1998 Outfall Benthic Monitoring Report

Massachusetts Water Resources Authority

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1998 OUTFALL BENTHIC MONITORING REPORT

Submitted to

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Executive Summary

The Benthic (Sea-Floor) Monitoring component of the MWRA Harbor and Outfall Monitoring (HOM) program addresses three main concerns: eutrophication, contaminants, and particulate inputs. Eutrophication, which could occur in the unlikely event (Hunt et al. 2000) that the transfer of effluent discharge through the outfall leads to appreciable changes in nutrient availability, might lead to increased phytoplankton blooms and subsequent deposition of the resulting carbon to the seafloor. Increased organic carbon deposition could depress oxygen levels in benthic habitats. Such hypoxia could have profound impacts on the benthos toxic contaminants introduced into the environment could accumulate in depositional areas. Sediments not only represent a long-term sink for chemical contaminants, but are also sources of nutrients, toxic chemicals, and pathogenic microbes to the overlying water column. Excess sediment and organic particles discharged from an outfall, which is not expected from the MWRA outfall, could smother benthic habitats under certain circumstances. Such disturbances to benthic sediments frequently result in characteristic and well-documented changes in the communities that inhabit them. Therefore, benthic community structure and function can be used to indicate the overall condition of the receiving water environment. Moreover, analysis of synoptic sediment samples for benthic community parameters and for concentrations of chemical contaminants, nutrients, and organic matter, often make it possible to attribute changes in benthic faunal community characteristics to particular chemical constituents of the effluent or, in some cases, to other sources of disturbance.

The benthic monitoring program includes four components. Sediment profile images (SPI) are collected to monitor the general condition of the soft-bottom benthic habitats in western Massachusetts Bay. In 1998, SPI were collected from 23 western Bay stations. Sediment geochemistry studies, conducted via the collection of sediment grab samples, consist of grain-size analysis, total organic carbon (TOC) content determination, and periodically contaminant concentration analyses. The presence of a sewage tracer, *Clostridium perfringens*, is quantified during these studies. Summer 1998 studies included 45 grain-size, TOC, and *Clostridium* samples. Contaminants were evaluated at four stations sampled in October. Infaunal communities in Massachusetts Bay and Cape Cod Bay are monitored via the collection of samples from 20 Nearfield and 11 Farfield stations. All stations were visited in 1998. Because of the preponderance of hard substrates in the vicinity of the outfall, semi-quantitative studies of the epifaunal communities associated with them are conducted yearly. In 1998, a remotely-operated vehicle was used to collect still photographs and videotapes from eight transects and at Diffuser #44 on the outfall. Summaries of the 1998 results from the components follow.

Sediment Profile Images

In 1998 the SPI study included a “Quick Look” analysis for the first time. This analysis was developed to deliver rapid data turnaround to permit assessment of a benthic trigger, a 50% reduction of the depth of the redox potential discontinuity (RPD). The analysis involved examination of the profile images soon after completion of the survey. The results of the Quick Look analysis, which were reported separately, were found to be comparable to a more detailed computer-based analysis. For any of the three parameters included in the Quick Look analysis (RPD, prism penetration, and surface relief), no more than 4 of the 69 replicates differed by more than 1 cm between the two types of analyses. A comparison of the within-station sensitivity of the Quick Look analysis showed that it had sufficient resolution to evaluate the RPD trigger.

The detailed SPI analysis showed that the average RPD value for 1998 (1.6 cm) was essentially the same as it was for 1997. Statistical comparison of RPD values for the seven stations that were measured for all for years (1992, 1995, 1997, 1998) showed that the values for the latter two years were significantly lower than those for the former two years. While pioneering successional Stage I communities prevailed in the Nearfield in 1992 to 1997, stage II communities were more common in 1998. The occurrence of stage III communities also increased in 1998 compared to the previous years. The overall Nearfield average Organism-Sediment Index (OSI), which integrates several SPI parameters as a general measure of habitat condition, was similar in 1998 to those calculated in 1992 and 1995, but was higher than the 1997 value. The low 1997 values might have reflected a seasonal change stress as SPI sampling was done in October rather than August. The 1998 SPI data showed that biological processes increased in importance as a structuring mechanism of the Nearfield communities, a trend that likely began in 1995.

Sediment Geochemistry

Generally, Nearfield sediments collected from most stations in 1998 were slightly coarser than those collected in 1997. However, Nearfield sediments sampled over the most recent few years have been reasonably consistent. Typically stations located within 2 km of the outfall diffuser have had relatively coarse sediments (mean phi < 3), whereas those located from 2 to 8 km from the diffuser have been relatively fine (mean phi > 3). Among the latter stations, NF02, NF04, and NF20 have been the least consistent. Farfield sediments have shown very consistent textural structure during the course of the monitoring program. In general, relatively coarse sediments have occurred at stations FF01A and FF09. Silty sediments have been found at stations FF04, FF07, and FF11. The remaining stations have shown intermediate textural structure. Sediments collected in 1998 fit within the general pattern described by the previous data.

Sediment TOC content generally was low in the Nearfield, with most stations having values of < 1%. Among stations located close to the diffuser, most had values for 1998 that were similar to those found in 1997. Two stations (NF14 and NF15) had higher values, and one station (NF24) had a lower value, in 1998 than in 1997. Among stations located from 2 to 8 km from the diffuser, most had lower values in 1998 than in 1997. Farfield sediments had TOC values in 1998 that were very consistent with those found for the other years of the program.

Densities of the sewage tracer *Clostridium perfringens* at Nearfield stations sampled in 1998 apparently were lower than those reported previously, especially at the stations located within 2 km of the diffuser. *Clostridium* values at station FF13 were noticeably lower in 1998 than in the past. The pattern of lower *Clostridium* values in 1998 than in previous years also was apparent among the Farfield stations.

Infaunal Communities

Examination of the 1992–1997 infaunal dataset revealed that species diversity in Massachusetts Bay has increased during the course of the monitoring program. Diversity, as measured by log-series alpha and species richness (numbers of species), was significantly higher in 1998 that for the combined 1992–1997 Nearfield data. Infaunal abundance in 1998 was also somewhat higher than for the 1992–1997 period.

Multivariate analysis of the 1998 Nearfield data showed that the infaunal community could be separated into two primary groups of stations. The first group was comprised of samples from stations NF13, NF17, and NF23 and was distinguished by high abundances of the annelids *Polygordius* sp. A and *Spiophanes bombyx*. These species were associated primarily with medium to fine sand sediments. The second group of stations revealed by the multivariate analysis was complex and consisted of samples from the remaining Nearfield (here including stations FF10, FF12, and FF13). Key taxa included the annelids *Prionospio steenstrupi*, *Mediomastus californiensis*, and *Aricidea catherinae*. These taxa were associated with a wide range of sediments, ranging from medium sands to silt. Multivariate analysis of the 1998 Farfield data showed that the infaunal community could be divided into three dissimilar groups. The first group included stations FF01A and FF09, which were characterized by relatively high numbers of the annelid *Prionospio steenstrupi* and the nut clam *Nucula delphinodonta*. The second cluster group consisted of stations located along the eastern portions of the Bay from off Cape Ann to the north and in Cape Cod Bay to the south. This group was characterized by a variety of taxa including the annelids

Euchone incolor, *Mediomastus californiensis*, *Aricidea quadrilobata*, and *Anobothrus gracilis*. The final cluster was comprised only of samples from station FF06 in Cape Cod Bay. Key taxa here were the annelids *Aricidea catherinae* and *Tharyx acutus* and the amphipod *Leptocheirus pinguis*.

Hard-bottom Communities

Classification analysis of the 1998 hard-bottom data showed that the community could be separated into three main groups of stations. The first group consisted primarily of moderate to high-relief drumlin top areas that had variable sediment drape. The encrusting coralline alga *Lithothamnion* was a common inhabitant of many areas that comprised this group. Other key taxa in Cluster 1 were the upright algae *Asparagopsis hamifera* and *Rhodymenia palmata*. Cluster 2 consisted of drumlin top and flank areas that had light to moderately-light sediment drape. *Lithothamnion* was the dominant taxon in this group. Cluster 3 consisted mainly of drumlin flank areas that had low to moderately-low relief and moderately-heavy sediment drape. Areas in this group were characterized by low abundances of algae and fish and had low to moderate abundances of invertebrates. The sea star *Asterias* was the most common taxon here. The hard-bottom communities near the outfall have been studied consistently for the past four years. During this time the communities, although spatially variable, have shown reasonable temporal stability.

1. INTRODUCTION

1.1 Program Background

The Benthic (Sea-Floor) Monitoring component of the MWRA Harbor and Outfall Monitoring (HOM) program addresses three main concerns: eutrophication, contaminants, and particulate inputs. Eutrophication, which could occur in the unlikely event (Hunt et al. 2000) that the transfer of effluent discharge through the outfall leads to appreciable changes in nutrient availability, might lead to increased phytoplankton blooms and subsequent deposition of the resulting carbon to the seafloor. Increased organic carbon deposition could depress oxygen levels in benthic habitats. Such hypoxia could have profound impacts on the benthos (Diaz and Rosenberg 1995). Toxic contaminants introduced into the environment could accumulate in depositional areas. Sediments not only represent a long-term sink for chemical contaminants, but are also sources of nutrients, toxic chemicals, and pathogenic microbes to the overlying water column (Salomons *et al.* 1987, Brown and Neff 1993). Excess sediment and organic particles discharged from an outfall, which is not expected from the MWRA outfall, could smother benthic habitats under certain circumstances. Such disturbances to benthic sediments frequently result in characteristic and well-documented changes in the communities that inhabit them (Pearson and Rosenberg 1978). Therefore, benthic community structure and function can be used to indicate the overall condition of the receiving water environment. Moreover, analysis of synoptic sediment samples for benthic community parameters and for concentrations of chemical contaminants, nutrients, and organic matter, often make it possible to attribute changes in benthic faunal community characteristics to particular chemical constituents of the effluent or, in some cases, to other sources of disturbance (NRC 1990).

1.2 Present MWRA Study

The Outfall Benthic Surveys provide quantitative measurements of benthic community structure and patterns of contaminant concentrations within sediments of Massachusetts and Cape Cod Bays. The 1998 outfall survey was conducted before effluent discharge began at the new outfall and continued the collection of baseline data. After effluent discharge into the Bay begins, the focus of the program will change from the collection of baseline data to an evaluation of the effects of the discharge on the Bay ecosystems. Outfall surveys conducted after 2000 will provide the data required for a quantitative assessment of the effects of discharged effluent on sediment chemistry and benthic infauna communities. The objectives of the monitoring program following the initiation of effluent discharge into the Bay are (1) to monitor versus NPDES permit requirements, (2) to test whether or not the discharge-related impacts are within the limits predicted by the SEIS, and (3) to determine if changes in the system exceed Contingency Plan thresholds (MWRA 1997).

The benthic monitoring program includes four components. Sediment profile images (SPI) are collected to monitor the general condition of the soft-bottom benthic habitats in western Massachusetts Bay. In this report, the analyses of the SPI that were collected from 23 western Bay stations are presented in Section 3. Sediment geochemistry studies, conducted via the collection of sediment grab samples, consist of grain-size analysis, total organic carbon (TOC) content determination, and periodically contaminant concentration analyses. The presence of a sewage tracer, *Clostridium perfringens*, is quantified during these studies. Summer 1998 studies included 45 grain-size, TOC, and *Clostridium* samples. Contaminants were evaluated at four stations sampled in October. These studies are presented in Section 4. Infaunal communities in Massachusetts Bay and Cape Cod Bay are monitored via the collection of samples from 20 Nearfield and 11 Farfield stations. All stations were visited in 1998. Analyses of the infaunal communities are described in Section 5. Because of the preponderance of hard substrates in the vicinity of the outfall, semi-quantitative studies of the epifaunal communities associated with them are conducted yearly. In 1998, a remotely-operated vehicle was used to collect still photographs and videotapes from eight transects and at Diffuser #44 on the outfall. Results of the 1998 hard-bottom study constitute Section 6. This report also includes a programmatic evaluation of each of the components. This evaluation is presented in Section 7.

The raw data for all of these studies are available from MWRA.

2. FIELD OPERATIONS

[by Roy K. Kropp and Jeanine D. Boyle]

2.1 Sampling Design

2.1.1 Soft-Bottom

Sediment Samples—The Nearfield benthic surveys, conducted annually in August, are designed to provide spatial coverage and local detail of faunal communities inhabiting depositional environments within about 8 km of the diffuser. Samples for sediment chemistry and benthic infauna were collected at 20 Nearfield stations (Figure 2-1). The target locations for the Nearfield stations are listed in the CW/QAPP (Kropp and Boyle 1998). The actual locations of each collected grabs sample are listed in Appendix A-1.

Farfield benthic surveys, also conducted annually in August each year, are designed to contribute reference and early-warning data on soft-bottom habitats in Massachusetts and Cape Cod Bays. Grab samples were collected at 11 stations in Massachusetts and Cape Cod Bays (Figure 2-2) for infaunal and chemical analyses. The target locations for the Farfield stations are listed in the CW/QAPP (Kropp & Boyle 1998). The actual locations of each collected grabs sample are listed in Appendix A-1.

The Nearfield Contaminant Special Study Surveys are designed to examine the possible short-term impacts of the new outfall discharge on sedimentary contaminant concentrations and their interrelationships with possible sedimentary organic carbon changes in depositional environments near the effluent outfall. In October 1998, samples were collected from four stations; NF08, NF22, NF24, and FF10. The historical (i.e., pre-1998) criteria used to select these four locations were:

- Historically, stations (except FF10) were comprised of fine grained material (>50% sand/silt);
- Stations were in relatively stable areas (except for FF10, grain size composition >50% sand/silt over the period monitored);
- Stations (except FF10) had high total organic carbon (TOC) content, relative to other locations nearby (at least 1% TOC);
- Stations were within the zone of increased particle deposition predicted by the Bay Eutrophication Model (BEM; Hydroqual and Normandeau 1995); and
- Selection of these stations complements and expands on stations sampled periodically by USGS (also avoids sampling from near USGS stations).

Stations FF10, NF08, and NF24 lie on a line extending to the northwest from the west end of the diffuser and along with station NF12, also sampled separately by USGS, provide a spatial gradient extending from the diffuser (Figure 2-3). This gradient extends towards the predicted high deposition area. Station NF22 lies to the southwest of the west end of the diffuser and is along the projected long-term effluent transport path from the diffuser. Station FF10 extends the area of impact sampled under the contaminant special studies task and represents a Farfield location near the center of the high deposition location predicted by the BEM model and is a sandier location. The actual locations of all grab samples collected on the contaminant special study survey are listed in Appendix A-2.

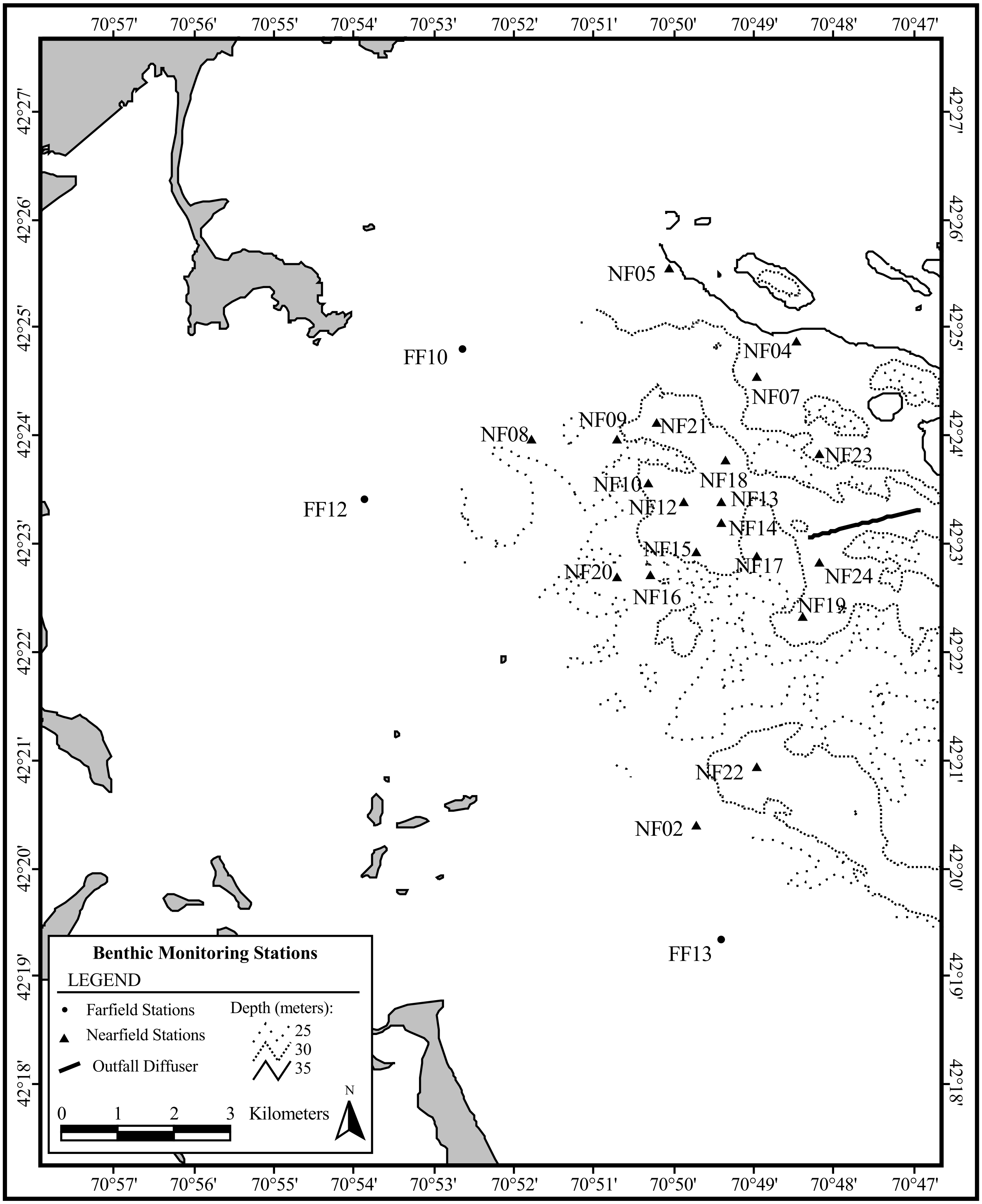


Figure 2-1. Locations of Nearfield and selected Farfield grab and SPI stations sampled in August 1998.

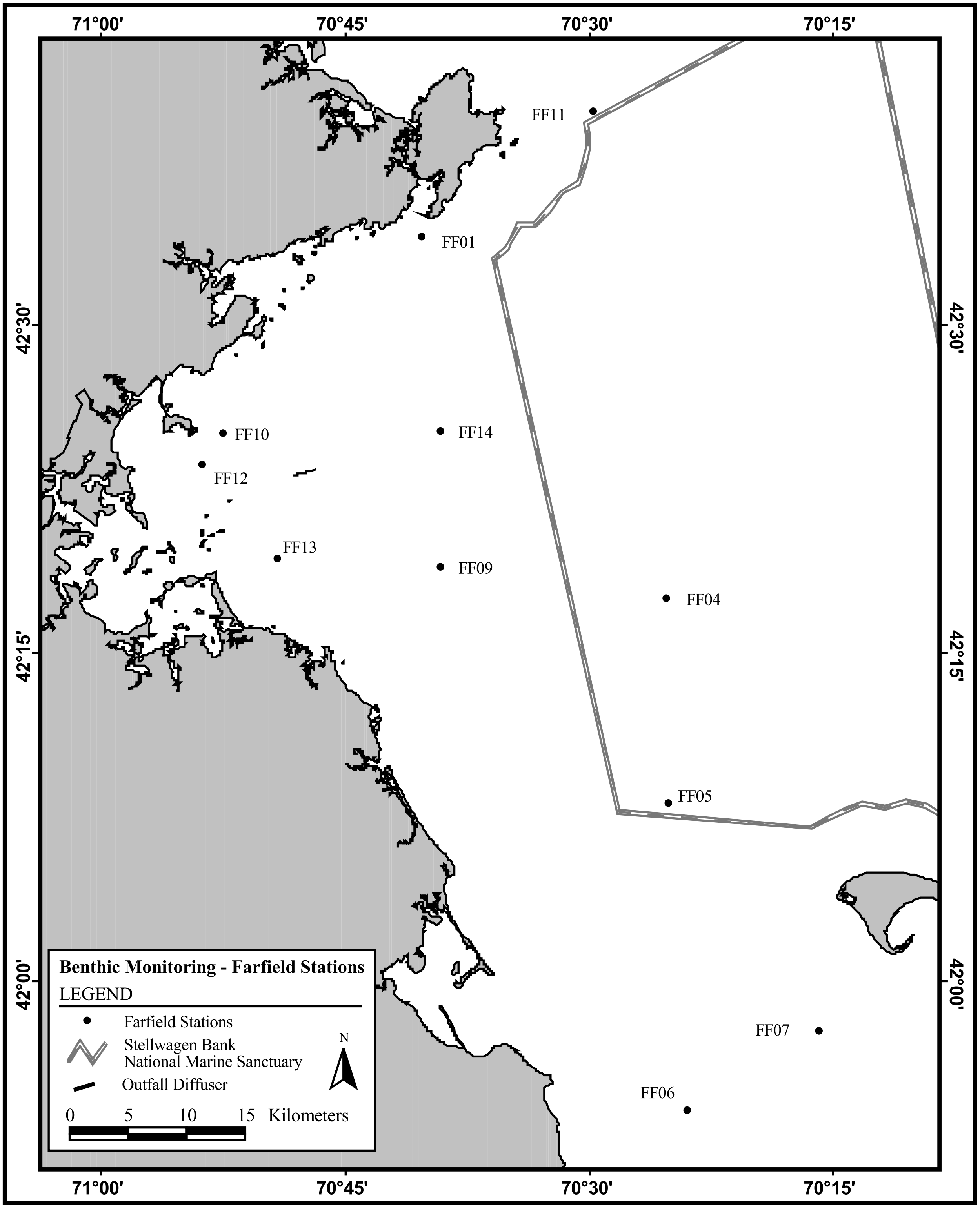


Figure 2-2. Locations of Farfield grab stations sampled in August 1998.

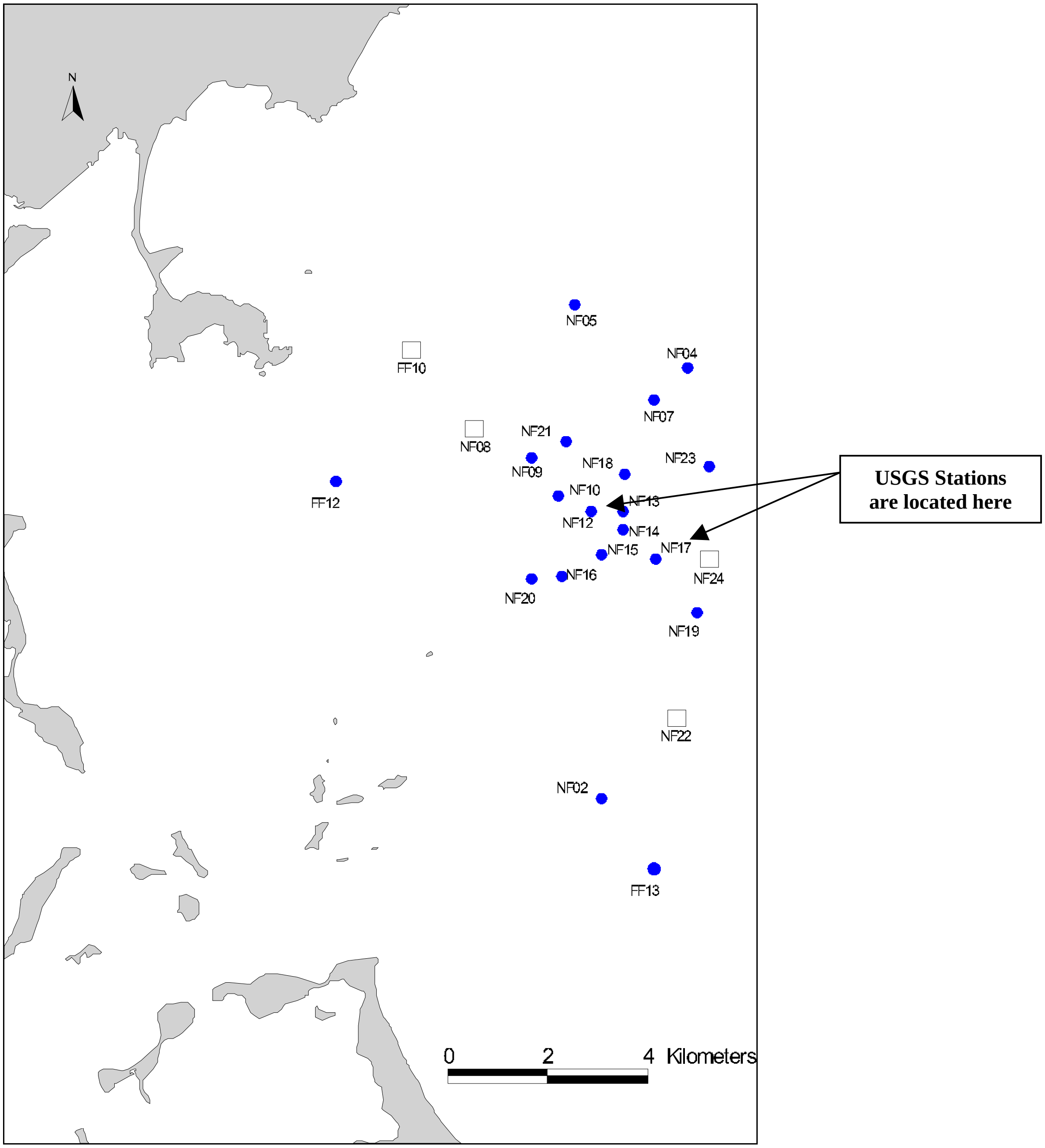


Figure 2-3. Locations of stations sampled on the 1998 Nearfield Contaminant Special Study Survey (open squares).

Sediment Profile Images—The Nearfield Sediment Profile Image surveys are conducted in August of each year at 20 Nearfield and 3 Farfield stations (Figure 2-1) to give an area-wide, qualitative/semi-quantitative assessment of sediment quality and benthic community status that can be integrated with the results of the more localized, quantitative surveys to determine sedimentary conditions near the outfall. Furthermore, these surveys provide rapid comparison of benthic conditions to the benthic triggering thresholds. Traditional sediment profile imagery (35-mm slides) allows a faster evaluation of the benthos to be made than can be accomplished through traditional faunal analyses. A more rapid analysis of the SPI data was accomplished by fitting the profile camera prism with a digital video camera arranged to view the same sediment profile as the 35-mm film camera. The target locations for the SPI sampling are the same as those for the grab sampling effort. The actual locations of all sediment profile images collected are listed in Appendix A-3.

2.1.2 Hard-Bottom

Because of the large amount of erosional rocky-bottom habitats in the Nearfield and in the vicinity of the diffusers, a continuing study of hard-bottom habitats has been implemented to supplement the soft-bottom studies. The Nearfield hard-bottom surveys are conducted in June of each year. Video tape footage and 35-mm slides were taken at waypoints along eight transects and at Diffuser #44 (Figure 2-4). Actual coordinates for hard-bottom stations sampled in June 1998 are listed in Appendix A-4.

2.2 Surveys/ Samples Collected

The dates of the outfall benthic surveys and the numbers of samples collected on them are listed in Table 2-1.

Table 2-1. Survey dates and numbers of samples collected on benthic surveys in 1998.

			Samples Collected							
Survey	**ID**	**Date(s)**	**Inf**	**TOC**	**Gs**	**Cp**	**C**	**SPI**	**35**	**V**
Nearfield Infauna	BN981	13, 14, 25, 31 Aug 1998	26	23	23	23	–	–	–	–
Farfield Infauna	BF981	13, 14, 18, 25, 31 Aug 1998	33	22	22	22	–	–	–	–
SPI	BR981	27 Aug 1998	–	–	–	–	–	138	–	138
Hard-bottom	BH981	25-28 Jun 1998	–	–	–	–	–	–	821	46
Nearfield Contaminant	BC981	17 Oct 1998	2	12	12	12	12	–	–	–

Key:

Inf, Infauna
Gs, grain size
C, contaminant
35, 35-mm slides (hard-bottom)
TOC, total organic carbon
Cp, *clostridium perfringens*
SPI, sediment profile images (slides)
V, video segments (hard-bottom)

2.3 Field Methods Overview

The following is a brief overview of the methods and protocols used on the benthic surveys. More detailed descriptions of the methods are contained in the CW/QAPP (Kropp and Boyle 1998).

2.3.1 Vessel/ Navigation

All benthic surveys were conducted onboard the Battelle-owned *R/V Aquamonitor*. Navigation procedures followed those described in the Water Column CW/QAPP (Albro et al. 1998).

2.3.2 Grab Sampling

Nearfield/Farfield Benthic Surveys—At all 11 Farfield stations and 3 Nearfield stations (NF12, NF17, and NF24), a 0.04-m^2 modified van Veen grab sampler was used to collect 3 replicate samples for infaunal analysis and 2 replicate samples for *Clostridium perfringens*, sediment grain size, and TOC analyses. At each of the remaining 18 Nearfield stations, 1 grab sample for infaunal analysis and one grab sample for *C. perfringens*, sediment grain size, and TOC content were collected. Infaunal samples were sieved onboard the survey vessel over a 300-μm-mesh sieve and fixed in buffered formalin. The "chemistry" sample was skimmed off the top 2 cm of the grab by using a Kynar-coated scoop, and was homogenized in a clean glass bowl before being distributed to appropriate storage containers. The TOC samples were frozen, whereas the *C. perfringens* and grain size samples were placed on ice in coolers.

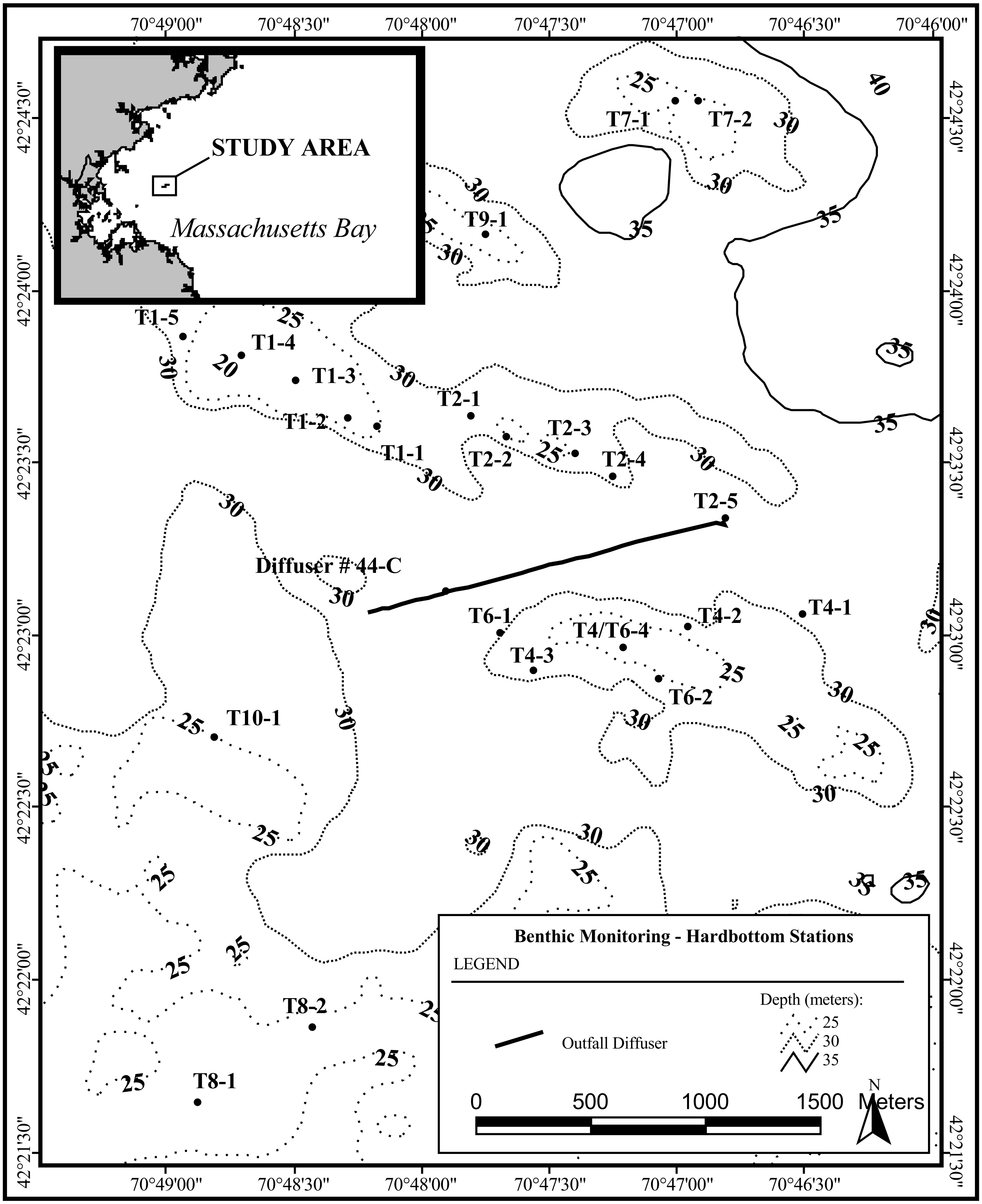


Figure 2-4. Locations of hard-bottom stations sampled in June 1998.

Nearfield Contaminant Special Study—At stations NF08, NF22, NF24, FF10, a 0.1-m^2 Kynar-coated van Veen grab sampler was used to collect three replicate grab samples for analysis of sedimentological and microbiological analyses. Samples were collected from the top 2 cm of the grab and processed as described above. In addition to *C. perfringens*, sediment grain size, and TOC, a subsample was collected for contaminant analysis.

2.3.3 SPI

At each station, a Hulcher Model Minnie sediment profile camera fitted with a digital video camera, to allow for real-time viewing of the sediment profiles, was deployed three times. The profile camera was set to take two pictures, using Fujichrome 100P slide film, on each deployment at 2 and 12 seconds after bottom contact. In the event that sediments were soft the two-picture sequence would ensure that the sediment-water interface would be photographed before the prism window over penetrated. The combination of video and film cameras ensured accurate and reliable collection of sediment profile images. Any replicates that appeared to be disturbed during deployment were retaken. The videotape ran during each drop and was narrated in real time by the Senior Scientist, Dr. Robert Diaz, as the photos were taken. The narration included the station, time, approximate prism penetration depth, and a brief description of the substrate. In addition, the Oxidation-Reduction Potential Discontinuity was estimated by Dr. Diaz at each Nearfield station. These measurements were recorded in Dr. Diaz's log, and the Battelle Survey logbook. Each touch down of the camera was marked as an event on the NAVSAM©. The video image was recorded for use as part of the Quick Look analysis.

2.3.4 Hard-Bottom

The June 1998 hard-bottom survey of the Nearfield examined 20 waypoints distributed along 6 transects (T1, T2, T4, T6, T7, and T8), plus 2 additional waypoints and Diffuser #44. A MiniRover MK II ROV equipped with a Benthos low-light, high-resolution video camera, a Benthos Model 3782 35-mm minicamera with strobe, 150 W halogen lamps, a compass, and a depth gauge was deployed from the survey vessel to obtain the necessary video and slides. The ROV was guided as close to the bottom as possible so that the clarity of the video and photographs was maximized. Approximately 20 minutes of video footage per waypoint were recorded along a randomly-selected heading. Along this route, still photographs were taken as selected by the Senior Scientist, Dr. Barbara Hecker, until an entire (36 exposure) roll of 35-mm film was exposed at each waypoint. At the outfall diffuser approximately 50% of the effort was devoted toward documenting the diffuser, itself and 50% toward documenting the seafloor nearby.

The date, time, and ROV depth were recorded on the videotapes and appeared on the video monitor during the recording. These data were not recorded on each photograph taken at the waypoints. These were recorded in a notebook and later transferred to the still photographs. Each videotape and 35-mm slide exposure was recorded as an "event" on the NAVSAM© system. The time displayed on the video monitor (and recorded on the tape) was synchronized with the NAVSAM© clock. When a still photograph was taken, the event also was marked verbally on the videotape. The NAVSAM© produced labels that were attached to each video cartridge. Slides were labeled manually after processing. Duplicate slides were made.

3. SEDIMENT PROFILE CAMERA RECONNAISSANCE OF BENTHIC HABITATS IN THE NEARFIELD AREA, AUGUST 1998

[by Robert J. Diaz]

3.1 Methods

This report contains results of the sediment profile camera survey conducted 27 August 1998 at 20 Nearfield and 3 Farfield stations in the vicinity of the outfall. The field methods for the SPI survey are discussed in Section 2.3.3. The stations at which sediment profile images were taken are shown in Figure 2-1.

3.1.1 Quick Look Analysis

The Quick Look analysis was developed to meet the needs of rapid data turn around for assessment of benthic triggers, one of which is a 50% reduction in the depth of the redox potential discontinuity (RPD) layer. The exposed film was developed 29 August 1998, the day after completion of field operations, and the Quick Look analysis completed 30 August 1998 (Diaz 1998).

The use of video and short turnaround time on film development allowed for a quick look report that evaluated benthic habitat condition two days after completion of field work. The initial evaluation of habitat conditions was done in real time onboard the research vessel (Boyle 1998). The features that the Quick Look focused on were:

Sediment grain size (category)
Sediment layering (present/absent)
Surface and subsurface fauna and structures
General benthic successional stage
Prism penetration (cm)
Surface relief (cm)
Apparent color RPD depth (cm)

Post field analysis included visual review of video tape and slide film data. Quantitative parameters were estimated to plus or minus one centimeter (Diaz 1998).

3.1.2 Image Analyses

The sediment profile images first were analyzed visually by projecting the images and recording all features seen into a preformatted standardized spreadsheet file. The images then were digitized by using a Polaroid Sprint Scan 35 Plus scanner and analyzed by using the Adobe PhotoShop and NTIS Image programs. Steps in the computer analysis of each image were standardized and followed the basic procedures in Viles and Diaz (1991). Data from each image were saved sequentially to a spread sheet file for later analysis. Details of how these data were obtained can be found in Diaz and Schaffner (1988), Rhoads and Germano (1986), and in the standardized image analysis procedures of Viles and Diaz (1991). A summary of major parameters measured follows:

Prism Penetration—was measured as the distance the sediment moved up the 23-cm length of the faceplate. The weight on the camera frame was kept constant at 180 lbs.

Surface Relief—(or boundary roughness) was measured as the difference between the maximum and minimum distance the prism penetrated.

Apparent Color Redox Potential Discontinuity (RPD) Layer—was defined as the area of all the pixels in the image discerned as being oxidized divided by the width of the digitized image. The area of the image with oxic sediment was obtained by digitally manipulating the image to enhance characteristics associated with oxic sediment (greenish-brown color tones). The enhanced area was then determined from a density slice of the image.

Sediment Grain Size—was determined by comparison of collected images with a set of standard images of sediments for which mean grain size had been determined in the laboratory. The sediment type descriptors used for image analysis followed the Wentworth classification as described in Folk (1974) and represented the major modal class for each image.

Phi Scale	Upper Limit Size (mm)	Grains per cm of image	SPI Descriptor	Sediment Size Class and Subclass
-2 to -6	64.0	<1	PB	Pebble
-1 to -2	4.0	2.5	GR	Gravel
1 to -1	2.0	5	MS	Coarse Sand
2 to 1	0.5	20	MS	Medium Sand
4 to 2	0.25	40	FS	Fine Sand
4 to 3	0.12	80	VFS	Very Fine Sand
5 to 4	0.06	160	FSSI	Fine Sand with Silt
8 to 5	0.0039	>320	SI	Silt
6 to 5	0.0039	>320	SIFS	Silt with Fine Sand
>8	<0.0005	>2560	CL	Clay

Surface Features—included a wide variety of features and were evaluated visually from each slide and compiled by type and frequency of occurrence.

Subsurface Features—included a wide variety of features and revealed much about physical and biological processes influencing the bottom. Surface features were evaluated visually from each slide and compiled by type and frequency of occurrence.

Successional Stage—was estimated by evaluating the following SPI parameters (– = not associated with, + = associated with, ++ = moderately associated with, +++ = strongly associated with).

Parameter	Successional Stage		
	I	II	III
Average RPD (cm)	<1	1-3	>2
Max depth RPD (cm)	<2	>2	>4
Small Tubes	+++	++	+
Large Tubes	–	++	+++
Burrows	–	++	+++
Feeding Voids	–	+	+++
Small Infauna	+++	++	+
Large Infauna	–	+	++
Epifauna	+	++	++

Organism-Sediment Index—was calculated by using the following parameter ranges and scores (taken from Rhoads and Germano 1986):

Depth of the apparent color RPD		Estimated successional stage	
(cm)	(score)	(stage)	(score)
0	0	Azoic	!4
>0-0.75	1	I	1
0.76-1.50	2	I-II	2
1.51-2.25	3	II	3
2.26-3.00	4	II-III	4
3.01-3.75	5	III	5
>3.75	6	I on III	5
		II on III	5
Other		**Score**	
Methane voids present		!2	
No/Low DO		!4	

3.2 Results and Discussion

3.2.1 Quick Look versus Detailed Analysis

The correspondence of Quick Look and detailed analyses results was very good. Categorical and quantitative parameters were determined accurately in the Quick Look analysis (Table 3-1). Prism penetration differed by more than 1 cm between the Quick Look and detailed analyses for only 1 of the 69 station-replicates (NF23-1). For surface relief, only four replicates differed by more than one centimeter.

For the apparent color RPD depth, one of the benthic trigger parameters, only three station-replicates differed by more than one centimeter (Table 3-1). In all cases the Quick Look analysis values were ≥3 cm and the detailed analyses were 0.9, 1.0, and 1.8 cm for NF14-2, NF14-3, and NF18-3, respectively. The overestimation of RPD depth in the Quick Look analysis appeared to be related to the overall light color and low contrast of sediments at these stations that was subsequently accounted for in the computer image analysis.

To test the within-station sensitivity of the Quick Look analysis for estimating RPD depths within 50% of the actual RPD value, the critical trigger level being a 50% change in RPD depth over the entire study area (MWRA 1997), the Quick Look value was expressed as a percentage of the computer analysis value (Table 3-2). For the 38 station-replicate images that had measured RPD depths, only 1 exceeded a difference of 50% (NF14-3). This indicated that Quick Look analysis had sufficient resolution to estimate RPD depths given the 50% change criterion. The difference between analyses for NF14-3 again was a result of the light color and low contrast of the sediments.

3.2.2 August 1998 Nearfield Image Data

Three replicate sediment profile images and taped video were collected at all 23 stations. A complete listing of SPI data can be found in Diaz (1998). A station summary of the SPI data is in Table 3-3. Table 3-4 provides a summary of within station variability for quantitative measurements made from the images—prism penetration, surface relief, RPD, OSI, and number of infauna and burrows. Table 3-5 contains an evaluation of within-station variability in apparent color RPD. One replicate image from each station is contained in Appendix B-1. Images were selected to show the range of physical and biological processes active in the area and, for the most part, those referred to in the text.

Table 3-1. Comparison of results from the Quick Look (QL) and detailed (D) analyses of selected SPI quantitative parameters from the August 1998 Nearfield survey.

		Penetration			Surface Relief			RPD		
Station	Rep	QL (cm)	D (cm)	Delta[a]	QL (cm)	D (cm)	Delta	QL (cm)	D (cm)	Delta
FF10	1	5	5.1	–0.1	<1	0.6	<1	2	2.2	–0.2
FF10	2	7	6.4	0.6	2	2.1	–0.1	2	2.0	0.0
FF10	3	6.5	6.5	0.0	<1	0.6	<1	2.5	2.7	–0.2
FF12	1	3.5	3.2	0.3	<1	0.7	<1	3	2.4	0.6
FF12	2	4	4.0	0.0	<1	0.6	<1	2	1.8	0.2
FF12	3	3	3.1	–0.1	<1	0.3	<1	>3	2.5	<1
FF13	1	17	17.4	–0.4	1.5	1.1	0.4	2.5	2.1	0.4
FF13	2	11	11.4	–0.4	>1	0.6	<1	3	2.4	0.6
FF13	3	10	9.7	0.3	1	1.1	–0.1	3	2.2	0.8
NF02	1	0	0.0	0.0	IND[b]	IND	IND	IND	IND	IND
NF02	2	0	0.0	0.0	IND	IND	IND	IND	IND	IND
NF02	3	1	1.0	0.0	IND	1.5	>1	IND	IND	IND
NF04	1	2.5	2.5	0.0	1	1.1	–0.1	>2.5	>2.5	<1
NF04	2	1.5	1.5	0.0	<1	0.6	<1	>1.5	>1.5	<1
NF04	3	1	1.4	–0.4	>1	2.9	>1	>1	>1.4	<1
NF05	1	5	5.1	–0.1	<1	0.4	<1	1.5	1.3	0.2
NF05	2	8	7.8	0.2	<1	0.4	<1	<1	1.0	<1
NF05	3	7	7.5	–0.5	1	1.0	0.0	1.5	1.7	–0.2
NF07	1	12	12.0	0.0	6	5.1	0.9	<1	0.5	<1
NF07	2	9	9.3	–0.3	<1	1.0	<1	<1	0.8	<1
NF07	3	11	10.3	0.7	2	2.5	–0.5	1	1.0	0.0
NF08	1	13.5	13.5	0.0	1	1.0	0.0	1.5	1.9	–0.4
NF08	2	8.5	8.7	–0.2	1	1.5	–0.5	1.5	1.4	0.1
NF08	3	15.5	15.2	0.3	<1	0.8	<1	2	2.0	0.0
NF09	1	9.5	9.4	0.1	1	1.0	0.0	2	2.3	–0.3
NF09	2	9.5	9.5	0.0	<1	1.0	<1	2	2.1	–0.1
NF09	3	9.5	9.2	0.3	<1	0.6	<1	1.5	1.4	0.1
NF10	1	10.5	10.3	0.2	<1	0.8	<1	2	2.2	–0.2
NF10	2	6.5	6.6	–0.1	1	0.8	0.2	1.5	1.3	0.2
NF10	3	7	7.2	–0.2	1	1.0	0.0	1.5	1.5	0.0
NF12	1	13.5	13.4	0.1	1	1.3	–0.3	2.5	1.9	0.6
NF12	2	15.5	15.3	0.2	<1	1.3	<1	2	2.0	0.0
NF12	3	12	12.0	0.0	<1	1.0	<1	2	2.2	–0.2
NF13	1	3.5	3.3	0.2	3	2.5	0.5	>3.5	>3.3	<1
NF13	2	3	3.0	0.0	1	2.1	–1.1	>3	>3.2	<1
NF13	3	4	3.6	0.4	3	4.4	–1.4	>4	IND	IND
NF14	1	2	2.3	–0.3	2	3.0	–1.0	>1	0.6	<1
NF14	2	5	4.8	0.2	<1	1.7	<1	>3	0.9	>1
NF14	3	4	3.9	0.1	<1	0.6	<1	3	1.0	2.0
NF15	1	4	4.2	–0.2	<1	0.8	<1	2.5	2.1	0.4
NF15	2	2.5	2.2	0.3	1	1.1	–0.1	>2.5	>2.2	<1
NF15	3	2.5	2.4	0.1	1	1.7	–0.7	>2.5	>2.4	<1
NF16	1	13.5	13.7	–0.2	1	1.1	–0.1	3	2.3	0.7
NF16	2	13.5	14.0	–0.5	2	1.5	0.5	<1	0.7	<1
NF16	3	12.5	12.6	–0.1	1.5	1.5	0.0	2	2.0	0.0

Table 3-1. (Continued)

Station	Rep	Penetration QL (cm)	Penetration D (cm)	Penetration Delta[a]	Surface Relief QL (cm)	Surface Relief D (cm)	Surface Relief Delta	RPD QL (cm)	RPD D (cm)	RPD Delta
NF17	1	2.5	2.1	0.4	<1	0.8	<1	>2.5	>2.1	<1
NF17	2	1.5	1.6	–0.1	<1	1.5	<1	>1.5	>1.6	<1
NF17	3	3.5	2.7	0.8	1	0.8	0.2	>3.5	>2.7	<1
NF18	1	6	5.9	0.1	1	1.3	–0.3	2	1.5	0.5
NF18	2	4	4.4	–0.4	1	1.0	0.0	2.5	1.7	0.8
NF18	3	3	3.0	0.0	2	2.1	–0.1	>3	1.8	>1
NF19	1	3	3.2	–0.2	<1	1.1	<1	<1	0.4	<1
NF19	2	1.5	1.7	–0.2	<1	0.6	<1	<1	0.5	<1
NF19	3	0	0.0	0.0	IND	IND	IND	IND	IND	IND
NF20	1	3	2.3	0.7	1	3.0	–2.0	IND	IND	IND
NF20	2	4	4.1	–0.1	<1	0.8	<1	2	1.5	0.5
NF20	3	8.5	8.6	–0.1	<1	0.2	<1	3	2.2	0.8
NF21	1	12	12.3	–0.3	<1	0.6	<1	1.5	1.7	–0.2
NF21	2	12	11.9	0.1	<1	0.8	<1	1.5	1.9	–0.4
NF21	3	14.5	14.5	0.0	1	1.3	–0.3	<1	0.4	<1
NF22	1	10	10.3	–0.3	<1	0.8	<1	2.5	2.1	0.4
NF22	2	7.5	7.5	0.0	1.5	2.1	–0.6	3	2.2	0.8
NF22	3	10	9.4	0.6	1	1.1	–0.1	2	1.4	0.6
NF23	1	4	5.2	–1.2	2.5	2.5	0.0	>3	3.2	<1
NF23	2	3	3.3	–0.3	1	1.3	–0.3	>3	>3.3	<1
NF23	3	2.5	2.3	0.2	<1	0.6	<1	>2.5	>2.3	<1
NF24	1	6.5	6.9	–0.4	<1	0.6	<1	2	1.4	0.6
NF24	2	8	7.8	0.2	<1	0.5	<1	2	1.7	0.3
NF24	3	7	7.0	0.0	<1	0.4	<1	<1	0.5	<1

[a] Delta is the difference between the QL and detailed analyses. A negative sign indicates that the detailed analysis produced a higher value for the parameter measured.
[b] Indeterminate.

Table 3-2. Nearfield stations, August 1998, difference between Quick Look and detailed image analyses for the apparent color RPD depth. Only images that had identifiable RPD layers were included. A 50% change in RPD would exceed the trigger threshold.

Station	Rep.	QL (cm)	Detail (cm)	Delta (cm)	Percent Difference
NF08	1	1.5	1.9	–0.4	–21
NF21	2	1.5	1.9	–0.4	–21
NF09	1	2	2.3	–0.3	–13
NF05	3	1.5	1.7	–0.2	–12
NF21	1	1.5	1.7	–0.2	–12
FF10	1	2	2.2	–0.2	–9
NF10	1	2	2.2	–0.2	–9
NF12	3	2	2.2	–0.2	–9
FF10	3	2.5	2.7	–0.2	–7
NF09	2	2	2.1	–0.1	–5
FF10	2	2	2.0	0	0
NF07	3	1	1.0	0	0
NF08	3	2	2.0	0	0
NF10	3	1.5	1.5	0	0
NF12	2	2	2.0	0	0
NF16	3	2	2.0	0	0
NF08	2	1.5	1.4	0.1	7
NF09	3	1.5	1.4	0.1	7
FF12	2	2	1.8	0.2	11
NF05	1	1.5	1.3	0.2	15
NF10	2	1.5	1.3	0.2	15
NF24	2	2	1.7	0.3	18
FF13	1	2.5	2.1	0.4	19
NF15	1	2.5	2.1	0.4	19
NF22	1	2.5	2.1	0.4	19
FF12	1	3	2.4	0.6	25
FF13	2	3	2.4	0.6	25
NF16	1	3	2.3	0.7	30
NF12	1	2.5	1.9	0.6	32
NF18	1	2	1.5	0.5	33
NF20	2	2	1.5	0.5	33
FF13	3	3	2.2	0.8	36
NF20	3	3	2.2	0.8	36
NF22	2	3	2.2	0.8	36
NF22	3	2	1.4	0.6	43
NF24	1	2	1.4	0.6	43
NF18	2	2.5	1.7	0.8	47
NF14	3	3	1.0	2	200

Table 3-3. Summary of SPI parameters by station for the August 1998 survey of the Nearfield area. Data from all three replicates were averaged for quantitative parameters and summed for the qualitative parameters (for example, the presence of infauna worms in one of the three replicates results in a + for the station).

	Pen	SR	RPD	Sediment	Surface Features and Epifauna					Subsurface Features				
Stat.	(cm)	(cm)	(cm)	Type	Surface	Layers	Amp	Tube	StkA	Wrm	Burr	Voids	SS	OSI
FF10	6.0	1.1	2.3	SIFS	BIO	–	–	+	+	+	+	OX	II/III	7.3
FF12	3.4	0.5	2.2	FS	BIO, BF	–	–	+	–	+	–	–	II/III	7.3
FF13	12.8	0.9	2.2	SIFS	BIO	–	–	+	+	+	+	OX,AN	II/III-III	7.7
NF02	0.3	1.5	IND	GR, PB, SA	PB	–	–	–	–	IND	IND	IND	IND	IND
NF04	1.8	1.5	>1.8	SH, FS	BIO, BF,SH	–	–	+	–	–	–	–	II	6.5
NF05	6.8	0.6	1.3	GR, SIFS	BIO, GR	–	–	+	+	+	+	OX	II-II/III	5.7
NF07	10.5	2.9	0.8	SIFS	BIO	–	–	+	+	+	+	OX,AN	II-II/III	5.3
NF08	12.5	1.1	1.8	SIFS	BIO	–	–	+	–	+	+	OX	II-III	6.3
NF09	9.4	0.9	1.9	SIFS, CL	BIO	–	–	+	+	+	+	OX	II/III-III	7.3
NF10	8.0	0.9	1.7	SIFS	BIO	–	–	+	+	+	+	OX	II/III-III	6.7
NF12	13.6	1.2	2.0	SIFS	BIO	–	–	+	+	+	+	OX,AN	II/III-III	7.3
NF13	3.3	3.0	>3.3	FSMS, GR, PB, SH, SIFS	BF, PB, GR, SH	–	–	+	–	–	–	–	II	8.0
NF14	3.7	1.8	0.8	PB, SIFS	PB, SH	–	–	+	–	+	+	–	II-II/III	5.0
NF15	2.9	1.2	>2.2	SH, FS, GR	BIO, SH	–	–	+	+	+	+	–	II-II/III	6.7
NF16	13.4	1.4	1.7	SIFS	BIO	–	–	+	+	+	+	OX,AN	II-II/III	6.7
NF17	2.1	1.0	>2.1	FS	BIO	–	–	+	+	–	–	–	II	6.3
NF18	4.4	1.5	1.7	GR, SH, SIFS	BIO, SH	–	–	+	+	+	–	–	I/II-II	5.3
NF19	1.6	0.9	0.5	FSSICL, SH, GR	BIO, SH	–	–	+	–	+	+	–	I-II	3.0
NF20	5.0	1.3	1.9	GR, SH, FSMS, SH, FS, CL, FSSICL	BIO, SH	–	–	+		+	+	OX	II-III	6.5
NF21	12.9	0.9	1.3	SIFS	BIO	–	–	+	+	+	+	OX,AN	II/III	6.3
NF22	9.1	1.3	1.9	SIFS	BIO	–	–	+	–	+	+	OX	II-III	6.7
NF23	3.6	1.5	>2.9	GR, FS, SH	BIO, BF, SH	–	–	+	–	+	–	–	II	7.3
NF24	7.2	0.5	1.2	FSSICL	BIO	–	–	+		+	+	OX	II-II/III	5.3

IND = Value for parameter was indeterminate.

> At least one of the three station replicates had an RPD layer deeper than the prism penetration.

Key:

Stat. = Station
Pen = Average prism penetration depth
SR = Average surface relief across the 15 cm width of the prism face plate
RPD = Average depth of the apparent color RPD
Sediment Type:

CL = Clay	PB = Pebble	SH = Shell
FS = Fine-sand	FSMS = Fine-Medium-sand	SIFS = Silty Fine-sand
FSSICL = Fine-sand-silt-clay	SA = Sand	GR = Gravel

Surface = Predominant sediment surface structuring features BIO = Biogenic surface, BF = Bedforms
Layers = Sediment layering
Amp = *Ampelisca* tubes
Tube = Worm tubes
StkA = Stick amphipod biogenic structures, likely the genus *Dyopedos*
Wrm = Subsurface infaunal worms
Burr = Infaunal burrows
Voids = Water filled inclusions in sediment, AN = Anoxic, OX = Oxic
SS = Estimated successional stage
OSI = Organism Sediment Index

Table 3-4. Nearfield station summary of SPI parameters for the August 1998 survey. Data from three replicates were averaged. Min. is minimum value at the station. Max. is maximum value at the station. SE is the standard error of the mean.

Station	Prism Penetration				Surface Relief				RPD				OSI			
	Mean	Min.	Max.	SE	Mean	Min.	Max	SE	Mean	Min.	Max	SE	Mean	Min.	Max	SE
FF10	6.0	5.1	6.5	0.45	1.1	0.6	2.1	0.50	2.3	2.0	2.7	0.21	7.3	7.0	8.0	0.33
FF12	3.4	3.1	4.0	0.28	0.5	0.3	0.7	0.12	2.2	1.8	2.5	0.22	7.3	7.0	8.0	0.33
FF13	12.8	9.7	17.4	2.34	0.9	0.6	1.1	0.17	2.2	2.1	2.4	0.09	7.7	7.0	8.0	0.33
NF02	0.3	0.0	1.0	0.33	1.5	1.5	1.5	0.00	IND	IND	IND	IND	IND	IND	IND	IND
NF04	1.8	1.4	2.5	0.35	1.5	0.6	2.9	0.70	>1.8	1.4	2.5	0.35	6.5	6.0	7.0	0.41
NF05	6.8	5.1	7.8	0.85	0.6	0.4	1.0	0.20	1.3	1.0	1.7	0.20	5.7	5.0	7.0	0.67
NF07	10.5	9.3	12.0	0.79	2.9	1.0	5.1	1.20	0.8	0.5	1.0	0.15	5.3	4.0	6.0	0.67
NF08	12.5	8.7	15.2	1.95	1.1	0.8	1.5	0.21	1.8	1.4	2.0	0.19	6.3	6.0	7.0	0.33
NF09	9.4	9.2	9.5	0.09	0.9	0.6	1.0	0.13	1.9	1.4	2.3	0.27	7.3	6.0	8.0	0.67
NF10	8.0	6.6	10.3	1.15	0.9	0.8	1.0	0.07	1.7	1.3	2.2	0.27	6.7	6.0	7.0	0.33
NF12	13.6	12.0	15.3	0.96	1.2	1.0	1.3	0.10	2.0	1.9	2.2	0.09	7.3	7.0	8.0	0.33
NF13	3.3	3.0	3.6	0.17	3.0	2.1	4.4	0.71	>3.3	3.2	3.3	0.04	8.0	8.0	8.0	0.00
NF14	3.7	2.3	4.8	0.73	1.8	0.6	3.0	0.69	0.8	0.6	1.0	0.12	5.0	4.0	6.0	0.58
NF15	2.9	2.2	4.2	0.64	1.2	0.8	1.7	0.26	>2.2	2.1	2.4	0.09	6.7	6.0	7.0	0.33
NF16	13.4	12.6	14.0	0.43	1.4	1.1	1.5	0.13	1.7	0.7	2.3	0.49	6.7	4.0	8.0	1.33
NF17	2.1	1.6	2.7	0.32	1.0	0.8	1.5	0.23	>2.1	1.6	2.7	0.32	6.3	6.0	7.0	0.33
NF18	4.4	3.0	5.9	0.84	1.5	1.0	2.1	0.33	1.7	1.5	1.8	0.09	5.3	5.0	6.0	0.33
NF19	1.6	0.0	3.2	0.92	0.9	0.6	1.1	0.20	0.5	0.4	0.5	0.04	3.0	2.0	4.0	0.82
NF20	5.0	2.3	8.6	1.87	1.3	0.2	3.0	0.85	1.9	1.5	2.2	0.29	6.5	5.0	8.0	1.22
NF21	12.9	11.9	14.5	0.81	0.9	0.6	1.3	0.21	1.3	0.4	1.9	0.47	6.3	5.0	7.0	0.67
NF22	9.1	7.5	10.3	0.83	1.3	0.8	2.1	0.39	1.9	1.4	2.2	0.25	6.7	5.0	8.0	0.88
NF23	3.6	2.3	5.2	0.85	1.5	0.6	2.5	0.55	>2.9	2.3	3.3	0.32	7.3	6.0	8.0	0.67
NF24	7.2	6.9	7.8	0.28	0.5	0.4	0.6	0.06	1.2	0.5	1.7	0.36	5.3	4.0	6.0	0.67

Station	Number of Infauna/ image				Number of Burrows/ image			
	Mean	Min	Max	SE	Mean	Min	Max	SE
FF10	4.0	3	6	1.00	1.3	0	3	0.88
FF12	4.7	3	7	1.20	0.0	0	0	0
FF13	5.7	0	13	3.85	3.0	2	4	0.58
NF02	.	.	.	.	.	.	.	.
NF04	0.0	0	0	0.00	0.0	0	0	0.00
NF05	5.3	3	9	1.85	3.0	2	4	0.58
NF07	6.0	3	11	2.52	2.3	0	4	1.20
NF08	4.3	3	6	0.88	1.0	0	2	0.58
NF09	6.7	4	9	1.45	1.3	0	3	0.88
NF10	8.0	5	12	2.08	2.7	2	3	0.33
NF12	4.3	1	10	2.85	3.0	3	3	0.00
NF13	0.0	0	0	0.00	0.0	0	0	0.00
NF14	0.7	0	2	0.66	0.3	0	1	0.33
NF15	0.7	0	2	0.66	1.7	0	4	1.20
NF16	1.7	1	2	0.33	1.3	0	3	0.88
NF17	0.0	0	0	0.00	0.0	0	0	0.00
NF18	0.7	0	1	0.33	0.0	0	0	0.00
NF19	0.5	0	1	0.41	0.5	0	1	0.41
NF20	6.0	3	9	2.45	2.0	0	4	1.63
NF21	2.7	1	6	1.67	1.3	0	4	1.33
NF22	5.7	5	6	0.33	1.0	0	2	0.58
NF23	0.7	0	2	0.66	0.0	0	0	0.00
NF24	4.0	1	8	2.08	2.7	2	3	0.33

Table 3-5. Within-station variability of apparent color RPD layer measurements at Nearfield stations for August 1998 (*n* = 3).

Station	Min. (cm)	Median (cm)	Max. (cm)	Mean(cm)	SD (cm)	CV (%)	Max-Min/Md (%)
FF10*	2	2.2	2.7	2.3	0.36	16	32
FF12	1.8	2.4	2.5	2.2	0.38	17	29
FF13*	2.1	2.2	2.4	2.2	0.15	7	14
NF02	.	.	.	.	.	.	.
NF04	>1.4	>1.5	>2.5	.	.	.	.
NF05	1	1.3	1.7	1.3	0.35	26	54
NF07	0.5	0.8	1	0.8	0.25	32	63
NF08	1.4	1.9	2	1.8	0.32	18	32
NF09	1.4	2.1	2.3	1.9	0.47	24	43
NF10	1.3	1.5	2.2	1.7	0.47	28	60
NF12*	1.9	2	2.2	2.0	0.15	7	15
NF13	>3.0	.	>3.3	.	.	.	.
NF14*	0.6	0.9	1	0.8	0.21	25	44
NF15	2.1	>2.2	>2.4	.	.	.	.
NF16	0.7	2	2.3	1.7	0.85	51	80
NF17	>1.6	>2.1	>2.7	.	.	.	.
NF18*	1.5	1.7	1.8	1.7	0.15	9	18
NF19*	0.4	0.4	0.5	0.5	0.07	16	25
NF20	1.5	1.8	2.2	1.9	0.49	26	39
NF21	0.4	1.7	1.9	1.3	0.81	61	88
NF22	1.4	2.1	2.2	1.9	0.44	23	38
NF23	>2.3	3.2	>3.3	.	.	.	.
NF24	0.5	1.4	1.7	1.2	0.62	52	86

* Sample size of three was adequate to detect a 50% change with 95% CI and 80% power.

Min. is minimum and Max. is maximum value at the station. SD is the standard deviation. CV is the coefficient of variation (SD/Mean) which expresses within station variability as a percentage of the mean. Max-Min/Md expresses within station variability of RPD as a percentage of the median.

Key:

Min = minimum value at station
Max = maximum value at station
SD = standard deviation
CV = Coefficient of Variation
Max-Min/Md = expression of with-in station variability of RPD as a percentage of the median

Physical processes and sediments—Grain size ranged from gravel, sand, and pebbles (NF02) to mixed sandy-silt-clay sediments (NF24) (Table 3-3, see Appendix B-1 for image plates). Traces of clay were also seen in a few replicate images (NF09, NF20). The modal grain size was silty-sand and within-station variation of sediment type was low. Grain size for all three replicates was the same at 15 of the 23 stations (Figure 3-1). The stations with the most spatial variability in sediment type were NF13, NF19, NF20, and NF23, where each of the replicates had a different sediment classification. Pure sands

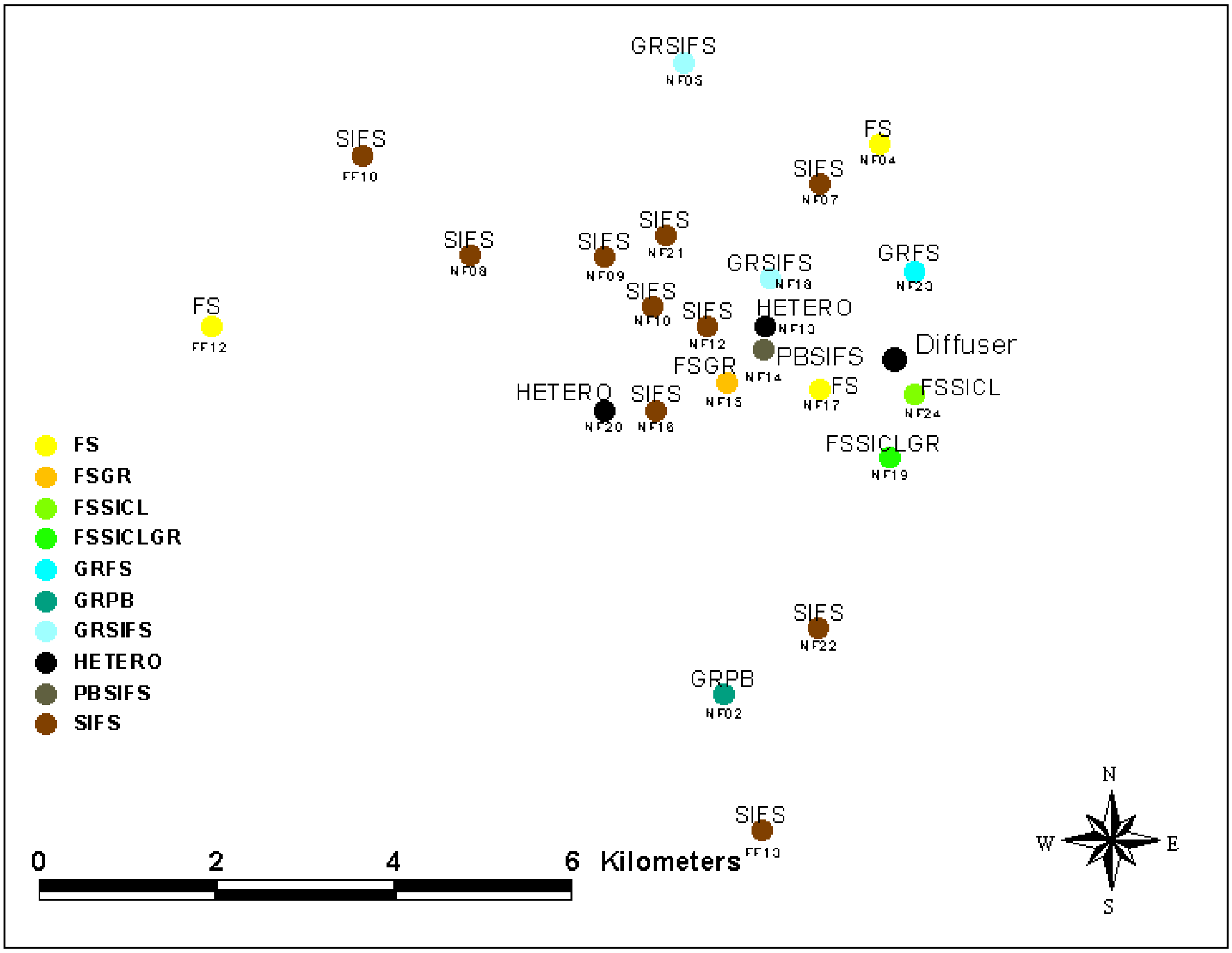


Figure 3-1. Distribution of SPI sediment types at Nearfield stations, August 1998. Abbreviations are as listed in Table 3-3; HETERD = heterogeneous.

and gravels, indicative of high kinetic energy bottoms, were seen at seven stations (FF12, NF02, NF04, NF15, NF17, NF23) scattered throughout the study area (Figure 3-1). Bedforms, also an indicator of high energy bottoms, were seen at four of these seven stations.

