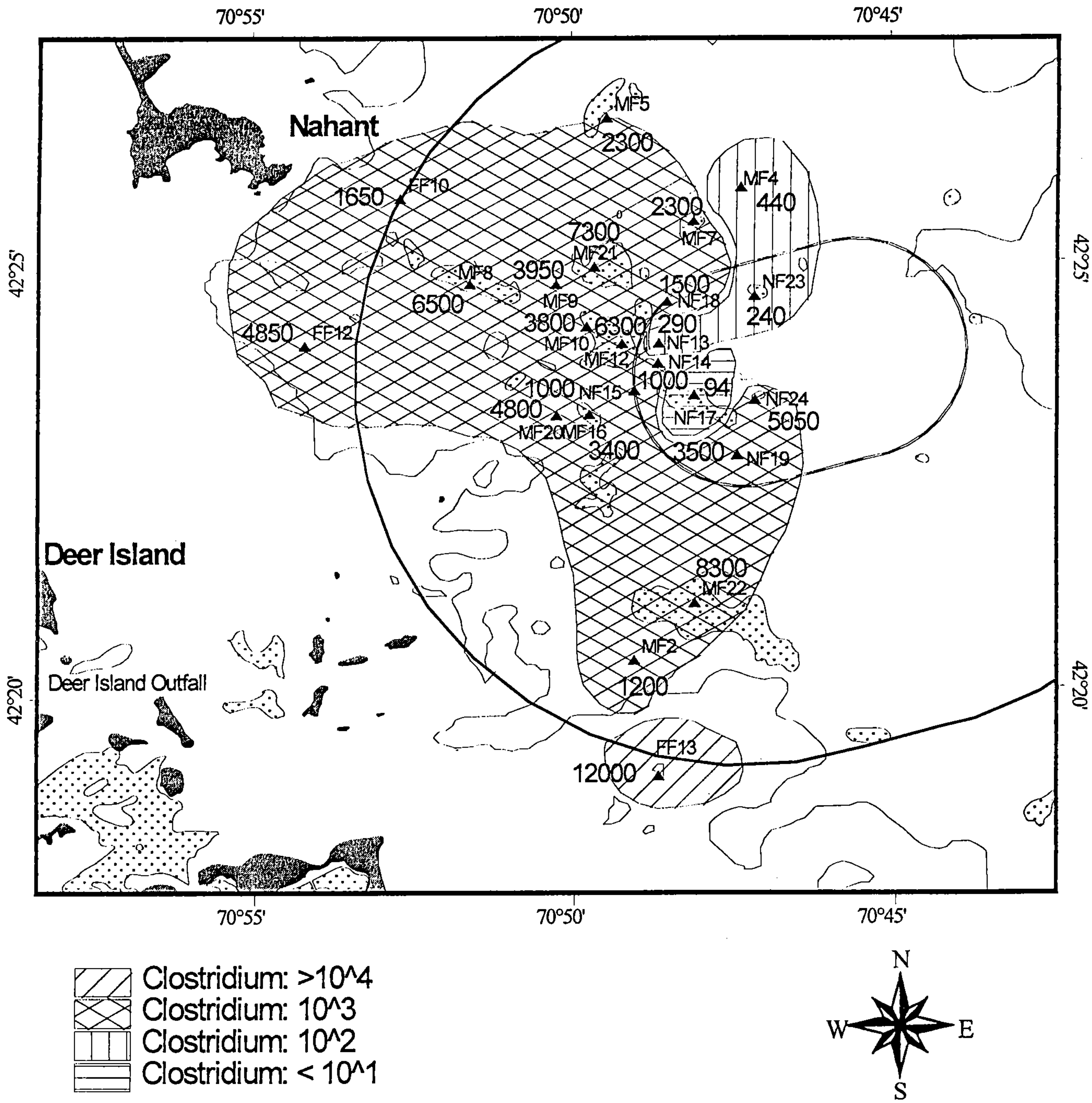

Figure 8. ***Clostridium perfringens*** **spore counts per gram dry weight at nearfield and midfield stations in August 1996.**

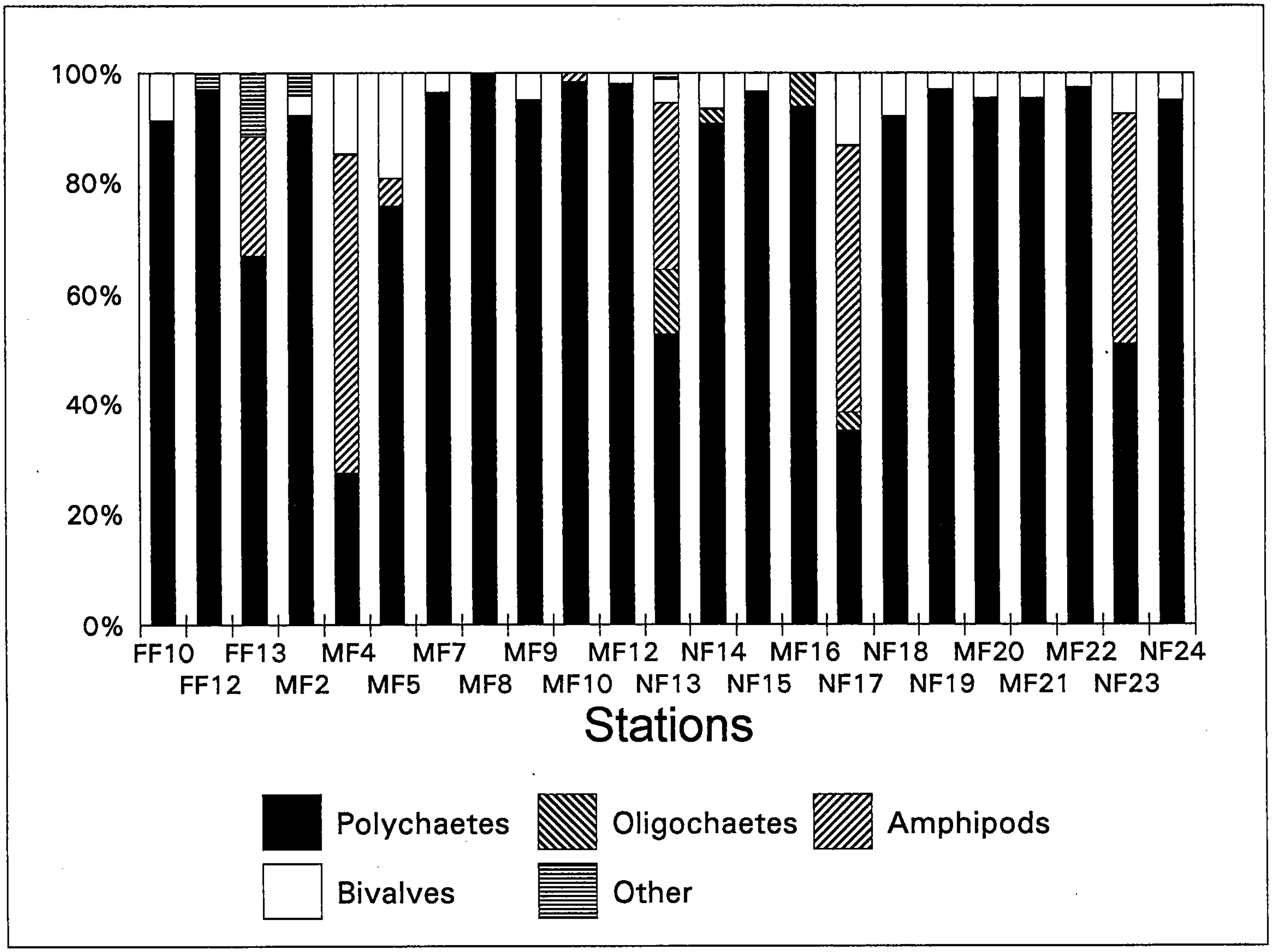

Figure 9. Taxonomic composition of benthic infauna samples taken at nearfield and midfield stations in August 1996.

this study, but was particularly common in 1996 (Figure 10), apparently because the sampling event took place just at the time the postlarvae were about to settle, but were not yet subject to predation. Up to about 80% of the individuals in a sample were only 5 setigers long, but could be identified to species because even very small juveniles have characteristic black aciculae. The suite of species occurring among the top ten dominants of at least one station comprised a total of 46 species, including an additional 19 polychaetes, 3 oligochaetes, 9 amphipods, 1 isopod, 7 bivalves, 1 phoronid, and 1 echinoderm.

While the abundances of spionids were generally high throughout the near- and midfield, there was a distinct pattern in the distribution of individual species (Figure 11). *Prionospio steenstrupi* was by far the most widespread spionid and made up a low percentage of all spionid polychaetes at only three stations in the midfield (MF4 and MF21 north of the diffuser and MF22 south of the diffuser). *Spio limicola* was the most abundant spionid at MF4 and MF21 and was also common at an additional four stations, all in a roughly north-south band to the west of the outfall (stations MF10, MF12, MF16, NF24). *Dipolydora socialis* (previously called *Polydora socialis*), on the other hand, seemed to prefer the somewhat more erosional environment in the nearfield, occurring in its highest densities at stations MF4, MF7, NF18, NF19 and NF23 (Figure 11). *Mediomastus californiensis* was common throughout the mid- and nearfield (Figure 12), reaching its peak abundances at a small group of midfield stations northwest of the diffuser (MF8, MF10 and MF12). This distributional pattern is roughly the same as that observed in 1995.

Distributional patterns of cirratulids (Figure 13) also were very similar to those seen in 1995, with *Aphelochaeta marioni* being most abundant in the nearfield and at offshore midfield stations, and *Tharyx acutus* and *Monticellina baptisteae* being most abundant at nearshore midfield stations, in close proximity to the Harbor (e.g., FF12). While *T. acutus* is a very common species in the Harbor, *M. baptisteae* is rare, and high abundances of this species are limited to the area west and north of the nearshore end of the diffuser (stations MF8, MF9, MF20, and MF21).

Two paraonid species, *Aricidea catherinae* and *Levinsenia gracilis*, are typically among the more widespread and abundant polychaetes in the near/midfield area, and they were again in 1996. Similar to the previous year, *A. catherinae* was found mostly in the nearshore midfield area, whereas *L. gracilis* was most abundant farther offshore (Figure 14). These two species appear to follow the main tidal currents out of the Harbor in their distribution, with *A. catherinae* living closest to the main tidal channels; this trend could also be seen in the distribution of this species in 1995. The currents may support both the larval dispersal and food supply out of the Harbor. However, this pattern is obscured somewhat by patchiness: neighboring stations often show opposite relative abundances (e.g., MF2 with mostly *Aricidea* and MF22 with mostly *Levinsenia*; see also MF4/MF7 and NF19/NF24). All these station pairs are characterized by a steep gradient in grain size (see section 3.1.1), and *Aricidea* shows a preference for the coarser grained sediments (mean phi around 2 or 3), while *Levinsenia* clearly prefers a siltier substratum (mean phi around 4 or 5).

The most common syllids in the area, two species of *Exogone*, are usually indicators of sandy sediments, and they have been seen at the coarser-grained stations in the nearfield since the inception of this program. The locations of their peak abundances shift slightly from year to year due to shifting sediments. In 1996, the stations with the highest abundances of *Exogone* spp. were NF13, 14, 19, 23, and MF4 (Figure 15). The remainder of the nearfield, with the exception of the mud patch station NF24, showed moderately high syllid abundances. The remainder of the midfield was characterized by low syllid abundances, with the exception of MF5 where abundances were also moderate.

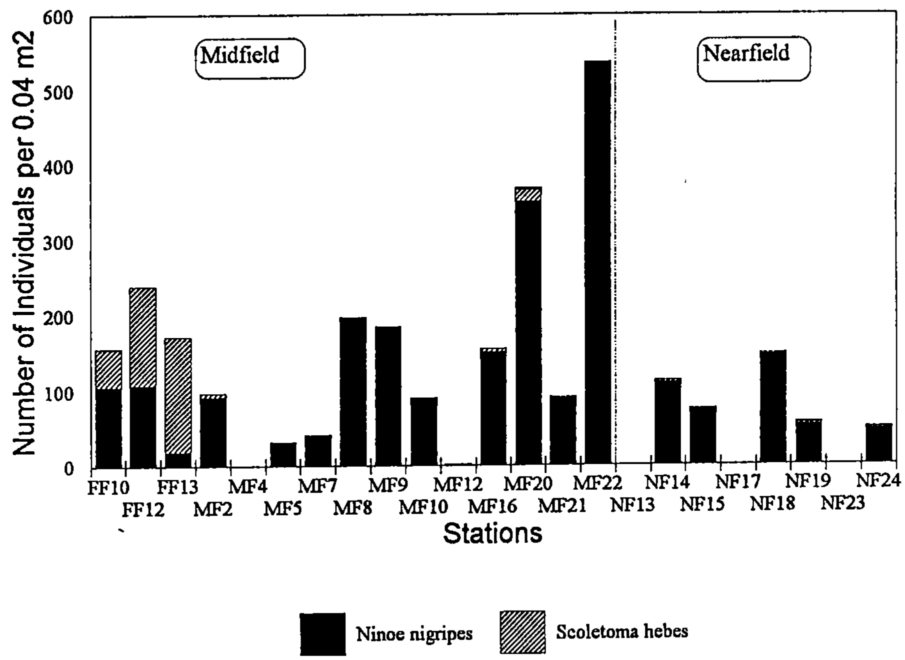

Figure 10. Density of *Ninoe nigripes* and *Scoletoma hebes* at the nearfield and midfield stations in August 1996.

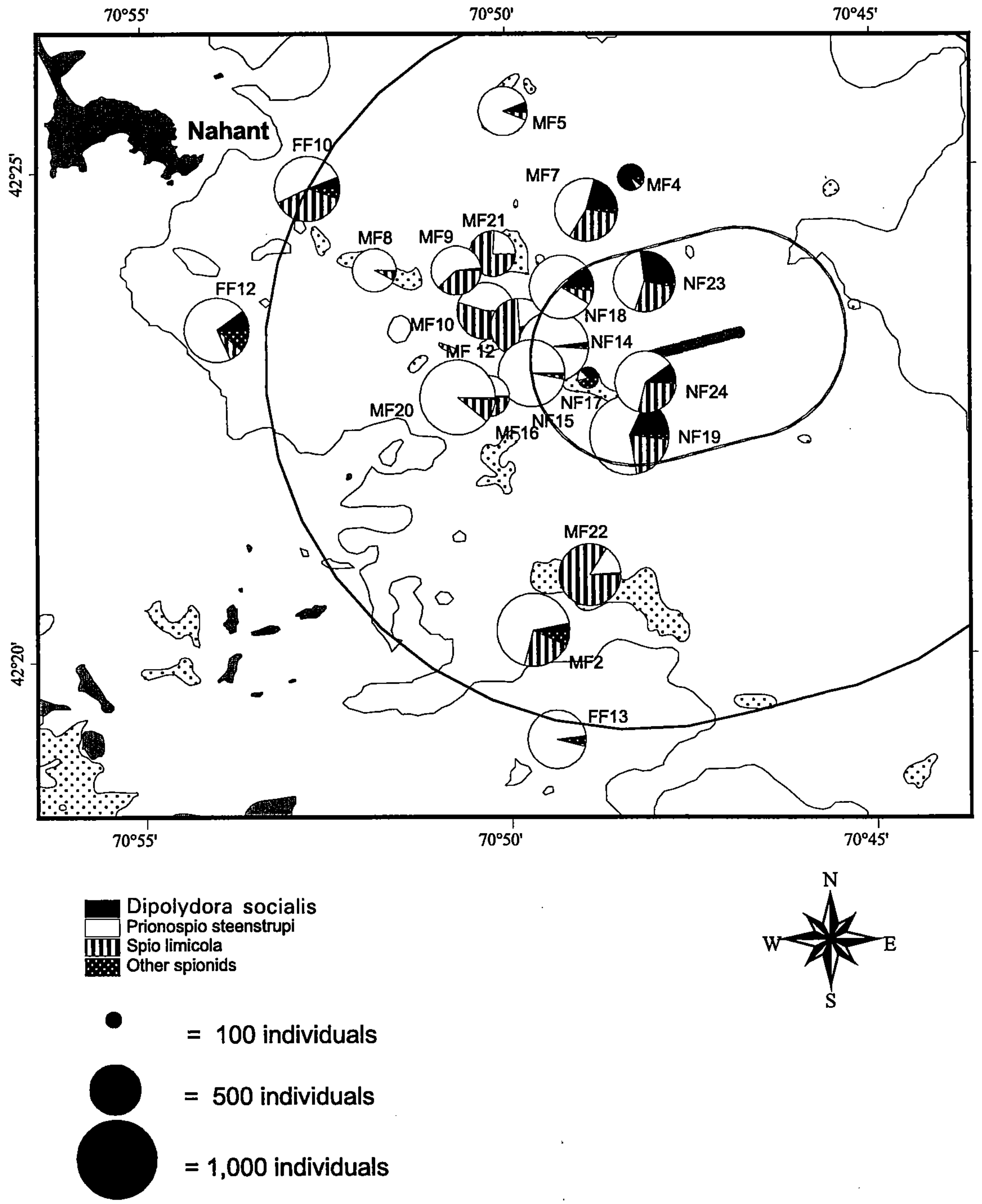

Figure 11. Densities of spionid polychaetes at the nearfield and midfield stations in August 1996.

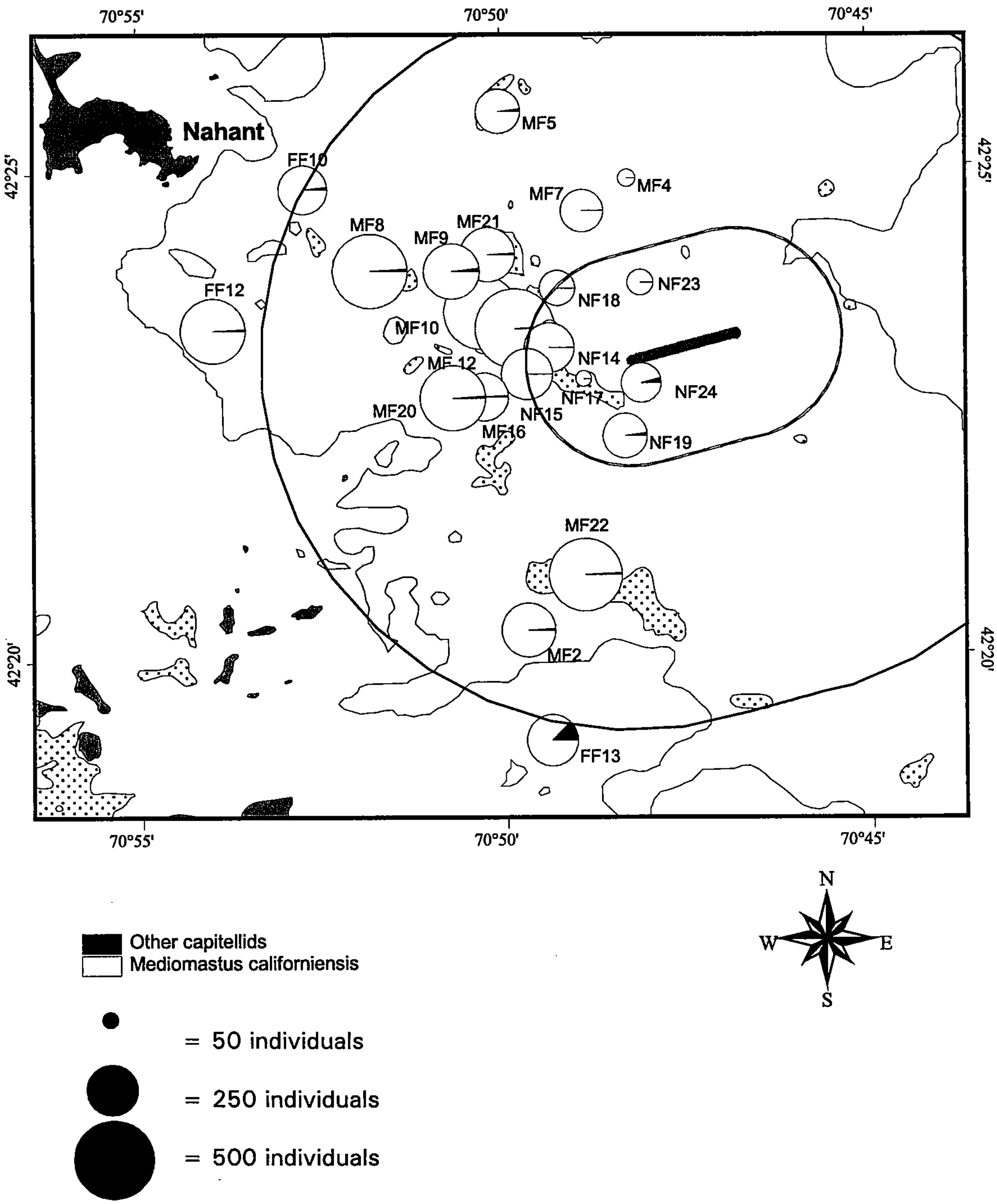

Figure 12. Densities of capitellid polychaetes at the nearfield and midfield stations in August 1996.

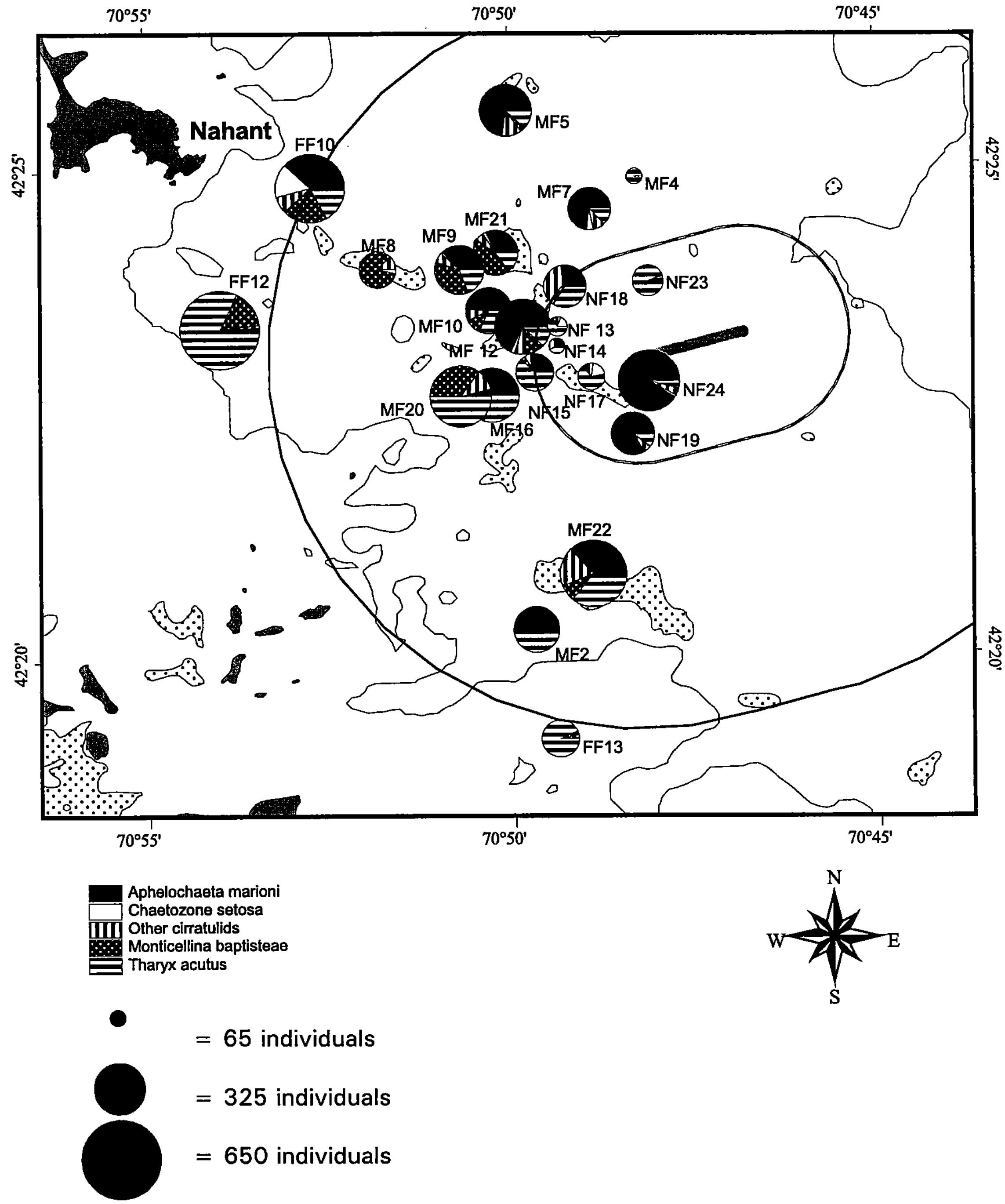

Figure 13. Densities of cirratulid polychaetes at the nearfield and midfield stations in August 1996.

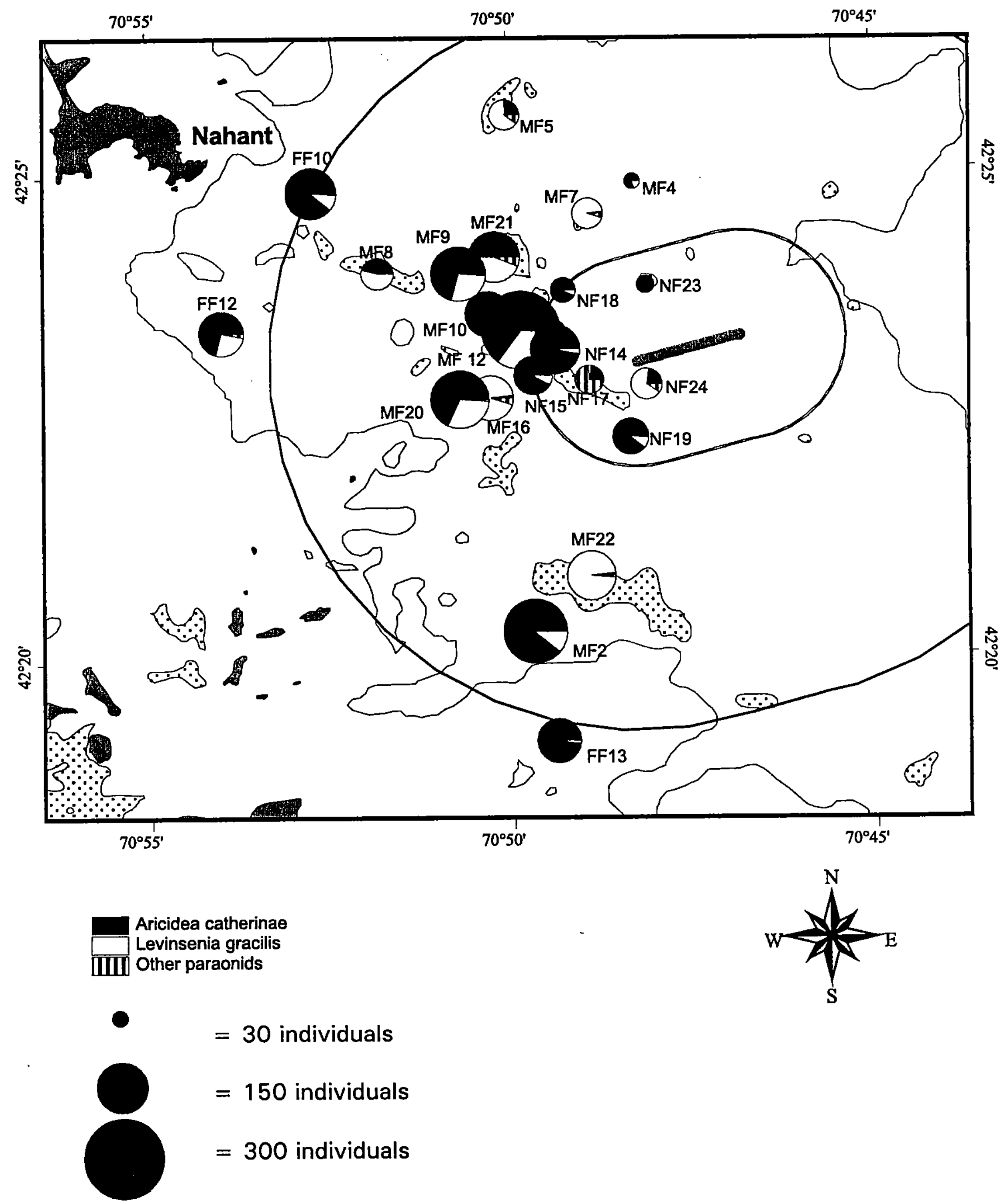

Figure 14. Densities of paraonid polychaetes at the nearfield and midfield stations in August 1996.

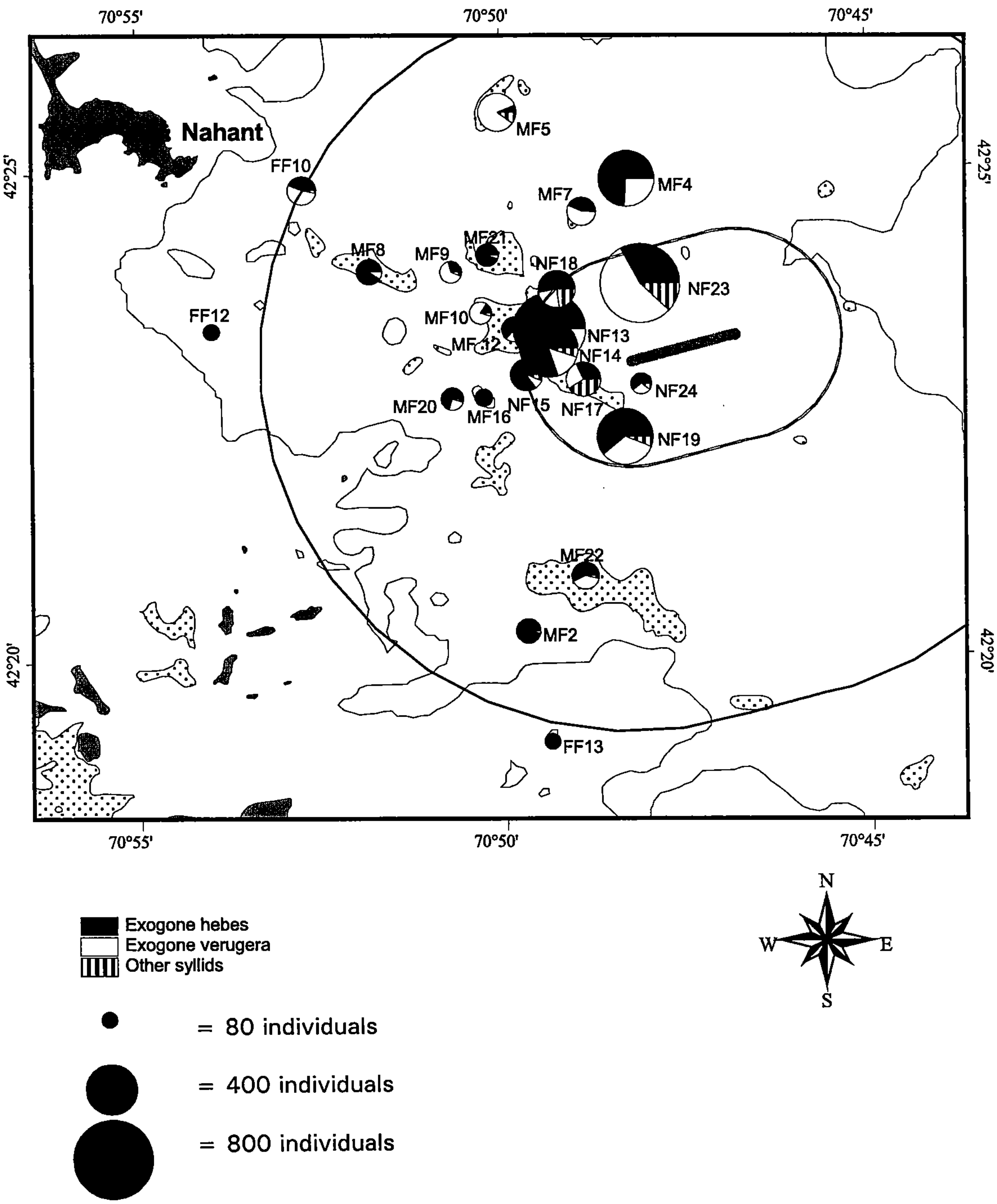

Figure 15. Densities of syllid polychaetes at the nearfield and midfield stations in August 1996.

The amphipod crustaceans occurring in moderate or high abundances in the nearfield and midfield are all sand-loving species, the most common being *Corophium crassicorne*. Because of their habitat preferences, these amphipods have been a very stable faunal element at the four sandiest stations in the area, MF4, NF13, NF17 and NF23. This pattern was again present in 1996 (Figure 16). While the amphipod fauna at stations MF4 and NF13 was clearly dominated by *C. crassicorne*, the other two stations had a more diverse amphipod fauna. At those stations, in addition to *C. crassicorne*, two species of *Unciola* and several other amphipods made up more than half of all amphipods at those stations. At station FF13, located just outside the southern entrance of the Harbor, crustaceans accounted for 17% of the fauna, and about a third of these were the amphipod *Ampelisca abdita*, the common ampeliscid in the Harbor. Station MF2, the station closest to FF13, and FF12, also in the midfield near the Harbor, were the only other stations with a few *A. abdita*. If the *Ampelisca* assemblage at FF13 is consistent in the future, that station may be a good reference point for changes taking place in the Harbor, rather than indicating possible impacts from the outfall.

Bivalves were an important faunal element at some stations in the area to the north of the diffuser (Figure 17). The richest bivalve fauna, both in terms of abundance and species richness, was found at NF23. *Crenella decussata*, the most abundant bivalve at that station, appears to prefer sandy sediments, as does *Cerastoderma pinnulatum*, a fairly common bivalve at MF4 and NF13. At muddier stations, where the abundance of bivalves as a whole was low, *Nucula delphinodonta* tended to be the most abundant species.

The top ten dominant species for each station are presented in Appendix C2. The contribution of each species has been calculated for the total fauna (juveniles and indeterminates included) and for the identified fauna (juveniles and indeterminates excluded). In terms of larger taxonomic groups, there is a distinct difference between the dominant fauna at muddy or gravelly stations and that at sandy stations (Figure 9). In the first group, polychaetes clearly predominate, contributing at least 90% of the top ten dominants (number of individuals); in one case (station MF8), even 100%. The reason why stations with such different substrata fall into the same group is probably the way gravel is distributed in the sediment column; the grab samples usually had a layer of mud over gravel at depth. In the second group, the percentage of polychaetes varies from 27 to 75%, amphipods contribute up to 58%, and bivalves up to 19%. This trend has been fairly constant throughout the duration of this study, and changes of stations from one group to the other may be an indicator for effluent-related effects on the infauna during post-disposal monitoring.

Species Richness and Diversity

Both the number of species identified from a grab sample and the number of individuals counted per grab varied by about a factor of 2 among the stations in the near- and midfield, with high and low values for each parameter sometimes found at neighboring stations (Table 4). For example, station MF8 was lowest in terms of number of species per grab (48); whereas station MF9, less than a mile to the east, had 76 species per grab. Similarly, MF16 had a low infaunal density (fewer than 1400 individuals per grab), while the adjacent station MF20 was among the high-density stations with nearly 2800 individuals per grab. There was no obvious pattern in the distribution of species richness or infaunal densities, but rather a very patchy distribution which most likely mirrors the patchiness of the sediment. This patchiness was seen to the same degree in the nearfield as in the midfield.

Diversity was measured with two methods, Hurlbert's rarefaction and the Shannon-Wiener index H′ (including evenness J′). The results were similar with both methods, indicating a strong influence of a few very abundant species. The number of expected species per 100 individuals ranged from about 15 to

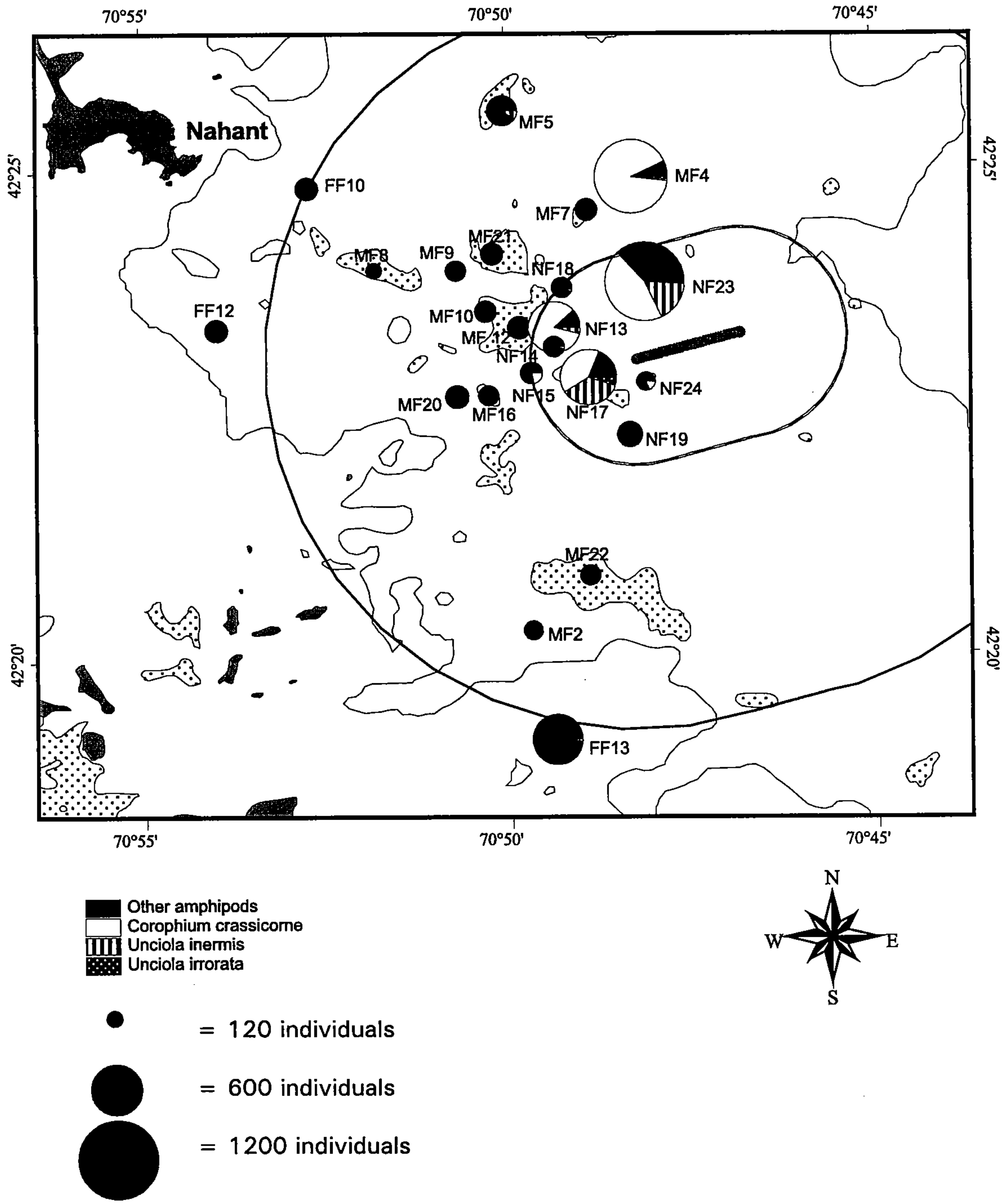

Figure 16. Densities of amphipods at nearfield and midfield stations in August 1996.

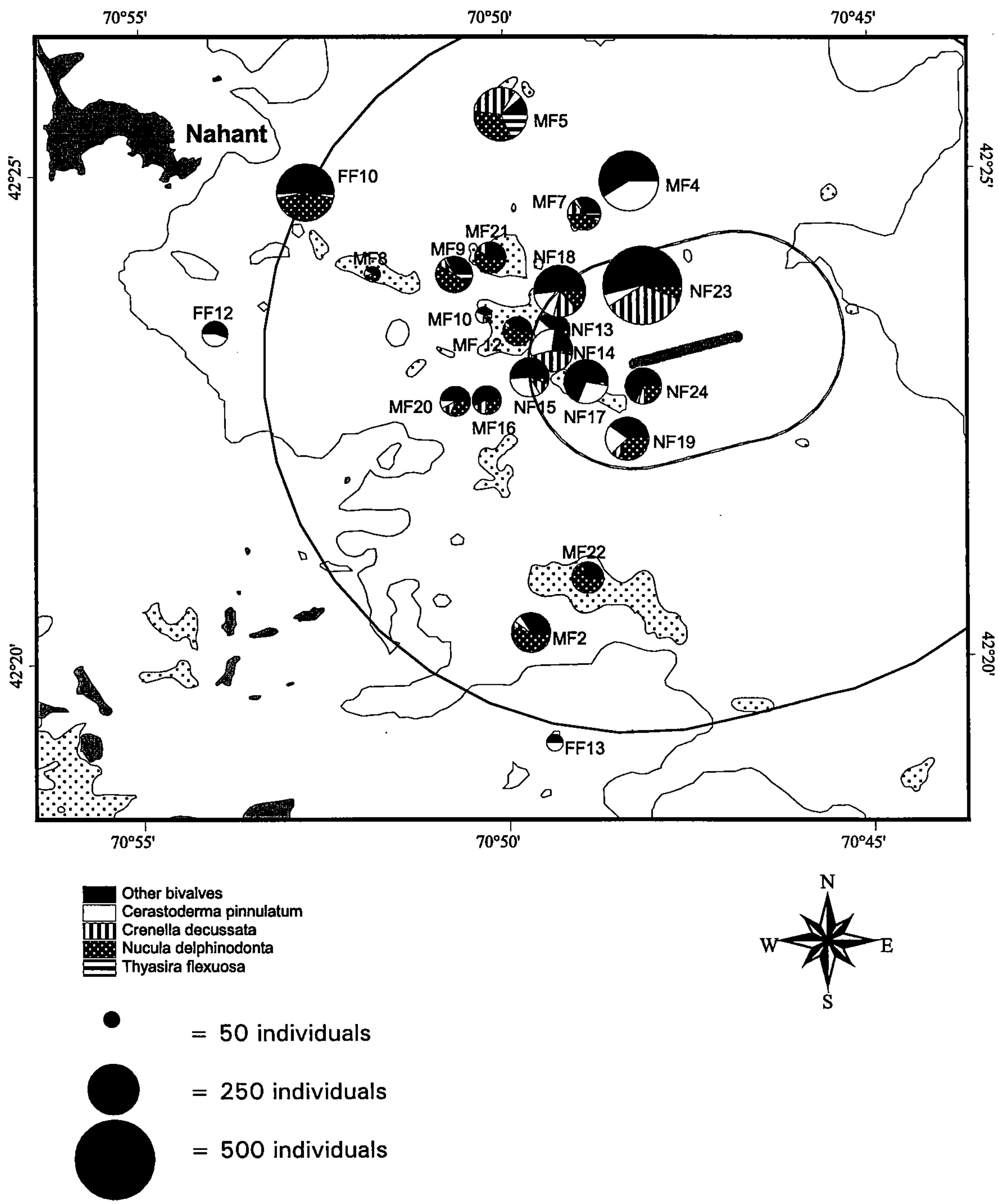

Figure 17. Densities of bivalves at nearfield and midfield stations in August 1996.