Homogeneous finer sediments, very-fine-sand and coarse-silts, were concentrated to the northwest of the diffuser but also occurred to the south (Figure 3-1). The finest sediments occurred at Station NF24 and appeared to be a mixture of fine-sand-silt-clay with an apparent modal phi >6. None of the stations appeared to have sediments that were composed only of silts and clays.

Prism penetration and sediment grain size were closely related with the lowest penetration occurring at hard sand-gravel-pebble-bottoms (NF02). Mixed sediments, fine-sand-silt, had the highest prism penetration (NF12). The range of average station prism penetration was 0.3 to 13.6 cm and reflected the high sand content of surface sediments throughout the Nearfield (see Section 4). Finer grained higher penetration stations clustered to the northwest and south of the diffuser (Figure 3-2).

Physical and biological roughness features were about the same magnitude. In physically dominated sandy habitats, surface relief (bed roughness) was typically small (from 0.6 to 2.5 cm high) sand ripples or bedforms (NF23). In muddy habitats, surface relief typically appeared as irregular surfaces caused by

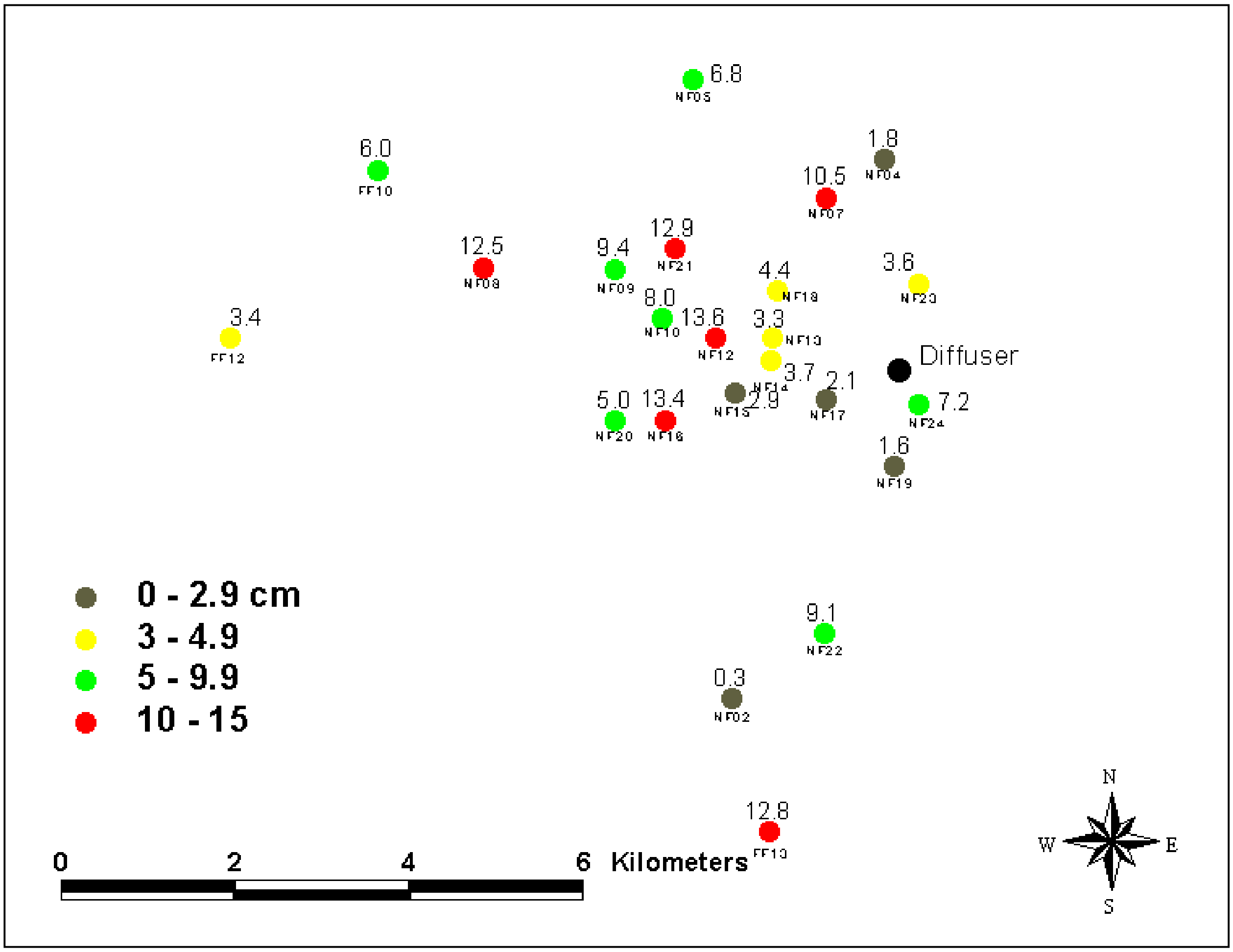


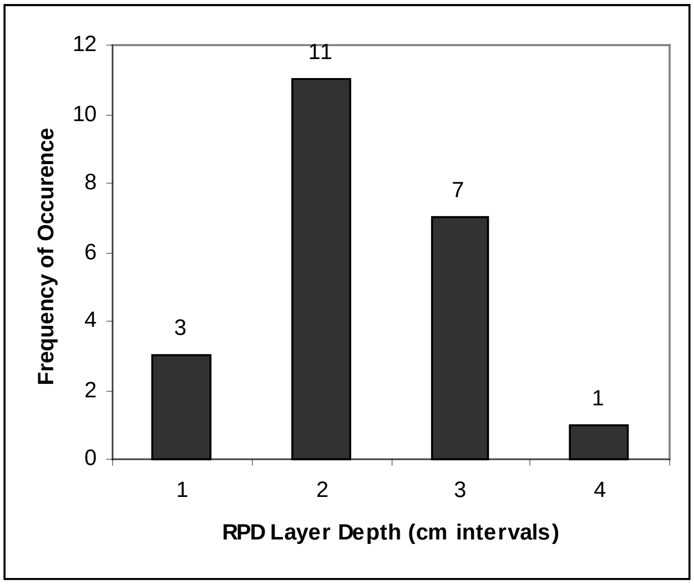
Figure 3-2. Distribution of SPI prism penetration at Nearfield stations, August 1998.

the biogenic activity of benthic organisms (NF22). Biological surface roughness ranged from fecal mounds (NF10) and tubes (NF10) to colonies of hydroids (NF14). Average biogenic surface relief ranged from 0.5 to 3.0 cm (Table 3-4).

Apparent Color RPD Depth—Porous sandy sediments (NF04) and mixed sediments with high levels of biogenic activity (NF12) had the deepest apparent color RPD measurements. The shallowest RPD measurements were associated with stations that had signs of physical disturbance (NF07) or a higher proportion of fine sediments (NF19). The average apparent color RPD depth at the 23 stations ranged from 0.5 to >3.3 cm (Table 3-4) with 11 stations in the modal interval of 1.0 to 1.9 cm (Figure 3-3). At five harder-bottom, coarse-sediment stations, the RPD was deeper than the prism penetration. The maximum actual RPD measurement for a replicate was 3.2 cm at NF23-1, with NF23-3 and NF13-1 being >3.3 cm because of shallow prism penetration, but the maximum depth to which oxidized sediments were observed was 6.3 cm at NF09-2. Biogenic activity deepened the penetration of oxic sediments at most stations, with the deeper maximum RPD depths associated with oxidized sediments around burrow structures. The average apparent color RPD layer depth for all stations was 1.8 cm (0.14 SE), with the deepest RPD layers in the vicinity of the diffuser to the west and north (Figure 3-4).

RPD long has been associated with benthic habitat quality, in particular organic enrichment (Pearson and Rosenberg 1978). As organic loading increases the RPD layer becomes shallower in response to increased sediment oxygen demand and the elimination of deep bioturbating fauna. Based on this close association between organic loading and habitat quality, RPD makes a good monitoring parameter with a

50% change in RPD depth set as a trigger level. However, factors other than organic loading can cause RPD layer depth to fluctuate. Factors such as season, grain size, pore water flow, water quality, and intensity of bioturbation are all known to contribute to small scale spatial and temporal variation to RPD layer depth (Rhoads and Boyer 1982, Jones and Jago 1993, Diaz and Rosenberg 1995, Aller and Aller 1998).



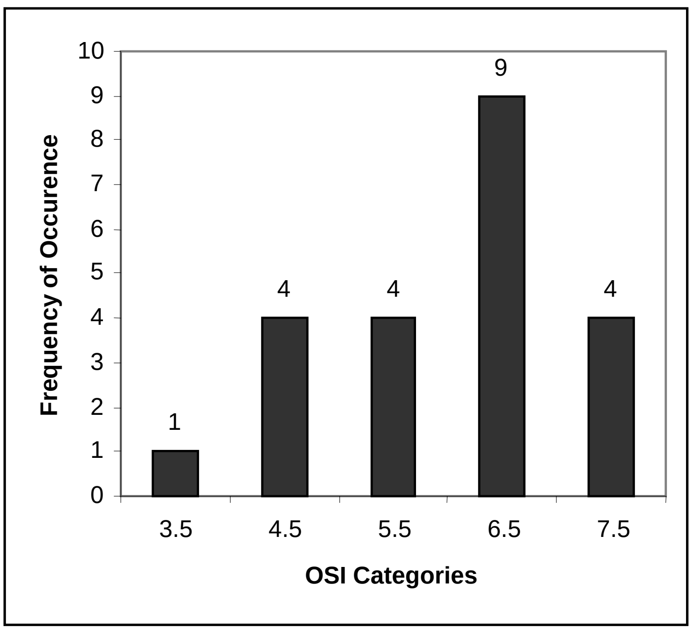


Figure 3-3. Histogram of apparent RPD layer depth and Organism Sediment Index determined by SPI at Nearfield stations, August 1998. RPD intervals are: 1 = 0-1.0 cm, 2 = 1.1-2.0, 3 = 2.1-3.0, 4 = 3.1-4.0. OSI intervals are: 3.5 = 3.0-4.4, 4.5 = 4.5-5.4, 5.5 = 5.5-6.4, 6.5 = 6.5-7.4, 7.5 = 7.5-8.4.

To test the sensitivity of SPI for estimating a 50% change in the apparent color RPD throughout the study area, the amount of change considered to represent a critical trigger level (MWRA 1997), the variance of the average station RPD at the 17 stations that had three RPD measurements was analyzed. At five stations the RPD for at least one of the three replicates images could not be determined. To detect a 50% change in RPD layer depth throughout the study area from one year to the next with a 95% confidence interval and 80% power would require approximately 10 stations to be sampled. This number is based on the assumption that a *t*-test would be used to assess the significance of the difference (Zar 1984). Twelve stations would give a 95% confidence interval and power. Fifteen stations would increase the power to 99%.

Within-station variation in RPD depth was greater than the overall variation within the study area. To determine if any of the three replicates differed by more than 50%, the range in RPD was divided by the median and expressed as a percentage (Table 3-5). For the 17 stations that had RPD measurements for all 3 replicate images, 6 exceeded a 50% difference. This high proportion of >50% stations was related to two factors; small sample size and small-scale spatial variation in RPD depth likely related to patchiness and spatial variation in the bioturbating fauna (see Section 5). Station NF12 was representative of stations with low RPD depth variation and NF21 was representative of stations with high RDP depth variation (Table 3-5).

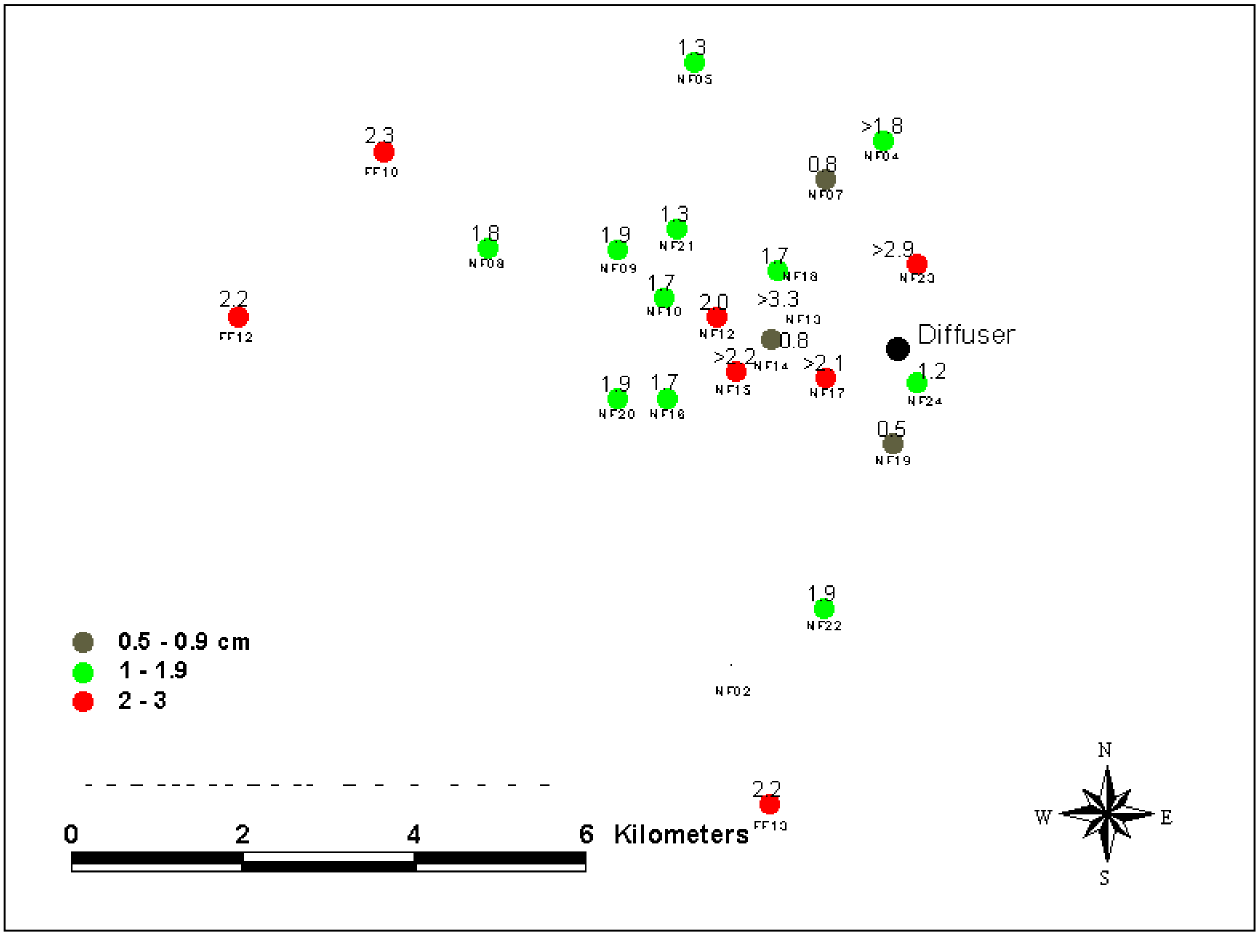


Figure 3-4. Distribution of SPI apparent color RPD layer depths at Nearfield stations, August 1998.

Biogenic Activity—The sediment surface at most stations was dominated by biogenic structures associated with successional stage II and III fauna (Table 3-3). Biogenic surface features also were present at most sand and gravel stations. The only exception was NF02, which was a pebble substrate. The surface biogenic structures observed included biogenic whips or sticks made by amphipods (Appendix B, Plate 3, FF13) likely in the genus *Dyopedos* (Mattson and Cedhagen 1989, Thiel 1997, Martin Thiel, personal communication), small and large worm tubes (NF10), epibenthic organisms (FF10), burrow openings (NF22), feeding pits (NF10), biogenic mounds (NF10) and shells (NF19).

Subsurface biogenic structures and actives were associated with infaunal organisms and included active oxic burrows (NF09), back-filled burrows (NF16), water filled oxic voids (NF07), water filled anoxic voids (NF12), and infaunal organisms (FF13). There also appeared to be large numbers of free burrowing worms at many stations. The 13 worms seen at station FF13 replicate 3 were in a line about 3 cm below the sediment surface.

Successional Stage and Organism Sediment Index—The modal successional stage was intermediate between stages II and III (II/III) indicating that communities in the Nearfield are well developed (see chapter on benthic communities). The high degree of biogenic sediment reworking observed in many images was consistent with the stage II/III successional designation. Stations NF18 and NF19 had the lowest overall successional stage designation (stage I to II) with little indication of subsurface biogenic activity (Table 3-3). Some small tubes were present at the sediment surface at these stations. Lower successional stage stations clustered around the western end of the diffuser (Figure 3-5).

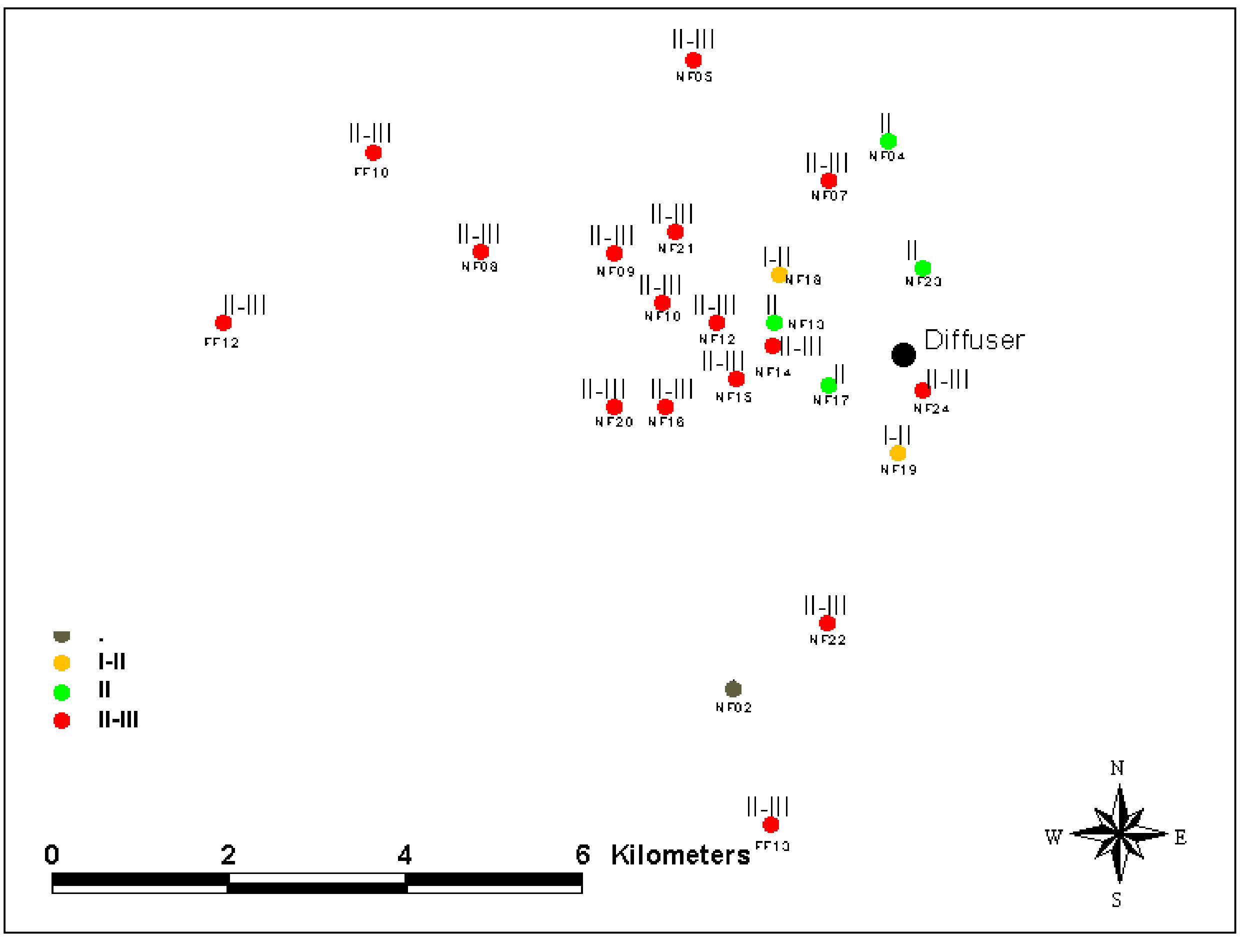


Figure 3-5. Distribution of SPI successional stage at Nearfield stations, August 1998. Stages are as defined in Section 3.2.1; hyphenated stages are intermediate between the two listed.

The Organism Sediment Index (OSI) at the Nearfield stations was in the range indicative of communities under some form of moderate stress (Rhoads and Germano 1986). Analysis of benthic community and other SPI data point to physical stress from water movement leading to dynamic surface sediments as the main source of stress in the Nearfield area. The modal OSI interval was 6.5 to 7.4, containing 11 of 22 stations, and the range was from 3.0 (NF19) to 8.0 (NF13 and FF13) (Figure 3-3, Table 3-4). The average OSI value was 6.4 (standard error = 0.25). In the case of the Nearfield stations the stress is most likely physical processes such as hydrodynamics and sediment transport. The lowest OSI values clustered in the vicinity of the diffuser to the south and west (Figure 3-6), and were associated with coarse and fine sediment types.

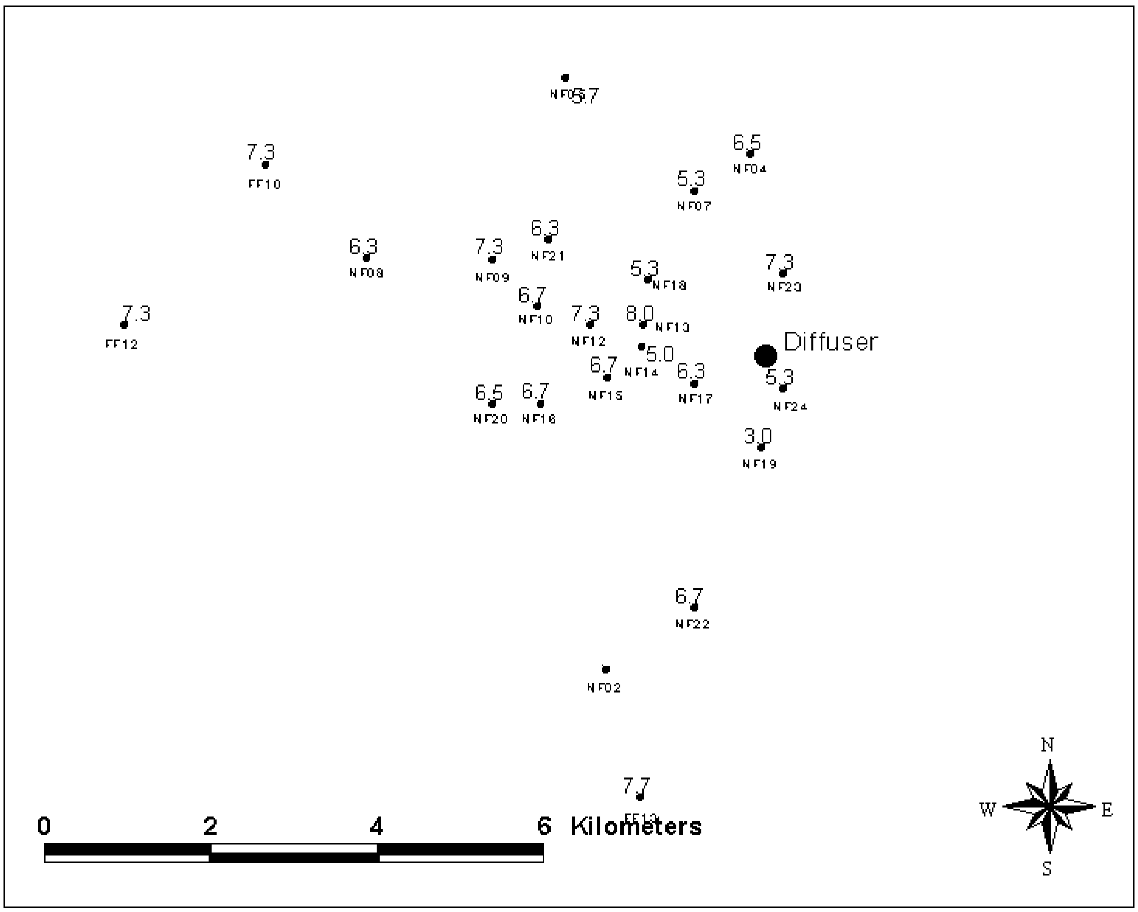


Figure 3-6. Distribution of SPI Organism Sediment Index (OSI) at Nearfield stations, August 1998.

4. 1998 SOFT-BOTTOM SEDIMENT CHEMISTRY

[by Deirdre Dahlen and Roy K. Kropp]

4.1 Methods

4.1.1 Laboratory Analyses for Ancillary Measurements

Laboratory procedures followed those outlined in the Benthic Monitoring CW/QAPP (Kropp and Boyle 1998). Concise summaries of the procedures are provided below.

Grain Size—Samples were analyzed for grain size by a sequence of wet sieving and dry sieving. Methodologies followed Folk (1974). The sand/gravel fraction was separated from the mud fraction. This sand/gravel fraction was transferred to a 200-mL beaker, decanted, and dried overnight at 95 ºC. The dried sand/gravel fraction was mixed by hand to disaggregate the material, and then dry-sieved on stacked !1-, 0-, 1-, 2-, 3-, and 4-phi sieves. Each size class was weighed to the nearest 0.1 mg on a top-loading balance. Particles smaller than 4 phi were analyzed using the pipette method. Data were presented in weight percent by size class. In addition, the gravel:sand:silt:clay ratio and a numerical approximation of mean size and sorting (standard deviation) was calculated. Grain size determinations were made by GeoPlan Associates.

TOC—A portion of the sample to be analyzed for TOC content was dried at 70 ºC for 24–36 hours and ground to a fine powder. The sample was treated with 10% HCl to remove inorganic carbon and dried at 70 ºC for 24 hours. Between 10 and 500 mg of dry, finely ground, and homogenized sample were weighed to the nearest 0.1 mg and placed in a crucible that had been precombusted for 4 hours at 500 ºC. A Coulometric Carbon Analyzer was used to determine the TOC content of the samples. TOC determinations were performed by Applied Marine Sciences, Inc. according to SOP AMS - TOC94.

***Clostridium perfringens*—**Sediment extraction methods for determination of *Clostridium perfringens* spores followed those developed by Emerson and Cabelli (1982), as modified by Saad (1992). The filters for enumeration of *C. perfringens* spores were incubated anaerobically at 44.5 ºC for 24 hours. Following incubation, the filter was exposed to ammonium hydroxide for 15–30 seconds. Yellowish colonies that turn red to dark pink upon exposure were counted as *C. perfringens*. Data are reported here as colony-forming units (cfu) per gram dry weight of sediment. This analysis was performed by MTH Environmental Associates.

4.1.2 Laboratory Analyses for Contaminants

Analyses of sediments for organic constituents and metals were performed following methods outlined in Table 4-1. Samples collected for the Sediment Contaminant Special Study were analyzed for linear alkyl benzenes (LABs), polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCBs), chlorinated pesticides and metals following general NS&T methodologies (Peven et al. 1993a, Peven et al. 1993b). More detailed information is provided in the CW/QAPP (Kropp and Boyle 1998).

4.1.3 Data Analyses

Sediment grain size results were evaluated using ternary plots to visually display the distribution of sand, silt and clay in sediment collected from Nearfield and Farfield stations.

Results from sediment grain size, total organic carbon (TOC), and *Clostridium* analyses were compared from all stations using histogram plots. In most plots, the results from the analyses of each replicate sample are included.

Table 4-1. Parameters and methods of analysis for organic constituents and metals.

Parameter	Unit of Measurement	Method	Reference
Linear Alkylbenzenes	ng/g	GC/MS	Battelle SOP 5-157
Polycyclic Aromatic Hydrocarbons	ng/g	GC/MS	Battelle SOP 5-157
Polychlorinated Biphenyls/ Pesticides	ng/g	GC/ECD	Battelle SOP 5-128
Major Metals (Al, Fe)	% Dry Weight	EDXRF	KLM Technical Procedure 7-40.48
Trace Metals (Cr, Ni, Pb, Zn, Cu)	μg/g	EDXRF	KLM Technical Procedure 7-40.48
Trace Metals (Ag, Cd, and Hg)	μg/g	GFAA (Ag, Cd) CVAA (Hg)	Battelle SOP 3-103 Battelle SOP 5-224

Linear regression analysis was performed on sediment grain size, TOC, and *Clostridium perfringens* data to examine the correlation between these parameters. Probability values were taken from Rohlf and Sokal (1969).

The numerical approximate mean phi, referred to simply as mean phi in the text, was calculated by weighting each class fraction measured and summing the weighted fractions (Table 4.2).

Table 4-2. An example of numerical approximate mean phi determination.

phi Class	Weight Factor[1]	% Fraction Measured (station FF01A)	Weighted Fraction[2]
phi<-1	!2	1.29	!0.0258
!1<phi<0	!0.5	1	!0.0050
0<phi<1	0.5	0.29	0.00145
1<phi<2	1.5	17.21	0.258
2<phi<3	2.5	7.91	0.198
3<phi<4	3.5	54.11	1.89
4<phi<8	6	17.5	1.05
phi>8	9	0.7	0.063
		Sum of weighted fractions Numerical approximate mean phi[3]	3.43

[1] Weight Factor represents middle of the phi class range
[2] Weighted Fraction = (Weight Factor)*(%Fraction Measure/100)
[3] Numerical approximate mean phi = Sum of weighted fractions

4.2 Results and Discussion

Sediment samples collected in August 1998 from the 20 Nearfield and 11 Farfield stations were analyzed for grain size composition, total organic carbon (TOC), and *Clostridium perfringens* as described in Section 4.1.1. Summary data are presented in Appendix C-1.

Sediment samples collected for the Sediment Contaminant Special Study were analyzed for grain size, TOC, *Clostridium*, organic contaminants, and metals as described in Section 4.1.1. Summary data are presented in Appendix C-2.

4.2.1 Grain Size

Nearfield—Sediments collected from Nearfield stations were predominantly comprised of sand, with small amounts of silt and clay (Figure 4-1). Sediments at five stations (NF02, NF04, NF13, NF17, and NF23) contained greater than 95% gravel and sand. Seven additional stations had sediments comprised of gravel and sand. The coarsest sediments (>80% sand) were located in close proximity to the diffuser. Sediments from stations NF14 and NF18 contained the greatest amounts of gravel, 51% and 60% respectively. Silty sediments (>50% silt plus clay, % fines) were collected from stations NF08, NF12, NF16, and NF21, located to the west and northwest of the diffuser.

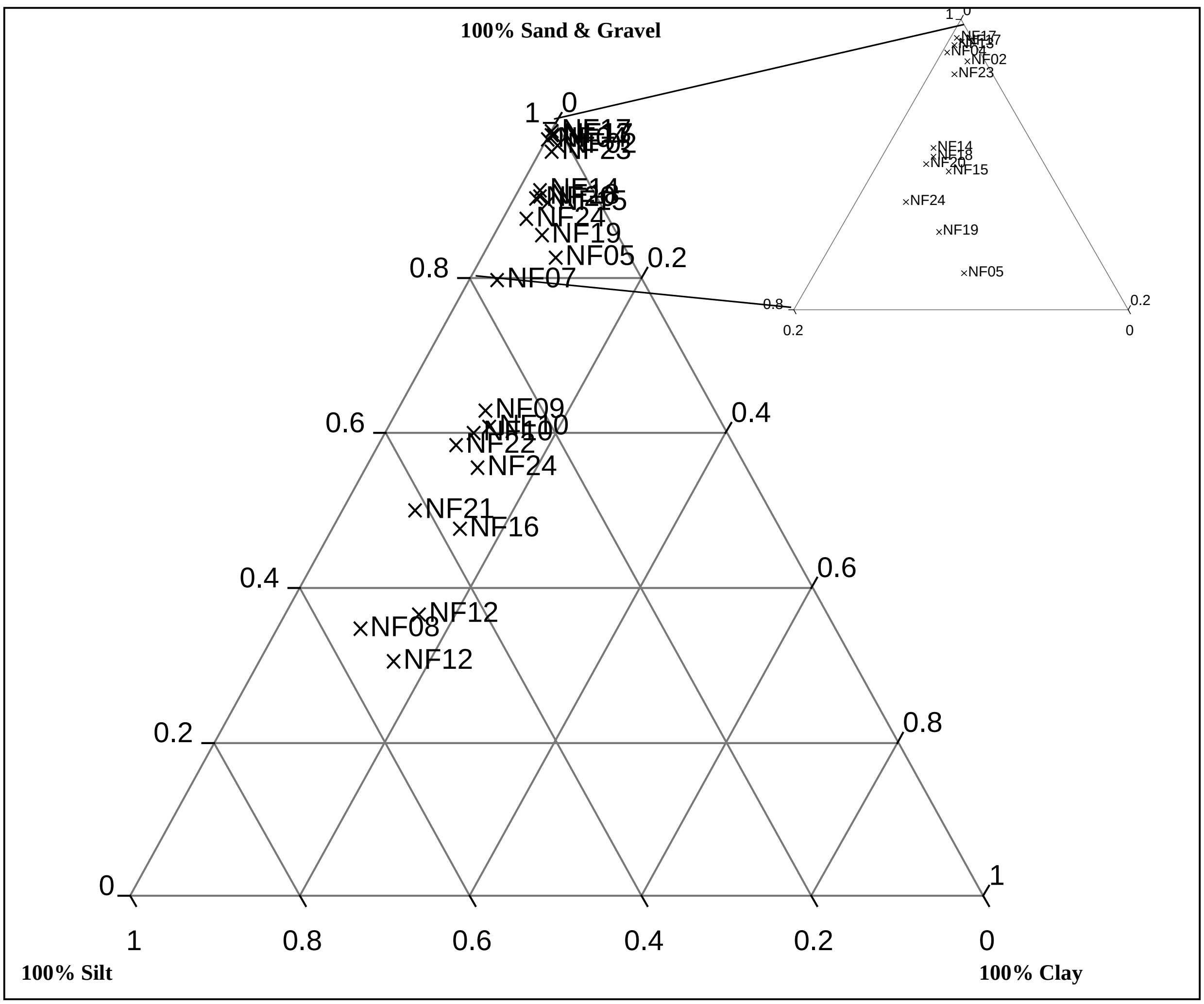


Figure 4-1. Grain size composition from sediments collected at Nearfield stations in August 1998.

The phi analysis revealed that sediments generally were comprised of medium, fine, and very fine sands, ranging from !0.02 (NF18) to 5.57 (NF12) mean phi (Figure 4-2). Very coarse and coarse sands were present only in small amounts, totaling no more than 11% (NF20). Within the sand category (!1< phi <4), medium and fine sands were the principal fractions in Nearfield sediments, except at stations NF08, NF09, NF10, NF12, NF16, NF21, and NF22 where the very fine sand fraction was ranked first.

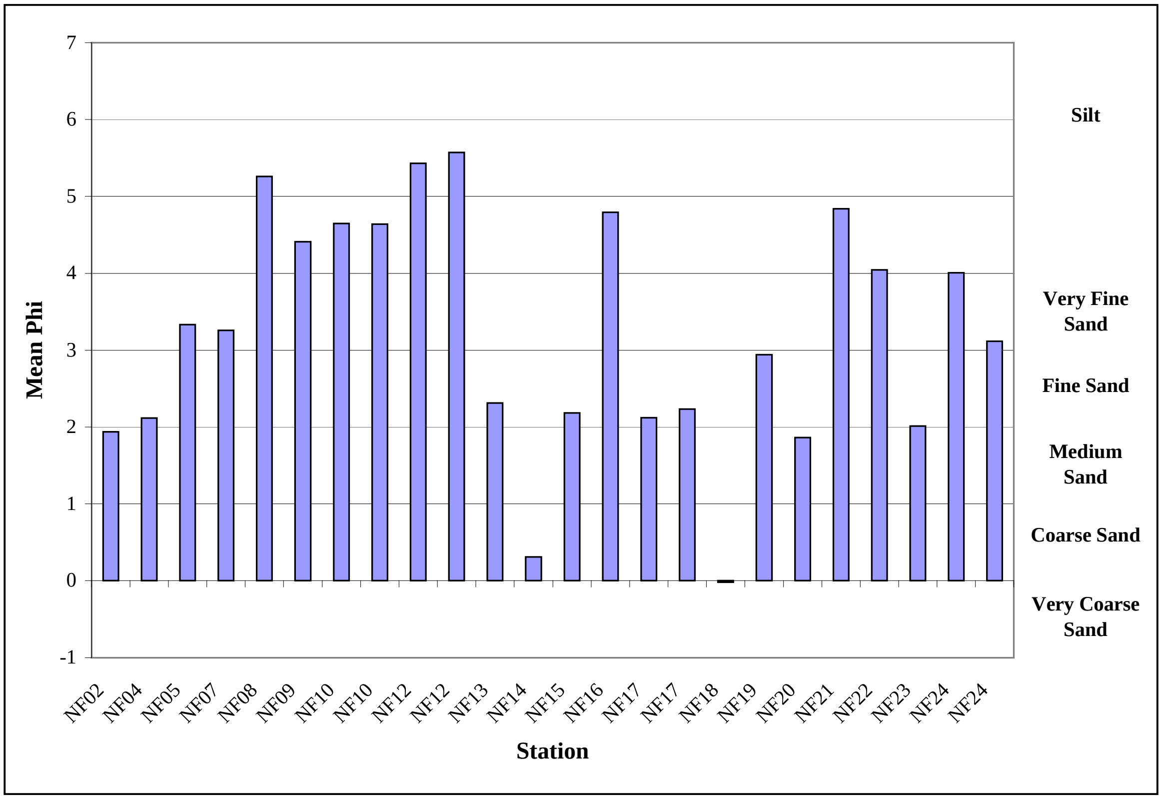


Figure 4-2. Numerical approximate mean phi in sediments collected from Nearfield stations in August 1998. Values are for each grab sample.

Laboratory triplicate analyses for grain size composition were performed on sediments from stations NF10, NF23, and NF24. In addition, replicate grab samples were taken for stations NF10, NF12, NF17, and NF24. Laboratory triplicate analyses were similar, with coefficients of variation (CV) ranging from 1% to 12% for those fractions measured at levels greater than 10 × MDL. The relative percent difference (R%D) between replicate grab samples was comparable (R%D<12% for values >10 × MDL), with the exception of station NF24 where the grain size composition varied considerably between grabs (R%D ranged from 21 to 125%, Figure 4-3). The significant variability between replicate grab samples from station NF24 may indicate that sediment was collected on the boundary between two different bottom types.

Farfield—Sediments collected from Farfield stations had varying grain size compositions ranging from very sandy (>90% sand and gravel) to very silty (>90% silt plus clay) (Figure 4-4). Sediment from only one replicate (from FF13) contained more than 95% gravel and sand, with the gravel fraction predominant (71%). However, the other replicate sample for station FF13 contained less than 60% combined sand and gravel, with only 1% gravel. Sediments from Farfield stations located closer to shore, including FF01A (off Gloucester), FF09 (western Massachusetts Bay), and FF10 (off Nahant) contained more than 80%

gravel and sand. Sediments collected from stations FF06 (Cape Cod Bay), FF11 (off Cape Ann), and FF14 (western Massachusetts Bay) were silty, ranging from 64% to 84% fines. Sediments from stations FF04 (Stellwagen Basin) and FF07 (Cape Cod Bay) were very silty (>90%fines) compared to sediments from all other Farfield stations.

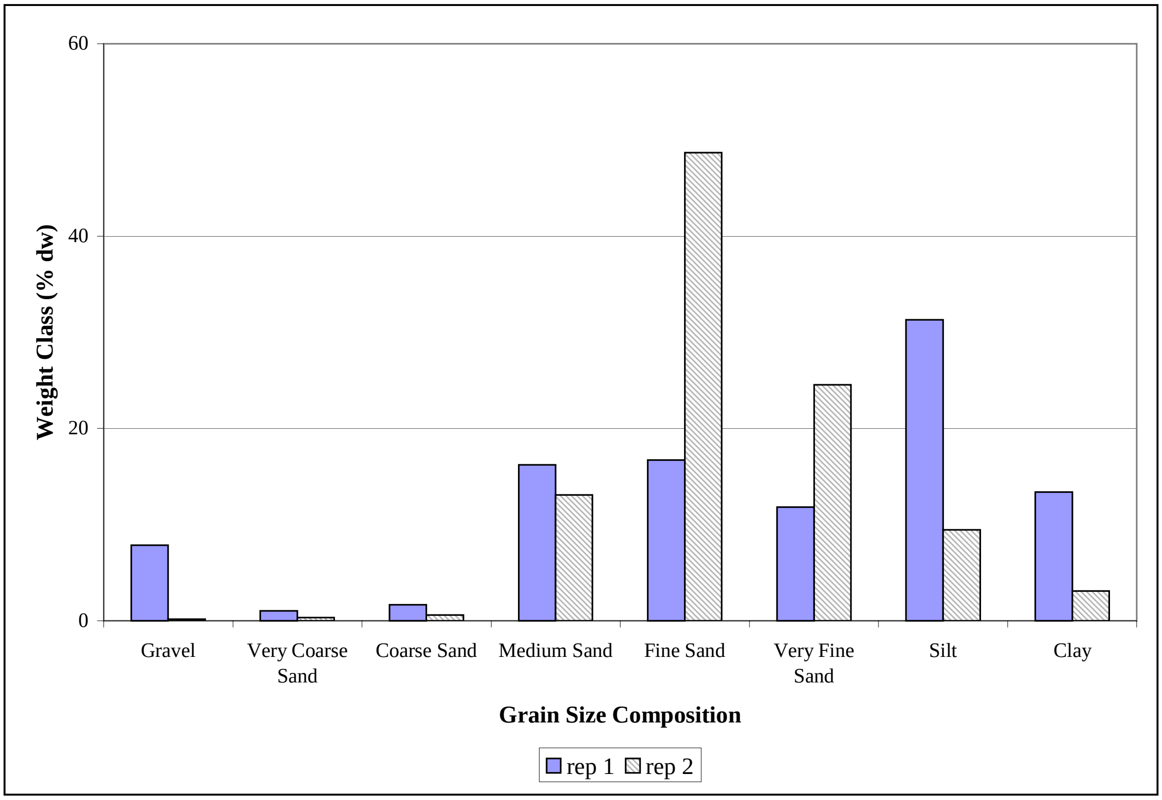


Figure 4-3. Grain size composition of replicate sediment grabs collected at station NF24 in August 1998.

The phi analysis revealed that sediments generally were comprised of fine and very fine sands, silt, and clay, ranging from 2.35 to 6.59 mean phi, with the exception of station FF13 (one replicate with mean phi = !0.89) (Figure 4-5). Very coarse and coarse sands were present only in small amounts, totaling no more than 12% at station FF13 (duplicate grab analysis). Within the sand classification (!1< phi <4), very fine sand was the predominant fraction in Farfield sediments, except at station FF09 where the fine sand fraction was ranked first.

Duplicate grab samples were collected at each Farfield station. In general, replicate results for % gravel, sand, silt, and clay were similar (R%D<30% for values >10 × MDL), with the exception of stations FF07 (R%D = 39% for clay), FF10 (R%D = 68% for silt), and FF13 (R%D = 69% for sand). Sediments from station FF13 had the greatest variability between replicate grabs (Figure 4-6). The mean phi values for sediments from the replicates collected at station FF13 were 4.46 and !0.89.

4.2.2 Total Organic Carbon

Nearfield—Sediments collected from Nearfield stations generally had low percentages of total organic carbon, ranging from 0.04 to 2.1% (Figure 4-7, top). Sediments from 17 Nearfield stations (85%) had TOC levels less than 1%. Sediments from station NF16 had the highest levels of TOC (2.1%). Generally, the percentage of TOC increased in sediments that had higher amounts of organic matter (i.e.

mud, % fines). The grain size composition analysis revealed that more silty sediments (>50% fines) were located to the west and northwest of the diffuser. Similarly, the TOC values were generally higher (>1%) in sediments located to the west and northwest of the diffuser (stations NF16, NF12, NF08). Stations with higher TOC content reflect areas where detrital organic matter accumulates during periods of low kinetic energy. Stations with low TOC content do not accumulate organic detritus due to frequent washing and sorting of the bottom by currents.

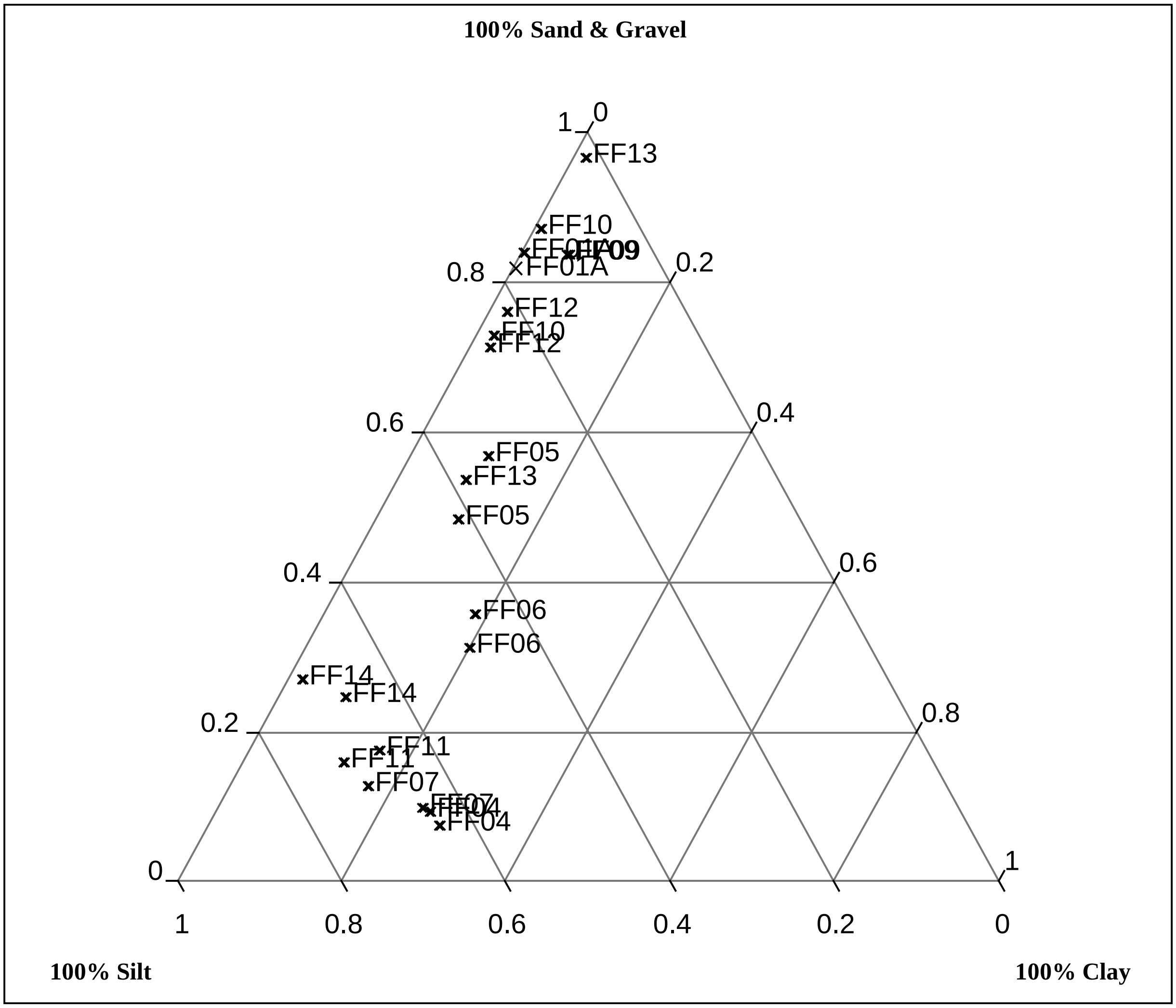


Figure 4-4. Grain size composition from sediments collected at Farfield stations in August 1998.

The relationship between TOC and % fines is illustrated in Figure 4-7 (bottom) (r = 0.77, n = 24, p < 0.01). With the exception of station NF16 (r = 0.84 when NF16 was excluded from the regression analysis), TOC correlated well with % fines at all Nearfield stations, as is typical for coastal sediments (Sanders 1958).

Replicate grab samples were taken for stations NF12, NF17, and NF24. TOC content was similar between replicate analyses (R%D<20% for values >10 × MDL), with the exception of station NF24 where TOC values (1.01% and 0.23%) differed by more than a factor of 4. The replicate analyses for grain size composition was also more variable at this station.

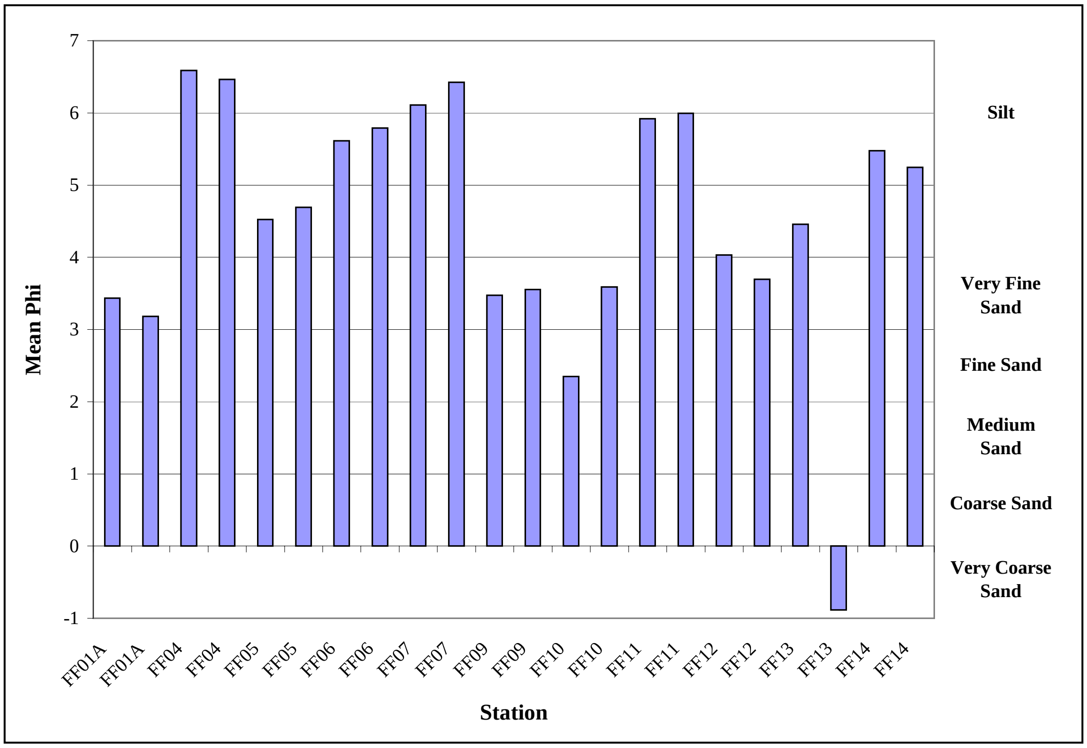


Figure 4-5. Numerical approximate mean phi in sediments collected from Farfield stations in August 1998. Values are for each replicate.

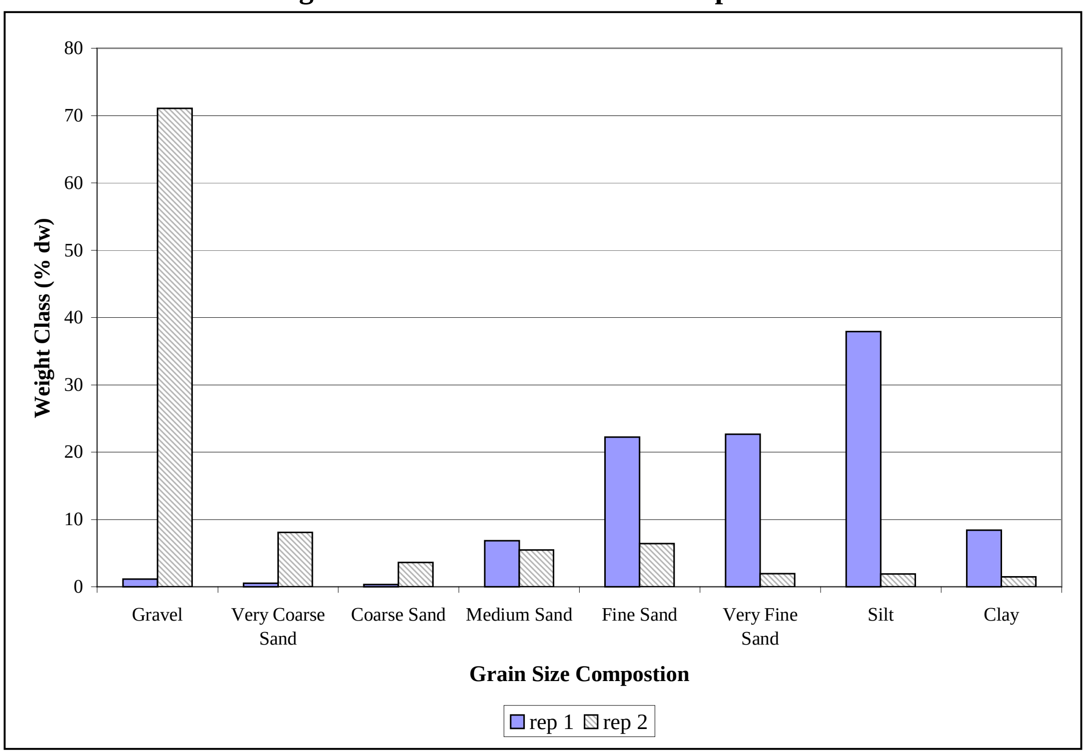
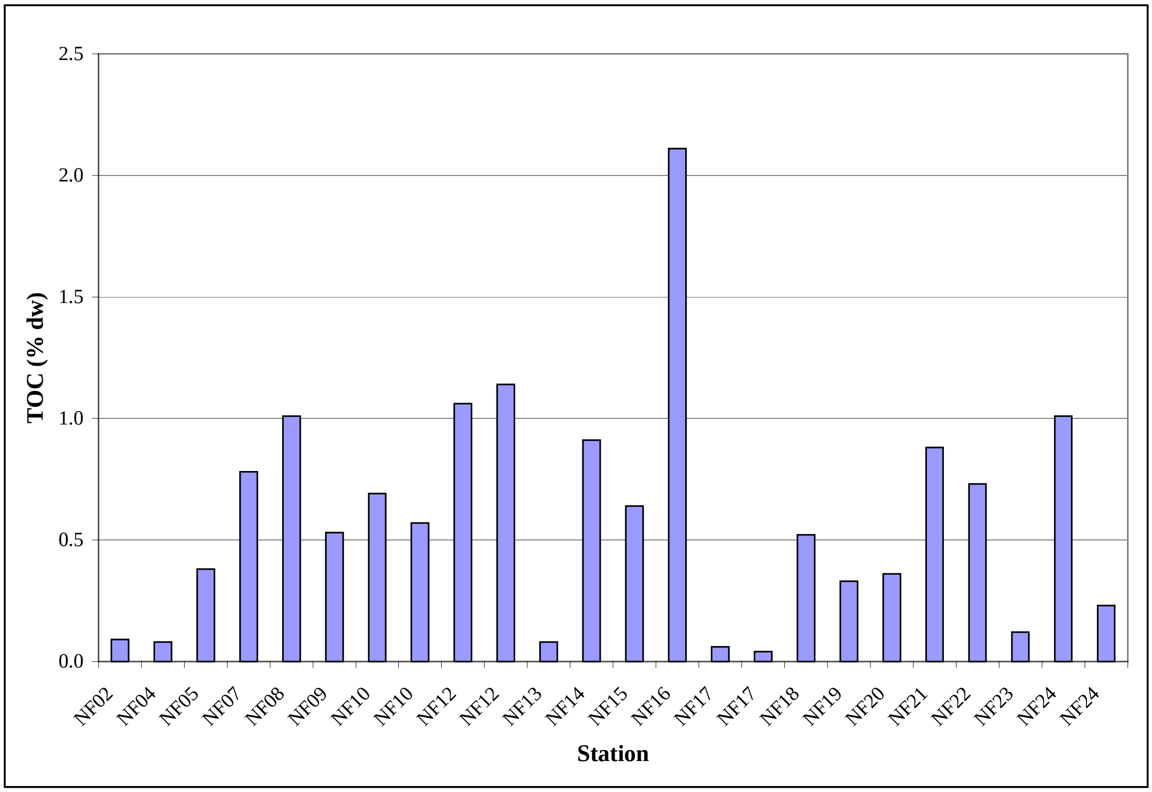


Figure 4-6. Grain size composition of replicate sediment grabs collected at station FF13 in August 1998.



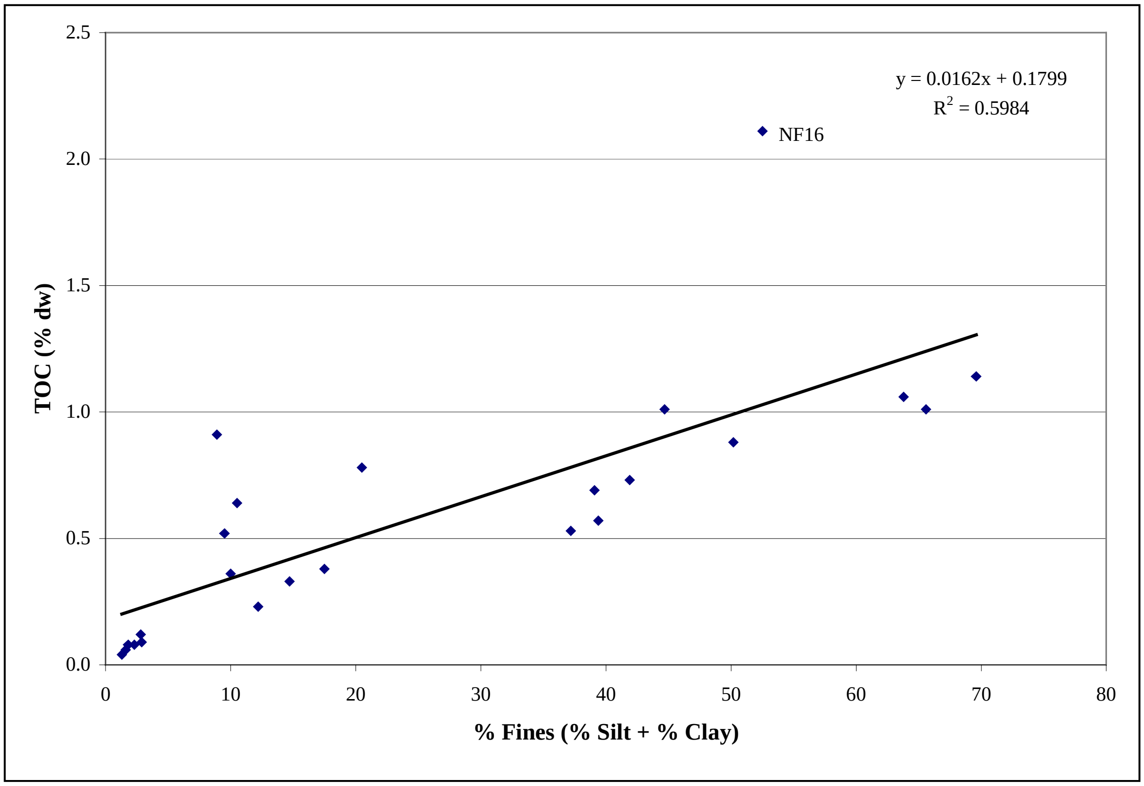


Figure 4-7. Total organic carbon content plotted by station (top) and versus % fines (bottom) in sediments collected at Nearfield stations in August 1998. Values are for each grab sample.

Farfield—TOC values ranged from 0.25 to 2.3% (Figure 4-8, top) in sediments collected from Farfield stations. The TOC content in Farfield sediments correlated well with sediment grain size (Figure 4-8, bottom, $r = 0.95$, $n = 22$, $p < 0.01$). Sediments from stations FF01A, FF09, FF10, and FF13 (one replicate) were more sandy (>80% sand) and had the lowest TOC values (<0.5%). Whereas, sediments from stations FF04, FF07, and FF11 were more silty (>80% silt and clay) and had the highest TOC values (>1.5%).

Duplicate grab samples were collected at each Farfield station. TOC content from replicate samples were similar (R%D<25%), with the exception of stations FF10 (53%R%D) and FF13 (88%R%D). The replicate analyses for grain size composition also were more variable at these two stations.

4.2.3 *Clostridium perfringens*

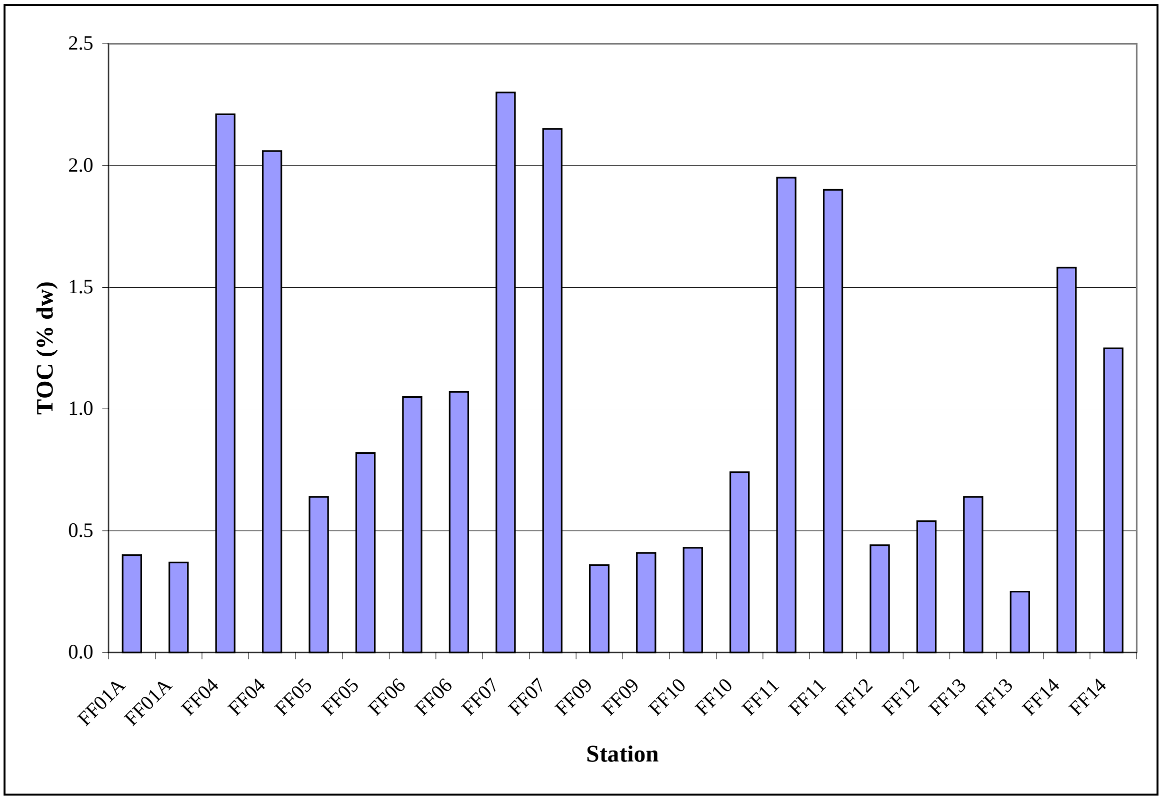
Nearfield—The density of *Clostridium perfringens* spores at Nearfield stations ranged from slightly more than 90 cfu at 3 stations (NF04, NF13, NF17) to 3,820 cfu at station NF08 (Figure 4-9, top). In general, spore density was higher at stations with finer sediments and higher levels of TOC ($r = 0.93$, $n = 24$, $p < 0.01$) (Figure 4-9, bottom).

Replicate grab samples were taken for stations NF12, NF17, and NF24. *Clostridium* spore counts from replicate samples were variable, with R%Ds ranging from 1% (NF10) to 124% (NF24). The highest variability was observed for NF24, similar to the variability noted for grain size and TOC at this location.

Farfield—The density of *Clostridium perfringens* spores at Farfield stations ranged from 570 cfu (FF09) to 3,770 cfu (FF04, one replicate) (Figure 4-10, top). Spore density did not correlate well with % fines in sediments collected from Farfield stations ($r = 0.42$, $n = 22$, $p > 0.05$; Figure 4-10, bottom), when all stations were included. Stations FF10, FF13, FF04 and FF12 were clear outliers in this plot. The correlation between % fines and density of *Clostridium perfringens* spores improved ($r = 0.60$, $n = 16$, $p < 0.05$) if stations FF10, FF12, and FF13 were removed from the regression analysis. The rationale for excluding stations FF10, FF12, and FF13 was that these locations were closer to Boston Harbor than to the remaining Farfield stations. Figure 4-10 (bottom) also reveals an anomalously high spore density value for one of the replicate grab sediments (rep 1 at 9 cm) collected at station FF04 (spore density = 3,770 cfu), located at Stellwagen Basin. There is no clear reason for the anomalously high value, however FF04 consistently has had high *Clostridium* counts and consistently high % fines and TOC content (see Section 7).

The USGS study (Parmenter and Bothner, 1993) also observed decreasing spore density (normalized to % fines) with distance from Boston Harbor. This trend was also observed with these 1998 results, with the exception of the anomalously high spore density observed in sediment collected from station FF04 (rep 1).

Duplicate grab samples were collected at each Farfield station. In general, the replicate analyses were variable, with R%Ds ranging from 11 to 126%. Variability between replicates decreased slightly when the *Clostridium* densities were normalized to % fines (R%Ds range from 4 to 103%).



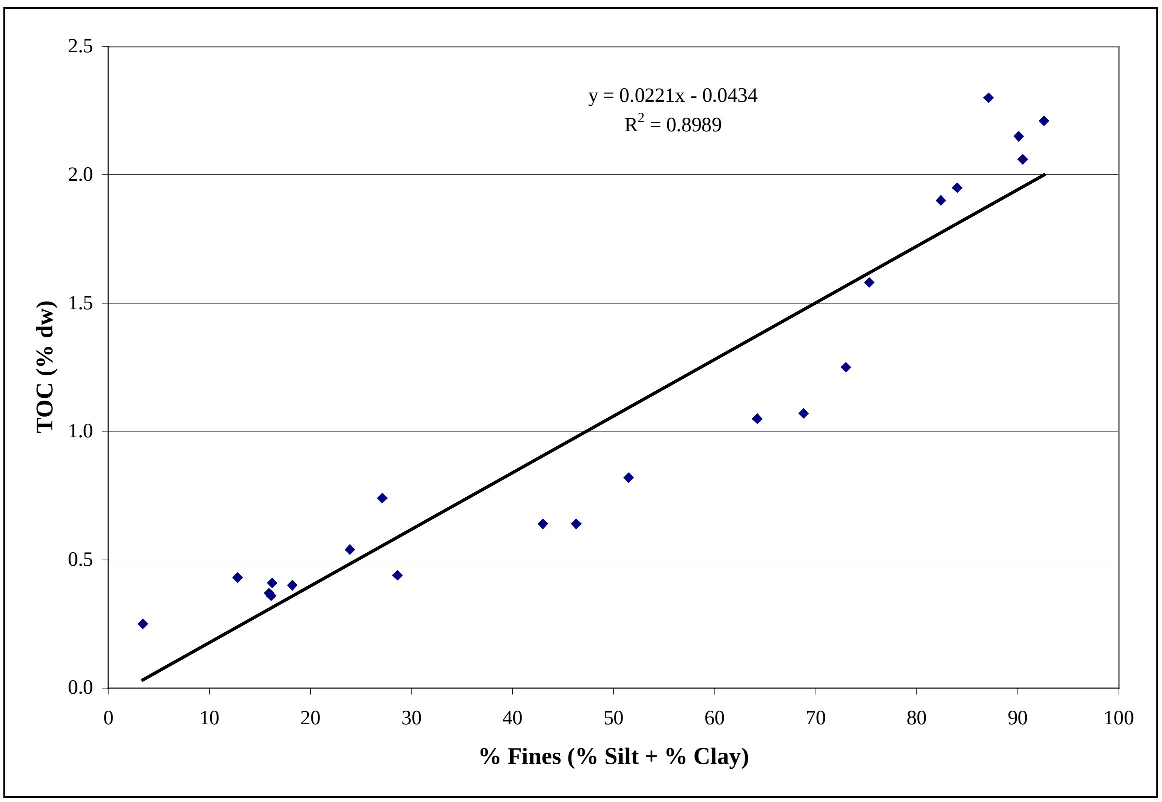


Figure 4-8. Total organic carbon content plotted by station (top) and against % fines (bottom) in sediments collected at Farfield stations in August 1998. Values are for each replicate.

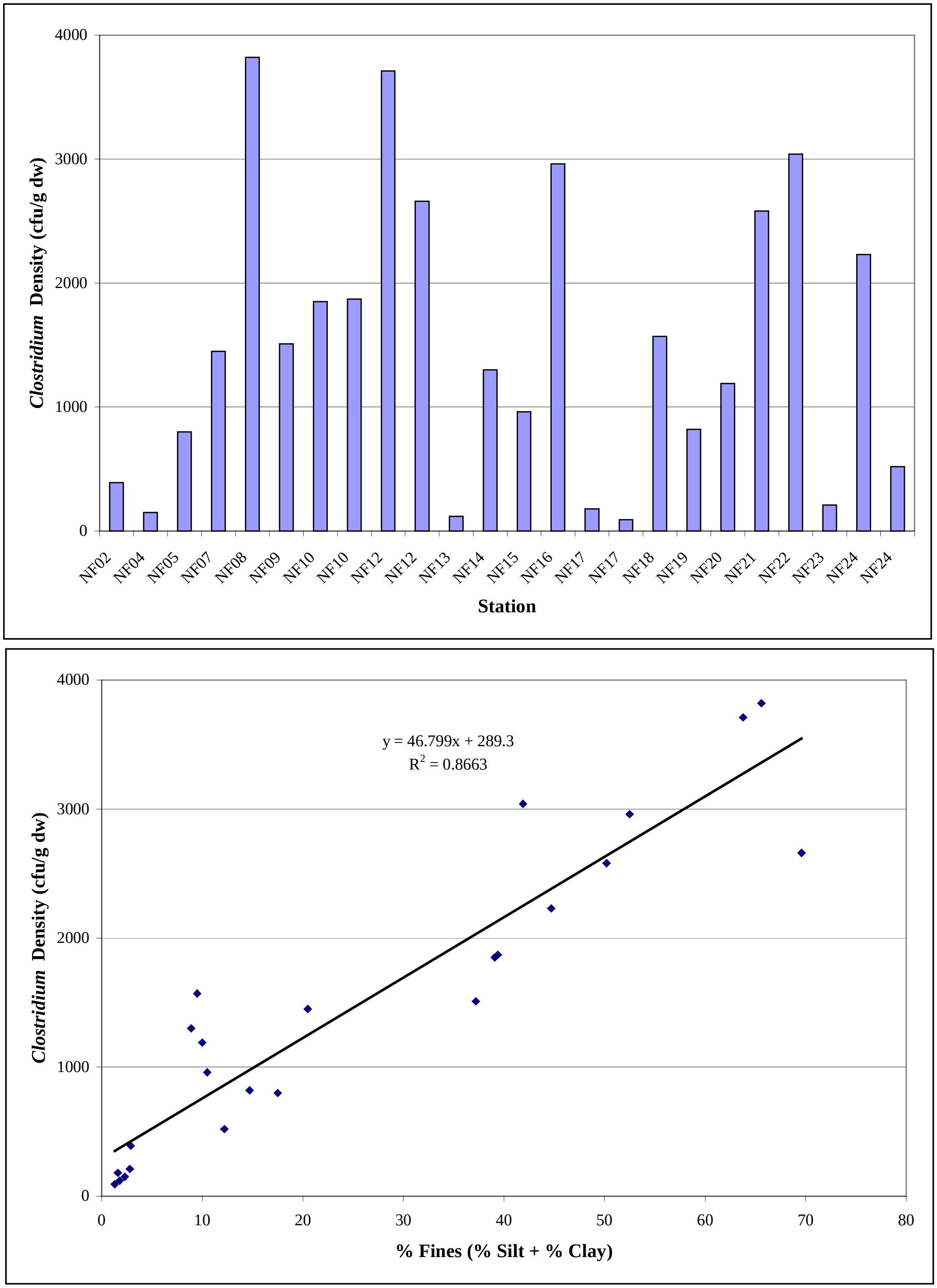
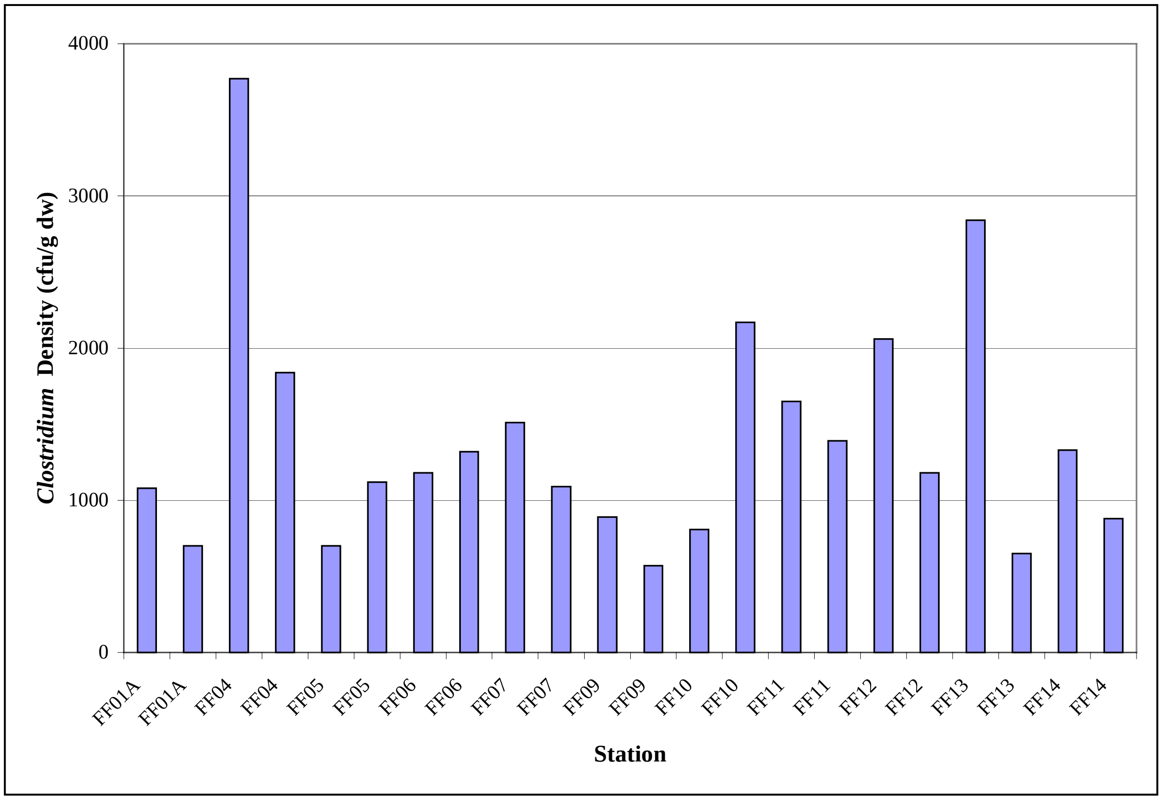


Figure 4-9. ***Clostridium perfringens*** **density by station (top) plotted and against % fines (bottom) in sediment collected at Nearfield stations in August 1998. Values are for each grab sample.**



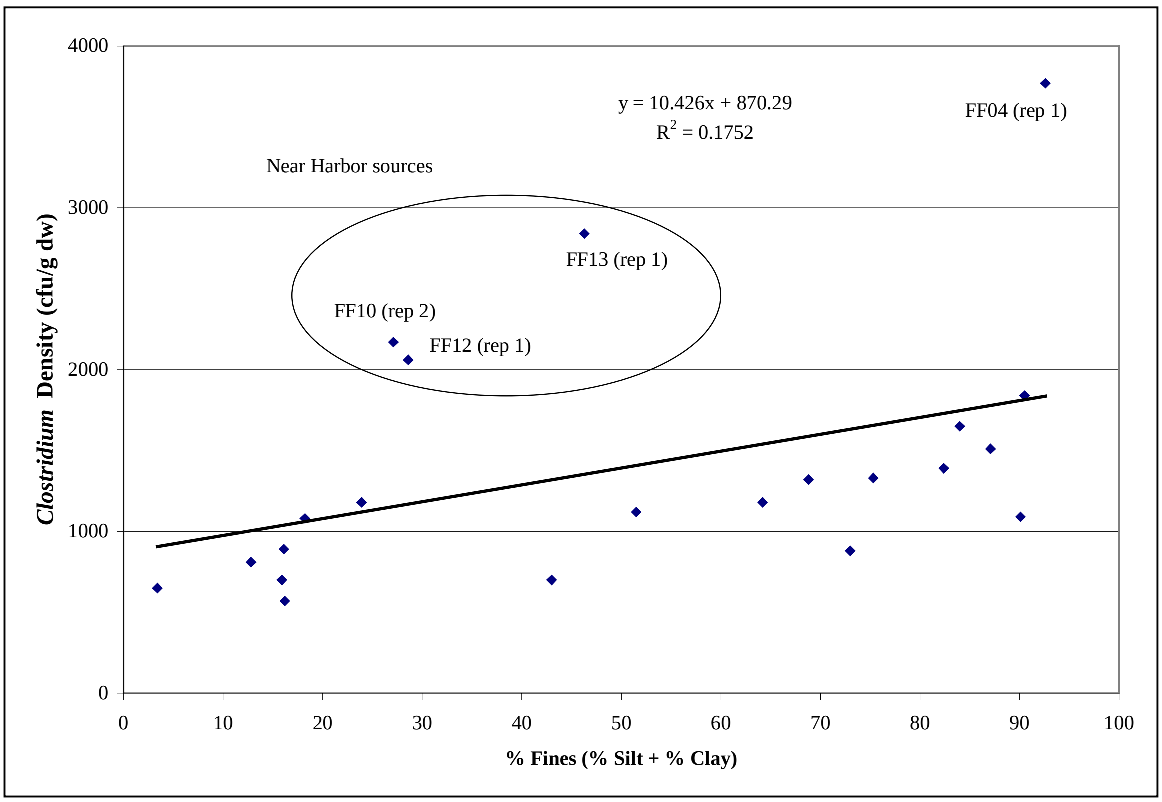


Figure 4-10. *Clostridium perfringens* density plotted by station (top) and versus % fines (bottom) in sediment collected from Farfield stations in August 1998. Values are for each replicate.

4.2.4 Contaminants

During the October 1998 Sediment Contaminant Special Study, sediments were collected in triplicate from stations NF08, NF22, NF24, and FF10 to address possible short-term transport and impact with a focus on high TOC/depositional areas.

Results from the replicate analyses of sediment samples collected during the October 1998 survey are reported in Table 4-3 and Appendix C-2. Data are presented as the average and standard deviation of the triplicate analyses.

Table 4-3. Average (Avg) and standard deviation (Stdev) results from triplicate analyses of sediment samples collected for organics and metal contaminants.

		NF08		NF22		NF24		FF10		
	Units	**Avg**	**Stdev**	**Avg**	**Stdev**	**Avg**	**Stdev**	**Avg**	**Stdev**	**ER-M[a]**
Total PAH	ng/g	6,763	2,349	3,904	705	17,122	20,237 [b]	2,122	135	44,792
Total PCB	ng/g	26.9	7.1	11.1	2.7	20.7	9.8	5.88	1.87	180
Total DDT	ng/g	11.03	10.73	2.5	0.4425	4.0	2.0	2.22	1.90	46.1
Total Chlorinated Pesticides	ng/g	0.68	0.12	0.27	0.06	0.27	0.27	0.10	0.09	6[c,d]
Total Other Pesticides	ng/g	0.74	0.24	0.14	0.12	0.23	0.28	0.01	0.01	NR
Total LAB	ng/g	290	53	184	18.9	191.0	54.8	79.2	12.6	NR
Dieldrin	ng/g	0.33	0.06	0.13	0.11	0.18	0.24	ND	ND	8[d]
Clay	pct	11.1	2.9	11.13	0.78	14.5	8.4	10.96	3.87	NR
Silt	pct	38.6	13.8	34.6	5.18	46.1	28.9	39.0	17.3	NR
% Fines	pct	49.8	16.7	45.8	6.0	60.6	37.2	49.9	21.2	NR
Sand	pct	48.5	13.8	51.8	1.28	38.7	34.7	49.0	19.8	NR
Gravel	pct	1.7	2.9	2.50	4.07	0.67	0.83	1.02	1.36	NR
TOC	pct	1.31	0.28	0.69	0.19	1.07	0.51	0.49	0.09	NR
Clostridium perfringens	cfu/gdw	4,590	361	3,230	534	2,613	1,756	1,627	180	NR
Aluminum	pct	5.86	0.26	5.90	0.02	5.74	1.04	5.32	0.02	NR
Cadmium	µg/g	0.24	0.06	0.11	0.02	0.11	0.07	0.06	0.06	9.6
Chromium	µg/g	119	14.8	73.4	8.8	95.1	56.2	70.1	8.3	370
Copper	µg/g	32.4	3.7	21.8	2.7	31.2	9.6	15.1	2.9	270
Iron	pct	2.78	0.16	2.57	0.08	2.52	0.80	1.83	0.11	NR
Lead	µg/g	49.6	3.0	40.0	2.9	55.4	23.5	31.4	1.5	218
Mercury	µg/g	0.34	0.05	0.35	0.07	0.32	0.18	0.27	0.26	0.71
Nickel	µg/g	21.8	1.0	19.8	3.1	19.9	7.8	15.0	1.7	51.6
Silver	µg/g	0.90	0.17	0.59	0.10	0.70	0.43	0.30	0.01	3.7
Zinc	µg/g	81.1	8.0	63.4	3.4	72.3	28.4	43.8	2.0	410

[a] From Long et al. (1995)
[b] One of the three 1998 samples had anomalously high pyrogenic PAH content
[c] ERM value is for Total Chlordane
[d] From Long and Morgan (1991)
Total PAH = sum of targeted 1998 PAH analytes
Total PCB = sum of targeted 1998 PCB analytes
Total DDT = sum of 2,4 and 4,4 DDD, DDE, and DDT
Total Chlorinated Pesticides = sum of cis-chlordane, heptachlor, hetpachlorepoxide, and trans-nonachlor
Total Other Pesticides = sum of aldrin, dieldren, endrin, hexachlorobenzene, lindane, and mirex
Total LAB = sum of C_{10}-C_{14} linearalkyl benzenes

Organic Contaminants—Sediments from station NF24, which consisted of a fine sediment (61% fines) with high TOC content (>1%), contained the highest levels of total PAH. The highest levels of chlorinated pesticides were found in sediments from station NF08. The highest levels of total PCBs were found at stations NF08 and NF24. However, the levels of chlorinated pesticides and PCBs in sediments from all stations were present only in trace amounts (<10 × MDL). The levels of organic contaminants generally were lowest in sediments from station FF10, a sandy location with low TOC content (<0.5%). Levels of total PAH, total DDT, total chlorinated pesticides, total other pesticides, and dieldrin were well below established ER-M values (Long and Morgan 1991). ER-M values are not available for total pesticide or total LAB (see Table 4-3).

Results from the analysis of triplicate field samples were variable. However, concentrations of organic contaminants generally were present at trace levels (<10 × MDL), with the exception of total PAH. The replicate analyses for total PAH were comparable (<35% CV), with the exception of sediments from station NF24 (118%CV). One of the triplicate sediments from station NF24 (sample_id BC981026) had much higher pyrogenic PAH content than the other replicates possibly attributed to a stray piece of coal ash or some other pyrogenic material.

Metal Contaminants—The levels of metal contaminants in sediments generally were similar, with the lowest contaminant levels found at station FF10. Levels of metals contaminants were well below established ER-M values.

Results from the analysis of triplicate field samples were similar (<25% CV for values >10 × MDL) for all sediments, with the exception of station NF24. The triplicate analyses of sediment from station NF24 were more variable, ranging from 18% to 63% CV.

5. 1998 SOFT-BOTTOM INFAUNAL COMMUNITIES

[by Roy K. Kropp and Eugene D. Gallagher]

5.1 Methods

5.1.1 Laboratory Analyses

Samples were rinsed with fresh water over 300-μm-mesh screens and transferred to 70–80% ethanol for sorting and storage. To facilitate the sorting process, all samples were stained in a saturated, alcoholic solution of Rose Bengal at least overnight, but no longer than 48 h. After rinsing with clean alcohol, small amounts of the sample were placed in glass dishes, and all organisms, including anterior fragments of polychaetes, were removed and sorted to major taxonomic categories such as polychaetes, arthropods, and mollusks. After samples were sorted, the organisms were sent to taxonomists (Appendix D-1) for identification and enumeration. Identifications were made at the lowest practical taxonomic level, usually species.

5.1.2 Data Analyses

Preliminary Data Treatment—Prior to performing any of the analyses of the 1998 and 1992-1998 MWRA datasets, several modifications were made. Several non-infaunal taxa were excluded (listed in Appendix D-2). Data for several taxa were pooled. Usually this involved pooling data for a taxon identified to a level higher than species (e.g., genus) with those data for a species within the higher taxon. This pooling was done only when only a single species of the higher taxon was identified. For example, *Byblis gaimardi* (an amphipod) was the only species of the genus found, so that any amphipods identified only to the genus (*Byblis* spp.) were treated as if they were *B. gaimardi*. Because the identification of some taxa has been inconsistent through the duration of the project, data for some species were pooled to a higher-level taxon. For example, Turbellarians were identified to species in 1993 and 1994, but have only been identified to phylum during the other years of the program. Therefore, data for Turbellaria sp. 1 and sp. 2 were pooled with data for Turbellaria spp. All such changes are listed in Appendix D-2.

Designation of Nearfield and Farfield stations—For these analyses, the stations termed “Nearfield” include all stations having NF designations plus stations FF10, FF12 and FF13. This was done to allow all western Massachusetts Bay Stations to be included in a single analysis. Stations termed “Farfield” include all stations having FF designations, except stations FF10, FF12, and FF13.

Diversity Analysis

All of the diversity calculations were done with a MATLAB™ program written by Gallagher. Magurran (1988) describes all of the diversity indices used here. The rarefaction method was introduced by Sanders (1968), but Hurlbert (1971) provided the correct equations for calculating the index. Smith and Grassle (1977), the definitive reference on this statistic, proves that the Sanders-Hurlbert expected number of species is an unbiased estimator of diversity and that $E(S_2)$ is mathematically identical to Simpson’s unbiased diversity. An unbiased statistic does not change in expected value as a function of sample size. Rosenzweig (1995) showed that several diversity estimators increase markedly with increasing sample size. He advocated using Simpson’s diversity and log-series alpha, because neither exhibited much sample-size bias. May (1975) is the definitive reference on the log-series alpha. Log-series alpha is used here as an unbiased estimator of species richness. Log-series alpha is completely insensitive to the changes in species evenness.

The Sanders-Hurlbert $E(S_n)$ index is sensitive to species evenness and to species richness. However, it isn’t very good at estimating either component independently. At the lowest sample size, 2, $E(S_n)$ is Simpson’s diversity, which is very sensitive to richness. In fact, Rosenzweig (1995) uses Simpson’s index as a richness index. At a large sample size, the Sanders-Hurlbert $E(S_n)$ will become more sensitive to species richness. However, the upper limit of *n* in comparing a group of samples is set by the minimum total for any one sample. In the present data set, that is about 100. At a sample size of 100, $E(S_n)$ is still very sensitive to the evenness component of diversity. So, despite the many strengths of $E(S_n)$, *H'*, *J'*, and log-series alpha were chosen for most of the comparisons of diversity. Shannon's *H'*, like $E(S_n)$, is sensitive to both the evenness and richness components of diversity.

Shannon's *H'* can be calculated by using Naparien logarithms, $\log_{10}$ or $\log_2$. Here *H'* was calculated by using $\log_2$ because that is closest to Shannon's original intent. Previous MWRA reports have presented *H' v*alues calculated by using $\log_e$. *H'* values calculated by using different logarithms vary substantially. Therefore, the reader must not compare values calculated for this report with those presented in earlier MWRA reports. Pielou's *J'* is a measure of the evenness component of diversity, first described by Pielou (1966). It is simply the observed *H'* divided by the maximum *H'*, which is simply log *s*.

Cluster & Ordination

Most analyses were performed with MATLAB™. The methods used for performing the principal components analysis of hypergeometric probabilities (PCA-H) analysis and cluster analysis are described in Trueblood et al. (1994). Cluster analysis was performed by using COMPAH96 (available on Eugene Gallagher's web page, http://www.es.umb.edu/edgwebp.htm). This program, originally written by Don Boesch (Boesch 1977), implements all of Williams' (1971) combinatorial clustering methods. The sample and species clusters presented here were generated by using unweighted pair-group mean average sorting (UPGMA; Sneath and Sokal 1973). With the PCA-H analysis, species habitat relationships were examined by *R*-mode cluster analysis. The clustering is based on Pearson's *r*. Pearson's *r* between columns of the hypergeometric matrix is cosine *2*, where *2* is the angle between the species shown in the covariance plots (Trueblood et al. 1994). UPGMA sorting of the cosine *2* similarities was used rather than the single-linkage clustering that Jardine and Sibson (1968) argued was the only method combinatorial with Pearson's *r*. However, Gallagher (unpublished) has since discovered major problems in interpretation that are introduced by using single-linkage clustering of variables. For example, two highly correlated variables (e.g., $r > 0.8$) may not cluster until a similarity level of near zero with single-linkage clustering. With UPGMA clustering, variables cluster at clustering levels approximating their original correlations.

All faunal similarities shown here were based on the chord normalized expected species shared, or CNESS (Trueblood et al. 1994). This is a metric version of Grassle and Smith's (1976) NESS faunal similarity that can be made more or less sensitive to the rare species in the samples by adjusting the random sample size (*m*).

Both indices are based on the ESS or the expected species shared. ESS represents the estimate of the number of species shared when *m* individuals are drawn at random from two samples. Formulas for ESS can be found in Trueblood et al. (1994).

By using the Kendall's correlation method described in Trueblood et al. (1994), a random sample size (*m*) of 15 was found to be appropriate for the 1992-1998 MA Bay data.

There are three basic graphs produced by a PCA-H analysis. The first type is the metric scaling plot, which shows a planar view of the data representing the major variation in CNESS distances among stations. A sample point, called H_{max}, which indicates the position of a hypothetical sample containing equal abundances of every species in the dataset was included. Sample points that plot at increasing distances from this point have lower species diversities (Gallagher and Keay 1998). The results of cluster analyses were superimposed on the metric scaling as convex hulls. Samples occurring in the same cluster were surrounded by a convex hull. These clusters also were identified in the sample cluster analyses, and the convex hulls were used to surround the most disparate 8 to 10 groups (Gallagher and Keay 1998).

A second plot type is the Gabriel Euclidean distance biplot, based on Gabriel (1971). In this plot, stations from the metric scaling are shown as points and species are depicted as vectors (arrows). The relative abundance of species in a sample can be found by projecting the sample points at right angles on the species vectors. The Gabriel Euclidean biplot shows the species that are important in explaining CNESS variation. This contribution to CNESS can be calculated directly by using the contribution statistics developed originally for correspondence analysis and described in Greenacre (1984). The contribution of species to CNESS is directly proportional to the species loadings on the respective eigenvectors in the eigenvalue ordination of CNESS distances.

The third major plot type is the Gabriel covariance biplot. This plot, described by Gabriel (1971) and more recently by Legendre and Legendre (1998), plots species as vectors. Species vectors that plot with acute angles reflect species that tend to occur in the same samples. Species vectors oriented at right angles indicate no or weak associations. Species vectors oriented with obtuse angles indicate species that are negatively associated.

5.2 Results and Discussion

5.2.1 1998 Nearfield Descriptive Community Measures

Abundance—Among individual Nearfield samples collected in 1998, infaunal abundance varied about six-fold, ranging from 783 to 4,788 individuals/0.04 m^2 (19,575–119,700/m^2) at stations NF17 (rep 1) and NF24 (rep 2), respectively (Table 5-1). Among the 6 replicated Nearfield stations, mean abundance per sample (± 95% confidence intervals, CI) ranged from 871 (± 49) to 4,050 (± 747) individuals/0.04 m^2 at stations NF17 and NF24, respectively (Figure 5-1).

Annelid worms were the most abundant higher infaunal taxon among the 1998 Nearfield samples (Figure 5-2). Annelids accounted for more than 80% of the infauna at 15 of the Nearfield stations, with the highest percentage (95.1%) at stations NF24 and FF13. Crustaceans typically were the second highest contributors to infaunal abundance. The highest proportions of crustaceans occurred at stations NF23 (25.0%) and NF17 (23.6%). Molluscs were relatively important contributors (14.8%) to infaunal abundance at station NF05. At a slightly finer scale, polychaete worms were the most abundant of the annelids, amphipods the most numerous crustaceans, and bivalves the most common molluscs (Figure 5-3).

Numbers of Species—The total numbers of species per individual Nearfield sample collected in 1998 varied slightly more than two-fold, ranging from 41 to 96 at station NF17 (rep 2) and stations NF14 and FF10 (rep 1), respectively (Table 5-1). Among the 6 replicated Nearfield stations, mean (± 95% CI) numbers of species per sample ranged from 48 (± 6.4) to 91 (± 4.5) species at stations NF17 and FF10, respectively (Figure 5-1).

Among the higher taxa, annelid worms contributed the highest percentage of species, accounting for about 46–60% of the species collected at each Nearfield station (Figure 5-4). Crustaceans and molluscs accounted for about 11–29% and about 6–18% of the species collected at each Nearfield station, respectively. Within each of the higher taxa, polychaetes, amphipods, and bivalves again provided the greatest contribution to species numbers (Figure 5-5).

Nearfield infaunal species numbers were not correlated with abundance ($r = 0.350$, $n = 23$, $p > 0.05$). However, this lack of correspondence appeared to be driven by annelids, which showed no species numbers:abundance correlation ($r = 0.371$, $n = 23$, $p > 0.05$). The numbers of species of crustaceans ($r = 0.786$, $n = 23$, $p < 0.01$) and molluscs ($r = 0.670$, $n = 23$, $p < 0.01$) were correlated with abundance of those taxa. Three stations that probably contributed to the lack of species numbers:abundance correlation among annelids were NF15 (2,759 individuals, 36 species), FF13 (3,020 individuals, 32 species), and NF24 (3,852 individuals, 40 species). All three stations were numerically dominated by *Prionospio steenstrupi*, which accounted for more than 48% of the infaunal abundance there.

Diversity—As measured by the traditional Shannon index (*H'*), diversity among individual Nearfield samples collected in 1998 varied from about 2.6 at stations NF24 (all reps) and FF13 (two reps) to about 4.8 at station NF05 (Table 5-1). Evenness (*J'*) among all Nearfield samples ranged from about 0.4 (several samples) to about 0.8 (NF05). Within-station variation was low at all replicated stations except FF13 and NF17 (Figure 5-1). Log-series alpha varied considerably among Nearfield stations, ranging from 10.0 (± 1.67) at station FF13 to 19.7 at the non-replicated station NF04. As for evenness, within-station variation in log-series alpha among replicated stations was high at stations FF13 and NF17 (Figure 5-1).

Most Abundant Species—The 12 most abundant species found at each Nearfield station in 1998 are listed in Appendix D-3. The spionid polychaete *Prionospio steenstrupi* was the most abundant species at 17 Nearfield stations. Where it was the most common species, *P. steenstrupi* accounted for 16–59% of the infaunal abundance. The numerical dominance of *P. steenstrupi* in the Nearfield was further demonstrated by its occurrence among the five most numerous species at those stations where it was not ranked first. *Mediomastus californiensis* and *Spiophanes bombyx* each were the most common species at two stations. The 12 most abundant taxa accounted for about 69–93% of the infaunal abundance at each station. A few Nearfield stations showed considerably different numerically dominant taxa in 1998 than were reported in 1997 (Blake et al. 1998). For example, at stations NF02 and NF07 only 3 of the 10 most abundant taxa in 1997 were ranked in the top 12 in 1998. At station NF04, only four of the most numerous species in 1997 were among the most common in 1998. Conversely, some stations showed relative consistency in the predominant species found in 1997 and 1998. For example, all 10 abundant species at stations NF12 and FF12 in 1997 were ranked in the top 12 in 1998. At three stations, NF21, NF22, and NF24, 9 of the most common species in 1997 were among the 12 most abundant in 1998.

5.2.2 1998 Nearfield Multivariate Analyses

Cluster/PCA-H Analyses—Results of the CNESS cluster analysis of the 1998 Nearfield samples showed that similarity among those collected from replicated stations was high (Figure 5-6). All three replicates collected at stations NF24, NF12, FF12, and NF17 were more similar to each other than they were to any other samples. The high similarity of the three replicates from NF24 is of interest because of the variability observed between the two grain-size replicates. The high faunal similarity among the replicates suggests that they were from similar sediments, which was also indicated by field observations. At stations FF10 and FF13, the three replicates clustered within the same group, but were joined in the group by a Nearfield sample.

Table 5-1. Summary of ecological variables for samples collected from the Nearfield in 1998.

Site	Rep	Total Ind	Total Spp	*H'*	*J'*	Hurlbert's E(Sn) n=							Log Series alpha
						2	10	17	50	100	200	500	
FF10	1	3155	96	4.09	0.62	1.86	6.60	9.52	18.17	26.01	36.52	54.33	18.70
FF10	2	1918	87	3.94	0.61	1.82	6.19	9.07	18.63	27.52	38.33	56.45	18.76
FF10	3	2996	91	4.23	0.65	1.88	6.85	9.90	19.11	27.37	37.52	53.61	17.72
FF12	1	2801	65	3.32	0.55	1.81	5.58	7.61	13.31	18.39	25.05	36.61	11.89
FF12	2	2540	61	3.21	0.54	1.78	5.45	7.45	12.84	17.59	23.84	34.76	11.25
FF12	3	1743	53	3.17	0.55	1.77	5.35	7.37	12.98	17.94	24.43	34.91	10.32
FF13	1	2760	55	2.55	0.44	1.66	4.25	5.72	10.55	15.34	21.59	31.37	9.73
FF13	2	4351	54	2.58	0.45	1.70	4.35	5.74	10.02	13.97	19.08	27.78	8.68
FF13	3	2418	62	3.11	0.52	1.78	5.27	7.07	11.87	16.32	22.68	34.42	11.60
NF02	1	1053	53	3.61	0.63	1.86	6.16	8.30	14.06	19.44	26.86	40.25	11.76
NF04	1	1891	90	4.60	0.71	1.91	7.27	10.67	21.88	32.53	45.14	62.99	19.67
NF05	1	1220	81	4.84	0.76	1.94	7.92	11.77	23.10	32.60	43.70	61.44	19.51
NF07	1	2817	91	3.68	0.57	1.78	5.76	8.35	17.08	25.71	36.63	53.92	17.98
NF08	1	2399	68	3.03	0.50	1.73	4.89	6.74	12.87	18.76	26.58	40.78	13.02
NF09	1	1573	80	4.29	0.68	1.89	7.00	10.17	19.51	27.56	37.68	54.46	17.81
NF10	1	2218	79	4.28	0.68	1.90	7.07	10.11	18.77	26.21	35.64	51.24	15.99
NF12	1	3115	90	4.38	0.68	1.92	7.32	10.43	18.88	26.24	35.63	50.84	17.31
NF12	2	2440	85	4.23	0.66	1.91	7.04	9.94	17.88	24.95	34.64	51.51	17.11
NF12	3	2505	79	4.39	0.70	1.92	7.35	10.48	18.79	26.08	35.72	51.42	15.52
NF16	1	2148	64	3.39	0.56	1.80	5.54	7.61	14.12	20.46	28.31	40.51	12.40
NF20	1	2711	76	3.50	0.56	1.76	5.62	8.20	16.42	23.59	32.01	45.62	14.52
NF21	1	2014	79	3.86	0.61	1.86	6.33	8.86	16.36	23.19	32.15	48.21	16.39
NF22	1	1966	72	4.14	0.67	1.90	6.90	9.76	17.75	24.97	34.10	48.01	14.68
NF13	1	1785	83	4.11	0.64	1.89	6.76	9.60	17.88	25.10	34.17	50.42	18.02
NF14	1	3951	96	3.92	0.60	1.88	6.54	9.07	15.83	22.09	30.76	46.02	17.74
NF15	1	3133	68	3.32	0.55	1.75	5.38	7.69	15.00	21.90	30.27	42.29	12.26
NF17	1	783	53	3.58	0.62	1.82	5.92	8.35	15.67	22.31	30.68	44.84	12.84
NF17	2	802	41	3.05	0.57	1.77	5.12	6.95	12.59	17.95	24.75	35.19	9.14
NF17	3	865	51	3.50	0.62	1.83	5.80	7.92	14.48	21.00	29.49	42.68	11.85
NF18	1	2909	92	4.07	0.62	1.88	6.65	9.35	17.18	24.73	35.02	52.53	18.09
NF19	1	2429	75	3.55	0.57	1.77	5.67	8.23	16.55	24.13	33.15	47.46	14.66
NF23	1	1187	70	4.11	0.67	1.89	6.71	9.40	17.72	26.20	37.39	54.88	16.26
NF24	1	3516	71	2.67	0.43	1.63	4.39	6.15	11.84	17.35	24.67	37.42	12.60
NF24	2	4788	66	2.58	0.43	1.64	4.34	5.95	10.85	15.40	21.39	32.13	10.83
NF24	3	3846	73	2.54	0.41	1.61	4.23	5.87	11.10	16.06	22.46	33.92	12.78

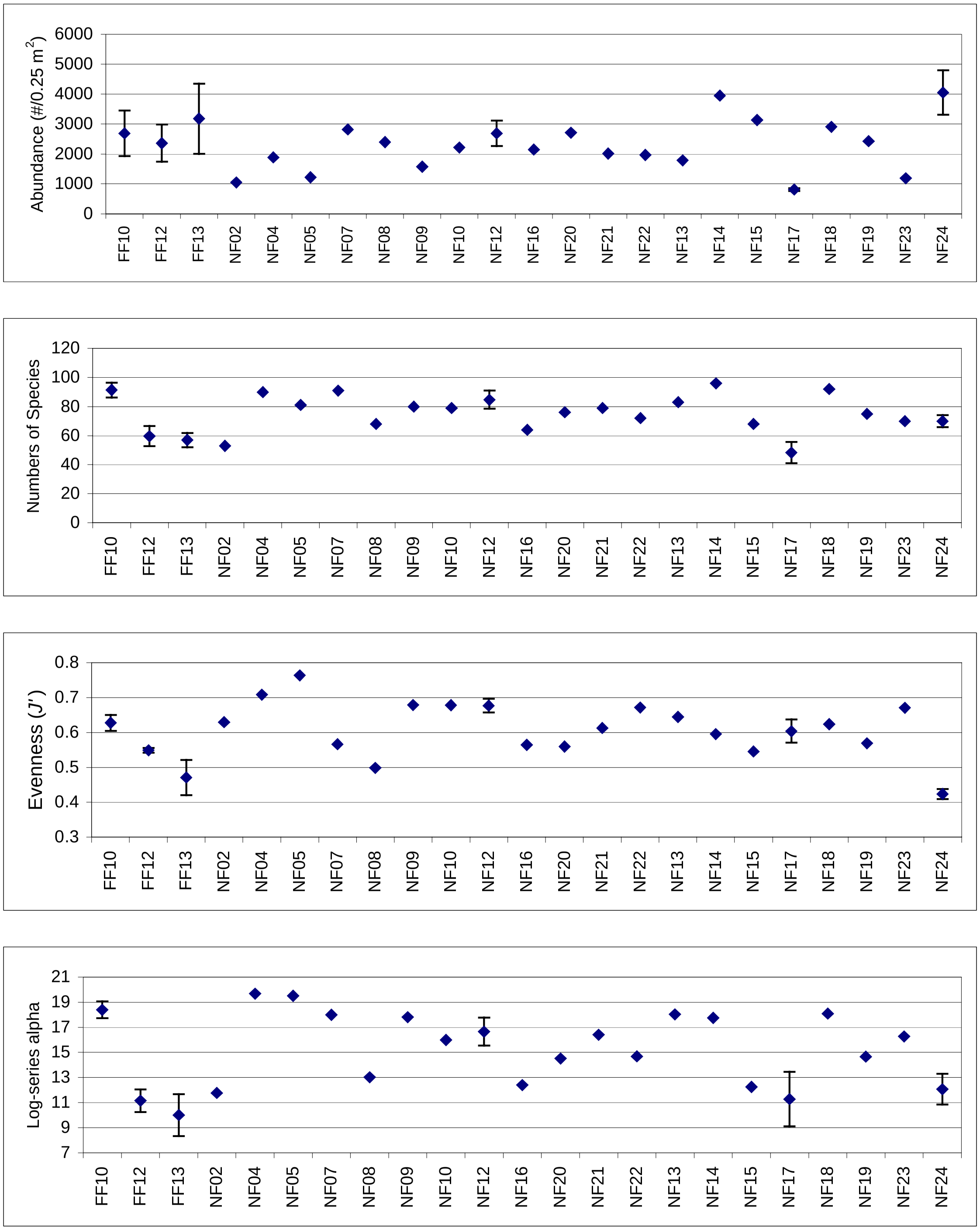


Figure 5-1. Infaunal abundance, numbers of species, evenness, and log-series alpha values for 1998 Nearfield stations. For replicated stations, the mean and 95% confidence intervals are shown.

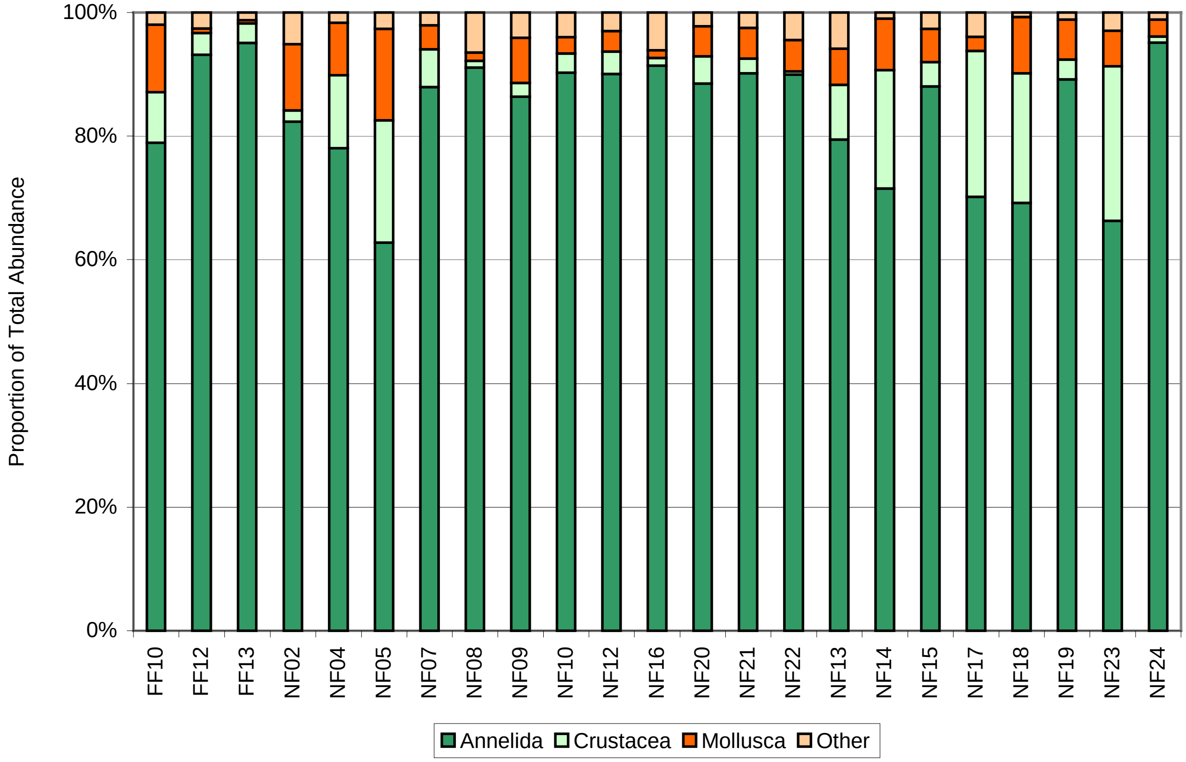


Figure 5-2. Relative contribution of higher taxa to infaunal abundance among 1998 Nearfield samples.

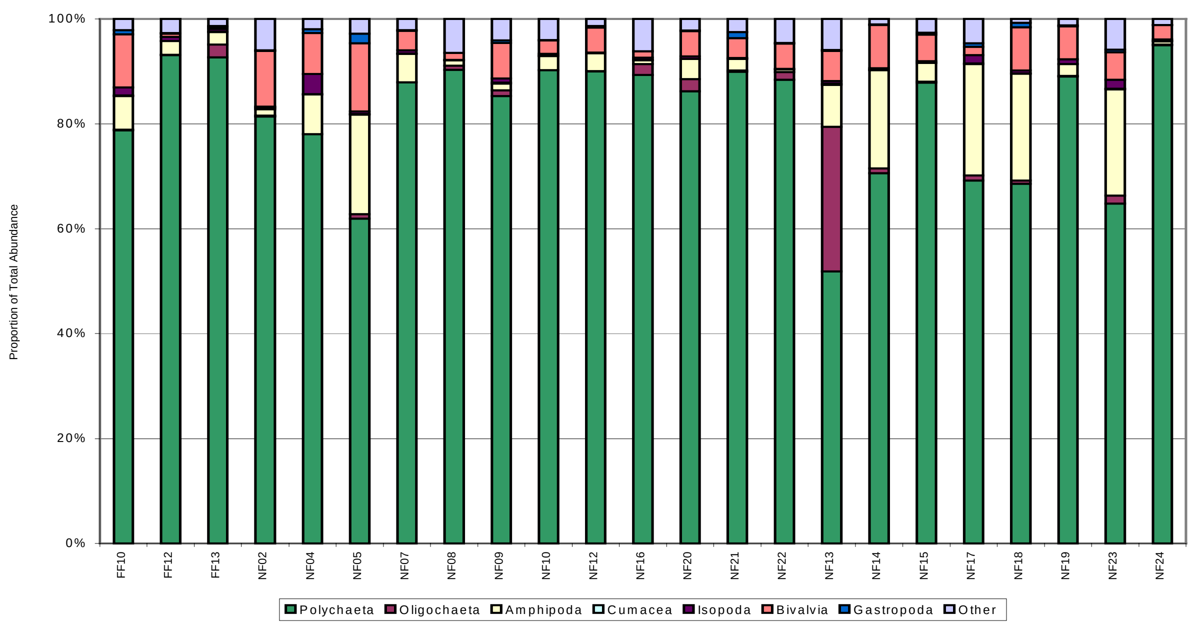


Figure 5-3. Relative contribution of lower-level taxa to infaunal abundance among 1998 Nearfield samples.

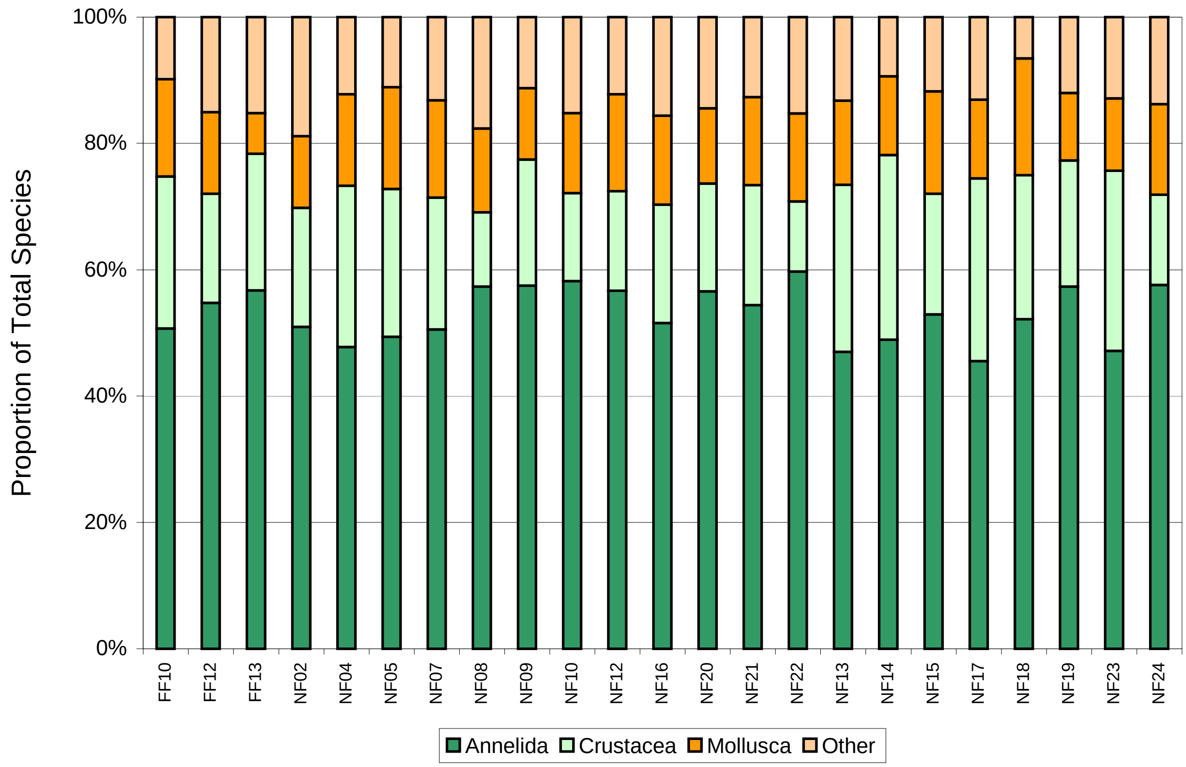


Figure 5-4. Relative contribution of higher taxa to numbers of infaunal species among 1998 Nearfield samples.

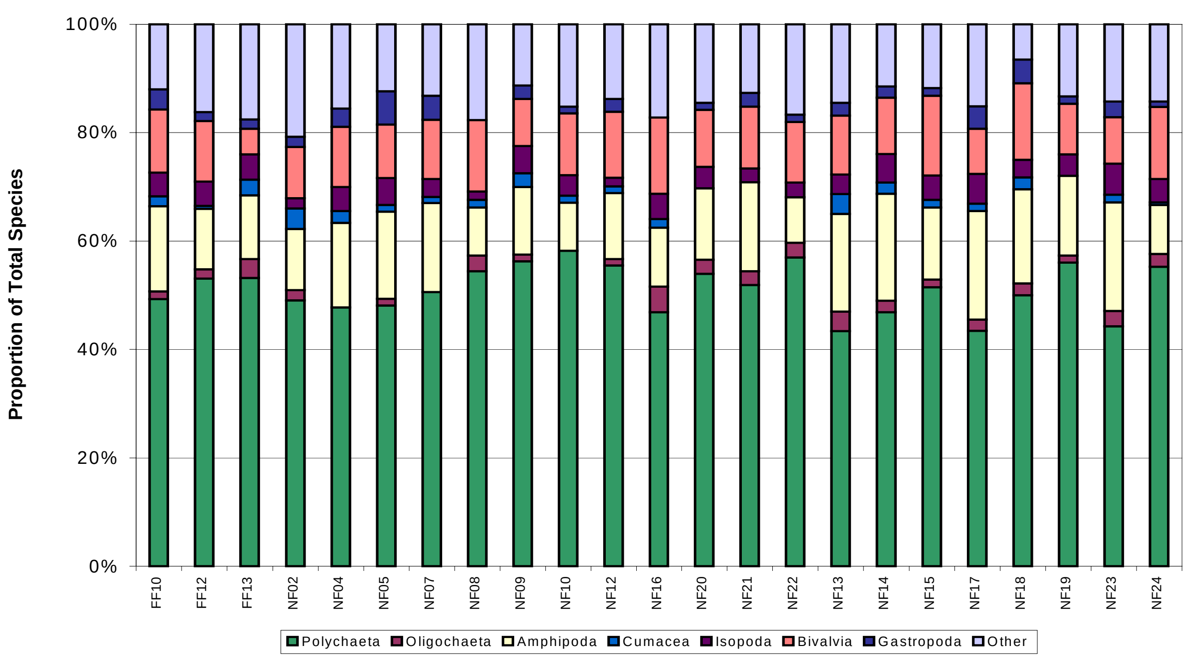


Figure 5-5. Relative contribution of lower-level taxa to numbers of infaunal species among 1998 Nearfield samples.

Examination of the cluster patterns showed that the species composition of one group of stations, those from NF13, NF17, and NF23, was very different from that at all of the other stations. Among the remaining Nearfield stations, three small groups of stations were distinguished from the main body of stations (i.e., those comprising the group bounded by stations FF10 and NF05 in Figure 5-6). In increasing order of similarity to the main group of stations, these small groups were comprised of stations NF04, NF14, and NF18, stations FF13 and NF02, and the three replicates from station FF12. These distinctions among station groups also are evident in the primary metric scaling plot resulting from the PCA-H analysis of the 1998 Nearfield data (Figure 5-7).

The PCA-H analysis of the 1998 Nearfield data revealed 33 taxa (Table 5-2) that were important contributors to the CNESS distances depicted in the dendrogram and primary metric scaling plot (PCA-H axes 1 versus 2). The species that best explain the distances depicted in the metric scaling plot are reflected in the Gabriel Euclidean Distance biplot (Figure 5-8) and are indicated in the PCA-H axis columns in Table 5-2. In the Euclidean biplot, the relative spatial distribution of the Nearfield stations shown in Figure 5-7 is retained. The biplot and Table 5-2 indicate that *Mediomastus californiensis*, *Polygordius* sp. A, *Spiophanes bombyx*, and *Prionospio steenstrupi* explained much of the variation along the first PCA-H axis, whereas *Exogone hebes*, *Owenia fusiformis*, *Exogone verugera*, and, to a lesser degree, *Aphelochaeta marioni* and *Tharyx acutus*, were the most important contributors to variation along the second PCA-H axis. The species contribution information (shown in Figure 5-8 as arrows indicative of relative abundance) in conjunction with the relative spatial alignment of stations (open circles in Figure 5-8), shows that the cluster group comprised of stations NF13, NF17, and NF23 were distinguished from the other Nearfield stations primarily by relatively high abundances (see Appendix D-3) of the archiannelid worm *Polygordius* sp. A (~3,000–4,400 individuals/m^2) and the spionid polychaete *Spiophanes bombyx* (~6,500–7,700 individuals/m^2). Additionally, these stations have very low abundances of *Mediomastus californiensis* (~0–25 individuals/m^2) and were among the lowest total infaunal abundances for all the Nearfield stations (Table 5-1, Figure 5-1). This community pattern has been previously documented for these stations (e.g., Blake et al. 1998). The large group of stations situated on the positive side of axis 1 (Figure 5-8) were linked primarily by relatively high abundances of *Mediomastus californiensis* (up to ~12,800 individuals/m^2) and, to a certain degree, *Prionospio steenstrupi* (Figure 5-8, and see Appendix D-3). A distinct cluster of stations was comprised of stations NF04, NF14, and NF18 (Figures 5-7 and 5-8). This group's orientation along PCA-H axis 1 was explained by low to moderate abundances of *Mediomastus californiensis* and *Polygordius* sp. A. However, the distinguishing feature of this group, as shown by its position along PCA-H axis 2, was the high abundances of the syllid polychaetes *Exogone hebes* and *Exogone verugera*, coupled with the absence or low abundance of the polychaetes *Owenia fusiformis*, *Tharyx acutus*, and *Monticelliua baptistae* (Figure 5-8). Abundances of the two *Exogone* species were higher in this group than elsewhere, although the relatively high numbers of the two at stations NF13 and NF23 separate those two stations from NF17, and "draw" them slightly toward the stations NF04, NF14, NF18 group (Figure 5-8). *Owenia fusiformis*, though typically found in low abundances, was much more abundant at station FF12 (7,750 individuals/m^2) than elsewhere, thus in part explaining the position of that station along PCA-H axis 2 (Figure 5-8).

The metric scaling plots of PCA-H axes 1 versus 3 (Figure 5-9), and its associated Gabriel biplot (Figure 5-10), provide some additional insights into infaunal community structure in the Nearfield. The most significant contributor to variation along this axis was the paraonid polychaete *Aricidea catherinae* (Table 5-2). Other contributions were made by *Prionospio steenstrupi*, *Ninoe nigripes*, and *Levinsenia gracilis*. As indicated earlier, station differences along PCA-H axis 1 were expressed by the *Mediomastus californiensis-Polygordius* sp. A/*Spiophanes bombyx* dichotomy. The primary distinction in

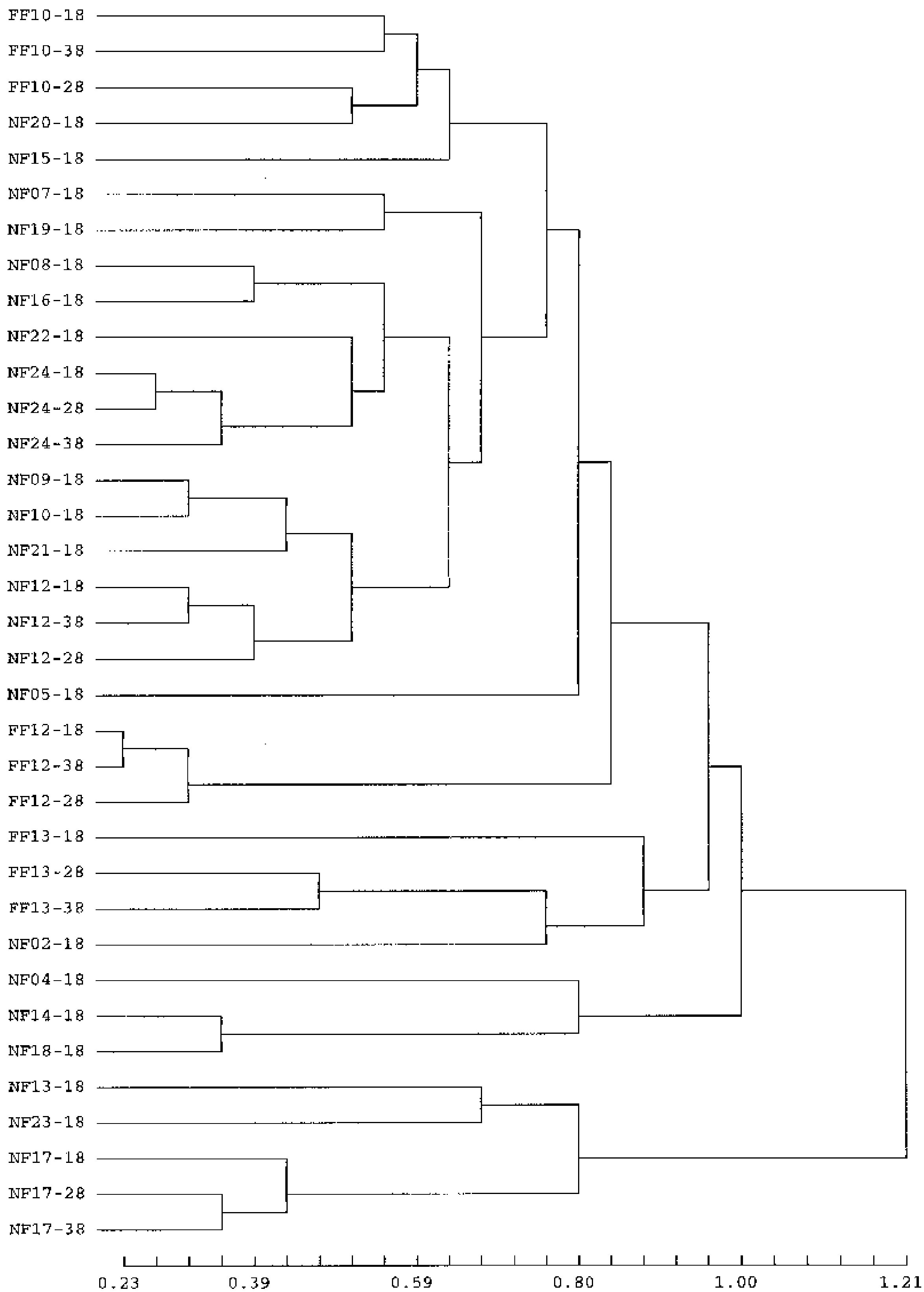


Figure 5-6. Dendrogram resulting from CNESS cluster analysis of 1998 Nearfield stations.

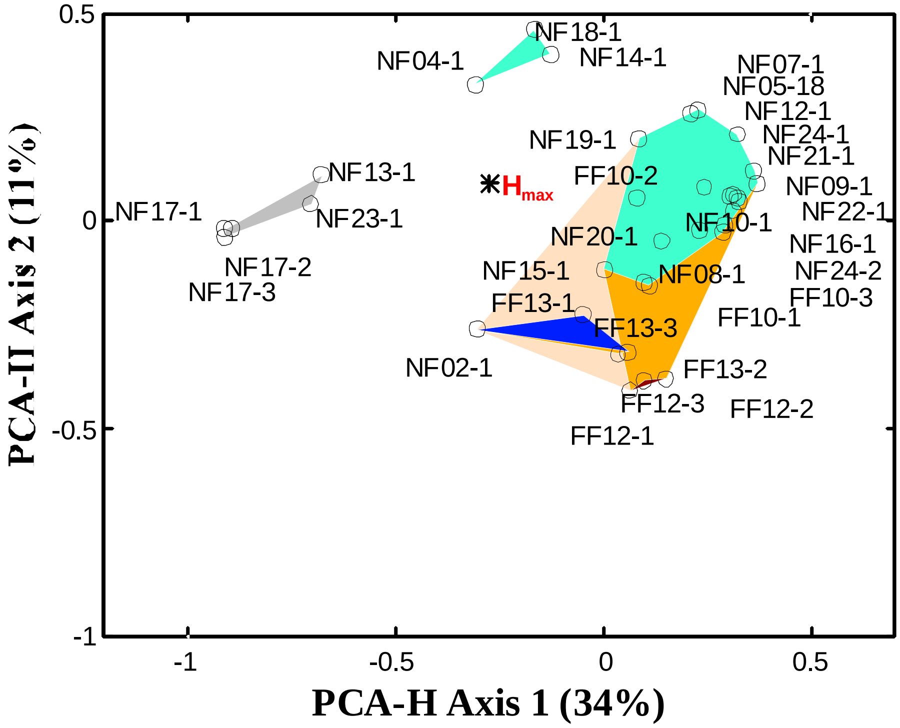


Figure 5-7. Metric scaling plot of CNESS distances, axes 1 versus 2, among Massachusetts Bay Nearfield stations sampled in 1998. Results of the CNESS cluster analysis are shown as convex hulls.

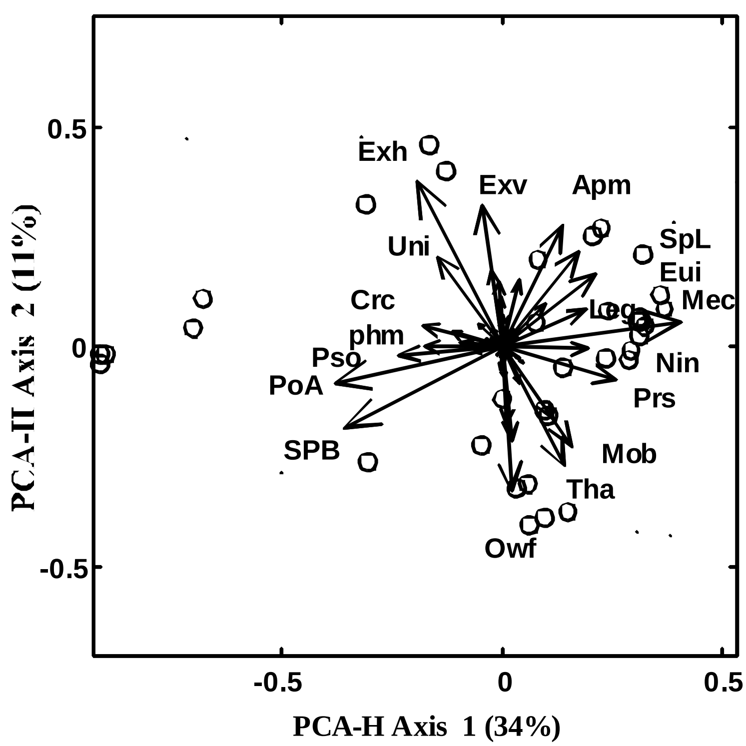


Figure 5-8. Gabriel Euclidean distance biplot, axes 1 versus 2, for the 1998 Massachusetts Bay Nearfield data showing those species that control the orientation of samples shown in Figure 5-7. Species codes are as listed in Table 5-2. Open circles represent the spatial pattern of samples shown in Figure 5-7.

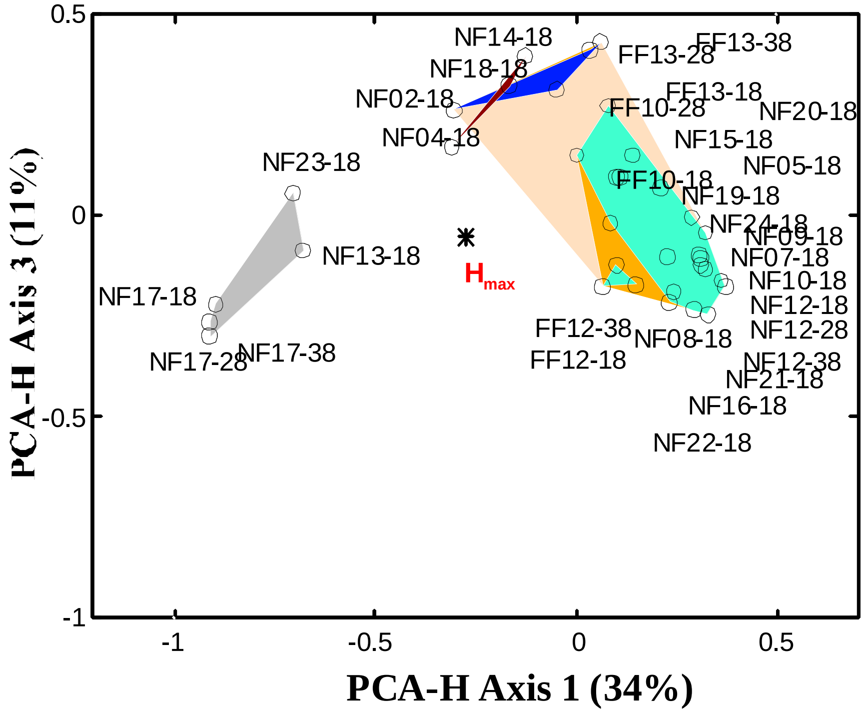


Figure 5-9. Metric scaling plot of CNESS distances, axes 1 versus 3, among Massachusetts Bay Nearfield stations sampled in 1998. Results of the CNESS cluster analysis are shown as convex hulls.

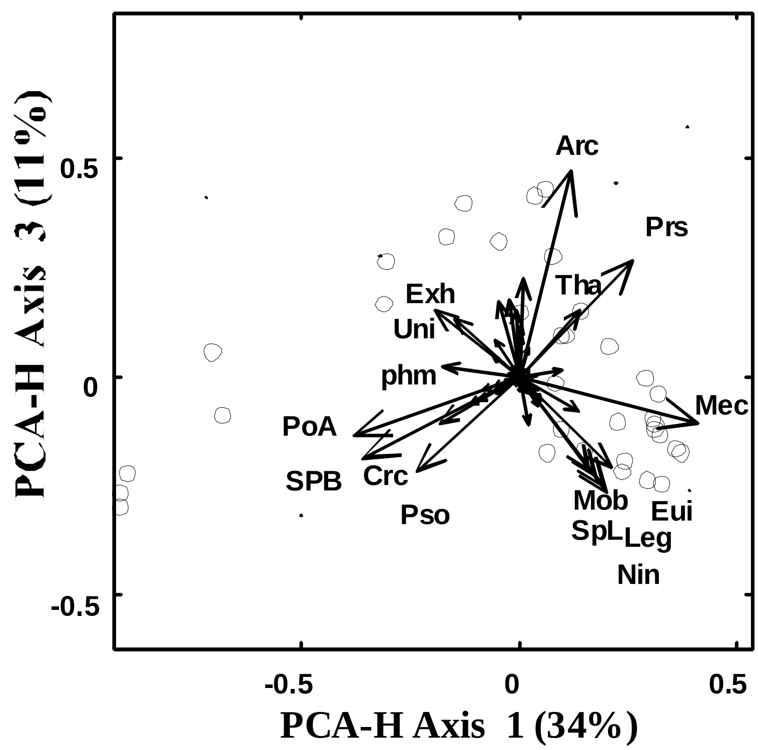


Figure 5-10. Gabriel Euclidean distance biplot, axes 1 versus 3, for the 1998 Massachusetts Bay Nearfield data showing those species that control the orientation of samples shown in Figure 5-9. Species codes are as listed in Table 5-2. Open circles represent the spatial pattern of samples shown in Figure 5-9.

Table 5-2. The 33 most important contributors to CNESS distances in the 1998 Massachusetts Bay Nearfield data are shown. "Cont" is the contribution to overall CNESS distances. "Total Cont" is the cumulative amount of CNESS variation explained by the ranked important species (90% by the top 33 species). The final columns indicate the contribution of each species to each of the first six PCA-H axes.