Table 4. Community parameters of nearfield and midfield stations, August 1996.

Station	No. spp. (0.04m²)	No. indiv. (0.04 m²)	spp./50 ind.	spp./100 ind.	spp./500 ind.	H′	J′
MF2	70	2456	17.01	22.96	41.69	2.80	0.66
MF4	58	1865	11.21	15.65	34.47	1.95	0.48
MF5	92	1500	20.73	30.65	65.38	3.16	0.70
MF7	74	1381	19.23	27.74	54.50	3.01	0.70
MF8	48	1329	13.76	19.09	35.16	2.38	0.61
MF9	76	1586	19.48	27.54	54.88	3.09	0.72
MF10	63	1580	14.82	20.37	41.39	2.58	0.62
MF12*	70	2222	16.46	22.70	43.92	2.76	0.65
NF13	56	1583	13.34	19.37	39.10	2.32	0.58
NF14	74	2024	15.48	21.94	45.20	2.52	0.59
NF15	69	1590	16.90	24.76	49.95	2.56	0.60
MF16	62	1389	17.93	23.77	43.10	2.98	0.72
NF17*	63	1455	16.73	23.80	45.52	2.57	0.62
NF18	81	1666	19.92	27.84	52.48	2.96	0.67
NF19	100	2342	20.19	29.34	59.73	3.10	0.67
MF20	83	2796	17.12	23.90	46.92	2.79	0.63
MF21	66	1341	18.68	25.06	46.48	2.98	0.71
MF22	70	2748	15.91	21.80	41.22	2.72	0.64
NF23	85	3315	19.44	26.23	47.55	3.09	0.69
NF24*	65	1499	15.97	22.84	45.35	2.62	0.63
FF10*	78	2115	21.87	31.01	58.31	3.30	0.70
FF12*	65	2974	15.32	21.16	39.96	2.64	0.59
FF13*	54	2343	16.88	22.30	38.66	2.83	0.66

*replicated station, numbers are means per replicate more than 30 (Table 4, Figure 18). No particular geographical pattern in the distribution of high and low diversity could be identified. The variability of the infaunal diversity was comparable in both the nearfield and midfield areas. The Shannon-Wiener indices generally ranged from about 2.3 to 2.8, with one station (MF4) exhibiting a low diversity with H′ under 2.0 and six stations (MF5, MF7, MF9, NF19, NF23, and FF10) having relatively high diversities with H′ values over 3.0.

Community Analysis

Based on the results from previous years, it was expected that the stations in the nearfield and midfield would cluster together by sedimentary characters such as grain size and organic carbon content and by the abundances of a few common species. This was generally the case, even though the clustering patterns differed slightly from those seen in 1995, an observation which is consistent with the patchy character of the sediments in this area.

The Bray-Curtis similarity analysis was run first with only the original nearfield/midfield station grouping and using only replicate 2 from replicated stations (Figure 19a) . In this analysis, the stations grouped into four clusters. The dendrogram shows three fairly similar clusters of stations that for the most part have fine-grained sediments and support benthic assemblages with slightly differing relative abundances of spionid and capitellid polychaetes. The fourth cluster is composed of four sandy stations that have grouped together in previous years because of a very consistent and characteristic benthic assemblage of amphipods, sand-dwelling polychaetes, bivalves, and oligochaetes.

The second Bray-Curtis analysis included all nearfield and midfield stations, including stations FF10, FF12 and FF13, with each replicate included and kept separate for analysis (Figure 20). Station replicates almost always grouped together before joining replicates from another station. The pattern of station groupings seen in this analysis is very similar to that seen in the previous dendrogram. The largest cluster (1) is equal to clusters 1-3 in the first dendrogram. With only minor exceptions, cluster 1a is equal to cluster 1; cluster 1b is equal to cluster 2 with the addition of all replicates from station FF10, and cluster 1c is equivalent to cluster 3. Cluster 2 (Figure 20) includes all replicates from FF12 and the single replicate collected at MF2. This grouping probably reflects the presence at these stations of the amphipod *Ampelisca abdita*. Cluster 3 includes only the three replicates taken at FF13, where up to 17% of the fauna was *A. abdita*. Cluster 4 includes the same stations in both dendrograms. Geographically, the station clusters are arranged in bands or patches approximately parallel to the mouth of the Harbor. A summary description of the Bray-Curtis clusters is presented in Table 5.

The CNESS technique, which is more sensitive to less abundant species than is Bray-Curtis, produced similar albeit slightly different station groupings (Figures 19b, 21, Table 6). The first dendrogram (Figure 19b) shows three clusters and a single outlier station (MF5). The clusters can be defined by the same parameters as the Bray-Curtis clusters, although not quite as clearly. Essentially, in addition to the outlier station, there are two large and fairly closely related clusters of muddy stations and the cluster of sandy stations equivalent to the Bray-Curtis cluster 4. Cluster 1, including almost the entire midfield and the "mud patch" station NF24, has mostly silty to fine sandy sediments with about 50% mud (range 10 to 73%, median 53.1%), a relatively high TOC concentration, and a high C/N ratio. Cluster 2 contains the finer-grained nearfield stations and MF7; this cluster is ill-defined in terms of sedimentary features, with a wide range of mean phi, percentage of mud and TOC concentrations. Cluster 3 is the group of sand stations, with the stations joined slightly differently than in the Bray-Curtis dendrogram. The outlier station, MF5, is fine-grained, with about 31% mud, low TOC and a moderate C/N ratio.

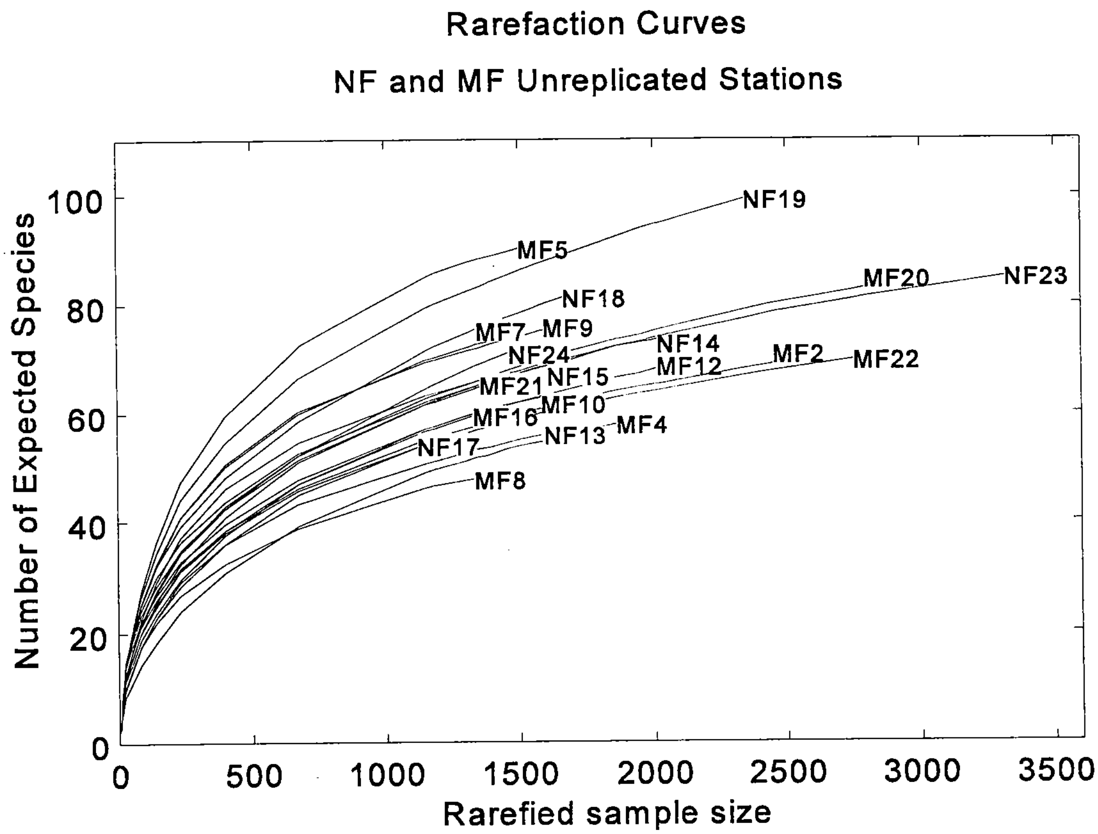

Figure 18. Rarefaction curves for nearfield and midfield unreplicated stations in August 1996.

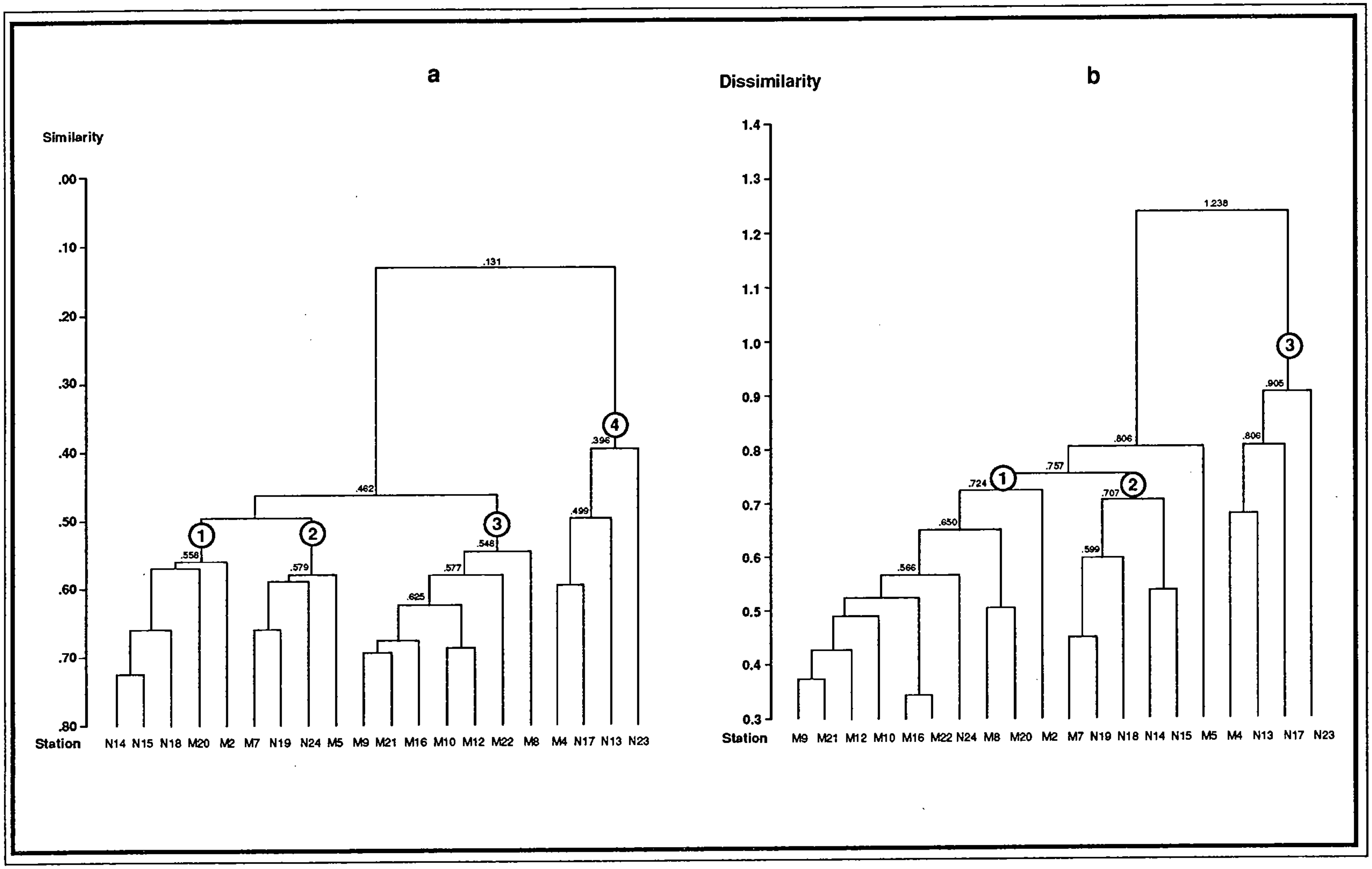

Figure 19. Bray-Curtis similarity (a) and CNESS dissimilarity (b) among nearfield and midfield stations (FF10, FF12, FF13 not included.)

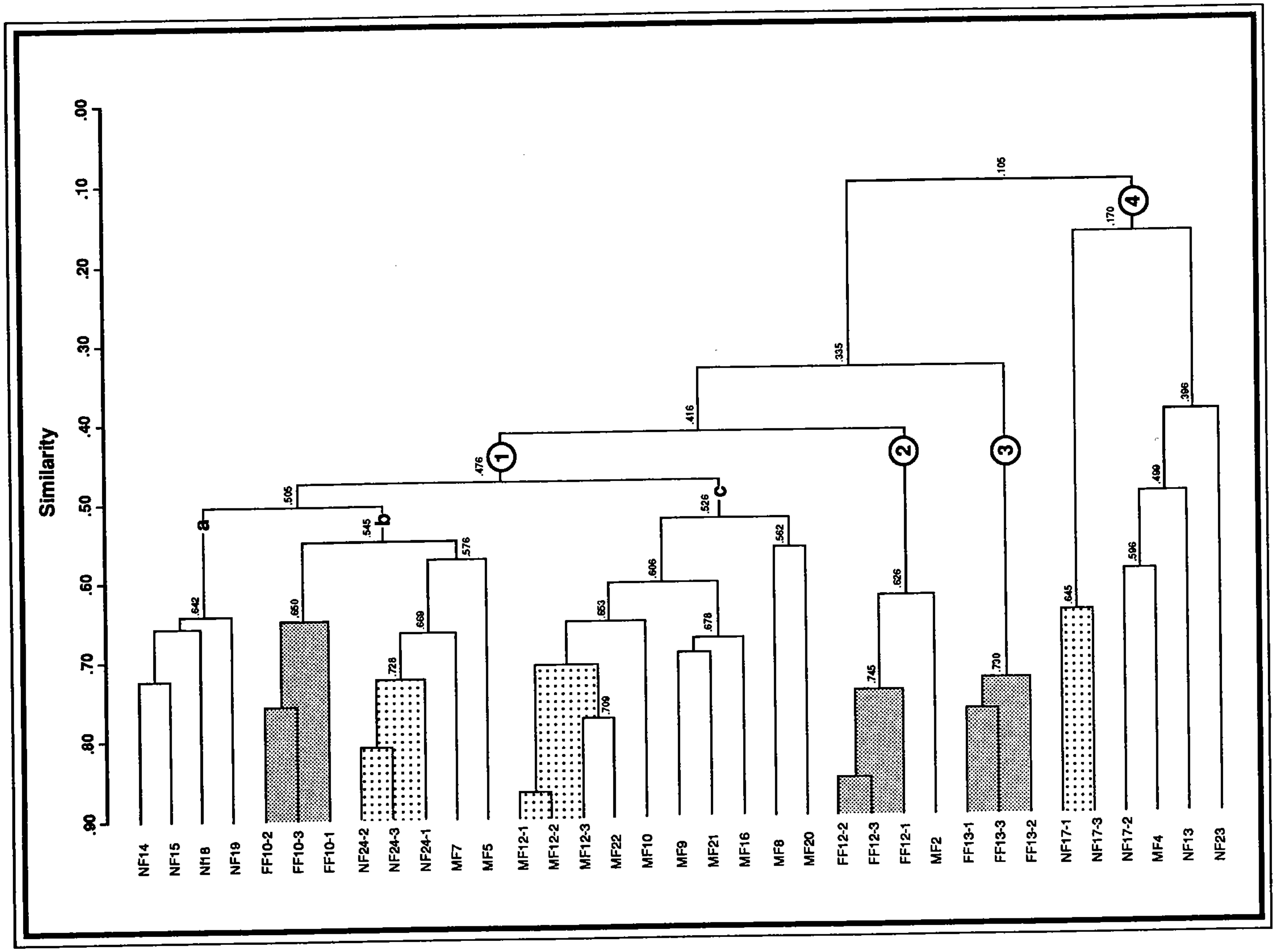

Figure 20. Bray-Curtis similarity among nearfield and midfield stations, replicates kept separate (FF10, FF12, FF13 included.)

Table 5. Characterization of nearfield/midfield station clusters generated with Bray-Curtis similarity measure (FF10, FF12, FF13 not included).

Cluster	Stations	Location	Sediment Grain Size (mean phi)	TOC and C/N Ratio	Infaunal Assemblage (individuals/m^2)
1	MF2, 20 NF14, 15, 18	nearshore (close to Harbor), discontinuous band of stations	variable, mean phi 1.7±1.63	TOC low, 0.5±0.13% C/N moderate, 10±2.5	high *Prionospio* (15,000) moderate *Mediomastus* (4500) high *Aricidea catherinae* (3500), a common Harbor species
2	MF5, 7 NF19, 24	offshore (close to diffuser), discontinuous band of stations	silt and very fine sand, mean phi 4±1 mud 40%	TOC variable, 0.9±0.8% C/N moderate, 9±3	moderate *Prionospio* (9500) low *Mediomastus* (2800) high *Spio* (3600) high *Aphelochaeta marioni* (5300)
3	MF8, 9, 10, 12, 16, 21, 22	nearshore, parallel to Harbor, all midfield	mostly silt+clay, mean phi 4.9±0.74 mud 47%	TOC high, 1.4±0.31% C/N high, 12	low *Prionospio* (3900) high *Mediomastus* (7800) high *Ninoe nigripes* (5000) high *Monticellina baptisteae* (1500)
4	MF4 NF13, 17, 23	offshore, stations close to diffuser	mostly medium sand, mean phi 2±0.7 mud 10%	TOC low, 0.1±0.1% C/N low, 6±1.5	high *Corophium crassicorne* high *Polygordius* sp. A high Enchytraeidae sp. 1 high *Exogone* spp. high bivalves, including *Cerastoderma*, *Hiatella*, and *Crenella*

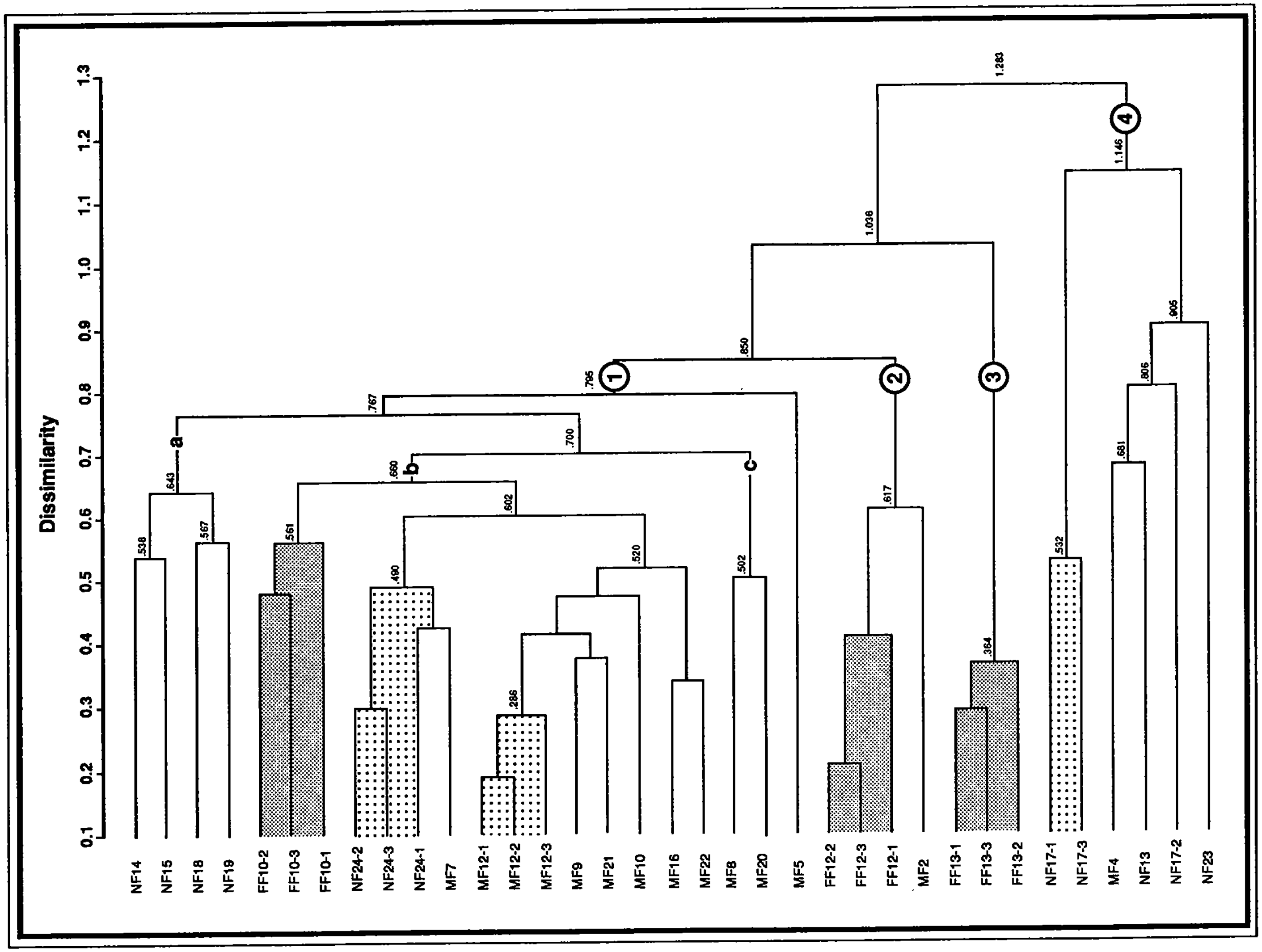

Figure 21. CNESS dissimilarity of nearfield and midfield stations, replicates kept separate (FF10, FF12, FF13 included.)

Table 6. Characterization of nearfield/midfield station clusters generated with the CNESS dissimilarity measure (FF10, FF12, FF13 not included).

Cluster	Stations	Location	Sediment Grain Size (mean phi)	TOC and C/N Ratio	Infaunal Assemblage (individuals /m^2)
1	MF2, 8, 9, 10, 12, 16, 20, 21, 22 NF24	nearly all of midfield and mud patch station in the nearfield	mostly silt+clay; sand 27 to 90% mean phi 4.5±1	TOC high, 1.2±0.5% C/N high, 11±2.7	moderate *Prionospio* (6900) high *Mediomastus* (14,000) high *Ninoe* (4700) also defining assemblage: *Euchone incolor*, *Levinsenia gracilis*, *Monticellina baptisteae*
2	MF7 NF14, 15, 18, 19	band of stations along western nearfield/midfield border	very variable, sand 22 to 87% mean phi 1.9±1.9	TOC moderate, 0.6±0.49% C/N high, 10±3	high *Prionospio* (14,000) moderate *Mediomastus* (3200) moderate *Ninoe* (2100) also defining assemblage: *Dipolydora socialis*, *Exogone verugera*
3	MF4 NF13, 17, 23	offshore, patch of stations close to diffuser	mostly medium sand; sand 90% mean phi 2±0.7	TOC low, 0.1±0.1% C/N low, 6±1.5	high *Corophium crassicorne* high *Exogone hebes* also defining assemblage: *Crenella decussata*, *Hiatella arctica*
outlier	MF5	northernmost station in midfield	very fine sand; sand 63% phi 3.7	TOC low, 0.1% C/N high, 10	moderate *Prionospio* (8000) moderate *Mediomastus* (3100) low *Ninoe* (800) high *Exogone verugera* (2800) high *Aphelochaeta marioni* (5000)

In the second CNESS dendrogram (Figure 21), which includes FF10, FF12 and FF13 as well as individual replicates from the nearfield and other midfield stations, clusters 2, 3 and 4 are identical to the Bray-Curtis clusters 2, 3 and 4, again reflecting the unique faunal assemblage and/or sedimentary regime at those stations. Cluster 1 corresponds to clusters 1 and 2 in the first CNESS dendrogram.

Principal components analysis of metrically scaled CNESS (m=18) distances (PCA-H) was employed to further examine community structure of the nearfield and midfield infauna. Figure 22 shows the position of stations (a) and dominant species (b) in the space defined by the first three axes of the PCA-H analysis. Distances among stations are directly related to similarities in their species composition, with stations close together having similar fauna and stations far apart having dissimilar fauna. Species occupying the extremities of an axis account for the most variation along that axis. Ten species account for 55% of the total variation in community structure as defined by CNESS distances. Table 7 shows the contribution of each of these species to the total CNESS variation and their relative contribution to the variation along the first three axes.

The first three axes represent 67% of the total variation in the community structure defined by the CNESS distances: 46% on axis 1, 11% on axis 2 and 10% on axis 3. Both axes 1 and 2 appear to reflect a sediment grain size gradient, with stations that have predominantly sandy sediment (>90% sand) having low values on axis 1 and stations that have a high percent fine-grained sediment having high values on both axis 1 and 2 (Figure 23). Figure 24 shows the relationship between axes 1 and 2, and percent mud fraction (a) and percent TOC (b). The stations with the highest mud concentrations (most of cluster 1) have the highest values on axis 1. The muddiest stations have the highest TOC concentrations and also occupy the high end of both axes. One anomaly is evident in the sample from MF7 in that it has a higher TOC concentration than its mud fraction would indicate.

The relationship between sediment grain size and axis 1 is reflected in the four species that contribute most to the variation along it, with the sand dwellers *Corophium crassicorne* (18%) and *Exogone hebes* (11%) dominating the stations in cluster 3, and the mud-dwelling polychaetes *Mediomastus californiensis* (10%) and *Ninoe nigripes* (8%) dominating the stations in clusters 1 and 2 (Figure 22b). Stations in clusters 1 and 2 further separate along the second axis. The four species that contribute most to the separation of stations along axis 2 are *Dipolydora socialis* (15%), *Aphelochaeta marioni* (13%), and *Exogone verugera* (12%) with high abundances in stations in cluster 2, and *Monticellina baptisteae* (10%) in high abundance in stations in cluster 1. Axis 3 separates stations within clusters 1 and 2. Three species mainly influence the position of stations along this axis, *Prionospio steenstrupi* (18%) is found in exceptionally high abundances at two stations (MF8 and MF20) in cluster 1 and in all but one station (MF7) in cluster 2, while *Spio limicola* (16%) and *Aphelochaeta marioni* (12%) are found in high abundances at the remaining stations.

Several stations group together the same way with Bray-Curtis as they do with CNESS. Bray-Curtis cluster 3 forms the largest part of CNESS cluster 1, which also includes stations MF2 and 20 (in cluster 1 of Bray-Curtis dendrogram) and NF24 (in cluster 2 of Bray-Curtis dendrogram). The remainders of Bray-Curtis clusters 1 and 2 join together in CNESS cluster 2, with the exception of MF5 which is an outlier with CNESS, most likely because of the abundance of *Exogone verugera* at that station and the overall mixed character of the faunal assemblage.

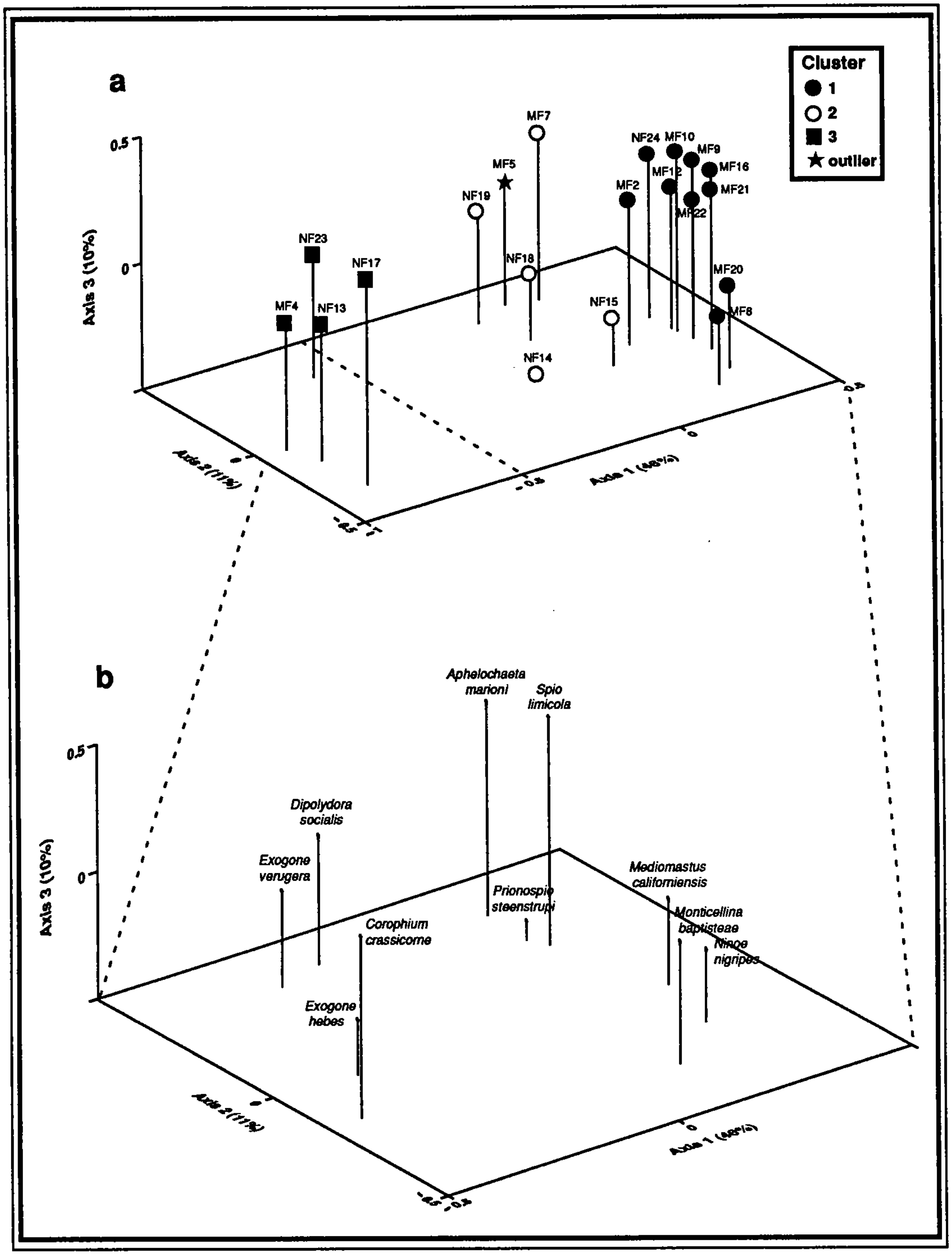

Figure 22. PCA-H analysis of CNESS distances for nearfield and midfield stations (a) and species (b). The first three axes account for 67% of the total variation.

Table 7. Species and their contribution to CNESS distances for nearfield/midfield stations.

Species	% Contribution to Total CNESS distances		% Contribution to Relative (Axes) CNESS distances		
	% Cont.	Cumul. %	Axis 1	Axis 2	Axis 3
Corophium crassicorne	9	9	18	2	5
Exogone hebes	7	16	11	0	8
Mediomastus californiensis	5	21	10	0	3
Ninoe nigripes	5	26	8	4	5
Aphelochaeta marioni	6	32	6	13	12
Dipolydora socialis	4	36	1	15	0
Exogone verugera	4	40	5	12	2
Monticellina baptisteae	3	43	2	10	0
Prionospio steenstrupi	6	49	5	6	18
Spio limicola	6	55	6	4	16

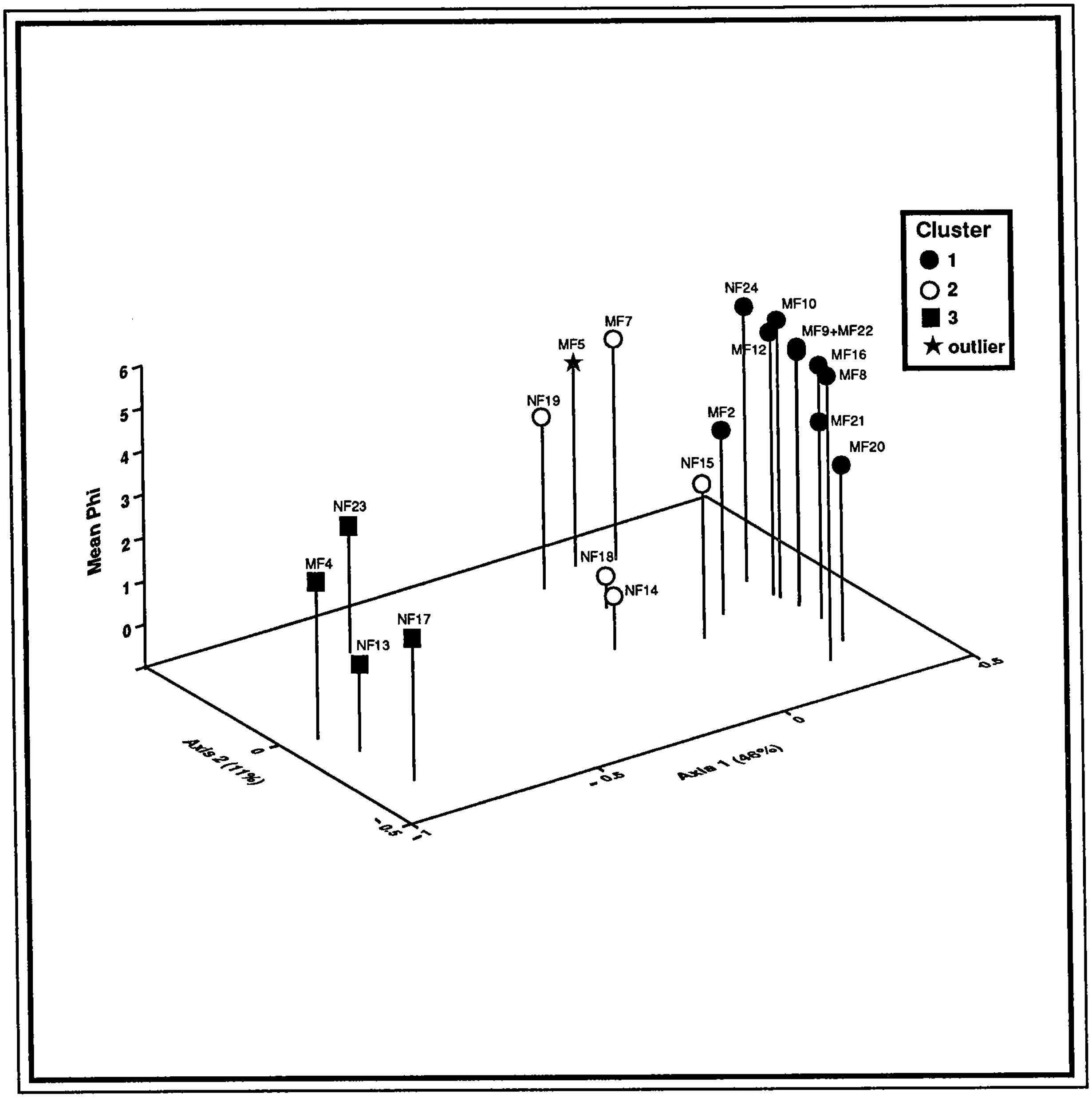

Figure 23. PCA-H analysis axes 1 and 2 vs. mean phi.

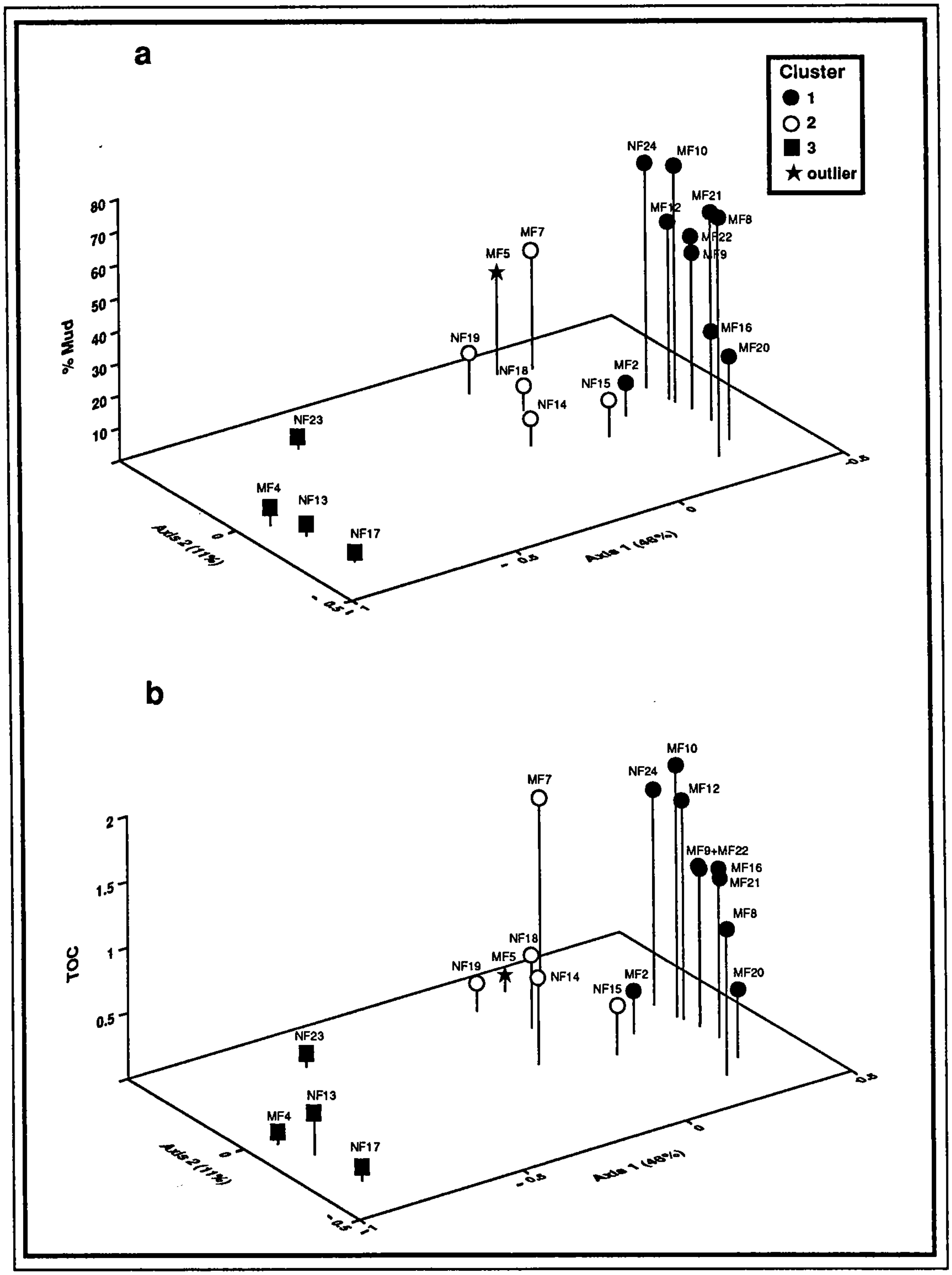

Figure 24. PCA-H analysis axes 1 and 2 vs percent mud (a) and total organic carbon (b).

3.2 Benthic Soft-bottom Communities and Sedimentology, Farfield

3.2.1 Sediment Grain Size
Sediment grain size composition at the farfield stations in Massachusetts Bay and Cape Cod Bay is given in detail in Appendix B4. Although there is a trend towards finer sediments offshore, sediments were very patchy, sometimes showing large differences between replicates taken at a single station. For example, replicate 1 at station FF1A had 79% total sand, while replicate 2 had only 26%. As in 1995, Station FF4 in Stellwagen Basin had the finest sediments, with less than 20% sand.

Other stations exhibited great consistency between replicates and between years. For example, station FF9, which has the sandiest sediments, had 83.9% total sand in 1995 compared to 84.8% and 82.8% sand for 1996 replicates 1 and 2, respectively. Stations FF5, FF11 and FF14 were also similar between replicates and years (except for FF14 rep 1, which differed significantly from the second replicate, see Appendix B4).

Sediments at the Cape Cod Bay stations were much coarser in 1996 than in 1995. Station FF6 had 35-39% sand (compared to 15% in 1995) and a mean phi of 5.5 to 5.6 (compared to 6.3). The other Cape Cod Bay station, FF7, had 17-20% sand (compared to 1.4% in 1995) and a mean phi of 6.0 - 6.2 (compared to 6.7).

3.2.2 Total Organic Carbon and Carbon/Nitrogen Ratio
The total organic carbon (TOC) content of the sediments is clearly related to the sediment grain size composition. The sandiest station FF9 again had the lowest TOC value (0.34%) while stations FF7 (Cape Cod Bay) and FF4 (Stellwagen Basin), which have the finest sediments had the highest TOC values (2.4% and 2.3%, respectively). Ranges and patterns of TOC values were similar to those seen in 1995. The C/N ratios ranged from a low of 8.56 at the Cape Cod Bay station FF7 to a high of 14.3 at FF1A, a nearshore station off Gloucester. The other six stations had values ranging from 8.66 to 10.52. Details of the TOC and TON concentrations at the farfield stations are given in Appendix B5.

3.2.3 Clostridium Spores
Densities of the *Clostridium* spores ranged from a low of 645 colony-forming spores per gram dry weight at station FF5 to a high of 3150 at FF4. There is a suggestion of a trend towards higher densities of *Clostridium* spores with increasingly fine sediments. Station FF4 had the finest sediments as well as the highest TOC values. The second lowest station, FF9, had the highest sand content and the lowest (0.342%) TOC. However, station FF5, with the lowest *Clostridium* count, was intermediate in terms of sediment composition and TOC concentrations compared to other farfield stations. Details of the *Clostridium* spore analysis are given in Appendix B6.

3.2.4 Benthic Infauna

Taxonomic Composition
Figure 25 shows the taxonomic composition of samples taken at the farfield stations. Polychaetes are dominant at all eight stations, with oligochaetes and molluscs also important components of the fauna. Polychaetes comprised between 54 and 85% of the identified fauna, oligochaetes about 4 to 8%, mollusks 6 to 10%, crustaceans generally 1 or 2%, and other taxa such as phoronids and anemones 2 to 10%.