No.	Species	Spp Code	Cont.	Total Cont.	PCA-H Axis					
					1	2	3	4	5	6
1	*Mediomastus californiensis*	Mec	7	7	17	0	1	0	2	0
2	*Aricidea catherinae*	Arc	6	13	1	3	22	12	22	8
3	*Spiophanes bombyx*	SPB	6	19	13	3	3	0	5	0
4	*Polygordius sp. A*	PoA	6	25	14	1	2	2	0	2
5	*Prionospio steenstrupi*	Prs	4	29	7	1	7	2	2	2
6	*Owenia fusiformis*	Owf	4	33	0	11	1	19	6	12
7	*Exogone hebes*	Exh	4	37	4	14	2	5	1	0
8	*Monticellina baptisteae*	Mob	4	41	3	5	4	7	9	1
9	*Tharyx acutus*	Tha	4	45	2	7	2	3	0	5
10	*Aphelochaeta marioni*	Apm	4	48	2	8	1	5	7	9
11	*Pseudunciola obliquua*	Pso	4	52	5	0	5	3	0	0
12	*Spio limicola*	SpL	4	56	3	5	5	6	2	1
13	*Euchone incolor*	Eui	3	59	4	3	4	4	0	0
14	*Ninoe nigripes*	Nin	3	62	4	0	7	3	0	9
15	*Unciola inermis*	Uni	3	65	2	4	2	6	1	5
16	*Nephtys cornuta*	NEC	3	68	0	3	5	3	14	5
17	*Levinsenia gracilis*	Leg	3	71	4	1	6	0	3	5
18	*Exogone verugera*	Exv	2	73	0	10	3	5	1	0
19	*Nucula delphinodonta*	Nud	2	75	1	1	0	0	13	1
20	*Phyllodoce mucosa*	phm	2	77	3	0	0	2	0	2
21	*Grania postclitello longiducta*	Grl	2	79	1	0	0	0	0	4
22	*Crassicorophium crassicorne*	Crc	2	80	3	0	1	0	0	0
23	*Protomedeia fasciata*	Prf	1	82	0	3	3	3	0	1
24	*Dipolydora socialis*	DiS	1	83	0	2	0	1	2	8
25	*Maldane sarsi*	Mas	1	84	0	0	0	0	0	0
26	*Crenella decussata*	Crd	1	85	0	2	2	2	0	3
27	*Scoletoma hebes*	Sch	1	86	0	5	0	2	0	0
28	*Tubificoides apectinatus*	Tua	1	87	0	0	1	1	1	0
29	*Tharyx kirkegaardi*	Thk	1	88	0	0	1	0	3	3
30	*Hiatella arctica*	Hia	1	89	0	0	1	0	0	0
31	*Ericthonius fasciatus*	Erf	1	89	0	1	1	0	0	0
32	*Hippomedon propinquus*	Hip	1	90	0	0	0	0	1	0
33	*Photis pollex*	PhP	1	90	0	0	1	0	0	2

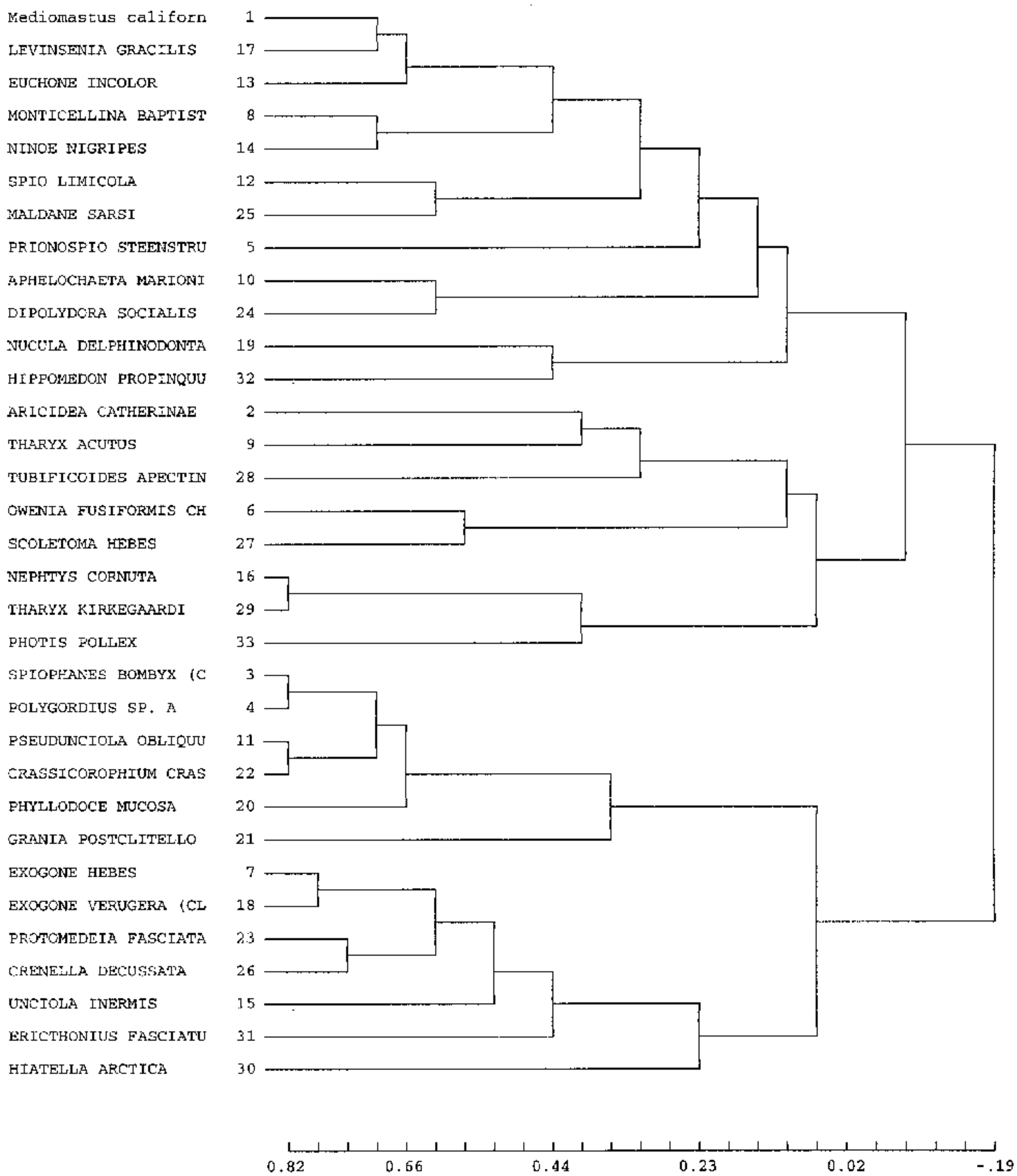


Figure 5-11. Dendrogram resulting from R-mode cluster analysis of the 33 greatest contributors to CNESS distances among the 1998 Nearfield stations. Numbers to the right of the species names indicate ranked contribution to CNESS variation.

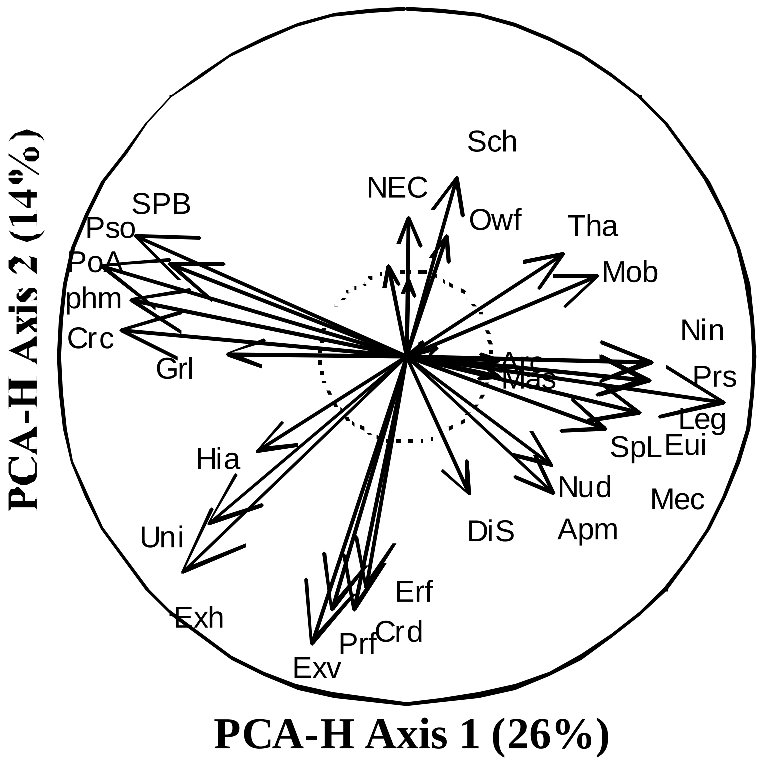
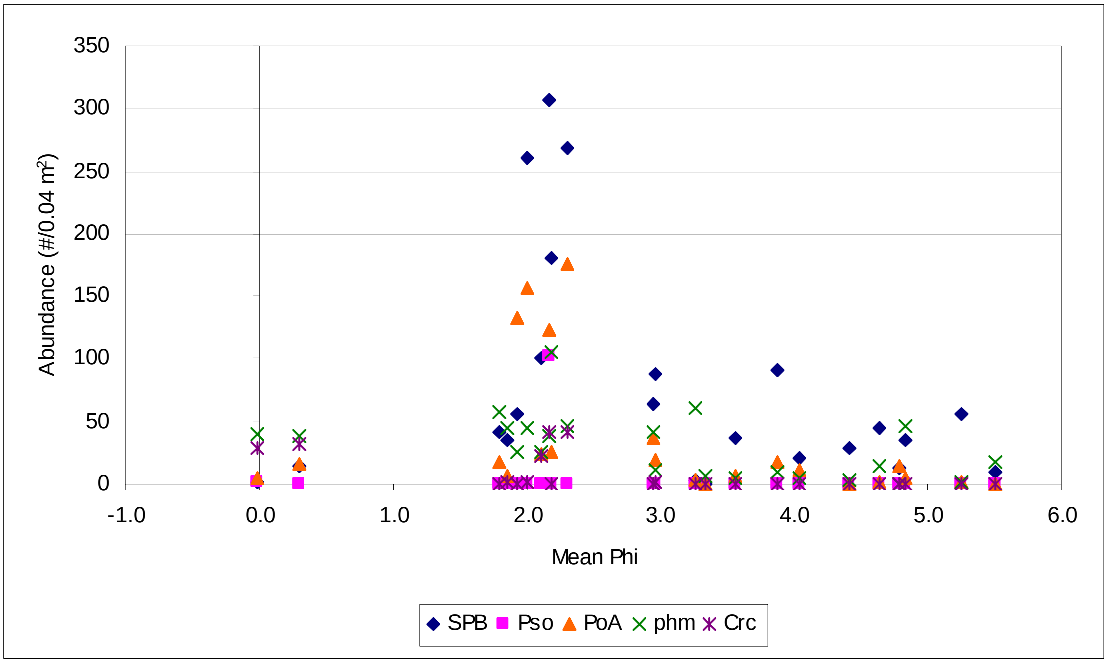


Figure 5-12. Gabriel covariance biplot, axes 1 versus 2, for the 1998 Massachusetts Bay Nearfield data.



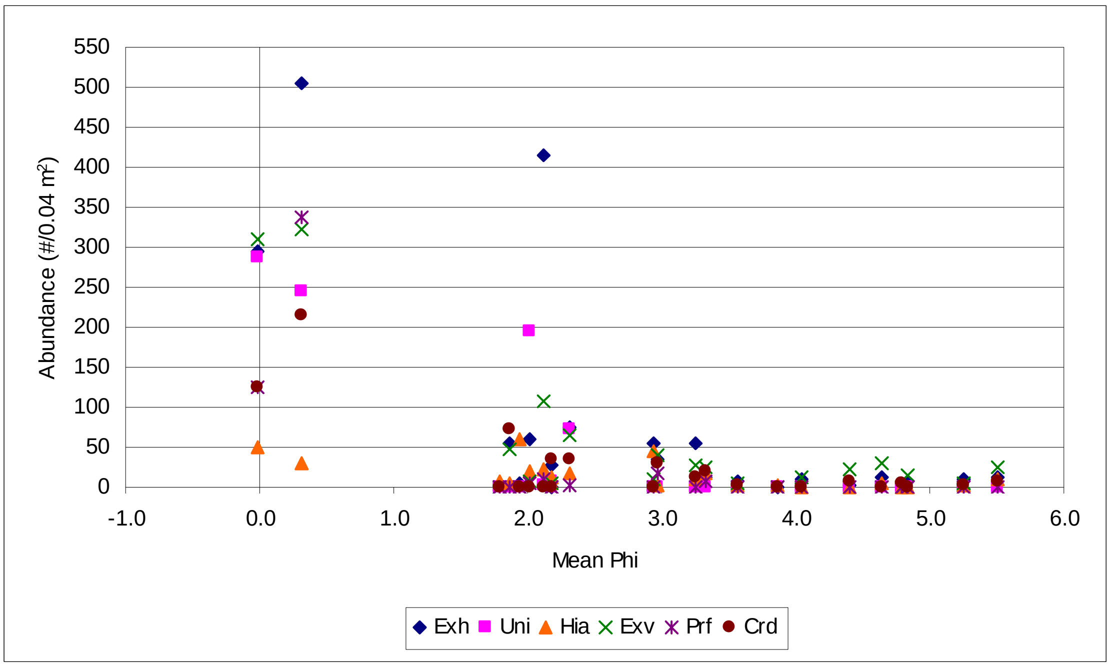


Figure 5-13. Association between infaunal abundance for selected taxa and sediment mean phi based on 1998 Massachusetts Bay Nearfield data. Species abbreviations are as listed in Table 5-2.

community structure displayed in Figure 5-9 is the separation of stations characterized primarily by *Mediomastus californiensis* and *Prionospio steenstrupi* into two groups, one having relatively high numbers of *Aricidea catherinae* (positive direction on axis 3; e.g., stations FF13, NF10, NF14, and NF15) and one having relatively high abundances of *Levinsenia gracilis* and *Ninoe nigripes* (negative direction on axis 3; e.g., stations NF12, NF16, and NF22).

Nearfield Infaunal Associations—R-mode cluster analysis of the 33 taxa making the most significant numerical contributions to CNESS distances in the Nearfield revealed several faunal "assemblages." The dendrogram shows two major, very dissimilar infaunal groups (Figure 5-11), each of which can be separated into two main subgroups. The two major groups included those taxa that separated Nearfield stations along the first PCA-H axis as shown in Figure 5-8. These two groups, and their subgroups, also are depicted in the Gabriel covariance biplot (Figure 5-12). The first major group of species included those in the clusters bounded by *Spiophanes bombyx* and *Exogone hebes* in the dendrogram and located on the left side of the Gabriel covariance plot. This major group of taxa was associated primarily with coarse to medium/fine sand sediments. Among these species, several were relatively strongly associated (indicated by very acute angles in the covariance biplot), including *Spiophanes bombyx*, *Polygordius* sp. A, *Phyllodoce mucosa*, *Pseudunciola obliquua*, and *Crassicorophium crassicorne*. This group of species was strikingly associated with medium to fine sand sediments (mean phi values ~2.0; Figure 5-13). Although some of the species also occurred in coarser and finer (mean phi up to ~6.0) sediments, their highest abundances occurred in the medium/fine sands. The second sand-associated subgroup of species, including *Exogone hebes*, *Unciola inermis*, *Exogone verugera*, and *Protomedeia fasciata*, was moderately strongly associated with medium/fine sands, was relatively uncommon in finer sediments, and showed relatively high abundances in coarse sands (mean phi ~0; Figure 5-13).

The second major faunal aggregation included taxa shown between *Mediomastus californiensis* and the amphipod *Photis pollex* in the dendrogram (Figure 5-11). This group primarily was comprised of polychaetes. Among the key taxa were *Mediomastus californiensis*, *Prionospio steenstrupi*, *Euchone incolor*, *Levinsenia gracilis*, *Owenia fusiformis*, *Tharyx acutus*, *Scoletoma hebes*, and *Monticellina baptistae*, as shown in the Gabriel covariance biplot (Figure 5-12). Species comprising this group occurred in a wide range of Nearfield sediments, with most taxa showing no strong affinity for any particular sediment type (Figure 5-14). For example, *Prionospio steenstrupi* was perhaps most abundant (>1,000/0.04 m^2) in fine to very fine sands (mean phi ~2.0–3.5), but also was fairly common in coarser and finer sediments. *Mediomastus californiensis* appeared to be most abundant in very fine sands to silts (mean phi ~3.3–5.5), but also was moderately abundant in coarser and finer sediments. The distinction between this aggregation's two primary subgroups, as shown in the covariance biplot (Figure 5-12), is difficult to determine by comparisons of abundance and mean phi (Figure 5-14). However, the distinction between the subgroups may be at least partly explained by the association between the subgroups constituent taxa and sediment TOC content. The aggregation of species shown in Figure 5-12 that includes *Prionospio steenstrupi*, *Mediomastus californiensis*, *Spio limicola*, *Levinsenia gracilis*, and *Euchone incolor* showed a tendency to be associated with TOC content (Figure 5-15). Two of the species, *Mediomastus californiensis* ($r = 0.748$, $n = 23$, $p < 0.01$) and *Levinsenia gracilis* ($r = 0.805$, $n = 23$, $p < 0.01$), were strongly associated with sediment TOC content. Two other species, *Euchone incolor* ($r = 0.597$, $n = 22$, $p < 0.01$) and *Spio limicola* ($r = 0.563$, $n = 22$, $p < 0.01$), showed significant correlation between abundance and sediment TOC if data from station NF16 were excluded. Neither was very abundant at station NF16, at which sediment TOC content was relatively high (2.11%). Taxa comprising the other subgroup, *Monticellina baptistae*, *Owenia fusiformis*, *Tharyx acutus*, *Scoletoma hebes*, and *Nephtys cornuta*, showed no significant association with sediment TOC content (Figure 5-15), even if data from station NF16 were excluded (r = !0.040–0.362, $n = 22$, $p > 0.05$).

5.2.3 1998 Farfield Descriptive Community Measures

Abundance—Among individual Farfield samples collected in 1998, infaunal abundance varied about six-fold, ranging from 723 to 4,287 individuals/0.04 m^2 (18,075–107,175/m^2) at stations FF06 (rep 1) and FF07 (rep 1), respectively (Table 5-3). Mean (± 95% CI) abundance among Farfield stations ranged from 1,006 (± 383) to 3,605 (± 1,008) individuals/0.04 m^2 at stations FF06 and FF07, respectively (Figure 5-16).

Annelid worms were the most abundant major infaunal taxon among the 1998 Farfield samples (Figure 5-17). Annelids accounted for more than 70% of the infauna at all but one of the Farfield stations, with the highest percentage (91.7%) at stations FF07. At station FF06, annelids accounted for slightly more than half (about 52%) of the total infaunal abundance. Molluscs typically were the second highest contributors to infaunal abundance. The highest proportions of molluscs occurred at stations FF14 (20.0%) and FF06 (18.1%). Crustaceans were relatively important contributors (26.4%) to infaunal abundance only at station FF06. At most stations, crustaceans accounted for less than 5% of the total abundance. At a slightly finer scale, polychaete worms were the most abundant of the annelids, amphipods the most numerous crustaceans, and bivalves the most common molluscs (Figure 5-18).

Numbers of Species—The total numbers of species per individual Farfield sample collected in 1998 varied less than two-fold, ranging from 53 to 92 at station FF04 (rep 3) and FF09 (rep 3), respectively (Table 5-3). Among the Farfield stations, mean (± 95% CI) numbers of species ranged from 58 (± 4.9) to 90 (± 2.4) at the same two, respectively (Figure 5-16).

Among the major taxa, annelid worms contributed the highest percentage of species, accounting for about 45–56% of the species collected at each Farfield station (Figure 5-19). Crustaceans and molluscs accounted for about 14–27% and about 12–19% of the species collected at each Farfield station, respectively. Within each of the major taxa, polychaetes, amphipods, and bivalves again provided the greatest contribution to species numbers (Figure 5-20).

As for the Nearfield, the numbers of species at Farfield stations were not correlated with infaunal abundance (r = !0.032, n = 8, p >0.05). All three major taxa showed no correlation between species numbers and abundance (annelids, r = !0.019; crustaceans, r = 0.350; molluscs, r = 0.622; all n = 8, p > 0.05).

Diversity—Diversity, as measured by the traditional Shannon Index (H') was fairly consistent across the Farfield (Table 5-3), as H' values among individual samples ranged from 2.98 (station FF01A) to 4.76 (station FF14). Evenness (J') ranged from about 0.5 (stations FF01A) to about 0.8 (station FF14). Within-station variation was generally small (Figure 5-16). Values for log-series alpha ranged from 10.9 (stations FF07) to 20.1 (station FF09). Within-stations variation was relatively high at five stations (Figure 5-16).

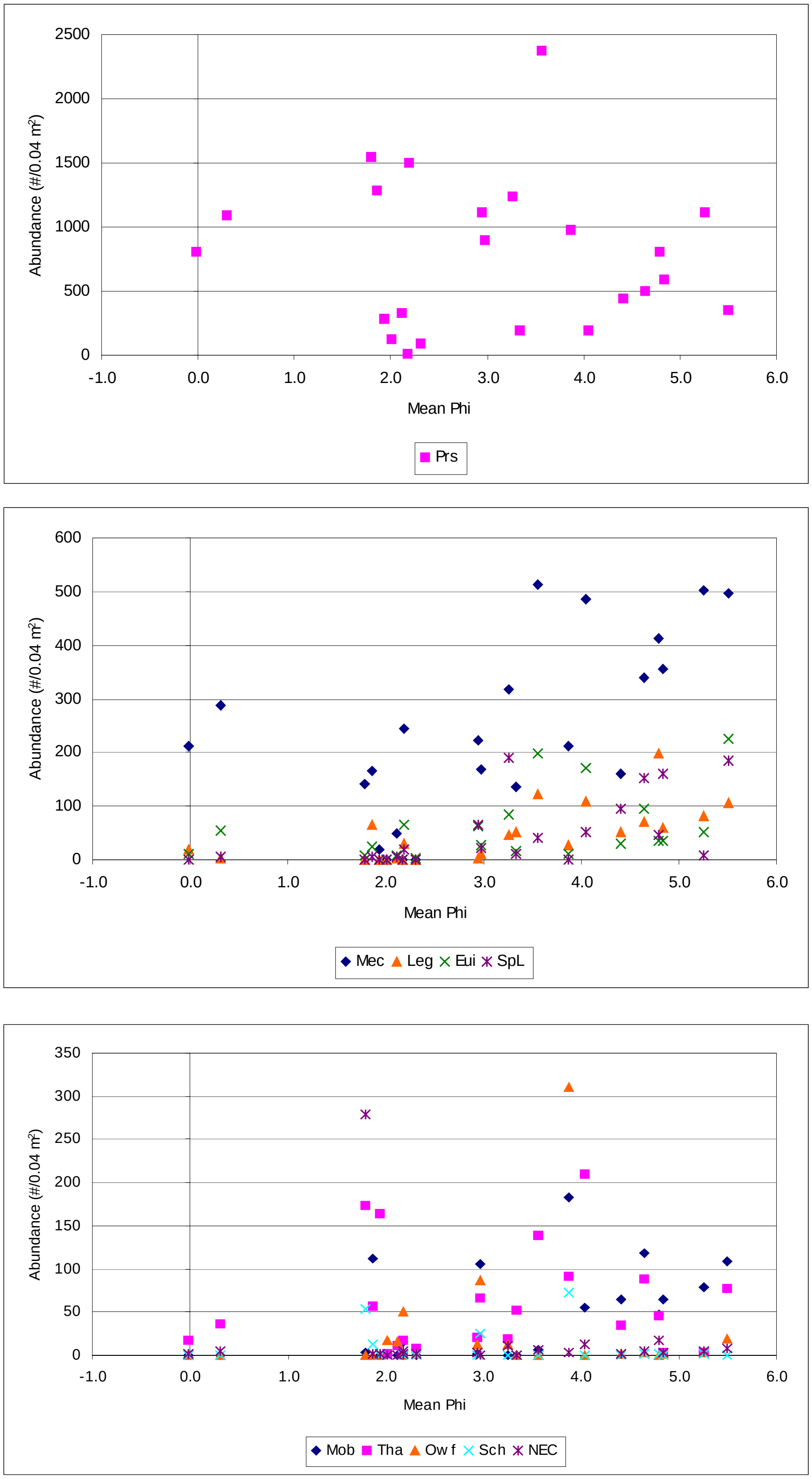


Figure 5-14. Association between infaunal abundance for selected taxa and sediment mean phi based on 1998 Massachusetts Bay Nearfield data. Species abbreviations are as listed in Table 5-2.

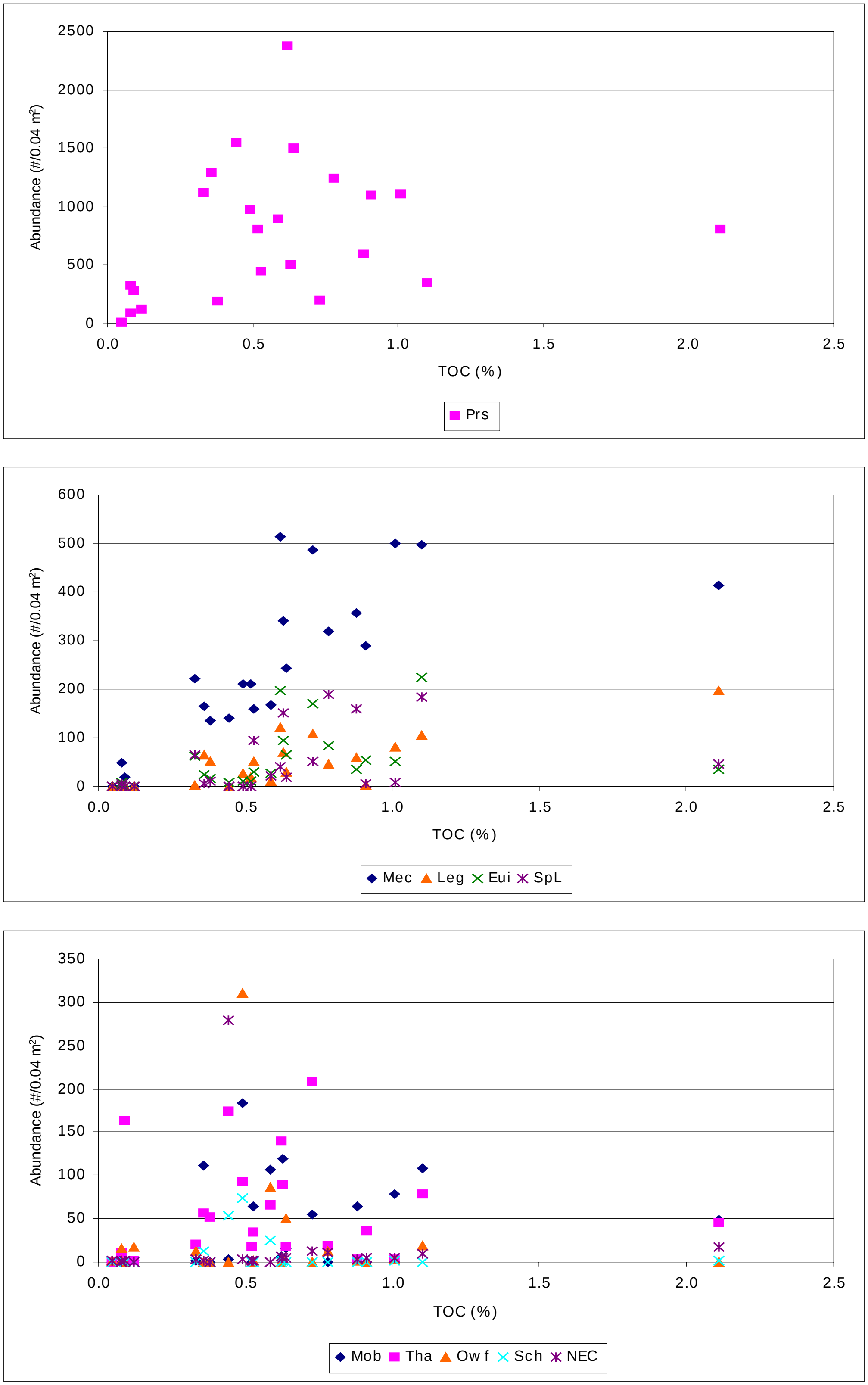


Figure 5-15. Association between infaunal abundance for selected taxa and sediment TOC content based on 1998 Massachusetts Bay Nearfield data. Species abbreviations are as listed in Table 5-2.

Table 5-3. Summary of ecological variables for samples collected from the Farfield in 1998.

Site	Rep.	Total Ind.	Total Spp.	*H'*	*J'*	Hurlbert's E(Sn) n= 2	10	17	50	100	200	500	Log-Series alpha
FF01A	1	2453	78	2.98	0.47	1.68	4.75	6.74	13.53	20.35	29.43	45.16	15.35
FF01A	2	2159	80	3.31	0.52	1.70	5.17	7.59	16.12	24.61	35.11	50.77	16.36
FF01A	3	2024	87	3.16	0.49	1.66	4.88	7.22	15.62	24.15	35.23	53.41	18.49
FF04	1	2431	61	3.70	0.62	1.83	6.20	8.83	16.16	21.85	28.40	39.07	11.36
FF04	2	2493	60	3.73	0.63	1.87	6.33	8.72	15.24	20.85	27.53	37.72	11.07
FF04	3	1384	53	3.51	0.61	1.79	5.84	8.40	15.92	21.94	28.72	39.19	10.93
FF05	1	1174	61	4.30	0.72	1.91	7.17	10.34	19.39	26.98	35.85	48.91	13.66
FF05	2	1014	62	4.16	0.70	1.90	6.90	9.81	18.39	26.18	35.67	49.84	14.56
FF05	3	1709	78	4.25	0.68	1.87	6.77	9.93	20.12	29.51	40.46	55.74	16.85
FF06	1	1381	65	4.29	0.71	1.91	7.22	10.34	18.88	25.76	33.93	47.73	14.16
FF06	2	915	58	4.43	0.76	1.93	7.60	10.94	19.56	26.22	33.87	46.82	13.77
FF06	3	723	61	4.53	0.76	1.94	7.70	11.16	20.28	27.81	37.49	53.88	15.89
FF07	1	4287	65	3.36	0.56	1.79	5.54	7.76	14.51	20.44	27.31	37.48	10.87
FF07	2	2597	62	3.59	0.60	1.84	5.89	8.05	14.96	21.54	29.35	40.85	11.41
FF07	3	3930	62	3.46	0.58	1.83	5.72	7.85	14.38	19.96	26.17	35.84	10.45
FF09	1	1741	88	4.18	0.65	1.87	6.67	9.62	19.09	28.04	39.04	57.09	19.55
FF09	2	1754	91	3.95	0.61	1.84	6.27	8.97	17.74	26.35	37.57	56.70	20.37
FF09	3	1842	92	4.33	0.66	1.88	6.90	10.10	20.13	29.35	40.85	59.91	20.38
FF11	1	1673	66	3.29	0.54	1.72	5.24	7.60	15.60	23.29	32.41	45.89	13.72
FF11	2	1847	70	3.23	0.53	1.73	5.20	7.46	14.83	21.87	30.45	44.38	14.40
FF11	3	1232	58	3.58	0.61	1.80	5.83	8.36	16.36	23.66	32.30	45.30	12.64
FF14	1	1993	72	4.62	0.75	1.94	7.80	11.37	20.81	28.10	36.42	49.27	14.63
FF14	2	1967	77	4.76	0.76	1.95	8.04	11.86	21.84	29.24	37.64	50.94	15.97
FF14	3	1660	68	4.74	0.78	1.95	8.09	11.95	21.77	28.65	36.19	47.73	14.27

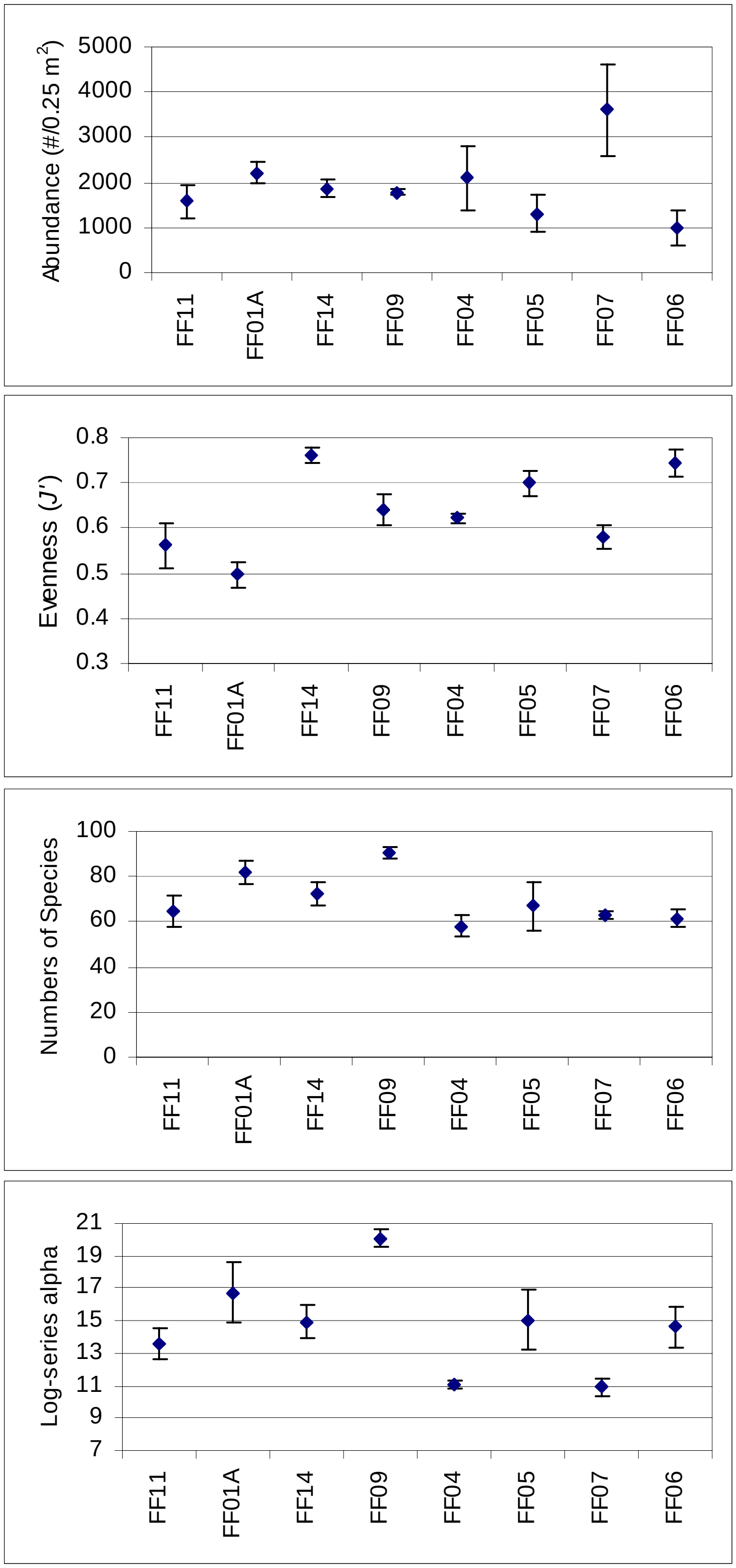


Figure 5-16. Infaunal abundance, numbers of species, evenness, and log-series alpha values for 1998 Massachusetts Bay Farfield stations. Mean and 95% confidence intervals are shown.

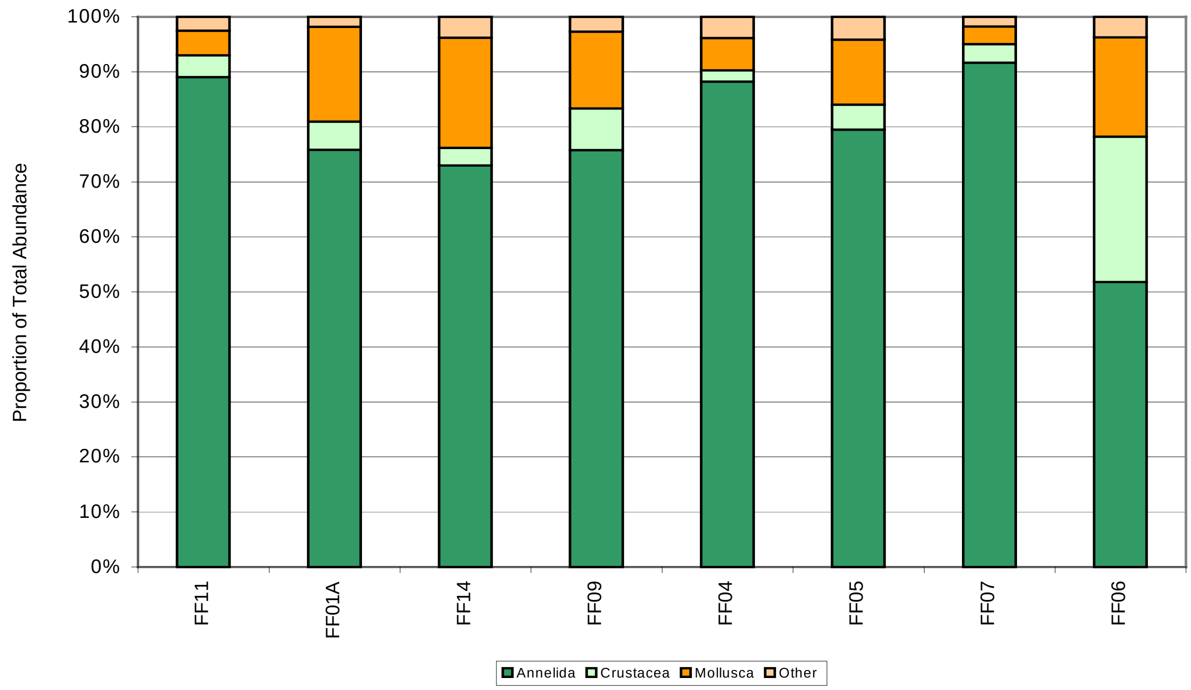


Figure 5-17. Relative contribution of higher-level taxa to infaunal abundance among 1998 Farfield samples .

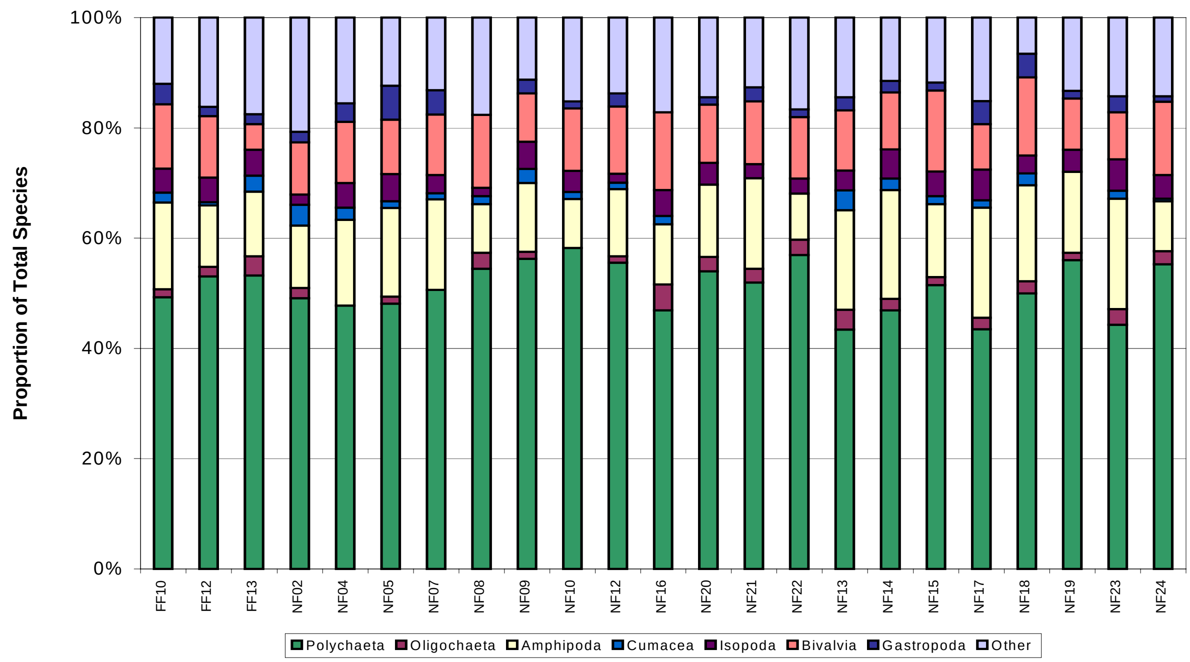


Figure 5-18. Relative contribution of lower-level taxa to infaunal abundance among 1998 Farfield samples.

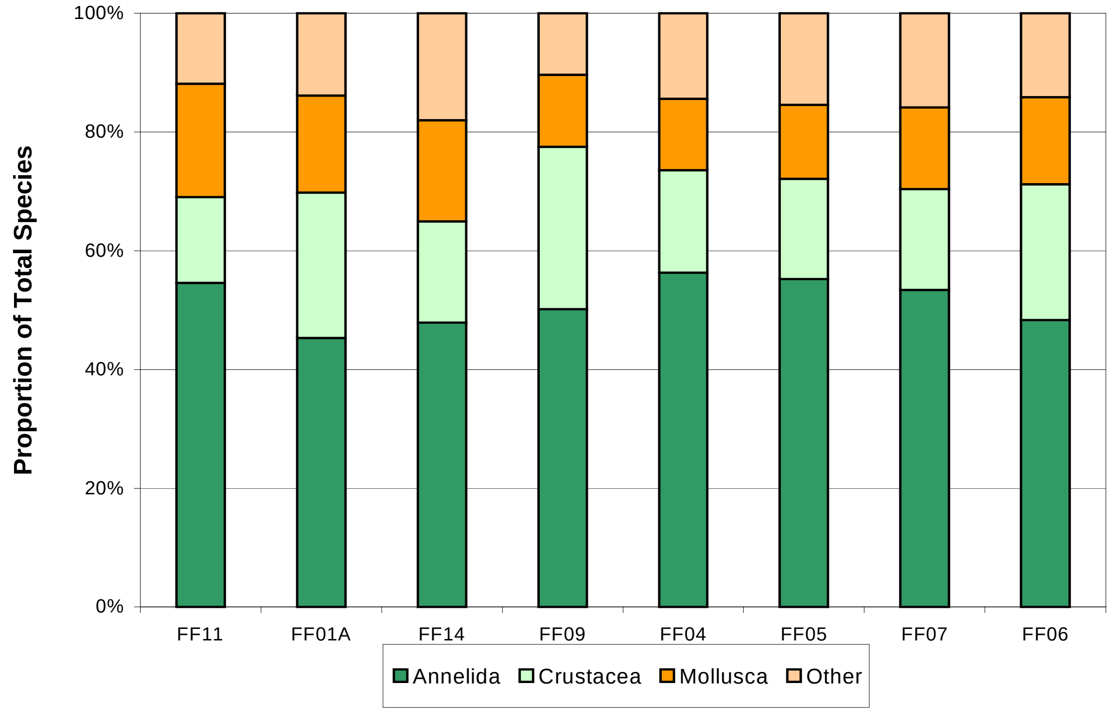


Figure 5-19. Relative contribution of higher-level taxa to numbers of infaunal species among 1998 Farfield samples.

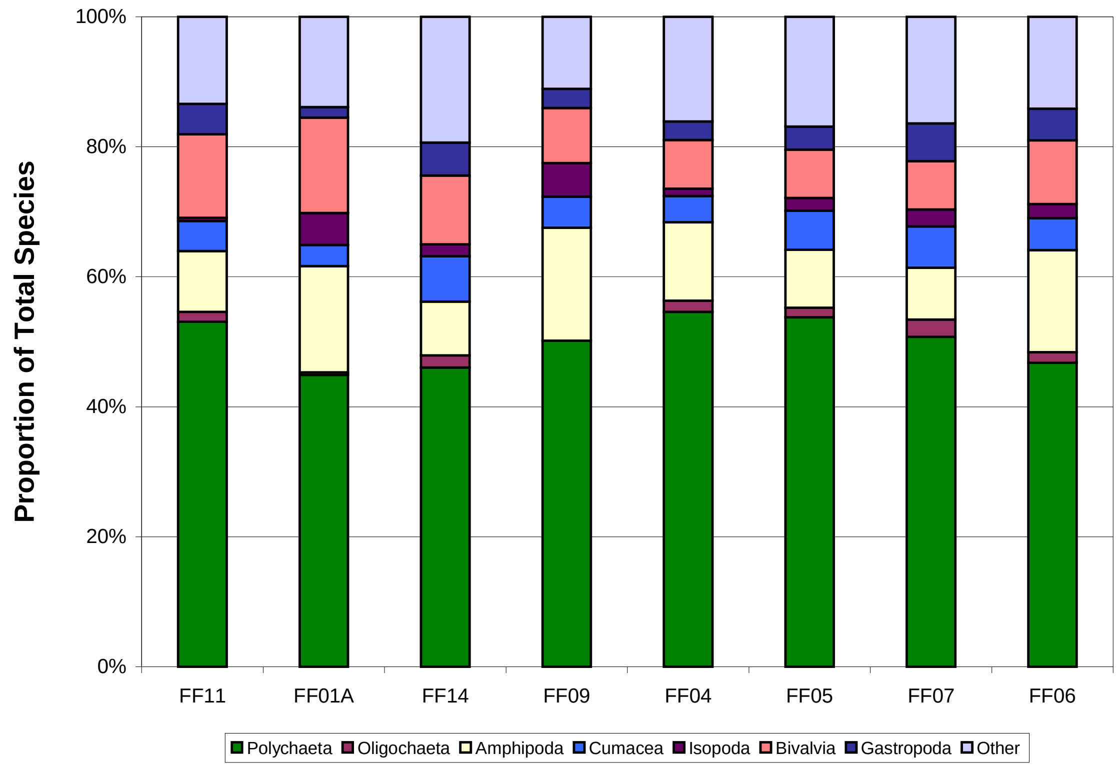


Figure 5-20. Relative contribution of lower-level taxa to numbers of infaunal species among 1998 Farfield samples.

Most Abundant Species—The 12 most abundant species found at each Farfield station in 1998 are listed in Appendix D-3. The sabellid polychaete *Euchone incolor* was the most abundant species at 3 stations (FF04, FF05, FF07) and ranked in the top 12 at 3 others (FF09, FF14, FF11). All of these stations were located towards the eastern edge of Massachusetts Bay. *Prionospio steenstrupi*, a spionid polychaete was the most abundant species at three stations, FF01A, FF09, and FF11, located in the northern portion of the Bay. *Anobothrus gracilis*, an ampharetid polychaete, was the top-rank species at station FF14, whereas *Leptocheirus pinguis*, an aorid amphipod, was the most numerous at station FF06. The top 12 species accounted for about 72–87% of the infaunal abundance at the Farfield stations in 1998.

5.2.4 1998 Farfield Multivariate Analyses

Cluster/PCA-H Analyses—Results of the CNESS cluster analysis of the 1998 Farfield samples showed that similarity among replicates at each station was high (Figure 5-21). All three replicates collected at each station were more similar to each other than they were to any other samples.

Examination of the cluster patterns shown in the dendrogram showed that three very dissimilar groups of stations were distinguished. The first group was comprised of samples from stations FF01A and FF09. The second group included station FF11 at the northern extreme of Massachusetts Bay, station FF14 well east of the Outfall, stations FF04 and FF05 near the eastern edge of Massachusetts Bay, and station FF07 in Cape Cod Bay. The third group was comprised solely of the replicate samples from station FF06, located in Cape Cod Bay. These distinctions among station groups also are evident in the primary metric scaling plot resulting from the PCA-H analysis of the 1998 Farfield data (Figure 5-22).

The PCA-H analysis of the 1998 Farfield data revealed 31 taxa (Table 5-4) that were important contributors to the CNESS distances depicted in the dendrogram and primary metric scaling plot (PCA-H axes 1 versus 2). The species that best explain the distances depicted in the metric scaling plot are reflected in the Gabriel Euclidean Distance biplot (Figure 5-23) and are indicated in the PCA-H axis columns in Table 5-4. The greatest separation of Farfield stations along PCA-H axis 1 is between stations FF04 and FF07 versus stations FF01A and FF09. The Gabriel Euclidean Distance biplot showed that four species were largely responsible for this separation. The polychaetes *Euchone incolor* (~18,450 and 30,075 individuals/m^2, respectively) and *Cossura longocirrata* (~4,675 and 19,875 individuals/m^2, respectively) distinguished stations FF04 and FF07, which had the highest abundances of these species in the Farfield. The polychaete *Prionospio steenstrupi* (~30,525 and 14,125 individuals/m^2, respectively) and the nut clam *Nucula delphinodonta* (~5,175 and 2,700 individuals/m^2, respectively) distinguished stations FF01A and FF09, which had the highest abundances of these species in the Farfield. Important contributors to CNESS distances along PCA-H axis 2 were *Cossura longocirrata*, *Anobothrus gracilis*, *Aricidea quadrilobata*, and *Leptocheirus pinguis* (Table 5-4). High abundances (~3,925 individuals/m^2) of the amphipod *Leptocheirus pinguis*, which occurred at only one other Farfield station, primarily served to separate station FF06 from the remaining Farfield stations. Additional separation resulted from the relatively low numbers of the other three key PCA-H axis 2 species at station FF06. Station FF14 was distinguished from other Farfield stations primarily by the relatively high numbers of the ampharetid polychaete *Anobothrus gracilis* (~4,375 individuals/m^2) that occurred there. Station FF11 separated from the other Farfield stations by having relatively high abundances of the paraonid polychaete *Levinsenia gracilis* (~3,725 individuals/m^2). The relative abundance of *Anobothrus gracilis* helped distinguish Station FF09 (~1,050 individuals/m^2) from stations FF01A (~175 individuals/m^2) along PCA-H axis 2.

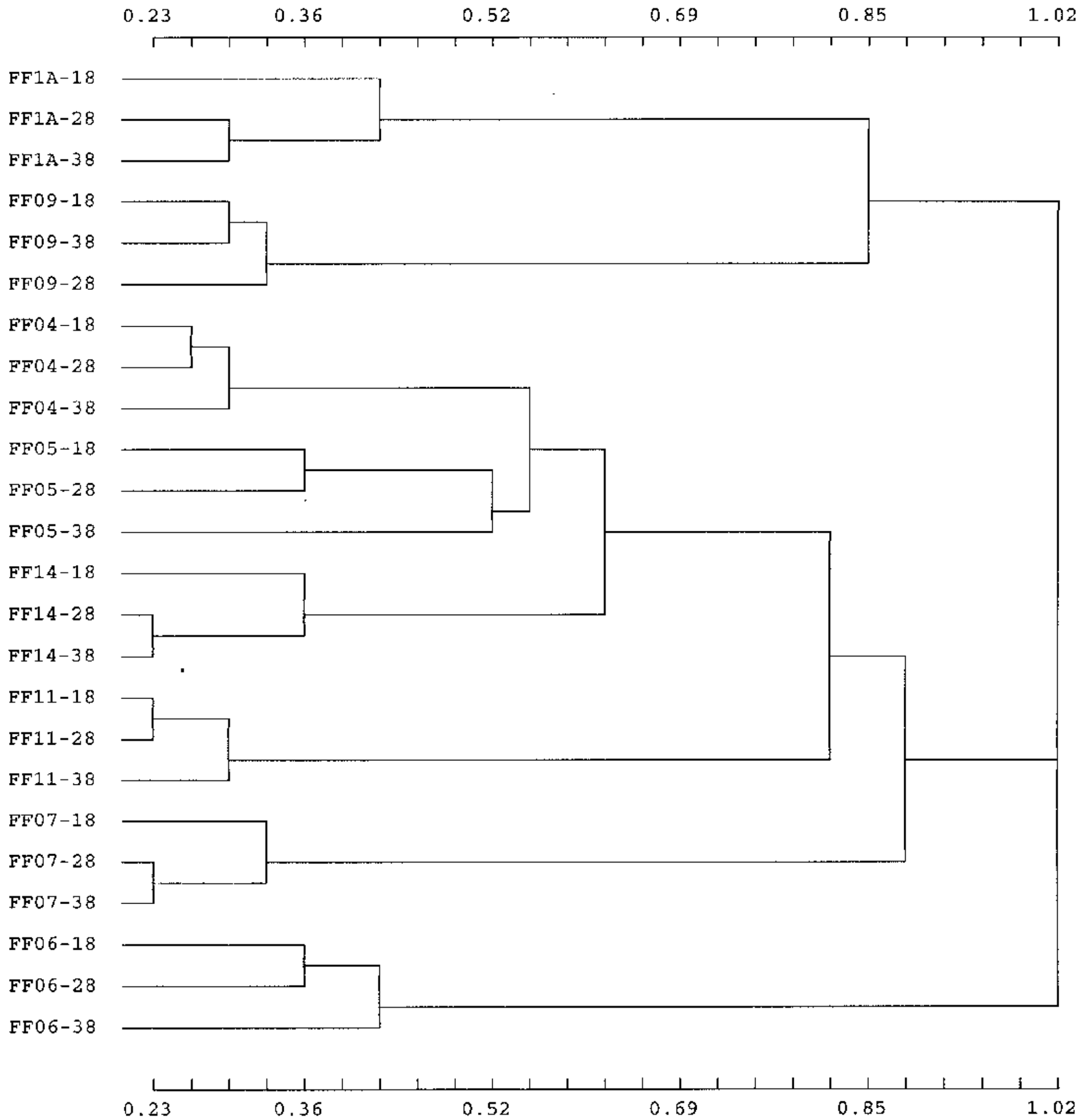


Figure 5-21. Dendrogram resulting from CNESS cluster analysis of 1998 Farfield stations.

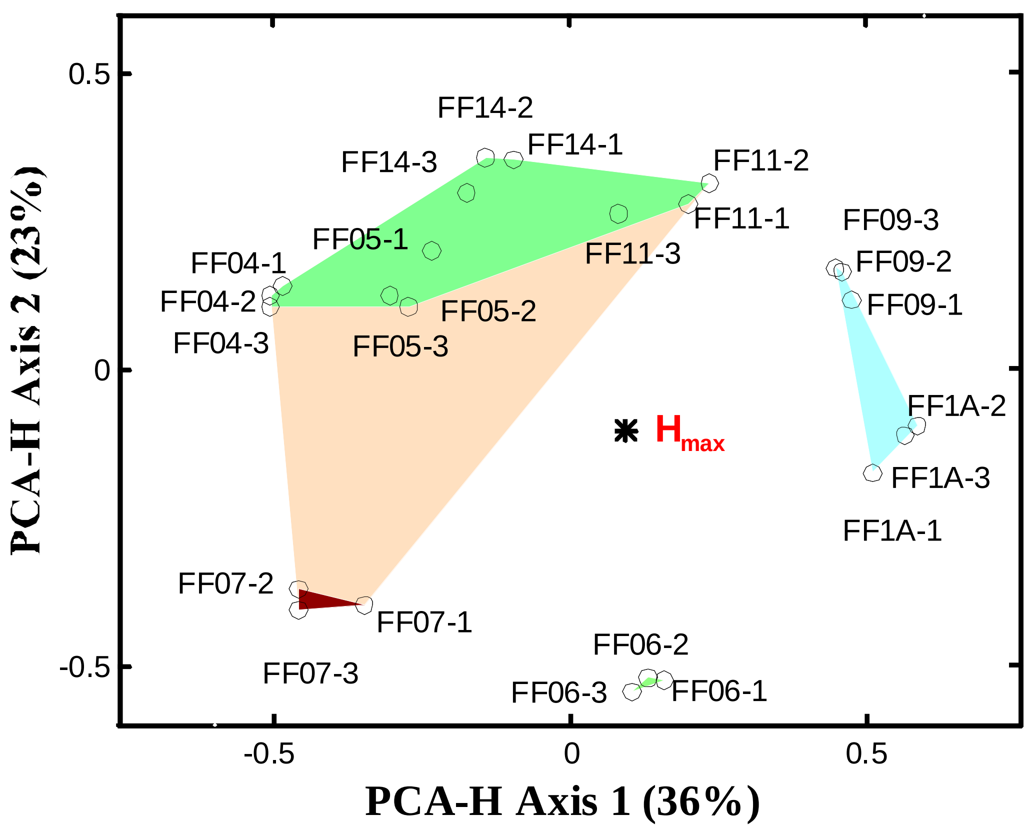


Figure 5-22. Metric scaling plot of CNESS distances, axes 1 versus 2, among Farfield stations sampled in 1998. Results of the CNESS cluster analysis are shown as convex hulls.

Table 5-4. The 31 most important contributors to CNESS distances in the 1998 Massachusetts Bay Farfield data. "Cont" is the contribution to overall CNESS distances, "Total Cont" is the cumulative amount of CNESS variation explained by species (92% by the top 31 species). The final columns indicate the contribution of each species to each of the first six PCA-H axes.

No.	Species	Spp.	Cont.	Total Cont.	PCA-H Axis 1	2	3	4	5	6
1	*Euchone incolor*	Eui	11	11	25	1	11	1	0	4
2	*Cossura longocirrata*	Col	8	19	12	12	2	0	7	2
3	*Prionospio steenstrupi*	Prs	8	27	18	4	0	5	2	1
4	*Anobothrus gracilis*	AnG	6	32	4	9	0	2	24	1
5	*Dipolydora socialis*	DiS	5	38	4	1	14	20	2	3
6	*Aricidea quadrilobata*	Arq	5	43	4	9	7	1	3	1
7	*Nucula delphinodonta*	Nud	5	48	11	1	0	1	9	5
8	*Leptocheirus pinguis*	Lep	4	52	0	7	9	8	4	0
9	*Levinsenia gracilis*	Leg	4	57	1	5	11	0	3	24
10	*Spio limicola*	SpL	4	60	1	2	7	11	7	1
11	*Mediomastus californiensis*	Mec	3	63	4	2	1	2	3	4
12	*Tubificoides apectinatus*	Tua	3	66	1	5	7	0	1	8
13	*Harpinia propinqua*	Hap	2	68	2	1	5	5	0	0
14	*Onoba pelagica*	Onp	2	70	0	3	3	4	4	4
15	*Tharyx acutus*	Tha	2	72	0	5	1	7	0	0
16	*Dentalium entale*	Dee	2	75	2	3	0	0	7	8
17	*Spiophanes bombyx*	SPB	2	76	2	0	0	11	1	0
18	*Tubificidae sp. 2 (Blake 1992)*	Tu2	2	78	1	3	1	0	4	1
19	*Sternaspis scutata*	Sts	2	80	0	3	3	0	0	4
20	*Apistobranchus typicus*	ApT	2	82	1	1	2	6	0	1
21	*Aricidea catherinae*	Arc	2	83	0	5	0	0	0	0
22	*Chaetozone setosa MB*	Chs	1	85	1	2	1	0	1	0
23	*Galathowenia oculata*	Gao	1	86	0	3	1	0	1	0
24	*Ninoe nigripes*	Nin	1	87	0	4	0	0	0	1
25	*Yoldia sapotilla*	Yos	1	88	0	1	0	3	3	5
26	*Terebellides atlantis*	TeA	1	89	0	3	0	0	0	0
27	*Thyasira gouldi*	Thg	1	90	0	0	1	0	3	7
28	*Thracia conradi*	Thc	1	91	0	1	0	0	2	5
29	*Nephtys incisa*	Nei	1	91	0	1	1	1	0	1
30	*Parougia caeca*	Pac	1	92	1	0	1	0	0	1
31	*Arctica islandica*	Ari	1	92	0	0	0	2	0	0

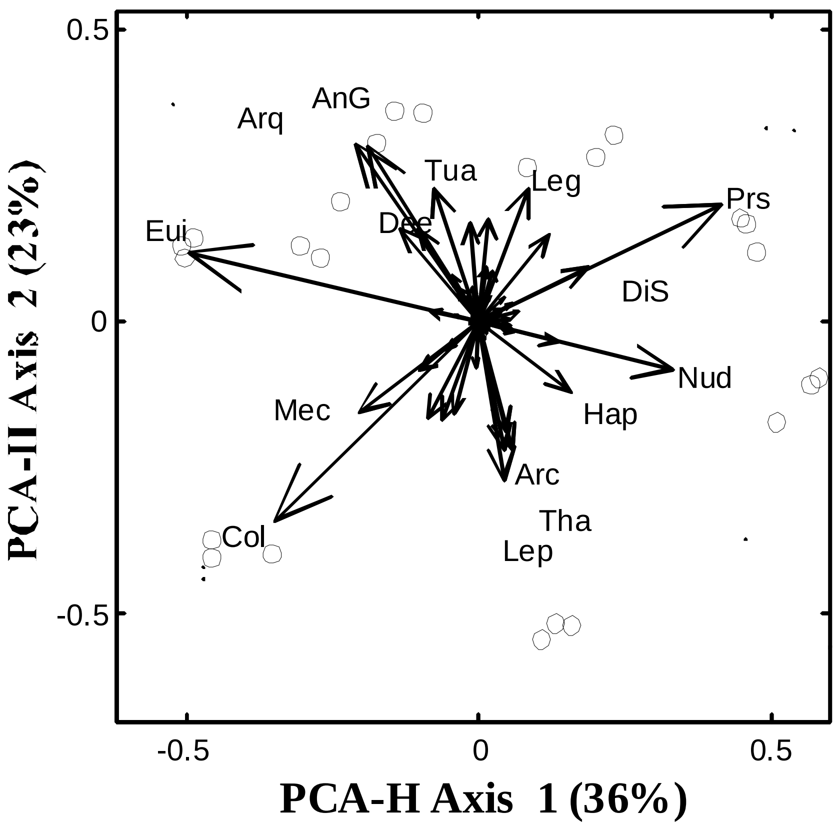


Figure 5-23. Gabriel Euclidean distance biplot, axes 1 versus 2, for the 1998 Massachusetts Bay Farfield data showing those species that control the orientation of samples shown in Figure 5-22. Species codes are as listed in Table 5-4. Open circles represent the spatial pattern of samples shown in Figure 5-22.

The metric scaling plot comparing PCA-H axis 1 versus 3 (Figure 5-24), and its associated Gabriel Euclidean Distance biplot (Figure 5-25), revealed some interesting details about community structure in the Farfield. First, stations FF01A and FF09 again were well separated from the other stations along PCA-H axis 1 (high numbers of *Nucula delphinodonta* and *Prionospio steenstrupi*). In this case, stations FF01A and FF09 separated from each other along PCA-H axis 3 primarily because of large numbers of *Dipolydora socialis* at the latter station (~5,475 individuals/m^2) as compared to the former station (~18 individuals/m^2). The other interesting feature revealed by the PCA-H axis 1 versus 3 comparison was the closeness of stations FF06 and FF11, two stations geographically quite distant from each other. The two stations were linked along PCA-H axis 1 by being fairly neutral in abundances of the key axis 1 taxa. Along PCA-H axis 3, the two were distinguished from the other Farfield stations by having low abundances of two of the most important contributors to axis 3, *Euchone incolor* and *Dipolydora socialis*, and by having anomalously high numbers of *Levinsenia gracilis* (station FF11) or *Leptocheirus pinguis* (station FF06). Additionally, both had moderately high abundances of the phoxocephalid amphipod *Harpinia propinqua*.

The Farfield differs from the Nearfield in many respects. One of the differences that may be a factor in determining community structure in the Farfield is its geographic extent and relatively wide depth range. While the Nearfield covers a fairly small geographic area and narrow depth range, the Farfield (excluding those stations analyzed as part of the Nearfield) spans about one-half degree in latitude and almost one-half degree in longitude. Station depths in the Farfield span about 55 m, ranging from about 35 to 90 m. Such differences may be reflected in the infauna found among the Farfield samples, therefore the interplay between depth and geography would be noticeable in the cluster analyses. The three primary cluster groups resulting from the 1998 Farfield analyses are somewhat associated with geography and depth. The first cluster group (stations FF01A and FF09) are shallow or northern stations; the second group (stations FF04, FF05, FF11, FF14, and FF07) are eastern and/or deep stations; and the third group (station FF06) is a southern, shallow station. Station FF07 did not appear to fit the pattern well. Geography and depth would have predicted that it would have clustered with station FF06. However, it was not very similar to the other stations in its cluster group.

Farfield Infaunal Associations—R-mode cluster analysis of the 31 taxa making the most significant numerical contributions to CNESS distances among the Farfield stations revealed several likely faunal assemblages. The dendrogram resulting from the CNESS analysis showed three primary faunal groups that were not very similar to each other (Figure 5-26). The first group was comprised of two of the important contributors to CNESS distances among the Farfield stations, *Euchone incolor* and *Cossura longocirrata*. Also constituents in the aggregation were the polychaetes *Mediomastus californiensis*, *Tharyx acutus*, and *Aricidea catherinae*, the amphipods *Leptocheirus pinguis* and *Harpinia propinqua*, and the gastropod *Onoba pelagica*. The second group consisted of the taxa bounded by the polychaete *Prionospio steenstrupi* and the clam *Thracia conradi* in the dendrogram. This group included two other bivalve molluscs, *Yoldia sapotilla* and small individuals of the ocean quahog *Arctica islandica*. The third group included an eclectic mix of annelids including *Anobothrus gracilis*, an important contributor to CNESS distances, the paraonid *Aricidea quadrilobata*, the sternaspid *Sternaspis scutata*, the oligochaete *Tubificoides apectinatus*, and the scaphopod mollusc (tusk shell) *Dentalium entale*.

These associations were evident in the Gabriel covariance biplots resulting from the PCA-H analyses. The biplot comparing the PCA-H axis 1 versus 2 (Figure 5-27) showed the complex mixture of species associations found among the Farfield infauna. In this figure, only the relatively coarse separation between the *Euchone incolor*-*Leptocheirus pinguis* and the *Anobothrus gracilis*-*Prionospio steenstrupi* groups was shown clearly. There appeared to be a general tendency for the *Euchone*-*Leptocheirus* group

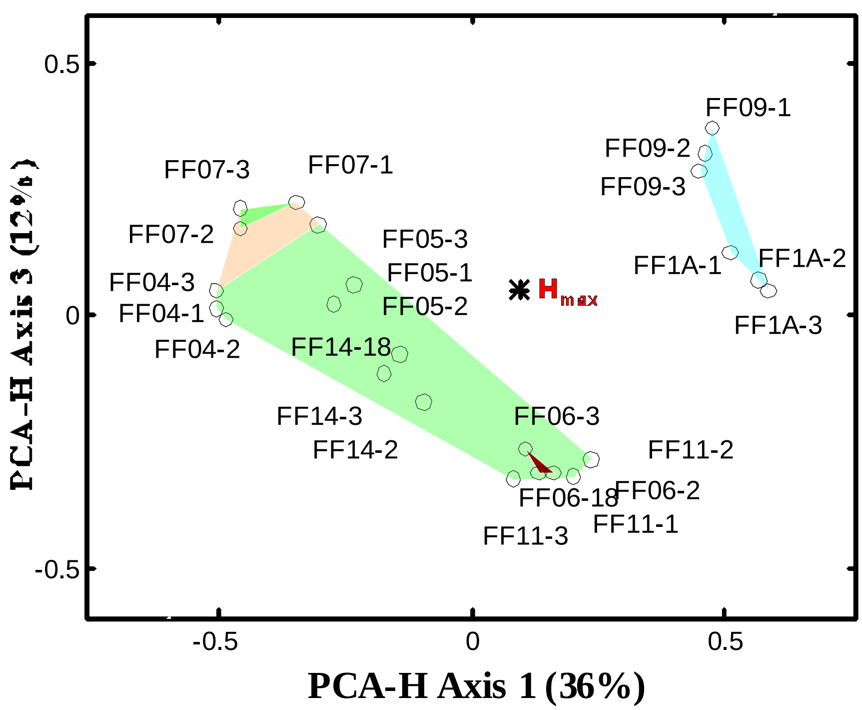


Figure 5-24. Metric scaling plot of CNESS distances, axes 1 versus 3, among Massachusetts Bay Farfield stations sampled in 1998. Results of the CNESS cluster analysis are shown as convex hulls.

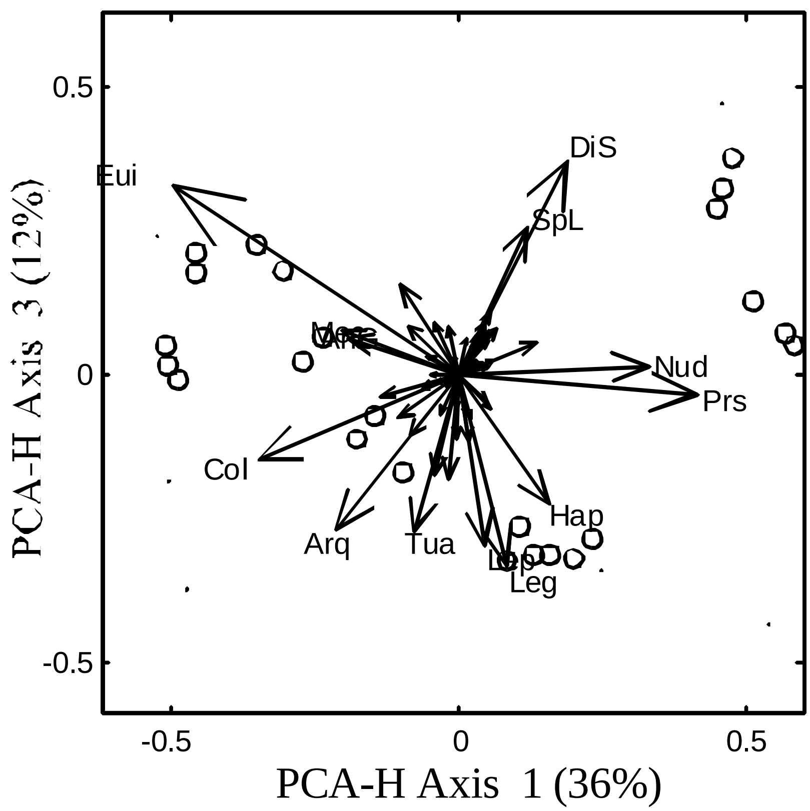


Figure 5-25. Gabriel Euclidean distance biplot, axes 1 versus 3, for the 1998 Massachusetts Bay Farfield data showing those species that control the orientation of samples shown in Figure 5-24. Species codes are as listed in Table 5-4. Open circles represent the spatial pattern of samples shown in Figure 5-24.

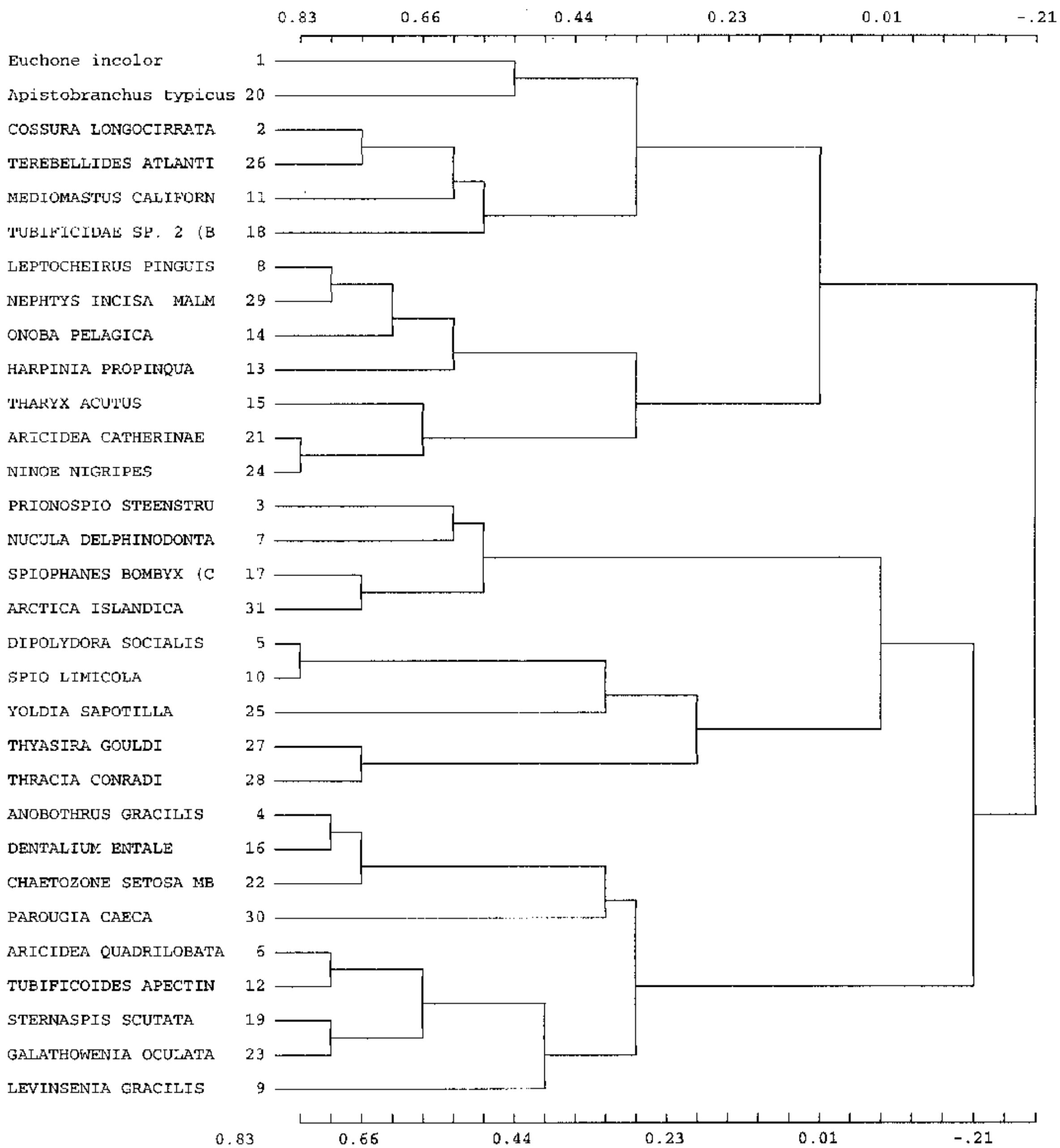


Figure 5-26. Dendrogram resulting from R-mode cluster analysis of the 31 greatest contributors to CNESS distances among the 1998 Massachusetts Bay Farfield stations. Numbers to the right of the species names indicate ranked contribution to CNESS variation.

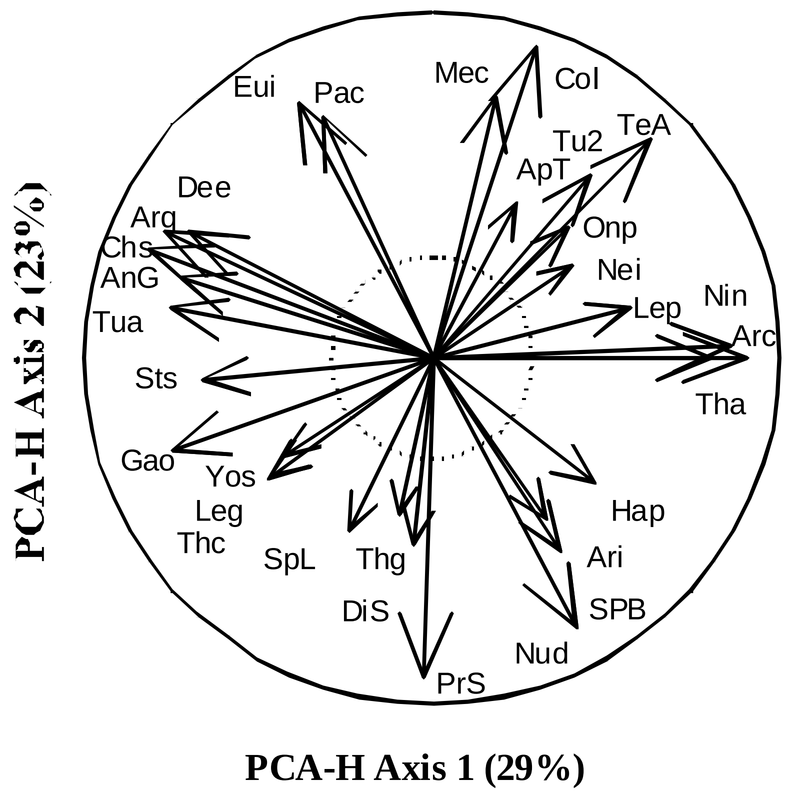


Figure 5-27. Gabriel covariance biplot, axes 1 versus 2, for the 1998 Massachusetts Bay Farfield data.

to be associated with fine sediments (mean phi > 4.0; Figure 5-28), although there was only one significant correlation between any of the group's constituent taxa and mean phi (*Parougia caeca*, r = 0.878, n = 8, p < 0.01). The *Anobothrus-Prionospio* group occurred in a variety of sediments (Figure 5-29, excluding *Prionospio*), with several taxa being relatively abundant in fine sediments (mean phi > 4.5) and relatively coarse sediments (mean phi ~3.5 or smaller). Comparison of PCA-H axis 1 versus 3 permitted division of the of *Euchone incolor-Leptocheirus pinguis* group into three components, one comprised of *Euchone incolor*, one consisting of *Harpinia propinqua*, *Leptocheirus pinguis*, and two other taxa, and one containing the remaining taxa (Figure 5-30). The factors contributing to this separation were not clear.

Depth might be a factor that contributed to the separation of the some of the faunal subgroups identified in the dendrogram. For example, the taxa comprising the *Anobothrus gracilis* subgroup appeared to be distinguished from the *Prionospio steenstrupi* subgroup taxa because of their occurrence at deeper stations (Figure 5-31, excluding *Prionospio*). Four of the species within the *Anobothrus gracilis* subgroup (not all species in the subgroups were compared to sediment grain size) showed significant positive association with depth (*Aricidea quadrilobata*, r = 0.841; *Levinsenia gracilis*, r = 0.721; *Chaetozone setosa* MB, r = 0.757; *Tubificoides apectinatus*, r = 0.780; all n = 8, p < 0.05). Similarly, within the *Euchone-Leptocheirus* group, some species within the *Leptocheirus* subgroup showed a tendency to be found only at shallower stations (*Leptocheirus pinguis*, *Aricidea catherinae*, *Tharyx acutus*, *Nucula delphinodonta;* Figure 5-32), although only two statistically significant associations were detected (*Aricidea catherinae*, r = -0.780; *Ninoe nigripes*, r = -0.836; both n = 8, p <0.01).

5.2.5 1998 Combined Nearfield/Farfield Multivariate Analyses

Cluster/PCA-H Analyses— Results of the CNESS cluster analysis of the 1998 combined Nearfield/Farfield data set showed the presence of three distinct stations groups (Figure 5-33). One group consisted of stations NF13, NF17, NF23, a group identified in the Nearfield CNESS analysis that retained its distinctive character when compared to all Massachusetts Bay stations. The second group consisted of Farfield stations FF04, FF05, FF14, FF11, FF07, and FF06. These stations are the Farfield stations most removed, either in distance or depth, from the Nearfield stations. The final cluster group was a very complex assemblage of Nearfield stations (including FF10, FF12, and FF13) and the two shallow, northern Farfield stations, stations FF01A and FF09. The linkage of the western Massachusetts Bay stations with ones to the north (FF01A) and east (FF09) implies that the faunal communities found there are part of a larger shallow infaunal biome occurring along coastal Massachusetts. These three primary groups were readily distinguished in the metric scaling plot of the first two PCA-H axes (Figure 5-34). The 43 most important contributors to CNESS distances among the combined Nearfield/Farfield data set are listed in Table 5-5.

The Gabriel Euclidean Distance biplot comparing PCA-H axis 1 versus 2 (Figure 5-35) showed that the distinctive character of the NF13, NF17, NF23 station group was attributable to high abundances of *Polygordius* sp. A, *Spiophanes bombyx*, and the amphipod *Pseudunciola obliquua*, as was determined during the Nearfield analyses. No Farfield stations had a similar composition. The second stations group, the Farfield stations removed from the Nearfield, differed from any Nearfield stations. As indicated by the Gabriel Euclidean Distance biplot, this difference could be ascribed to the high abundances of the polychaetes *Euchone incolor*, *Cossura longocirrata*, *Aricidea quadrilobata*, and *Anobothrus gracilis*. The third stations group, primarily the Nearfield stations, was distinguished by high numbers of the polychaetes *Mediomastus californiensis*, *Prionospio steenstrupi*, *Tharyx acutus*, *Aricidea catherinae*, *Ninoe nigripes*, and *Monticellina baptistae*.

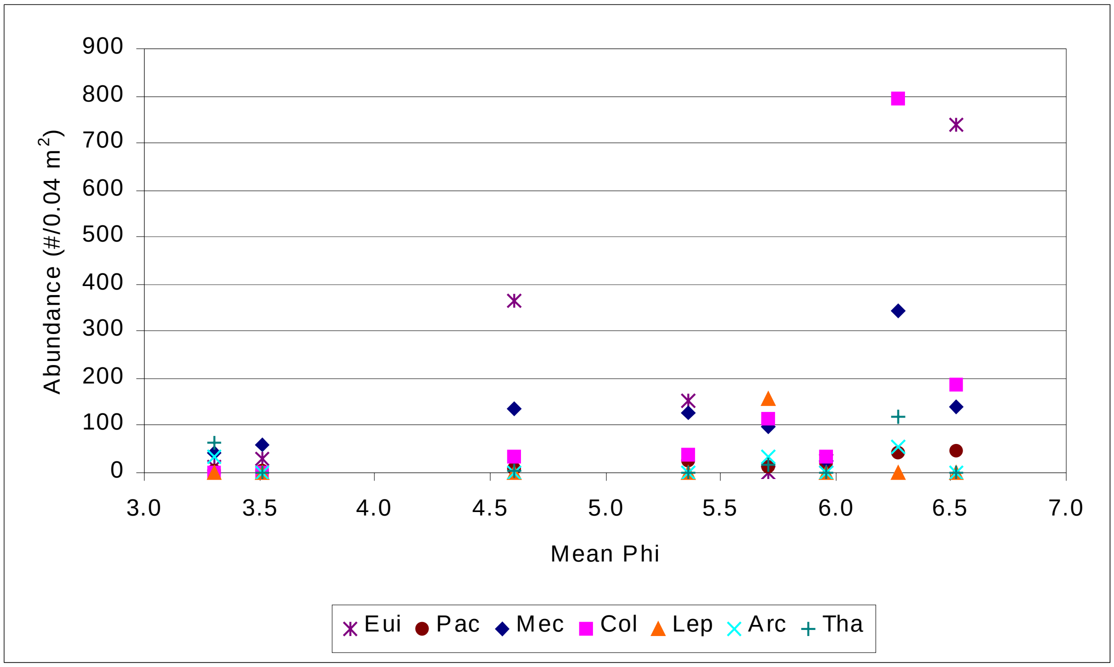
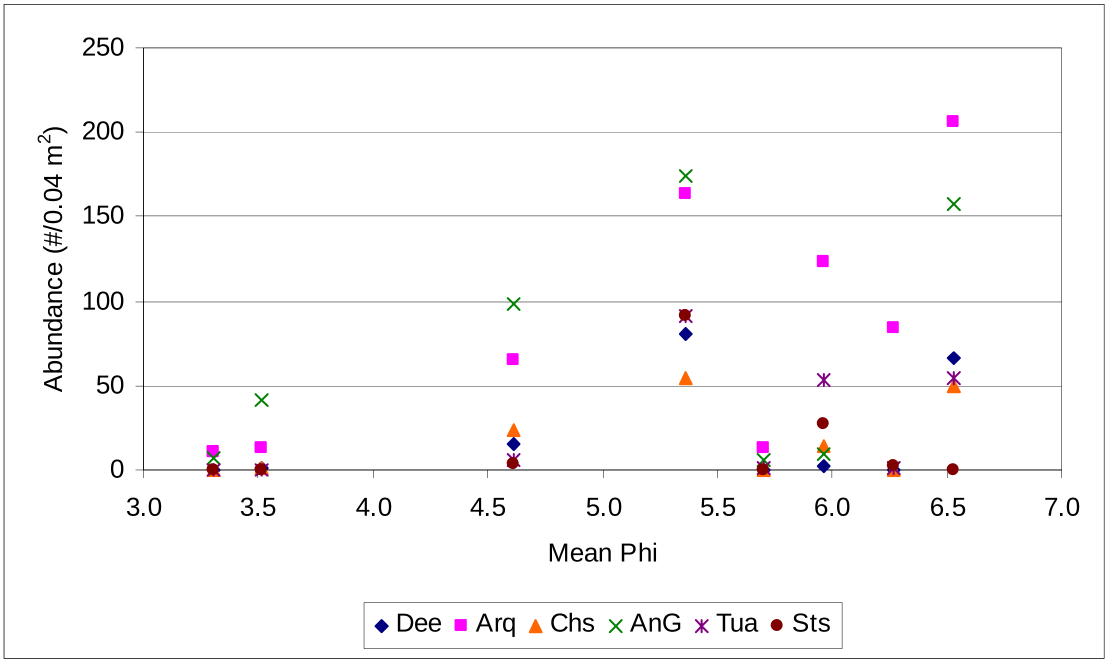


Figure 5-28. Association between infaunal abundance for selected taxa and sediment mean phi based on 1998 Massachusetts Bay Farfield data. Species abbreviations are as listed in Table 5-4.



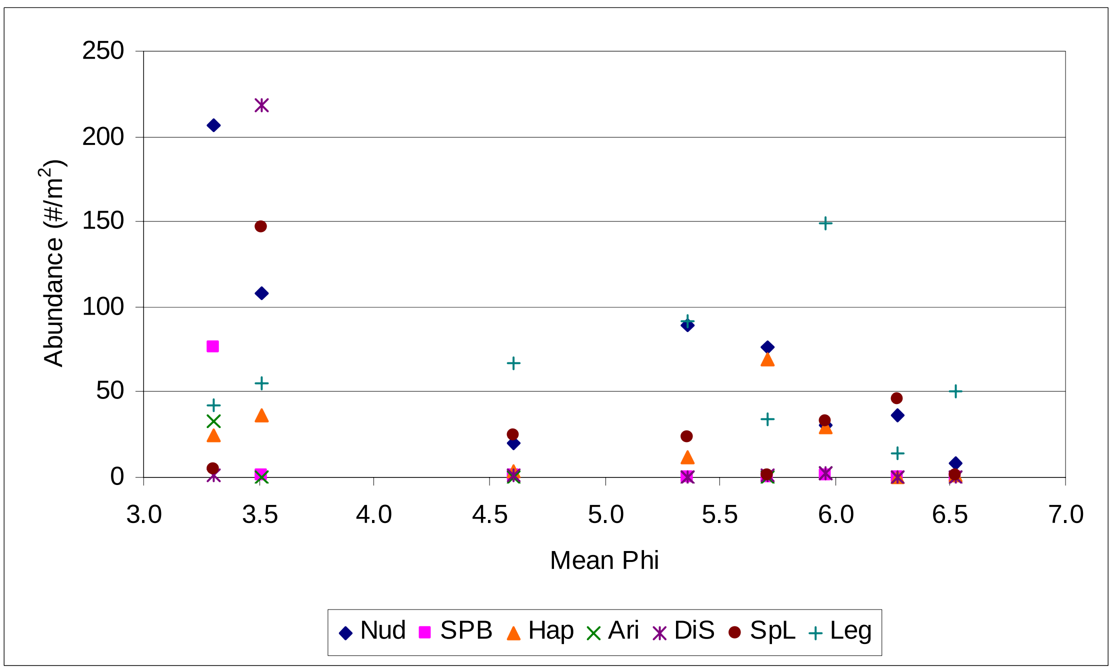


Figure 5-29. Association between infaunal abundance for selected taxa and sediment mean phi based on 1998 Massachusetts Bay Farfield data. Species abbreviations are as listed in Table 5-4.

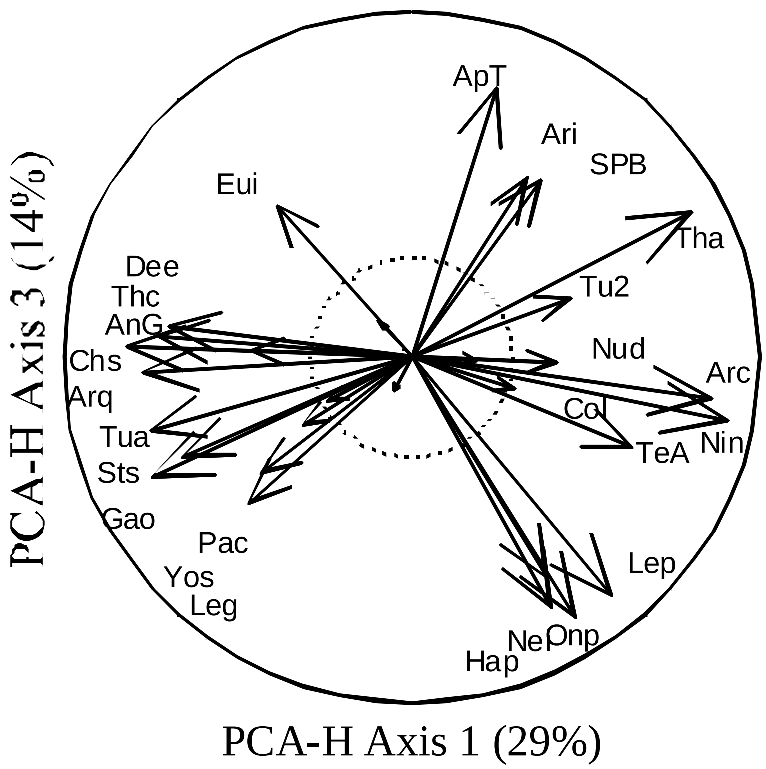
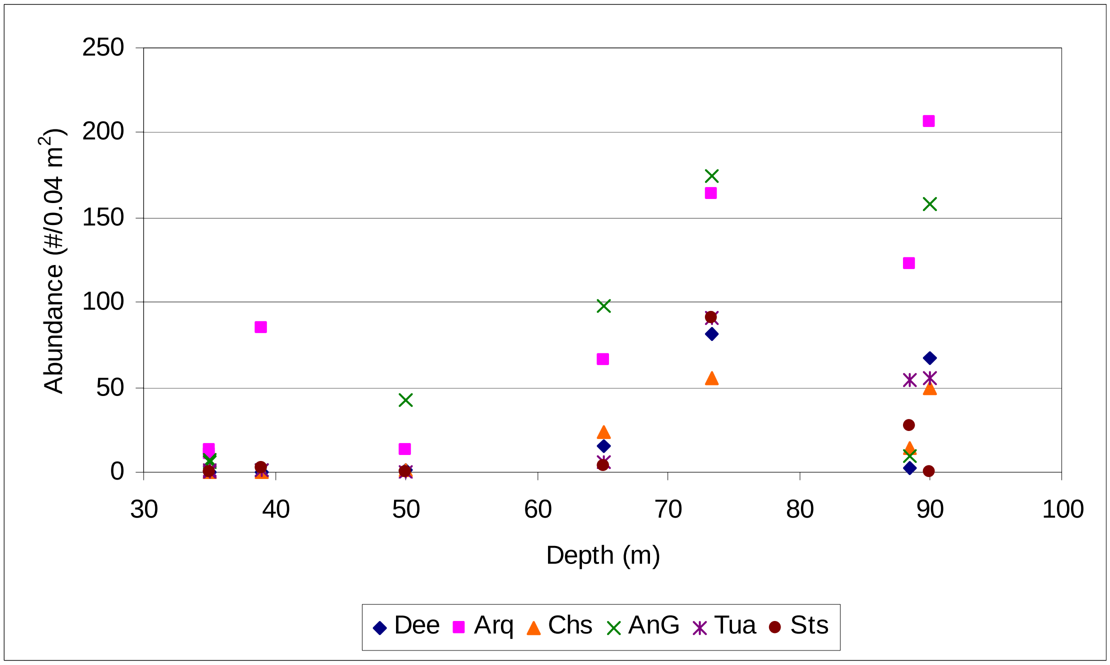


Figure 5-30. Gabriel covariance biplot, axes 1 versus 3, for the 1998 Massachusetts Bay Farfield data.



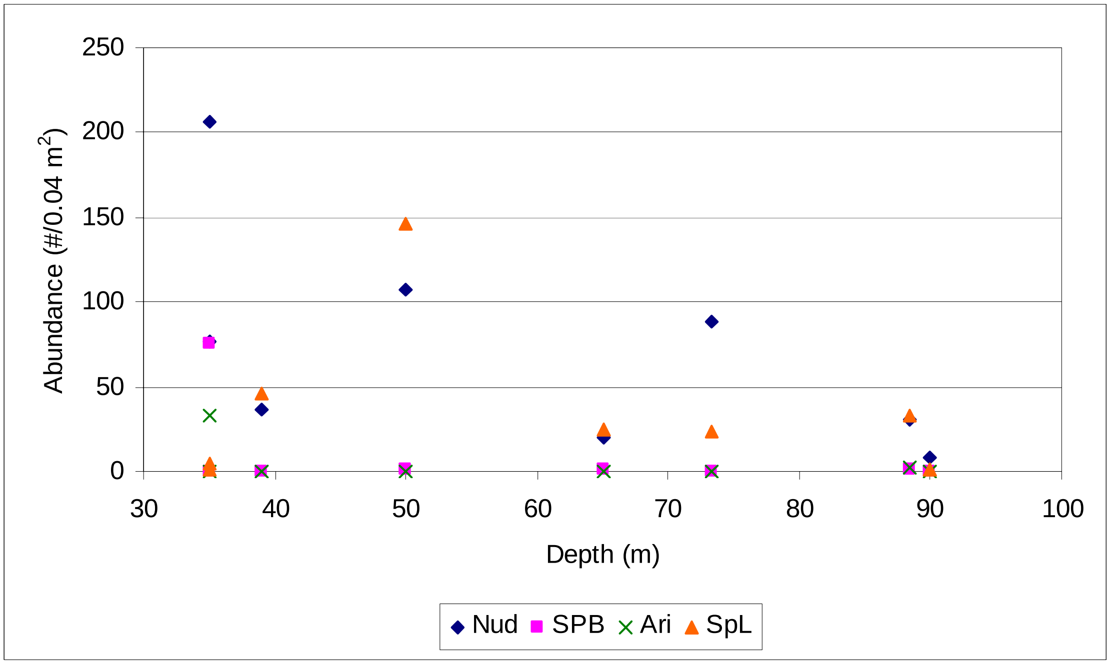
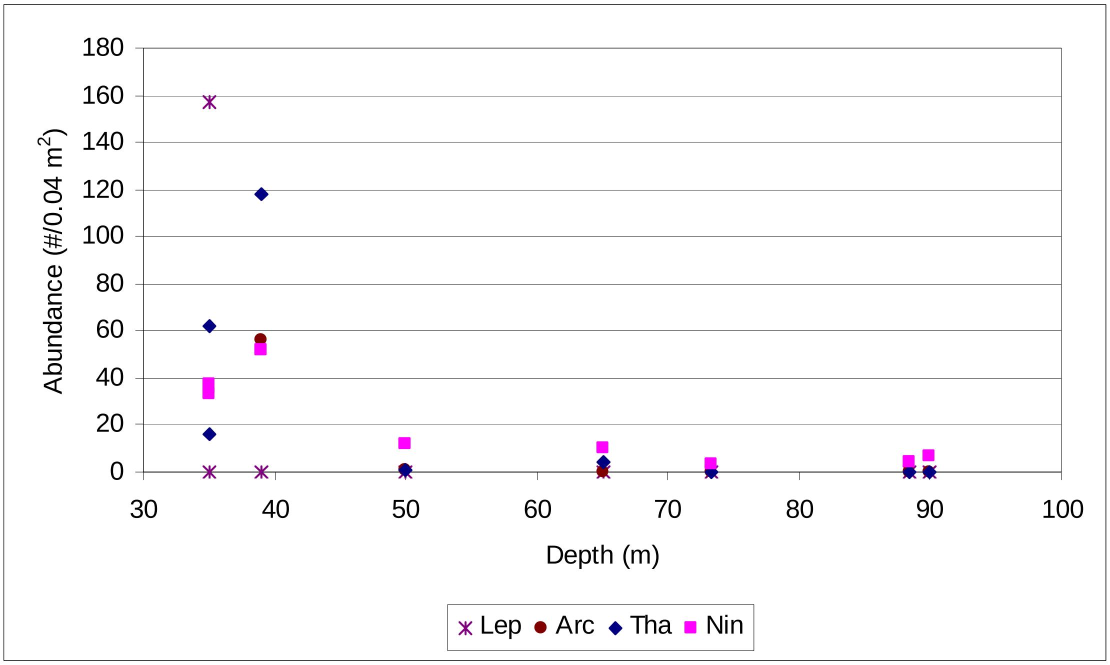


Figure 5-31. Association between infaunal abundance for selected taxa and station depth based on 1998 Massachusetts Bay Farfield data. Species abbreviations are as listed in Table 5-4.



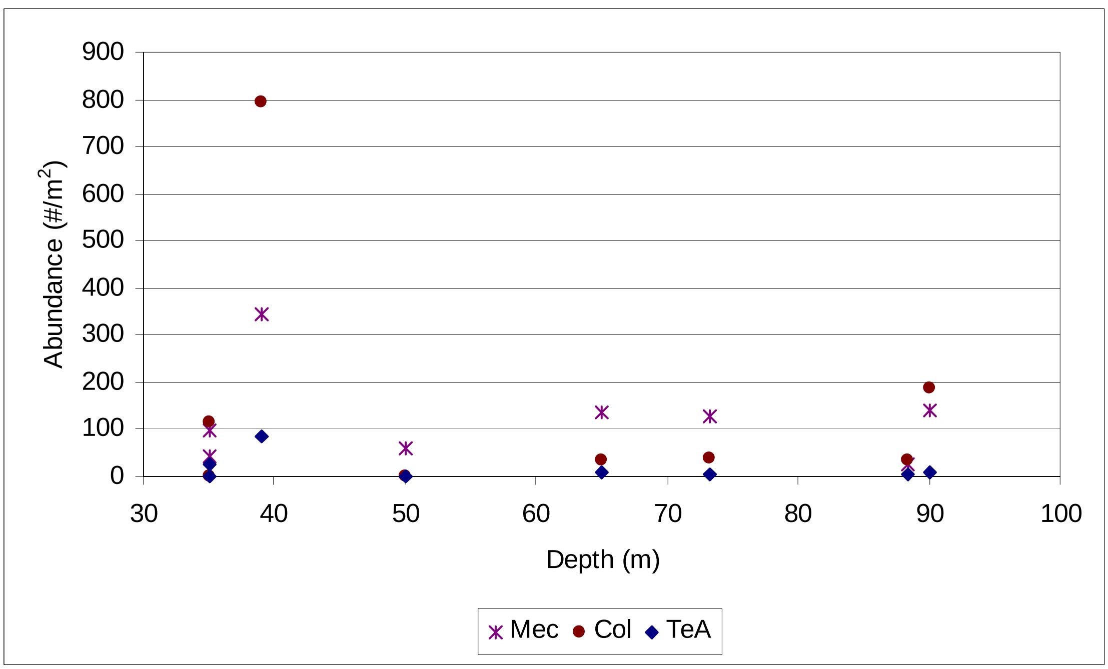


Figure 5-32. Association between infaunal abundance for selected taxa and station depth based on 1998 Massachusetts Bay Farfield data. Species abbreviations are as listed in Table 5-4.

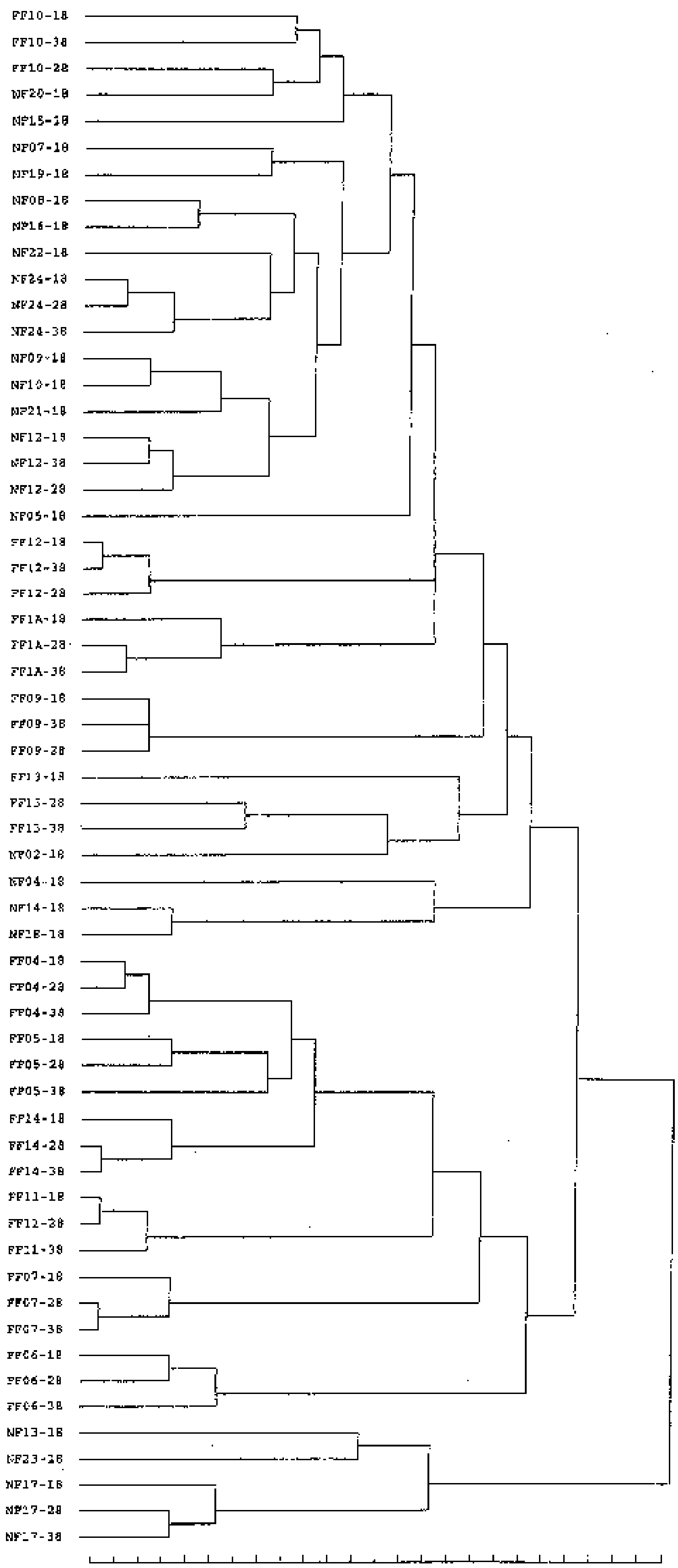


Figure 5-33. Dendogram resulting from CNESS cluster Analysis of the 1998 combined Nearfield/ Farfield data set.

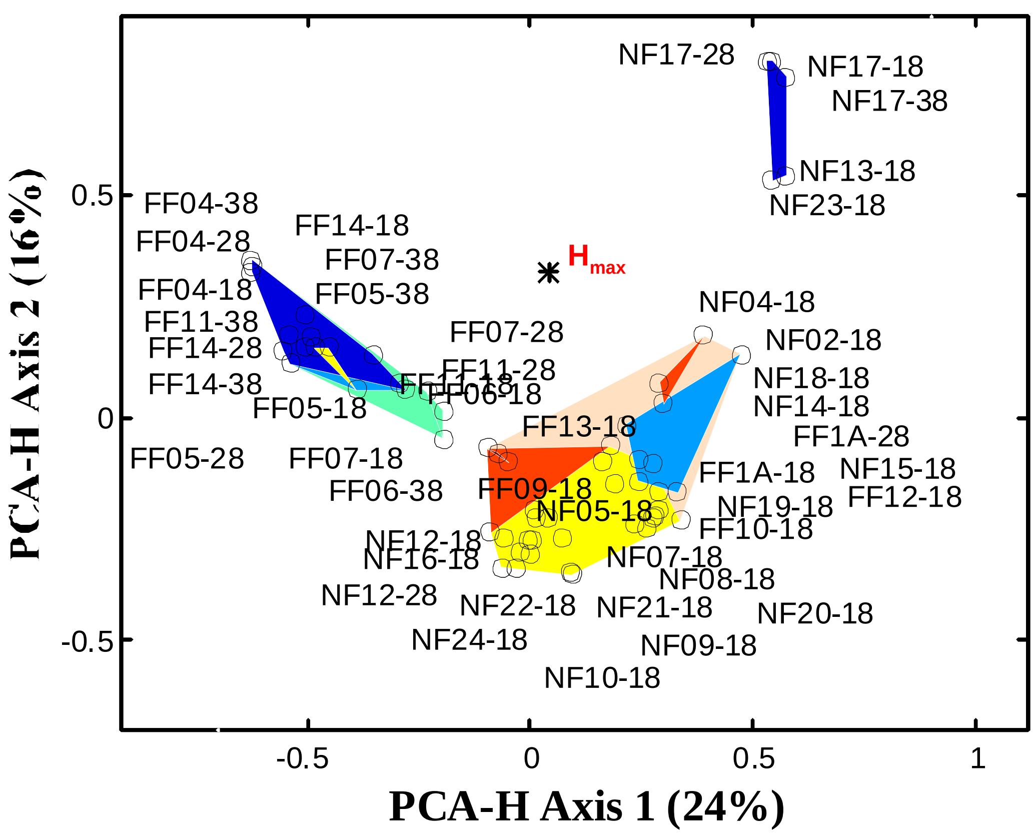


Figure 5-34. Metric scaling plot of CNESS distances, axes 1 versus 2, among combined Nearfield/Farfield stations sampled in 1998. Results of the CNESS cluster analysis are shown as convex hulls.

Table 5-5. The 43 most important contributors to CNESS distances among all 59 1998 Massachusetts Bay samples. "Cont" is the contribution to overall CNESS distances, "Total Cont" is the cumulative amount of CNESS variation explained by species (91% by the top 43 species). The final columns indicate the contribution of each species to each of the first six PCA-H axes.

No.	Species	Spp. Code	Cont.	Total Cont.	PCA-H Axis					
					1	2	3	4	5	6
1	*Euchone incolor*	Eui	6	6	17	0	7	14	0	1
2	*Prionospio steenstrupi*	Prs	5	12	3	15	11	0	7	4
3	*Cossura longocirrata*	Col	5	16	10	3	8	8	5	0
4	*Spiophanes bombyx*	SPB	5	21	12	5	0	0	2	5
5	*Aricidea catherinae*	Arc	5	26	3	5	4	5	1	11
6	*Mediomastus californiensis*	Mec	4	30	2	14	8	3	0	0
7	*Aricidea quadrilobata*	Arq	4	34	10	3	2	0	5	1
8	*Nucula delphinodonta*	Nud	4	37	0	1	11	9	6	3
9	*Polygordius sp. A*	PoA	3	41	5	10	0	0	0	2
10	*Levinsenia gracilis*	Leg	3	44	4	1	6	0	3	5
11	*Anobothrus gracilis*	AnG	3	47	6	2	2	1	1	1
12	*Spio limicola*	SpL	3	50	0	3	5	9	3	4
13	*Tharyx acutus*	Tha	3	53	1	4	6	3	1	1
14	*Exogone hebes*	Exh	3	55	3	2	1	5	7	4
15	*Monticellina baptisteae*	Mob	2	58	1	5	2	1	3	7
16	*Dipolydora socialis*	DiS	2	60	0	1	7	3	8	0
17	*Owenia fusiformis*	Owf	2	63	1	1	1	0	5	4
18	*Ninoe nigripes*	Nin	2	65	0	6	2	0	0	9
19	*Aphelochaeta marioni*	Apm	2	67	0	2	0	6	2	0
20	*Pseudunciola obliquua*	Pso	2	69	1	5	0	0	0	4
21	*Unciola inermis*	Uni	2	71	1	1	0	1	1	3
22	*Nephtys cornuta*	NEC	2	72	0	0	0	1	3	5
23	*Tubificoides apectinatus*	Tua	2	74	1	0	1	1	5	3
24	*Exogone verugera*	Exv	1	75	1	0	0	2	5	4
25	*Leptocheirus pinguis*	Lep	1	77	0	0	0	8	4	2
26	*Phyllodoce mucosa*	phm	1	78	2	1	0	0	0	0
27	*Harpinia propinqua*	Hap	1	79	0	0	2	7	2	2
28	*Onoba pelagica*	Onp	1	80	1	0	0	3	2	1
29	*Dentalium entale*	Dee	1	81	1	1	0	0	1	0
30	*Crassicorophium crassicorne*	Crc	1	82	1	3	0	0	0	1
31	*Apistobranchus typicus*	ApT	1	83	1	0	1	0	0	0
32	*Grania postclitello longiducta*	Grl	1	83	0	1	0	0	0	0
33	*Tubificidae sp. 2 (Blake 1992)*	Tu2	1	84	0	0	2	0	1	0
34	*Yoldia sapotilla*	Yos	1	85	1	0	1	0	0	0
35	*Sternaspis scutata*	Sts	1	86	1	0	1	0	1	0
36	*Protomedeia fasciata*	Prf	1	86	0	0	0	0	1	4
37	*Crenella decussata*	Crd	1	87	0	0	0	0	1	2
38	*Thyasira gouldi*	Thg	1	88	1	0	1	0	0	0
39	*Chaetozone setosa MB*	Chs	1	88	1	1	0	0	1	0
40	*Maldane sarsi*	Mas	1	89	0	0	0	0	0	1
41	*Scoletoma hebes*	Sch	1	89	0	0	0	0	2	0
42	*Galathowenia oculata*	Gao	1	90	1	0	2	0	1	0
43	*Hiatella arctica*	Hia	1	91	1	0	0	0	0	1

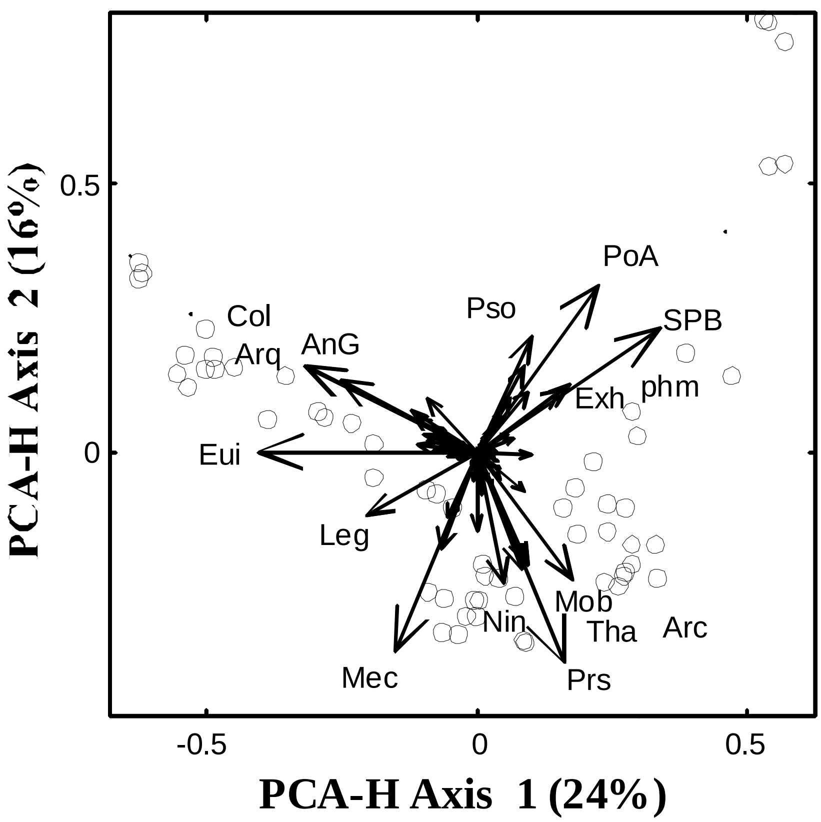


Figure 5-35. Gabriel Euclidean distance biplot, axes 1 versus 2, for all 1998 Massachusetts Bay samples showing those species that control the orientation of samples shown in Figure 5-33. Species codes are as listed in Table 5-5. Open circles represent the spatial pattern of samples shown in Figure 5-33.

6. 1998 HARD-BOTTOM STUDIES

[by Barbara Hecker]

6.1 Methods

Still photographs and video coverage were obtained at all 23 waypoints (Table 6-1). The photographic coverage ranged from 14–28 minutes of video footage and 24–33 still photographs at each waypoint. A total of 695 still photographs was used for the following data analysis.

Table 6-1. Photographic coverage at locations surveyed during the 1998 Nearfield hard-bottom survey.

Transect	Waypoint	Location on drumlin	Depth (feet)	Depth (meters)	Video (min)	Stills (# frames)
1	1	Top	88	27	23	33
	2	Top	86	26	20	31
	3	Top	80	24	21	30
	4	Top	82	25	21	31
	5	Flank	99	30	20	29
2	1	Top	105	32	20	24
	2	Top	84	26	19	32
	3	Top	86	26	21	32
	4	Flank	99	30	21	29
	5	Low/diffuser #2	117	35	26	31
4	1	Flank	116	35	20	31
	2	Flank	110	33	22	30
	3	Flank	95	29	21	29
4&6	4	Top	74	23	21	32
6	1	Flank	105	32	21	29
	2	Flank	102	31	14	31
7	1	Top	81	25	20	29
	2	Top	83	25	21	29
8	1	Top	78	24	21	31
	2	Top	81	25	19	32
9	1	Top	85	26	20	30
10	1	Top	96	29	20	32
Diffuser #44			111	33	28	28

6.1.1 Visual Analyses

Each 35-mm slide was projected and analyzed for sea-floor characteristics (i.e., substratum type and size class, and amount of sediment drape) and biota. A summary of the 1998 slide analyses is included in Appendix E-1. Most recognizable taxa were recorded and counted. Several very abundant taxa (for which accurate counts were impossible to obtain) were assessed in terms of percent cover or relative abundance. The abundance of the encrusting coralline alga *Lithothamnion* was assessed as rough estimates of percent cover. Several other taxa , *Asparagopsis hamifera* (a filamentous red alga), *Rhodymenia palmata* (dulse), 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 of the local flora and fauna (Martinez and Harlow, 1994; Weiss, 1995). Many of the encrusting species could not be identified to species. Most of them were assigned to descriptive categories (e.g., "orange-tan encrusting"); however, each of these descriptive categories possibly includes several species. Additionally, some species might be split between two similar descriptive categories (e.g., "orange encrusting" and "orange lumpy encrusting"), as a result of differences in viewing angles and lighting. Due to high relief in many of the habitats surveyed, all reported abundances should be considered to be extremely conservative. In many areas, only part of the surfaces of large boulders were visible; thus, actual faunal abundances in these areas are probably much higher than the counts indicate.

The video tapes were viewed to provide additional information about uniformity of the habitat at each of the sites. A summary of the 1998 video analyses is included in Appendix E-2. Notes on habitat relief, substrate size classes, and relative amount of sediment drape were recorded. Rare, large, and clearly identifiable organisms were enumerated. With the exception of the cunner *Tautogolabrus adspersus* (which was frequently very abundant), all fish were enumerated. Counts of abundant motile organisms and all encrusting organisms were not attempted due to the large amount of time accurate counts would require and the general lack of resolution of the video footage.

6.1.2 Data Analysis

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 differences in the number of slides from each site. Hydroids and small barnacles and/or spirorbids were omitted from the data analysis because they consisted of several species, could not be accurately assessed, and it was impossible to tell if they were alive. General taxonomic categories (i.e., fish, sponge, etc.) were used for estimates of total faunal abundances, but were omitted from community analysis. Only taxa with abundances of ten or more in the entire data set were retained for community analysis. This process resulted in 42 out of the original 81 taxa being retained. Juvenile and adult *Asterias vulgaris* (northern sea stars) and white and pink *Halocynthia pyriformis* (sea peach tunicates) were pooled.

Hierarchical classification was used to examine the data obtained from the still photographs. This analysis consisted of a pair wise comparison of the species composition of all waypoints using the percent similarity coefficient. This coefficient was chosen because it relies on the relative proportion that each species contributes to the faunal composition, and as a result is 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.

6.2 Results and Discussion

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

6.2.1 Distribution of Habitat Types

The sea floor on the drumlin tops usually consisted of a mix of glacial erratics in the boulder and cobble size categories. These areas frequently had numerous boulders interspersed with cobbles, and were generally characterized by moderate to high relief. Several exceptions to this pattern of moderate to high relief on the tops of drumlins were noted. The sea floor at three sites in the middle of the drumlin directly north of the diffuser (T1-1, T1-2, and T2-1) consisted mainly of cobbles and/or gravel and had moderately low relief. Two of the reference sites southwest of the diffuser (T8-1 and T8-2) also had moderately low relief, consisting of a cobble pavement occasionally interrupted by boulders. In contrast, the sea floor at the other southwestern reference site (T10-1) mostly consisted of large boulders and was characterized by high relief. Sediment drape on the tops of drumlins was variable. Some areas had mostly clean rock surfaces (T1-3, T1-4, T8-1, and T8-2), while other areas had a moderate (T2-1, T2-2, T2-3, and T9-1) or thick (T10-1) sediment drape. The sea floor on the flanks of the drumlins frequently consisted of a low-relief cobble pavement, interrupted occasionally by patches of boulders or gravel. Sediment drape in these regions ranged from a moderately light drape (T4-3 and T6-2) to a moderately heavy mat-like cover (T4-2 and T6-1). The sea floor in the vicinity of the diffuser (T2-5 and Diffuser #44) consisted of angular rocks in the large cobble to small boulder category. Sediment drape near the diffusers tended to be moderate to heavy.

6.2.2 Distribution and Abundance of Epibenthic Biota

Eighty-four taxa were seen during the visual analyses of the 1998 Nearfield hard-bottom survey still photographs and video tapes (Table 6-2). Eighty one of these taxa were seen on the still photographs. Taxonomic counts or estimates of abundances included 8,479 algae, 14,505 invertebrates, and 1,144 fish (Table 6-3). The two most abundant taxa observed were two algae, the encrusting coralline red alga *Lithothamnion* spp. and a red filamentous alga *Asparagopsis hamifera*, with abundances of 5,183 individuals and 2,443 individuals, respectively. The abundances of both of these algae were estimated and should be viewed as being very conservative. Two other algae, the dulse *Rhodymenia palmata* and the shot-gun kelp *Agarum cribosum*, also were seen during this survey. The most abundant invertebrates observed on the still photographs were: juveniles and adults of the northern sea star *Asterias* (2,888 and 348 individuals, respectively), the horse mussel *Modiolus modiolus* (1,764 individuals), the sea pork tunicate *Aplidium* spp. (1,283 individuals), the brachiopod *Terebratulina septentrionalis* (695 individuals), the blood sea star *Henrecia sanguinolenta* (683 individuals), and the frilled anemone *Metridium senile* (598 individuals). Other common invertebrate inhabitants of the drumlins included: barnacles (582 individuals), the scarlet holothurian *Psolus fabricii* (494 individuals), the red soft coral *Gersemia rubiformis* (395 individuals), the green sea urchin *Strongylocentrotus droebachiensis* (300 individuals), and many sponges and encrusting organisms. The most abundant fish observed in the still photographs was the cunner *Tautogolabrus adspersus* (1,109 individuals).

Lithothamnion was the most abundant and widely distributed taxa encountered during the survey. This encrusting coralline alga was seen at all waypoints. Its mean areal coverage ranged from <1% at T2-5, T4-1, T10-1 and Diffuser #44, to 82% at T1-4. *Lithothamnion* was the dominant inhabitant in drumlin top areas that had minimal sediment drape on the rock surfaces. In contrast, two upright algae, *Asparagopsis hamifera* and dulse frequently dominated areas that had high relief and a moderate to heavy sediment drape. The reduced percent cover of *Lithothamnion* in areas supporting high abundances of upright algae appeared to be related to fine particles being trapped by the holdfasts of the upright algae and blanketing the rock surfaces. In areas with heterogeneous substrate characteristics, *Asparagopsis* and dulse frequently dominated the tops of boulders, while *Lithothamnion* dominated the cobbles and smaller boulders in between.

Table 6-2. Taxa observed during the 1998 Nearfield hardbottom survey.

Taxon	Common Name	Taxon	Common Name
Algae		bivalve	
Lithothamnion sp.	coralline algae	*Modiolus modiolus*	horse mussel
Asparagopsis hamifera	filamentous red algae	*Placopecten magellanicus*	sea scallop
Rhodymenia palmata	dulse	*Arctica islandica*	quahog
Agarum cribrosum	shotgun kelp	bivalve siphons	
Fauna		Crustaceans	
Sponges		*Balanus* spp.	acorn barnacle
sponge		*Cancer* spp.	Jonah or rock crab
Aplysilla sulfurea	sponge (yellow encrust)	*Homarus americanus*	lobster
Halichondria panicea	crumb-of-bread sponge	Echinoderms	
Haliclona spp.	finger sponge	*Strongylocentrotus droebachiensis*	green sea urchin
Melonanchora elliptica	warty sponge	starfish	
Suberites spp.	fig sponge	small white starfish	juvenile *Asterias*
white divided	sponge on brachiopod	*Asterias vulgaris*	northern sea star
orange/tan encrusting		*Henricia sanguinolenta*	blood star
orange encrusting		*Crossaster papposus*	spiny sunstar
pale orange encrusting		*Pteraster militaria*	winged sea star
gold encrusting		*Porania insignis*	badge star
tan encrusting		*Ophiopholis aculeata*	daisy brittle star
pink fuzzy encrusting		*Psolus fabricii*	scarlet holothurian
dark red/brown encrusting		Tunicates	
white translucent		tunicate	
cream encrusting		*Aplidium* spp.	sea pork tunicate
rust-cream encrusting		*Boltenia ovifera*	stalked tunicate
white chalice		*Dendrodoa carnea*	drop of blood
filamentous white encrusting		*Didemnum albidum*	northern white crust
Encrusting organisms		*Halocynthia pyriformis*	sea peach tunicate
general encrusting		white globular tunicate	
white crust		white *Halocynthia pyriformis*	
Coelenterates		Bryozoans	
hydroid		bryozoan	
Corymorpha pendula	solitary hydroid	*Crisia* spp.	
Obelia geniculata	hydroid	red crust bryozoan	
anemone		Miscellaneous	
Fagesia lineata	lined anemone	*Myxicola infundibulum*	slime worm
Metridium senile	frilly anemone	spirorbids	
Urticina felina	northern red anemone	*Terebratulina septentrionalis*	northern lamp shell
Cerianthus borealis	northern cerianthid	Fish	
Gersemia rubiformis	red soft coral	fish	
Mollusks		*Gadus morhua*	cod
gastropod		*Hemitripterus americanus*	sea raven
Tonicella marmorea	mottled red chiton	*Myoxocephalus* spp.	sculpin
Crepidula plana	flat slipper limpet	*Macrozoarces americanus*	ocean pout
Notoacmaea testudinalis	tortoiseshell limpet	*Pholis gunnellus*	rock gunnel
Buccinum undatum	waved whelk	*Pleuronectes americanus*	winter flounder
Busicotypus canaliculatus	channeled whelk	*Sebastes fasciatus*	rose fish
Neptunea decemcostata	ten-ridged whelk	*Tautogolabrus adspersus*	cunner
nudibranch			

Table 6-3. List of taxa seen on still photographs taken during the 1998 Nearfield hardbottom survey, arranged in order of abundance.

Taxon	Count	Taxon	Count
Algae		tan encrusting sponge	13
Lithothamnion spp.	5183[1]	*Ophiopholis aculeata*	13
Asparagopsis hamifera	2443[1]	*Arctica islandica*	12
Rhodymenia palmata	754	*Crepidula plana*	10
Agarum cribrosum	99	sponge	8
Total algae	**8479**	rust-cream encrusting sponge	7
		Corymorpha pendula	7
Invertebrates		*Crossaster papposus*	7
juvenile *Asterias* spp.	2888	*Haliclona* spp.	6
Modiolus modiolus	1764	dark red/brown encrusting sponge	5
Aplidium spp.	1283	filamentous white encrusting sponge	5
Terebratulina septentrionalis	695	*Notoacmaea testudinalis*	4
Henricia sanguinolenta	683	*Cancer* spp.	4
Metridium senile	598	*Homarus americanus*	3
Balanus spp.	582	*Pteraster militaria*	3
orange/tan encrusting sponge	535	*Buccinum undatum*	2
orange encrusting sponge	504	nudibranch	2
Psolus fabricii	494	bivalve siphons	2
pale orange encrusting sponge	431	*Boltenia ovifera*	2
white translucent sponge	429	*Melonanchora elliptica*	1
general encrusting organism	410	white encrusting organism	1
Gersemia rubiformis	395	*Urticina felina*	1
Asterias vulgaris	348	*Fagesia lineata*	1
Strongylocentrotus droebachiensis	300	gastropod	1
Didemnum albidum	273	*Neptunea decemcostata*	1
white divided sponge on brachiopod	249	*Busycon canaliculatum*	1
pink fuzzy encrusting sponge	228	starfish	1
Suberites spp.	181	*Porania insignis*	1
Dendrodoa carnea	180	white globular tunicate	1
Aplysilla sulfurea	153	Hydroids	*
Myxicola infundibulum	140	Spirorbid/barnacle complex	*
red crust bryozoan	109	**Total Invertebrates**	**14505**
Halocynthia pyriformis	104		
cream encrusting sponge	87	**Fish**	
Crisia spp.	78	*Tautogolabrus adspersus*	1109
Tonicella marmorea	77	*Pleuronectes americanus*	14
Obelia geniculata	62	fish	7
Halichondria panicea	52	*Myoxocephalus spp.*	7
anemone	47	*Macrozoarces americanus*	2
white *Halocynthia pyriformis*	44	*Gadus morhua*	2
white chalice sponge	34	*Hemitripterus americanus*	1
Placopecten magellanicus	23	*Sebastes fasciatus*	1
bryozoan	17	*Pholis gunnellus*	1
gold encrusting sponge	14	**Total fish**	**1144**
Ceriantthus borealis	14		

*not counted
[1]estimated

Several of the dominant invertebrate taxa also exhibited wide distributional patterns. The northern sea star *Asterias vulgaris* was found at all of the sites. Juvenile *Asterias* were usually much more abundant than adults. An exception to this was noticed on the head of Diffuser #44, where adults outnumbered juveniles by 3 to 1. In general, adult *A. vulgaris* were most abundant on sediment and cobble substrates, whereas juveniles were most abundant on boulders. The highest abundances of juvenile *A. vulgaris* were found at T1-2, T1-3, T1-4, and T4-4 and the lowest abundances were found at T8-1 and T8-2. The horse mussel *Modiolus modiolus* was also very widely distributed, occurring at all but two sites (T4-1 and Diffuser #44). It was most abundant on the top of drumlins, where large numbers frequently were observed nestled among cobbles and at the bases of boulders (T1-3, T1-2, T1-4, and T4-4). Because of their cryptic nature of being nestled in among rocks and frequently being almost totally buried, the observed mussel abundances should be considered very conservative. The numbers of mussels definitely would be underestimated in areas of high-relief, because the bases of larger boulders frequently were not visible in the images. The sea pork tunicate *Aplidium* also was found at all but two of the sites and was most abundant at T2-3, T2-4, T8-1, and T8-2. The blood sea star *Henrecia sanguinolenta* was observed at all of the sites, and was most abundant on boulders in high-relief areas (T10-1 and T4-4).

Several other abundant taxa exhibited much more restricted distributions. Three of these species appeared to be restricted primarily to large boulders. The brachiopod *Terebratulina septentrionalis* was found at 13 sites, but was only seen in high abundances at 4 of them (T2-3, T2-4, T4-4, and T9-1). This species appeared to be restricted to the sides of large boulders where it might be protected from heavy sediment loading. Another species that showed a marked occurrence on large boulders was the frilled anemone *Metridium senile*. This anemone was found at 16 sites, but was abundant at only 3 of them (T1-3, T2-3, and Diffuser #44). It usually was seen on the tops of large boulders and on the diffuser head. The third species that appeared to be restricted to large boulders was the soft coral *Gersemia rubiformis*, which had a very restricted distribution. It was seen only at T10-1, where it dominated the fauna attached to the large boulders characteristic of this site.

The green sea urchin *Strongylocentrotus droebachiensis* showed a habitat preference that appeared to be related to food availability rather than specific substrate characteristics. This urchin was widely distributed, but was only found in high abundances in regions that had a high percent cover of *Lithothamnion* (T1-2, T1-3, T1-4, and T4-4), on which it grazes (Sebens 1986). The red holothurian *Psolus fabricii* also was widely distributed. This holothurian was found at 19 sites, but was abundant at only 3 of them (T1-3, T1-4, and T8-2). Reasons for its high abundance at some sites, but not at others, were not readily apparent.

Encrusting invertebrate taxa generally were most abundant in moderate to high relief areas that had a light to moderate sediment drape on the rock surfaces. This is not surprising because most juveniles of attached taxa require sediment-free surfaces for settlement. Additionally, clean rock surfaces are indicative of strong currents that could provide adequate food supplies for suspension-feeding organisms. Large substrate types also provide a physically more stable environment than small types as they are more resistant to mechanical disturbance.

The fish fauna was dominated by the cunner *Tautogolabrus adspersus*, which was observed at all 23 waypoints. This fish was most abundant in high-relief areas, where it tended to congregate among large boulders (T1-3, T1-4, T7-1, T7-2, and T10-1). In areas of heterogeneous habitat types, *T. adspersus* frequently was seen only in the vicinity of boulders. Fourteen individuals of the winter flounder *Pleuronectes americanus* also were seen. They were usually seen in areas of low relief. The other six species of fish seen were too sparse to determine their habitat preferences or requirements.

6.2.3 Community Structure

Classification of the 23 waypoints and 42 taxa (retained for analysis) defined three clusters of stations and three outlier areas (Figure 6-1). The three clusters further divided into more cohesive subgroups. The first cluster (Cluster 1) consisted mainly of moderate to high-relief drumlin top areas that had variable sediment drape. The second cluster (Cluster 2) consisted of drumlin top and flank areas that had light to moderately-light sediment drape. The third cluster (Cluster 3) consisted mainly of drumlin flank areas that had low to moderately-low relief and moderately-heavy sediment drape. The three outlier areas had no common habitat characteristics. The clustering structure appeared to be determined by a combination of drumlin topography, habitat relief, and sediment drape. Habitat characteristics and percent composition of dominant taxa for each of the cluster groups are presented in Table 6-4.

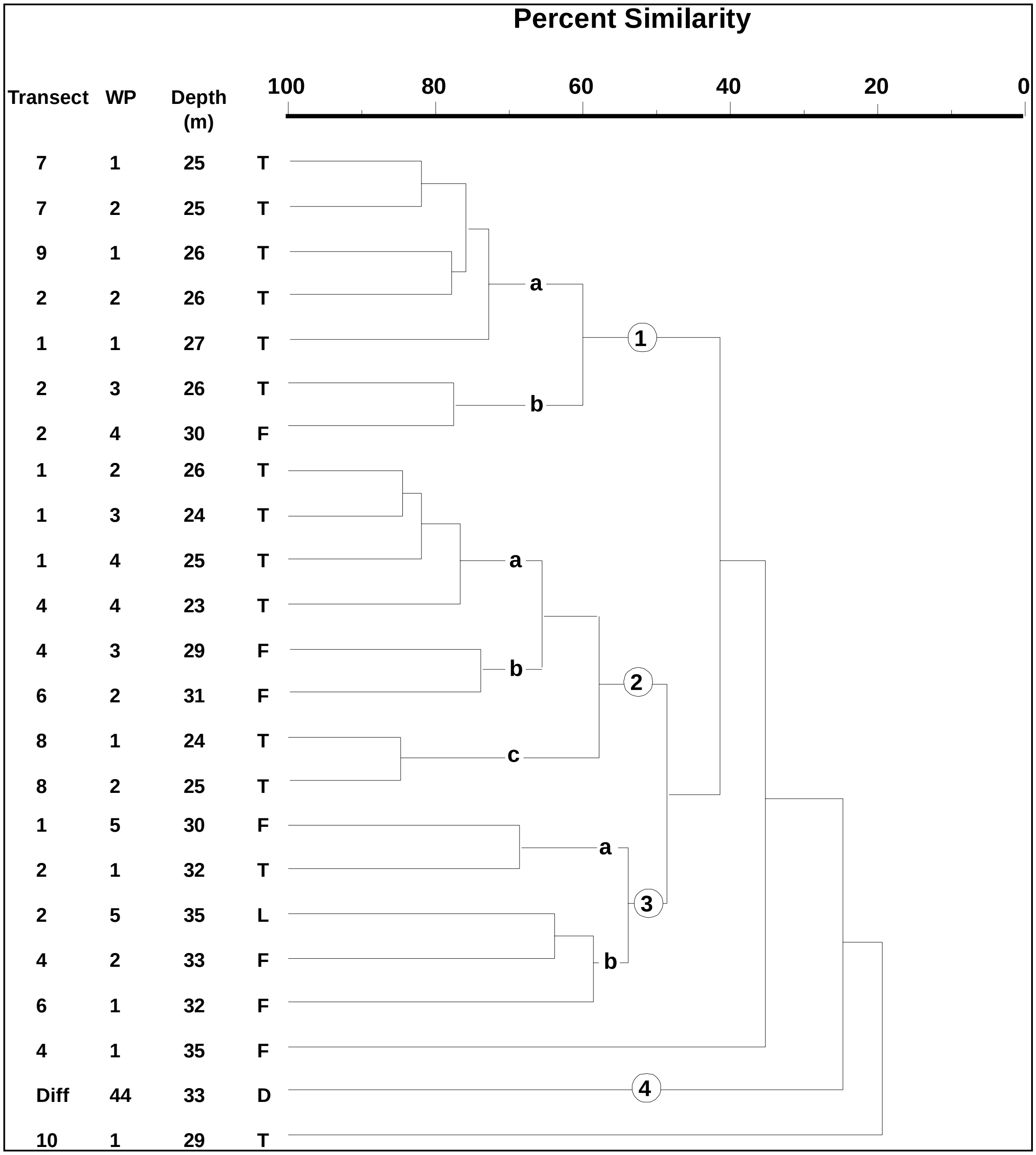


Figure 6-1. Cluster analysis of data collected from still photographs taken during the 1998 hard-bottom survey.

Table 6-4. Habitat characteristics and range of percent composition of selected taxa in the clusters defined by classification analysis. Ranges of algae, invertebrates, and fish are means of average number per picture.