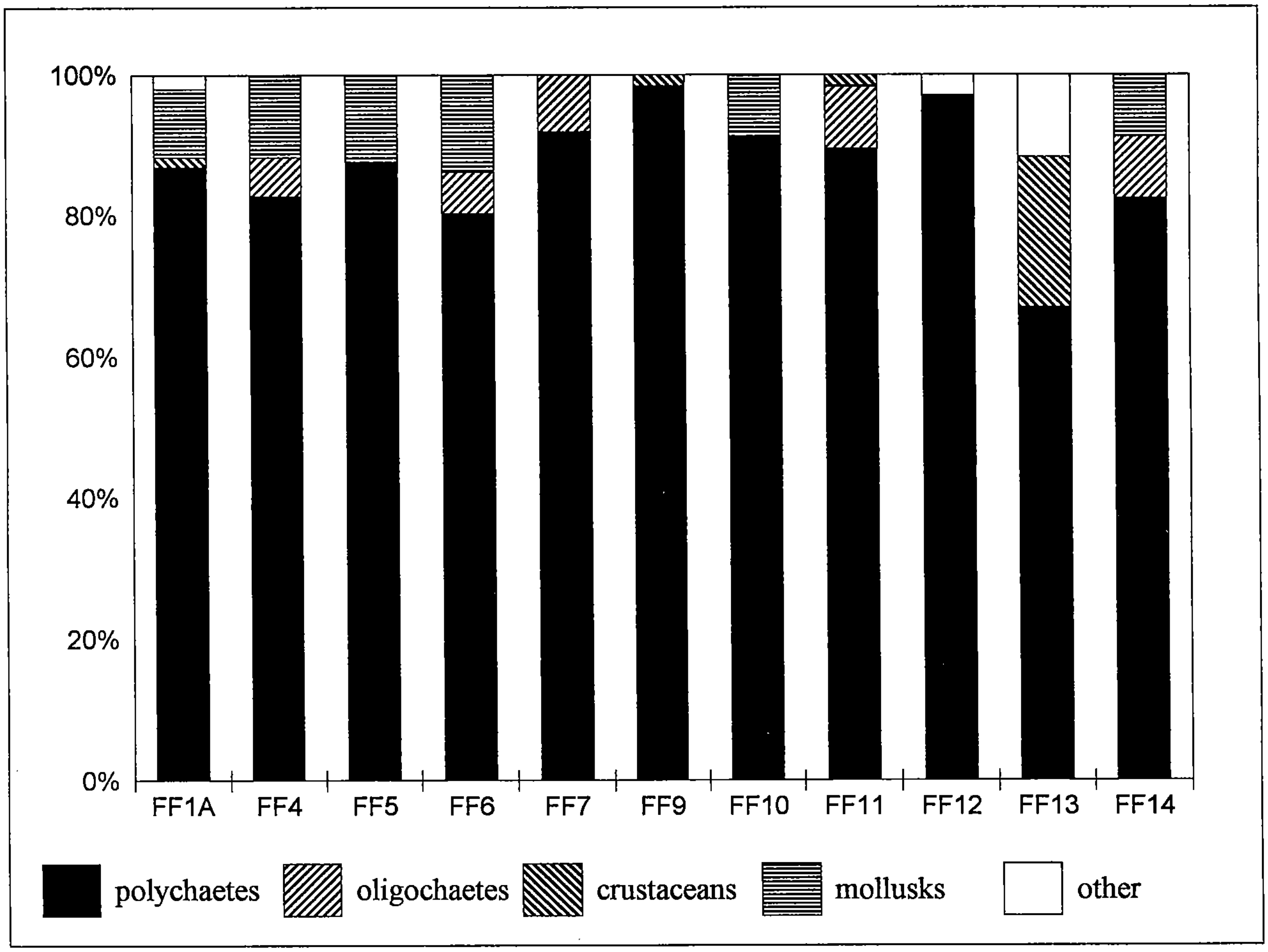

Figure 25. Taxonomic composition of benthic infauna samples taken at farfield stations in August 1996.

Distribution and Density of Dominant Species

The top dominant species at each of the eight farfield stations are presented in Appendix C3. The most common species were the same as in previous years, with *Mediomastus californiensis* present among the dominants throughout the farfield, and ranking among the top five species at all but two stations (FF11 and FF14). *Prionospio steenstrupi* ranked first at all Massachusetts Bay stations, but ranked very low or was absent from the list of dominant species at the two Cape Cod Bay stations. *Spio limicola* was among the dominants at six stations, but did not rank very high in most cases, with the exception of FF9 in western Massachusetts Bay, where it ranked second. Compared to the nearfield and midfield, the dominant species were more consistent from station to station, so that the list of top ten dominants consists of only 35 species, including 22 polychaetes, 2 tubificid oligochaetes, 2 amphipods, 1 isopod, 5 bivalves, 1 gastropod, 1 anemone, and *Phoronis*.

The greatest abundances of spionids were seen at stations hugging the coastline of Massachusetts Bay and at station FF9, which had shown the same affinities with nearshore farfield stations in 1995. In Cape Cod Bay, spionids were much less abundant, and, in contrast to Massachusetts Bay, *Spio limicola* rather than *Prionospio steenstrupi* was the dominant spionid (Figure 26). *Mediomastus californiensis* had very similar distributional patterns in 1995 and 1996, with peak abundances in Cape Cod Bay (FF6 and FF7), while stations farther offshore, including FF9, were characterized by only moderate abundances of capitellids (Figure 27). Cirratulids showed the same trend toward lower abundances offshore, but also a clear shift in species composition (Figure 28). While *Tharyx acutus* was the most common cirratulid at the nearshore stations, *Chaetozone setosa* was most characteristic of the stations farther offshore in Massachusetts Bay.

The distribution of paraonid polychaetes shows a shift in species composition from nearshore to offshore as well (Figure 29). Nearshore stations are clearly marked by a predominance of *Aricidea catherinae* and a smaller percentage of *Levinsenia gracilis*, whereas the offshore stations (FF9 and FF14 in the center of Massachusetts Bay, FF4 and FF5 in Stellwagen Basin, and also FF11 off Cape Ann) show *Aricidea quadrilobata* and a much higher percentage of *L. gracilis*. Stations FF1A (Gloucester) and FF6 and FF7 (Cape Cod Bay) are mixed, with both species of *Aricidea* and varying abundances of *L. gracilis*. The highest abundances of all paraonids combined was observed at station FF11.

Amphipods are of little importance in the farfield in terms of abundances, but are of some interest with regard to species composition. The most abundant amphipod species at nearly all stations in Massachusetts Bay was *Harpinia propinqua* (Figure 30), followed by smaller numbers of *Photis pollex* and several other species. In Cape Cod Bay, the majority of the amphipods belonged to several other species, while *Harpinia* and *Photis* made up a smaller segment of the amphipod fauna.

Bivalves were most abundant at FF1A, a nearshore station with relatively coarse sediment and occurred at roughly similar abundances throughout the remainder of the farfield (Figure 31). *Cerastoderma pinnulatum* and *Nucula delphinodonta* had their main distribution closest to shore, while *Thyasira flexuosa* and *Yoldia sapotilla* tended to occur in highest numbers farther offshore. About half of the bivalves throughout the farfield belonged to a variety of species other than the above four.

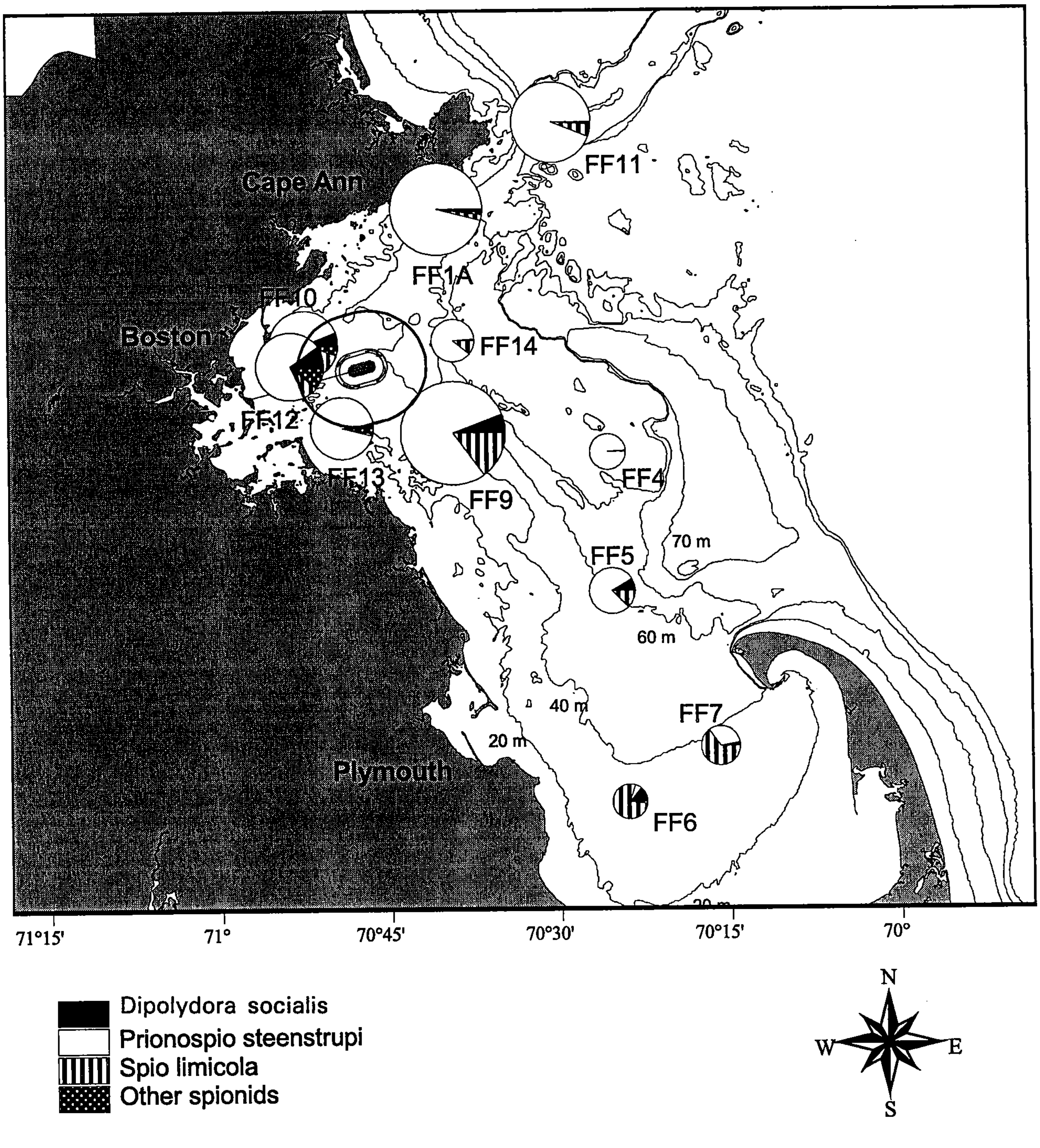

Figure 26. Densities of spionid polychaetes at the farfield stations in August 1996. Diffuser, nearfield and midfield also indicated.

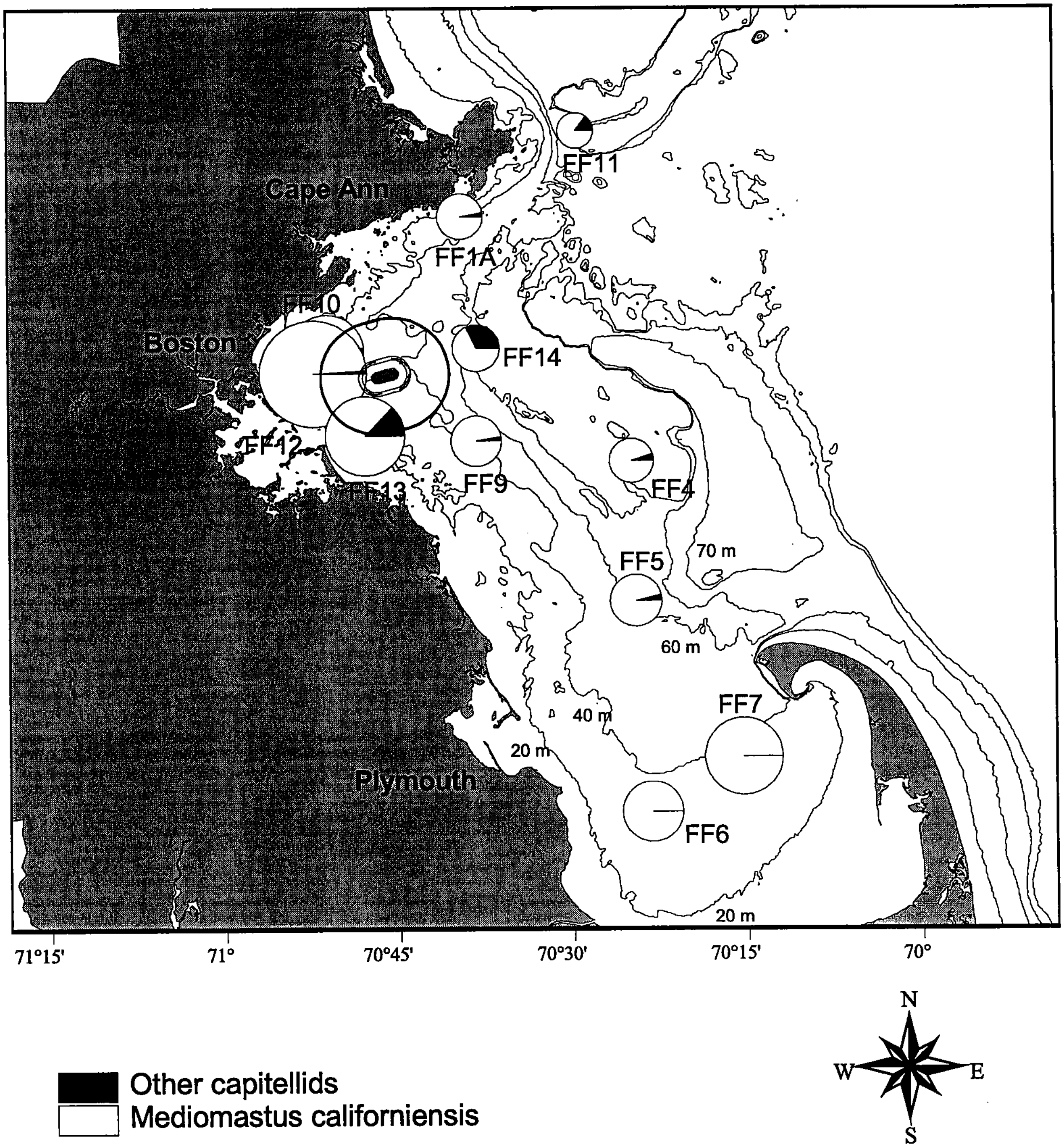

Figure 27. Densities of capitellid polychaetes at the farfield stations in August 1996. Diffuser, nearfield and midfield also indicated.

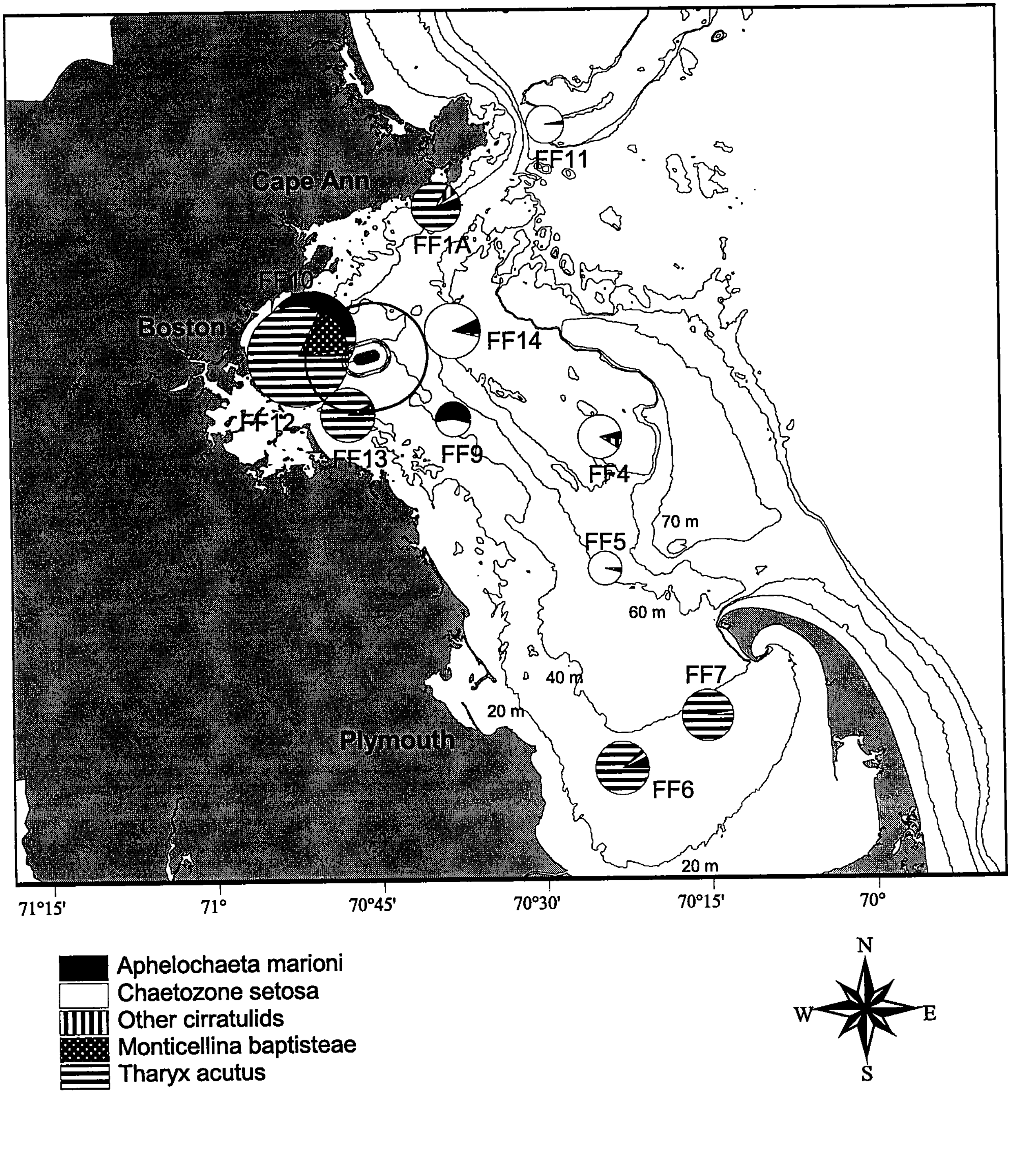

Figure 28. Densities of cirratulid polychaetes at the farfield stations in August 1996. Diffuser, nearfield and midfield also indicated.

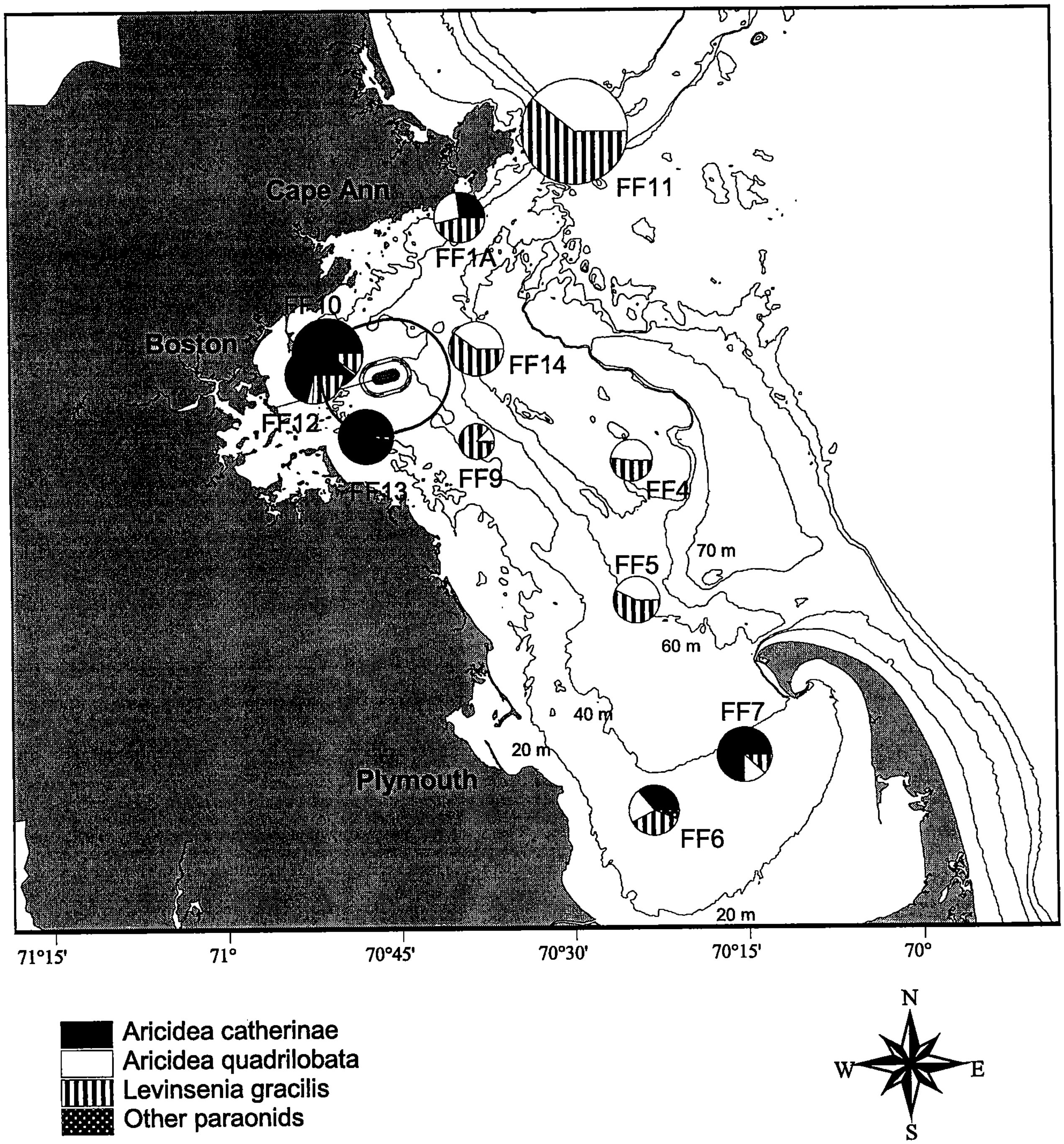

Figure 29. Densities of paraonid polychaetes at the farfield stations in August 1996. Diffuser, nearfield and midfield also indicated.

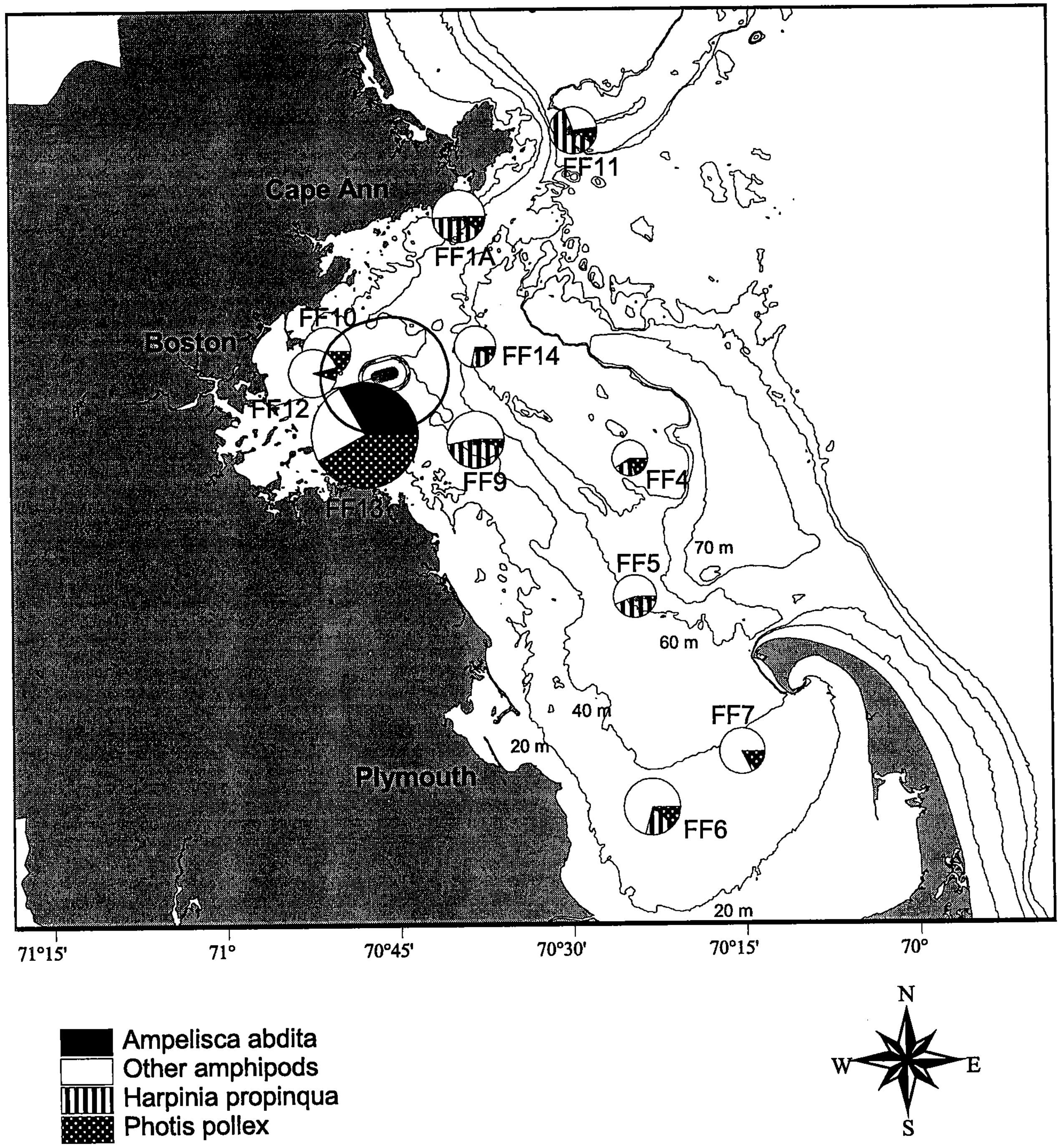

Figure 30. Densities of amphipods at the farfield stations in August 1996. Diffuser, nearfield and midfield also indicated.

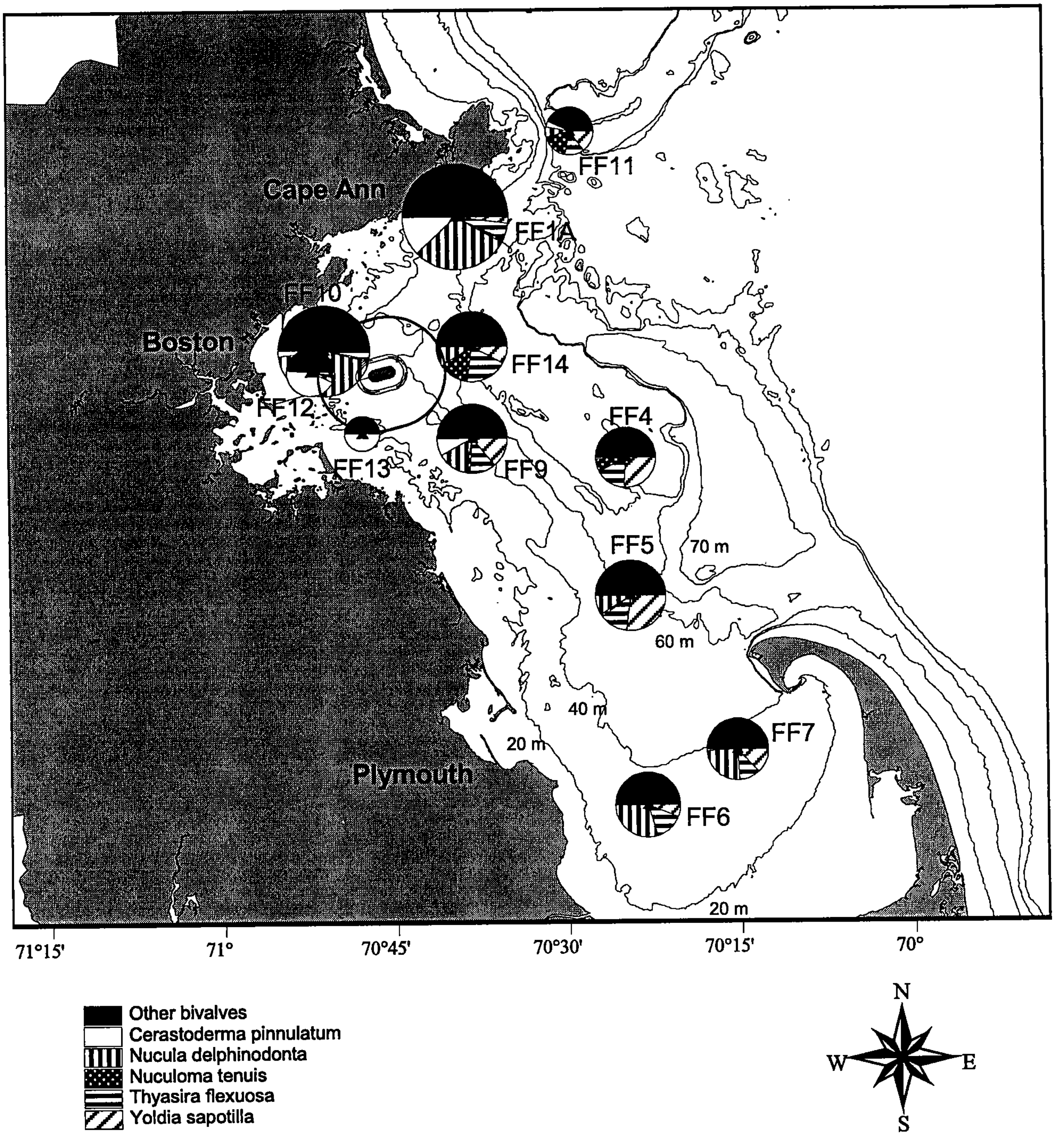

Figure 31. Densities of bivalves at the farfield stations in August 1996. Diffuser, nearfield and midfield also indicated.

Species Richness and Diversity
In general, species richness at the farfield stations was high in 1996, with the number of species identified from the three replicate grabs collected at each station ranging from 69 to 106 (Table 8). The majority of stations (including the six replicated near- and midfield stations MF12, NF17, NF24, FF10, FF12, FF13) had about 80 to 100 species . Generally, the increase in species richness since 1995 was within the range of previous observations, but it may have been in part due to improved identifications of subadult and juvenile mollusks, resulting in 5 to 10 additional species per station. The number of individuals per station varied between nearly 1500 at station FF4 to nearly 9000 at station FF12 in the midfield.

Diversity, expressed as number of expected species per 100 individuals (Hurlbert's rarefaction), was only slightly higher in the farfield than in the nearfield or midfield, ranging from about 18 to 30 (compared to 15 to 31 in the nearfield/midfield) (Figure 32). The highest diversities were found at stations FF5 and FF14. The lowest diversity was seen at station FF11, and was probably the result of the high relative abundance of the top dominant *Prionospio steenstrupi*, which accounted for over 50% of the total fauna. The Shannon-Wiener indices for the farfield stations were very similar to those for the near- and midfield stations, ranging from a low of 2.03 at station FF11 to a high of 3.29 at station FF6 (Table 8). H′ was higher at all farfield stations in 1996 than in 1995.

Community Analysis
Similarity analyses with Bray-Curtis and CNESS produces somewhat different groupings of stations, with the main differences related to stations located in nearshore areas (including the replicated nearfield and midfield stations). However, the underlying pattern of a nearshore/offshore zonation of the fauna emerged with both methods. The Bray-Curtis dendrogram (Figure 33a) shows four clusters and one outlier station; two of the clusters are groups of nearshore stations, one cluster contains offshore Massachusetts Bay stations, and the fourth cluster consists of the two Cape Cod Bay stations. The outlier is station NF17, one of the sandy nearfield stations. Table 9 lists the clusters depicted in Figure 33a, with a definition of each cluster in terms of geographical location, sediment grain size, total organic carbon, and some of the most characteristic faunal elements.

Cluster 1 consists of the nearshore stations north of the midfield area (FF1A and FF11) and FF9, the offshore station that had shown affinities with stations close to shore in 1995 and did so once again in 1996. Sediments were relatively sandy at these stations and had moderately high concentrations of organic carbon; C/N ratios were high, indicating relatively old, broken-down organic material. The infaunal assemblage was characterized by high abundances of *Prionospio*, only moderate abundances of *Spio*, low counts of *Mediomastus*, and high counts of the paraonid polychaete *Levinsenia gracilis*.

Cluster 2, also a nearshore cluster, consists of the midfield stations (MF12, FF10, FF12, FF13) and the mud patch in the nearfield (NF24). The sedimentary parameters were very similar to those of cluster 1, with slightly less sand and a slightly lower C/N ratio (indicative of fresh organic material). The infaunal communities differed from those in cluster 1 in the abundances of spionid and capitellid polychaetes and also in the high abundances of the cirratulid polychaete *Aphelochaeta marioni* and the deposit feeding bivalve *Nucula delphinodonta*.

Table 8. Community parameters for farfield and replicated nearfield/midfield stations.

Station	No. spp. ($0.12 m^2$)	No. indiv. ($0.12 m^2$)	spp./50 ind.	spp./100 ind.	spp./500 ind.	H′	J′
FF1A	97	6415	15.11	23.23	49.77	2.13	0.47
FF4	69	1459	18.52	25.06	47.41	2.98	0.71
FF5	92	2205	21.77	30.82	59.11	3.22	0.71
FF6	84	2972	21.60	30.18	56.63	3.29	0.74
FF7	81	4620	16.63	22.70	42.90	2.70	0.61
FF9	106	7157	13.63	20.73	45.31	2.05	0.44
FF10*	112	6346	21.87	31.01	58.31	3.30	0.70
FF11	79	4965	12.68	18.10	37.36	2.03	0.46
FF12*	90	8923	15.32	21.16	39.96	2.64	0.59
FF13*	71	7029	16.88	22.30	38.66	2.83	0.66
FF14	87	2707	21.89	30.76	56.84	3.26	0.72
MF12	99	6665	16.76	23.19	45.43	2.83	0.61
NF17	100	4364	20.55	29.78	56.06	3.13	0.68
NF24	100	4497	16.74	24.49	49.74	2.72	0.59

*Included in midfield as of 1996.

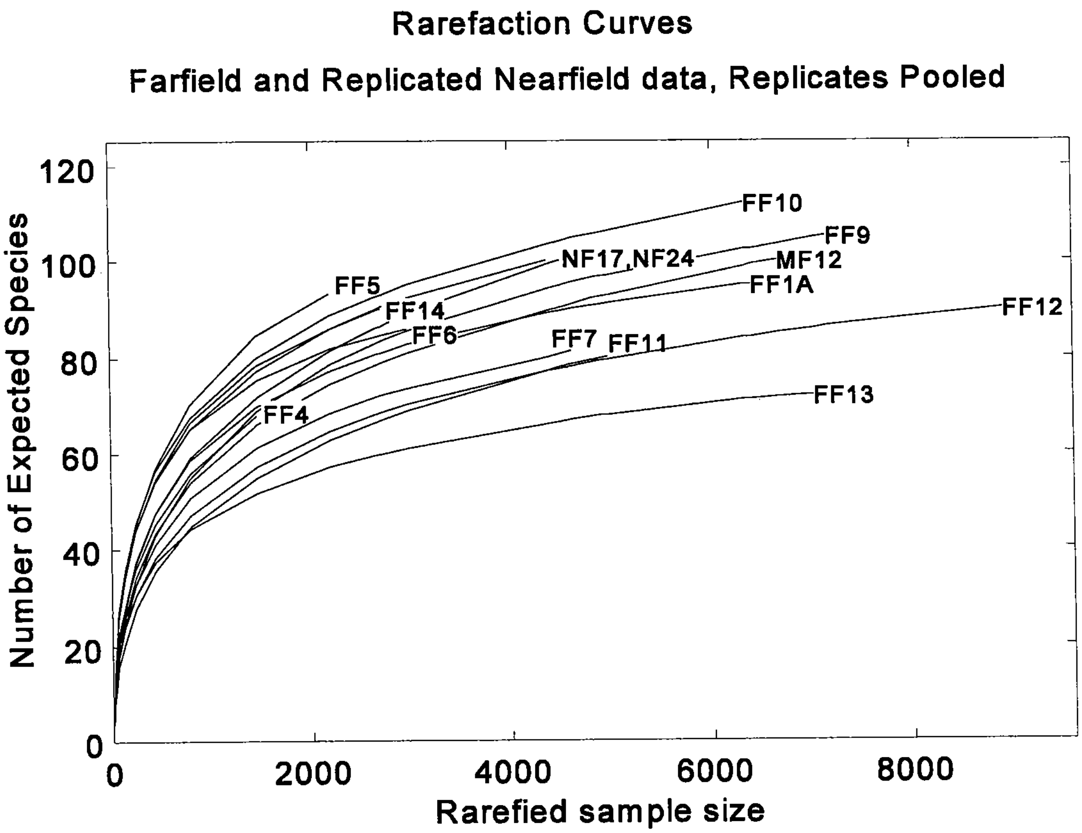

Figure 32. **Rarefaction curves for farfield and replicated nearfield and midfield stations in August 1996.**

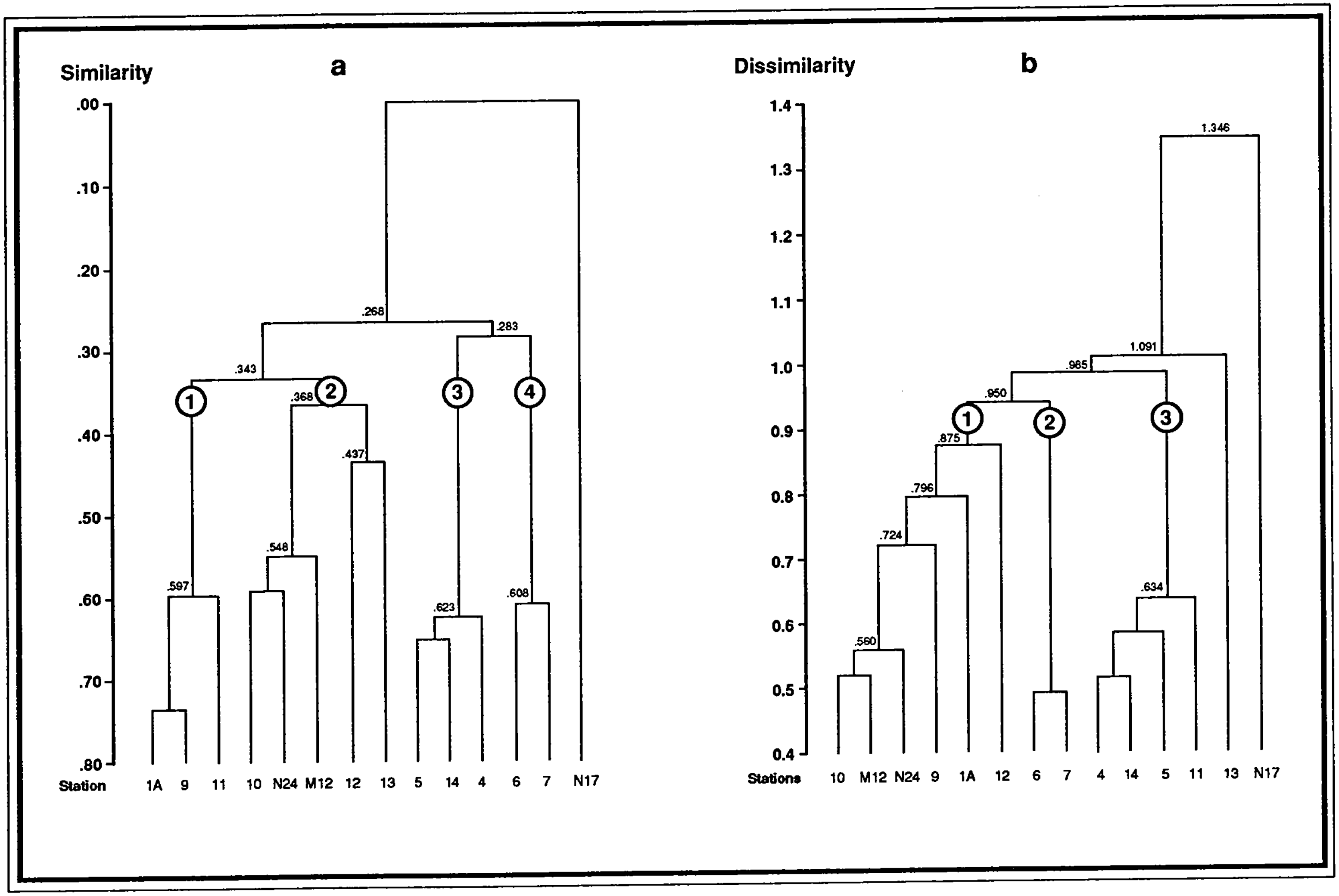

Figure 33. Bray-Curtis similarity (a) and CNESS dissimilarity (b) dendrograms for the farfield and replicated nearfield and midfield stations in August 1996.

Table 9. Characterization of farfield station clusters generated with Bray-Curtis similarity measure.

Cluster	Stations	Location and Depth (m)	Sediment Grain Size (mean phi)	TOC and C/N Ratio	Infaunal Assemblage (ind./m^2)
1	FF1A, 9, 11	nearshore, just outside midfield 56±28.2	mean phi 4.5±1.5 sand 53±30%	TOC moderate, 1±0.9% C/N high, 11.5±2.5	high *Prionospio* (29,000) moderate *Spio* (2800) low *Mediomastus* (1400) high *Levinsenia* (1900)
2	FF10, 12, 13 MF12, NF24	midfield and mudpatch in nearfield 28±7.7	mean phi 4.6±0.7 sand 48±19%	TOC moderate, 1±0.6% C/N moderate, 9±1	moderate *Prionospio* (9900) high *Spio* (4200) high *Mediomastus* (5700) high *Aphelochaeta marioni* (3600) high *Nucula delphinodonta* (1000)
3	FF4, 5, 14	offshore, near Stellwagen Basin 75±13	mean phi 5.7±0.7 sand 24±19%	TOC high, 1.6±0.7% C/N moderate, 9	low *Prionospio* (3400) low *Spio* (400) high *Aricidea quadrilobata* (900) high *Thyasira flexuosa* (600) high *Yoldia sapotilla* (700)
4	FF6, 7	Cape Cod Bay 35	mean phi 5.8 sand 28%	TOC high, 2% C/N moderate, 9	low *Prionospio* (500) high *Spio* (1700) high *Cossura longocirrata* (7600) high Tubificidae sp. 2 (1800) high *Terebellides atlantis* (1500)
outlier	NF17	nearfield 29	mean phi 2.3 sand 98%	TOC low, 0.1% C/N low, 5	high *Polygordius* sp. A (5900) high *Euclymene collaris* (2700) high *Corophium crassicorne* (5800) high *Unciola inermis* (5200)

Cluster 3 includes offshore stations FF4, FF5 and FF14, which are near Stellwagen Basin and have very fine-grained sediments high in organic carbon. Spionid densities were low, but abundances of the paraonid *Aricidea quadrilobata* and the bivalves *Thyasira flexuosa* and *Yoldia sapotilla* were high. Both *A. quadrilobata* and thyasirid bivalves are typical outer shelf and deep-sea animals, and this area may represent the shallow border of their distribution.

Cluster 4 consists of the Cape Cod Bay stations FF6 and FF7, which have sedimentary characteristics very similar to Stellwagen Basin, but have always supported a fauna different from that of Massachusetts Bay. Faunal differences include the presence of *Cossura longocirrata*, the oligochaete Tubificidae sp. 2, and high abundances of the terebellomorph polychaete *Terebellides atlantis*. This species is a large tube-building surface deposit feeder and probably takes advantage of the rich organic carbon source.

The outlier station NF17 differs from all other stations in this analysis because of its exceptionally sandy sediments with very low organic carbon content and a fauna composed of typical sand-dwellers that are rare or entirely absent from the other stations. Among those species are *Euclymene collaris* (a deep-burrowing head-down deposit feeder), the polychaete *Polygordius* sp. A (a typical sand-loving organism in Boston Harbor), and two amphipod species.

The CNESS dissimilarity measure, being less sensitive to highly abundant species, produced only three clusters and two outliers (Figure 33b, Table 10). The clusters were essentially defined by closeness to shore and geography (Cape Cod Bay versus Massachusetts Bay). Cluster 1 is the nearshore group of stations, including FF9, characterized by relatively sandy sediments with moderate organic carbon content, high abundances of spionids and capitellids, typical nearshore polychaetes such as *Tharyx acutus* and *Aricidea catherinae*, and the bivalve *Cerastoderma pinnulatum* which tends to prefer sand over mud.

Cluster 2 is identical to cluster 4 in the Bray-Curtis dendrogram, joining stations FF6 and 7 in Cape Cod Bay because of the unique fauna. In the Bray-Curtis analysis, FF6 and FF7 join offshore stations FF4, FF5, and FF 14 before joining with the nearshore group; with CNESS, FF6 and FF7 join the nearshore group before the offshore group.

The corresponding Massachusetts Bay offshore cluster (cluster 3) is much the same as that in the Bray-Curtis diagram, with the exception that it also includes FF11 (which joins with nearshore stations in the Bray-Curtis analysis). Spionid and capitellid densities were low at these stations, *Aricidea quadrilobata* replaced its congener *A. catherinae*, and the most abundant bivalves were *Thyasira flexuosa* and *Yoldia limulata*. Sediments were fine-grained and high in organic carbon.

One of the outliers, station NF17, is also an outlier with Bray-Curtis; the other outlier is station FF13, located in the midfield just outside the mouth of the Harbor. While Bray-Curtis links that station with the other midfield stations because of similar spionid abundances, CNESS separates it out because the fauna had several elements that are very typical of the Harbor, but not the mid- and nearfield. These Harbor species include *Phoronis architecta*, the polychaetes *Nephtys cornuta* and *Phyllodoce mucosa*, and *Ampelisca abdita*.

Table 10. Characterization of farfield station clusters generated with CNESS dissimilarity measure.

Cluster	Stations	Location and Depth (m)	Sediment Grain Size (mean phi)	TOC and C/N Ratio	Infaunal Assemblage (ind./m²)
1	FF1A, 9, 10, 12 MF12, NF24	nearshore, including midfield and mud patch in nearfield 34±9	mean phi 4.3±0.9 sand 55±22%	TOC moderate, 1±0.6% C/N high, 10±2	high *Prionospio* (16,000) high *Spio* (4700) high *Dipolydora socialis* (1100) high *Mediomastus* (4600) high *Tharyx* (3100) high *Aricidea catherinae* (1800) high *Cerastoderma pinnulatum* (400)
2	FF6, 7	Cape Cod Bay 35	mean phi 5.8 sand 28%	TOC high, 2% C/N moderate, 9	high *Cossura longocirrata* (7600) high Tubificidae sp. 2 (1800) high *Terebellides atlantis* (1500)
3	FF4, 5, 11, 14	offshore, near Stellwagen Basin to off Cape Ann 78±12	mean phi 5.8±0.6 sand 24±15%	TOC high, 1.7±0.6% C/N moderate, 9±0.5	moderate *Prionospio* (8100) low *Spio* and *Dipolydora* low *Mediomastus* (1300) high *Aricidea quadrilobata* (1200) high *Thyasira flexuosa* (500) high *Yoldia limatula* (500)
outlier	FF13	midfield, near southern mouth of Harbor 19	mean phi 4.7 sand 48%	TOC high, 1.5% C/N low, 8	high *Phoronis architecta* (5500) high *Nephtys cornuta* (7900) high *Leitoscoloplos acutus* (2100) high *Phyllodoce mucosa* (1300) high *Photis pollex* (4700) high *Ampelisca abdita* (3700)
outlier	NF17	nearfield 29	mean phi 2.3 sand 98%	TOC low, 0.1% C/N low, 5	high *Polygordius* sp. A (5900) high *Corophium crassicorne* (5800) high *Unciola inermis* (5200)

Principal components analysis of metrically scaled CNESS (m=18) distances (PCA-H) was employed to further examine community structure of the farfield infauna. Figure 34 shows the position of stations (a) and dominant species (b) in the space defined by the first three axes of the PCA-H analysis. The first three axes account for 61% of the variance in the CNESS distances among stations: 25% on axis 1, 21% on axis 2 and 15% on axis 3. Axis 1 clearly reflects the depth gradient between the deeper offshore stations (cluster 3) and the remaining shallower nearshore stations (Figure 35a). Figure 35b is a regression of depth and axis 1 (R^2= .936). The second axis is primarily a reflection of the extreme position occupied by the sandy nearfield outlier station NF17, when compared to the muddier farfield stations. Axis 3 reflects the geographic position of the Cape Cod Bay stations FF6 and FF7 (cluster 2) in relation to the Massachusetts Bay stations (clusters 1 and 3).

Thirteen species account for 51% of the total variation in the infaunal community structure as defined by the CNESS distances (Table 11). Six of these species account for more than half (57%) of the variation on axis 1. *Tharyx acutus* (11%) and *Aricidea catherinae* (5%) inhabit the shallower nearshore stations in clusters 1 and 2, while *Chaetozone setosa* (11%), *Levinsenia gracilis* (11%), *Aricidea quadrilobata* (10%), and *Tubificoides apectinatus* (9%) inhabit the deeper offshore stations in cluster 3. Five species account for 48% of the variance of stations on the second axis, with *Corophium crassicorne* (10%), *Polygordius* sp. A (10%) and *Unciola inermis* (9%) being characteristic inhabitants of the sandy sediments of the outlier station NF17, and *Spio limicola* (12%) and *Mediomastus californiensis* (7%) being characteristic inhabitants of the shallow and intermediate depth, muddy stations in clusters 1 and 2. Two species account for 51% of the variance of stations on the third axis, with *Prionospio steenstrupi* (26%) being the most abundant species in the Massachusetts Bay stations and *Cossura longocirrata* (25%) being abundant only at the Cape Cod Bay stations (cluster 2).

Overall, the array of species separating the station clusters in the farfield is very similar to 1995, and as in 1995, depth and geographic location seem to be the most important factors in the farfield, in contrast to the nearfield/midfield where grain size and associated sedimentary parameters strongly influence infaunal patterns. The overwhelming influence of the outlier station NF17 on axis 2 obscures any other underlying patterns along that axis, and in future analyses should probably be excluded. Similar to the previous year, there are two spionid-dominated Massachusetts Bay assemblages (mid/nearfield and offshore farfield) and a Cape Cod Bay assemblage characterized by *Cossura longocirrata*, the trichobranchid polychaete *Terebellides atlantis*, and the oligochaete Tubificidae sp. 2.

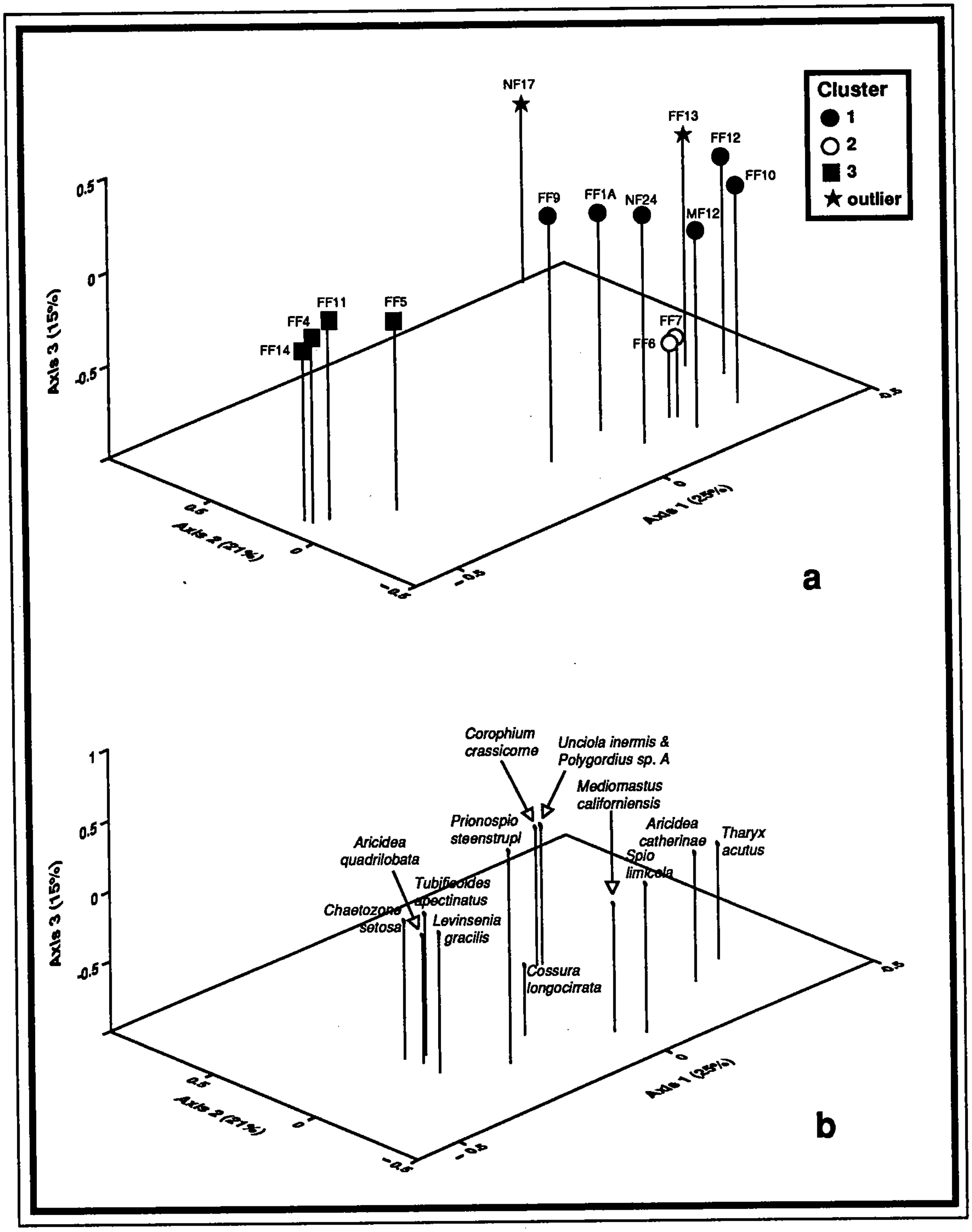

Figure 34. PCA-H analysis of CNESS distances for farfield stations (a) and dominant species (b). The first three axes account for 61% of the total variation.

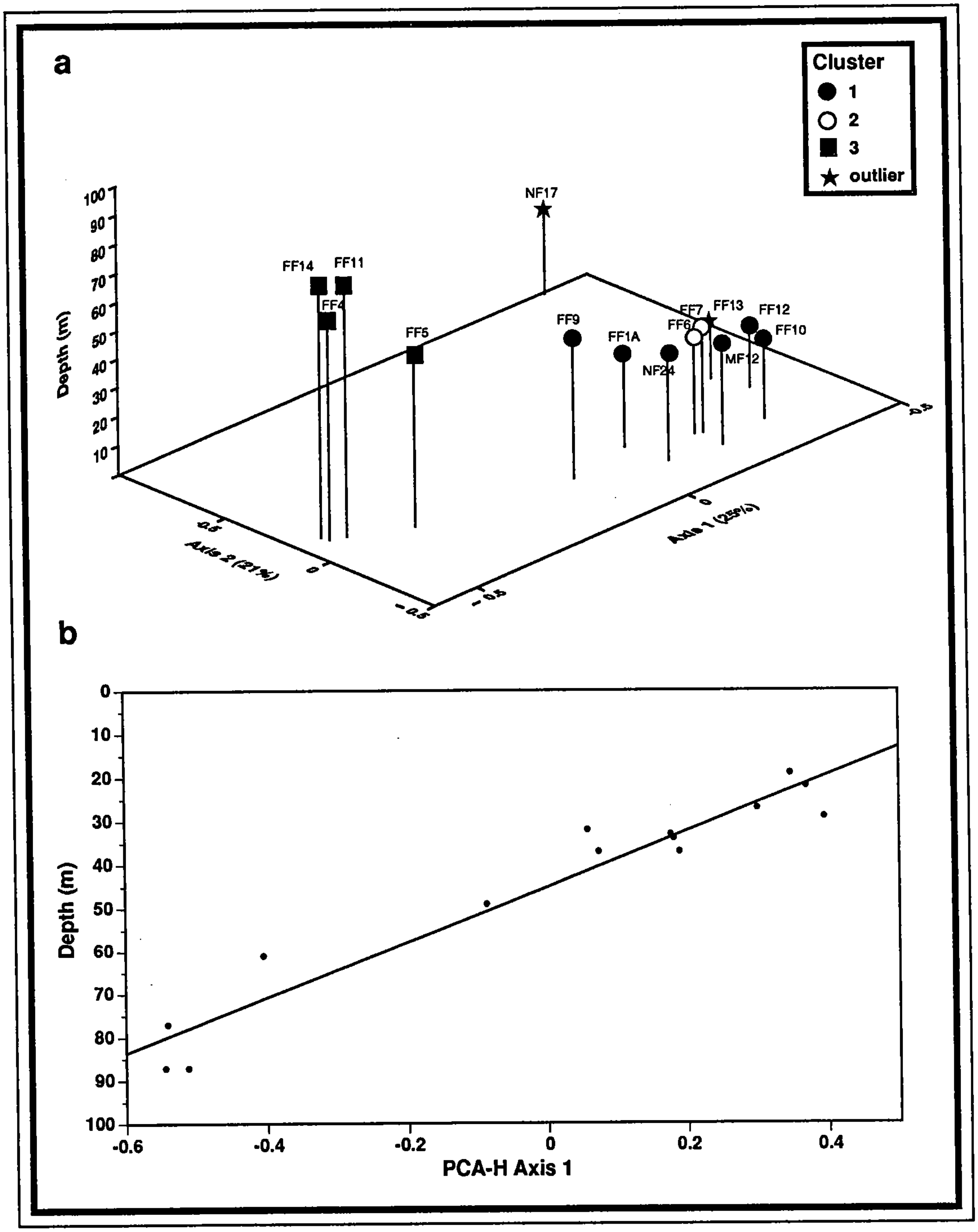

Figure 35. PCA-H analysis axes 1 and 2 vs. depth (a) and the regression of depth vs. axis 1(b).

Table 11. Species and their contribution to CNESS distances, farfield stations.

Species	% Contribution to Total CNESS distances		% Contribution to Relative (Axes) CNESS distances		
	% Cont.	Cumul. %	Axis 1	Axis 2	Axis 3
Tharyx acutus	5	5	11	1	3
Chaetozone setosa	4	9	11	1	0
Levinsenia gracilis	3	12	11	0	0
Aricidea quadrilobata	3	15	10	0	1
Tubificoides apectinatus	4	19	9	1	0
Aricidea catherinae	3	22	5	3	1
Spio limicola	6	28	0	12	0
Corophium crassicorne	3	31	1	10	0
Polygordius sp. A	3	34	1	10	0
Unciola inermis	3	37	1	9	0
Mediomastus californiensis	2	39	0	7	1
Prionospio steenstrupi	7	46	5	3	26
Cossura longocirrata	5	51	1	0	25

3.3 Nearfield Hard-bottom Communities

Still photographs were obtained at 18 of the 20 waypoints. Of 565 photographs taken during the survey, 525 were clear enough to provide data suitable for analysis. The number of usable photographs per waypoint ranged from a low of 21 to a high of 35. Two hundred and seventy nine of the photographs were taken on the tops of drumlins, 218 were taken on the flanks, and the remaining 28 were taken at the eastern-most end of the diffuser.

Video tape coverage was obtained at each of the 20 waypoints. A total of 441 minutes of tape was analyzed: 248 minutes from drumlin tops, 173 minutes from drumlin flanks, and 20 minutes in the vicinity of and on the diffuser head.

Habitat characterizations and dominant taxa determined separately from the video images and still photographs were very similar, indicating that the still photographs were representative of the areas surveyed. Differences between the two types of images were usually related to the higher occurrences of sparsely distributed larger taxa observed in the greater geographic coverage afforded by the video tapes, and the higher occurrences of encrusting taxa afforded by the superior resolution of the still photographs.

3.3.1 Distribution of Habitat Types

The sea floor on the drumlin tops generally consisted of a mix of glacial erratics in the boulder and cobble size category. Most of the drumlin top areas surveyed had moderate to high-relief with numerous boulders. A notable exception to this was the reference site southwest of the outfall (T8), which consisted of a low-relief cobble pavement. The sediment drape on the tops of drumlins generally ranged from none to moderate, but was usually light. The sea floor on the flanks of drumlins generally consisted of a cobble pavement with occasional boulders and gravel patches. Sea floor relief on the flanks ranged from low to moderate, but tended towards low. Sediment drape on the flanks of the drumlins ranged from a light dusting to a heavy mat-like cover, but most areas had a moderate to heavy drape. The sea floor in the vicinity of the diffuser head consisted of a pile of angular rocks in the large cobble size category. Sediment drape in this area was light.

3.3.2 Distribution and Abundance of Epibenthic Flora and Fauna

A total of 72 taxa were seen on the visuals from this survey (Table 12). The 31 taxa that were identified only from the still photographs were mostly encrusting forms that would be impossible to discern consistently on the video images. The three taxa observed only on the video tapes were quite rare and only seen once or twice during the entire survey.

Table 12. List of taxa observed during the 1996 hard-bottom survey.

	Taxon	Common Name
	Algae	
	Lithothamnion spp.	coralline algae
	Asparagopsis hamifera	filamentous red algae
	Rhodymenia palmata	dulse
	Agarum cribrosum	shotgun kelp
	Fauna	
	Sponges	
	sponge	
**	*Aplysilla sulfurea*	sponge (yellow encrust)
	Halichondria panicea	crumb-of-bread sponge
	Haliclona spp.	finger sponge
	Phakellia spp.	chalice sponge
	Suberites spp	fig sponge (cream, globular)
	white divided	sponge on brachiopod
**	orange/tan encrusting	
**	orange encrusting	
**	orange lumpy	
**	gold encrusting	
**	tan encrusting	
**	dark red/brown encrusting	
**	white translucent	
**	cream encrusting	
	Encrusting organisms	
**	general encrusting	
**	white translucent crust	
**	white crust	
**	red/orange crust	
**	dark tan translucent crust	
	Coelenterates	
	hydroid	
	Campanularia sp.	hydroid
	Obelia geniculata	hydroid
	anemone	
	Fagesia lineata	lined anemone
	Metridium senile	frilly anemone
	Urticina felina	northern red anemone
	Cerianthus borealis	northern cerianthid
	Gersemia rubiformis	red soft coral
	Mollusks	
**	gastropod	
	Tonicella marmorea	mottled red chiton
**	*Crepidula plana*	flat slipper limpet
**	*Notoacmaea testudinalis*	tortoiseshell limpet
	Buccinum undatum	waved whelk
*	*Busycon canaliculatum*	channeled whelk
**	*Ilyanassa trivittata*	dog whelk
	Neptunea decemcostata	ten-ridged whelk
**	nudibranch	
**	bivalve	
	Modiolus modiolus	horse mussel
	Placopecten magellanicus	sea scallop
**	*Arctica islandica*	quahog
	Crustaceans	
	Balanus spp.	acorn barnacle
	Homarus americanus	lobster
	Cancer spp.	Jonah or rock crab
	Echinoderms	
	Strongylocentrotus droebachiensis	green sea urchin
	starfish	
	small white starfish	juvenile *Asterias*
	Asterias vulgaris	northern sea star
	Henricia sanguinolenta	blood star
	Porania insignis	badge star
	Crossaster papposus	spiny sunstar
*	*Solaster endeca*	smooth sunstar
	Pteraster militaria	winged sea star
**	*Ophiopholis aculeata*	daisy brittle star
	Psolus fabricii	scarlet holothurian
	Tunicates	
**	tunicate	
	Aplidium spp.	sea pork tunicate
	Boltenia ovifera	stalked tunicate
	Ciona intestinalis	sea vase tunicate
**	*Dendrodoa carnea*	drop of blood tunicate
**	*Didemnum albidum*	northern white crust tunicate
**	*Halocynthia pyriformis*	sea peach tunicate
**	white globular tunicate	
**	clear globular tunicate	
	Bryozoans	
**	bryozoans	
**	*?Bugula spp.*	spiral tufted bryozoan
**	*Membranipora* sp.	sea lace bryozoan
	Miscellaneous	
	Myxicola infundibulum	slime worm
	spirorbids	
	serpulids	
**	sabellid	
	Terebratulina septentrionalis	northern lamp shell
	Fish	
	fish	
	Anarhichas lupus	wolffish
	Myoxocephalus spp.	sculpin
	Macrozoarces americanus	ocean pout
	Pleuronectes americanus	winter flounder
	Sebastes faciatus	rosefish
	Tautogolabrus adspersus	cunner
*	*Urophyis* spp.	hake

* seen only on video tape
**identified only on still photographs

A total of 7432 invertebrates and 253 fish were counted on the still photographs (Table 13). An additional 975 algae were counted and 7306 encrusting coralline and filamentous red were also estimated to be present. These two algae, the coralline red alga *Lithothamnion* spp. and a filamentous red alga *Asparagopsis hamifera*, were the most abundant taxa observed, with estimated abundances of 4398 individuals and 2908 individuals, respectively. These estimates should be viewed as being very conservative and many more individuals were probably seen. The six next most abundant organisms were: the horse mussel *Modiolus modiolus* (1520 individuals), the dulse alga *Rhodymenia palmata* (922 individuals), the limpet *Crepidula plana* (911 individuals), small white starfish, which appear to be juvenile *Asterias* (878 individuals), an unidentified orange-tan encrusting sponge (452 individuals), the green sea urchin *Strongylocentrotus droebachiensis* (452 individuals), the sea pork tunicate *Aplidium* spp. (450 individuals), and the blood star *Henricia sanguinolenta* (412 individuals). Other common inhabitants of the drumlins included: barnacles, brachiopods, and a number of sponges and encrusting organisms. The frilled sea anemone *Metridium senile* was the most abundant organism seen at the diffuser head, where a number of individuals had colonized the top surface and ports. The most abundant fish observed in the still photographs was the cunner *Tautogolabrus adspersus* (224 individuals).

Lithothamnion spp. was both the most abundant and the most widely distributed taxa encountered during this survey. Encrusting coralline algae were seen at all waypoints surveyed, ranging from <1 percent cover at the diffuser to 90 percent cover on top of some drumlins. In areas with minimal sediment drape on the rock surfaces, this alga totally dominated the benthic community. In areas with moderate to heavy sediment drape, the percent cover of *Lithothamnion* was substantially less. In high relief areas, *Asparagopsis hamifera* frequently replaced *Lithothamnion* as the dominant inhabitant of the tops of large boulders. This exclusion of *Lithothamnion* by *Asparagopsis* appeared to be related to fine particles being trapped by the holdfasts of the filamentous algae and blanketing the rock surface. In these areas, *Asparagopsis* frequently dominated the tops of large boulders, while *Lithothamnion* dominated on the cobbles and smaller boulders in between. Dulse and shotgun kelp were also frequently observed on the large boulders of the shallowest drumlin tops.

The horse mussel *Modiolus modiolus* was found at all 18 waypoints for which still photographs were obtained. However, it was most abundant on the tops of shallower drumlins, where large numbers were observed nestled among the cobbles and at the bases of boulders. The same distributional pattern was seen for the green urchin *Strongylocentrotus droebachiensis* and juveniles of the starfish *Asterias*. The distribution of *S. droebachiensis* appeared to mirror that of *Lithothamnion* on which it grazes. The juveniles of *Asterias* appeared to prefer the tops of boulders that were also colonized by upright growing algae. The flat slipper limpet *Crepidula plana* was seen at nine of the waypoints, but was found in high abundances at only three of the waypoints. The distribution of *C. plana* may be related to chance colonization events, since their occurrences were very sporadic and they occurred in exceptionally high densities on the sides or undersides of only a few boulders. Encrusting taxa were generally most abundant in areas of moderate to high relief that had minimal sediment drape. This is not surprising since most juveniles of attached taxa require sediment-free surfaces for successful attachment. Clean rock surfaces are also indicative of stronger currents which would provide higher food supplies for suspension-feeding organisms. Also, boulders are more resistant to mechanical disturbance than cobbles, and thus provide a more stable attachment surface.

Table 13. List of taxa seen on the still photographs, arranged in order of abundance.

Algae		General starfish	7
Lithothamnion spp.	4398	*Ophiopholis aculeata*	7
Asparagopsis hamifera	2908	Sabellid polychaete	7
Rhodymenia palmata	922	General anemone	5
Agarum cribosum	53	White globular tunicate	5
Total algae	**8281**	*Cancer* spp.	4
		Pteraster militaria	4
Invertebrates		?*Bugula* spp.	4
Modiolus modiolus	1520	*Phakellia* spp.	3
Crepidula plana	911	*Campanularia* sp.	3
Small white starfish	878	General nudibranch	3
Orange/tan encrusting	452	*Arctica islandica*	3
Strongylocentrotus droebachiensis	452	General tunicate	3
Aplidium spp.	450	*Halocynthia pyriformis*	3
Henricia sanguinolenta	412	*Boltenia ovifera*	3
Balanus spp.	350	Tan encrusting	2
Terebratulina septentrionalis	235	Dark red/brown encrusting	2
Metridium senile	185	*Urticina felina*	2
Dark tan translucent crust	171	General bivalve	2
Asterias vulgaris	160	*Placopecten magellanicus*	2
Didemnum albidum	158	*Porania insignis*	2
Dendrodoa carnea	125	*Crossaster papposus*	2
Orange encrusting	122	*Haliclona* spp.	1
Aplysilla sulfurea	99	*Cerianthus borealis*	1
White divided (sponge?)	78	General gastropod	1
Suberites spp.	64	*Notoacmaea testudinalis*	1
White translucent crust	60	*Buccinum undatum*	1
Tonicella marmorea	57	*Ilyanassa trivittata*	1
White translucent	51	*Neptunea decemcostata*	1
Orange lumpy	35	*Homarus americanus*	1
Clear globular tunicate	34	*Membranipora* sp.	1
Halichondria panicea	32	**Total Invertebrates**	**7432**
General encrusting	30		
White crust	30	**Fish**	
Obelia geniculata	30	*Tautoglabrus adspersus*	224
Psolus fabricii	27	General fish	12
Gersemia rubiformis	20	*Myoxocephalus* spp.	11
Ciona intestinalis	19	*Pleuronectes americanus*	4
Gold encrusting	18	*Macrozoarces fasciatus*	1
Myxicola infundibulum	18	*Sebastes fasciatus*	1
General sponge	14	**Total Fish**	**253**
Fagesia lineata	14		
General bryozoan	14		
Cream encrusting	13		

The fish fauna was totally dominated by the cunner *Tautogolabrus adspersus*, which was observed at all 20 waypoints. This fish was most abundant in the high relief areas on the tops of drumlins, where they tended to congregate around larger boulders. Sculpin, *Myoxocephalus* spp., were observed at 13 of the waypoints and tended to be seen mostly on the tops of drumlins. They were not abundant enough to be able to determine if they have specific substratum preferences.

3.3.3 Community Structure

Classification of the 18 waypoints and 43 taxa (retained for analysis) defined three clusters and one outlier area (Figure 36). The two main clusters are each composed of both drumlin top and flank areas, but subdivisions within the clusters separate the tops from the flanks. The third cluster consists of two waypoints located on the western flank of the drumlin immediately south of the diffuser. The outlier reflects the different habitat provided by the diffuser heads (T2-WP5). The clustering structure appears to be determined by a combination of drumlin topography, depth, and sea-floor relief. Habitat and taxa characteristic of each of the cluster groups are presented in Table 14. Most of the areas in the first two clusters had moderate to high relief with boulders being the dominant size class, while the areas in the third cluster were characterized by a low-relief mix of substratum size classes. Algal and faunal abundances tended to be higher on the tops of drumlins than on the flanks, and the lowest abundances of both were found in the area of the outfall.

Lithothamnion was a common inhabitant of most of the areas in the first three clusters. Differences between the areas in the first two clusters are related to the relative proportion of the two dominant algae, *Lithothamnion* spp. and *Asparagopsis hamifera*. The areas in cluster 1 supported high abundances of both algae, while the areas in cluster 2 supported high abundances of only *Lithothamnion*. The areas in cluster 1 are characterized by high relief, with the tops of large boulders supporting high abundances of *A. hamifera*, and the smaller boulders and cobbles supporting mostly *Lithothamnion*. The filamentous red alga dominated the tops (1b) and flanks (1c) of the drumlins located north of the outfall, while the drumlin top immediately south of the outfall (1a) was dominated by *Lithothamnion*. The drumlin top areas in this cluster supported high abundances of algae (19.6 to 33.2 individuals per slide) and moderate to high abundances of invertebrates (10.5-15.9 and 14.3-25.3 individuals per slide for 1b and 1a respectively). The two flank areas in this cluster (1c) supported moderate abundances of algae (6.4 and 13 individuals per slide) and high abundances of invertebrates (16.9 and 17.1 individuals per slide).

The areas in cluster 2 were characterized by either lesser or more variable relief than the areas in cluster 1. Sediment drape ranged from none to moderate, but tended to be very light. All of the areas in this cluster supported high abundances of *Lithothamnion* and very low abundances of *A. hamifera*. *Lithothamnion* was most abundant (81.7 to 89.7 percent cover) in the drumlin top areas (2a). The sea floor in these areas was characterized by low to moderate relief with little sediment drape. One of the flank areas (T1-WP5) had several boulders that supported dense aggregations of *Crepidula plana*. The areas in this cluster generally supported slightly lower abundances of both algae and invertebrates than the areas in cluster 1.

The two areas in cluster 3 are located on the western flank of the drumlin immediately south of the outfall. The sea floor in these areas consisted of a low relief mix of substratum size classes with a heavy sediment drape. These two areas were quite depauperate in both flora and fauna. The rock rubble at the easternmost end of the outfall was quite depauperate and mainly inhabited by the starfish *Asterias vulgaris*, while the diffuser head supported a lush population of *Metridium senile* (cluster 4).

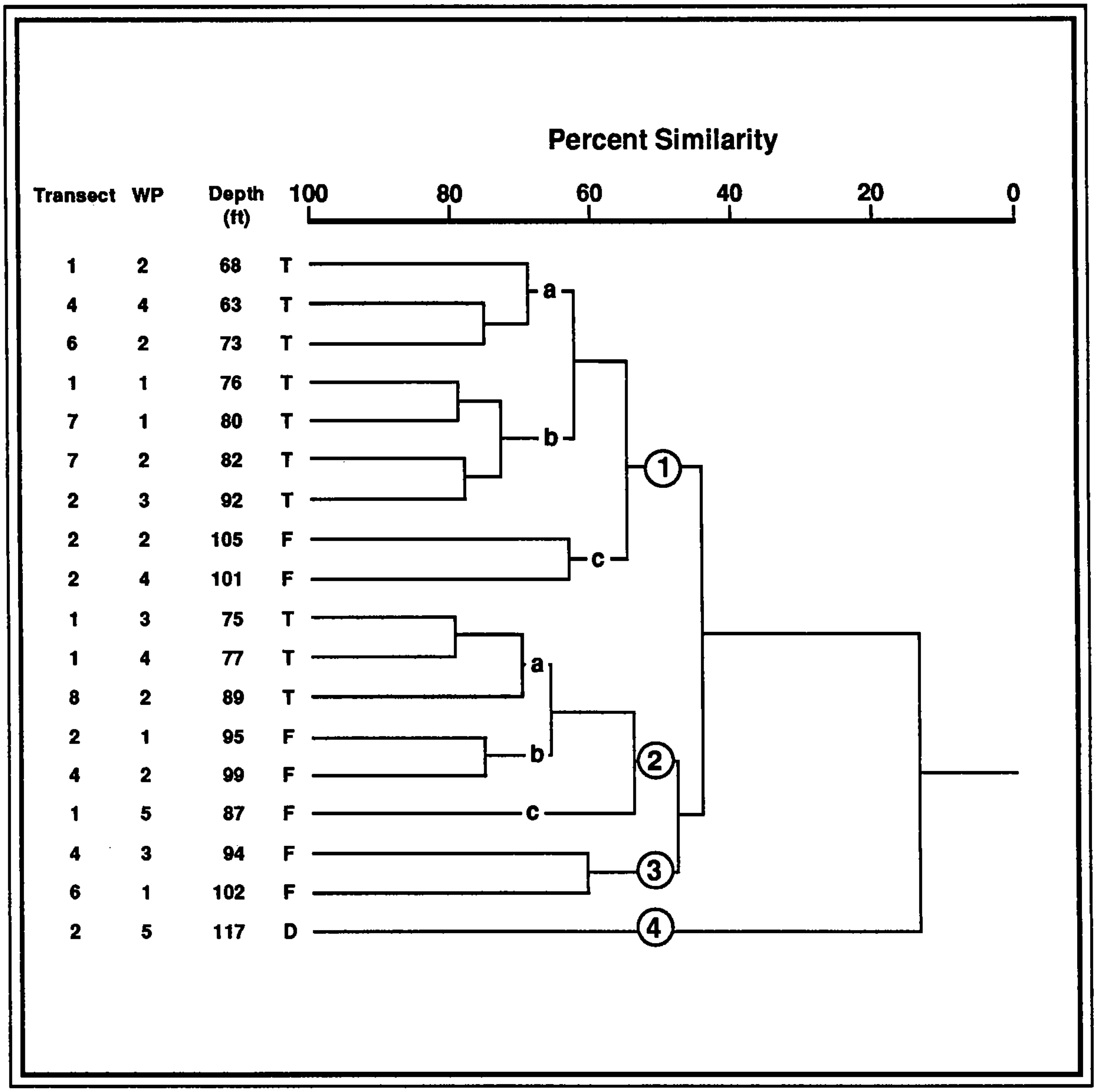

Figure 36. Similarity among waypoints, based on still photographs. WP = waypoint, T = drumlin top, F = flank, D = diffuser.

Table 14. Range of abundance of selected taxa in the clusters defined by classification analysis. Ranges are means of number of individuals per picture.

Cluster	1			2			3	4
	a	b	c	a	b	c		
Transects	1+4+6	1+2+7	2	1+8	2+4	1	4+6	2
Depth (ft)	63-73	76-91	101-105	75-89	95-99	87	94-102	117
Location on drumlin	T	T	F	T	F	F	F	D
Substrate	b+c	b+c	b+c	b+c*+mix	mix	b+c	mix	diffuser
Sediment drape	l*-m	l-m	m*-h	c-l*-m	l-m	l	l-vh*	l-h
Lithothamnion spp. (percent cover)	68.7-72.3	27.4-65.2	5.3-7.0	81.7-89.7	41.3-44.7	68	1.7-11.9	0.1
Lithothamnion spp. (converted)	12.8-13.9	5.5-12.03	1.4-1.6	15.0-17.0	6.6-8.0	13.3	0.8-3.0	0.1
Asparagopsis hamifera	10.0-13.0	16.8-38.5	7.7-17.3	0.0-0.8	0.0-3.1	3.7	-	-
Rhodymenia palmata	0.7-8.9	0.8-5.8	0.1-1.7	-	-	0.1	-	-
Agarum cribosum	0.0-0.3	0.0-0.8	-	-	-	-	-	-
Modiolus modiolus	2.0-6.0	1.4-6.5	0.9-2.1	2.3-9.5	0.8-1.2	3.4	0.1-0.7	-
Crepidula plana	0.0-7.0	0.0-2.4	0.0-1.1	0.0-5.2	0.0-0.3	18.7	-	-
small white starfish (*Asterias* juv.)	1.9-6.0	1.0-2.4	2.4-2.6	0.8-1.1	0.6-1.7	1.0	0.2-0.7	0.2
orange/tan encrusting sponge	0.5-1.7	0.2-1.3	1.7-2.3	0.0-0.3	1.1-1.2	0.7	0.8-1.7	-
Strongylocentrotus droebachiensis	1.4-2.9	0.2-0.7	0.2-0.3	0.8-1.9	0.5-0.8	1.2	0.1-1.1	0.1
Aplidium spp.	0.8-1.5	0.2-1.5	1.2-3.0	0.4-0.6	0.1-0.3	1.2	0.6-0.9	-
Henrecia sanguinolenta	1.4-2.5	0.5-1.0	0.5-0.8	0.2-1.2	0.1-0.3	1.0	0.2-0.7	0.2
Balanus spp.	0.7-1.4	0.1-0.9	0.3-1.1	0.6-0.9	0.9-1.0	0.4	0.3-0.5	-
Terebratulina septentrionalis	0.0-0.3	0.0-3.5	0.0-2.0	-	-	-	-	-
Metridium senile	0.0-0.8	0.0-1.2	0.1-0.3	0.0-0.1	-	-	0.0-0.1	3.6
dark tan encrusting organism	0.0-0.2	0.0-0.4	0.1-0.2	0.2-0.5	0.3-1.7	0.6	0.4-0.5	-
Asterias vulgaris	0.0-0.3	0.0-0.2	0.4	0.0-0.8	0.3-0.8	1.2	0.2-0.4	0.5
Didemnum albidum	0.3-0.5	0.0-0.5	0.4-0.9	0.0-0.5	0.1	0.4	0.0-0.2	-
Dendrodoa carnea	0.2-0.6	0.1-0.6	0.1-0.4	0.1-0.7	0.0-0.4	0.4	0.0-0.1	-
Tautogolabrus adspersus	0.3-0.9	0.1-0.6	0.4-1.2	0.0-0.6	0.1-0.5	0.7	0.1	0.1
Total algae	22.4-28.8	19.6-33.2	6.4-13.0	15.0-17.4	6.6-9.9	15.6	0.8-3.0	0.1
Total invertebrates	14.3-25.3	10.5-15.9	16.9-17.1	6.3-21.8	8.1-9.0	31.0	4.2-8.0	5.0
Total fish	0.5-1.0	0.2-0.6	0.4-1.3	0.0-0.6	0.1-0.5	0.7	0.1-0.2	0.2

* predominant

Table 15 shows habitat characteristics and abundances of selected fauna determined from the video tapes, with the waypoints arranged in order of the clustering determined for the still photographs. In general, the results between the two techniques were quite similar. The role of the two algae, *Lithothamnion* spp. and *Asparagopsis hamifera*, in determining the cluster structure is readily apparent. The encrusting alga *Lithothamnion* was found in reasonably high abundances in most drumlin top areas, while upright algae, *A. hamifera*, *Rhodymenia palmata* and *Agarum cribosum* were mostly restricted to areas of high relief. The tops of drumlins generally supported higher abundances of both invertebrates and fish than the flanks. The horse mussel *Modiolus modiolus*, the green sea urchin *Strongylocentrotus droebachiensis*, the sea-pork tunicate *Aplidium* spp., and the cunner *Tautogolabrus adspersus* were all more abundant on the tops of drumlins. In contrast, the fig sponge *Suberites* spp. was most abundant on the flanks. Numerous individuals of the frilled anemone *Metridium senile* had colonized the easternmost diffuser of the outfall. Its high abundances on the diffuser head are not surprising, since this anemone appears to require high relief in that it is usually restricted to large boulders. The rosefish *Sebastes fasciatus* was only seen in the vicinity of the diffuser.

Table 15. Abundances of selected taxa identified from the video tapes. Waypoints are presented in the order they clustered in the classification analysis of the still photographs.

Cluster	1									2							3			4
	a			b				c		a				b		c				
Transect	1	4	6	1	7	7	2	2	2	1	1	8	8	2	4	1	4	4	6	2
Waypoint	2	4	2	1	1	2	3	2	4	3	4	1	2	1	2	5	3	1	1	5
Useable minutes	22	22	23	26	21	21	22	25	22	22	31	17	21	20	20	22	25	15	24	20
Start depth (ft)	70	63	72	81	75	86	95	102	106	73	71	80	90	96	102	84	94	105	101	117
End depth (ft)	65	65	74	75	78	79	92	108	106	75	73	79	86	94	103	87	95	107	103	116
Location on drumlin	T	T	T	T/F	T	T	T	F	F	T	T	T	T	F	F	F	F	F	F	L (D)
Primary substrate	bc	b	b	bc/cp	b	b	bc	mx	c	b/cgp	cp/b	cp	c	sc	mx	bc	c	cp	cp	sg
Sediment drape	1	c	vl	1	1	1-h	1	h		1	1	1-m	1		1-m	1	m-h	1-m	h	
Lithothamnion spp.	a	va	a (c)	va	a (c)	a	c	r	f	a	va	a	a	a (b)	c	a	f	f	r	-
Asparagopsis hamifera	a	va	va (b)	a (b)	va	va	a	f	a	f	f	-	-	f	-	c	-	-	-	-
Rhodymenia palmata	f	f	c	a (b)	f	c	c	-	c	-	-	-	-	-	-	r	-	-	-	-
Agarum cribrosum	19	6	41	-	42	188	2	-	-	-	-	-	-	-	-	-	-	-	-	-
Strongylocentrotus droebachiensis	68	154	390	3	61	26	22	25	6	101	268	28	94	36	52	163	78	2	-	3
small white starfish	22	74	88	>100	69	46	70	77	55	1	66	12	22	14	3	27	13	8	22	7
Asterias vulgaris	1	6	10	4	5	1	27	19	14	2	98	13	4	29	10	94	1	24	47	70 (15)
Henricia sanguinolenta	4	12	15	12	12	23	22	13	4	-	7	2	10	1	1	11	51	1	10	4 (4)
Modiolus modiolus	26	259	119	-	248	182	21	17	-	>100	>100	14	176	-	8	66	17	1	1	-
Suberites spp.	-	-	-	1	-	1	37	82	130	-	-	-	2	2	21	-	10	-	-	-
Metridium senile	1	17	29	3	2	23	74	5	36	9	9	-	-	-	2	-	5	-	-	147 (143)
Aplidium spp.	>100	-	-	>100	-	-	-	>100	-	-	-	-	-	-	-	-	-	-	-	-
Halichondria panicea	3	13	2	-	1	2	1	1	-	1	-	-	3	1	-	1	4	-	-	-
white divided sponge	-	-	-	-	-	-	42	-	3	-	-	-	-	-	-	-	-	-	-	-
Obelia geniculata	10	2	11	-	9	84	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cerianthus borealis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	3	-	40	2	1
Gersemia rubiformis	7	-	-	-	-	-	-	3	-	1	1	-	-	-	-	-	-	-	-	-
Placopecten magellanicus	-	-	-	-	-	-	-	5	-	-	-	-	-	-	4	1	-	12	5	1
Balanus spp.	5	16	21	-	20	4	5	9	6	5	13	10	12	22	62	11	17	9	15	4
Homarus americanus	-	-	-	-	-	-	1	-	-	1	-	-	3	-	1	-	-	-	-	-
Cancer spp.	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	4	1
Psolus fabricii	6	7	10	1	-	-	-	4	1	9	3	-	8	-	1	12	3	-	-	-
Tautogolabrus adspersus	110	121	82	110	245	129	135	34	135	32	160	1	6	84	30	58	11	8	15	57
Myoxocephalus spp.	3	1	-	1	-	1	-	1	1	3	2	-	3	1	1	-	2	-	4	-
Pleuronectes americanus	1	2	-	-	-	2	1	-	4	1	1	-	1	6	-	-	-	5	1	-
Sebastes fasciatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10 (8)

4.0 DISCUSSION

4.1 Overview

Baseline monitoring of the soft-bottom benthic communities began in 1992 and will continue until outfall discharge begins, thus providing a substantial database from which to characterize the dynamics of the physical environment and patterns of change in the benthic communities. Information content has been improved since 1992, including taxonomic identification of the species comprising the benthic communities. Juveniles of several polychaete and mollusc species can be identified, thus providing both a greater understanding of the species richness of the fauna and of the biological events contributing to the apparent dominance of a particular species. It will be important for the same level of discrimination to be maintained in the future in order to preclude misinterpretation of apparent changes in the benthic communities.