	1		2			3			4	
	a	**b**	**a**	**b**	**c**	**a**	**b**	**4-1**	**Diffuser # 44**	**10-1**
Depth	24-27	26-30	22-26	29-31	24-24	30-32	32-35	35	32	27
Habitat relief[a]	M-MH	M-MH	LM-MH	LM	LM	L-LM	L-LM	L		H
Sediment Drape[b]	l-mh	m-mh	l	Lm	l	lm-mh	mh	m	h	h
Location[c]	T	T&F	T	F	T	T&F	F&L	F		T
Asparagopsis hamifera	**22-32**	**11-18**	0-1	-	-	-	-	-	-	3
Rhodymenia palmata	**2-11**	**6-7**	-	-	-	-	-	-	-	1
Lithothamnion spp.	15-20	9-10	**25-34**	**34-45**	**41-48**	12-26	4-18	17	-	-
Lithothamnion spp. (% cover)	33-54	18-39	77-82	45-56	65-75	9-39	1-9	1	-	-
Asterias vulgaris (adult & juvenile)	8-14	6-11	**16-22**	**16-17**	2-3	**15-19**	**27-43**	**47**	**28**	4
Modiolus modiolus	3-11	2-3	**13-19**	0-1	5-9	1-2	0-3	-	-	2
Aplidium spp.	0-4	**12-16**	0-3	0-11	**18-23**	11-21	1-5	-	1	1
Strongylocentrotus droebachiensis	-	-	**3-4**	1-2	1-2	-	-	-	-	-
Placopecten magellanicus	-	-		-	-	-	0-1	**20**	-	-
Metridium senile	0-1	0-9	0-5	-	-	0-1	-	-	**45**	-
Gersemia rubiformis	-	-	-	-	-	-	-	-	-	**38**
Tautogolabrus adspersus	2-12	2-3	3-7	2-3	0-2	1	1-6	1	3	**14**
Algae	20-29	12-22	15-17	9-12	13-14	2-5	1-2	<1	<1	1
Encrusting invertebrates	6-10	16-17	5-7	6-8	9-10	8-8	4-7	<1	<1	13
Sessile invertebrates	3-11	9-16	11-20	2-4	5-6	2-3	1-3	<1	10	15
Motile invertebrates	4-6	5-6	11-19	6-6	2	3-4	4-6	2	6	5
Fish	1-6	1-2	2	<1	<1	<1	<1	<1	<1	5
Total	38-54	44-61	45-64	26-27	29-32	16-20	13	3	17	38

Key

[a] Habitat relief: L= low, LM= moderately low, M= moderate, MH= moderately high, H= high

[b] Sediment drape: l= light, lm= moderately light, m= moderate, mh= moderately heavy, h= heavy

[c] Location: T= drumlin top, F= drumlin flank

The encrusting coralline alga *Lithothamnion* was a common inhabitant of most of the areas comprising the first two cluster groups. Differences among the areas in these two cluster groups were related mainly to the relative proportion of encrusting and upright algae. The areas in Cluster 1 were dominated by upright algae, *Asparagopsis hamifera* and *Rhodymenia palmata*, whereas the areas in Cluster 2 were dominated by *Lithothamnion*. This is not surprising because the sea floor of all except one area in Cluster 1 had moderate to high relief, and upright algae appeared to be more common on the tops of boulders. Differences among the areas reflected slight differences in the composition of the communities inhabiting them. The areas in Subgroup 1a supported higher abundances of *Asparagopsis hamifera*, and the two areas in Subgroup 1b supported higher abundances of the tunicate *Aplidium*. Algae and encrusting or sessile invertebrates, were relatively abundant in all of the areas in Cluster 1.

The areas in Cluster 2 were characterized by either less, or more variable, habitat relief than the areas in Cluster 1. Additionally, the areas in Cluster 2 also had less sediment drape. All of the areas in this cluster were dominated by *Lithothamnion* and supported few, if any, other algae. However, the faunal composition of the communities inhabiting these areas varied considerably. The drumlin top areas in Subgroup 2a supported high abundances of *Modiolus modiolus*, whereas the two drumlin top areas in Subgroup 2c supported high abundances of *Aplidium*. The two drumlin flank areas in Subgroup 2b did not have a distinctive fauna, they supported high abundances of the sea star *Asterias vulgaris* as did the Subgroup 2a areas. The drumlin top areas in Subgroup 2a were inhabited by moderately high numbers of a variety of sessile invertebrates and relatively high numbers of fish. In contrast, the areas in Subgroups 2b and 2c generally supported lower abundances of algae, invertebrates, and fish.

Cluster 3 consisted mostly of drumlin flank areas that had low to moderately-low relief and moderately-heavy sediment drape. All of these areas supported quite low abundances of algae and fish, and low to moderate abundances of invertebrates. *Asterias vulgaris* was the most common faunal inhabitant of most of the areas in this cluster. *Lithothamnion* and *Aplidium* were more abundant in areas in Subgroup 3a and *Asterias vulgaris* was more abundant in the areas in Subgroup 3b.

The three outlier areas supported very few, if any, algae. The T4-1 area consisted mainly of a low-relief cobble and gravel pavement that was quite depauperate. Here, occasional *Asterias vulgaris* and sea scallops *Placopecten magellanicus* were the main inhabitants. In contrast, the large boulders of the T10-1 area supported many invertebrates and fish. The fauna at this site was dominated by the soft coral *Gersemia rubiformis*, which was not seen at any of the other sites. The high-relief of this area also provided suitable habitat for numerous cunner. The other outlier area, the head of Diffuser #44, was inhabited mainly by *Metridium senile* and *Asterias vulgaris*.

7. PROGRAMMATIC EVALUATION (1992–1998)

7.1 Spatio-temporal Trends in Sediment Profiles [by Robert J. Diaz]

Nearfield stations were first sampled with sediment profile imaging (SPI) in 1992 (Blake et al. 1993b) and then again in 1995 (Hilbig et al. 1996), 1997 (Blake et al. 1998), and 1998 (see Section 3.0). Sediments at most stations were consistent through time with little or no variation (Table 7.1-1). Very-fine-sand (3–4 phi) to Silty-fine-sand (4–5 phi) was the dominant sediment type. Several stations did exhibit temporal variation in sediment type, in particular NF02, which alternated between finer and coarser sediments from 1992 to 1998. Stations NF13 and NF14, which from 1992 to 1997 had consistently finer sediments, became coarser in 1998. It does not appear that the sediments at any station have become finer through time. Station NF20 consistently had the most heterogeneous sediments in both space and time (Table 7.1-1).

Assessment of the depth of the apparent color RPD through time is complicated by shallow prism penetration. At many stations one or more of the replicate images did not penetrate sufficiently to see the RPD layer (Table 7.1-1). Yearly averages for RPD calculated various ways are:

	1992	**1995**	**1997**	**1998**
All stations, only measured RPDs	2.6	2.5	1.7	1.6
All stations, all values (includes > values)	2.6	4.2	3.1	2.3
Stations sampled all 4 years, only measured	3.1	2.3	1.6	1.6
Stations sampled all 4 years, all values	2.7	2.7	1.6	1.6

These summaries point to a decline in average RPD layer depth from 1992–1995 to 1997–1998. Examination of data from the seven stations that had measured RPDs for all years (Table 7.1-1) via analysis of variance, followed by Tukey's multiple comparison test, indicated that the decline was statistically significant (df = 3, F = 7.93, $p = 0.001$) (Figure 7.1-1). The decline in RPD from 1992–1995 to 1997–1998 may be linked to the interaction of physical and biological process at work in structuring bottom communities. Blake et al. (1998) concluded that bottom instability (caused by waves and currents) leads to a patchy mosaic of successional stage I pioneering communities, which are associated with shallower RPD measurements. Stage I communities dominated the Nearfield area from 1992 to 1997, with stage II communities dominating in 1998 (Table 7.1-1). In 1995 the first signs of amphipod tubes, characteristic of stage II community development, were seen in the Nearfield (Stations NF05, NF04, NF16, NF21, Hilbig et al. 1996). In 1998, however, the widespread stage II communities did not appear to lead to deeper RPD layers, nor did the increased occurrence of stage III communities. There appeared to be an increase in the amount of surface and subsurface biogenic activity in 1998, relative to the other years, which accounted for the increase in stage III successional stage.

The Organism Sediment Index (OSI, Rhoads and Germano 1986) indicated that physical processes exerted stress on benthic communities and played an important role in structuring the communities. The average yearly OSI values were:

1992	**1995**	**1997**	**1998**
6.9	6.1	4.8	6.4

Table 7.1-1. Comparison of sediment profile image data at Nearfield stations collected from 1992 to 1998. Data for 1992 are from Blake et al. (1993b), 1995 (see Section 3.0) are from Hilbig et al. (1996), 1997 are from Blake et al. (1998), and 1998 from Diaz (1999).

Stat	Major Modal Sediment Descriptor				Apparent Color RPD				Estimated Successional Stage				Organism Sediment Index			
	1992	1995	1997	1998	1992	1995	1997	1998	1992	1995	1997	1998	1992	1995	1997	1998
NF01	FS	.*	.	.	IND	.	.		I	.*	.	.	IND	.	.	
NF02	VFS	CS	SIFS	PB, GR, SA	0.9	>2.7	2.7	IND	I	I	I-II on III	IND	4.0	5.0	7.5	IND
NF03	VFS	.	.	.	1.7	.	.		I-III	.	.	.	6.3	.	.	
NF04	FS	FS	VFS	FS	IND	>3.8	>1.4	>1.8	I	I-II	I-II	II	IND	7.7	3.7	6.5
NF05	FS	VFS	VFS	VFS	4.1	1.8	1.4	1.3	I	I-II	I on III	II-III	8.5	4.7	7.3	5.7
NF06	VFS	.	.	.	2.3	.	.		I-III	.	.	.	8.6	.	.	
NF07	VFS	VFS	VFS	VFS	2.9	1.6	1.7	0.8	I-III	I	I	II-III	7.6	3.3	3.7	5.3
NF08	VFS	SIFS	VFS	VFS	2.1	2.8	1.8	1.8	I-III	I	I-II	II-III	7.0	5.3	4.3	6.3
NF09	VFS	VFS	VFS	VFS	1.7	2.7	1.8	1.9	I	I on III	I	II-III	6.7	9.0	4.0	7.3
NF10	VFS	VFS	VFS	VFS	4.1	2.9	1.3	1.7	IND	I-I on III	I-II	II-III	8.3	6.3	3.7	6.7
NF11	VFS	.	.	.	2.8	.	.		II-III	.	.	.	IND	.	.	
NF12	VFS	SI	SIFS	SIFS	4.8	2.3	1.6	2.0	I	I-I on III	I+II on III	II-III	9.7	7.0	7.7	7.3
NF13	FS	FS, VFS	FS	FSMS GR, PB	2.2	>3.9	>1.9	>3.3	I	I	I	II	4.0	7.0	4.0	8.0
NF14	FS	VFS	VFS	PB, VFS	2.6	>4.2	>3.1	0.8	I	I	I	II-III	9.0	6.7	5.7	5.0
NF15	FS	VFS	VFS	FS, GR	2.0	3.3	>1.7	>2.2	I	I	I	II-III	5.7	5.7	4.0	6.7
NF16	VFS	SIFS	VFS	SIFS	2.3	>3.7	1.1	1.7	I	II-I on III	I	II-III	5.5	9.3	2.7	6.7
NF17	FS	FS	FS	FS	IND	>5.7	>2.1	>2.1	I	I	I	II	8.0	7.0	4.0	6.3
NF18	VFS	VFS	VFS	GR, VFS	2.3	1.8	1.4	1.7	.	I	I+II on III	I-II	4.6	3.7	5.0	5.0
NF19	.	CS, VFS	VFS	FSSI CL	.	2.2	>1.4	0.5	I	I	I-II	I-II	.	4.0	4.0	3.5
NF20	VFS	SI, CS, VFS	GR, FSMS	GR, FSMS , SICL	3.6	1.8	IND	1.9	.	I	I	II-III	8.0	3.5	IND	6.5
NF21	.	SIFS	VFS	SIFS	.	2.9	2.0	1.3	.	II-I on III	I	II-III	.	7.0	2.0	6.3
NF22	.	SIFS	SIFS	SIFS	.	2.8	0.7	1.9	.	I on III	I+II on III	II-III	.	7.7	6.3	6.7
NF23	.	CS, VFS	FS	FS	.	3.3	>2.0	>2.9	.	I	I	II	.	6.0	4.0	7.7
NF24	.	SI	SIFS	FSSI CL	.	2.8	2.4	1.2	.	I	I-I on III	II-III	.	5.3	7.3	4.7
FF10	VFS	.	VFS	VFS	1.5	.	>3.0	2.3	I-III	.	I	II-III	5.5	.	5.5	7.3
FF12	.	.	VFS	FS	.	.	>1.5	2.2	.	.	I	II-III	.	.	3.7	7.7
FF13	.	.	SIFS	SIFS	.	.	2.1	2.2	.	.	I-II	II-III	.	.	6.0	8.0

* . Station not sampled.
IND Parameter indeterminant.
CS Coarse-sand, possibly gravel
FS Fine-sand
GR Gravel
SA Sand
MS Medium-sand
SI Silt
SICL Silt-clay
SIFS Silty-fine-sand
VFS Very-fine-sand
FSSICL Fine-sand-silt-clay
PB Pebbles

\> Indicates that the RPD layer, in at least 1 of 3 replicate images, was deeper than prism penetration.

* . Station not sampled
I Stage I pioneering community
II Stage II intermediate community
III Stage III equilibrium community
I on III Stage I community at surface over Stage III community
II on III Stage II community at surface over Stage III community

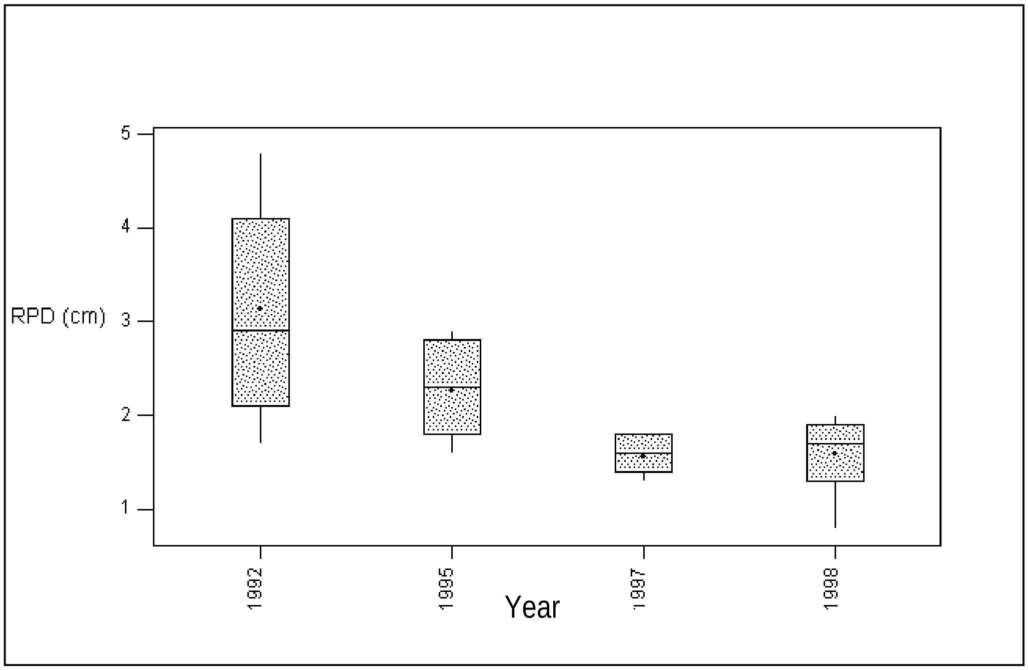


Figure 7.1-1. Nearfield boxplots of RPD layer depth for the seven stations that were sampled all four years (data are from Table 7.1-1). Whiskers are range, box is center 50% of values, line is median, circle is mean.

OSI values less than 6 indicate some form of disturbance is affecting community development (Rhoads, personal communication). The lower values for 1997 may be related to the additional stress of seasonal change as some stations were sampled in October while the other years were all sampled in August. The distribution of OSI values can be seen in Figure 7.1-2.

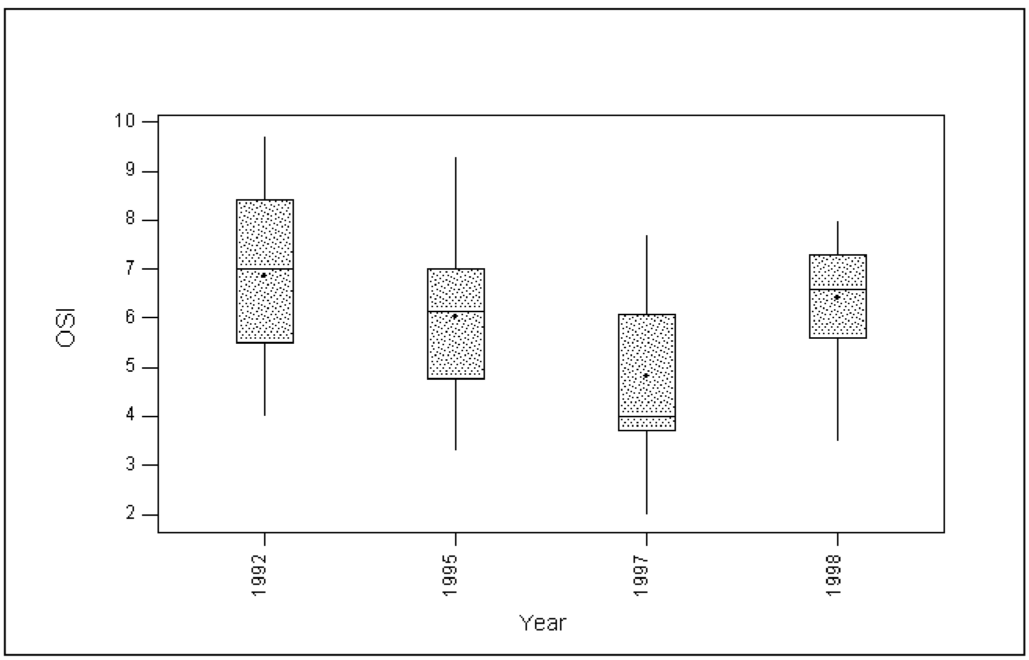


Figure 7.1-2. Nearfield boxplots of OSI values (data are from Table 7.1-1). Whiskers are range, box is center 50% of values, line is median, circle is mean.

Based on the sediment profile image data, the general physical and biological conditions at the Nearfield stations reflect the physically dynamic nature of the processes that dominate the area. The 1998 data indicated an increasing trend in the importance of biological processes that may have started in 1995.

7.2 Spatio-temporal Trends in Sedimentary Parameters [by Deirdre Dahlen]

7.2.1 Sediment Texture

Nearfield—In general, sediments collected in the Nearfield displayed fairly consistent composition over time, ranging from very sandy (>80% sand) to silty (>50% silt). With the exception of station NF24, sediments collected at Nearfield stations within 2 km of the diffuser (NF13, NF14, NF15, NF17, NF18, NF19, NF21, and NF24) were sandy (>80% sand) and clustered in the upper apex of the sand and gravel/silt/clay ternary diagram (Figure 7.2-1). Sediment composition at Station NF24 has varied more over the seven-year time study period, with high silt content in years 1994, 1996, and 1997; clayey composition in 1995, but sandier in 1998 (Figures 7.2-1 and 7.2-2). Sediments collected from Nearfield stations located further away from the diffuser (2–8 km; NF02, NF04, NF05, NF07, NF08, NF09, NF10, NF12, NF16, NF20, NF21, and NF22) aligned along the right-hand side of the ternary diagram and ranged from sandy (NF02, NF04, NF05, and NF07) to silty sediments (NF08, NF12, and NF21) (Figure 7.2-1).

With few exceptions, there were only subtle differences between 1997 and 1998 mean phi values indicating no clear trend in sediment texture. Exceptions included stations NF14, NF18, and NF24, which were considerably more coarse (lower mean phi) in 1998 compared to 1997 (Figure 7.2-3). Sediments from stations NF14 and NF18 contained much greater amounts of gravel in 1998 compared to 1997, returning to levels measured in 1996 (Figure 7.2-2). However, sediments from station NF24 contained higher amounts of sand with less silt and clay compared to 1997 findings. Despite that, sediments collected at all Nearfield stations demonstrated fairly consistent sediment composition over course of the study period. For example, the mean phi at all Nearfield stations located within 2 km of the diffuser, except NF24, has been less than 3 for the last 4 years (Blake et al. 1998, this report Section 4). Similarly, the mean phi at Nearfield stations located 2–8 km from the diffuser were generally greater than 3 for the last four years, with the exception of three stations NF02 (1995, 1997, 1998), NF04 (1995–1998), and NF20 (1997, 1998) (Blake et al. 1998, this report Section 4). Station NF17 has demonstrated the greatest level of consistency in sediment texture (Figure 7.2-2), containing greater than 98% sand over the seven-year study period.

Farfield—In general, sediments collected in the Farfield displayed fairly consistent patterns of sediment composition over time (Figure 7.2-4), ranging from very sandy (>80% sand and gravel) to very silty (>80% silt and clay). In general, coarser-grained sediments (>80% sand, mean phi>4) were located at Farfield stations FF01A, FF09, and FF10 and clustered near the upper apex of the sand and gravel/silt/clay ternary diagram (Figure 7.2-4). However, sediments collected from Farfield stations FF04, FF07, and FF11 are very silty (>80% silt and clay, mean phi>6) and clustered along the bottom right quadrant of the ternary diagram (Figure 7.2-4). Sediments from stations FF05, FF06, and FF14 were more intermediate in texture and aligned along the right-hand side of the ternary diagram with % silt and clay ranging from 50–75%. Station FF13 displayed more variable sediment composition over the seven-year study period, with high gravel and sand content in 1992 and 1998; silty sediments (>50% silt and clay) in 1996 and 1997; and more sandy in 1993, 1994, and 1995 (Figure 7.2-5). Sediment from this station is aligned along the right-hand side of the tertiary diagram and spans three quadrants of the tertiary diagram (Figure 7.2-4). Samples from stations FF09 and FF12 have displayed the most consistent patterns in sediment composition, clustering quite tightly in the upper quadrants of the tertiary diagram (Figure 7.2-4).

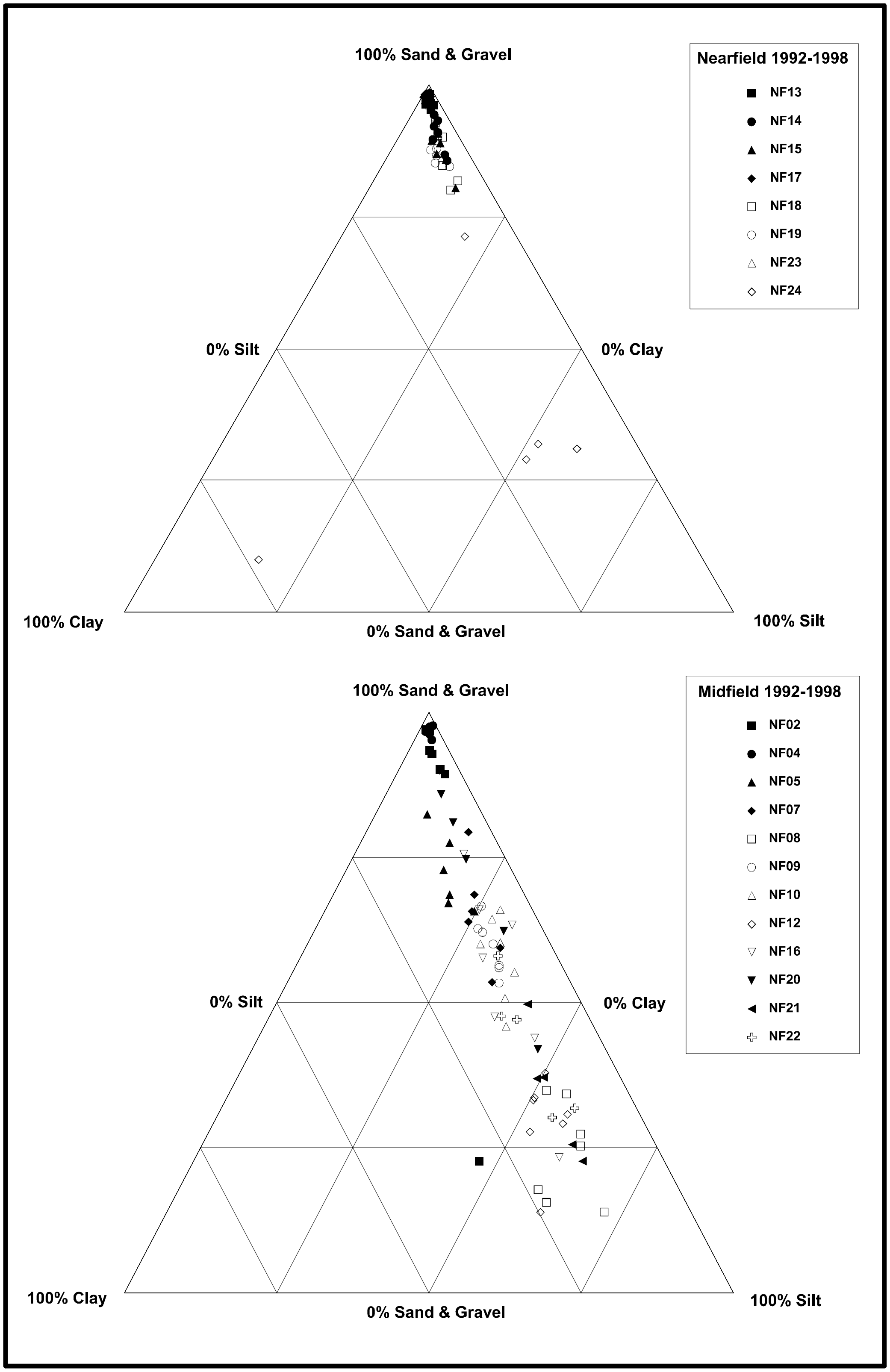


Figure 7.2-1. Ternary diagram of % sand and gravel/% silt/% clay composition at Nearfield stations from 1992–1998. The term "midfield" is used to note Nearfield stations located at 2-8 km from the diffuser.

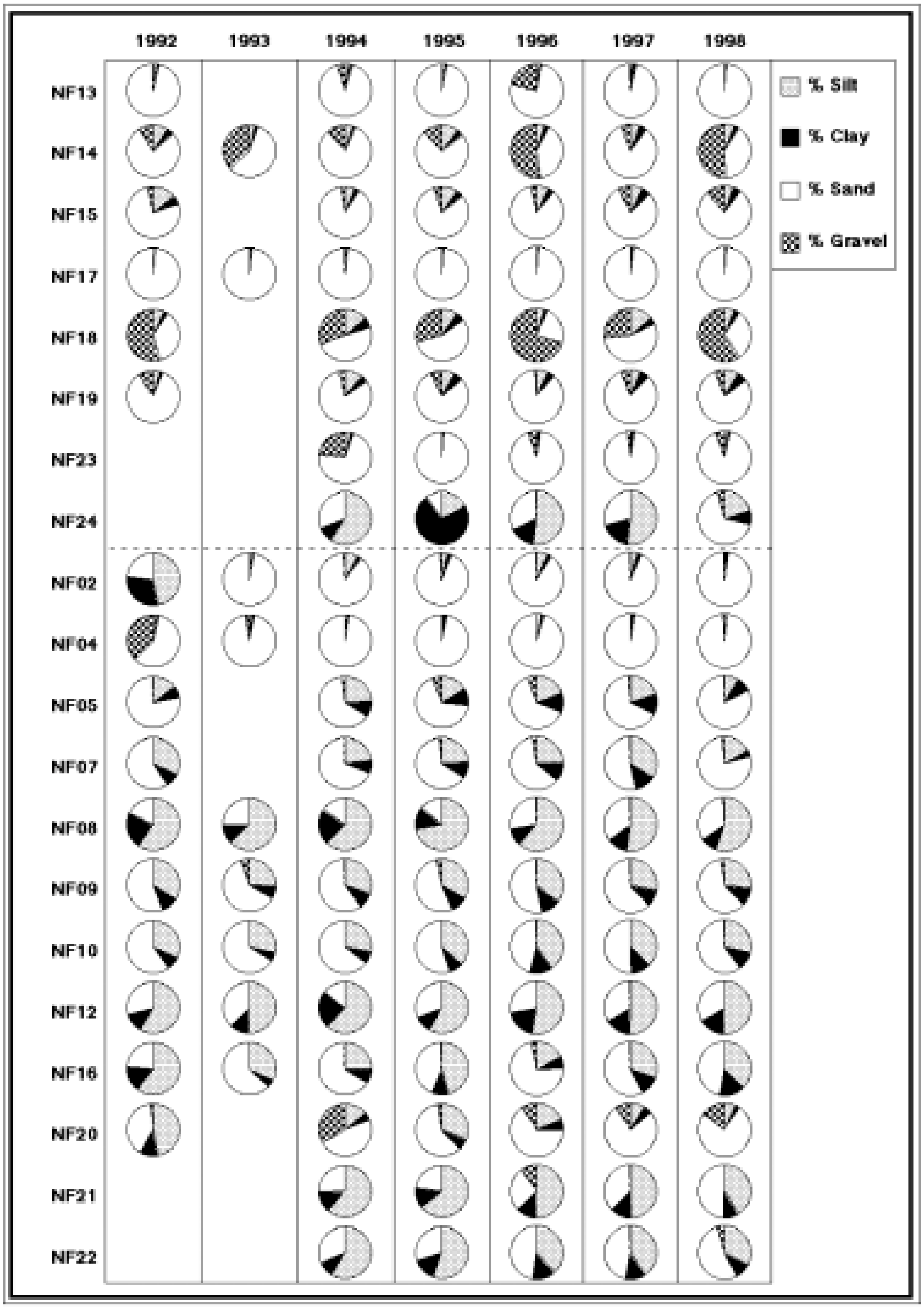


Figure 7.2-2. Sediment composition at Nearfield stations from 1992–1998.

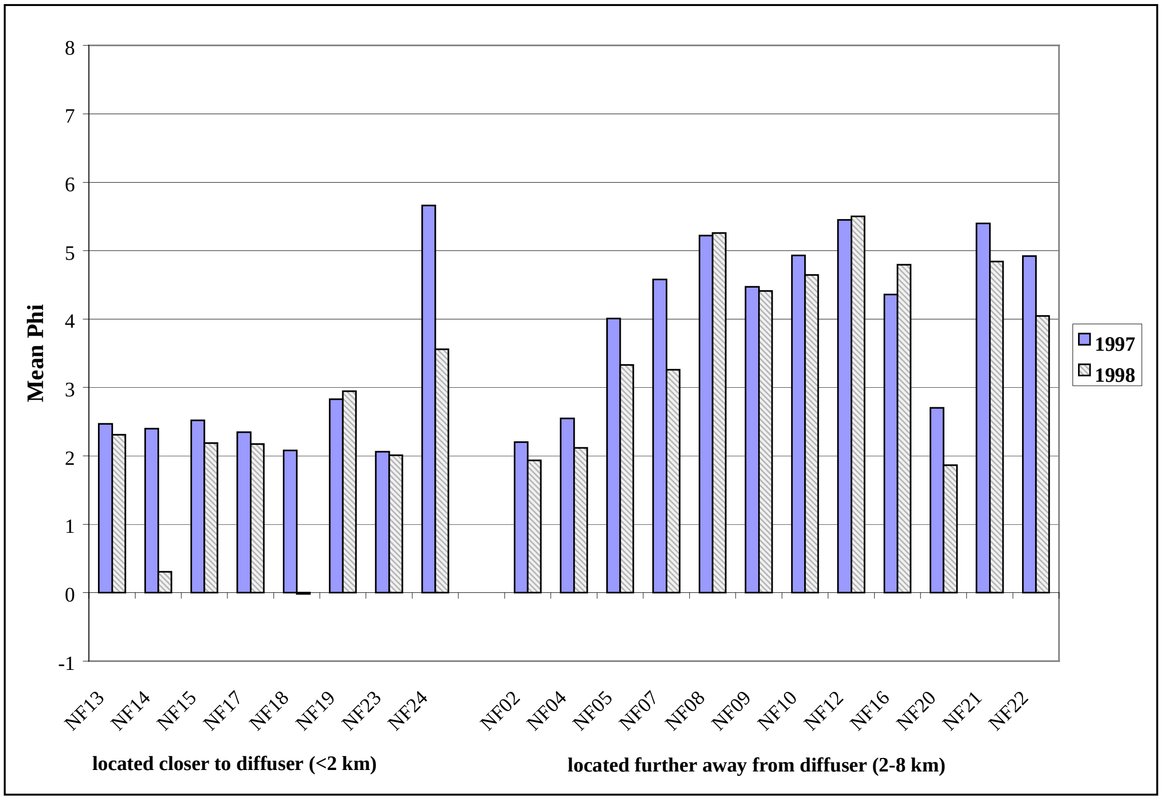


Figure 7.2-3. Comparison of numerical approximate mean phi at Nearfield stations in 1997 and 1998.

With the exception of station FF13 (rep 2), there were only subtle differences between 1997 and 1998 mean phi values indicating no clear trend in sediment texture. Station FF13 (rep 2) was considerably more coarse (lower mean phi) in 1998 compared to 1997 (Figure 7.2-6). The high variability between replicate grabs at station FF13 in 1998 may indicate that sediment was collected on the boundary between two different bottom types. Sediments from station FF13 contained significantly greater amounts of gravel in 1998 compared to 1993–1997, returning to levels measured in 1992 (Figure 7.2-5). Despite that, sediments collected at all Farfield stations have demonstrated very consistent sediment composition over time (Figure 7.2-5).

7.2.2 Total Organic Carbon Content

Nearfield—TOC values ranged from very low (<0.1%) to just greater than 3.1% at station NF08 in 1992 (Blake *et al*. 1998). The lowest levels of TOC were found consistently at stations NF02, NF04, NF13, NF17, and NF23 (Figure 7.2-7); where sediments were coarser-grained (>80% sand and gravel). The exception to this pattern was a high TOC value at station NF02 in 1992 when the sediments there were fine. However, TOC values were higher at stations NF24, NF08, NF12, NF16, NF21, and NF22 (Figure 7.2-7) where sediment composition was more silty (<50% silt and clay).

TOC content at most Nearfield stations located further from the diffuser (2–8 km) generally decreased in 1998 compared to 1997 values, with the exception of NF16, which increased from 1.2 to 2.1% TOC (Figure 7.2-8). Conversely, there was no clear trend in TOC values between 1997 and 1998 at Nearfield stations located within 2 km of the diffuser. TOC content remained comparable at stations NF13, NF17, NF18, NF19, and NF23; increased in 1998 at stations NF14 and NF15; and decreased in 1998 at station NF24 (Figure 7.2-8).

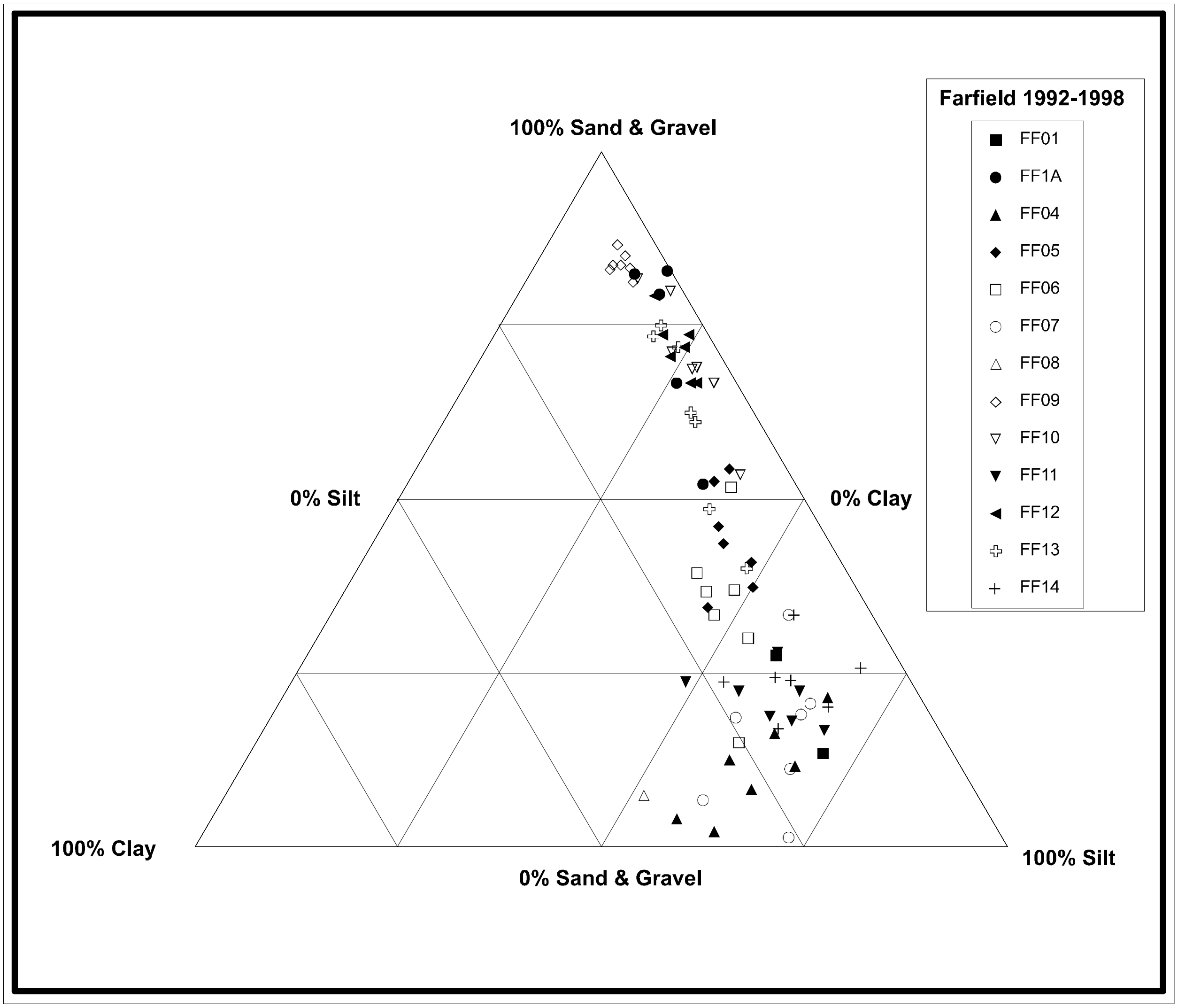


Figure 7.2-4. Ternary diagram of % sand and gravel/% silt/% clay composition at Farfield stations from 1992–1998.

Farfield—Patterns in TOC content were very consistent over the seven-year study period and generally corresponded well with sediment grain size. Sediments from stations FF01A, FF09, FF10, and FF12 were more sandy and had the lowest TOC values over time (Figure 7.2-9). The highest TOC values were consistently found at stations FF04, FF07, FF11, and FF14 which were comprised of more silty sediments (>75% silt and clay) (Figure 7.2-9).

TOC values at Farfield stations in 1998 were generally comparable to 1997 values, with the exception of stations FF05 and FF13. TOC content at these stations decreased by slightly more than a factor of two in 1998 compared to 1997 values. Despite this, TOC content has remained very consistent over the seven-year study period.

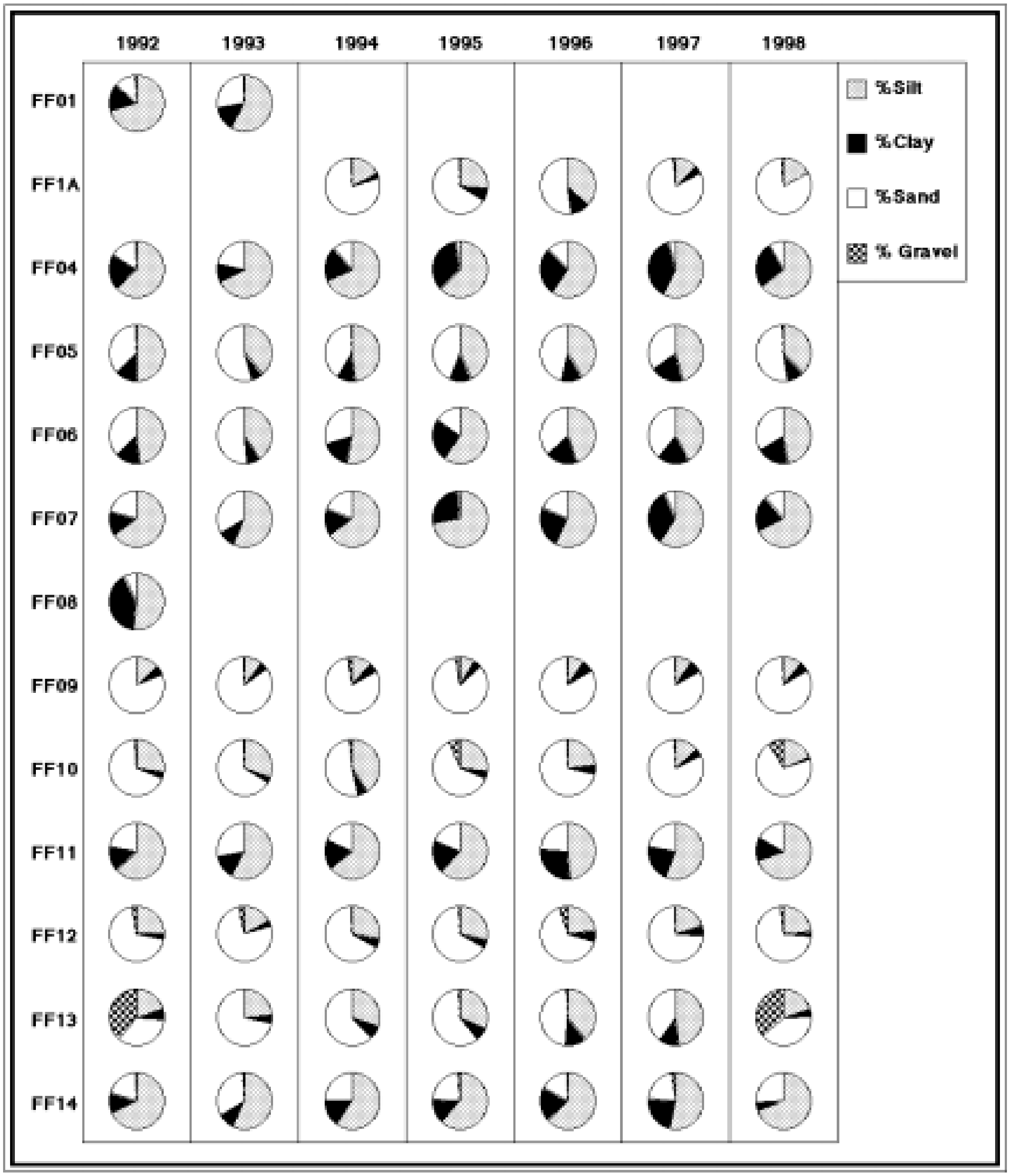


Figure 7.2-5. Sediment composition at Farfield stations from 1992–1998.

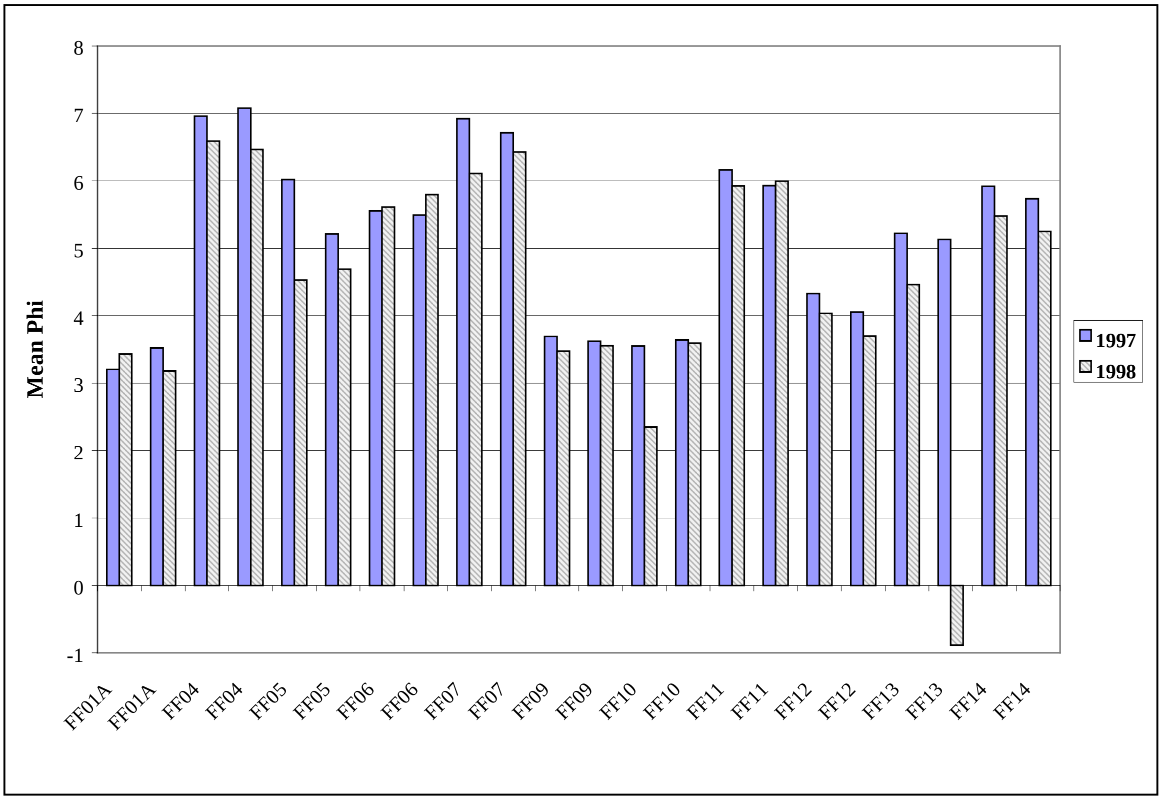


Figure 7.2-6. Comparison of mean phi at Farfield stations in 1997 and 1998.

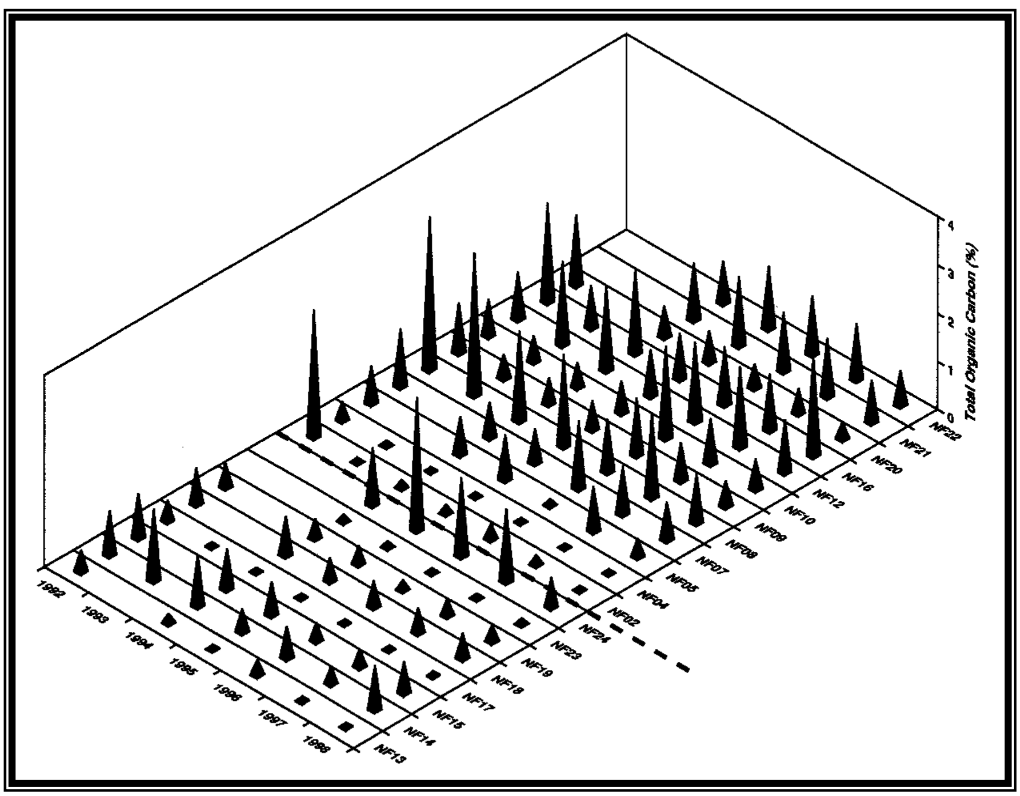


Figure 7.2-7. Distribution of TOC content at Nearfield stations from 1992–1998.

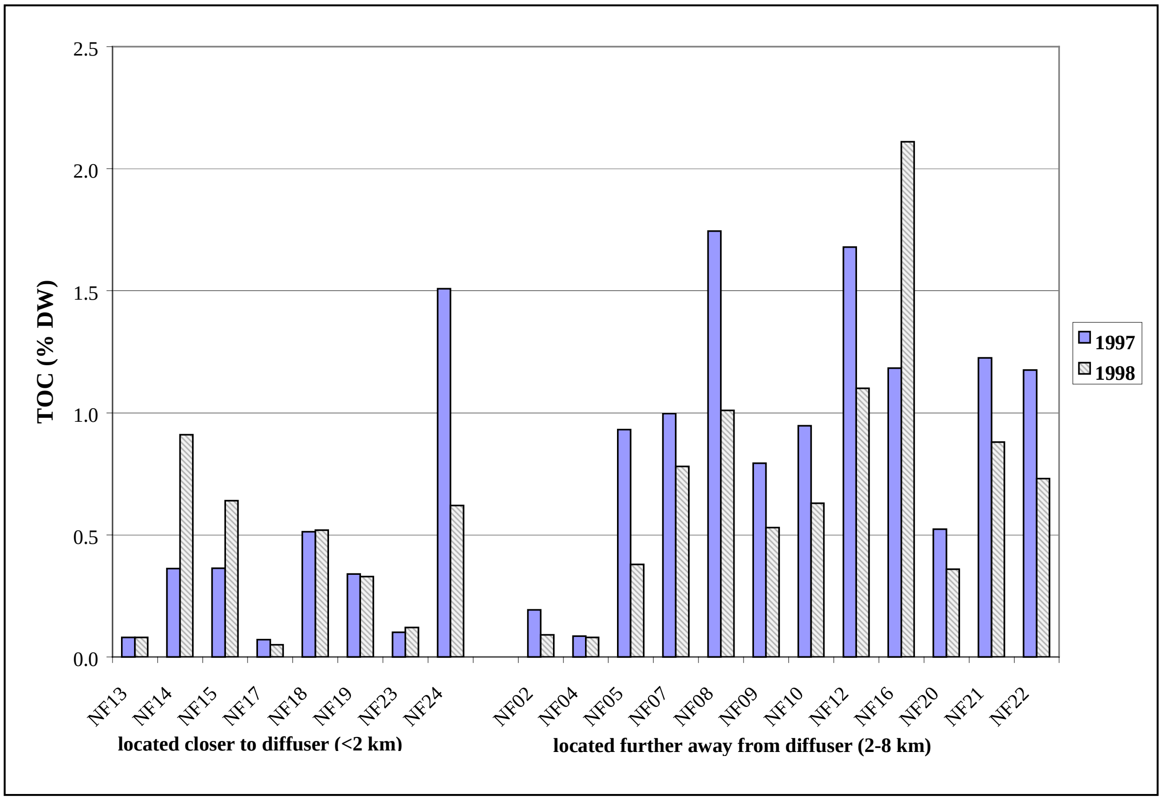


Figure 7.2-8. Comparison of TOC content at Nearfield stations in 1997 and 1998.

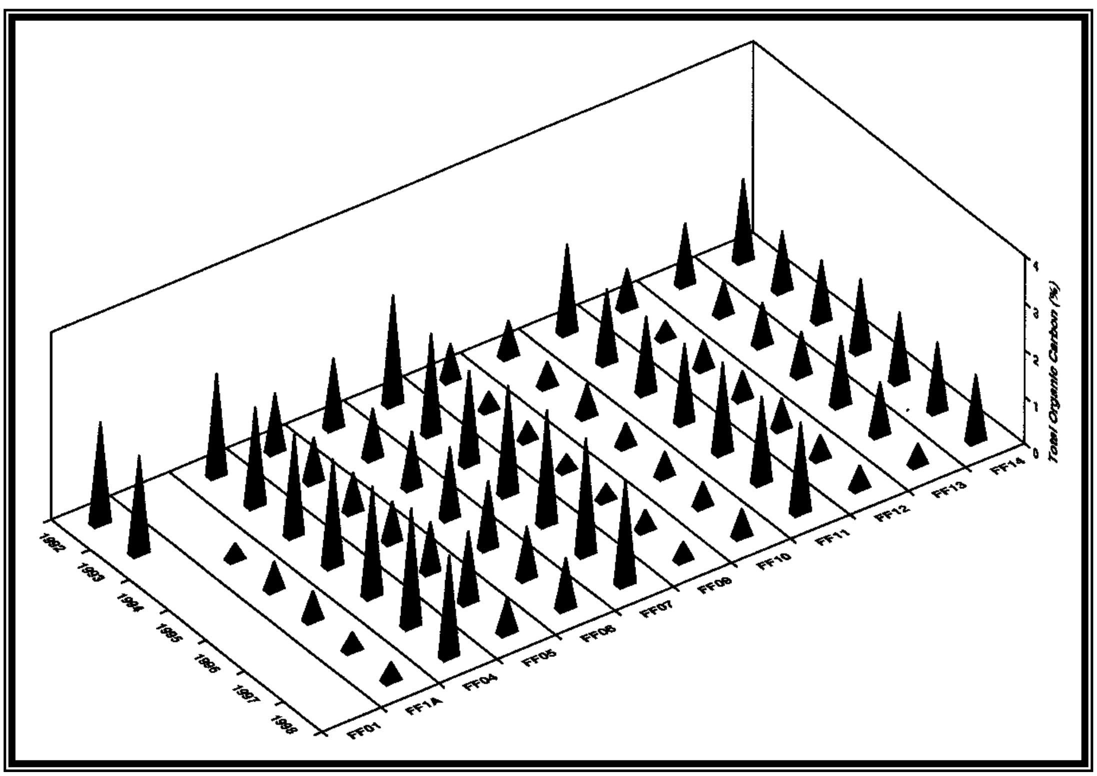


Figure 7.2-9. Distribution of TOC content at Farfield stations 1992–1998.

7.2.3 *Clostridium perfringens*

Nearfield—*Clostridium* densities ranged from <100 cfu (NF17 in 1996 and 1998) to 17,000 cfu (station NF24 in 1995; Figure 7.2-10). Patterns of *Clostridium* densities were generally higher at stations with finer sediments and higher levels of TOC. For example, Nearfield stations comprised of more silty sediments (>50 silt and clay), and with numerical mean phi values greater than 3, included NF08, NF12, NF21, NF22, and NF24. *Clostridium* densities and TOC values at these stations were higher compared to sandy stations over the seven-year study period (Figures 7.2-10 and 7.2-7). In addition, the highest *Clostridium* densities were measured at station NF24 in 1995, when the % fines (silt + clay) was approximately 95% with a high TOC value (>2.5%). Spore densities were lower at Nearfield stations with sandy sediments and lower TOC values. For example, Nearfield stations predominantly comprised of coarser-grained sediments (>80% sand and gravel) and with approximate numerical mean phi values less than 3 include NF02, NF04, NF13, NF14, NF15, NF17, NF18, NF19, NF20, and NF23. *Clostridium* densities and TOC values at these stations were generally low during the study period (Figures 7.2-10 and 7.2-7).

In general, *Clostridium* densities were lower in 1998 compared to 1997 values, consistent with the overall decrease in TOC content in 1998 compared to 1997.

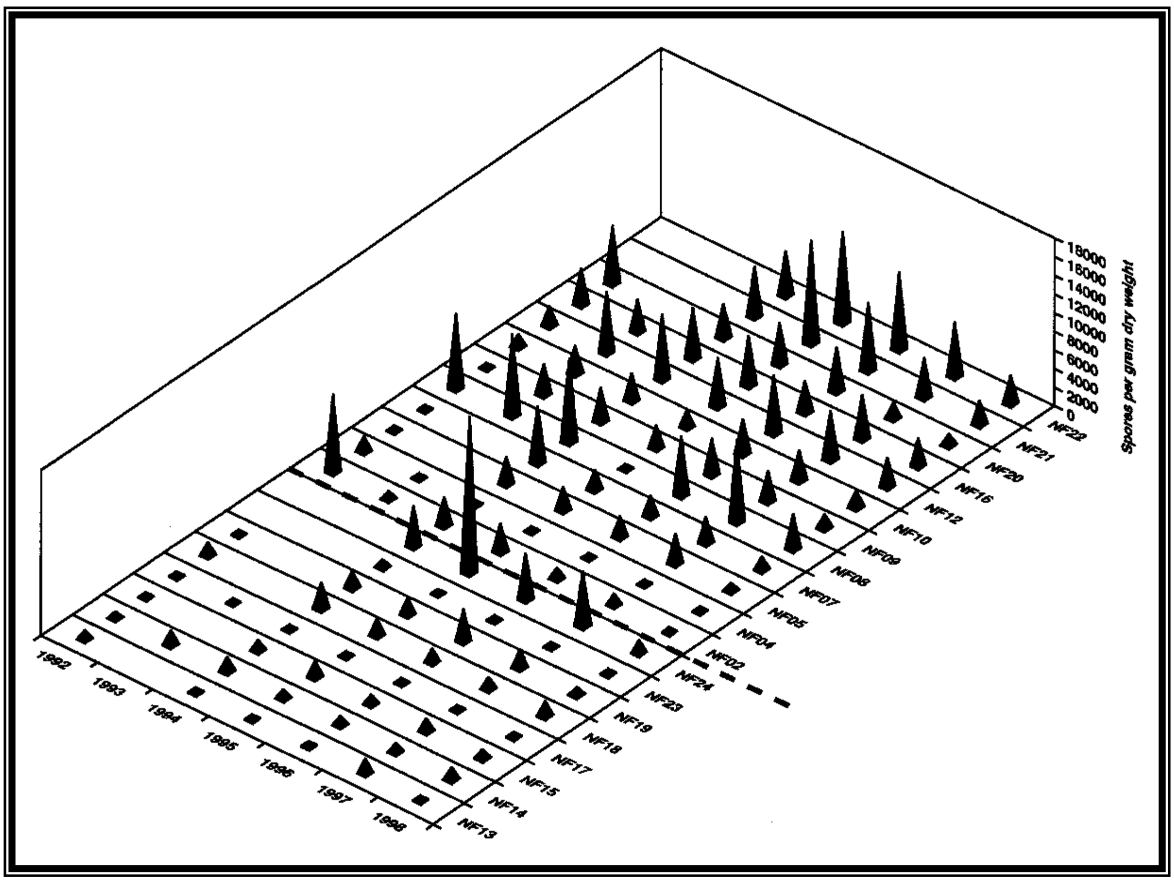


Figure 7.2-10. Distribution of *Clostridium perfringens* spores at Nearfield stations from 1992 – 1998.

Farfield—Patterns in *Clostridium* densities at Farfield stations have been fairly consistent during the seven year time period studied (1992–1999) (Figure 7.2-11). In general, *Clostridium* densities have been low at all Farfield stations, ranging from 150 cfu at station FF07 (Cape Cod Bay) in 1992 to 18,000 cfu at station FF13 in 1995 (Blake et al. 1998). The abundance of *Clostridium* spores was less clearly related to sediment grain size and TOC content as was observed with Nearfield sediments. For example, sediments collected at stations FF04, FF06, FF07, FF11, and FF14 were more silty (>50% silt and clay), however, the highest levels of *Clostridium perfringens* spores were found at station FF13 and FF12 (Figure 7.2-11).

Values of *Clostridium* densities decreased from 1997 to 1998 at most Farfield stations, consistent with the overall decrease in TOC content in 1998 compared to 1997 values. The most noticeable decrease occurred at station FF13, where *Clostridium* densities decreased from a station mean of 6,750 cfu in 1997 to 1,745 cfu in 1998. Similarly, TOC content decreased by more than a factor of two and sediment composition switched from silty in 1997 (>50% silt and clay) to sandy (75% gravel and sand, station mean) in 1998. Despite this, patterns in *Clostridium* densities at Farfield stations have been fairly consistent from 1992 through 1998.

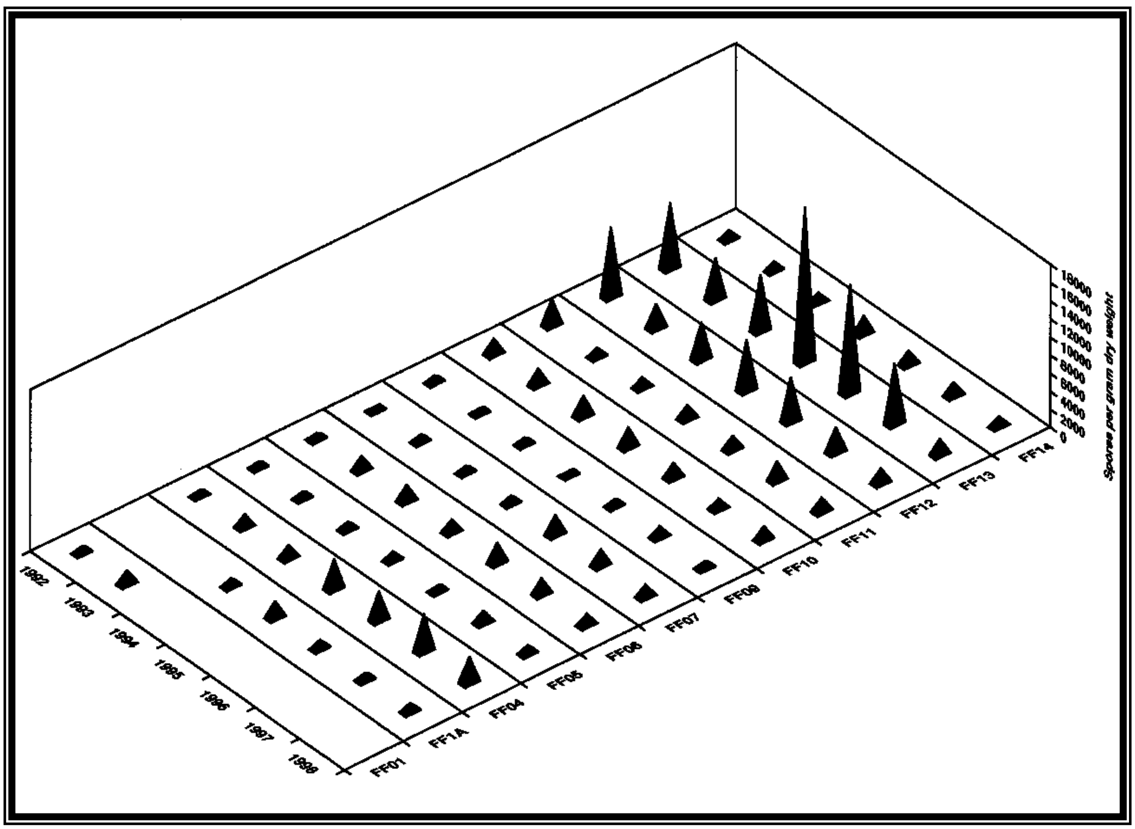


Figure 7.2-11. Distribution of *Clostridium perfringens* spores at Farfield stations from 1992–1998.

7.2.4 Contaminants

Baselines in Massachusetts and Cape Cod Bays were established for contaminants in sediment based on the mean areal distribution for all Nearfield stations plus FF10, FF12, and FF13. Baselines and 95% confidence intervals were determined for each sampling year from 1992 through 1998 and were evaluated against monitoring thresholds based on the Long et al. (1995) ER-M values.

The temporal response of the baseline for representative organic and metal contaminants showed relatively constant means without substantial variability (Figures 7.2-12, 7.2-13). Baseline mean values for organic and metal contaminants were well below ER-M thresholds and the ability to detect change before thresholds are approached is high.

Correspondence between bulk sediment properties and contaminants was evaluated for all Nearfield stations plus FF10, FF12, and FF13 using 1995 results. 1995 results were used because this was the most recent sampling event for which all stations were sampled and analyzed for physical and chemical parameters. Organic and metals contaminants correlated well with grain size and TOC. Figures 7.2-14 and 7.2-15 show the correlation with representative contaminants.

In conclusion, concentrations of organic and metal contaminants were generally low and the system was highly variable. Variability was primarily controlled by bulk sediment properties (grain size and TOC). Baseline mean values for organic and metal contaminants were well below ER-M thresholds and concentrations of organic and metal contaminants were similar over time.

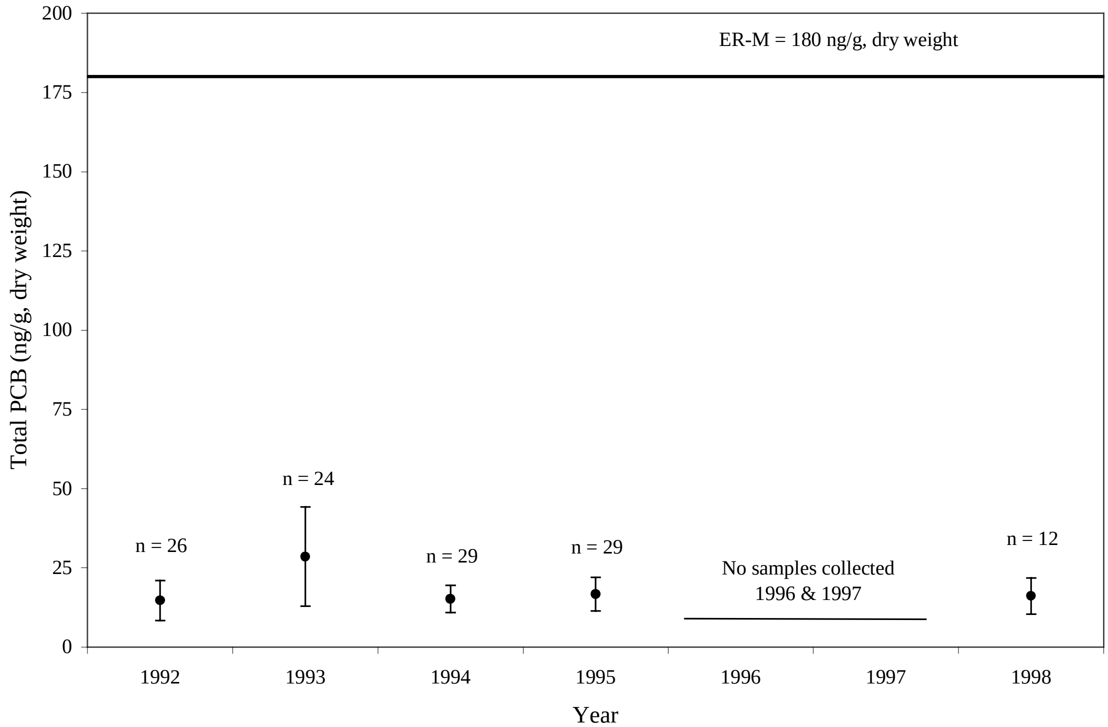


Figure 7.2-12. Total PCB baseline comparison thresholds from 1992–1998. In 1998, four stations were sampled in triplicate.

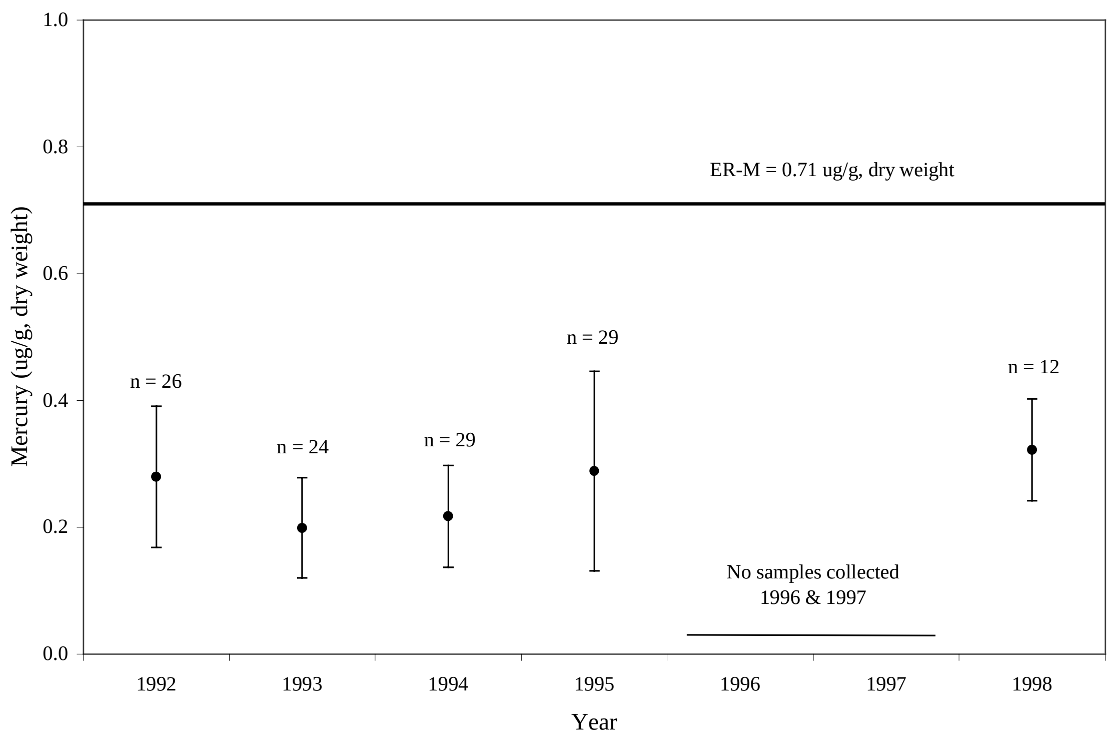


Figure 7.2-13. Mercury baseline comparison thresholds from 1992–1998. In 1998, four stations were sampled in triplicate.