In addition, surveys with the sediment profile image (SPI) camera were conducted in 1992 and 1995, and will be routine from 1997 forward; these surveys, coupled with determination of sediment phi classes instead of simple sand-silt-clay percentages, have provided a finer scale of understanding of the sedimentary environment, which, in the immediate vicinity of the outfall, has been shown to be complex both physically and biologically. The diffuser or terminus of the outfall is situated in a hard-bottom environment that consists of drumlins alternating with swales or hollows. Much of the area immediately adjacent to the diffuser is a rocky habitat where pockets of sediment or depositional areas are rare. The soft-bottom study area lies mostly to the west of the diffuser, and grades westerly from sediments consisting primarily of sand to a finer-grained depositional area.

The MWRA is considering several hypotheses as a means to assess the impacts of sewage discharge in Massachusetts Bay. These hypotheses include:

1: *The diversity of the nearfield benthic community at muddy stations (>70% fine-grained sediments) within the nearfield area will not decrease to one-half the baseline diversity.*

2: *The diversity of the nearfield benthic community at stations with primarily coarse-grained sediments will not decrease to one-half the baseline diversity.*

3: *The diversity of the benthic community outside of the area of predicted impact will not show a statistically significant downward trend relative to the baseline for any three-consecutive-year period.*

4: *The composition of the soft-bottom benthic community outside of the SEIS predicted area of impact will not change to one typical of a degraded benthic community.*

Alternate: *The species composition and relative abundance patterns of communities at stable midfield soft-bottom sites will not significantly depart from those measured during the baseline monitoring period.*

5: T*he depth of oxygenated sediment (Redox potential discontinuity) in the nearfield area will not decrease to one-half the depth measured during the baseline monitoring period.*

Summary averages of the 1992-1996 baseline nearfield and midfield benthic parameters (density, number of species, and diversity) are presented in section 4.3, representing an initial effort to provide parameters against which post-discharge results can be tested for hypotheses 1-3. Tests for hypothesis 4 and the alternate hypothesis may require development of an index which is being considered separately. Hypothesis 5 will be considered after the results of the 1997 SPI survey are available.

4.2 Spatial and Temporal Trends in Sediment Texture, TOC, and *Clostridium*

SPI surveys in 1992 and 1995 defined clear kinetic boundaries between sedimentary regimes in the nearfield and midfield and indicated that sediment movement and deposition are dynamic processes throughout much of the nearfield study area (Hilbig *et al.*, 1996). Because of these shifts in sediment cover, the benthic faunal assemblages are not entirely consistent from year to year and some stations exhibit wide swings in dominance of benthic species. For example, sand overlying mud was clearly evident at several stations in the 1995 survey, implying that finer sediments were available to normally sandy stations in 1994, thus accounting to some degree for the faunal differences in that year.

The sediment texture at the nearfield and midfield stations has exhibited great consistency at some stations and a patchy and therefore somewhat inconsistent nature at others. In general, sediments were slightly coarser in 1996 compared to 1995. Stations in the nearfield (within 2 km of the outfall) are usually coarser-grained than those in the midfield (2-7 km from the outfall) (Figures 37 and 38). Station NF17 has been one of the most consistent over time in terms of sediment texture (Figure 39); this station is also one of the sandiest, comprising 98% total sand each year. Stations NF13, NF14, NF18 showed significantly higher amounts of gravel in 1996 compared to 1995. For stations NF13 and NF14, this was the highest amount of gravel recorded at those stations, whereas for NF18, these results were similar to those seen in 1992. Station NF24, sometimes referred to as a "mud patch" station, had far less clay and more sand in 1996 than in 1995, making it similar in texture to that recorded in 1994.

The midfield stations, while generally finer-grained, also showed varying degrees of stability or change compared to 1995. Sediment texture at the sandy stations MF2, MF4, MF5, MF9 and MF20 was consistent with 1995 results. Stations MF2 and MF4 in particular have been very consistent over the 1993-1996 time period, but very different from the initial sediment texture recorded in 1992. Silty stations MF8, MF12, MF21 and MF22 were either similar to last year or had slight increases in the sand and/or gravel fractions. Stations FF10, FF12, and FF13 have all been fairly consistent over time; of these three stations, FF13 has been the most variable, with much less gravel in 1993-1996 compared to 1992 (Figure 40 and 41).

For the period 1992-1996, stations FF5, FF9, and FF14 were the most consistent of the six farfield Massachusetts Bay stations (Figures 40 and 41); the first two stations being very sandy and the third very fine-grained. The other three farfield stations were either slightly sandier (FF4), slightly less sandy (FF1A), or the same (FF11) compared to 1995. The two Cape Cod Bay stations (Figure 40 and 41) were somewhat sandier in 1996 compared to 1995, but 1995 appears to be the exceptional year in having reduced amounts of sand at those two stations.

The shift from fine to coarse sediments at station MF2 resulted in significantly lower concentrations of total organic carbon (TOC) and *Clostridium* spore counts after 1992 (Figures 42 and 43). At Station NF24, the highest levels of TOC and *Clostridium* spores were seen in 1995, corresponding to the year with the highest percentage of silt+clay. At other stations, there is no clear relationship between TOC or *Clostridium* and corresponding sediment texture. For example, stations MF16 and MF20 did not exhibit the same trend of significantly reduced TOC and *Clostridium* as seen at station MF2, even though the changes in sediment texture were similar at those stations. The coarse-grained nearfield stations generally have low levels of both TOC and *Clostridium.*

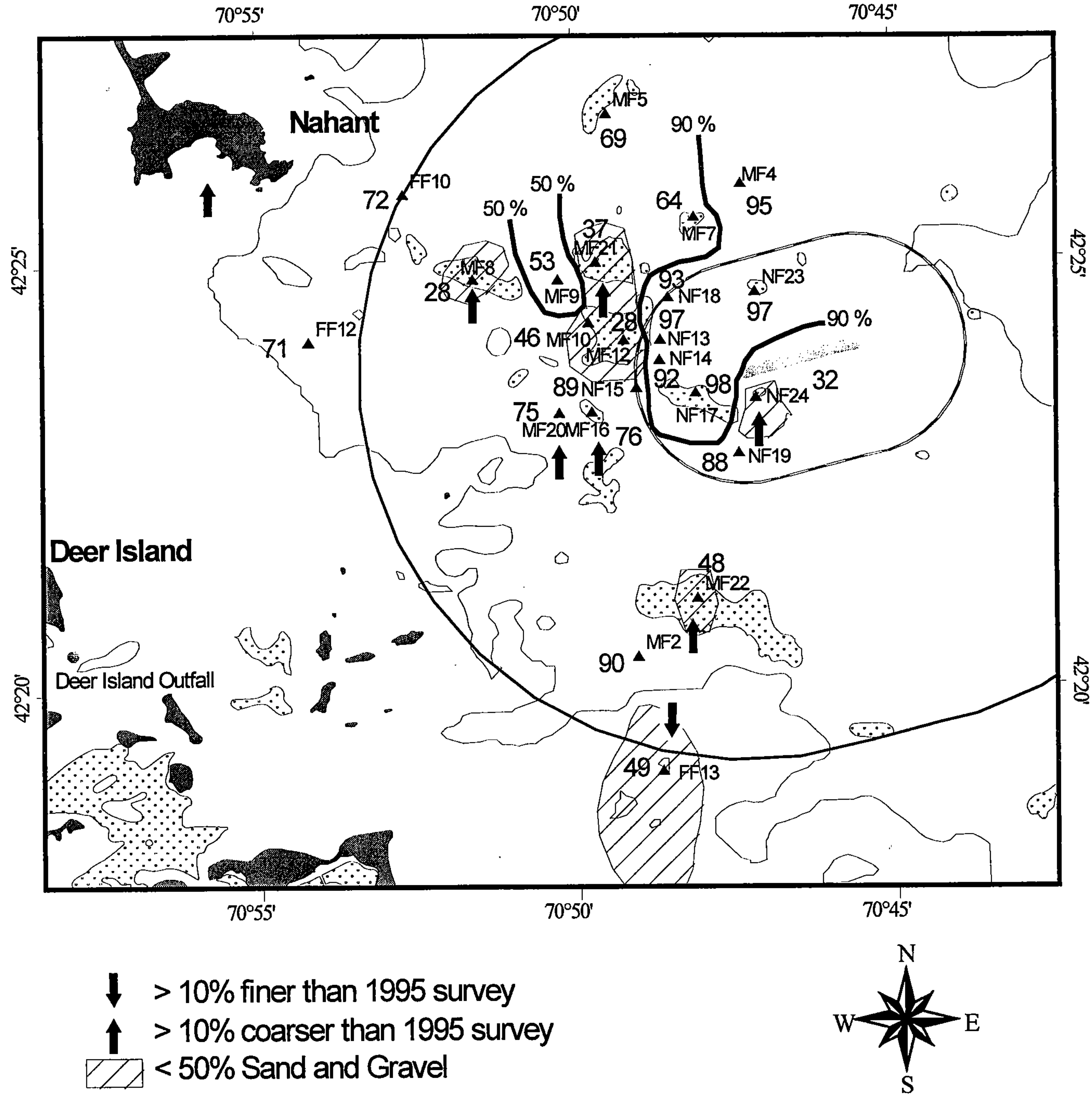

Figure 37. Percent sand and gravel at nearfield and midfield stations in August 1996. Changes relative to August 1995 indicated by arrows.

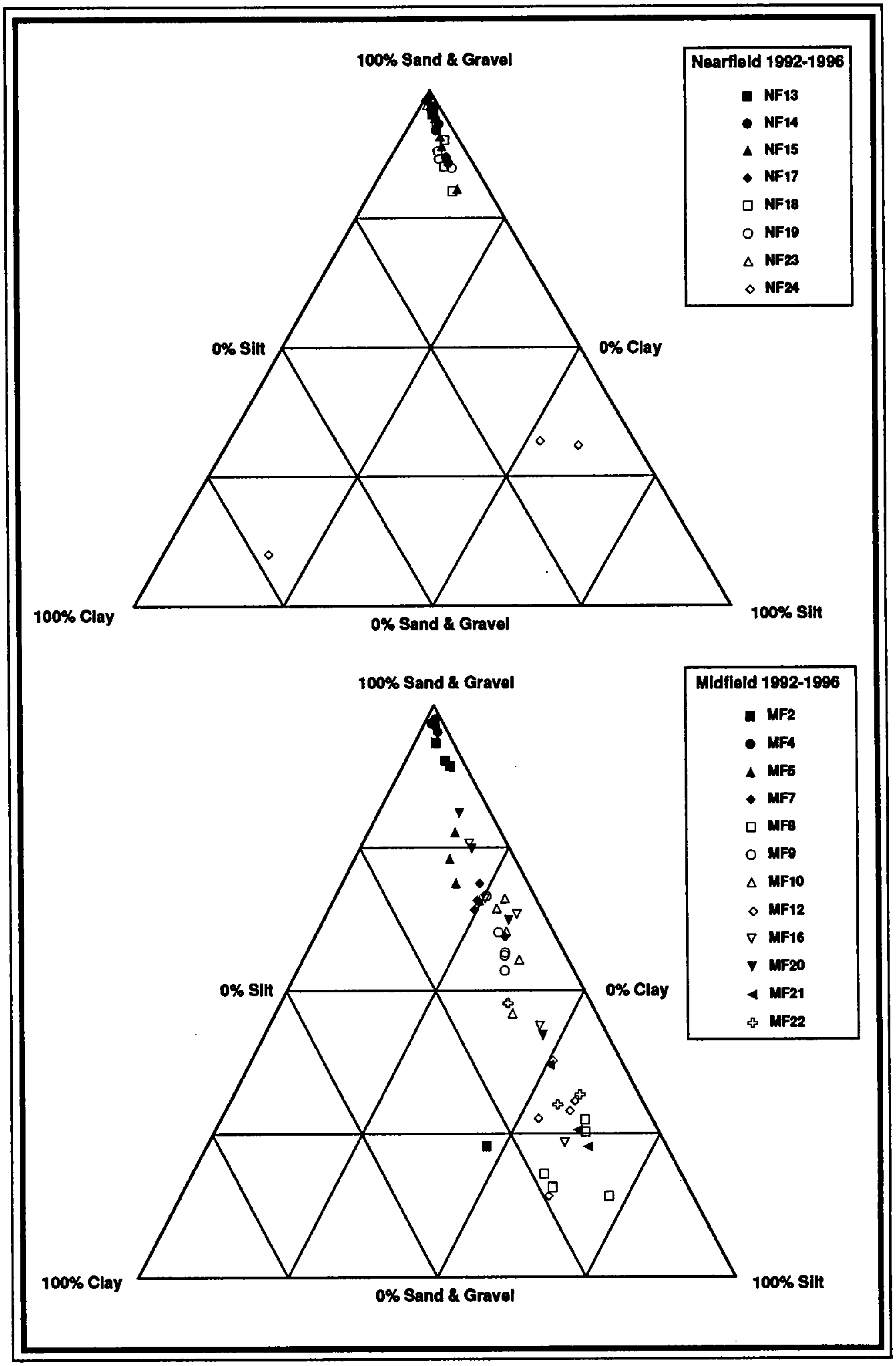

Figure 38. Sand/silt/clay triangle diagrams showing relative sediment composition at nearfield and midfield stations for the period 1992-1996.

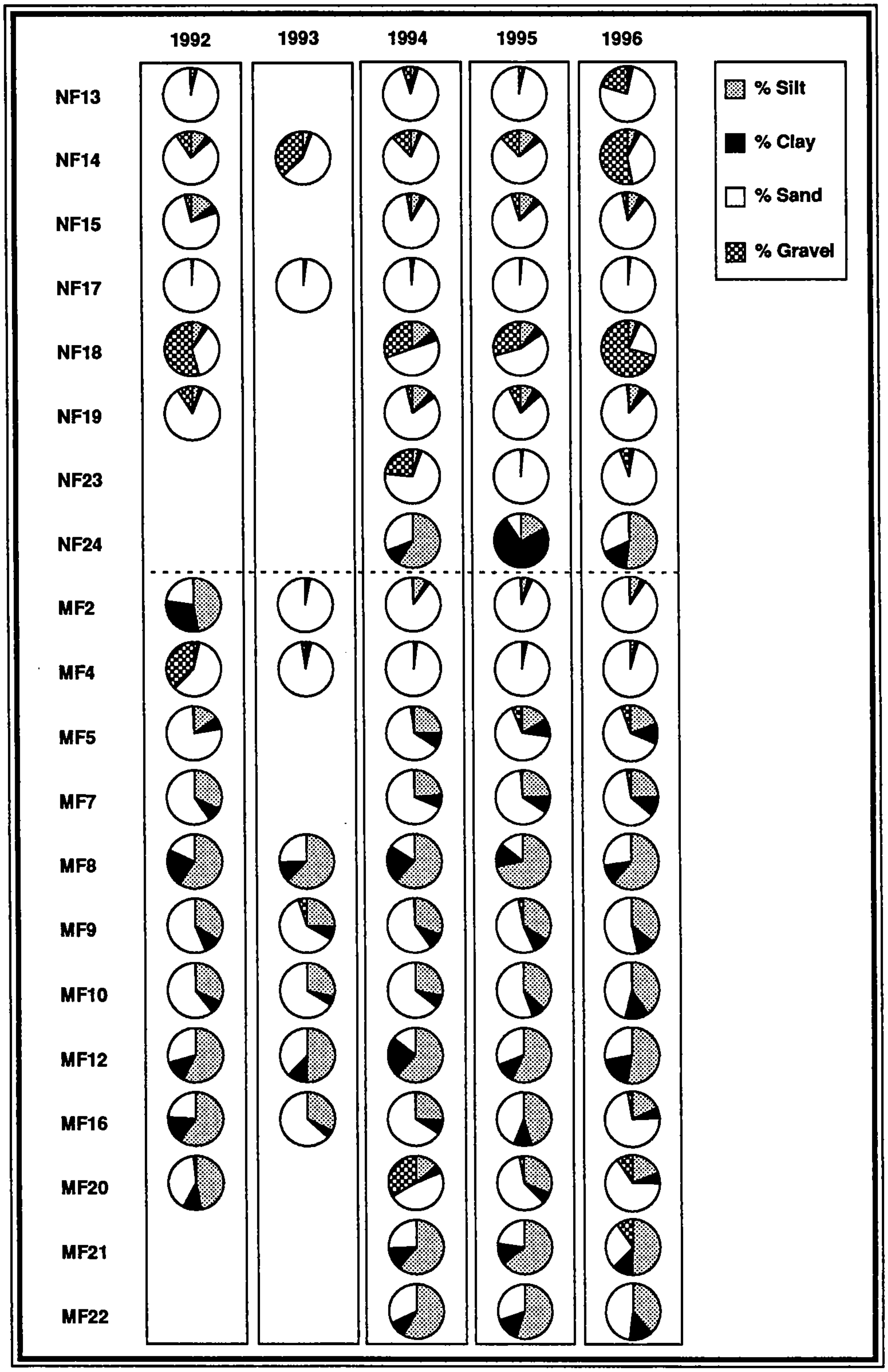

Figure 39. Sediment composition at nearfield and midfield stations for the period 1992-1996.

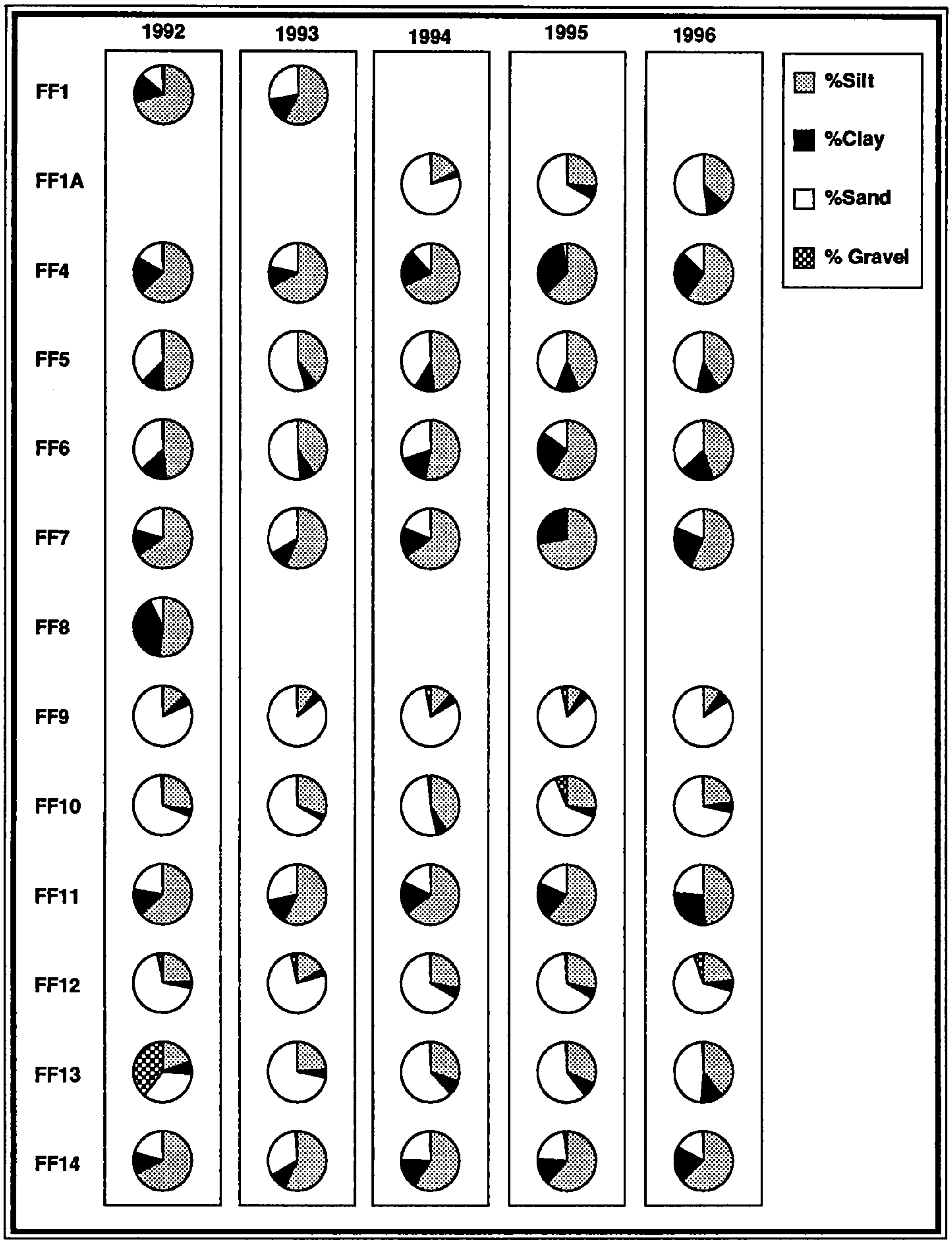

Figure 40. Sediment composition at farfield stations for the period 1992-1996.

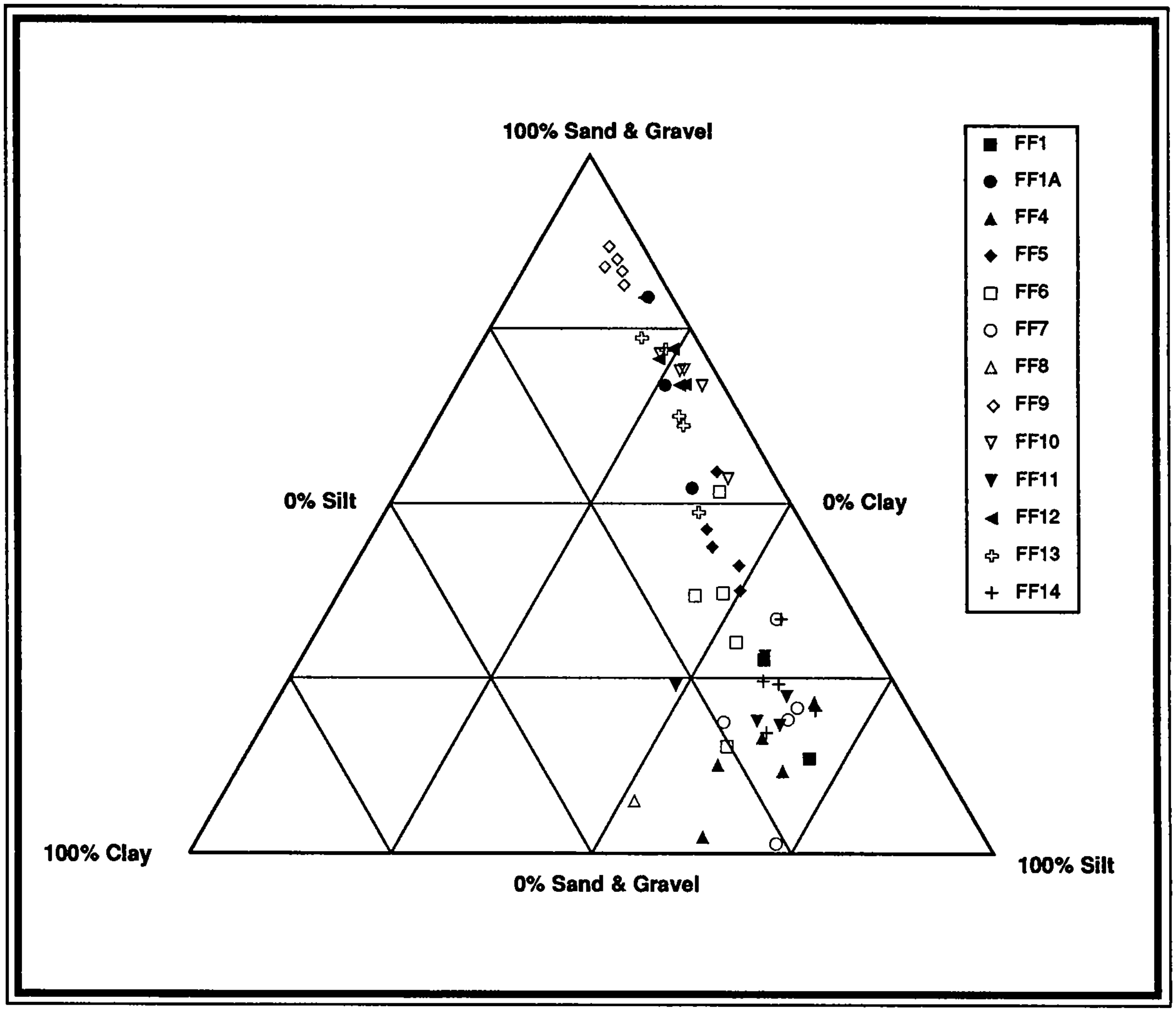

Figure 41. Sand/silt/clay triangle diagram showing relative sediment composition at farfield stations for the period 1992-1996.

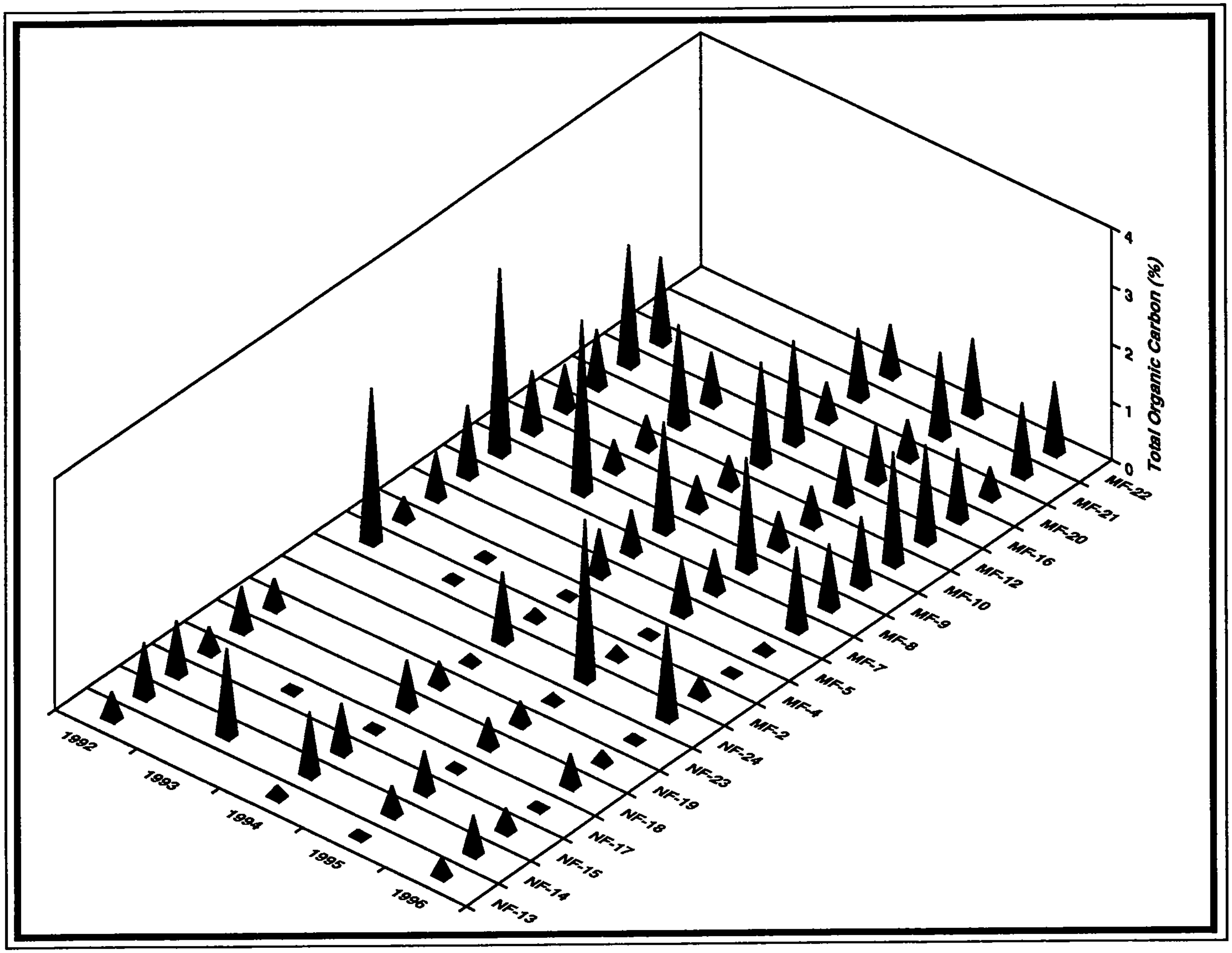

Figure 42. Total organic carbon concentrations at the nearfield and midfield stations for the period 1992-1996.

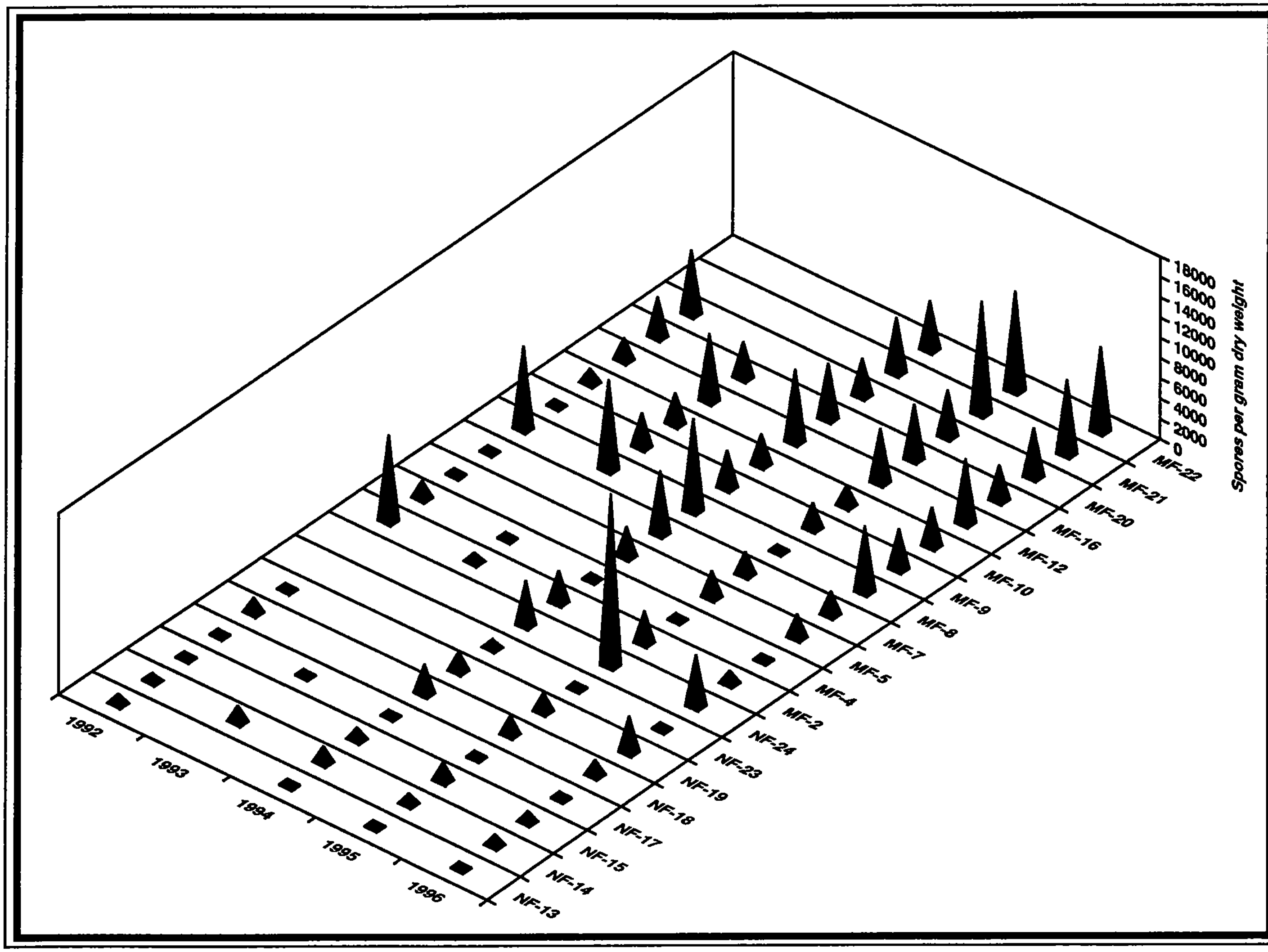

Figure 43. Densities of *Clostridium perfringens* spores at the nearfield and midfield stations for the period 1992-1996.

Levels of TOC and *Clostridium* spores are low at all farfield stations (Figures 44 and 45). The two Cape Cod Bay stations are indistinguishable from the Massachusetts Bay stations in terms of these parameters, and all stations are generally similar over time.

4.3 Spatial and Temporal Trends in Benthic Infauna

4.3.1 Nearfield and Midfield

The nearfield sampling program consists of eight stations and the midfield of 15 stations that are sampled annually with single, non-replicated 0.04-m^2 grabs. Six stations, however, are replicated with three samples each and provide data on within-station variability as well as comparability with the farfield station array.

Faunal Assemblage Patterns

The stations closest to the diffuser array (i.e., the nearfield) are located in an area of shifting sands that exhibit layering due to periodic deposits of fine sediments that are then overlain with sand. These sedimentary events certainly contribute to the year-to-year differences observed at many stations since monitoring began in 1992. Even so, three faunal assemblages have been identified in the nearfield/midfield study area and although the stations at which these assemblages are found shift somewhat from year to year, there has been a basic consistency in the presence of these assemblages.

Faunal assemblage A is dominated by syllid polychaetes (*Exogone*), enchytraeid oligochaetes, *Polygordius*, and the amphipod *Corophium crassicorne*, all species associated with sandy sediments. Stations MF4 and NF17 are typical of the stations at which this assemblage is found; in 1996 stations NF13 and NF 23 also were dominated by this species group. These stations are located more or less in a boundary area between the rock outcrops and drumlins to the east and the finer-grained sediments to the west.

There are typically two faunal assemblages in the finer sediments. Assemblage B is dominated by the spionid polychaetes *Prionospio steenstrupi*, *Spio limicola*, and sometimes *Dipolydora socialis*. Stations at which this assemblage is found typically include NF14, NF15, NF18, and midfield station MF7. This assemblage is transitional to Assemblage C, a *Mediomastus*-dominated community to the west, found at midfield stations MF8-MF10, MF16, MF20 and MF21. Over the time period of the monitoring program, these two assemblages have appeared to shift among the stations, and certain species have occurred as dominants in some years and been much less important in other years. Faunal patterns for 1992-1995 can be found in Hilbig et al., 1996; the pattern for 1996 is shown in Figure 46. These maps show the areal distribution of the three assemblages described above, reflected by CNESS clustering patterns. The sand assemblage (A) is the most consistent one, despite any changes in sediment texture: stations NF4 and NF17 have been dominated by the same fauna for all five years of monitoring.

In order to demonstrate year-to-year variability among some of the dominant species, their densities have been plotted at six nearfield/midfield stations, which were selected to represent different sedimentary regimes of the study area and which have been sampled in each of the five years of database development (Figures 47 and 48). The often-dominant spionid *Prionospio steenstrupi* exhibited its highest densities at these selected stations in 1995, whereas *Spio limicola* showed its highest densities in 1994, and otherwise comparable values for all other years. Both *Dipolydora socialis* and *Tharyx acutus* appear patchy in terms of occurrence and density, with 1992 and 1994 being years in which *D. socialis* was common, and 1992, 1994, and 1996 being years in which *Tharyx acutus* was common. With some exceptions, both *Aricidea catherinae* and *Mediomastus californiensis* show consistent densities at the stations plotted (Figure 48), particularly station MF12, which has a fairly stable sediment grain-size

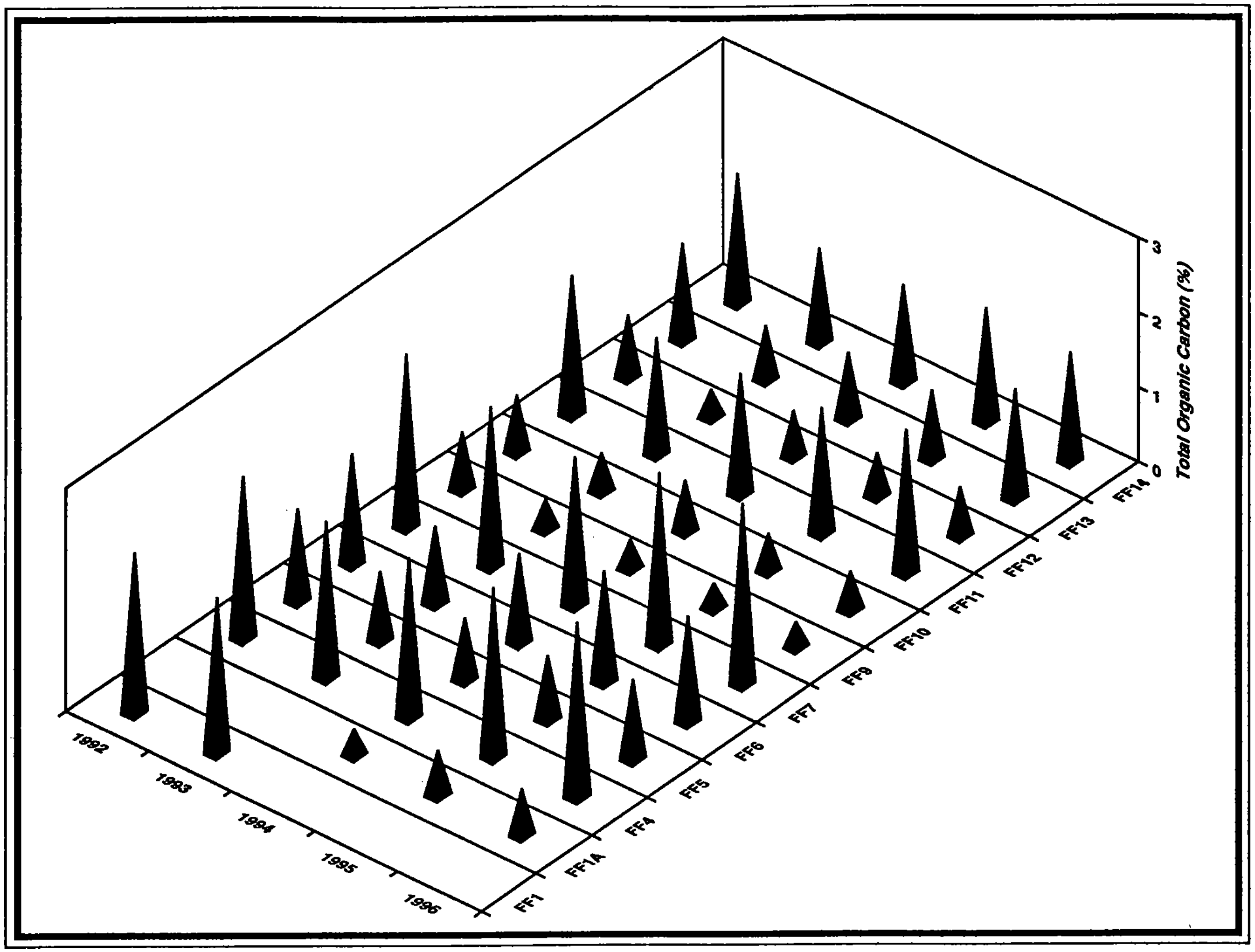

Figure 44. Total organic carbon concentrations at the farfield stations for the period 1992-1996.

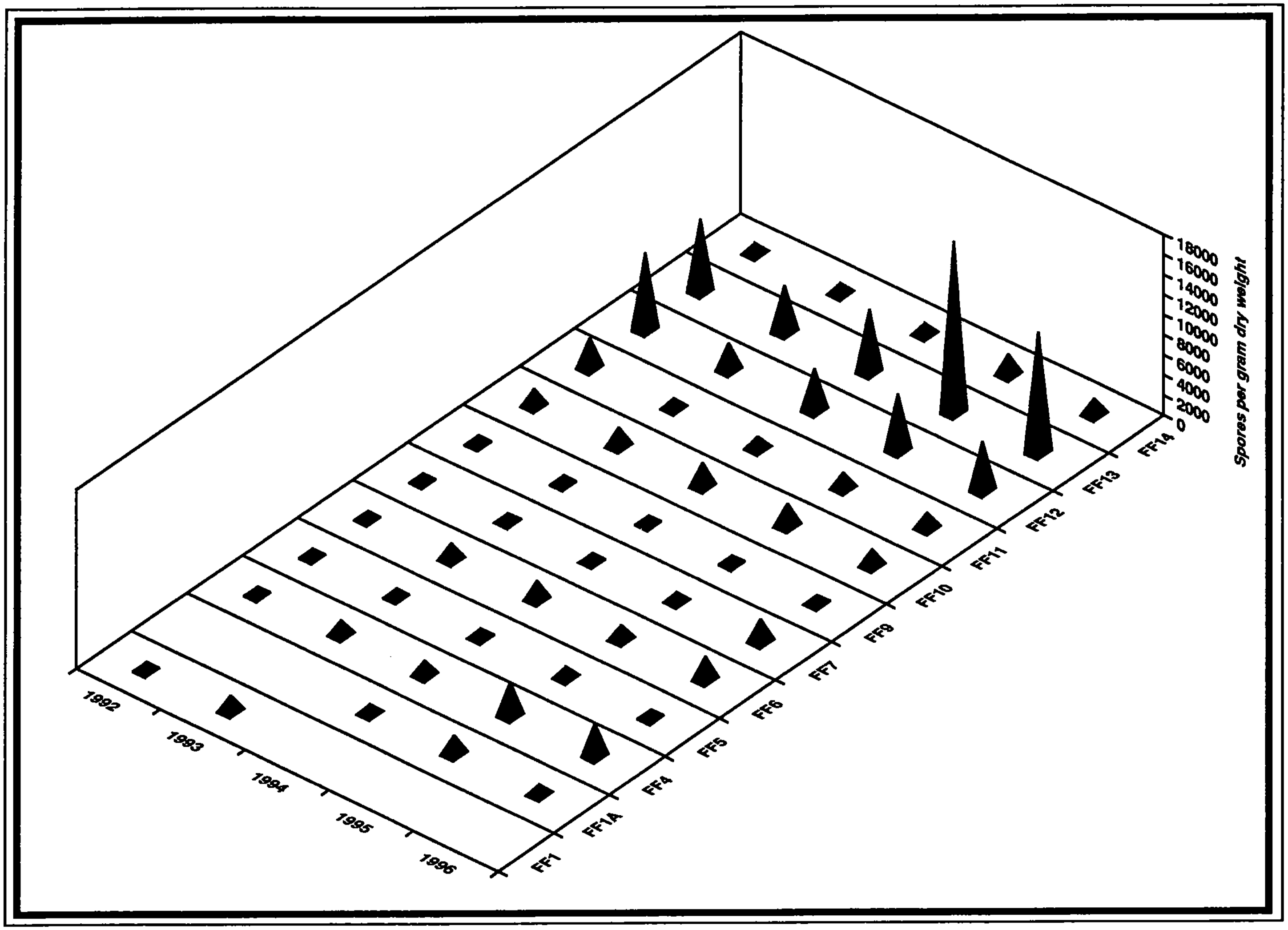

Figure 45. Densities of *Clostridium perfringens* spores at the farfield stations for the period 1992-1996.