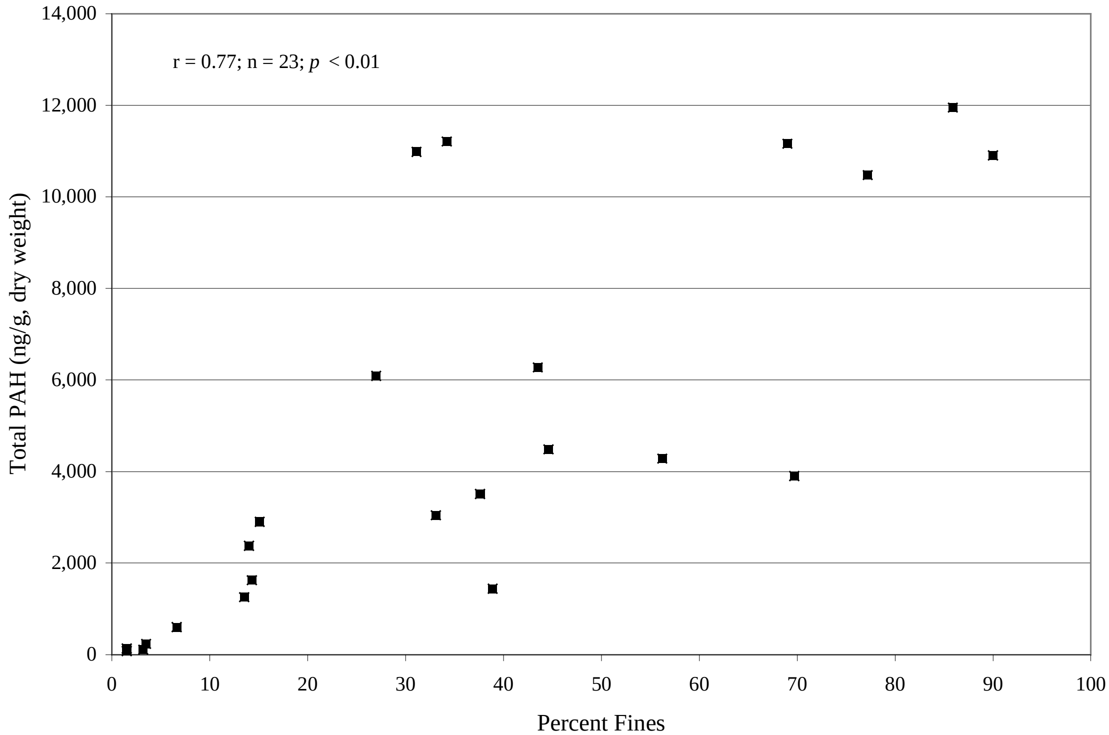


Figure 7.2-14. Percent fines versus Total PAH in the Nearfield—1995 results. Station means are reported.

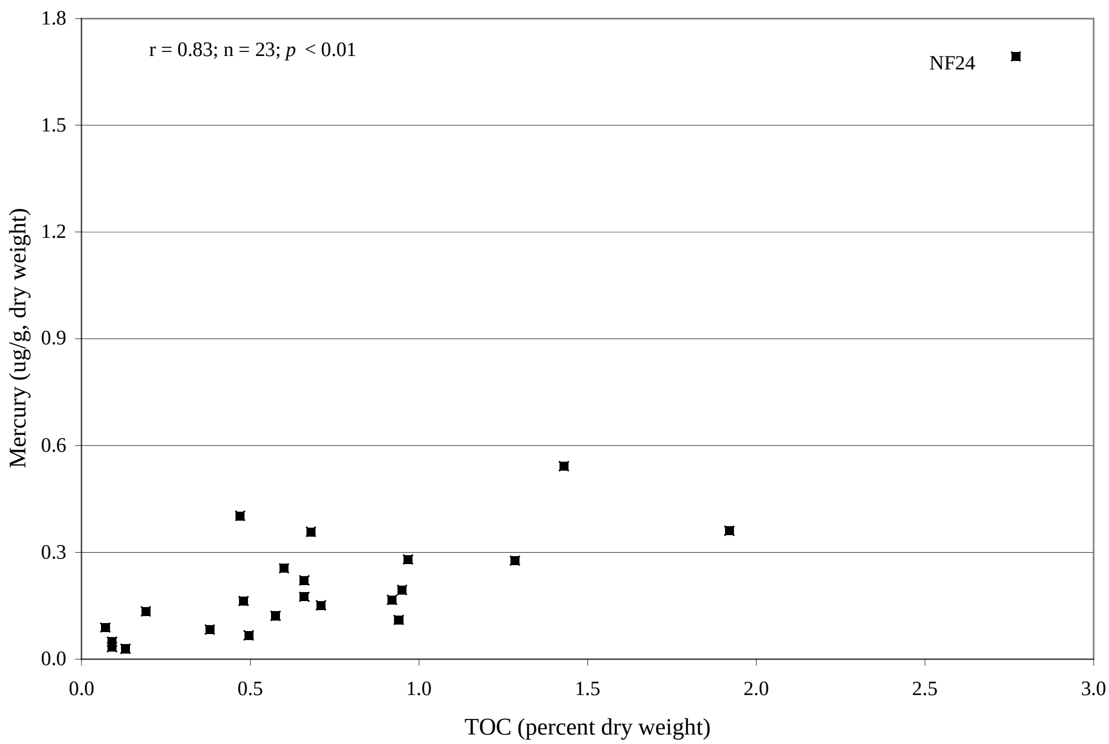


Figure 7.2-15. TOC versus Mercury in the Nearfield—1995 results. Station means are reported.

7.3 Spatio-temporal Trends in Infaunal Communities [by Eugene Gallagher and Roy K. Kropp]

The reader is reminded that for these analyses the term "Nearfield" includes all stations designated "NF" and stations FF10, FF12, and FF13. Also, the sampling design for the Nearfield changed during the early years of the program. These changes were summarized by Blake et al. (1998). Four western Massachusetts Bay stations (NF01, NF03, NF06, NF11) were sampled in 1992 only. The stations and numbers of replicates sampled during each of the program's years are listed in Table 7.3-1.

7.3.1 Nearfield and Farfield Descriptive Community Measures, Combined 1992–1998 Data Set

In this section, an general consideration of the variability in infaunal abundance, numbers of species, and diversity among the Massachusetts Bay samples is presented. In Section 7.3.5, some of these features are examined in more detail, including an evaluation of possible trends.

Abundance—During the course of the monitoring program, infaunal abundances per Nearfield sample have varied considerably (Appendix F-1; Figures 7.3-1 and 7.3-2), ranging from about 130 individuals (NF17, 1993) to about 5,600 individuals (NF07, 1992). Among Farfield stations, infaunal abundances per sample (Figure 7.3-2) also have varied, ranging from about 280 individuals (FF05, 1994) to about 4,300 individuals (FF07, 1998).

Table 7.3-1. Numbers of samples collected at each Nearfield station for each year of the monitoring program.

	1992	1993	1994	1995	1996	1997	1998	1999
FF10	3	3	3	3	3	3	3	3
FF12	3	3	3	3	3	3	3	3
FF13	3	3	3	3	3	3	3	3
NF12	1	3	3	3	3	3	3	3
NF17	1	3	3	3	3	3	3	3
NF24	0	0	3	3	3	3	3	3
NF02	2	3	1	1	1	1	1	1
NF04	1	3	1	1	1	1	1	1
NF08	1	3	1	1	1	1	1	1
NF09	1	3	1	1	1	1	1	1
NF10	1	3	1	1	1	1	1	1
NF14	1	3	1	1	1	1	1	1
NF16	1	3	1	1	1	1	1	1
NF05	1	0	1	1	1	1	1	1
NF07	1	0	1	1	1	1	1	1
NF13	1	0	1	1	1	1	1	1
NF15	1	0	1	1	1	1	1	1
NF18	1	0	1	1	1	1	1	1
NF19	1	0	1	1	1	1	1	1
NF20	1	0	1	1	1	1	1	1
NF21	0	0	1	1	1	1	1	1
NF22	0	0	1	1	1	1	1	1
NF23	0	0	1	1	1	1	1	1

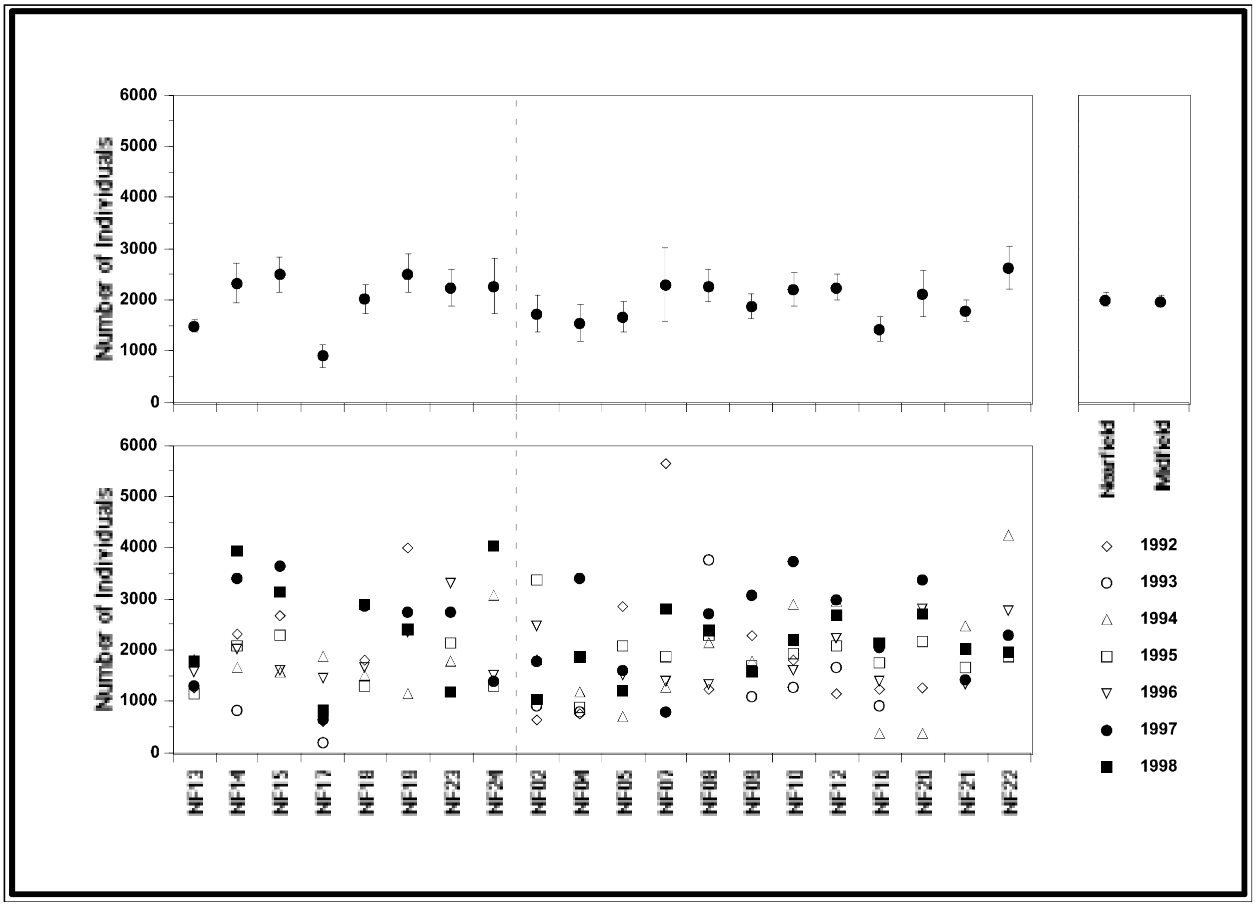


Figure 7.3-1. Infaunal abundance per sample (0.04 m^{-2}) for Nearfield stations (excluding FF10, FF12, and FF13) sampled from 1992 to 1998. Stations to the left of the dashed line are those that are located < 2 km from the diffuser; those to the right are located 2–8 km from the diffuser. The upper diagram shows the mean and standard error of all years for each station and the lower diagram shows the individual year values for each station.

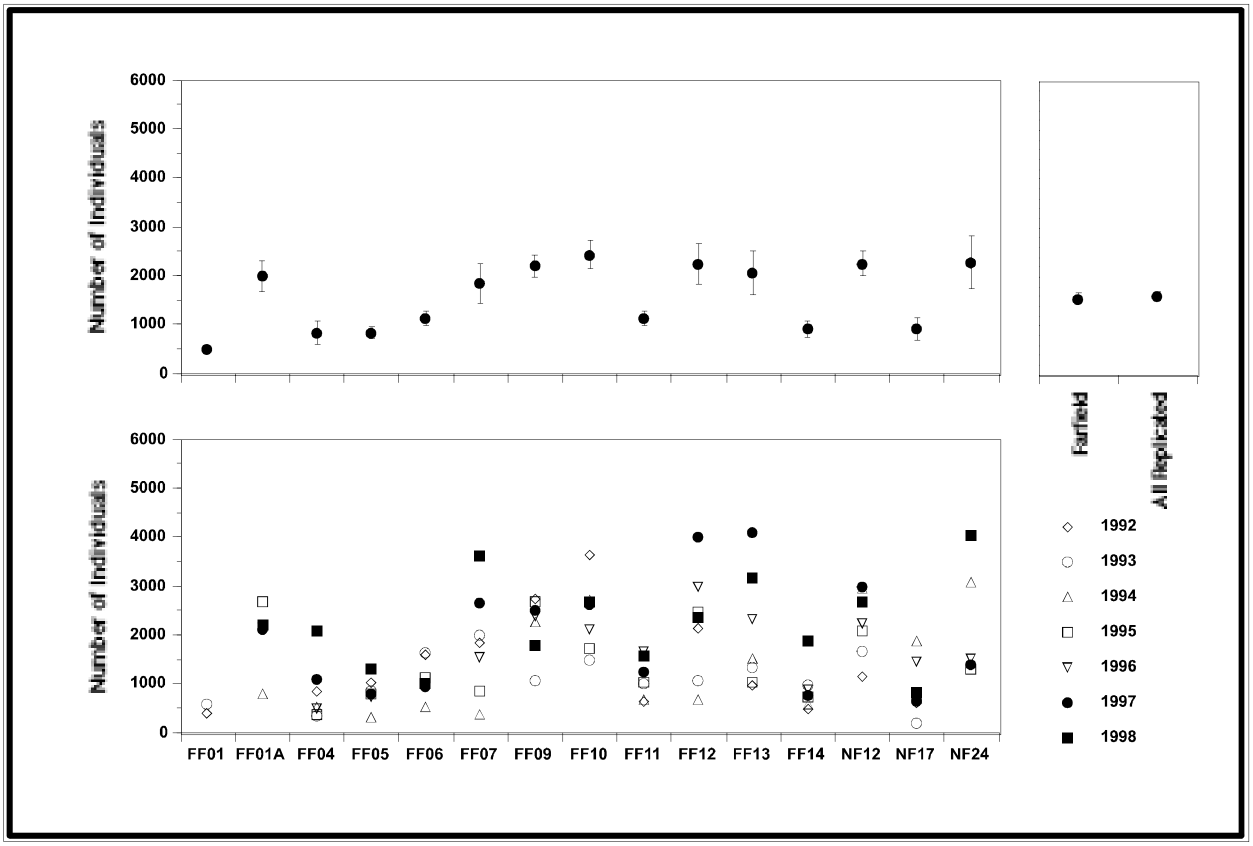


Figure 7.3-2. Infaunal abundance per sample (0.04 m^{-2}) for Farfield stations (including FF10, FF12, and FF13) and replicated Nearfield stations sampled from 1992 to 1998. The upper diagram shows the mean and standard error of all years for each station and the lower diagram shows the individual year values for each station.

Numbers of Species—As indicated for abundance, the numbers of species per Nearfield sample also has varied considerably during the course of the monitoring program (Appendix F-1; Figures 7.3-3 and 7.3-4), ranging from 22 (NF17, 1993) to 114 (NF18, 1997). Among Farfield stations, species per sample (Appendix F-1; Figure 7.3-4) ranged from 27 (FF07, 1994) to 104 (FF09, 1997).

Diversity—Several measure of species diversity have been used during the program. Here, a traditional measure, the Shannon Index (*H'*) is presented. Log-series alpha is discussed in Section 7.3.5. Shannon diversity, as calculated by using $\log_2$, ranged from about 2.1 (NF17, 1994) to about 4.9 (NF05, 1997) (Appendix F-1; Figures 7.3-5 and 7.3-6). Among Farfield stations, Shannon diversity (Appendix F-1; Figure 7.3-6) ranged from about 2.0 (FF05, 1992) to about 4.8 (FF14, 1998).

7.3.2 Nearfield Multivariate Analyses, Combined 1992–1998 Data Set

Normal, Q-mode cluster analysis (Boesch, 1977) was performed on the complete 1992–1998 Nearfield data set, using CNESS as the similarity measure. The results, as shown in the dendrogram (Appendix F-2) and associated metric scaling plot (Figure 7.3-7) showed a large-scale pattern of two major groups of stations. Also, one sample, collected at station NF05 in 1994, did not cluster with any other station and appeared to be an outlier. Coats (1995) did not include this station in his analysis and stated that it was very likely that the sample had been damaged at some point along the analytical pathway. This sample probably should excluded from future analyses. The two major Nearfield station groups clustered together at a relatively high CNESS dissimilarity value of about 1.27 (Appendix F-2). The smaller of the two groups was comprised primarily of stations NF17 (all years), NF13 (1994–1998), NF23 (1994–1998), and NF04 (1992–1996). Within this group of samples, most of those collected from station NF17 formed an unbroken cluster. Two NF17 samples collected in 1996 and one collected in 1995 did not join this cluster. Another interesting inclusion within this major group, was the presence of the 1998 sample from station NF02, which was part of a small group that included samples from stations NF13 and NF23 also collected in 1998. In the analysis of the 1998 data alone (Section 5), station NF02 was not very similar to the cluster that included NF13, NF23, and NF17 (Figure 5-6). The most important contributors to CNESS distances among the 1992–1998 Nearfield samples are listed in Table 7.3-2.

Examination of the Gabriel Euclidean Distance biplot comparing PCA-H axes 1 versus 2 (Figure 7.3-8), in conjunction with the appropriate metric scaling plot (Figure 7.3-7), indicated that the primary species explaining the similarity between samples in this first cluster group were the annelids *Exogone hebes*, *Spiophanes bombyx*, and *Polygordius* sp. A, and the amphipod *Crassicorophium crassicorne*. The 1998 analyses showed that these species were strongly associated with coarse to medium/fine sands. Of the 38 samples included within this cluster (excluding the 1992 NF01 sample because the station is no longer sampled), 30 were from stations located within 2 km of the diffuser. Therefore it seems reasonable to characterize this station group as one associated with sandy sediments in the Nearfield (*sensu* Blake et al. 1998).

The second major cluster group included all remaining Nearfield (in the broad sense) samples. As shown by the metric scaling plot (Figure 7.3-7) and the Gabriel Euclidean Distance biplot (Figure 7.3-8), the primary species contributing to similarity among these samples were the annelids *Spio limicola*, *Aphelochaeta marioni*, *Monticellina baptistae*, *Mediomastus californiensis*, *Prionospio steenstrupi*, *Tharyx acutus*, and *Aricidea catherinae*. Often this particular group of species has been described as being associated with “mud”. The 1998 analyses, in which abundances of these species were compared to sediment mean phi, showed that the relationships of these species to sediment texture was more complex. All of the species were fairly abundant in sediments that might be termed “muds” (i.e., those having mean phi values > 4.0), but some were also numerous, or most abundant (e.g., *Prionospio steenstrupi*), at lower mean phi ranges, including those that were medium to fine sands (mean phi ~2.0–3.0, Figure 5-14). Therefore, Nearfield stations that have sediments with high mean phi values (> 4.0) may be expected to

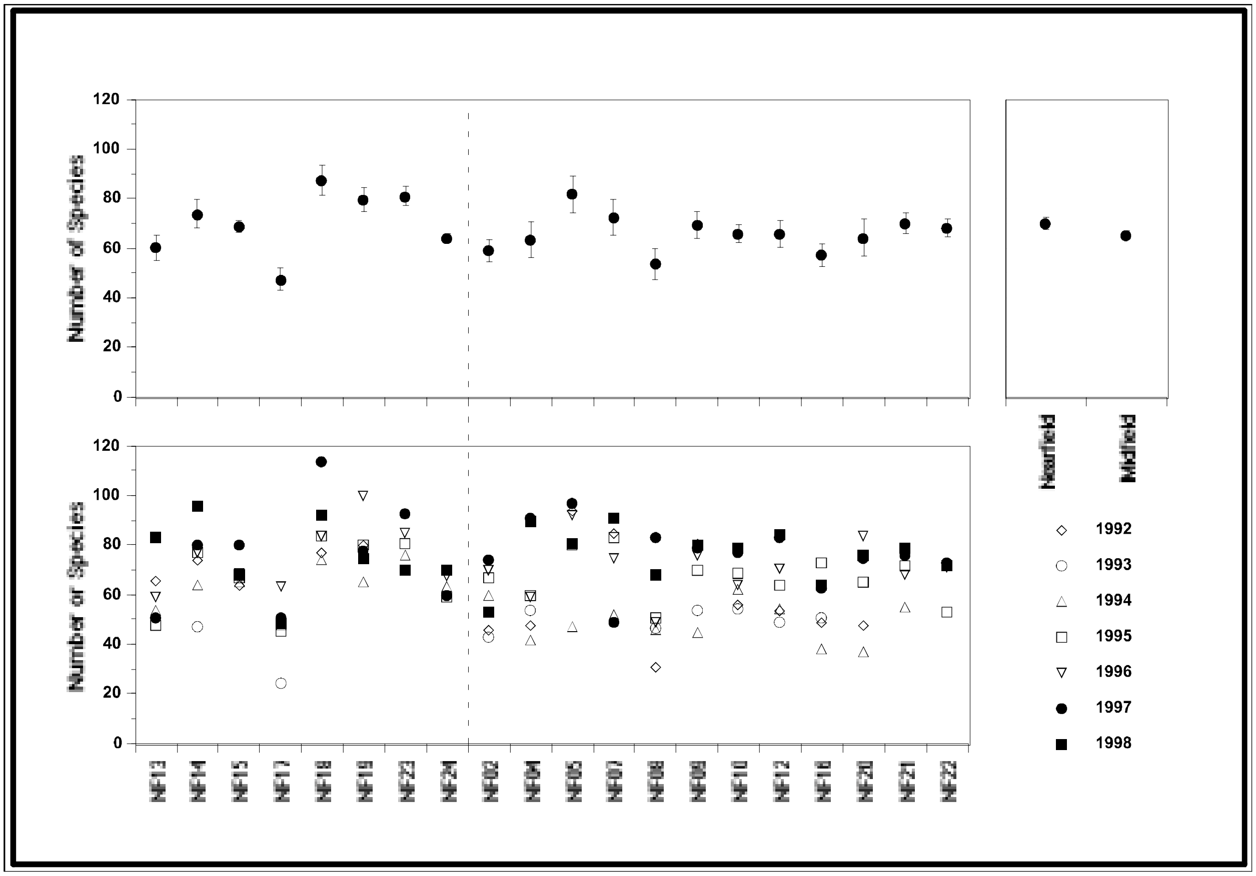


Figure 7.3-3. Number of species per sample for Nearfield stations (excluding FF10, FF12, and FF13) sampled from 1992 to 1998. Stations to the left of the dashed line are those that are located < 2 km from the diffuser; those to the right are located 2–8 km from the diffuser (also called "midfield"). The upper diagram shows the mean and standard error of all years for each station and the lower diagram shows the individual year values for each station.

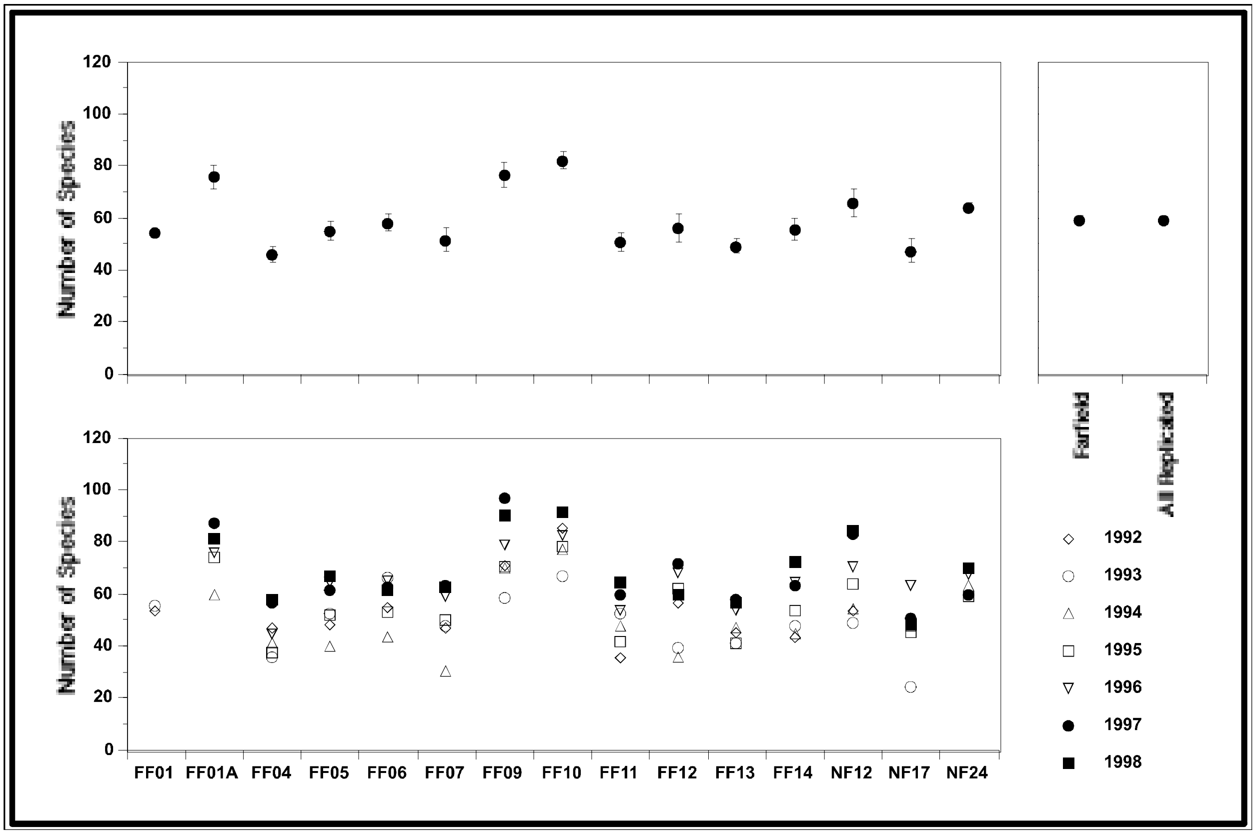


Figure 7.3-4. Numbers of species per sample for Farfield stations (including FF10, FF12, and FF13) and replicated Nearfield stations sampled from 1992 to 1998. The upper diagram shows the mean and standard error of all years for each station and the lower diagram shows the individual year values for each station.

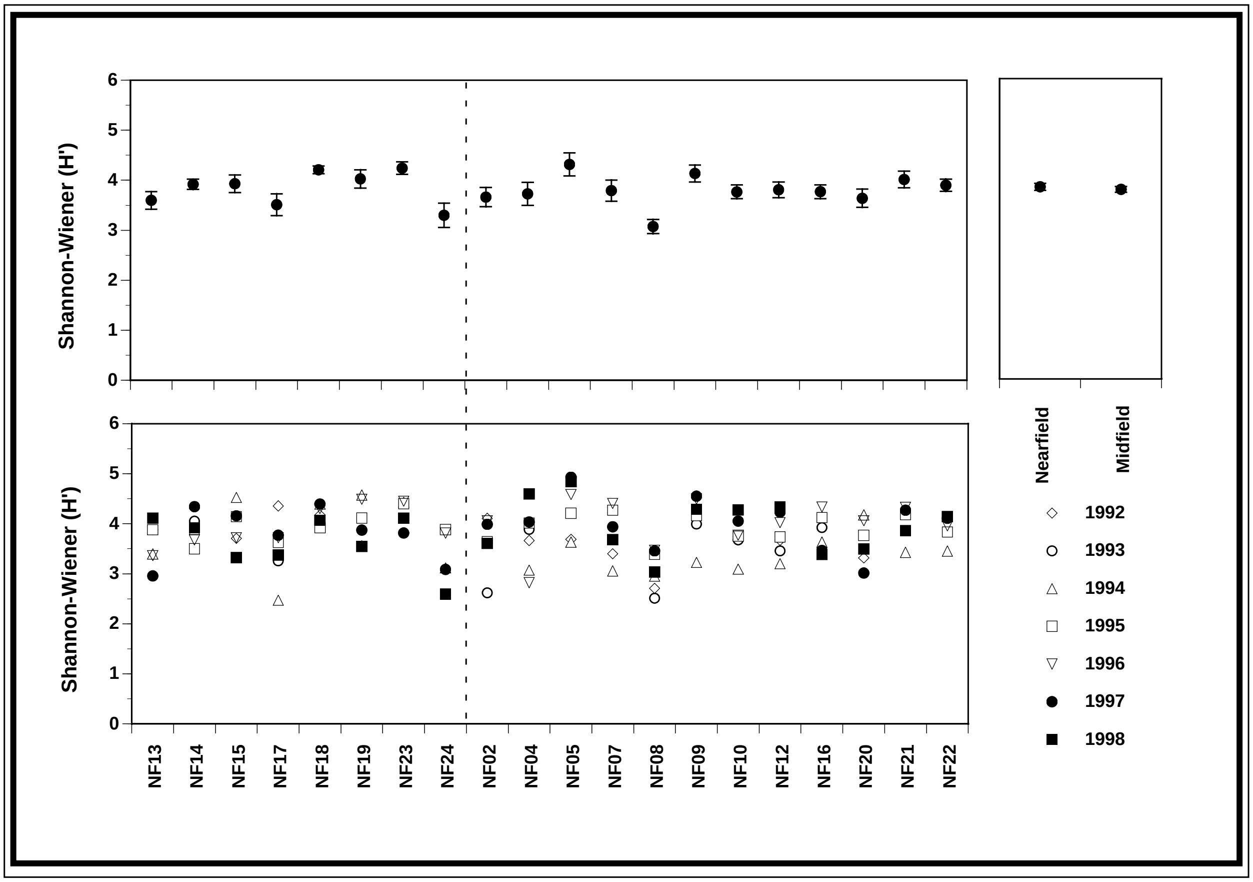


Figure 7.3-5. Shannon's *H'* (log_2) for Nearfield stations (excluding FF10, FF12, and FF13) sampled from 1992 to 1998. Stations to the left of the dashed line are those that are located < 2 km from the diffuser; those to the right are located 2–8 km from the diffuser. The upper diagram shows the mean and standard error of all years for each station and the lower diagram shows the individual year values for each station.

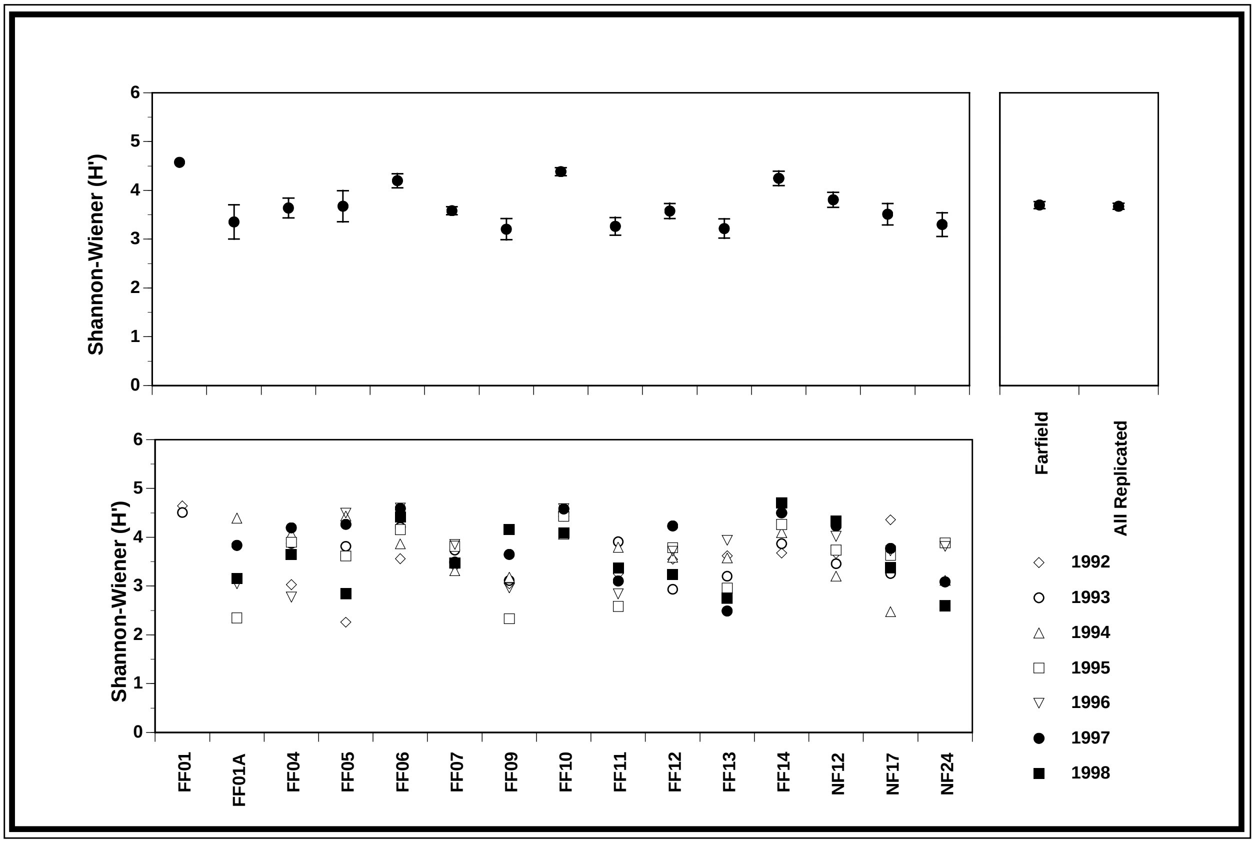


Figure 7.3-6. Shannon's *H'* (log_2) for Farfield stations (including FF10, FF12, and FF13) and replicated Nearfield stations sampled from 1992 to 1998. The upper diagram shows the mean and standard error of all years for each station and the lower diagram shows the individual year values for each station.

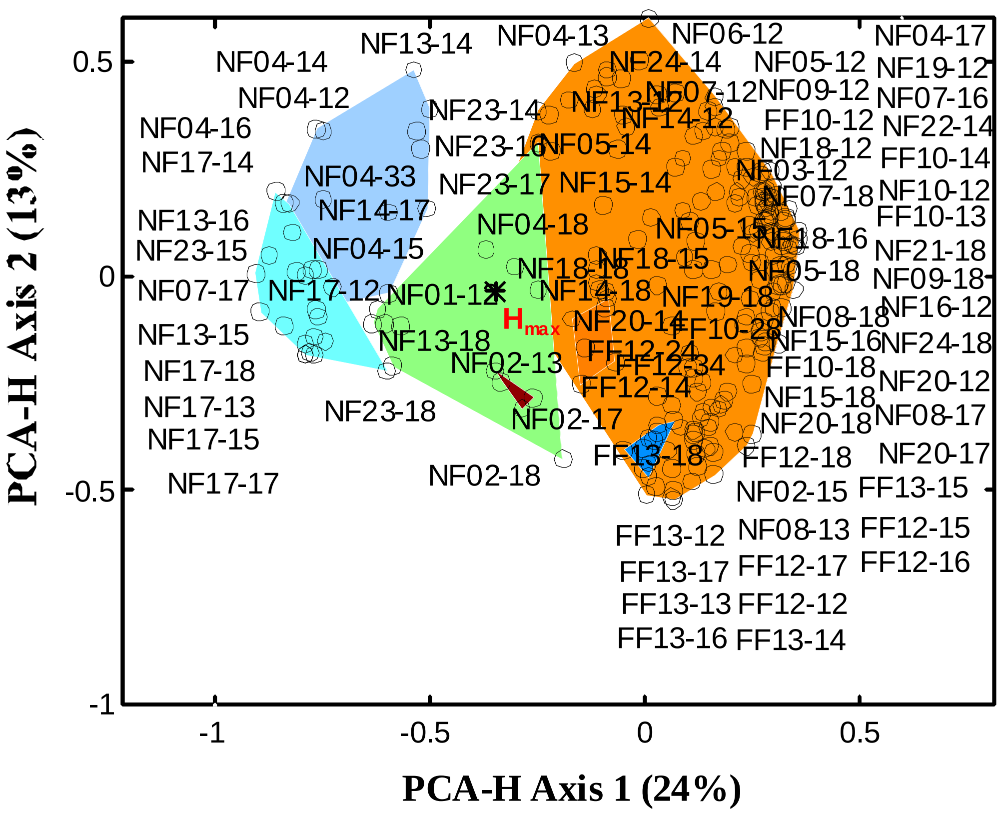


Figure 7.3-7. Metric scaling plot of CNESS distances, axes 1 versus 2, among Massachusetts Bay Nearfield stations sampled from 1992 to 1998. Results of the CNESS cluster analysis are shown as convex hulls. All stations are not labeled; some labels have been placed outside their respective clusters. The labels consist of station number – replicate and year where 2 = 1992, 3 = 1993, etc.

Table 7.3-2. The 38 most important contributors to CNESS distances among all Massachusetts Bay Nearfield stations from 1992-1998. "Cont" is the contribution to overall CNESS distances, "Total Cont" is the cumulative amount of CNESS variation explained by species (89% by the top 39 species). The final columns indicate the contribution of each species to each of the first six PCA-H axes.

No.	Species	Spp. Code	Cont.	Total Cont.	PCA-H Axis					
					1	2	2	4	5	6
1	*Spio limicola*	SpL	8	8	9	31	3	1	2	5
2	*Prionospio steenstrupi*	Prs	7	14	9	3	47	1	0	0
3	*Dipolydora socialis*	DiS	5	19	1	18	1	16	14	2
4	*Mediomastus californiensis*	Mec	5	24	16	0	0	0	1	1
5	*Aricidea catherinae*	Arc	5	29	2	6	23	1	14	0
6	*Exogone hebes*	Exh	4	34	8	4	2	1	10	2
7	*Crassicorophium crassicorne*	Crc	4	38	12	0	0	5	0	0
8	*Tharyx acutus*	Tha	4	42	3	6	3	3	7	1
9	*Aphelochaeta marioni*	Apm	3	45	3	5	1	4	2	5
10	*Monticellina baptisteae*	Mob	3	48	3	0	3	4	0	16
11	*Ninoe nigripes*	Nin	3	51	5	0	0	5	2	8
12	*Exogone verugera*	Exv	2	53	1	5	2	3	11	1
13	*Hiatella arctica*	Hia	2	56	1	0	0	5	1	1
14	*Spiophanes bombyx*	SPB	2	58	3	2	0	5	5	2
15	*Owenia fusiformis*	Owf	2	60	0	1	1	0	8	24
16	*Polygordius* sp. A	PoA	2	63	3	0	0	3	0	0
17	*Levinsenia gracilis*	Leg	2	65	3	0	1	7	1	0
18	*Nucula delphinodonta*	Nud	2	67	1	2	1	0	0	3
19	*Pseudunciola obliquua*	Pso	2	68	2	0	0	7	3	1
20	*Euchone incolor*	Eui	2	70	2	0	2	4	0	0
21	*Nephtys cornuta*	NEC	2	72	0	3	0	3	0	9
22	*Cerastoderma pinnulatum*	Cep	2	73	2	0	0	0	0	0
23	*Unciola inermis*	Uni	2	75	2	0	0	0	2	0
24	*Crenella decussata*	Crd	1	76	0	1	0	1	3	1
25	*Leitoscoloplos acutus*	Lea	1	77	2	1	1	0	0	0
26	*Dipolydora quadrilobata*	DiQ	1	79	0	2	0	2	0	1
27	*Phyllodoce mucosa*	phm	1	80	0	2	0	1	0	4
28	*Grania postclitello longiducta*	Grl	1	81	1	0	0	0	1	0
29	*Scoletoma hebes*	Sch	1	82	0	2	1	1	1	5
30	*Photis pollex*	PhP	1	83	0	0	0	2	0	0
31	Tubificidae sp. 2 (Blake 1992)	Tu2	1	83	0	0	0	0	1	1
32	*Maldane sarsi*	Mas	1	84	0	0	0	0	0	0
33	*Asabellides oculata*	Aso	1	85	0	0	0	1	0	0
34	*Dyopedos monacanthus*	Dym	1	86	0	0	0	1	1	1
35	*Phoronis architecta*	pha	1	86	0	0	0	1	2	0
36	*Ampharete acutifrons*	Ama	1	87	0	1	0	0	0	0
37	*Chiridotea tuftsi*	Cht	1	87	1	0	0	2	1	0
38	*Euclymene collaris*	Euc	1	88	1	0	0	0	0	0
39	*Aglaophamus circinata*	Agc	1	89	1	0	0	0	0	0

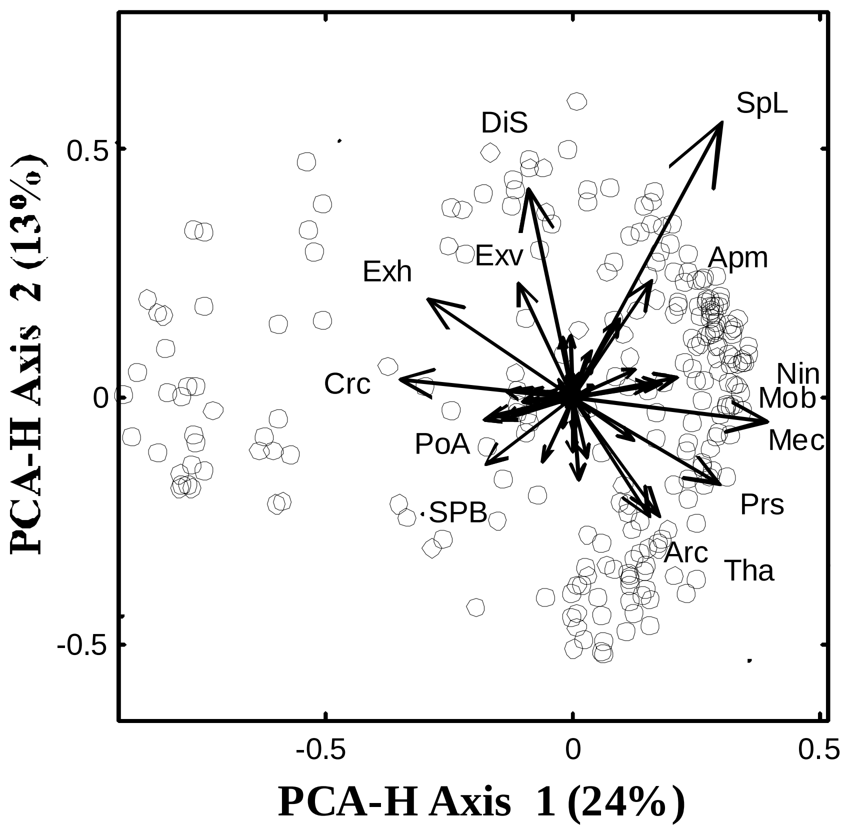


Figure 7.3-8. Gabriel Euclidean distance biplot, axes 1 versus 2, for the 1992–1998 Massachusetts Bay Nearfield data showing those species that control the orientation of samples shown in Figure 7.3-7. Species codes are as listed in Table 7.3-2. Open circles represent the spatial pattern of samples shown in Figure 7.3-7.

be characterized by some combination of the annelids mentioned above, but the presence of those species in abundance at a Nearfield station should not be construed to mean that the sediments found there were "muddy".

Within this complex major group of samples there were several dissimilar subgroups, two of which were equally dissimilar from the remaining groups. The two dissimilar groups, one comprised of station NF02 (1993 and 1997) samples and one consisting of 1994 samples from stations FF12, NF16, and NF20, were identifiable in the metric scaling plot comparing PCA-H axes 1 versus 3 (Figure 7.3-9) and its associated Gabriel Euclidean Distance biplot (Figure 7.3-10). The distinctive character of the NF02 samples from 1993 may be related to the shift in sedimentary structure from primarily fine (silt and clay) to sands that occurred at the station between 1992 and 1993 (Figure 7.2-2). The primary change in the infaunal community was the influx of large numbers of the clam *Hiatella arctica*, which reached about 14,800 individuals/m^2, many of which were very small and likely recently settled (R. Kropp, personal observation). In conjunction with this influx were relatively low numbers of polychaetes, which were more abundant in samples collected in 1994 and succeeding years (Figure 7.3-11). The 1997 sample collected at NF02 was similar to the 1993 samples in that it had high numbers of *Hiatella arctica* (9,550 individuals/m^2), but differed by having higher numbers of *Prionospio steenstrupi* and the northern dwarf-cockle *Cerastoderma pinnulatum* (Figure 7.3-11).

The 1994 FF12, NF16, and NF20 samples were distinctive because of very low (i.e., relative to numbers found during other years) abundances of the annelids *Prionospio steenstrupi* and *Mediomastus californiensis*, and relatively high abundances of *Aricidea catherinae* (Figure 7.3-12). These differences were detectable in the metric scaling plot comparing PCA-H axes 1 versus 3 (Figure 7.3-9) and its associated Gabriel Euclidean Distance biplot (Figure 7.3-10) where the separation of this group from the other "non-sandy" stations was along axis 3 (low *Prionospio steenstrupi*, high *Aricidea catherinae* abundances). The separation of the NF16 and NF20 samples from the FF12 samples was primarily related to lower abundances of *Aricidea catherinae* there as compared to those at station FF12.

Rather than examining the fine details of each subcluster of the remaining stations, a more useful approach is to consider subsets of stations defined by interest to the monitoring program and to examine those subsets for consistency in community structure. The station subsets can be defined as those within the immediate (< 2 km) proximity of the diffuser, those comprising the "midfield" (2–8 km from the diffuser), and those midfield stations nearest the mouth of Boston Harbor (primarily FF12, FF13, NF02, and NF22). To a certain extent there appeared to be some degree of separation among the three station subsets, even though they were defined rather artificially. First, there was a general tendency for the Nearfield samples close to the diffuser to cluster together in sets of up to three stations. Samples from NF24 generally were more similar to each other than to other samples, but those collected in 1994–1996 were quite different from those collected in 1995–1998. Although not immediately clear from the metric scaling plots and Gabriel Euclidean Distance biplots, the distinction of the 1997 and 1998 samples from the others was probably a result of very high abundances of the annelids *Prionospio steenstrupi*, *Mediomastus californiensis*, and *Aricidea catherinae* found during those years as compared to the others. Furthermore, abundances of *Spio limicola*, *Aphelochaeta marioni*, and *Monticellina baptistae* were much lower in 1997 and 1998 than 1994–1996. The 1994 samples were distinctive in that they had high abundances of the polychaetes *Dipolydora socialis, Spio limicola*, and *Exogone verugera* and the clam *Hiatella arctica*.

The other Nearfield stations also showed a tendency to cluster together. Samples from NF14 (1993, 1995–96, 1998) and NF18 (1994–1998) were part of the same cluster. The samples from NF19 (1995–1998) clustered together. Samples from NF15 varied considerably in their cluster group affinities, with no more than two samples comprising the same major subgroup.

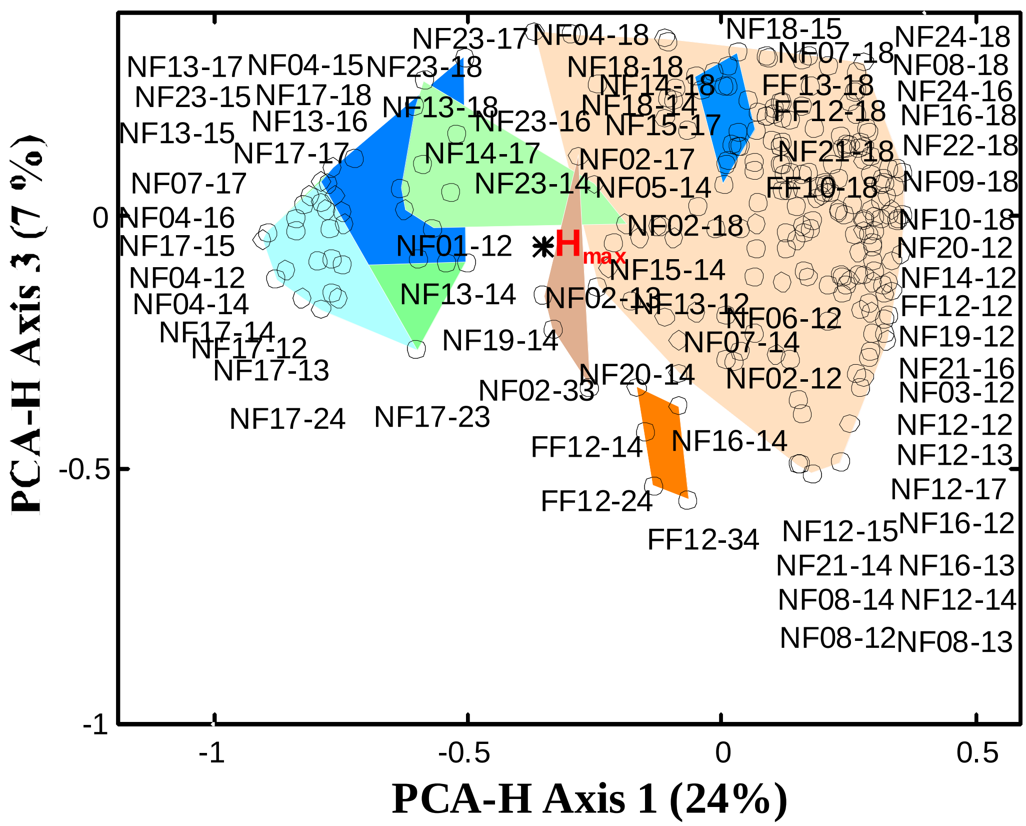


Figure 7.3-9. Metric scaling plot of CNESS distances, axes 1 versus 3, among Massachusetts Bay Nearfield stations sampled from 1992 to 1998. Results of the CNESS cluster analysis are shown as convex hulls. All stations are not labeled; some labels have been placed outside their respective clusters.

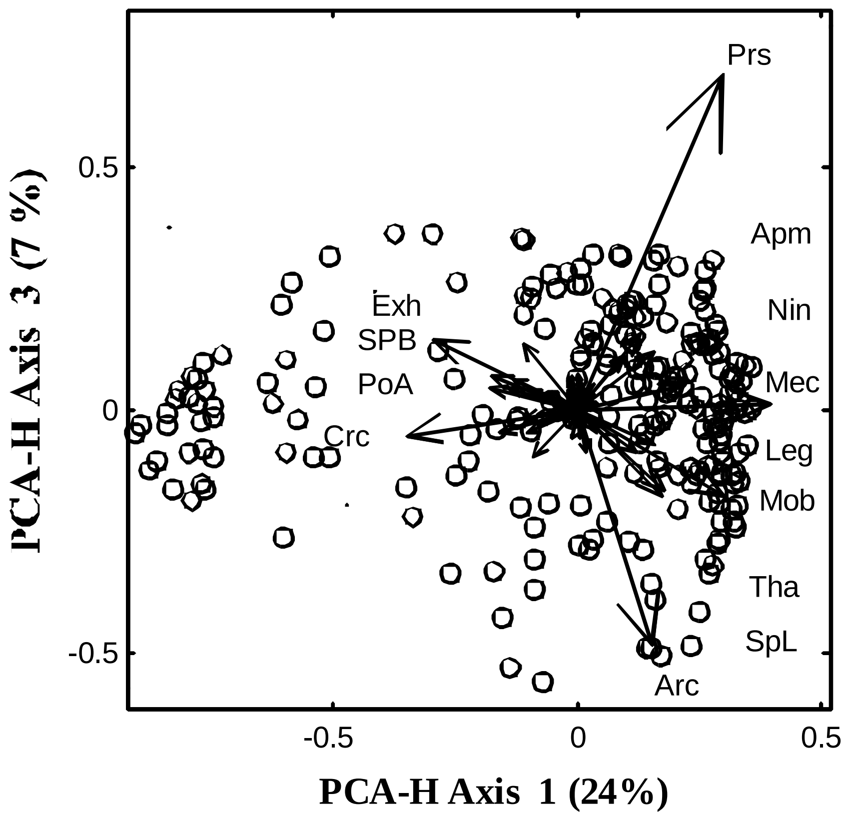


Figure 7.3-10. Gabriel Euclidean distance biplot, axes 1 versus 3, for the 1992–1998 Massachusetts Bay Nearfield data showing those species that control the orientation of samples shown in Figure 7.3-9. Species codes are as listed in Table 7.3-2. Open circles represent the spatial pattern of samples shown in Figure 7.3-9.

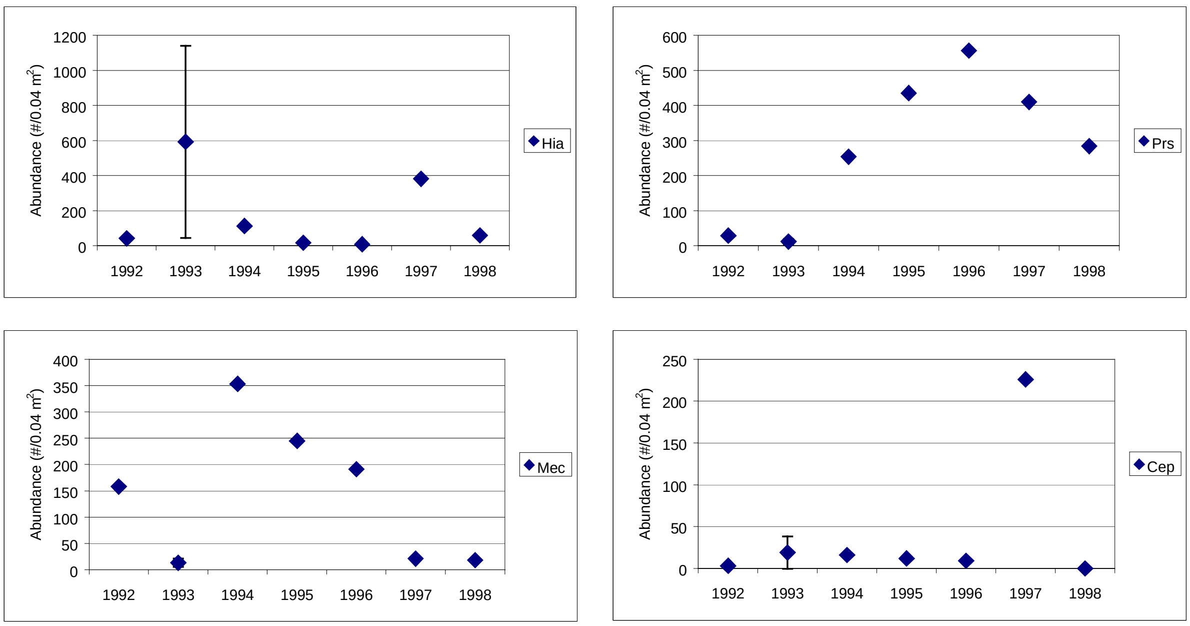


Figure 7.3-11. Abundance of selected infaunal species at station NF02 sampled during 1992–1998. Species codes are as listed in Table 7.3-2. For 1993, the mean and 95 % confidence intervals are shown.

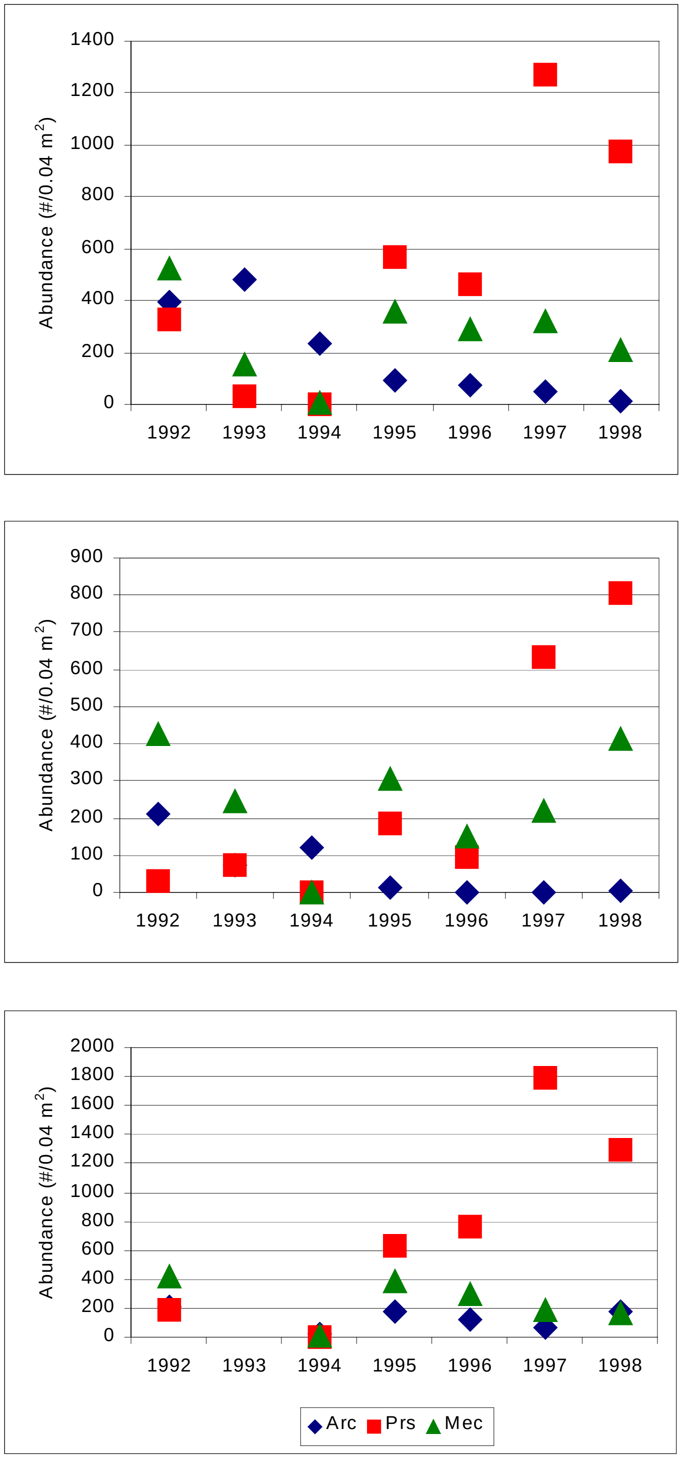


Figure 7.3-12. Abundance of selected annelid species at stations FF12 (top), NF16 (middle), and NF20 (bottom) sampled during 1992–1998. Species codes are as listed in Table 7.3-2. Station NF20 was not sampled in 1993.

A very noticeable feature of the cluster analysis of all Nearfield samples was a large subgroup (71 samples) that included only one sample (NF18, 1992) that was collected < 2 km from the outfall (Appendix F-2). This cluster was comprised of samples collected > 2 km from the outfall, but excluded all of those collected from stations near the mouth of Boston Harbor (FF12, FF13, NF02, NF22). These samples generally were characterized by higher abundances of annelids that were associated with a wide range of sediments and low abundances of animals that tended to be associated only with sandy sediments (Figure 7.3-10).

Among the stations located close to the mouth of Boston Harbor, samples from station NF02 did not tend to cluster together, indicating that samples collected during different years of the program were not very similar. Samples from station NF22 (which has been sampled only since 1994) showed some degree of consistency as those collected from 1995–1997 clustered together. However, those collected in 1994 and 1998 differed quite a bit from each other and from those collected during the other three years. Samples collected from station FF13 generally aligned into two widely dissimilar sets. All samples collected in 1996 and 1997 joined as one set that also included single samples collected during 1992, 1995, and 1998. All samples collected during 1993 and 1994 and two replicates collected in 1995 and 1998 were part of the same subset of stations, which also was relatively similar to the two remaining replicates collected in 1992. With the exception of the 1994 samples discussed earlier, samples collected from station FF12 during the program have been fairly similar. Those collected from 1992 and 1993 formed one distinct subset and those collected since 1995 formed another distinct group. Both groups were much more similar to each other than they were to the 1994 samples. The samples collected after 1995 appeared to be linked by high abundances of *Prionospio steenstrupi*, *Tharyx acutus*, and, in particular, *Owenia fusiformis* (Figure 7.3-13). The 1992–1993 samples were distinguished by relatively high numbers of *Aricidea catherinae* and low numbers of *Owenia fusiformis*.

7.3.3 Nearfield/Farfield Multivariate Analyses, Combined 1992–1998 Data Set

Q-mode cluster analysis was performed on all Massachusetts Bay samples collected from 1992 to 1998. The dendrogram depicting the results of this analysis is presented in Appendix F-3). Examination of the dendrogram, and the metric scaling plot comparing PCA-H axes 1 versus 2 (Figure 7.3-14), showed the interrelationships among Nearfield and Farfield samples. Observations included the retention of the Nearfield sandy stations (primarily NF13, NF17, and NF23) as a distinct group (upper right corner of Figure 7.3-14), primarily characterized by the annelid *Exogone hebes* and the amphipod *Crassicorophium crassicorne* (Figure 7.3-15). Samples from the two Cape Cod Bay stations, FF06 and FF07, formed a distinct cluster, more clearly distinguished in the metric scaling plot comparing PCA-H axes 1 versus 3 (Figure 7.3-16). Samples from the eastern and northern Farfield stations (FF01A, FF04, FF05, FF11, and FF14) comprised a relatively large subgroup (Figure 7.3-14 and Figure 7.3-16) characterized primarily by high abundances of the annelids *Cossura longocirrata*, *Levinsenia gracilis*, *Chaetozone setosa* MB, and *Tubificoides* sp. A (Figure 7.3-15). All samples collected from station FF09 comprised one group that was most similar to some samples from stations NF07, NF15, and NF19 (Figure 7.3-16). These were characterized primarily by relatively high abundances of *Spio limicola* (Figure 7.3-17). This analysis showed that station location was usually more important than year in determining the alliances within the various cluster groups. Thus, the samples collected in 1998 fit well within the overall Massachusetts/ Cape Cod Bay baseline observed since 1992.

The 41 most important contributors to CNESS distances among the 1992–1988 Nearfield data are listed in Table 7.3-3.

Table 7.3-3. The 41 most important contributors to CNESS distances among all Massachusetts Bay samples collected from 1992 to 1998. "Cont" is the contribution to overall CNESS distances, "Total Cont" is the cumulative amount of CNESS variation explained by species (85% by the top 41 species). The final columns indicate the contribution of each species to each of the first six PCA-H axes.

No.	Species	Spp. Code	CONT	TCON	PCA-H Axes					
					1	2	3	4	5	6
1	*Spio limicola*	SpL	7	7	8	4	34	11	5	0
2	*Prionospio steenstrupi*	Prs	7	14	1	9	2	56	3	1
3	*Aricidea catherinae*	Arc	5	19	4	9	7	5	9	0
4	*Dipolydora socialis*	DiS	4	24	2	0	20	3	7	14
5	*Cossura longocirrata*	Col	4	28	6	2	8	9	10	1
6	*Tharyx acutus*	Tha	4	32	2	10	6	1	1	5
7	*Mediomastus californiensis*	Mec	4	35	2	15	1	1	0	0
8	*Levinsenia gracilis*	Leg	3	39	11	0	0	1	3	6
9	*Exogone hebes*	Exh	3	42	7	3	3	0	1	2
10	*Aricidea quadrilobata*	Arq	3	44	11	4	0	0	0	0
11	*Crassicorophium crassicorne*	Crc	2	47	5	7	0	0	0	3
12	*Euchone incolor*	Eui	2	49	2	0	1	0	13	7
13	*Chaetozone setosa* MB	Chs	2	52	5	4	0	1	3	0
14	*Aphelochaeta marioni*	Apm	2	54	0	2	2	0	0	9
15	*Nucula delphinodonta*	Nud	2	56	0	1	0	0	6	4
16	*Monticellina baptisteae*	Mob	2	58	0	5	0	0	5	8
17	*Ninoe nigripes*	Nin	2	60	0	6	0	0	1	11
18	*Tubificoides apectinatus*	Tua	2	62	3	2	0	1	4	1
19	*Exogone verugera*	Exv	2	64	2	0	4	0	2	1
20	*Spiophanes bombyx*	SPB	2	65	3	1	0	1	1	1
21	*Hiatella arctica*	Hia	2	67	2	0	0	0	0	1
22	*Owenia fusiformis*	Owf	1	68	1	0	0	1	0	0
23	Tubificidae sp. 2 (Blake 1992)	Tu2	1	70	0	0	1	2	3	0
24	*Polygordius* sp. A	PoA	1	71	1	2	0	0	0	1
25	*Anobothrus gracilis*	AnG	1	72	2	1	0	0	0	0
26	*Scalibregma inflatum*	Sci	1	73	1	0	1	0	1	1
27	*Cerastoderma pinnulatum*	Cep	1	74	1	1	0	0	0	0
28	*Pseudunciola obliquua*	Pso	1	75	1	2	0	0	1	1
29	*Nephtys cornuta*	NEC	1	76	0	0	1	0	1	5
30	*Leitoscoloplos acutus*	Lea	1	77	0	1	0	0	6	0
31	*Crenella decussata*	Crd	1	78	0	0	1	0	0	0
32	*Thyasira gouldi*	Thg	1	79	2	0	0	0	0	0
33	*Unciola inermis*	Uni	1	80	1	1	0	0	0	0
34	*Maldane sarsi*	Mas	1	80	0	0	0	0	1	0
35	*Phyllodoce mucosa*	phm	1	81	1	0	0	0	1	2
36	*Dipolydora quadrilobata*	DiQ	1	82	0	0	1	0	0	0
37	*Yoldia sapotilla*	Yos	1	83	2	0	0	0	0	0
38	*Onoba pelagica*	Onp	1	83	0	0	1	1	1	0
39	*Scoletoma hebes*	Sch	1	84	0	0	0	0	1	1
40	*Grania postclitello longiducta*	Grl	1	84	0	0	0	0	0	0
41	*Photis pollex*	PhP	1	85	0	0	0	0	0	2

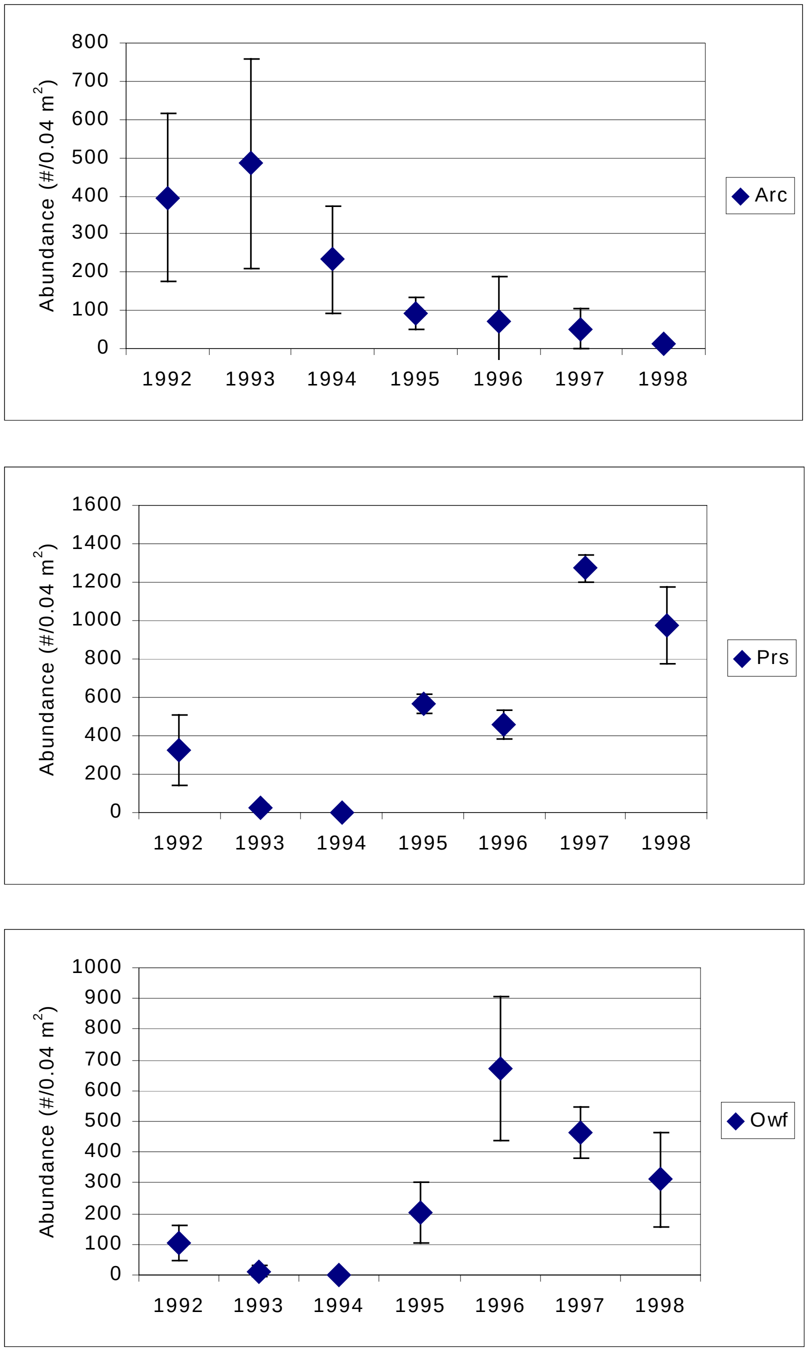


Figure 7.3-13. Abundance of selected annelid species at station FF12 sampled during 1992–1998. Species codes are as listed in Table 7.3-2. For each year, the mean and 95 % confidence intervals are shown.