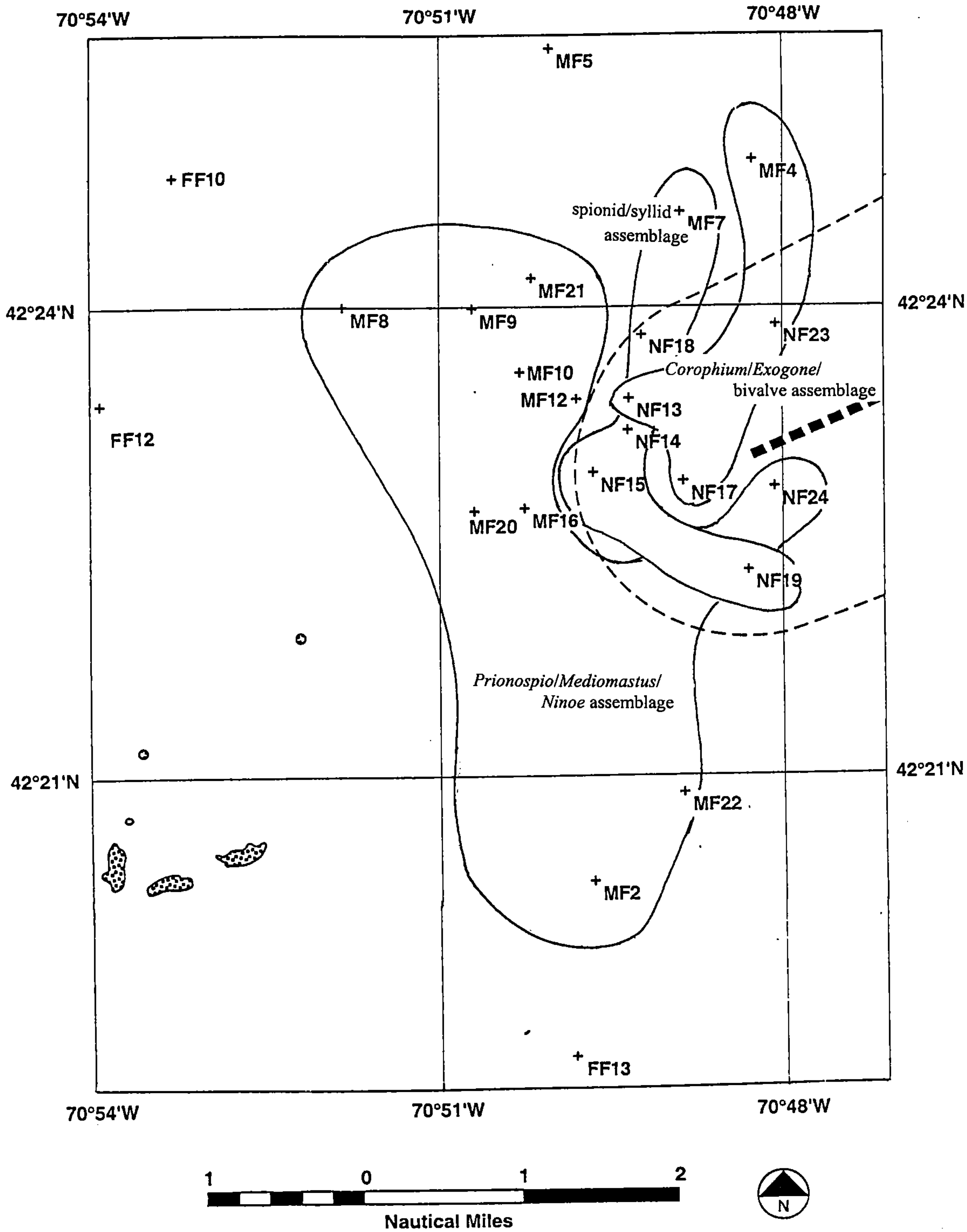

Figure 46. Faunal assemblages in the nearfield and midfield, based on the CNESS similarity analysis.

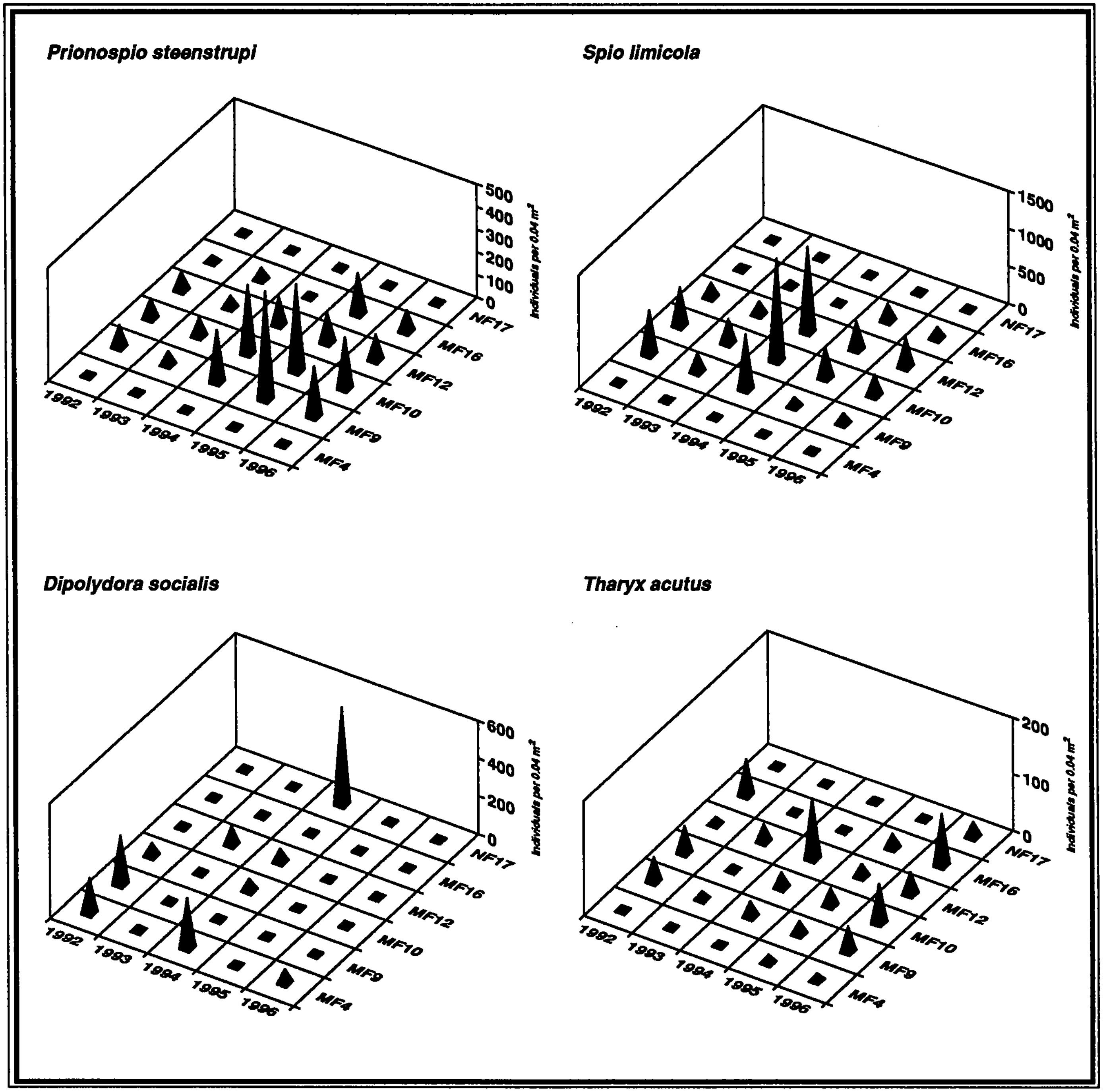

Figure 47. Relative abundances of three spionid and one cirratulid species at selected nearfield and midfield stations for the period 1992-1996. Note varying scales of the z-axes.

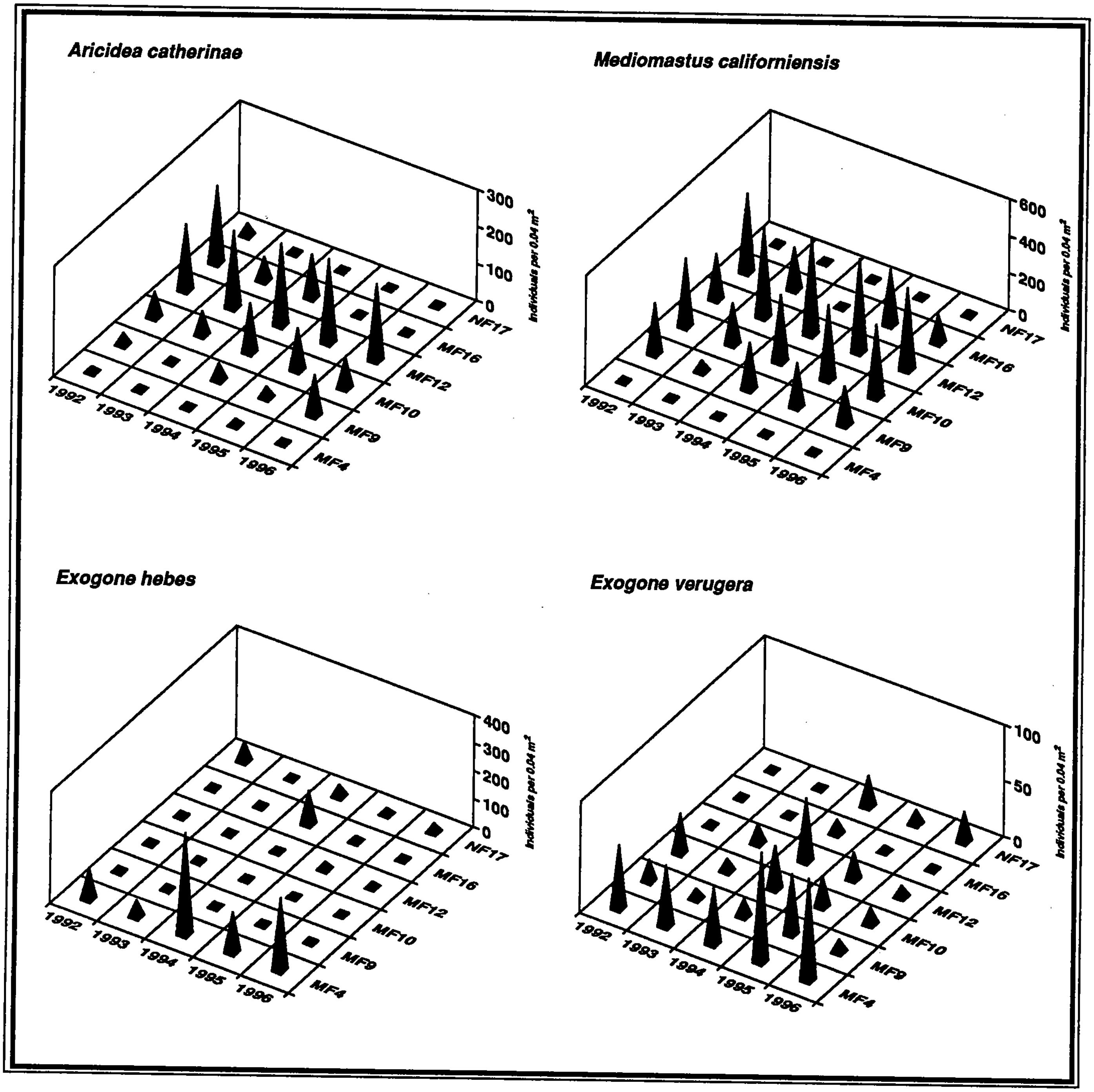

Figure 48. **Relative abundances of a paraonid, a capitellid and two syllid species at selected nearfield and midfield stations for the period 1992-1996. Note varying scales of the z-axes.**

composition (see Figure 39). The two syllid polychaetes *Exogone hebes* and *E. verugera* exhibit large swings in population density. The latter species is more widespread (Figure 48) and shows these large population shifts even at stations with consistent grain size (e.g., stations MF4 and MF12).

Trends in Total Faunal Abundance

Total densities of infauna, presented as numbers of individuals per square meter, vary greatly from year to year at the majority of nearfield and midfield stations (Figure 49). Stations NF13 and NF18 show the most consistent densities. The reason for these large fluctuations is due at least in part to the intense settlements of one or two species. For example, the very high densities recorded in 1992 at stations NF19, MF5, and MF7 were due to *Spio limicola*, which accounted for up to 33% of the total fauna at those stations. The timing of sampling in relation to settlement events will affect densities recorded at each station. The mean density at each station (averaged over years 1992-1996) is given in Appendix D. The grand mean density for the nearfield stations (44,159 individuals/m^2) is slightly lower than the grand mean density for the midfield stations (45, 315 individuals/m^2), however, the respective standard deviations are so large that there is probably no statistically significant difference between the results.

Species Richness and Diversity

Species richness, i.e., the number of species recorded at each station, is plotted for the years 1992-1996 in Figure 50. As seen for total density, the majority of stations exhibit large fluctuations in the number of species recorded. Considered separately, several of the nearfield stations show the smallest range of results (e.g., NF15, NF18, NF23) , but when averaged together show a range comparable to that recorded at the midfield stations (Figure 50, Appendix D). The grand mean for number of species recorded 1992-1996 at the nearfield stations is slightly higher (68.9±13.82) than that recorded at the midfield stations (63.2 ± 14.43); but as with total abundance, the wide standard deviations suggest that there is no statistical significance to these differences.

Diversity as measured with the Shannon-Wiener H′ index appears to be more consistent over time than either total abundance or species richness (Figure 51). In 1996, the mean H′ at the nearfield stations was 2.71±0.29 and at the midfield stations was 2.8±0.33. When averaged, the grand mean H′ (all samples, all years, all stations) for the nearfield stations is 2.71±0.32 and for midfield stations is 2.57±0.35. This first attempt at establishing a base diversity measure by which future results might be compared indicates that the stations closest to the western edge of the diffuser array have a higher diversity than stations located more than than 2 km from the diffuser. However, the standard deviation around the mean of each value implies that the diversities are essentially identical.

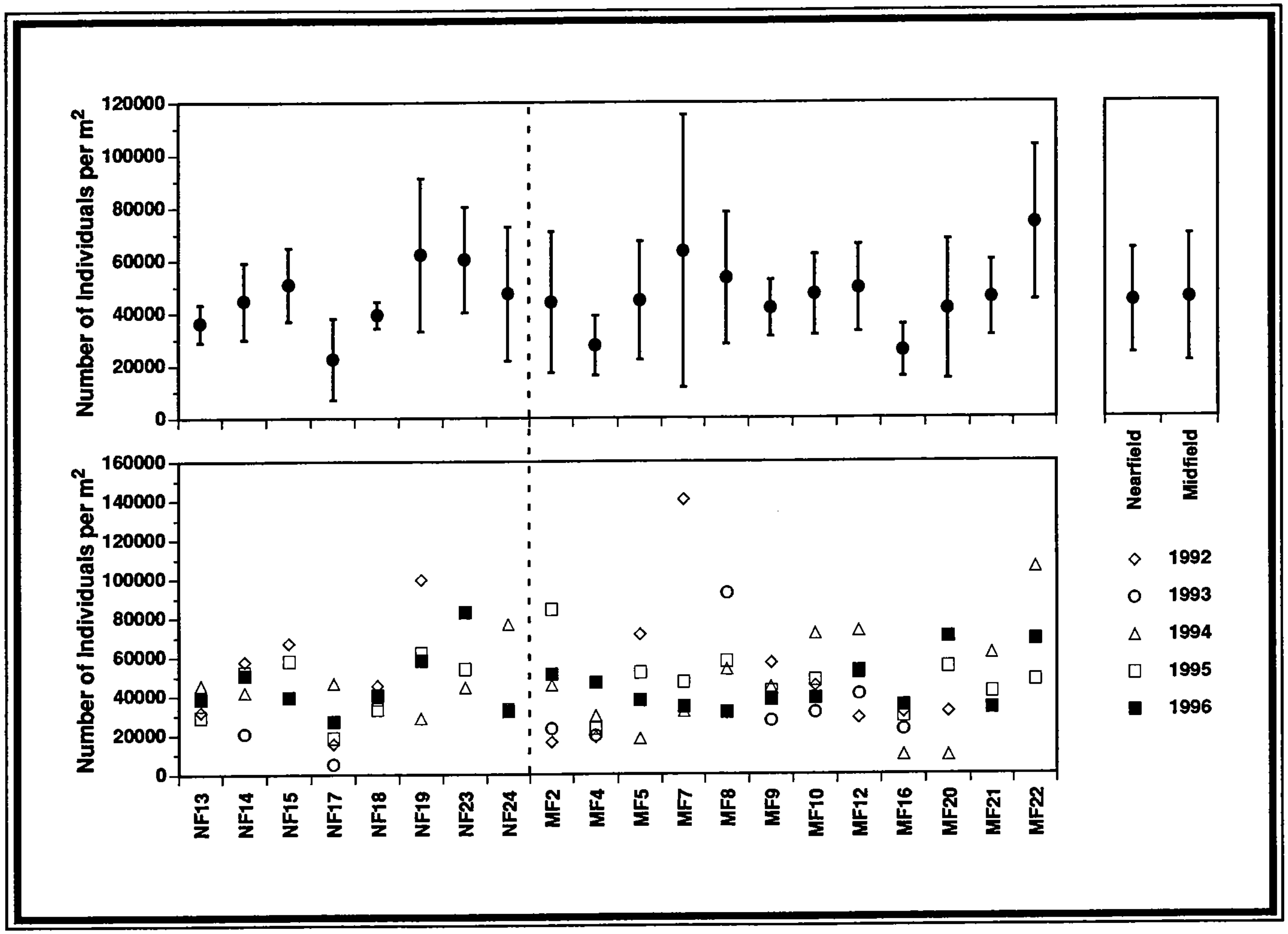

Figure 49. Infaunal densities at nearfield and midfield stations for the period 1992-1996. Top diagram shows the mean and one standard deviation for each station; bottom diagram shows abundances for each year.

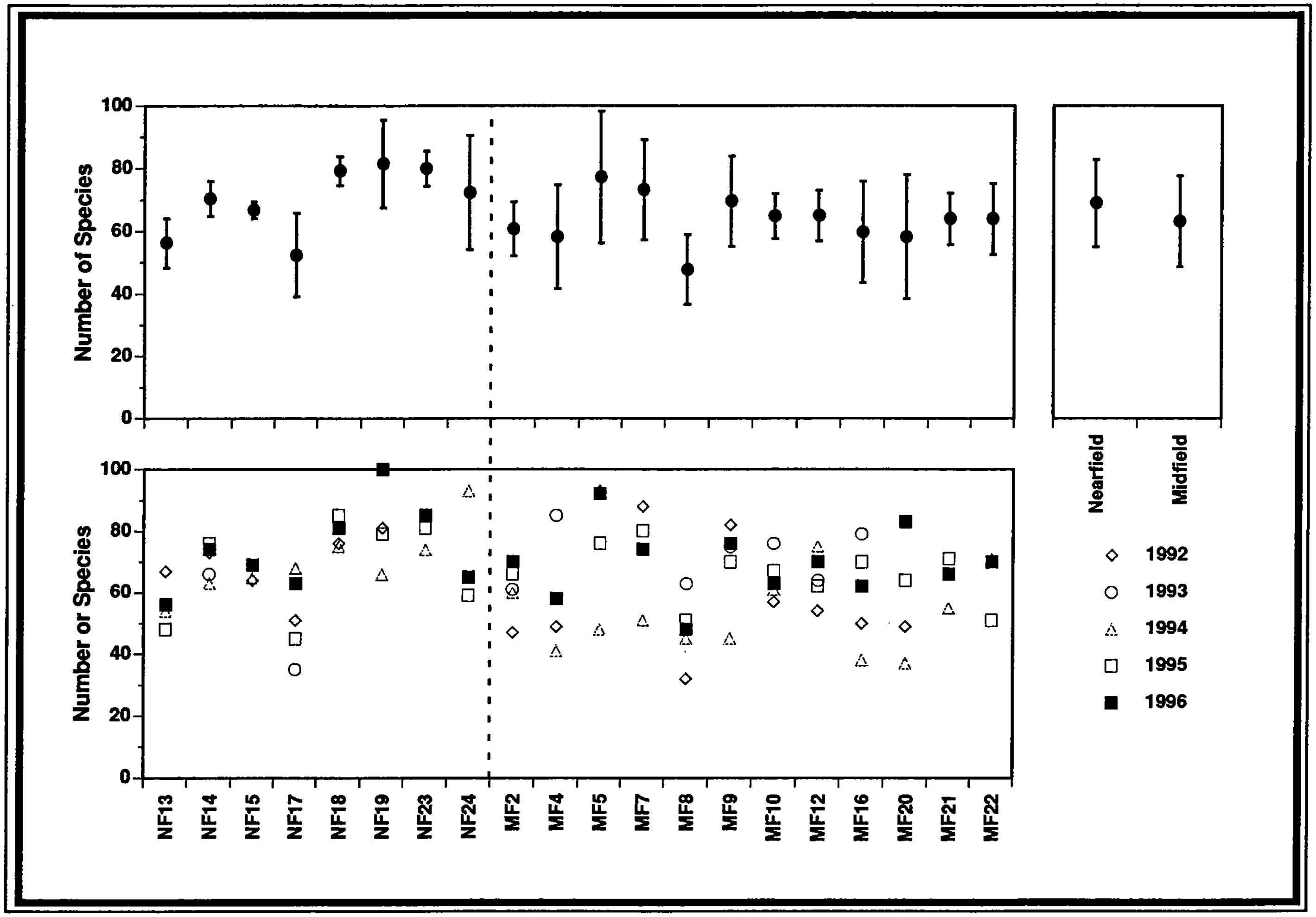

Figure 50. Number of species at nearfield and midfield stations for the period 1992-1996. Top diagram shows the mean and one standard deviation for each station; bottom diagram shows values for each year.

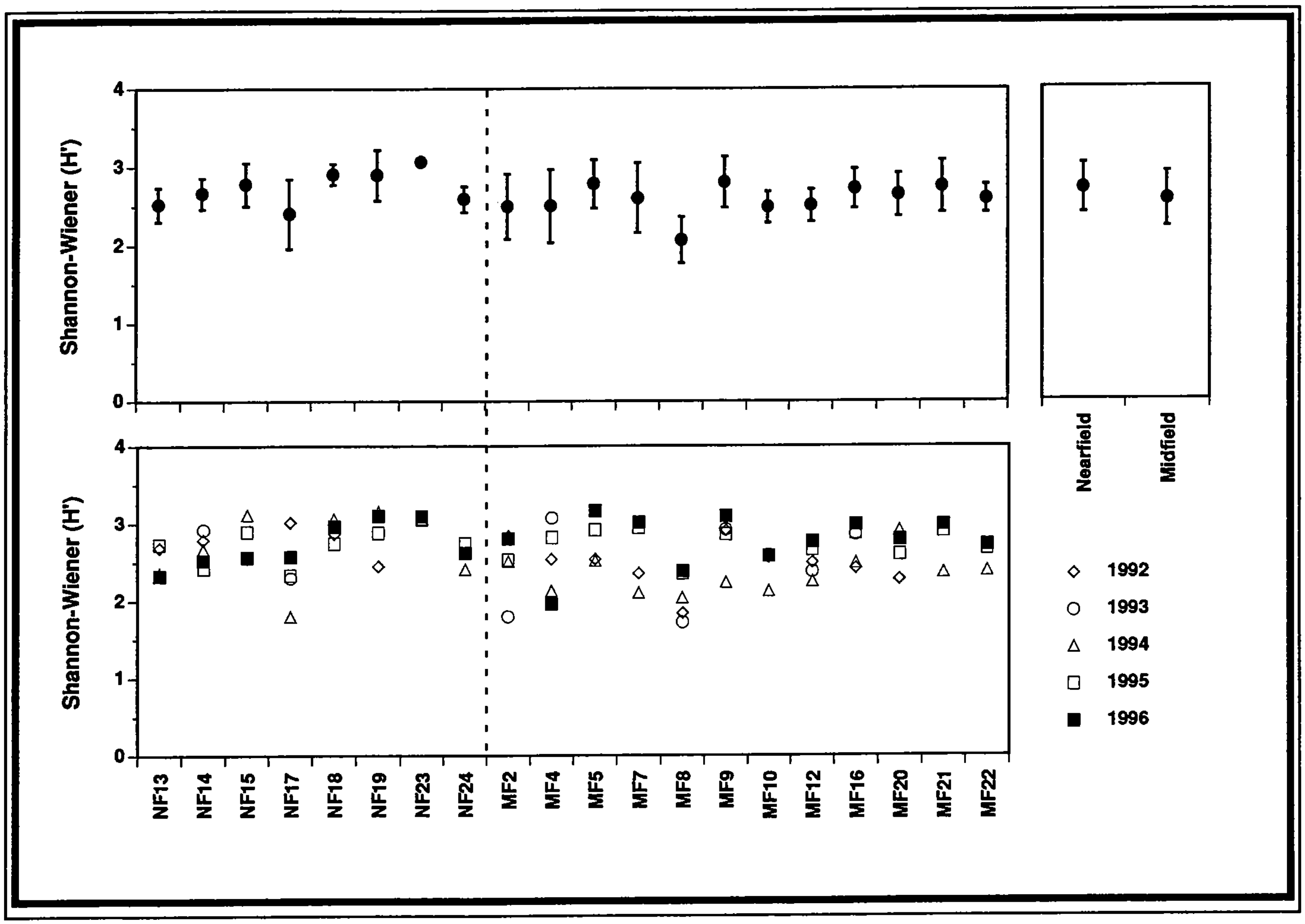

Figure 51. Shannon-Wiener diversity at nearfield and midfield stations for the period 1992-1996. Top diagram shows the mean and one standard deviation for each station; bottom diagram shows H′ for each year.

4.3.2 Farfield

The farfield sampling program consists of eight stations where triplicate 0.04-m^2 grabs are collected and analyzed. Three stations that were originally part of the farfield design (FF10, FF12, and FF13) have been reclassified as midfield stations. These three stations are approximately 8 km from the outfall, but more importantly are nearshore of the diffuser array. In terms of faunal communities, at least two of these stations appear to be transitional between Boston Harbor and the rest of the nearfield/midfield stations. The eight remaining farfield stations are widely distributed in Massachusetts and Cape Cod Bays and ensure that changes due to natural processes will be documented in an area that is well beyond the area potentially impacted by the outfall. Most of the farfield stations appear to be more stable from year to year than the nearfield and midfield stations, being removed from the influence of the Harbor and nearshore sediment transport processes. However, there are still considerable year-to-year differences in faunal abundances and density of dominant species.

Faunal Assemblage Patterns

The cluster and ordination analyses of the farfield stations consistently demonstrate three general groupings of stations. The most consistent of these groups comprises the two stations (FF6 and FF7) in Cape Cod Bay, which support a faunal assemblage different from that found at the Massachusetts Bay stations. For example, the polychaete *Cossura longocirrata* is dominant at these stations but rare elsewhere in the larger study area. A second fairly consistent assemblage includes the offshore stations in the vicinity of Stellwagen Basin, including stations FF4, FF5, FF11 and FF14. The other two stations, FF1A and FF9, show affinities with both nearshore and offshore communities.

Trends in Faunal Abundance

Records of infaunal abundance from 1992 through 1996 are shown in Figure 52. Infaunal densities show large annual variations, as indicated by the wide standard deviations shown in Figure 52(A). Densities recorded in 1996 tended to be average to high at the majority of stations. The grand mean abundance at the farfield stations (Appendix D) is 33,505 individuals /m^2, with a standard deviation of 20,640. This result indicates a slightly lower faunal density in the farfield compared to the nearfield or midfield.

Trends in abundance for selected dominant species are plotted in Figure 53. Most species show wide variations in abundance from year to year. These patterns very likely reflect variances in the timing of settlement of larvae of benthic organisms, a process influenced by environmental conditions. Timing of sample collection in relation to larval or juvenile recruitment will also affect results. Although variations in abundance of individual species do not appear to greatly affect the overall assemblage patterns as revealed in cluster analysis, traditional benthic community parameters such as diversity are considerably influenced.

Species Richness and Diversity

The actual number of species recorded at each station is shown in Figure 54; it can be seen that the number of species identified at each station was higher in 1996 than in most previous years. In future years it will be critical to maintain similar levels of species identifications so that apparent changes in diversity can be evaluated by considering the underlying database as well as external events. The grand mean number of species at the farfield stations for the period 1992-1996 was 76.8±17.34, slightly higher than but perhaps not significantly different from the mean number of species recorded at the nearfield or midfield stations (Appendix D).

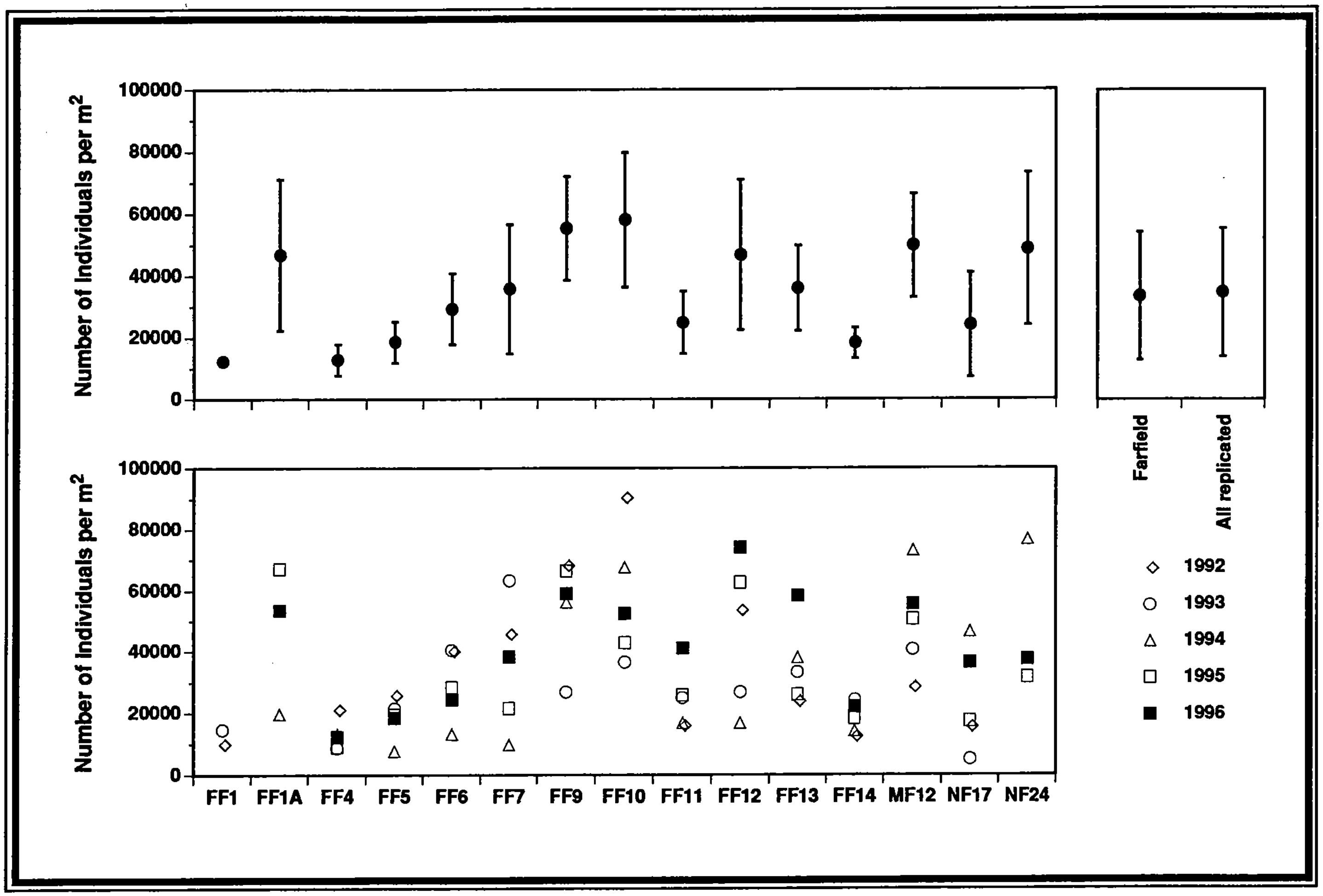

Figure 52. Infaunal densities at farfield stations for the period 1992-1996.
Top diagram shows the mean and one standard deviation for each station; bottom diagram shows abundances for each year.

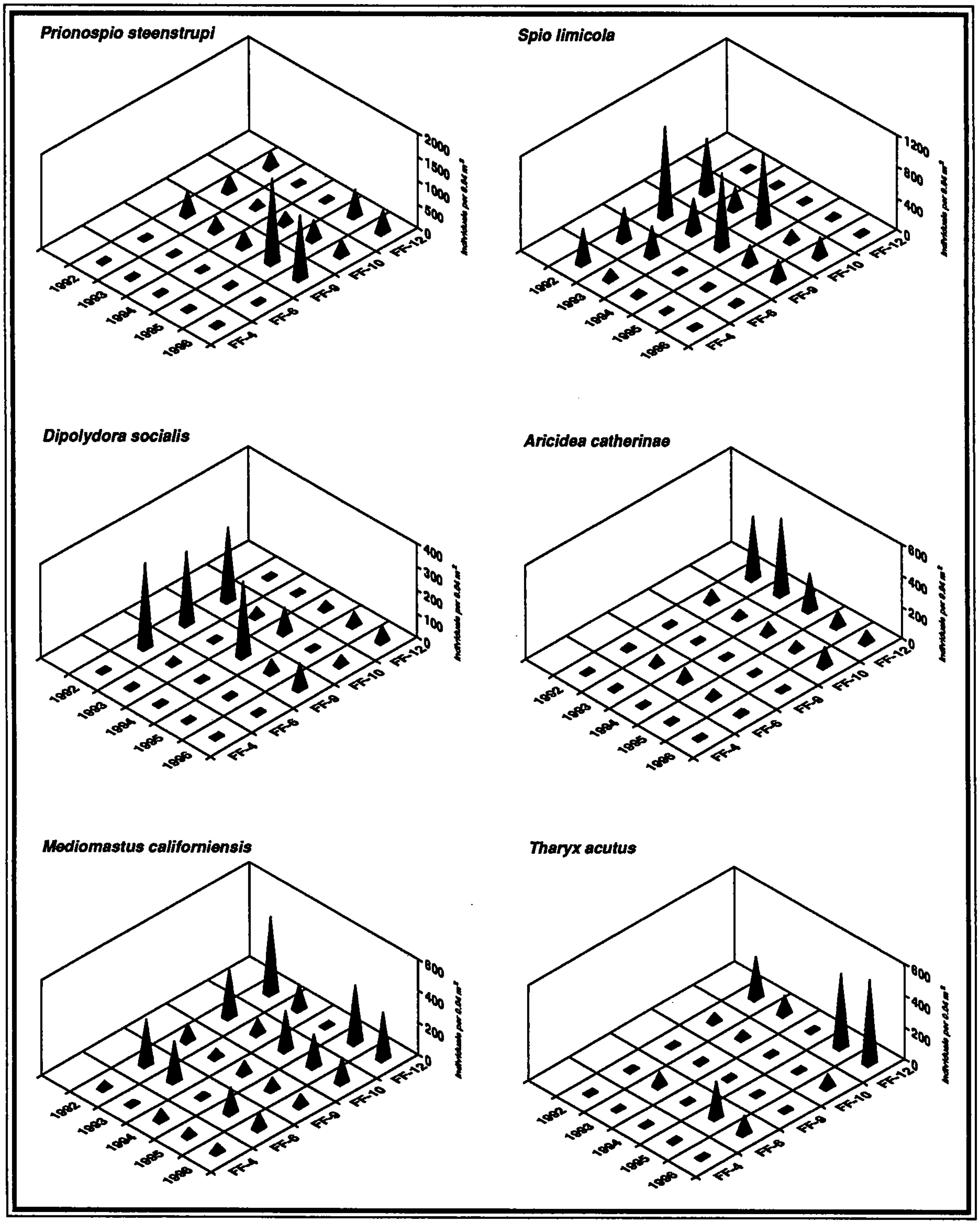

Figure 53. Relative abundances of six dominant species at selected farfield stations for the period 1992-1996. Note varying scales of z-axes.

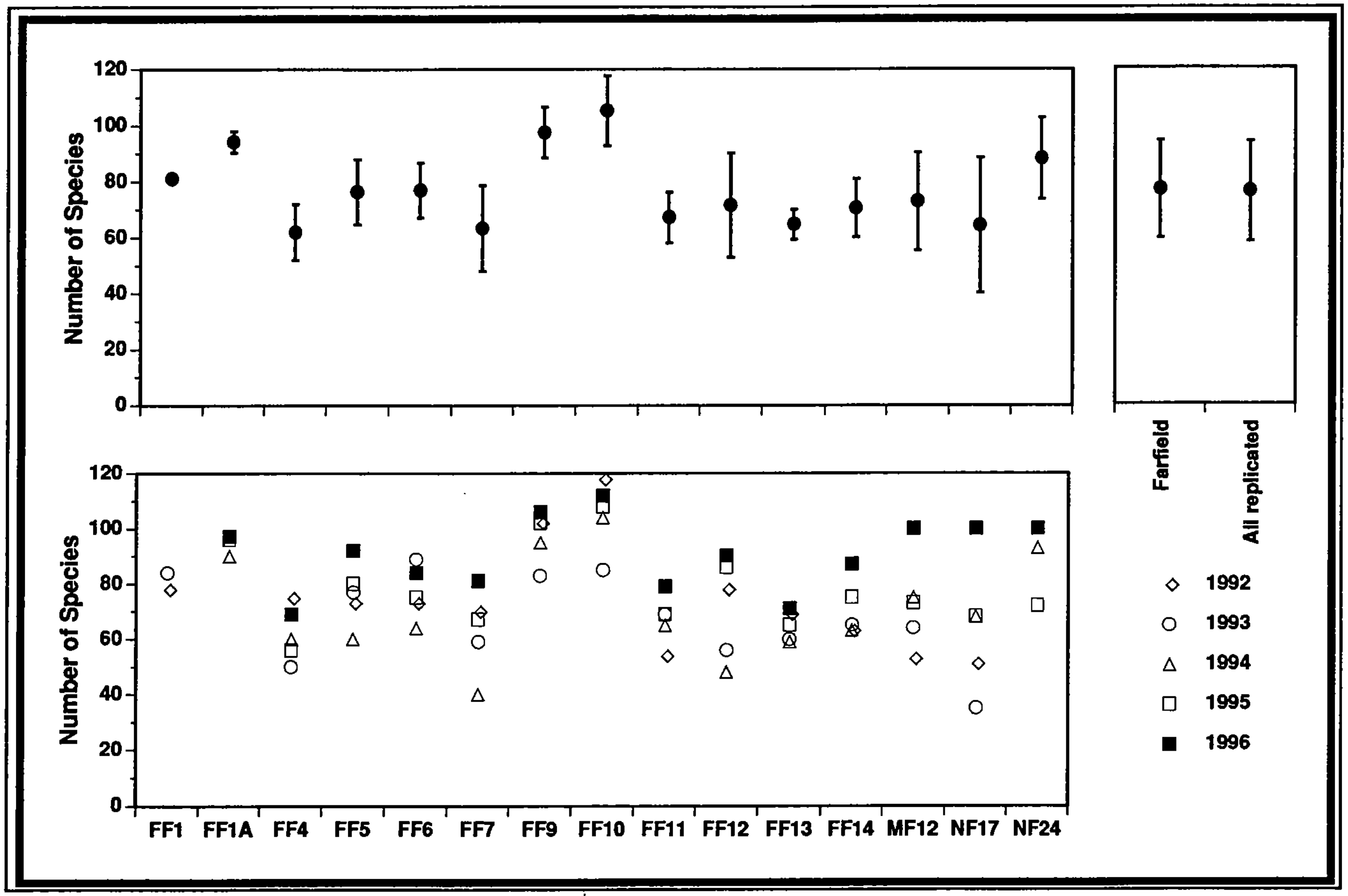

Figure 54. Number of species at farfield stations for the period 1992-1996. Top diagram shows the mean and one standard deviation for each station; bottom diagram shows values for each year.

Species diversity as measured by the Shannon-Wiener index (H') is relatively consistent from year to year at most farfield stations but exhibits a wide range at others (e.g., FF1A, FF5, FF11) (Figure 55). In some cases diversity is clearly influenced by sets of juveniles. For example, the large apparent drop in diversity at station FF1A between 1994 and 1995 can be explained by the presence of a large population of the polychaete *Prionospio steenstrupi*. Although the number of species at FF1A was actually higher in 1995 than in 1994, diversity appeared lower because of the dominance of this one species in the samples. Diversities appeared slightly higher in 1996 than in 1995, in some but not all cases meeting or exceeding the highest diversities recorded at the farfield stations. In addition to natural fluctuations in community structure, some of this increase may be due to greater resolution of species identifications of the molluscs and the juveniles of other faunal groups.

The average H' diversity calculated for all farfield stations is 2.62, with a standard deviation of 0.455 (Appendix D). Thus, diversities at the farfield stations are essentially identical to those at the nearfield and midfield stations (see page 87).

4.4 Spatial and Temporal Trends in the Nearfield Hard-Bottom Benthos

Analysis of the hard-bottom video and 35-mm images shows that location on the drumlins, depth, substratum type, habitat relief, and sediment drape all appear to play a role in determining the structure of benthic communities inhabiting hard-bottom areas in the vicinity of the outfall. Some of the taxa show strong preferences for specific habitats, while others are broadly distributed. Many of the taxa were very patchily distributed. Variances of the abundances of most of the taxa were quite high both within and between habitats. While some areas were homogeneous in terms of substratum type and the fauna inhabiting them, most of the areas exhibited a high degree of patchiness in terms of habitat types. Even cobble pavement areas were occasionally interrupted by groups of larger boulders that supported a different and more diverse community. The high variances noted in the distributions of many of the taxa appear to reflect the habitat variability. Some of the variance may be related to difficulties in distinguishing between some of the encrusting organisms that may encompass several species. However, a fair amount of the variability appears to be due to the inherently patchy nature of the hard-bottom habitats.

The analysis of the still photographs shows finer details of the structure of benthic communities inhabiting hard-bottom areas in the vicinity of the new sewage outfall than can be discerned from the video tapes. The two techniques are complementary in that the video survey provides greater areal coverage, while the still photographs provide more accurate assessments of the benthic communities inhabiting these areas. Both techniques are valuable for establishing baseline data of the drumlin areas.

The distributions of some of the taxa did show obvious substratum preferences. Not surprisingly, degree of sediment drape appeared to be an important controlling factor for many of the encrusting forms. The apparent greater tolerance of the upright algae to higher degrees of sediment drape may be misleading in that they probably trap sediment. Frequently, totally clean cobbles and boulders were adjacent to heavily sedimented boulders. In these instances, the sedimented boulders were usually inhabited by upright algae, while the clean cobbles and boulders were usually encrusted with *Lithothamnion*. Sediment loading appeared to be a problem for many of the other encrusting taxa, in that they were frequently restricted to the sides and underhangs of boulders in areas that had sediment drape.

The inherent within-area heterogeneity of the hard-bottom habitats in the vicinity of the diffuser presents a formidable task for environmental monitoring of the outfall discharges. In terms of detecting habitat degradation as a result of the outfall coming on line, the coralline alga *Lithothamnion* spp. appears to hold the greatest promise as an indicator species. It appears to be the most predictable taxon in terms of

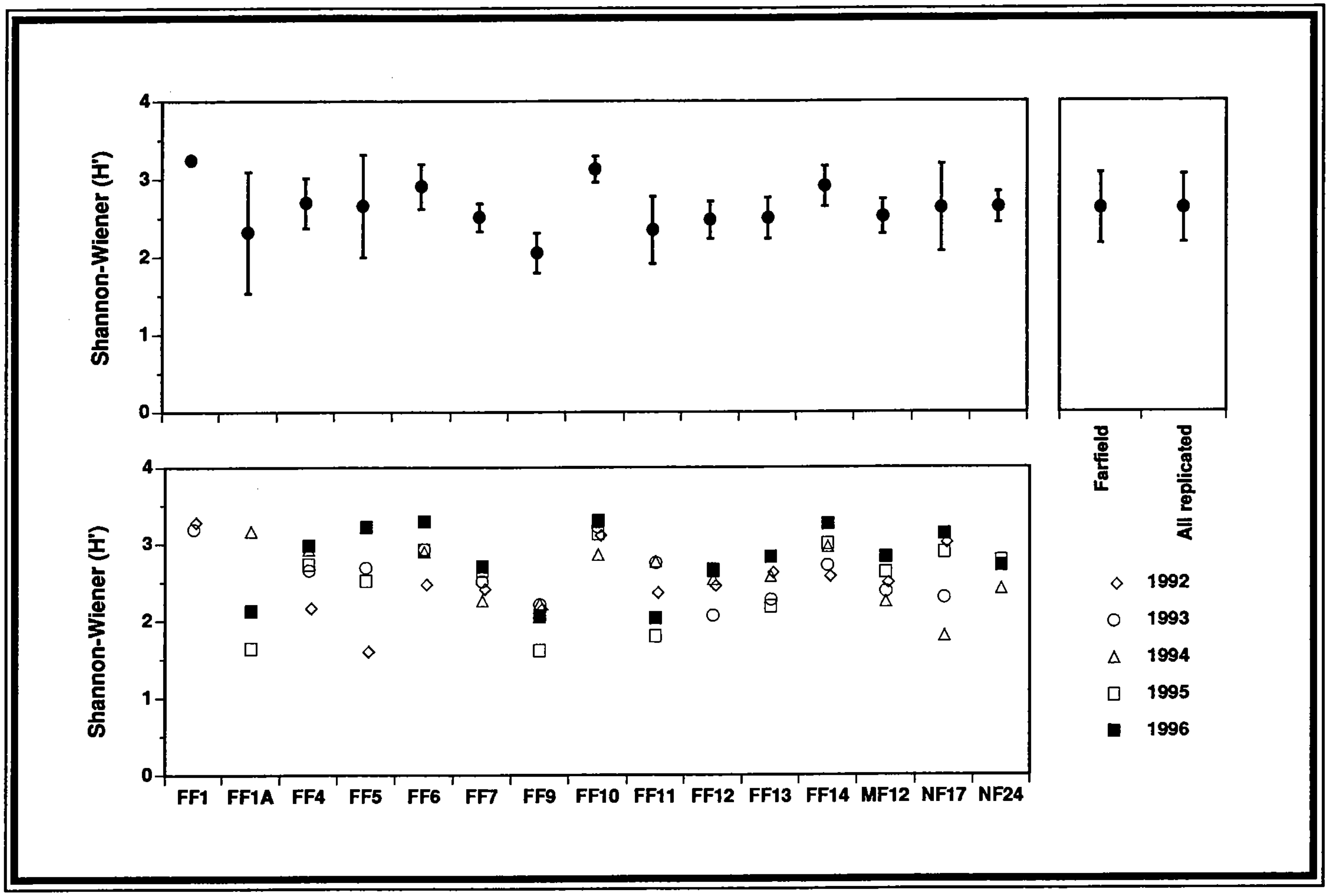

Figure 55. Shannon-Wiener diversity at farfield stations for the period 1992-1996. Top diagram shows the mean and one standard deviation for each station; bottom diagram shows H′ for each year.

habitat requirements and hence its probable distribution. It is very abundant, widely distributed, and less patchy than the other taxa (Table 16). It appears to dominate in all areas that are shallower than 110 ft and have little sediment drape. Additionally, it is common in areas of both high (clusters 1a, 1b, and 2c) and low relief (cluster 2a). By focusing on *Lithothamnion* spp. as an indicator, it is quite likely that major changes in the benthic communities inhabiting the nearfield hard-bottom areas could be detected.

Potential impacts might be anticipated in terms of changes in sediment loading of the sea floor on the drumlins. If materials discharged from the outfall were to accumulate in the vicinity of the drumlins, it is anticipated that this would result in a marked decrease in the coverage of *Lithothamnion* spp. If the discharges from the outfall alter properties of the water column that affect light penetration, then changes might be expected in the depth distribution of *Lithothamnion* spp. If water clarity were reduced, the lower depth limit of high coralline algal coverage might be reduced. Conversely, if water clarity were increased, then it is expected that such algal coverage would extend into some of the deeper areas. The extensive water column monitoring carried out by the MWRA, coupled with the complementary USGS program, will record any changes in water clarity, thus providing data with which changes in algal coverage could be correlated.

The results of the 1996 survey generally agree with the findings based on the more limited coverage (still photographs) obtained during the 1995 survey. Direct comparisons of abundances and community composition of specific areas are hampered by the inherent within-habitat variability of the drumlins. Slight lateral shifts in the area being surveyed can result in apparent dramatic shifts in the composition of the community. Additionally, the limited number of still photographs taken in 1995 were not as randomly distributed as the ones taken in 1996, since the original purpose of the 1995 still photographs was to provide ground truth images for taxonomic identifications and pretty habitat shots. Despite these differences in protocol, the general conclusions concerning the structure of the benthic communities inhabiting the drumlins and the factors that control the distributions of the dominant taxa are quite consistent between the two surveys. Both surveys identified similar differences between the communities inhabiting drumlin tops and flanks.

The results of the 1995 and 1996 surveys are similar to those found by Coats *et al.* (1995a) from a video survey conducted in 1994. Four of the six transects covered in this report (transects 1, 2, 4 and 6) were the same as those included in the 1994 survey. The 1994 survey consisted of near-continuous video coverage along the transects, while the present design focuses on topographically selected points (waypoints) along the transects that included representative drumlin top and flank locations. Differences between the results of the two surveys appear to be related to visual resolution of the films and taxonomic designations. The 1995 and 1996 surveys identified 76 and 72 taxa, respectively, compared to 37 taxa identified from the 1994 video survey. Many of the additional taxa identified in the present study are encrusting and attached organisms. Rather than indicating changes in the benthic communities in this region, the difference in number of taxa is undoubtedly due to the greater resolution afforded by the ROV being closer to the sea floor in the present study (right on the bottom as opposed to an altitude of 1 to 3 meters). Coats *et al.* identified an abundant pinnate red alga as *Rhodymenia* sp A: this species appears to be the filamentous red alga identified as *Asparagopsis hamifera* in the present study. Additionally, their Porifera sp. A was an orange encrusting sponge, and is probably the orange/tan sponge commonly seen during the present study.

Another video survey of the area west of the new sewage outfall identified 23 taxa (Etter *et al.*, 1987). The lower number of species seen in that survey was probably due to habitat differences between the areas surveyed. The 1987 survey covered mostly depositional sediment areas, whereas the present study

Table 16. Range of algal and invertebrate abundances (number per photograph) and their coefficients of variation for cluster groups formed by classification analysis.

Cluster	1 a	1 b	1 c	2 a	2 b	2 c	3	4
Location	T	T	F	T	F	F	F	L/D
Depth (ft)	63-74	75-95	102-108	71-90	94-103	84-87	94-107	117
Relief	high	high	moderate	low	variable	high	low	variable
Substrate	boulders	boulders	cobbles	cobbles	mix	boulders	cobbles	gravel
Sediment drape	clean	light	variable	clean-light	light	light	heavy	variable
Lithothamnion (%cover)	70	30-60	6	80-90	45	70	1-11	<1
CV	30-40%	30-120%	190%	10%	20-50%	25%	50-100%	367%
Asparagopsis	6-9	12-17	5-10	<1	0-2	2	-	-
CV	70-130%	30-40%	100%	200%	150%	150%	-	-
Algal abundance	22-29	20-33	6-13	15-18	6-10	15	1-3	<1
CV	30-60%	20-40%	70-100%	14%	55%	30%	60%	371%
Invertebrate abundance	14-25	10-16	17	6-22	8-9	31	4-8	5
CV	40-140%	50-200%	60-100%	50-90%	40-60%	150%	50%	175%

Lithothamnion spp. - most abundant in areas with little sediment
- more variable in high relief areas

Asparagopsis hamifera - only abundant in high relief areas
- tolerant of and may cause sediment drape
- high within habitat variance

Invertebrates - most abundant in high relief areas
- high within habitat variance

concentrated mostly on erosional hard substratum areas (drumlins). At any given depth, soft sediment generally supports fewer epifaunal species per unit area than does hard substrate.

General faunal distribution patterns were similar between all the surveys. Algae are most abundant on the tops of drumlins. Coats *et al.* reported that *Rhodymenia palmata*, *Rhodymenia* sp. A (a pinnate red alga), and *Agarum cribosum* were found together on hard substratums at shallower depths. We found that the benthic communities inhabiting drumlin tops are dominated by algae, cobbles and smaller boulders are dominated by *Lithothamnion*, and the tops of larger boulders are dominated by *Asparagopsis hamifera*. While Coats *et al.* estimated percent cover of *Lithothamnion*, they did not discuss its distribution. All three surveys also found that the anemone *Metridium senile* and the cunner *Tautogolabrus adspersus* were most abundant near large boulders. Coats *et al.* reported that the distribution of the green sea urchin *Strongylocentrotus droebachiensis* was depth related, with the urchins being most abundant at shallower depths. We found a similar result in that this urchin was most abundant on the tops of drumlins, but we attribute their distribution to availability of their primary food source, the coralline alga *Lithothamnion*.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The recommendations in this chapter are those of the authors of this report and not necessarily those of the MWRA.

5.1 Sedimentology

- Sediments at the nearfield stations tend to be coarser-grained than sediments at midfield or farfield stations: in 1996, the majority (5 of 8 stations) had sediments with greater than 90% sand and gravel. The sand fraction at the midfield stations tends to be composed of fine- rather than coarse-grained sand. In general, sediments were slightly coarser in 1996 compared to 1995.

- Coarse-grained nearfield stations generally have low levels of total organic carbon (TOC) and *Clostridium perfringens* spores, while at other stations there is no clear relationship between TOC or *Clostridium* and corresponding sediment texture, although some year-to-year changes can be attributed to changes in sediment texture. Levels of both parameters at the farfield stations have been low throughout the 1992-1996 sampling period.

5.2 Soft-bottom Infaunal Communities

- Benthic community parameters observed in 1996 were generally similar to those seen in previous baseline monitoring years, both in the vicinity of the new outfall and throughout Massachusetts and Cape Cod Bays. Three faunal assemblages have been identified in the nearfield/midfield study area; of these, the *Exogone-Corophium*-oligochaete assemblage found at the coarse-sand stations is the most consistent. Nearfield stations NF4 and NF17 have been dominated by this fauna for all five years of monitoring.

- The structure of the benthic communities in the nearfield and midfield was largely determined by sediment grain size, whereas in the farfield water depth and location were of primary importance.

- Species richness (i.e., number of species recorded) was apparently higher in 1996 than in earlier years. This result may be due in part to better identification of juvenile polychaetes and molluscs. It will be of primary importance to maintain similar levels of taxonomic discrimination in the years after the outfall comes on line: any apparent changes in species diversity should be evaluated first by comparison of the underlying database.

- Calculation of an average species diversity (Shannon-Wiener H′) suggests that diversity at the nearfield stations is essentially identical to the average diversity at either midfield or farfield stations. H′ values averaged over the period 1992-1996 were 2.71 ± 0.32 for the nearfield, 2.57 ± 0.35 for the midfield, and 2.62 ± 0.46 for the farfield. These values will be refined after the 1997 samples have been analyzed.

- Similar calculations for number of species and numbers of individuals suggest that the farfield stations have only slightly higher numbers of species (76.8 vs. 68.9 for nearfield and 63.2 for midfield) and the nearfield and midfield have slightly higher abundances compared to the farfield (44,159 individuals/m^2 in the nearfield, 45,315 in the midfield and 33,505 in the farfield.) For all three parameters, the standard deviations are large, suggesting that the three study areas are comparable, despite substantial variability.

5.3 Hard-bottom Benthos

- Location on the drumlins, depth, substratum type and habitat relief all appear to play a role in determining the structure of the benthic communities inhabiting hard-bottom areas in the vicinity of the outfall. Some taxa show strong preferences for specific habitats, while others are broadly distributed.

- Some areas are homogeneous in terms of substratum type and the fauna inhabiting them, while other areas exhibit more patchiness. Some of the variability observed in the data may be related to difficulties in distinguishing between some of the categories of encrusting organisms that may encompass several species. However, a fair amount of the variability may be due to the inherently patchy nature of hard-bottom habitats and the fauna that inhabit them.

- Results obtained in 1996 generally agree with the 1995 findings, even though the areal coverage of the still photographs taken in 1995 was limited and also not as random compared to the 1996 survey. Direct comparisons of abundances and community composition of specific areas are hampered by the inherent within-habitat variability of the drumlins.

- Analysis of the still photographs shows finer details of the benthic communities than can be discerned from the video tapes. The two techniques are complimentary in that the video survey provides greater areal coverage and the still photographs provide a more accurate assessment of the taxa inhabiting these areas. Both techniques are valuable for establishing baseline data. The ability to use these data to detect possible future impacts would be enhanced if the still photographs were collected in a manner that permitted quantitative density estimates to be made.

- As with the soft-bottom benthic community analysis, consistency in taxonomic identifications will be of primary importance in ensuring the ability to make comparisons between baseline and post-operational data.

- The best potential indicator species for detecting change due to the outfall is the abundant and widely distributed coralline alga *Lithothamnion.*

- The distribution of sea urchins, *Strongylocentrotus droebachiensis,* on drumlin tops is believed to be correlated to availability of *Lithothamnion*, on which the urchins feed.

6.0 ACKNOWLEDGMENTS

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Appendix A

Station Data

Appendix A1. Target locations for outfall survey stations.

Station	Latitude	Longitude	Depth (m)
		Nearfield Stations	
NF13	42°23.40′N	70°49.35′W	33
NF14	42°23.20′N	70°49.36′W	33
NF15	42°22.93′N	70°49.67′W	32
NF17	42°22.88′N	70°48.89′W	29
NF18	42°23.80′N	70°49.31′W	35
NF19	42°22.30′N	70°48.30′W	32
NF23	42°23.86′N	70°48.10′W	36
NF24	42°22.83′N	70°48.10′W	37
		Midfield Stations	
MF2	42°20.31′N	70°49.69′W	30
MF4	42°24.93′N	70°48.39′W	36
MF5	42°25.62′N	70°50.03′W	36
MF7	42°24.60′N	70°48.89′W	33
MF8	42°24.00′N	70°51.81′W	32
MF9	42°23.99′N	70°50.69′W	29
MF10	42°23.57′N	70°50.29′W	35
MF12	42°23.40′N	70°49.83′W	34
MF16	42°22.70′N	70°50.26′W	29
MF20	42°22.69′N	70°50.69′W	28
MF21	42°24.16′N	70°50.19′W	33
MF22	42°20.87′N	70°48.90′W	36
FF10	42°24.84′N	70°52.72′W	27
FF12	42°23.40′N	70°53.98′W	22
FF13	42°19.19′N	70°49.38′W	19
		Farfield Stations	
FF1A	42°33.84′N	70°40.55′W	32
FF4	42°17.30′N	70°25.50′W	87
FF5	42°08.00′N	70°25.35′W	61
FF6	41°53.90′N	70°24.20′W	33
FF7	41°57.50′N	70°16.00′W	37
FF9	42°18.75′N	70°39.40′W	49
FF11	42°39.50′N	70°30.00′W	87
FF14	42°25.00′N	70°39.29′W	77

Appendix A2. Transects and waypoints visited during the nearfield hard-bottom survey, July 1996.

Transect	Waypoint	Latitude	Longitude	Depth (m)	Date	Start Time
T1	1	42°23.576'N	70°48.213'W	25	7/17/96	17:44
T1	2	42°23.621'N	70°48.312'W	23	7/17/96	18:47
T1	3	42°23.621'N	70°48.638'W	22	7/17/96	19:38
T1	4	42°23.832'N	70°48.863'W	21	7/18/96	08:13
T1	5	42°23.846'N	70°48.915'W	25	7/18/96	10:14
T2	2	42°23.593'N	70°47.696'W	30	7/18/96	12:42
T2	1	42°23.611'N	70°47.888'W	29	7/18/96	11:30
T2	3	42°23.550'N	70°47.417'W	29	7/18/96	13:33
T2	4	42°23.535'N	70°47.265'W	32	7/18/96	14:30
T2	5	42°23.330'N	70°47.786'W	36	7/18/96	15:28
T4	1	42°23.046'N	70°46.502'W	33	7/18/96	16:40
T4	2	42°23.012'N	70°46.927'W	30	7/18/96	17:22
T4	3	42°23.855'N	70°47.576'W	30	7/19/96	09:11
T4/T6*	4	42°22.957'N	70°47.184'W	22	7/19/96	08:19
T6	1	42°23.002'N	70°47.682'W	32	7/19/96	09:54
T6	2	42°22.901'N	70°47.030'W	23	7/19/96	11:03
T7	1	42°24.489'N	70°46.899'W	22	7/19/96	11:57
T7	2	42°24.554'N	70°46.926'W	26	7/19/96	14:39
T8	1	42°21.638'N	70°48.956'W	25	7/19/96	13:20
T8	2	42°21.841'N	70°48.499'W	27	7/19/96	15:50

* The fourth waypoints for T4 and T6 are the same (i.e., intersection of the two transects).

Appendix B

Sediment Data

Appendix B1. Grain-size composition of sediment from 23 Massachusetts Bay nearfield and midfield stations in August 1996. Data are percentages of total initial sample weight.

Station	% Gravel	% Very Coarse Sand	% Coarse Sand	% Medium Sand	% Fine Sand	% Very Fine Sand	% Total Sand	% Silt	% Clay	Mean Phi
	>2.00 mm	>1.00 to 2.00 mm	>0.50 to 1.00 mm	>0.25 to 0.50 mm	>0.125 to 0.25 mm	>0.0625 to 0.125 mm	>0.0625 to 2.00 mm	>0.0039 to 0.0625 mm	<0.003 9 mm	
	Phi < -1	-1 < Phi < 0	0 < Phi < 1	1 < Phi < 2	2 < Phi < 3	3 < Phi < 4	-1 < Phi < 4	4 < Phi < 8	Phi > 8	
MF-2	0.2	0.42	0.76	3.87	55.52	29.56	90.1	6.7	3.0	3.15
MF-4	0.1	0.05	0.42	11.26	76.28	7.28	95.3	2.9	1.7	2.66
MF-5	5.4	1.74	2.15	6.73	41.12	11.64	63.4	19.2	12.0	3.69
MF-7	2.6	0.53	1.21	8.65	31.09	20.08	61.5	24.5	11.4	4.07
MF-8	0.1	0.30	0.22	0.27	5.15	21.43	27.4	61.2	11.3	5.57
MF-9	0.1	0.11	0.75	3.31	12.27	36.90	53.3	34.9	11.6	4.79
MF-10	0.2	0.38	0.80	2.22	10.47	31.94	45.8	39.9	14.1	5.08
MF-12 Rep. 1	0.0	0.08	0.54	1.79	11.65	20.19	34.2	51.2	14.5	5.41
MF-12 Rep. 2	0.0	0.28	0.63	1.15	5.05	14.33	21.4	54.5	24.1	6.08
NF-13	20.7	3.11	21.23	31.93	18.88	0.83	76.0	2.0	1.4	1.00
NF-14	52.9	9.07	9.93	10.20	8.69	1.30	39.2	5.0	2.9	0.19
NF-15	3.2	0.72	5.74	30.50	39.00	9.79	85.7	7.5	3.5	2.52
MF-16	2.9	0.75	2.82	15.59	42.46	11.09	72.7	18.0	6.3	3.30
NF-17 Rep. 1	0.0	0.28	1.15	30.18	65.10	1.44	98.1	0.9	1.0	2.28
NF-17 Rep. 2	0.1	0.94	34.25	55.48	7.98	0.09	98.7	0.3	0.9	1.30
NF-18	70.8	2.58	3.77	10.72	4.03	1.02	22.1	4.7	2.4	-0.26
NF-19	0.8	1.18	3.54	13.69	55.15	13.58	87.1	7.3	4.7	2.92
MF-20	9.3	4.61	5.39	12.70	24.22	18.51	65.4	18.8	6.4	3.02
MF-21	9.6	0.26	0.37	0.65	5.78	20.50	27.6	50.4	12.3	4.87
MF-22	0.0	0.17	0.58	5.88	13.98	27.12	47.7	38.2	14.0	4.94

Appendix B1. Continued

Station	% Gravel	% Very Coarse Sand	% Coarse Sand	% Medium Sand	% Fine Sand	% Very Fine Sand	% Total Sand	% Silt	% Clay	Mean Phi
	>2.00 mm	>1.00 to 2.00 mm	>0.50 to 1.00 mm	>0.25 to 0.50 mm	>0.125 to 0.25 mm	>0.0625 to 0.125 mm	>0.0625 to 2.00 mm	>0.0039 to 0.0625 mm	<0.003 9 mm	
	Phi < -1	-1 < Phi < 0	0 < Phi < 1	1 < Phi < 2	2 < Phi < 3	3 < Phi < 4	-1 < Phi < 4	4 < Phi < 8	Phi > 8	
NF-23	5.4	0.98	2.62	48.11	37.69	2.36	91.8	1.0	1.9	1.90
NF-24 Rep. 1	0.2	0.39	2.03	8.98	7.49	12.18	31.1	54.4	14.4	5.31
NF-24 Rep. 2	0.3	0.58	1.27	6.73	11.11	12.71	32.4	49.6	17.7	5.39
FF-10 Rep. 1	6.3	1.58	2.84	7.41	21.54	33.18	66.5	22.5	4.7	3.49
FF-10 Rep. 2	0.5	0.54	1.22	3.03	16.80	49.51	71.1	22.2	6.2	4.09
FF-12 Rep. 1	1.9	0.51	0.70	2.23	8.56	56.18	68.2	23.8	6.1	4.16
FF-12 Rep. 2	8.3	0.46	0.83	1.94	9.89	49.75	62.9	22.8	6.1	3.81
FF-13 Rep. 1	0.6	0.53	0.94	3.06	12.54	20.89	38.0	48.3	13.1	5.16
FF-13 Rep. 2	1.0	0.22	0.97	20.07	21.40	15.25	57.9	29.9	11.2	4.16

Appendix B2. Total organic carbon (% C), total organic nitrogen (% N), and carbon/nitrogen ratio (C/N) in sediment samples from 23 Massachusetts Bay nearfield and midfield stations taken in August 1996.

Station	Total Organic % C	Station Mean	Total Organic % N	Station Mean	Carbon/Nitrogen C/N	Station Mean
MF-2	0.316	0.316	0.062*	0.062	5.93	5.93
MF-4	0.066	0.066	0.013*	0.013	5.89	5.89
MF-5	1.102	1.102	0.132	0.132	9.76	9.76
MF-7	1.420	1.420	0.134	0.134	12.35	12.35
MF-8	1.098	1.098	0.139	0.139	9.18	9.18
MF-9	1.186	1.186	0.117	0.117	11.82	11.82
MF-10	1.917	1.917	0.195	0.195	11.46	11.46
MF-12; Rep. 1; Rep. 2	1.503; 1.815	1.659	0.158; 0.212	0.185	11.11; 10.05	10.58
NF-13	0.313	0.313	0.043*	0.043	8.44	8.44
NF-14	0.640	0.640	0.058	0.058	12.92	12.92
NF-15	0.373	0.373	0.041*	0.041	10.65	10.65
MF-16	1.208	1.208	0.090*	0.090	15.70	15.70
NF-17: Rep.1; Rep.2	0.116; 0.045	0.081	0.027*; 0.011*	0.019	5.02; 4.88	4.95
NF-18	0.540	0.540	0.066	0.066	9.52	9.52
NF-19	0.206	0.206	0.045*	0.045	5.34	5.34
MF-20	0.506	0.506	0.061*	0.061	9.75	9.75
MF-21	1.230	1.230	0.105	0.105	13.62	13.62
MF-22	1.211	1.211	0.149	0.149	9.45	9.45
NF-23	0.095	0.095	0.018*	0.018	6.01	6.01
NF-24: Rep.1; Rep. 2	1.511; 1.749	1.630	0.160; 0.204	0.182	11.03; 10.00	10.52
FF-10: Rep. 1; Rep. 2	0.510; 0.536	0.523	0.069; 0.067*	0.068	8.58; 9.32	8.95
FF-12: Rep. 1; Rep. 2	0.831; 0.473	0.652	0.131; 0.063*	0.097	7.39; 8.81	8.10
FF-13: Rep. 1; Rep. 2	1.386; 1.559	1.473	0.199; 0.213	0.206	8.13; 8.54	8.34

* Near detection limit for nitrogen

Appendix B3. *Clostridium perfringens* spore analysis of sediment samples from the 23 Massachusetts Bay nearfield stations taken in August 1996.

Station	% Water	Counts	Mean	Coefficient of Variation	*C. perfringens* Wet weight	Spores per Gram Dry Weight Sample Mean	Station Mean
MF-2	28	70, 47	58.5	.28	850	1200	1200
MF-4	26	2, 8	5.0	.85	320	440	440
MF-5	34	23, 23	23.0	.00	1500	2300	2300
MF-7	35	18, 28	23.0	.31	1500	2300	2300
MF-8	42	63, 52	57.5	.14	3800	6500	6500
MF-9	30	41, 53	47.0	.18	2900	4100	3950
MF-9 Dup.	32	42, 42	42.0	.00	2600	3800	-
MF-10	45	26, 39	32.5	.28	2100	3800	3800
MF-12 Rep. 1	39	44, 36	40.0	.14	2800	4600	6300
MF-12 Rep. 2	44	68, 78	73.0	.10	4500	8000	-
NF-13	24	22, 19	20.5	.10	220	290	290
NF-14	20	61, 65	63.0	.04	800	1000	1000
NF-15	26	59, 58	58.5	.01	770	1000	1000
MF-16	24	34, 42	38.0	.15	2600	3400	3400
NF-17 Rep. 1	24	5, 9	7.0	.40	88	120	94
NF-17 Rep. 2	24	5, 1	3.0	.94	39	51	-
NF-17 Rep. 2 Dup.	20	4, 7	5.5	.39	68	85	-
NF-18	14	18, 22	20.0	.14	1300	1500	1500
NF-19	24	69, 65	67.0	.04	840	3500	3500
MF-20	27	61, 47	54.0	.18	3500	4800	4800
MF-21	38	59, 77	68.0	.19	4500	7300	7300
MF-22	40	81, 75	78.0	.05	5000	8300	8300
NF-23	23	2, 4	3.0	.47	190	240	240
NF-24 Rep. 1	45	36, 19	27.5	.44	1700	3200	5050
NF-24 Rep. 2	50	51, 59	55.0	.10	3400	6900	-
FF-10 Rep.1	30	6, 7	6.5	.11	980	1400	1650
FF-10 Rep.2	31	13, 16	14.5	.15	1100	1600	-
FF-10 Rep. 2 Dup	32	18, 19	18.5	.04	1500	2200	-
FF-12 Rep. 1	29	45, 51	48.0	.09	3800	5300	4850
FF-12 Rep. 2	27	37, 50	43.5	.21	3200	4400	-
FF-13 Rep. 1	43	48, 42	45.0	.09	7500	13000	12000
FF-13 Rep. 2	44	99, 106	102.5	.05	6400	11000	-

Appendix B4. Grain-size composition of sediment from eight Massachusetts Bay and Cape Cod Bay farfield stations in August 1996. Data are percentages of total initial sample weight.

Station	% Gravel	% Very Coarse Sand	% Coarse Sand	% Medium Sand	% Fine Sand	% Very Fine Sand	% Total Sand	% Silt	% Clay	Mean Phi
	>2.00 mm	>1.00 to 2.00 mm	>0.50 to 1.00 mm	>0.25 to 0.50 mm	>0.125 to 0.25 mm	>0.0625 to 0.125 mm	>0.0625 to 2.00 mm	>0.0039 to 0.0625 mm	<0.0039 mm	
	Phi < -1	-1 < Phi < 0	0 < Phi < 1	1 < Phi < 2	2 < Phi < 3	3 < Phi < 4	-1 < Phi <	4 < Phi < 8	Phi > 8	
FF-1A Rep. 1	0.1	0.51	3.38	6.02	14.08	54.76	78.7	16.8	4.4	3.78
FF-1A Rep. 2	0.1	0.20	0.93	2.70	4.47	17.35	25.7	56.4	17.9	3.46
FF-4 Rep. 1	0.0	0.68	1.71	2.20	2.88	4.20	11.7	60.9	27.5	6.38
FF-4 Rep. 2	0.0	0.92	1.51	2.16	3.66	5.17	13.4	58.3	28.3	6.35
FF-5 Rep. 1	0.0	0.39	1.62	3.05	8.65	31.39	45.1	42.2	12.7	5.04
FF-5 Rep. 2	0.1	0.47	1.28	3.90	9.55	32.20	47.4	40.5	12.0	4.94
FF-6 Rep. 1	0.0	0.37	0.49	0.82	4.89	32.34	38.9	43.5	17.6	5.46
FF-6 Rep. 2	0.0	0.11	0.15	0.46	6.65	27.19	34.6	45.8	19.6	5.64
FF-7 Rep. 1	0.1	0.20	1.21	3.59	5.01	10.57	20.6	56.2	23.2	6.01
FF-7 Rep. 2	0.0	0.59	1.87	2.46	3.74	8.07	16.7	58.3	24.9	6.16
FF-9 Rep. 1	0.3	0.43	0.91	4.20	38.52	40.78	84.8	8.7	6.2	3.53
FF-9 Rep. 2	0.0	0.64	1.03	3.87	37.28	39.96	82.8	10.5	6.8	3.63
FF-11 Rep. 1	0.0	0.11	0.42	1.18	3.77	16.95	22.4	56.1	21.5	6.01
FF-11 Rep. 2	0.0	0.11	0.25	1.05	4.31	19.69	25.4	41.2	33.4	6.29
FF-14 Rep. 1	0.2	0.46	1.63	4.03	5.84	20.08	3.0	52.2	15.5	5.44
FF-14 Rep. 2 Dup. 1	0.2	0.19	1.22	2.96	5.07	16.00	25.4	57.0	17.3	5.71
FF-14 Rep. 2 Dup. 2	0.1	0.20	0.93	2.70	4.47	17.35	25.7	56.4	17.9	5.75
FF-14 Rep. 2 Dup. 3	0.2	0.42	1.21	3.09	4.60	17.43	26.8	54.5	18.6	5.71

Appendix B5. Total organic carbon (% C), total organic nitrogen (% N), and carbon/nitrogen ratio (C/N) in sediment samples from eight Massachusetts Bay and Cape Cod Bay farfield stations taken in August 1996.

Station	Total Organic % C	Station Mean	Total Organic % N	Station Mean	Carbon/Nitrogen C/N	Station Mean
FF-1A: Rep. 1; Rep. 2	0.316; 0.897	0.607	0.035*; 0.058*	0.047	10.54; 18.05	14.30
FF-4: Rep. 1; Rep. 2	2.321; 2.343	2.332	0.317; 0.297	0.307	8.54; 9.19	8.87
FF-5: Rep. 1; Rep. 2	0.953; 1.158	1.056	0.129; 0.155	0.142	8.58; 8.74	8.66
FF-6: Rep. 1; Rep. 2	1.155; 1.693	1.424	0.130; 0.221	0.176	10.34; 8.95	9.65
FF-7: Rep. 1; Rep. 2	2.414; 2.442	2.428	0.339; 0.324	0.332	8.31; 8.80	8.56
FF-9: Rep. 1; Rep. 2	0.306; 0.378	0.342	0.038*; 0.038*	0.038	9.47; 11.57	10.52
FF-11: Rep. 1; Rep. 2	1.943; 1.905	1.924	0.243; 0.222	0.233	9.34; 10.03	9.69
FF-14: Rep. 1; Rep. 2	1.704; 1.209	1.457	0.231; 0.144	0.188	8.60; 9.79	9.20

* Near detection limit for nitrogen

Appendix B6. ***Clostridium perfringens*** **spore analysis of sediment samples from eight Massachusetts Bay and Cape Cod Bay farfield stations taken in August 1996.**

Station	% Water	Counts	Mean	Coefficient of Variation	*C. perfringens* Wet Weight	Spores per Gram Dry Weight Sample Mean	Spores per Gram Dry Weight Station Mean
FF-1A Rep. 1	26	50, 42	46.0	.12	620	840	920
FF-1A Rep. 2	27	69, 46	57.5	.28	730	1000	-
FF-4 Rep. 1	65	21, 16	18.5	.19	1400	4000	3150
FF-4 Rep. 2	61	12, 11	11.5	.06	900	2300	-
FF-5 Rep. 1	43	4 , 5	4.5	.16	340	600	645
FF-5 Rep. 2	45	6, 4	5.0	.28	380	690	-
FF-6 Rep. 1	52	10, 15	12.5	.28	940	2000	2250
FF-6 Rep. 2	47	15, 17	16.0	.09	1300	2500	-
FF-7 Rep. 1	59	9, 5	7.0	.40	580	1400	2200
FF-7 Rep. 2	65	16, 10	13.0	.33	1000	3000	-
FF-9 Rep. 1	28	8, 6	7.0	.20	540	750	780
FF-9 Rep. 2	31	8, 8	8.0	.00	560	810	-
FF-11 Rep. 1	55	11, 8	9.5	.22	780	1700	1500
FF-11 Rep. 2	56	7, 9	8.0	.18	570	1300	-
FF-14 Rep. 1	52	40, 53	46.5	.20	580	1200	1550
FF-14 Rep. 2	52	66, 65	65.5	.01	890	1900	-

APPENDIX C1

SPECIES IDENTIFIED FROM THE 1995/1996 BENTHIC INFAUNA SAMPLES (ALL STATIONS)

CNIDARIA
Ceriantheopsis americana (Verrill, 1866)
Cerianthus borealis Verrill, 1873
Corymorpha pendula L. Agassiz, 1862
Edwardsia elegans Verrill, 1869
Halcampa duodecimcirrata (Sars, 1851)

PLATYHELMINTHES
Turbellaria spp.

NEMERTEA
Amphiporus angulatus (Fabricius, 1774)
Amphiporus groenlandicus Oersted, 1844
Carinomella lactea Coe, 1905
Cerebratulus lacteus (Leidy, 1851)
Lineus pallidus Verrill, 1879
Micrura sp.
Nemertea sp. 2
Nemertea sp. 5
Nemertea sp. 6
Nemertea sp. 7
Tetrastemma vittatum Verrill, 1874
Tubulanus pellucidus (Coe, 1895)

PRIAPULA
Priapulus caudatus Lamarck, 1816

SIPUNCULA
Golfingia improvisa (Théel, 1905)
Phascolion strombi (Montagu, 1804)

ECHIURA
Echiurus echiurus (Pallas, 1767)

ANNELIDA
Polychaeta
Ampharetidae
Ampharete acutifrons Grube, 1860
Ampharete finmarchica (Sars, 1864)
Ampharete lindstroemi Malmgren, 1867
Amphicteis gunneri (Sars, 1835)
Anobothrus gracilis (Malmgren, 1866)
Asabellides oculata (Webster, 1879)
Melinna cristata (Sars, 1851)
Amphinomidae
Paramphinome jeffreysii (McIntosh, 1868)
Aphroditidae
Aphrodita sp.
Apistobranchidae
Apistobranchus typicus (Webster & Benedict, 1887)
Capitellidae
Capitella capitata complex (Fabricius, 1780)
Heteromastus filiformis (Claparède, 1864)
Mediomastus californiensis Hartman, 1944
Chaetopteridae
Spiochaetopterus oculatus Webster, 1879
Chrysopetalidae
Dysponetus pygmaeus Levinsen, 1879
Cirratulidae
Aphelochaeta marioni (Saint-Joseph, 1894)
Aphelochaeta monilaris (Hartman, 1960)
Caulleriella sp. B
Chaetozone setosa Malmgren, 1867
Chaetozone vivipara (Christie, 1985)
Cirratulus cirratus (O.F. Müller, 1776)
Monticellina baptisteae Blake, 1991
Monticellina dorsobranchialis (Kirkegaard, 1959)
Tharyx acutus Webster & Benedict, 1887
Tharyx sp. A

Cossuridae
Cossura longocirrata Webster & Benedict, 1887
Dorvilleidae
Dorvillea sociabilis (Webster, 1879)
Ophryotrocha cf. *labronica* La Greca & Bacci, 1962
Ophryotrocha sp. 1
Parougia caeca (Webster & Benedict, 1884)
Flabelligeridae
Brada incrustata Støp Bowitz, 1948
Diplocirrus hirsutus (Hansen, 1879)
Pherusa affinis (Leidy, 1855)
Glyceridae
Glycera capitata Oersted, 1843
Goniadidae
Goniada maculata Oersted, 1843
Hesionidae
Microphthalmus aberrans (Webster & Benedict, 1887)
Microphthalmus listensis Westheide, 1967
Lumbrineridae
Ninoe nigripes Verrill, 1873
Scoletoma fragilis (O.F. Müller, 1776)
Scoletoma hebes (Verrill, 1880)
Maldanidae
Axiothella catenata (Malmgren, 1865)
Clymenella torquata (Leidy, 1855)
Clymenura sp. A
Euclymene collaris (Claparède, 1870)
Maldane glebifex Grube, 1860
Maldane sarsi Malmgren, 1865
Petaloproctus tenuis (Théel, 1879)
Praxillella gracilis (Sars, 1861)
Praxillella praetermissa (Malmgren, 1866)
Praxillura ornata Verrill, 1880
Rhodine loveni Malmgren, 1865
Nephtyidae
Aglaophamus circinata (Verrill, 1874)
Nephtys caeca (Fabricius, 1780)
Nephtys ciliata (O.F. Müller, 1776)
Nephtys cornuta Berkeley & Berkeley, 1945
Nephtys discors Ehlers, 1868
Nephtys incisa Malmgren, 1865
Nephtys paradoxa Malm, 1874
Nereididae
Neanthes virens (Sars, 1835)
Nereis grayi Pettibone, 1956
Nereis procera Ehlers, 1868
Nereis zonata Malmgren, 1867
Oenonidae
Drilonereis magna Webster & Benedict, 1887
Labrorostratus parasiticus Saint-Joseph, 1888
Opheliidae
Ophelina acuminata Oersted, 1843
Orbiniidae
Leitoscoloplos acutus (Verrill, 1873)
Leitoscoloplos sp. B
Scoloplos acmeceps Chamberlin, 1919
Scoloplos armiger (O.F. Müller, 1776)
Scoloplos (Leodamas) ?rubra (Webster, 1879)
Oweniidae
Galathowenia oculata (Zachs, 1923)
Myriochele heeri Malmgren, 1867
Owenia fusiformis Delle Chiaje, 1844
Paraonidae
Aricidea catherinae Laubier, 1967
Aricidea minuta Southward, 1956
Aricidea quadrilobata Webster & Benedict, 1887
Levinsenia gracilis (Tauber, 1879)
Paradoneis lyra (Southern, 1914)

Pectinariidae
- *Pectinaria granulata* (Linnaeus, 1767)

Pholoidae
- *Pholoe minuta* (Fabricius, 1780)
- *Pholoe tecta* Stimpson, 1854

Phyllodocidae
- *Eteone flava* (Fabricius, 1780)
- *Eteone heteropoda* Hartman, 1951
- *Eteone longa* (Fabricius, 1780)
- *Mystides borealis* Théel, 1879
- *Paranaitis speciosa* (Webster, 1880)
- *Phyllodoce arenae* Webster, 1879
- *Phyllodoce groenlandica* Oersted, 1843
- *Phyllodoce maculata* (Linnaeus, 1767)
- *Phyllodoce mucosa* Oersted, 1843

Polygordiidae
- *Polygordius* sp. A

Polynoidae
- *Arcteobia anticostiensis* (McIntosh, 1874)
- *Austrolaenilla mollis* (Sars, 1872)
- *Bylgides sarsi* (Kinberg, 1865)
- *Enipo gracilis* Verrill, 1874
- *Enipo torelli* (Malmgren, 1865)
- *Gattyana amondseni* (Malmgren, 1867)
- *Harmothoe extenuata* (Grube, 1840)
- *Harmothoe imbricata* (Linnaeus, 1767)
- *Hartmania moorei* Pettibone, 1955

Sabellidae
- *Chone duneri* Malmgren, 1867
- *Chone infundibuliformis* Krøyer, 1856
- *Euchone elegans* Verrill, 1873
- *Euchone incolor* Hartman, 1978
- *Euchone papillosa* (Sars, 1851)
- *Laonome kroeyeri* Malmgren, 1866
- *Myxicola infundibulum* (Renier, 1804)

Scalibregmatidae
- *Scalibregma inflatum* Rathke, 1843

Sphaerodoridae
- *Sphaerodoridium* sp. A
- *Sphaerodoropsis minuta* (Webster & Benedict, 1887)

Spionidae
- *Laonice cirrata* (Sars, 1851)
- *Laonice* sp. 1
- *Polydora caulleryi* Mesnil, 1897
- *Polydora concharum* Verrill, 1880
- *Polydora quadrilobata* Jacobi, 1883
- *Dipolydora socialis* (Schmarda, 1861)
- *Polydora websteri* Hartman, 1943
- *Prionospio steenstrupi* Malmgren, 1867
- *Spio filicornis* (O.F. Müller, 1776)
- *Spio limicola* Verrill, 1880
- *Spio thulini* Maciolek, 1990
- *Spiophanes bombyx* (Claparède, 1870)
- *Spiophanes kroeyeri* Grube, 1860
- *Streblospio benedicti* Webster, 1879

Sternaspidae
- *Sternaspis scutata* (Otto, 1821)

Syllidae
- *Exogone hebes* (Webster & Benedict, 1884)
- *Exogone longicirris* (Webster & Benedict, 1887)
- *Exogone verugera* (Claparède, 1868)
- *Pionosyllis* sp. A
- *Sphaerosyllis brevifrons* Webster & Benedict, 1884
- *Sphaerosyllis longicauda* Webster & Bendict, 1887
- *Syllides convoluta* Webster & Benedict, 1884
- *Syllides japonica* Imajima, 1966
- *Syllides longocirrata* Oersted, 1845
- *Typosyllis* sp. 1

Terebellidae
- *Lanassa venusta venusta* (Malm, 1874)
- *Pista cristata* (O.F. Müller, 1776)
- *Polycirrus eximius* (Leidy, 1855)
- *Polycirrus* cf. *haematodes* (Claparède, 1864)
- *Polycirrus medusa* Grube, 1850
- *Proclea graffii* (Langerhans, 1880)

Trichobranchidae
- *Terebellides atlantis* Williams, 1984
- *Terebellides stroemi* Sars, 1835

Trochochaetidae
- *Trochochaeta carica* (Birula, 1897)
- *Trochochaeta multisetosa* (Oersted, 1844)

Oligochaeta

Tubificidae
- *Adelodrilus* sp. 1
- *Adelodrilus* sp. 2
- Tubificidae sp. 2
- Tubificidae sp. 4
- *Tubificoides apectinatus* Brinkhurst, 1965

Enchytraeidae
- Enchytraeidae sp. 1

CRUSTACEA

Amphipoda

Ampeliscidae
- *Ampelisca abdita* Mills, 1864
- *Ampelisca macrocephala* Lilljeborg, 1852
- *Byblis gaimardi* (Krøyer, 1847)
- *Haploops fundiensis* Wildish & Dickinson, 1982

Amphilochidae
- *Gitanopsis arctica* Sars, 1895

Aoridae
- *Leptocheirus pinguis* (Stimpson, 1853)

Argissidae
- *Argissa hamatipes* (Norman, 1869)

Caprellidae
- *Aeginina longicornis* (Krøyer, 1842-43)
- *Caprella linearis* (Linnaeus, 1767)
- *Mayerella limicola* Huntsman, 1915
- *Paracaprella tenuis* Mayer, 1903

Corophiidae
- *Corophium acherusicum* Costa, 1857
- *Corophium crassicorne* Bruzelius,1859
- *Corophium insidiosum* Crawford, 1937
- *Corophium tuberculatum* Shoemaker, 1834
- *Pseudunciola obliqua* (Shoemaker, 1949)
- *Unciola inermis* Shoemaker, 1942
- *Unciola irrorata* Say, 1818

Gammaridae
- *Gamarellus angulosus* (Rathke, 1843)

Haustoriidae
- *Acanthohaustorius millsi* Bousfield, 1965

Isaeidae
- *Photis pollex* Walker, 1895
- *Protomedea fasciata* Krøyer, 1842

Ischyroceridae
- *Erichthonius rubricornis* Smith, 1873
- *Ischyrocerus anguipes* Krøyer, 1838
- *Jassa marmorata* Holmes, 1903

Lysianassidae
- *Anonyx lilljeborgi* Boeck, 1871
- *Hippomedon propinquus* Sars, 1895
- *Hippomedon serratus* Holmes, 1905
- *Orchomene pinguis* (Boeck, 1861)
- *Orchomenella minuta* Krøyer, 1846

Melitidae
- *Casco bigelowi* (Blake, 1929)
- *Maera loveni* (Bruzelius, 1859)
- *Melita* nr. *dentata* (Krøyer, 1842)

Oedicerotidae
Bathymedon obtusifrons (Hansen, 1887)
Monoculodes intermedius Shoemaker, 1830
Monoculodes packardi Boeck, 1871
Monoculodes tesselatus Schneider, 1884
Monoculodes tuberculatus Boeck, 1870
Monoculodes sp. 1
Westwoodilla brevicalcar Goës, 1866
Phoxocephalidae
Eobrolgus spinosus (Holmes, 1905)
Harpinia propinqua Sars, 1895
Phoxocephalus holbolli (Krøyer, 1842)
Rhepoxynius hudsoni Barnard & Barnard, 1982
Pleustidae
Pleusymtes glaber (Boeck, 1861)
Stenopleustes inermis Shoemaker, 1949
Podoceridae
Dulichia falcata (Bate, 1857)
Dyopedos monacanthus (Metzger, 1875)
Paradulichia typica Boeck, 1870
Pontogeneiidae
Pontogeneia inermis (Krøyer, 1842)
Stenothoidae
Metopella angusta Shoemaker, 1949
Proboloides holmesi Bousfield, 1973
Synopiidae
Syrrhoe crenulata (Goës, 1866)

Cirripedia
Balanidae
Balanus crenatus Bruguiere, 1789
Cumacea
Diastylidae
Diastylis cornuifer (Blake, 1929)
Diastylis polita (S.I. Smith, 1879)
Diastylis quadrispinosa (Sars, 1871)
Diastylis sculpta Sars, 1871
Leptostylis ampullacea (Lilljeborg, 1855)
Leptostylis longimana (Sars, 1865)
Lampropidae
Lamprops quadriplicata S.I. Smith, 1879
Leuconidae
Eudorella hispida Sars, 1871
Eudorella pusilla Sars, 1871
Eudorellopsis deformis (Krøyer, 1846)
Leucon acutirostris Sars, 1865
Leucon fulvus Sars, 1865
Leucon nasicoides Lilljeborg, 1855
Nannastacidae
Campylaspis rubicunda (Lilljeborg, 1855)
Campylaspis nr. *sulcata* Sars, 1869
Pseudocumatidae
Petalosarsia declivis (Sars, 1865)

Decapoda
Cancridae
Cancer borealis Stimpson, 1859
Paguridae
Pagurus acadianus Benedict, 1901

Isopoda
Anthuriidae
Ptilanthura tenuis Harger, 1879
Chaetiliidae
Chiridotea tuftsi (Stimpson, 1883)
Cirolanidae
Politolana polita (Stimpson, 1853)
Idoteidae
Edotia montosa (Stimpson, 1853)
Idotea balthica (Pallas, 1772)
Munnidae
Munna sp. 1
Paramunnidae
Pleurogonium inerme Sars, 1882
Pleurogonium rubicundum (Sars, 1863)
Pleurogonium spinosissimum (Sars, 1866)

Mysidacea
Mysidae
Erythrops erythrophthalma (Göes, 1863)
Neomysis americana (S.I. Smith, 1873)

Tanaidacea
Nototanaidae
Tanaissus psammophilus (Wallace, 1919)

Mollusca
Aplacophora
Chaetodermatidae
Chaetoderma nitidulum canadense (Nierstrasz, 1902)
Bivalvia
Arctidae
Arctica islandica (Linnaeus, 1767)
Astartidae
Astarte borealis (Schumacher, 1817)
Astarte undata Gould, 1841
Cardiidae
Cerastoderma pinnulatum (Conrad, 1831)
Carditidae
Cyclocardia borealis (Conrad, 1831)
Hiatellidae
Hiatella arctica (Linnaeus, 1767)
Lyonsiidae
Lyonsia arenosa Möller, 1842
Montacutidae
Pythinella cuneata Dall, 1899
Myidae
Mya arenaria Linnaeus, 1758
Mytiliidae
Crenella decussata (Montagu, 1808)
Crenella glandula (Totten, 1834)
Musculus discors (Linnaeus, 1767)
Musculus niger (Gray, 1824)
Mytilus edulis Linnaeus, 1758
Nuculidae
Nucula annulata Hampson, 1971
Nucula delphinodonta Mighels & Adams, 1842
Nuculoma tenuis (Montagu, 1808)
Nuculanidae
Megayoldia thraciaeformis (Storer, 1838)
Nuculana nr. *messanensis* (Seguenza, 1877)
Yoldia sapotilla (Gould, 1841)
Yoldiella lucida Lovén,1846
Pandoridae
Pandora nr. *inflata* Boss & Merrill, 1965
Periplomatidae
Periploma papyratium (Say, 1822)
Solemyidae
Solemya sp.
Solenidae
Ensis directus Conrad, 1843
Siliqua costata Say, 1822
Tellinidae
Macoma balthica (Linnaeus, 1758)
Thyasiridae
Thyasira flexuosa (Montagu, 1803)
Thyasira nr. *minutus* (Verrill and Bush, 1898)

Thraciidae
Asthenothaerus hemphilli Dall, 1886
Thracia conradi Couthouy, 1838
Veneridae
Pitar morrhuanus Linsley, 1848

Gastropoda
Nudibranchia
Corambidae
Doridella sp.

Opisthobranchia
Acteocinidae
Acteocina canaliculata (Say, 1822)
Cylichnidae
Cylichna alba (Brown, 1827)
Cylichna gouldi (Couthouy, 1839)
Diaphanidae
Diaphana minuta (Brown, 1827)
Retusidae
Retusa obtusa (Montagu, 1807)

Prosobranchia
Buccinidae
Colus pygmaeus (Gould, 1841)
Calyptraeidae
Crepidula fornicata (Linnaeus, 1758)
Nassariidae
Ilyanassa trivittata (Sars, 1822)
Naticidae
Euspira heros (Say, 1822)
Pyramidellidae
Odostomia sulcosa (Mighels, 1843)
Rissoidae
Onoba mighelsi (Stimpson, 1851)
Onoba pelagica (Stimpson, 1851)
Pusillina harpa (Verrill, 1880)
Trochidae
Margarites costalis (Gould, 1841)
Turridae
Oenopota harpularia (Couthouy, 1838)
Oenopota incisula Verrill, 1882
Propebela exarata (Möller, 1842)

Polyplacophora
Polyplacophora spp.
Scaphopoda
Dentaliidae
Dentalium entale Linnaeus, 1758

PHORONIDA
Phoronis architecta Andrews, 1890

ECHINODERMATA
Asteroidea
Ctenodiscus crispatus (Retzius, 1805)
Echinoidea
Echinarachnius parma (Lamarck, 1816)
Holothuroidea
Molpadia oolitica (Pourtalès, 1851)
Ophiuroidea
Axiognathus squamatus (Delle Chiaje, 1828)
Ophiocten sericeum (Forbes, 1852)
Ophiura sarsi Lütken, 1855
Ophiura sp. 2

HEMICHORDATA
Stereobalanus canadensis (Spengel, 1893)

CHORDATA
Ascidiacea
Molgulidae
Molgula manhattensis (DeKay, 1843)
Bostrichobranchus pilularis (Verrill, 1871)
Styelidae
Cnemidocarpa mollis (Stimpson, 1852)

APPENDIX C2

DOMINANT SPECIES AT NEARFIELD AND MIDFIELD STATIONS

Rank	Species	Percent of Total Fauna	Percent of Identified Fauna	Density (Ind./0.04m^2)
	Station MF2 - single sample			
1	*Prionospio steenstrupi* (P)	26.02	27.16	556
2	*Owenia fusiformis* (P)	19.15	19.98	409
3	*Mediomastus californiensis* (P)	8.94	9.33	191
4	*Aricidea catherinae* (P)	8.75	9.14	187
5	*Spio limicola* (P)	8.33	8.70	178
6	*Aphelochaeta marioni* (P)	4.96	5.18	106
7	*Tharyx acutus* (P)	4.68	4.89	100
8	*Ninoe nigripes* (P)	4.31	4.49	92
9	*Phoronis architecta* (PH)	3.84	4.01	82
10	*Nucula delphinodonta* (B)	3.37	3.52	72
	Total - 10 Taxa	92.35	96.40	1973
	Remaining Fauna - 78 Taxa	7.65	--	163
	Total Fauna - 88 Taxa	100	--	2136
	Station MF4 - single sample			
1	*Corophium crassicorne* (A)	48.29	50.62	944
2	*Exogone hebes* (P)	13.30	13.94	260
3	*Hiatella arctica* (B)	6.70	7.02	131
4	*Cerastoderma pinnulatum* (B)	6.50	6.81	127
5	*Exogone verugera* (P)	4.65	4.88	91
6	*Dipolydora socialis* (P)	3.84	4.02	75
6	*Aglaophamus circinata* (P)	1.99	2.09	39
8	*Protomedea fasciata* (A)	1.23	1.29	24
9	*Photis pollex* (A)	0.82	0.86	16
10	*Unciola inermis* (A)	0.66	0.70	13
	Total - 10 Taxa	87.98	92.23	1704
	Remaining Fauna - 62 Taxa	12.02	--	251
	Total Fauna - 72 Taxa	100	--	1955

Rank	Species	Percent of Total Fauna	Percent of Identified Fauna	Density (Ind./0.04m^2)
	Station MF5 - single sample			
1	*Prionospio steenstrupi* (P)	20.09	21.45	322
2	*Aphelochaeta marioni* (P)	12.54	13.39	201
3	*Mediomastus californiensis* (P)	7.67	8.19	123
4	*Exogone verugera* (P)	6.92	7.40	111
5	*Nucula delphinodonta* (B)	5.36	5.73	86
6	*Crenella decussata* (B)	4.99	5.33	80
7	*Haploops fundiensis* (A)	3.37	3.60	54
8	*Thyasira flexuosa* (B)	2.74	2.93	44
9	*Tharyx acutus* (P)	2.18	2.33	35
10	*Ninoe nigripes* (P)	1.93	2.07	31
	Total - 10 Taxa	67.79	72.42	1087
	Remaining Fauna - 96 Taxa	32.21	--	516
	Total Fauna - 106 Taxa	100	--	1603
	Station MF7 - single sample			
1	*Prionospio steenstrupi* (P)	19.06	20.07	276
2	*Spio limicola* (P)	13.67	14.40	198
3	*Aphelochaeta marioni* (P)	9.19	9.67	133
4	*Dipolydora socialis* (P)	9.05	9.53	131
5	*Mediomastus californiensis* (P)	7.67	8.07	111
6	*Ninoe nigripes* (P)	2.83	2.98	41
7	*Nucula delphinodonta* (B)	2.69	2.84	39
8	*Levinsenia gracilis* (P)	2.62	2.76	38
9	*Euchone incolor* (P)	2.49	2.62	36
10	*Exogone verugera* (P)	2.07	2.18	30
	Total - 10 Taxa	71.34	75.12	1033
	Remaining Fauna - 75 Taxa	28.66	--	415
	Total Fauna - 85 Taxa	100	--	1448

Rank	Species	Percent of Total Fauna	Percent of Identified Fauna	Density (Ind./0.04m^2)
Station MF8 - single sample				
1	*Mediomastus californiensis* (P)	28.96	31.56	397
2	*Prionospio steenstrupi* (P)	19.04	20.75	261
3	*Ninoe nigripes* (P)	14.37	15.66	197
4	*Monticellina baptisteae* (P)	7.80	8.51	107
5	*Euchone incolor* (P)	2.92	3.18	40
6	*Parougia caeca* (P)	2.77	3.02	38
7	*Leitoscoloplos acutus* (P)	2.63	2.86	36
8	*Exogone hebes* (P)	2.33	2.54	32
9	*Levinsenia gracilis* (P)	1.82	1.99	25
10	*Aricidea catherinae* (P)	1.53	1.67	21
	Total - 10 Taxa	84.17	91.74	1154
	Remaining Fauna - 52 Taxa	15.83	--	217
	Total Fauna - 62 Taxa	100	--	1371
Station MF9 - single sample				
1	*Prionospio steenstrupi* (P)	13.32	14.81	224
2	*Mediomastus californiensis* (P)	12.43	13.81	209
3	*Ninoe nigripes* (P)	10.94	12.16	184
4	*Spio limicola* (P)	8.44	9.39	142
5	*Aricidea catherinae* (P)	6.54	7.27	110
6	*Aphelochaeta marioni* (P)	5.35	5.95	90
7	*Monticellina baptisteae* (P)	5.17	5.75	87
8	*Nucula delphinodonta* (B)	3.57	3.97	60
9	*Euchone incolor* (P)	2.85	3.17	48
10	*Tharyx acutus* (P)	2.68	2.97	45
	Total - 10 Taxa	71.29	79.25	1199
	Remaining Fauna - 82 Taxa	28.71	--	483
	Total Fauna - 92 Taxa	100	--	1682

Station MF10 - single sample				
Rank	**Species**	**Percent of Total Fauna**	**Percent of Identified Fauna**	**Density (Ind./0.04m^2)**
1	*Mediomastus californie*nsis (P)	23.95	25.50	395
2	*Spio limicola* (P)	16.74	17.82	276
3	*Prionospio steenstrupi* (P)	13.83	14.72	228
4	*Aphelochaeta marioni* (P)	6.49	6.91	107
5	*Ninoe nigripes* (P)	5.46	5.81	90
6	*Aricidea catherinae* (P)	4.97	5.29	82
7	*Tharyx acutus* (P)	4.18	4.45	69
8	*Ampharete acutifrons* (P)	3.64	3.87	60
9	*Leitoscoloplos acutus* (P)	1.94	2.07	32
10	*Metopella angusta* (A)	1.39	1.48	23
10	*Monticellina baptist*eae (P)	1.39	1.48	23
	Total - 11 Taxa	83.98	89.40	1385
	Remaining Fauna - 67 Taxa	16.02	--	264
	Total Fauna - 77 Taxa	100	--	1649

Station MF12 - replicated station				
Rank	**Species**	**Percent of Total Fauna**	**Percent of Identified Fauna**	**Density (Ind./0.12m^2)**
1	*Mediomastus californiensis* (P)	20.11	21.20	1339
2	*Spio limicola* (P)	17.18	18.11	1144
3	*Aphelochaeta marioni* (P)	9.90	10.43	659
4	*Aricidea catherinae* (P)	9.40	9.91	626
5	*Ninoe nigripes* (P)	6.83	7.20	455
6	*Prionospio steenstrupi* (P)	5.05	5.32	336
7	*Levinsenia gracilis* (P)	4.87	5.13	324
8	*Euchone incolor* (P)	4.24	4.46	282
9	*Leitoscoloplos acutus* (P)	1.76	1.85	117
10	*Nucula delphinodonta* (B)	1.74	1.84	116
	Total - 10 Taxa	81.08	85.45	5317
	Remaining Fauna - 117 Taxa	18.92	--	1341
	Total Fauna - 127 Taxa	100	--	6658

Station FF10 - off Nahant				
Rank	**Species**	**Percent of Total Fauna**	**Percent of Indentified Fauna**	**Density (Ind./0.12m^2)**
1	*Prionospio steenstrupi* (P)	14.95	15.95	1005
2	*Spio limicola* (P)	11.20	11.95	753
3	*Mediomastus californiensis*(P)	6.78	7.24	456
4	*Nucula delphinodonta* (B)	5.68	6.06	382
5	*Aphelochaeta marioni* (P)	5.65	6.03	380
6	*Aricidea catherinae* (P)	5.27	5.62	354
7	*Monticellina baptisteae* (P)	4.73	5.05	318
8	*Ninoe nigripes* (P)	4.72	5.03	317
9	*Tharyx acutus* (P)	3.72	3.97	250
10	*Leitoscoloplos acutus* (P)	2.28	2.43	153
	Total - 10 Taxa	64.98	69.33	4368
	Remaining Fauna - 133 Taxa	35.02	--	2354
	Total Fauna - 143 Taxa	100.00	--	6722

Station FF12 - off Nahant				
Rank	**Species**	**Percent of Total Fauna**	**Percent of Identified Fauna**	**Density (Ind./0.12m²)**
1	*Owenia fusiformis* (P)	21.74	22.66	2015
2	*Tharyx acutus* (P)	16.94	17.66	1570
3	*Prionospio steenstrupi* (P)	14.90	15.53	1381
4	*Mediomastus californiensis* (P)	9.42	9.82	873
5	*Scoletoma hebes* (P)	4.24	4.42	393
6	*Ninoe nigripes* (P)	3.50	3.64	324
7	*Monticellina baptisteae* (P)	3.44	3.59	319
8	*Phoronis architecta* (PH)	2.52	2.63	234
9	*Aricidea catherinae* (P)	2.33	2.43	216
10	*Dipolydora socialis* (P)	2.16	2.25	200
	Total - 10 Taxa	81.19	84.63	7525
	Remaining Fauna - 105 Taxa	18.81	--	1745
	Total Fauna - 115 Taxa	100	--	9270
Station FF13 - off Hull				
1	*Prionospio steenstrupi* (P)	20.56	21.08	1477
2	*Nephtys cornuta* (P)	13.14	13.47	944
3	*Phoronis architecta* (PH)	9.26	9.49	665
4	*Photis pollex* (A)	7.92	8.12	569
5	*Mediomastus californiensis* (P)	6.25	6.41	449
6	*Ampelisca abdita* (A)	6.14	6.29	441
7	*Tharyx acutus* (P)	5.30	5.44	381
8	*Aricidea catherinae* (P)	3.86	3.95	277
9	*Leitoscoloplos acutus* (P)	3.48	3.57	250
10	*Pleurogonium rubicundum* (I)	2.80	2.87	201
	Total - 10 Taxa	78.71	80.69	5654
	Remaining Fauna - 86 Taxa	21.29	--	1531
	Total Fauna - 96 Taxa	100	--	7185

Rank	Species	Percent of Total Fauna	Percent of Identified Fauna	Density (Ind./0.04m²)
Station NF13 - single sample				
1	*Exogone hebes* (P)	30.19	31.29	480
2	*Corophium crassicorne* (A)	25.53	26.47	406
3	Enchytraeidae sp. 1 (O)	10.38	10.76	165
4	*Exogone verugera* (P)	9.31	9.65	148
5	*Aglaophamus circinata* (P)	2.89	3.00	46
6	*Cerastoderma pinnulatum* (B)	2.83	2.93	45
7	*Apistobranchus typicus* (P)	2.01	2.09	32
8	*Echinarachnius parma* (E)	1.19	1.24	19
9	*Crenella decussata* (B)	1.07	1.11	17
9	*Euclymene collaris* (P)	1.07	1.11	17
9	*Unciola inermis* (A)	1.07	1.11	17
10	*Tharyx acutus* (P)	1.01	1.04	16
	Total - 13 Taxa	88.55	91.80	1408
	Remaining Fauna - 54 Taxa	11.45	--	182
	Total Fauna - 67 Taxa	100	--	1590
Station NF14 - single sample				
1	*Prionospio steenstrupi* (P)	34.51	36.22	733
2	*Exogone hebes* (P)	14.60	15.32	310
3	*Mediomastus californiensis* (P)	7.67	8.05	163
4	*Aricidea catherinae* (P)	5.65	5.93	120
5	*Ninoe nigripes* (P)	5.13	5.39	109
6	*Crenella decussata* (B)	3.11	3.26	66
7	*Exogone verugera* (P)	2.78	2.92	59
8	*Euchone incolor* (P)	2.31	2.42	49
9	*Cerastoderma pinnulatum* (B)	2.26	2.37	48
10	Tubificidae sp. 2 (O)	2.16	2.27	46
	Total - 10 Taxa	80.18	84.15	1703
	Remaining Fauna - 83 Taxa	19.82	--	421
	Total Fauna - 93 Taxa	100	--	2124

Rank	Species	Percent of Total Fauna	Percent of Indentified Fauna	Density (Ind./0.04m^2)
Station NF15 - single sample				
1	*Prionospio steenstrupi* (P)	40.59	42.42	666
2	*Mediomastus californiensis* (P)	10.66	11.15	175
3	*Tharyx acutus* (P)	5.18	5.41	85
4	*Ninoe nigripes* (P)	4.45	4.65	73
5	*Exogone hebes* (P)	4.14	4.33	68
6	*Aricidea catherinae* (P)	3.96	4.14	65
7	*Euchone incolor* (P)	2.93	3.06	48
8	*Cerastoderma pinnulatum* (B)	2.68	2.80	44
9	*Aphelochaeta marioni* (P)	2.25	2.36	37
10	*Parougia caeca* (P)	1.40	1.46	23
	Total - 10 Taxa	78.24	81.78	1284
	Remaining Fauna - 72 Taxa	21.76	--	357
	Total Fauna - 82 Taxa	100	--	1641
Station MF16 - single sample				
1	*Mediomastus californiensis* (P)	10.25	10.92	152
2	*Ninoe nigripes* (P)	10.18	10.85	151
2	*Spio limicola* (P)	10.18	10.85	151
4	*Aphelochaeta marioni* (P)	9.64	10.27	143
5	*Euchone incolor* (P)	6.88	7.33	102
6	*Levinsenia gracilis* (P)	6.34	6.75	94
6	*Prionospio steenstrupi* (P)	6.34	6.75	94
8	*Tharyx acutus* (P)	6.14	6.54	91
9	Tubificidae sp. 2 (O)	4.59	4.89	68
10	*Monticellina baptisteae* (P)	3.71	3.95	55
	Total - 10 Taxa	74.25	79.10	1101
	Remaining Fauna - 68 Taxa	25.75	--	382
	Total Fauna - 78 Taxa	100	--	1483

Station NF17 - replicated station				
Rank	**Species**	**Percent of Total Fauna**	**Percent of Identified Fauna**	**Density (Ind./0.12m²)**
1	*Polygordius* sp. A (P)	18.47	21.80	704
2	*Corophium crassicorne* (A)	18.18	21.46	693
3	*Unciola inermis* (A)	16.32	19.26	622
4	*Euclymene collaris* (P)	5.82	6.87	222
5	*Hiatella arctica* (B)	3.88	4.58	148
6	*Cerastoderma pinnulatum* (B)	3.78	4.46	144
7	*Unciola irrorata* (A)	2.86	3.37	109
8	Tubificidae sp. 4 (O)	2.73	3.22	104
9	*Crenella glandula* (B)	2.68	3.16	102
10	*Exogone hebes* (P)	2.47	2.91	94
	Total - 10 Taxa	77.19	91.09	2942
	Remaining Fauna - 117 Taxa	22.81	--	870
	Total Fauna - 127 Taxa	100	--	3812

Station NF18 - single sample				
Rank	**Species**	**Percent of Total Fauna**	**Percent of Identified Fauna**	**Density (Ind./0.04m²)**
1	*Prionospio steenstrupi* (P)	29.35	32.01	518
2	*Ninoe nigripes* (P)	8.33	9.09	147
3	*Hiatella arctica* (B)	5.38	5.87	95
4	*Mediomastus californiensis* (P)	4.02	4.39	71
5	*Dipolydora socialis* (P)	3.91	4.26	69
6	*Exogone hebes* (P)	3.63	3.96	64
7	*Euchone incolor* (P)	3.57	3.89	63
8	*Tharyx acutus* (P)	3.46	3.77	61
9	*Aphelochaeta marioni* (P)	2.72	2.97	48
10	*Spio limicola* (P)	2.66	2.90	47
	Total - 10 Taxa	67.03	73.11	1183
	Remaining Fauna - 88 Taxa	32.97	--	582
	Total Fauna - 98 Taxa	100	--	1765

Rank	Species	Percent of Total Fauna	Percent of Identified Fauna	Density (Ind./0.04m^2)
Station NF19 - single sample				
1	*Prionospio steenstrupi* (P)	23.75	24.89	579
2	*Exogone hebes* (P)	8.78	9.20	214
3	*Spio limicola* (P)	7.96	8.34	194
4	*Dipolydora socialis* (P)	6.93	7.27	169
5	*Aphelochaeta marioni* (P)	6.44	6.75	157
6	*Mediomastus californiensis* (P)	4.96	5.20	121
7	*Exogone verugera* (P)	4.84	5.07	118
8	*Euchone incolor* (P)	2.30	2.41	56
9	*Aricidea catherinae* (P)	2.21	2.32	54
9	*Nucula delphinodonta* (B)	2.21	2.32	54
10	*Ninoe nigripes* (P)	2.09	2.19	51
	Total - 11 Taxa	72.47	75.96	1767
	Remaining Fauna - 112 Taxa	27.53	--	671
	Total Fauna - 123 Taxa	100	--	2438
Station MF20 - single sample				
1	*Prionospio steenstrupi* (P)	26.32	27.36	765
2	*Ninoe nigripes* (P)	12.08	12.55	351
3	*Mediomastus californiensis* (P)	10.25	10.66	298
4	*Tharyx acutus* (P)	6.71	6.97	195
5	*Euchone incolor* (P)	5.13	5.33	149
6	*Monticellina baptisteae* (P)	4.68	4.86	136
7	*Aricidea catherin*ae (P)	4.09	4.26	119
8	Tubificidae sp. 2 (O)	3.72	3.86	108
9	*Spio limicola* (P)	2.89	3.00	84
10	*Levinsenia gracilis* (P)	1.89	1.97	55
	Total - 10 Taxa	78.12	80.82	2260
	Remaining Fauna - 89 Taxa	21.88	--	646
	Total Fauna - 99 Taxa	100.00	--	2906

Rank	Species	Percent of Total Fauna	Percent of Identified Fauna	Density (Ind./0.04m²)
Station MF21 - single sample				
1	*Spio limicola* (P)	16.98	18.20	244
2	*Mediomastus californiensis* (P)	13.99	15.00	201
3	*Monticellina baptisteae* (P)	6.40	6.86	92
4	*Ninoe nigripes* (P)	6.05	6.49	87
5	*Euchone incolor* (P)	5.50	5.89	79
6	*Prionospio steenstrupi* (P)	5.21	5.59	75
7	*Aricidea catherinae* (P)	4.66	5.00	67
8	*Aphelochaeta marioni* (P)	4.45	4.77	64
9	*Levinsenia gracilis* (P)	4.11	4.40	59
10	*Nucula delphinodonta* (B)	3.34	3.58	48
	Total - 10 Taxa	70.69	75.78	1016
	Remaining Fauna - 75 Taxa	29.31	--	421
	Total Fauna - 85 Taxa	100	--	1437
Station MF22 - single sample				
1	*Ninoe nigripes* (P)	18.14	19.43	534
2	*Spio limicola* (P)	16.95	18.16	499
3	*Mediomastus californiensis* (P)	12.87	13.79	379
4	*Euchone incolor* (P)	7.44	7.97	219
5	*Aphelochaeta marioni* (P)	5.74	6.15	169
6	*Tharyx acutus* (P)	5.64	6.04	166
7	*Levinsenia gracilis* (P)	3.87	4.15	114
8	*Prionospio steenstrupi* (P)	3.06	3.28	90
9	*Parougia caeca* (P)	2.58	2.77	76
10	*Nucula delphinodonta* (B)	2.00	2.15	59
	Total - 10 Taxa	78.29	83.89	2305
	Remaining Fauna - 77 Taxa	21.71	--	639
	Total Fauna - 87 Taxa	100	--	2944

Rank	Species	Percent of Total Fauna	Percent of Identified Fauna	Density (Ind./0.04m^2)
Station NF23 - single sample				
1	*Corophium crassicorne* (A)	15.07	16.47	546
2	*Exogone verugera* (P)	11.54	12.61	418
3	*Prionospio steenstrupi* (P)	6.99	7.63	253
4	*Exogone hebes* (P)	6.90	7.54	250
5	*Unciola inermis* (A)	5.60	6.12	203
6	*Crenella decussata* (B)	5.16	5.64	187
7	*Spio limicola* (P)	4.45	4.86	161
8	*Dipolydora socialis* (P)	4.33	4.74	157
9	*Protomedea fasciata* (A)	3.89	4.25	141
10	*Erichthonius rubricornis* (A)	3.56	3.89	129
	Total - 10 Taxa	67.49	73.75	2445
	Remaining Fauna - 95 Taxa	32.51	--	1177
	Total Fauna - 105 Taxa	100	--	3622

Rank	Species	Percent of Total Fauna	Percent of Identified Fauna	Density (Ind./0.12m^2)
Station NF24 - replicated station				
1	*Prionospio steenstrupi* (P)	25.75	27.59	1067
2	*Aphelochaeta marioni* (P)	25.73	27.56	1066
3	*Spio limicola* (P)	11.85	12.69	491
4	*Mediomastus californiensis* (P)	6.61	7.08	274
5	*Euchone incolor* (P)	5.43	5.82	225
6	*Ninoe nigripes* (P)	3.33	3.57	138
7	*Astarte undata* (B)	2.46	2.64	102
8	*Pholoe minuta* (P)	2.03	2.17	84
9	*Nucula delphinodonta* (B)	1.88	2.02	78
10	*Levinsenia gracilis* (P)	1.83	1.96	76
	Total - 10 Taxa	86.90	93.10	3601
	Remaining Fauna - 123 Taxa	13.10	--	542
	Total Fauna - 133 Taxa	100	--	4143

APPENDIX C3

DOMINANT SPECIES AT FARFIELD STATIONS

Station FF1A - off Gloucester				
Rank	**Species**	**Percent of Total Fauna**	**Percent of Identified Fauna**	**Density (Ind./0.12m²)**
1	*Prionospio steenstrupi* (P)	56.26	58.77	3771
2	*Nucula delphinodonta* (B)	5.39	5.63	361
3	*Tharyx acutus* (P)	3.78	3.94	253
4	*Mediomastus californiensis* (P)	2.70	2.82	181
5	*Ninoe nigripes* (P)	2.27	2.37	152
6	*Cerastoderma pinnulatum* (B)	2.22	2.32	149
7	*Levinsenia gracilis* (P)	1.75	1.82	117
8	*Edwardsia elegans* (C)	1.60	1.67	107
9	*Spio limicola* (P)	1.33	1.39	89
10	*Harpinia propinqua* (A)	1.10	1.15	74
	Total - 10 Taxa	78.43	81.88	5254
	Remaining Fauna - 107 Taxa	21.57	--	1445
	Total Fauna - 117 Taxa	100	--	6699
Station FF4 - Stellwagen Basin				
1	*Prionospio steenstrupi* (P)	16.58	17.88	261
2	*Chaetozone setosa* (P)	11.18	12.05	176
3	*Mediomastus californiensis* (P)	10.55	11.37	166
4	*Levinsenia gracilis* (P)	6.54	7.05	103
5	*Aricidea quadrilobata* (P)	6.10	6.58	96
6	*Yoldia sapotilla* (B)	5.21	5.62	82
7	*Tubificoides apectinatus* (O)	3.94	4.25	62
8	*Cossura longocirrata* (P)	3.88	4.18	61
9	*Euchone incolor* (P)	3.56	3.84	56
10	*Thyasira flexuosa* (B)	3.18	3.42	50
	Total - 10 Taxa	70.72	76.24	1113
	Remaining Fauna - 75 Taxa	29.28	--	461
	Total Fauna - 85 Taxa	100	--	1574

Rank	Species	Percent of Total Fauna	Percent of Identified Fauna	Density (Ind./0.12m²)
Station FF5 - Stellwagen Basin				
1	*Prionospio steenstrupi* (P)	21.03	22.72	501
2	*Mediomastus californiensis* (P)	9.40	10.16	224
3	*Levinsenia gracilis* (P)	5.46	5.90	130
4	*Yoldia sapotilla* (B)	5.21	5.62	124
5	*Anobothrus gracilis* (P)	4.95	5.35	118
6	*Aricidea quadrilobata* (P)	4.11	4.44	98
7	*Spio limicola* (P)	3.53	3.81	84
8	*Euchone incolor* (P)	2.81	3.04	67
8	*Chaetozone setosa* (P)	2.81	3.04	67
10	*Thyasira flexuosa* (B)	2.60	2.81	62
	Total - 10 Taxa	61.91	66.89	1457
	Remaining Fauna - 103 Taxa	38.09	--	907
	Total Fauna - 113 Taxa	100	--	2382
Station FF6 - Cape Cod Bay				
1	*Tharyx acutus* (P)	10.44	11.76	343
2	*Cossura longocirrata* (P)	9.98	11.24	328
3	*Mediomastus californiensis* (P)	9.50	10.70	312
4	*Ninoe nigripes* (P)	6.33	7.13	208
5	*Spio limicola* (P)	5.48	6.17	180
6	*Terebellides atlantis* (P)	5.39	6.07	177
7	*Onoba pelagica* (G)	5.11	5.76	168
8	Tubificidae sp. 2 (O)	3.68	4.15	121
9	*Nucula delphinodonta* (B)	3.50	3.94	115
10	*Levinsenia gracilis* (P)	2.77	3.12	91
	Total - 10 Taxa	62.18	70.04	2043
	Remaining Fauna - 104 Taxa	37.82	--	1242
	Total Fauna - 114 Taxa	100	--	3285

Station FF7 - Cape Cod Bay				
Rank	**Species**	**Percent of Total Fauna**	**Percent of Identified Fauna**	**Density (Ind./0.12m²)**
1	*Cossura longocirrata* (P)	30.64	32.57	1497
2	*Mediomastus californiensis* (P)	10.07	10.70	492
3	*Tharyx acutus* (P)	6.84	7.27	334
4	Tubificidae sp. 2 (O)	6.26	6.66	306
5	*Spio limicola* (P)	4.71	5.00	230
6	*Euchone incolor* (P)	4.65	4.94	227
7	*Ninoe nigripes* (P)	4.40	4.68	215
8	*Aricidea catherinae* (P)	4.30	4.57	210
9	*Terebellides atlantis* (P)	3.48	3.70	170
10	*Prionospio steenstrupi* (P)	2.29	2.44	112
	Total - 10 Taxa	77.64	82.53	3793
	Remaining Fauna - 96 Taxa	22.36	--	1092
	Total Fauna - 106 Taxa	100	--	4885
Station FF9 - western Massachusetts Bay				
1	*Prionospio steenstrupi* (P)	53.96	57.84	4091
2	*Spio limicola* (P)	10.30	11.04	781
3	*Dipolydora socialis* (P)	4.23	4.54	321
4	*Mediomastus californiensis* (P)	2.89	3.10	219
5	*Levinsenia gracilis* (P)	1.85	1.98	140
6	*Scalibregma inflatum* (P)	1.69	1.81	128
7	*Harpinia propinqua* (A)	1.38	1.48	105
8	*Euchone incolor* (P)	1.35	1.44	102
9	*Ninoe nigripes* (P)	1.33	1.43	101
10	*Exogone hebes* (P)	1.25	1.34	95
	Total - 10 Taxa	80.23	86.00	6083
	Remaining Fauna - 132 Taxa	19.77	--	1499
	Total Fauna - 142 Taxa	100	--	7582

Station FF11 - Cape Ann				
Rank	**Species**	**Percent of Total Fauna**	**Percent of Identified Fauna**	**Density (Ind./0.12m²)**
1	*Prionospio steenstrupi* (P)	51.58	54.42	2679
2	*Levinsenia gracilis* (P)	8.47	8.94	440
3	*Tubificoides apectinatus* (O)	7.59	8.00	394
4	*Aricidea quadrilobata* (P)	5.58	5.89	290
5	*Spio limicola* (P)	2.81	2.97	146
6	*Cossura longocirrata* (P)	2.45	2.58	127
7	*Chaetozone setosa* (P)	2.21	2.34	115
8	*Mediomastus californiensis* (P)	1.93	2.03	100
8	*Euchone incolor* (P)	1.71	1.81	89
10	*Harpinia propinqua* (A)	1.48	1.56	77
	Total - 10 Taxa	85.81	90.54	4457
	Remaining Fauna - 88 Taxa	14.19	--	737
	Total Fauna - 98 Taxa	100	--	5194

Station FF14 - western Massachusetts Bay				
Rank	**Species**	**Percent of Total Fauna**	**Percent of Identified Fauna**	**Density (Ind./0.12m²)**
1	*Prionospio steenstrupi* (P)	15.54	17.06	451
2	*Chaetozone setosa* (P)	13.51	14.83	392
3	*Levinsenia gracilis* (P)	5.79	6.36	168
4	*Tubificoides apectinatus* (O)	5.38	5.90	156
5	*Sternaspis scutata* (P)	5.10	5.60	148
6	*Mediomastus californiensis* (P)	4.69	5.15	136
7	*Aricidea quadrilobata* (P)	3.89	4.28	113
8	*Thyasira flexuosa* (B)	3.14	3.44	91
9	*Nuculoma tenuis* (B)	2.31	2.53	67
10	*Cossura longocirrata* (P)	2.17	2.38	63
	Total - 10 Taxa	61.52	67.53	1785
	Remaining Fauna - 106 Taxa	38.48	--	1117
	Total Fauna - 116 Taxa	100	--	2902

APPENDIX D

MEANS AND STANDARD DEVIATIONS OF COMMUNITY PARAMETERS 1992-1996

Station	spp. mn	spp. sd	Density mn	Density sd	H' mn	H' sd
NF13	56.3	7.93	36219	7251.6	2.53	0.215
NF14	70.4	5.59	44585	14533.1	2.66	0.201
NF15	66.8	2.63	50881	13832.2	2.78	0.276
NF17	52.4	13.37	22518	15589.6	2.40	0.444
NF18	79.3	4.65	39331	5024.3	2.91	0.136
NF19	81.5	14.01	62181	29102.2	2.90	0.322
NF23	80.0	5.57	60392	20048.1	3.07	0.021
NF24	72.3	18.15	47314	25552.6	2.59	0.167
MF2	60.8	8.70	44102	26805.5	2.50	0.417
MF4	58.2	16.57	27600	11465.3	2.50	0.466
MF5	77.3	21.00	44669	22539.0	2.78	0.309
MF7	73.3	15.90	63488	51886.9	2.60	0.446
MF8	47.8	11.17	53280	25061.0	2.07	0.296
MF9	69.6	14.40	41867	10782.5	2.80	0.327
MF10	64.8	7.22	47045	15301.8	2.49	0.200
MF12	65.0	8.00	49417	16544.8	2.51	0.206
MF16	59.8	16.19	25560	9948.0	2.72	0.251
MF20	58.3	19.86	41363	26490.1	2.65	0.275
MF21	64.0	8.19	45633	14429.7	2.75	0.332
MF22	64.0	11.27	74117	29401.6	2.59	0.178
NF Grand Mean	68.9	13.82	44159	19889.4	2.71	0.316
MF Grand Mean	63.2	14.43	45315	24231.8	2.57	0.350

Station	spp. mn	spp. sd	Density mn	Density sd	H' mn	H' sd
FF1	81.0		12317		3.24	
FF1A	94.3	3.79	46758	24354.8	2.31	0.781
FF4	62.0	10.02	12822	5085.8	2.69	0.323
FF5	76.4	11.59	18535	6671.5	2.65	0.663
FF6	77.0	9.77	29307	11471.0	2.90	0.287
FF7	63.4	15.27	35720	20954.2	2.51	0.177
FF9	97.6	9.07	55343	16686.3	2.05	0.255
FF10	105.4	12.52	58062	21620.0	3.13	0.166
FF11	67.2	9.01	24855	10099.6	2.34	0.431
FF12	71.6	18.62	46780	24223.1	2.47	0.239
FF13	64.8	5.31	35913	13791.5	2.50	0.267
FF14	70.6	10.43	18237	4926.0	2.90	0.263
MF12	73.0	17.42	49743	16709.6	2.52	0.223
NF17	64.4	24.17	24175	16893.4	2.63	0.563
NF24	88.3	14.57	48611	24606.6	2.64	0.199
FF Grand Mean	76.8	17.34	33505	20640.0	2.62	0.455
All Rep Grand Mn	76.1	17.88	34679	20739.5	2.62	0.437

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