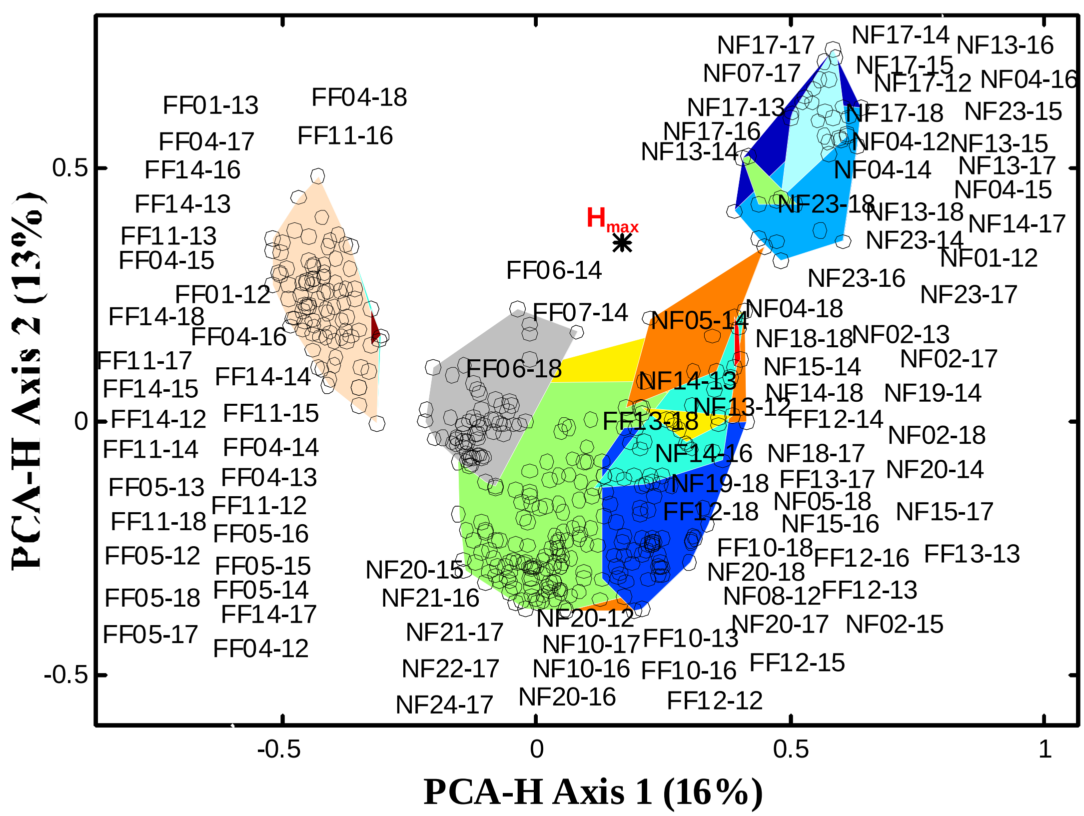


Figure 7.3-14. Metric scaling plot of CNESS distances, axes 1 versus 2, among Massachusetts Bay Nearfield and Farfield stations sampled from 1992 to 1998. Results of the CNESS cluster analysis are shown as convex hulls. All stations are not labeled; some labels have been placed outside their respective clusters.

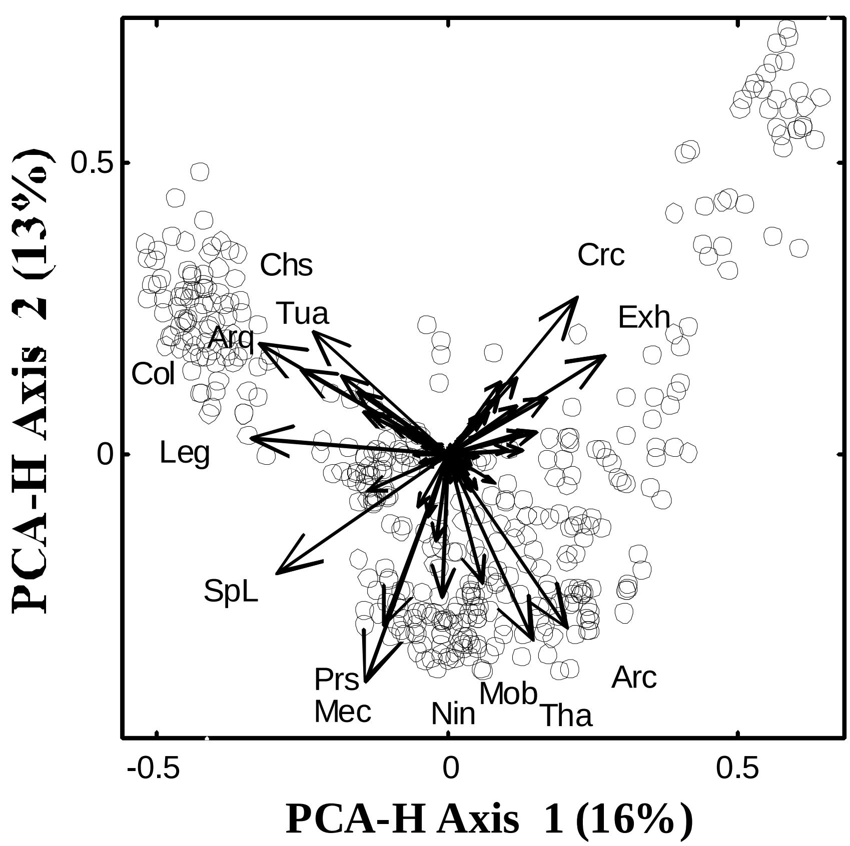


Figure 7.3-15. Gabriel Euclidean distance biplot, axes 1 versus 2, for the 1992–1998 Massachusetts Bay Nearfield and Farfield data showing those species that control the orientation of samples shown in Figure 7.3-14. Species codes are as listed in Table 7.3-3. Open circles represent the spatial pattern of samples shown in Figure 7.3-14.

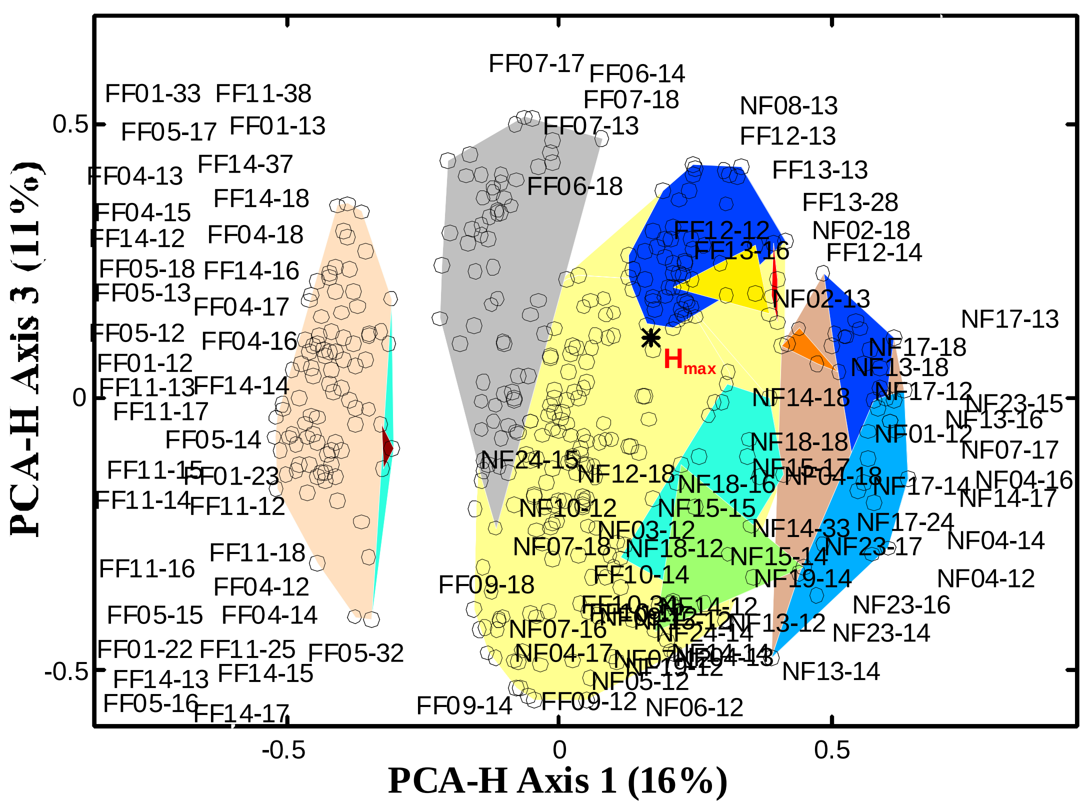


Figure 7.3-16. Metric scaling plot of CNESS distances, axes 1 versus 3, among Massachusetts Bay Nearfield and Farfield stations sampled from 1992 to 1998. Results of the CNESS cluster analysis are shown as convex hulls. All stations are not labeled; some labels have been placed outside their respective clusters.

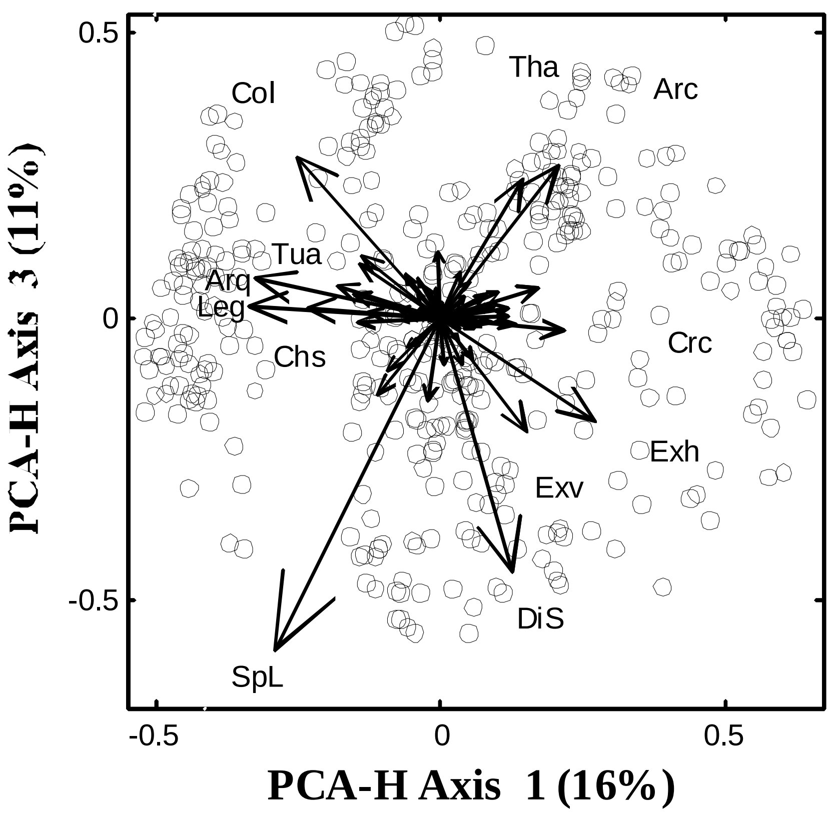


Figure 7.3-17. Gabriel Euclidean distance biplot, axes 1 versus 3, for the 1992–1998 Massachusetts Bay Nearfield and Farfield data showing those species that control the orientation of samples shown in Figure 7.3-16. Species codes are as listed in Table 7.3-3. Open circles represent the spatial pattern of samples shown in Figure 7.3-16.

7.3.4 Summary of Findings

Among the key findings of the 1998 outfall benthic analyses are

- The infaunal community metrics calculated for the 1998 samples where generally similar to those calculated in previous years of the program.

- The Nearfield sand-dwelling infaunal community, found at stations NF04, NF14, and NF18, has been found consistently throughout the program although specific station composition of the community changes occasionally. Characteristic taxa include *Exogone hebes* and *Exogone verugera*.

- A second group of Nearfield stations, NF13, NF17, and NF23 were clearly distinguished from the other Nearfield stations, as they have generally been in the past. In 1998, this group was characterized primarily by *Polygordius* sp. A and *Spiophanes bombyx*.

- The general features of the 1998 combined Nearfield and Farfield analysis were similar to those presented in earlier studies.

- Consideration of the entire monitoring program data set (1992–1998) revealed an increasing trend in species diversity since 1993. This will be discussed in more detail in Section 7.5.

7.4 Spatio-temporal Trends in Hard-Bottom Communities (1994–1998) [by Barbara Hecker]

Baseline monitoring of the Nearfield hard-bottom communities in the vicinity of the outfall has been conducted for the last 5 years. This has provided a data base that has allowed characterization of the habitat characteristics and benthic community structure of Nearfield hard-bottom areas. During this time period the sampling design and approach have evolved to maximize the probability of detecting potential impacts of future outfall operations. The 1994 survey consisted of video coverage along a series of transects of hard-bottom areas adjacent to the outfall. Since 1994 the sampling protocol has been changed to surveying discrete stations (waypoints) on the drumlins immediately north and south of the outfall, and at several reference sites on drumlins further away (Figure 7.4-1). The 1995 sampling plan consisted of 19 waypoints, 17 near the outfall (on Transects 1, 2, 4 and 6) and 1 at each of 2 reference sites (Transects 7 and 8). In 1996, one additional waypoint was added at each of the reference sites and T6-3 was dropped because it was found to be exceptionally depauperate. Two new reference sites (Transects 9 and 10), and the head of Diffuser #44, were added during the 1997 survey. Diffuser #44 was added to the survey protocol because it is not scheduled to go online and hence represents a worst case scenario of potential impact. This sampling protocol of 23 waypoints, 16 on the drumlins near the outfall, 6 at reference sites, and Diffuser #44, was repeated in 1998.

The emphasis on data products also has evolved during this time period. The 1994 and 1995 data sets relied mainly on an analysis of video footage. During the 1995 survey a few still photographs also were taken at each of the sites. Analysis of these photographs showed that the resolution afforded by the still photographs was far superior to that of the video tapes, and hence subsequent emphasis has been shifted to analysis of still photographs. The video images cover a much broader area than the still photographs, and are used primarily to assess habitat relief and heterogeneity and the occurrence of large motile fauna. The still photographs are used to provide detailed data on habitat characteristics (substrate size classes and amount of sediment drape), estimated percent cover of encrusting algae, estimated relative abundance of upright algae, and faunal composition of the benthic communities.

Analysis of the last four years of video and 35-mm still photographs showed a temporally stable pattern in the structure of benthic communities inhabiting the hard-bottom areas in the vicinity of the outfall. The hard-bottom habitats are spatially quite variable, but showed several consistent trends during the study period. Figure 7.4-2 shows the pattern of habitat characteristics observed during the 1995 to 1998 surveys. Location on the drumlins appeared to be a primary factor in determining habitat relief. The sea floor on the tops of drumlins usually consisted of a mix of boulders and cobbles. Habitat relief varied from high in areas dominated by boulders (T2-2, T2-3, T4-4, T7, T9, and T10) to moderate in areas consisting of a mix of cobbles and boulders (T1 and T8). Sediment drape on the tops of drumlins ranged from light to moderate at some locations (T1-3, T1-4, T4-4, T7, and T8) and heavy at others (T2-2, and T9, T10). The sea floor on the flanks of drumlins was quite variable, but usually consisted of a cobble pavement interspersed with patches of sand, gravel, and occasional boulders. Habitat relief of the drumlin flanks ranged from low to moderate, depending on how many boulders were present. Sediment drape in the flank areas usually ranged from moderate to heavy. Lateral shifts in ROV position in relation to drumlin topography frequently resulted in substantially different habitat characteristics (i.e., T1-1, T1-2, T2-2 and T2-3).

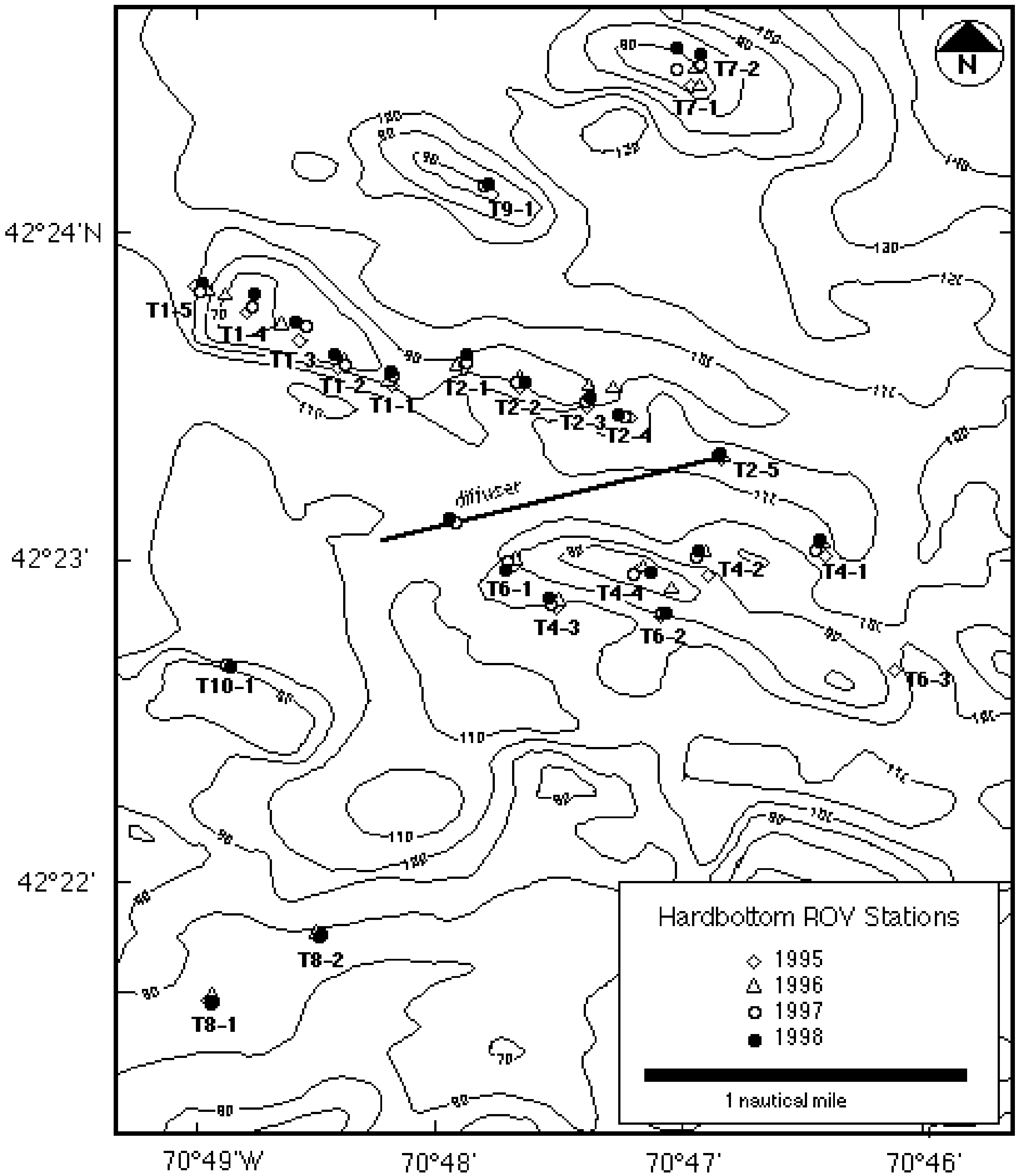


Figure 7.4-1. Nearfield hard-bottom stations surveyed from 1995 to 1998.

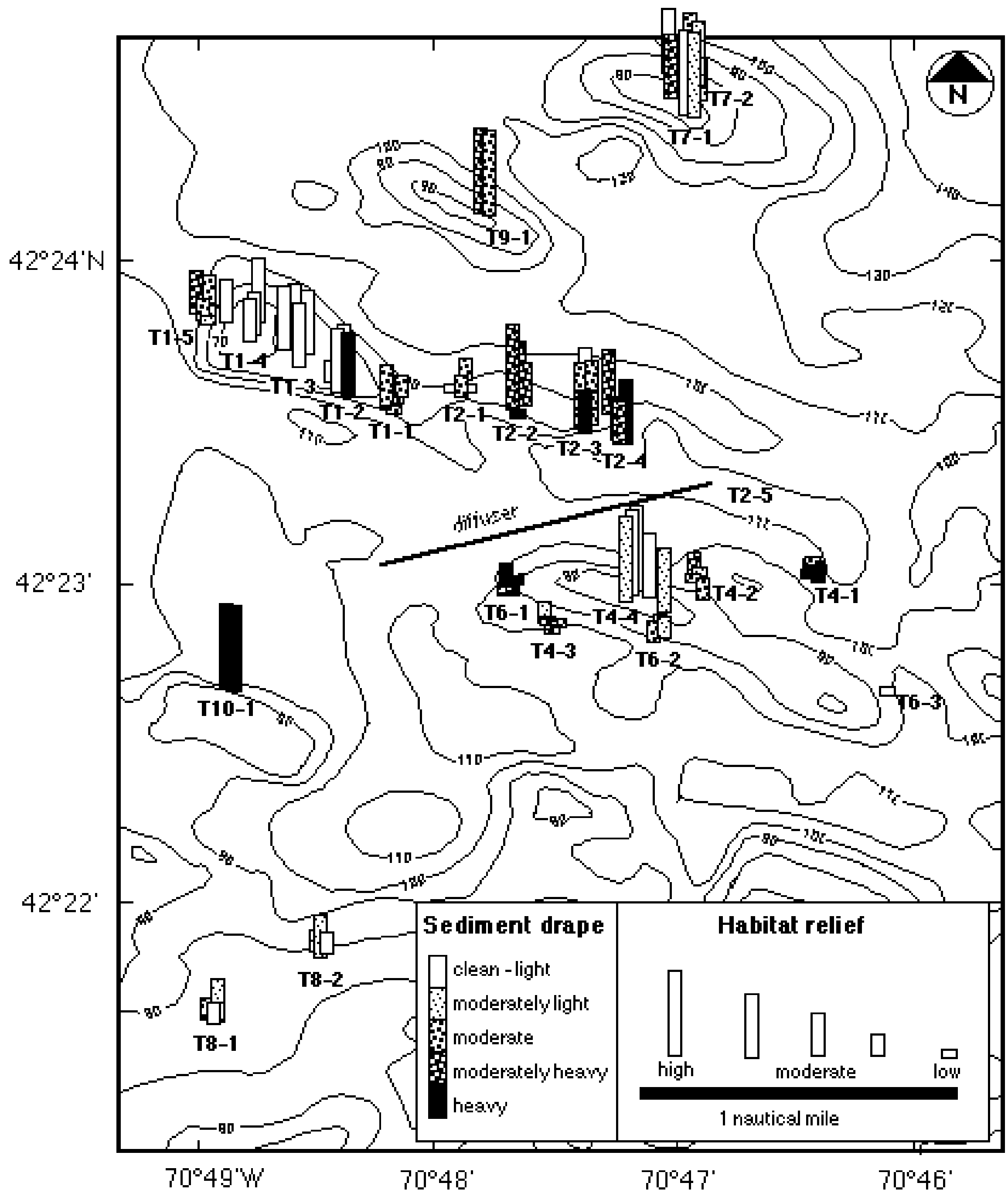


Figure 7.4-2. Sea floor characteristics, habitat relief and sediment drape, determined from the 1995 to 1998 Nearfield hard-bottom surveys.

The benthic communities inhabiting the hard-bottom areas showed a temporally consistent trend during the 1995 to 1998 time period. Algae usually dominated on the tops of drumlins, while invertebrates (mostly encrusting or attached forms) were increasingly dominant on the flanks. The encrusting coralline alga *Lithothamnion* spp. was the most common and widely distributed alga encountered during this study. Its distribution and areal cover were temporally quite stable during the four years of this study. Figure 7.4-3 shows the percent cover of *Lithothamnion* estimated from the 35-mm images taken from 1995 to 1998. It was most abundant on the top of drumlins (50 to 96 percent cover), less abundant on the flanks of drumlins (0 to 20 percent cover), and least abundant near the diffuser (0 to 2 percent cover). Table 7.4-1 shows the percent cover of *Lithothamnion* estimated for the three years (1996-1998) in which comparable data were collected. The percent cover of *Lithothamnion* was most variable near the edges of the tops or on the flanks of drumlins, where small lateral shifts in location resulted in very different habitat characteristics. Part of the decrease in percent cover with distance from the top of drumlins is undoubtedly related to light attenuation with depth. Figure 7.4-4 shows the relationship between percent cover of *Lithothamnion* and depth at the sites covered during the surveys. There is a general trend of lower coverage of *Lithothamnion* with increasing depth. However, at most of the depths surveyed the percent cover varied from 5 to 90 percent. A plot of mean percent cover of *Lithothamnion* versus habitat characteristics shows that its abundance appears to be mainly related to sediment drape; percent cover was highest in areas that had little sediment drape and lowest in areas with moderate to heavy sediment drape (Figure 7.4-5). This is not surprising, because the encrusting growth form of *Lithothamnion* would make it susceptible to smothering by fine particles.

In contrast, the abundance and distribution of three upright algae, the filamentous red alga *Asparagopsis hamifera*, the dulse *Rhodymenia palmata*, and the shotgun kelp *Agarum cribosum*, appeared to be controlled mainly by habitat relief. These algae were patchily distributed and were only abundant on the tops of boulders in areas of moderate to high relief. Figure 7.4-6 shows the relationship between *A. hamifera* and habitat relief. The abundance of *A. hamifera* increased with increasing habitat relief. Sediment drape in areas supporting high abundances of upright algae ranged from moderate to high. The holdfasts of the algae appeared to trap sediment actively, thereby excluding the encrusting *Lithothamnion*. Additionally, invertebrates and fish (mainly the cunner, *Tautogolabrus adspersus*) were generally more abundant in areas of moderate to high relief and less abundant in areas of low relief.

The pattern of benthic community structure in the hard-bottom areas was remarkably consistent from 1996 to 1998. Figure 7.4-7 shows the distribution of benthic communities defined by hierarchical classification analysis. The dendrograms were remarkably similar among the three years (see Blake et al. 1997, Blake et al. 1998 for 1996 and 1997 dendrograms). Of 10 instances of waypoints differing in their cluster designations among the years, 6 appeared to reflect slight lateral shifts in relation to drumlin topography (Table 7.4-2). The other four instances of different cluster group designations appeared to be related to the generally patchy nature of the hard-bottom habitats. Communities dominated by upright algae were found on the tops of drumlins on either side of the diffuser (T1-1, T2-2, T2-3, T2-4, and T4-4) and at all three of the northern reference sites (T7-1, T7-2, and T9-1). In contrast, *Lithothamnion* dominated the benthic communities on top of a drumlin located northwest of the diffuser (T1-2, T1-3, and T1-4), at two of the southwestern reference sites (T8-1 and T8-2), and at some of the drumlin flank sites. Two of the flank sites located just south of the diffuser had exceptionally low abundances of *Lithothamnion* and were relatively depauperate (T4-3 and T6-1). The diffuser heads that were surveyed were colonized by *Metridium senile* and *Asterias vulgaris* (T2-5 and Diffuser #44). These patterns also generally agree with the results obtained in 1995. No attempt at a direct community analysis comparison with the 1995 data was made, because of the limited number and non-random collection of the 35-mm images taken during that year.

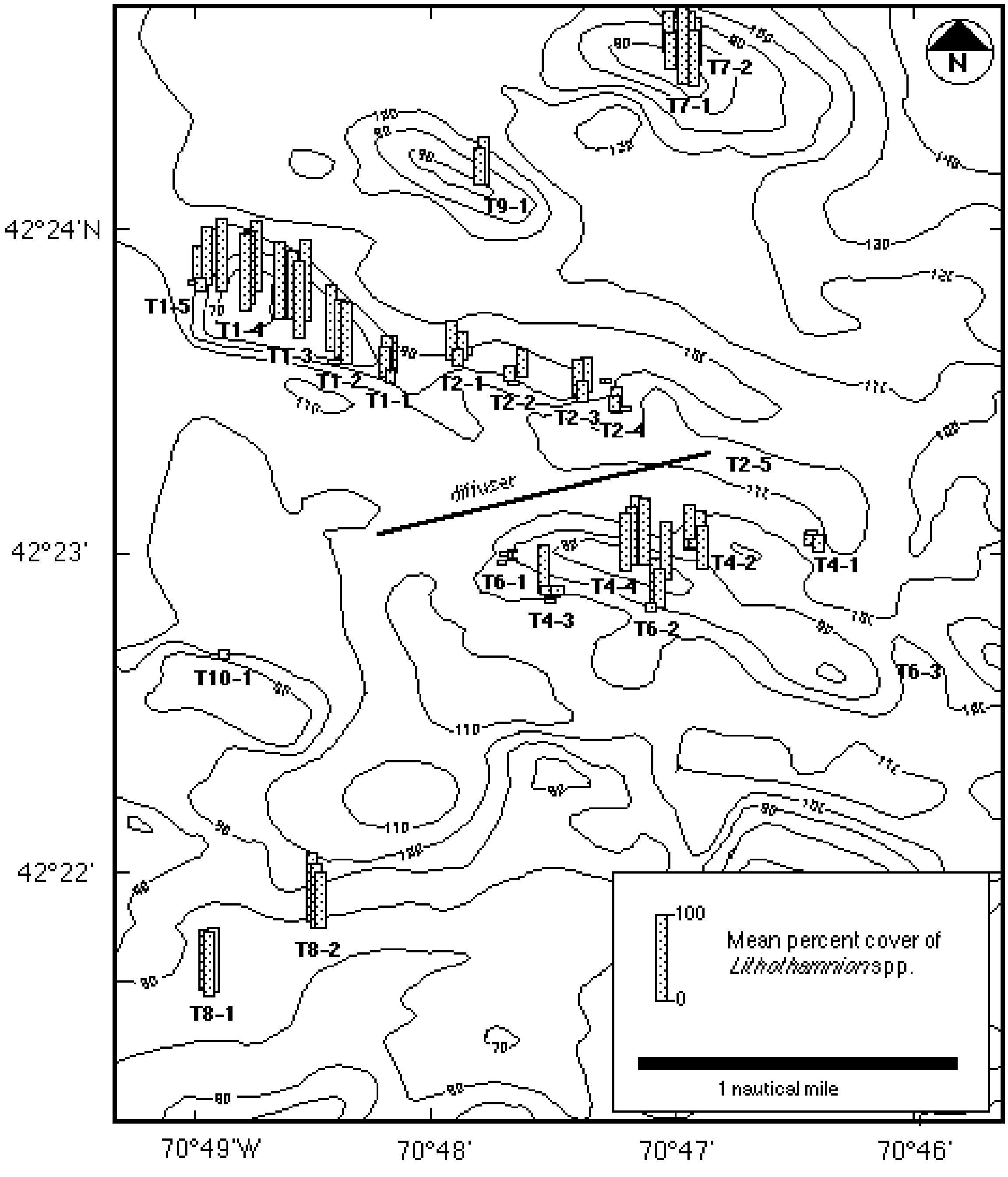


Figure 7.4-3. Mean percent cover of the encrusting coralline alga *Lithothamnion* spp. determined from the 1995 to 1998 Nearfield hard-bottom surveys.

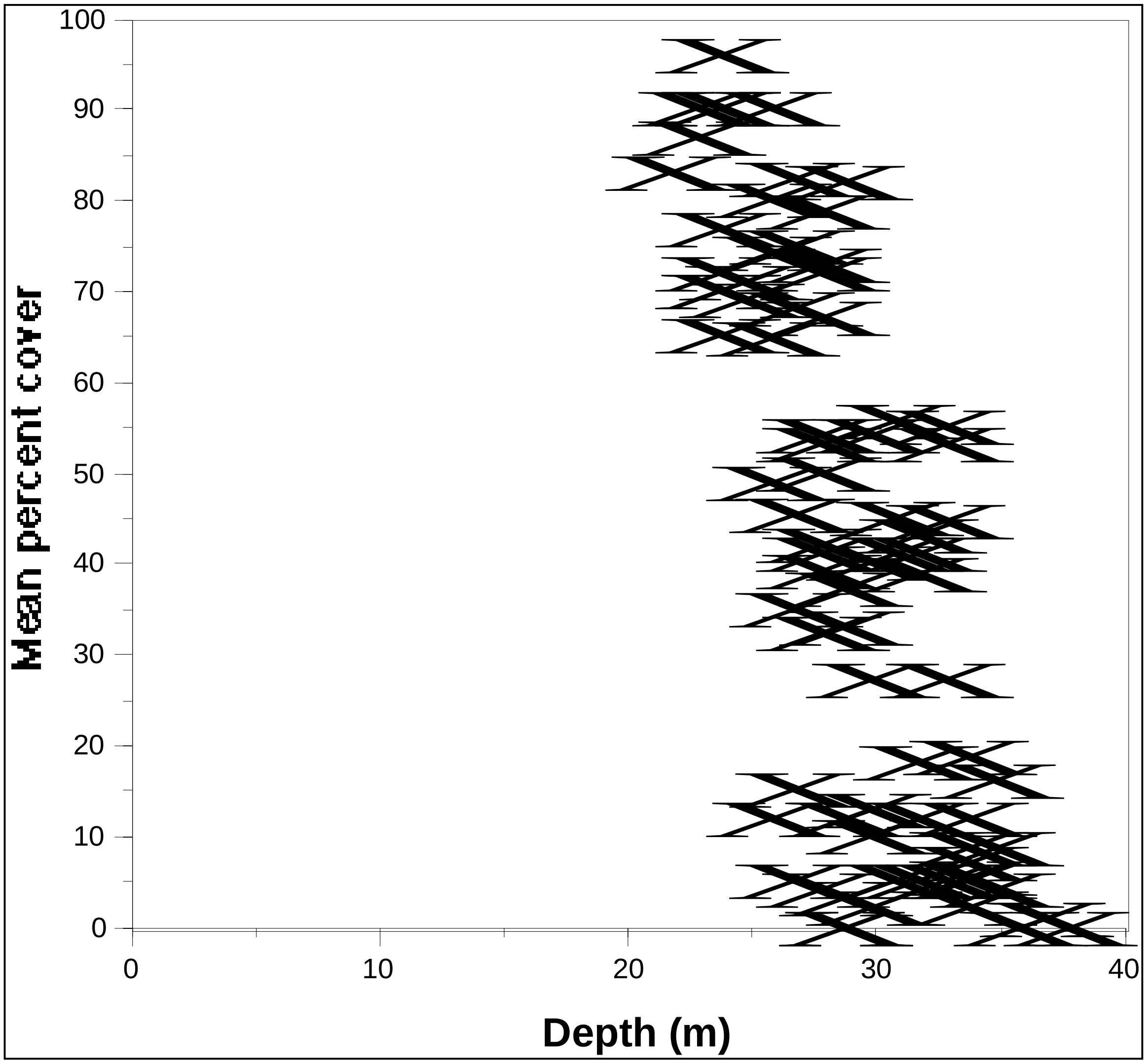


Figure 7.4-4. Mean percent cover of *Lithothamnion* spp. versus depth from the 35-mm images taken at each waypoint during the 1995 to 1998 Nearfield hard-bottom surveys.

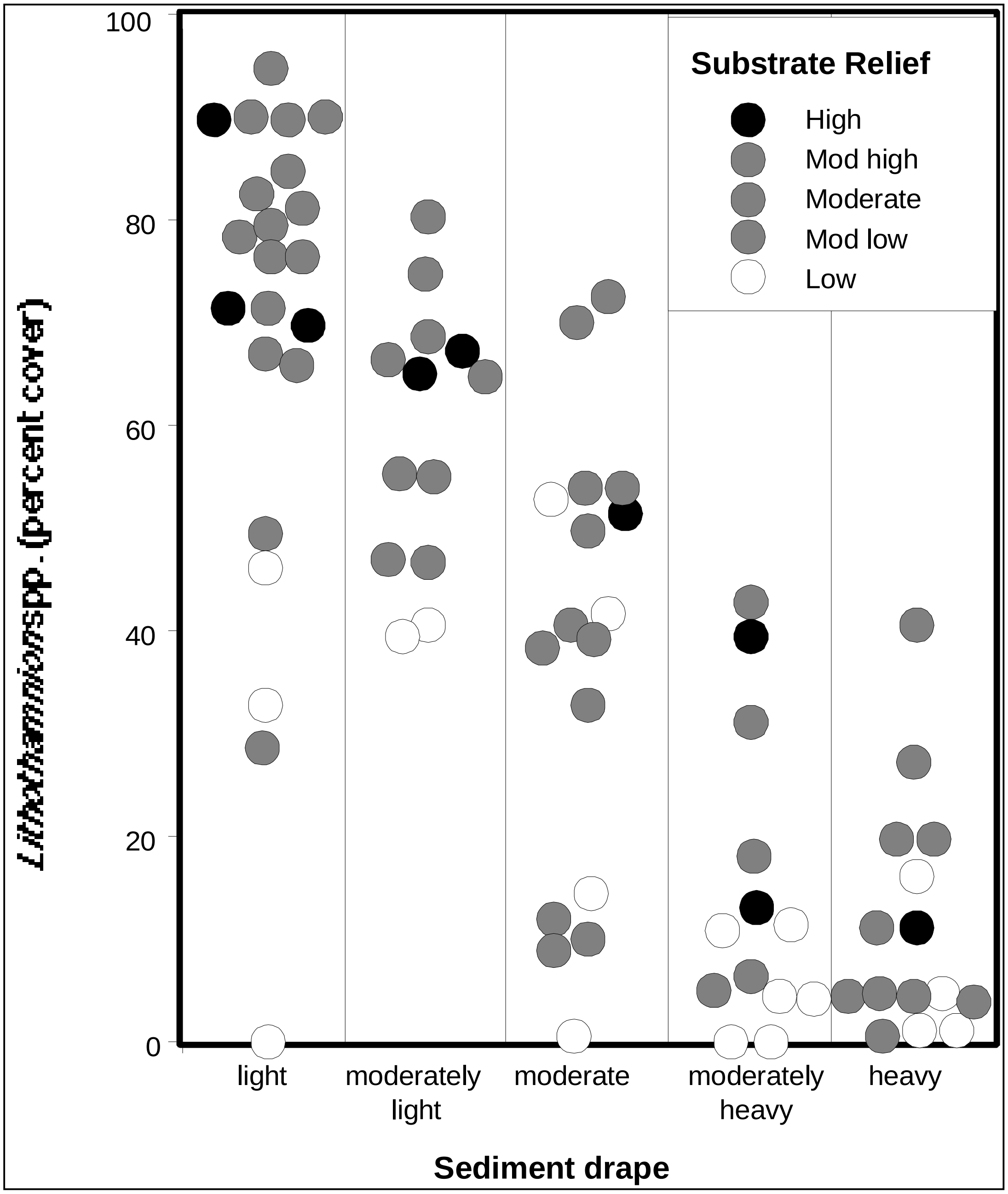


Figure 7.4-5. Percent cover of *Lithothamnion* spp. in relation to sediment drape and habitat relief. Based on yearly averages of 35-mm images taken at each waypoint during the 1995 to 1998 Nearfield hard-bottom surveys.

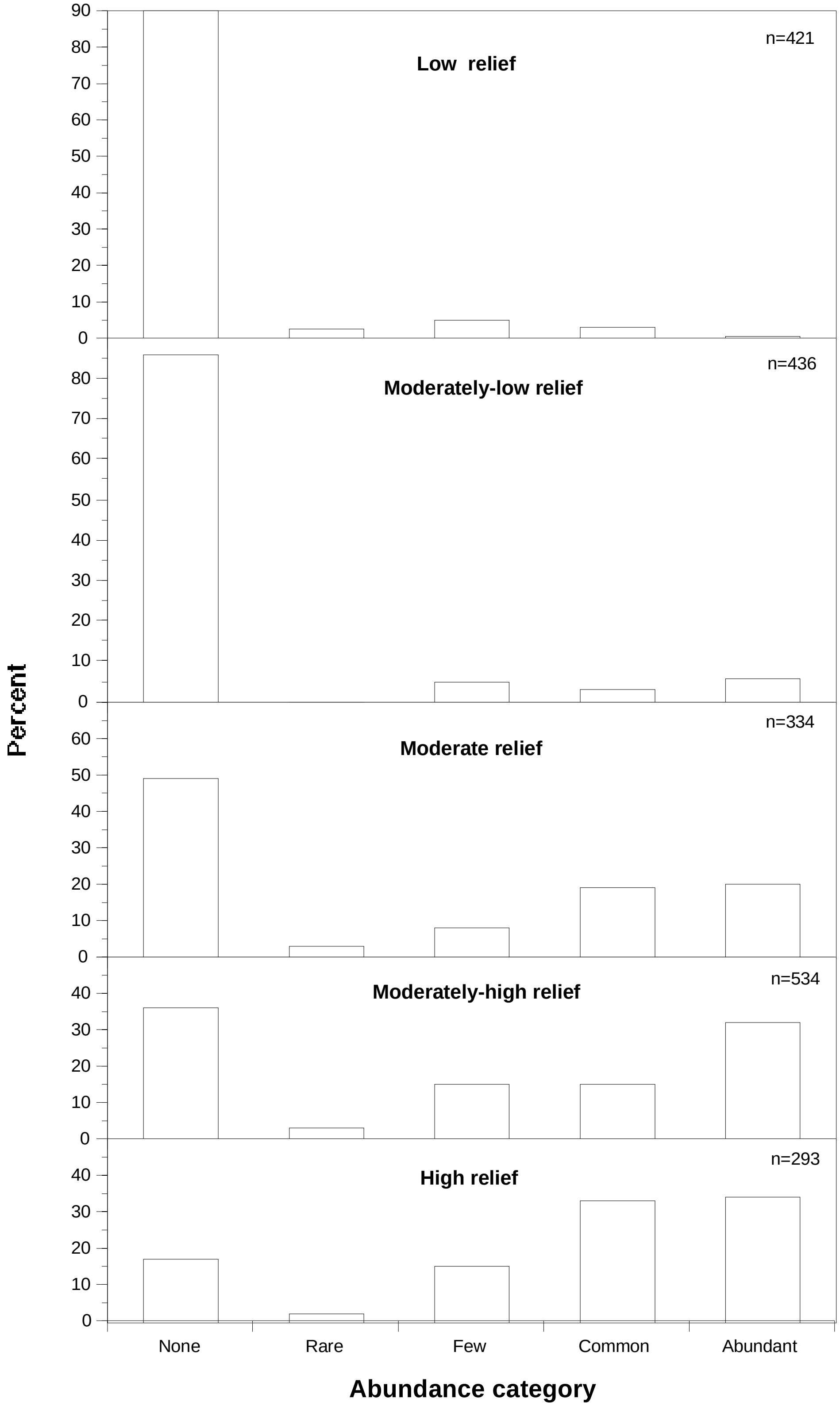


Figure 7.4-6. Relative abundance of the filamentous red alga *Asparagopsis hamifera* in relation to habitat relief. Based on individual 35-mm images taken during the 1995 to 1998 Nearfield hard-bottom surveys.

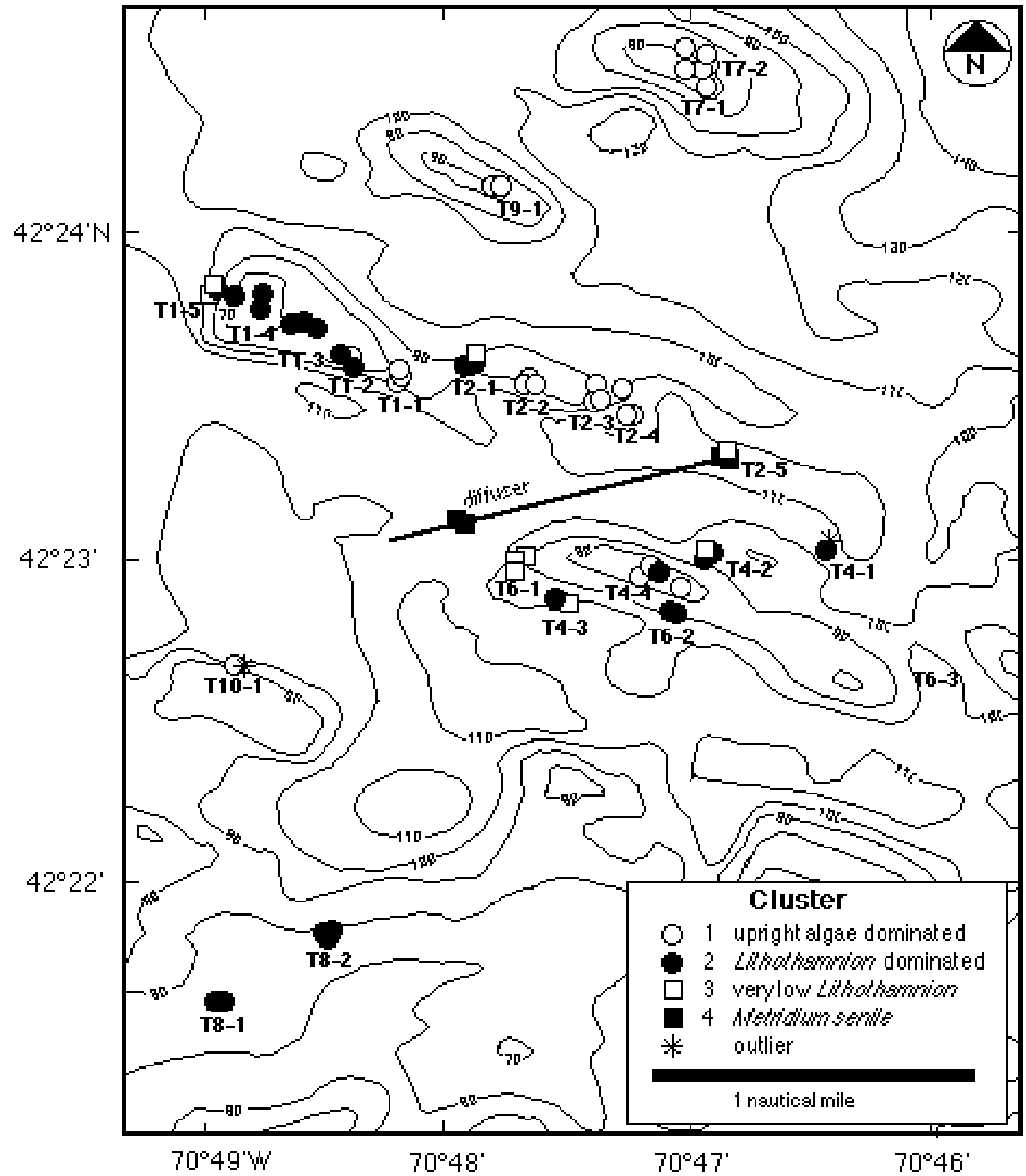


Figure 7.4-7. Map of benthic communities defined from classification of the 35-mm images taken during the 1996 to 1998 Nearfield hard-bottom surveys.

Table 7.4-1. Estimated mean percent cover of *Lithothamnion* spp. from 1996 to 1998. Large differences are high lighted in bold. Asterisks mark differences that appear to be related to shifts in position of the areas surveyed.

Transect	Waypoint	1996	1997	1998
1	1	35	42	37
	2	71	72	79
	3	90	96	80
	4	87	83	82
	5	**68***	**12***	**39***
2	1	45	33	**9***
	2	5	13	**33***
	3	27	41	39
	4	**7***	27	18
	5	<1	<1	<1
4	1		16	**<1***
	2	41	53	**9***
	3	12	12	**56***
	4	72	67	77
6	1	2	4	5
	2	**69***	55	45
7	1	65	43	49
	2	53	54	45
8	1		73	74
	2	82	75	65
9	1		40	54
10	1		12	**<1**
Diff	44		<1	<1

Table 7.4-2. Cluster group designations defined by classification analysis of the waypoints surveyed from 1996 to 1998. Differences are high lighted in bold. Asterisks mark differences that appear to be related to shifts in position of the areas surveyed.

Transect	Waypoint	1996	1997	1998
1	1	1	1	1
	2	**1**	2	2
	3	2	2	2
	4	2	2	2
	5	**2***	3	3
2	1	2	2	**3***
	2	1	1	1
	3	1	1	1
	4	1	1	1
	5	4	4	3*
4	1		2	**outlier***
	2	2	2	**3**
	3	3	3	**2**
	4	1	1	**2***
6	1	3	3	3
	2	**1***	2	2
7	1	1	1	1
	2	1	1	1
8	1		2	2
	2	2	2	2
9	1		1	1
10	1		1	**outlier**
Diff	44		4	4

The 1998 results are generally similar to those reported by Coats et al. (1995) from the video survey conducted in 1994. Four of the eight 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 appeared to be related to visual resolution of the film and taxonomic designations. The 1995, 1996, 1997, and 1998 surveys respectively identified 76, 72, 100 and 84 taxa, compared to 37 identified from the 1994 video survey. Many of the additional taxa identified in the present study are encrusting or other attached organisms. Rather than indicating changes in the benthic communities in this region, the difference in numbers of taxa is undoubtedly a result of the greater resolution afforded by the ROV being closer to the sea floor (right on the bottom as opposed to an altitude of 1–3 m), and the greater reliance on still photographs, in the present study. Coats et al. identified an abundant pinnate red alga as *Rhodymenia* sp. A, this appears to be the filamentous red alga that we have identified as *Asparagopsis hamifera*. Additionally, their Porifera sp. A was an orange encrusting sponge, which 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 partially related to habitat differences between the areas surveyed. The 1987 survey covered mostly depositional sediment areas, whereas the present study concentrated mostly on erosional hard substratum areas (drumlins). At any given depth, sediment generally supports fewer epifaunal species per unit area than does hard substrate (B. Hecker, personal observation). This may be related to the generally more limited availability of hard substrates in subtidal environments. Even in the deep sea, occasional hard surfaces (i.e., boulders, ship wrecks, airplane wrecks, and nuclear-waste drums) are almost always heavily colonized by attached taxa.

General faunal distribution patterns were similar among all the surveys. Algae were 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 substrata at shallower depths. In later surveys (1995–1998), cobbles and smaller boulders were dominated by *Lithothamnion* and the tops of larger boulders were dominated by *Asparagopsis hamifera*. While Coats et al. estimated percent cover of *Lithothamnion*, they did not discuss its distribution. All three sets of 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. A similar result, that this urchin was most abundant on the tops of drumlins, was found in the later surveys, but the distribution of the urchin was attributed to availability of their primary food source, the coralline alga *Lithothamnion*.

Because of the different overall focus of the Coats et al. (1995) report, more detailed comparisons of community structure and factors that control it can not be made. Moreover, use of a different navigational grid by Coats et al. makes direct comparisons of respective transect locations impossible.

The baseline surveys showed that the hard-bottom benthic communities near the outfall were relatively stable over the 1995 to 1998 time period. The remarkable similarity among the 1996 to 1998 surveys indicated that substantial departures from baseline conditions should be detectable. The expanded emphasis on 35-mm images has enabled better resolution of factors controlling the distributions of several of the dominant taxa. Larger boulders appeared to be the predominant substrate for upright algae and a number of attached invertebrate taxa. This is not surprising since larger rocks would be less susceptible to mechanical disturbance. Boulders were frequently the dominant size class observed on the top of drumlins. In contrast, the distribution of the encrusting coralline alga *Lithothamnion* appeared to be related primarily to degree of sediment drape. Not surprisingly, sediment loading also appeared to restrict many other encrusting and sessile taxa, which frequently were restricted to the sides and underhangs of boulders. Sediment drape was frequently heavier on the flanks of drumlins.

The amount of sediment drape on rocks frequently varied widely within sites, with totally clean rocks adjacent to rocks heavily covered with sediment. This resulted in a fair amount of small-scale within-site heterogeneity in the distributions of many of the taxa. Concerning the detection of habitat degradation as a result of the outfall coming on line, *Lithothamnion* appeared to hold the greatest promise as an indicator species. It was the most predictable taxon encountered in terms of abundance, distributional pattern, and habitat requirements. It was the least patchily distributed taxon, and appeared to dominate in all areas that were shallower than 33 m (~110 ft) and that had little sediment drape. Additionally, it was common in areas of high and low relief. By focusing on *Lithothamnion* as an indicator, it is likely that major changes in the benthic communities inhabiting the hard-bottom areas near the outfall could be detected.

Potential impacts might include changes in the amount of particulate material reaching the sea floor. A marked decrease in the percent coverage of *Lithothamnion* likely would result if materials discharged from the outfall were to accumulate in the vicinity of the drumlins. 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*. If water clarity were reduced it is expected that the lower depth limit of high coralline algal coverage would be reduced. Conversely, if water clarity were increased, then it is expected that high coralline algal coverage would extend into some of the deeper areas.

7.5 Evaluation of species diversity during baseline monitoring, 1992–1998 [by Eugene D. Gallagher and Kenneth E. Keay]

Once outfall discharge begins, Contingency Plan thresholds (MWRA 1997) based on species diversity analyses will be used to rapidly assess (as soon as raw data pass internal QA/QC checks) whether there has been an unexpected change in benthic community structure from conditions measured during baseline monitoring. More detailed assessments, analyses, and interpretations will continue to be included in annual synthesis reports (e.g. this report). Analyses in this Section were carried out to explore issues of detectable change for the diversity measures to be used in threshold testing. Serendipitously, these analyses revealed a striking change in infaunal species richness in the system that has occurred during baseline sampling.

7.5.1 Methods

Four diversity indices were used for this exploratory analysis: Log-Series alpha, an unbiased estimator of species richness; Pielou's *J'*, an unbiased estimator of species eveness; Shannon's *H'*, a diversity measure sensitive to both species richness and evenness; and the total number of species per grab, another estimator of species richness.

Two simple evaluations were used to determine if statistically significant change could be detected in the baseline data. 1992–1998 data were parsed into two bins, a "Nearfield" pool consisting of all Nearfield stations and stations FF10, FF12, and FF13, and a Farfield pool containing all remaining Farfield stations. All samples were pooled independently; replicate grabs from a station were not averaged together before annual or "baseline" averages were calculated.

First, for each bin (Nearfield and Farfield) all samples collected from 1992 through 1997 were pooled. The mean of this "sample" was compared with pooled replicate grabs from 1998. This univariate ANOVA only tests the difference between these means. After the outfall goes online, the same type of statistical test could be performed to compare the entire baseline dataset versus the data for a discharge year. This should not be regarded as a formal test for effect of the outfall. Indeed, according to Hurlbert (1984), the program's sampling design suffers from pseudoreplication. The problem is caused by using potentially inappropriate variance estimators and degrees of freedom to test the hypotheses of interest.

Second, for each bin, annual means and 95% confidence intervals were calculated. The annual means were then visually examined to see if any temporal trends were apparent.

Although initial testing of relevant Contingency Plan thresholds will be restricted to comparisons of an individual discharge year's data against a numeric threshold derived from baseline monitoring results, they are not the only diversity analyses that can be carried out for evaluation annual synthesis reports. For example, as multiple years of discharge monitoring data are obtained, pre- versus post-discharge ANOVAs using all available data could be carried out to more formally detect whether patterns of variability differ between all baseline and all discharge years. This might be a more formal test of an "outfall effect". However, our preliminary evaluation, based in part on the results discussed in this report, is that the substantial heterogeneity among stations within the Nearfield might require such analyses be carried out separately for each individual station, resulting in a formidable challenge to design, execute, and evaluate the analyses (Gallagher, personal observation).

7.5.2 Results/Discussion

As described above, ANOVA analyses were used to test whether the 1998 mean diversity was significantly different from the 1992–1997 baseline. Table 7.5-1 shows that, for Nearfield data, log-series alpha, total species, and Pielou's *J'* are significantly different in 1998 from the 1992–1997 baseline. The mean log-series alpha for the 1998 Nearfield stations and 95% confidence limits were 14.6 ± 1.1. The 1992–1997 mean log-series alpha is 12.7 ± 0.4. For the Farfield data, the mean for only total species was significantly different in 1998 compared to the 1992–1997 baseline.

In testing the 1998 Nearfield versus the pooled 1992–1997 Nearfield data, the assumption of homoscedasticity was not violated at an alpha of 0.05 (using the F_{max} test; Sokal and Rohlf 1995), although the *J'* homoscedasticity test was accepted with a probability of only 0.07. This indicated that the data should be checked carefully for homoscedasticity for similar tests in future years.

Upon inspection of the annual means (Table 7.5-2), it became clear that species richness, as measured by log-series alpha and species per grab, has been increasing in the Massachusetts Bay/Cape Cod Bay system (Figures 7.5-1, 7.5-2). No apparent trend was observed for either *J'* or *H'*.

Two distinct patterns are seen in the plots of species richness. For Farfield data, mean total species and log-series alpha remained somewhat stable from 1992 through 1995, then increased substantially in 1996 and again in 1997. In contrast, Nearfield data showed a dramatic decrease in richness from 1992–1993 (by ~33% for total species), then increased annually from 1994–1997. For both indices and for both Nearfield and Farfield data, mean species richness in 1998 was similar to that measured in 1997 (Figures 7.5-1, 7.5-2).

Table 7.5-1. Means and 95% confidence limits for selected diversity variables.

Variable	Near-Far	Case	N	Mean	Lower Bound	Upper Bound	*p*
Log-series alpha	Nearfield	1998	35	14.6	13.4	15.7	0.003
		1992–1997	205	12.7	12.3	13.2	
		All	240	13.0	12.6	13.4	**
Pielou's *J'*	Nearfield	1998	35	0.59	0.56	0.62	0.007
		1992–1997	205	0.63	0.62	0.64	
		All	240	0.63	0.61	0.64	**
Shannon's *H'*	Nearfield	1998	35	3.6	3.4	3.9	0.398
		1992–1997	205	3.7	3.7	3.8	
		All	240	3.7	3.6	3.8	ns
Total Species	Nearfield	1998	35	72.9	67.9	77.9	<0.001
		1992–1997	205	62.2	60.0	64.5	
		All	240	63.8	61.7	65.9	***
Log-series alpha	Farfield	1998	24	14.6	13.4	15.9	0.010
		1992–1997	144	12.9	12.4	13.4	
		All	168	13.2	12.7	13.6	ns
Pielou's *J'*	Farfield	1998	24	0.64	0.60	0.68	0.725
		1992–1997	144	0.65	0.63	0.67	
		All	168	0.65	0.63	0.66	ns
Shannon's *H'*	Farfield	1998	24	3.89	3.66	4.12	0.214
		1992–1997	144	3.71	3.60	3.82	
		All	168	3.74	3.64	3.84	ns
Total species	Farfield	1998	24	69.8	65.0	74.6	<0.001
		1992–1997	144	56.0	53.7	58.4	
		All	168	58.0	55.7	60.3	***

ns = not statistically significant

Table 7.5-2. Nearfield yearly means and 95% confidence limits (CI) for selected diversity variables. Probabilities derived from ANOVA significance tests are given in the final column.

Variable	Year	Nearfield				Farfield			
		N	Mean	Lower 95% CI	Upper 95% CI	N	Mean	Lower 95% CI	Upper 95% CI
Log-series alpha	1992	29	12.7	11.6	13.8	24	11.4	10.3	12.6
	1993	36	10.4	9.6	11.3	24	12.1	11.3	13.0
	1994	35	11.0	10.1	11.9	24	12.0	10.9	13.0
	1995	35	13.2	12.2	14.3	24	12.0	11.2	12.9
	1996	35	14.4	13.4	15.4	24	14.5	13.3	15.6
	1997	35	14.7	13.5	15.9	24	15.6	14.3	16.9
	1998	35	14.6	13.4	15.7	24	14.6	13.4	15.9
Pielou's *J'*	1992	29	0.63	0.60	0.66	24	0.59	0.54	0.64
	1993	36	0.63	0.59	0.67	24	0.69	0.66	0.73
	1994	35	0.61	0.57	0.65	24	0.71	0.67	0.75
	1995	35	0.65	0.63	0.66	24	0.59	0.53	0.65
	1996	35	0.64	0.62	0.66	24	0.65	0.59	0.71
	1997	35	0.61	0.57	0.64	24	0.65	0.61	0.69
	1998	35	0.59	0.56	0.63	24	0.64	0.59	0.68
Shannon's *H'*	1992	29	3.8	3.6	3.9	24	3.4	3.1	3.6
	1993	36	3.5	3.3	3.7	24	3.9	3.7	4.1
	1994	35	3.5	3.3	3.7	24	3.9	3.7	4.1
	1995	35	3.8	3.7	4.0	24	3.4	3.0	3.7
	1996	35	4.0	3.8	4.2	24	3.8	3.5	4.1
	1997	35	3.8	3.6	4.0	24	3.9	3.7	4.2
	1998	35	3.6	3.4	3.9	24	3.9	3.7	4.1
Total Species	1992	29	63.3	57.1	69.6	24	50.2	45.6	54.7
	1993	36	47.6	43.8	51.3	24	52.2	48.2	56.1
	1994	35	55.2	50.5	59.8	24	47.2	41.5	52.9
	1995	35	63.8	59.1	68.5	24	54.2	48.9	59.5
	1996	35	70.4	66.4	74.4	24	63.5	58.5	68.5
	1997	35	73.7	68.1	79.3	24	69.0	62.5	75.5
	1998	35	72.9	67.9	77.9	24	69.8	65.0	74.6
Total Individuals	1992	29	2108	1636	2580	24	1204	849	1558
	1993	36	1277	962	1592	24	1062	805	1318
	1994	35	1922	1575	2268	24	758	492	1023
	1995	35	1750	1531	1969	24	1292	924	1660
	1996	35	2018	1812	2224	24	1358	1056	1660
	1997	35	2583	2177	2989	24	1520	1155	1886
	1998	35	2421	2085	2758	24	1933	1579	2286

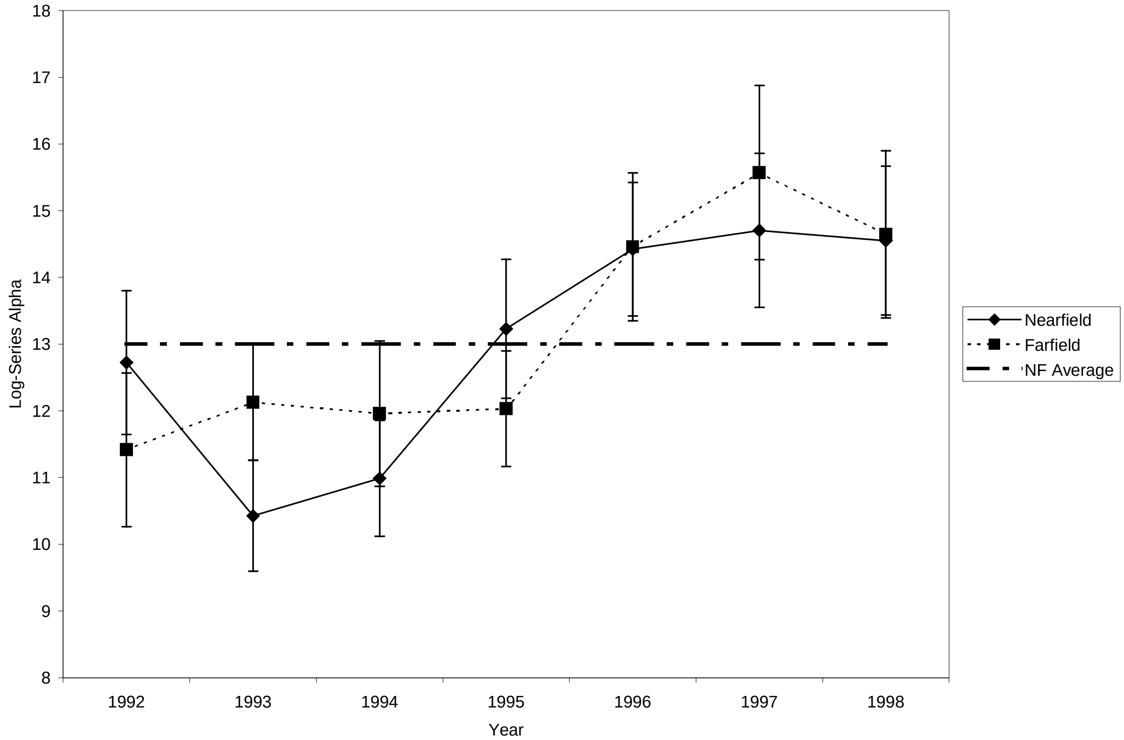


Figure 7.5-1. Mean (± 95% confidence intervals) log-series alpha calculated for Nearfield and Farfield samples collected from 1992 to 1998. The 1992–1998 Nearfield average value is indicated by the broken horizontal line.

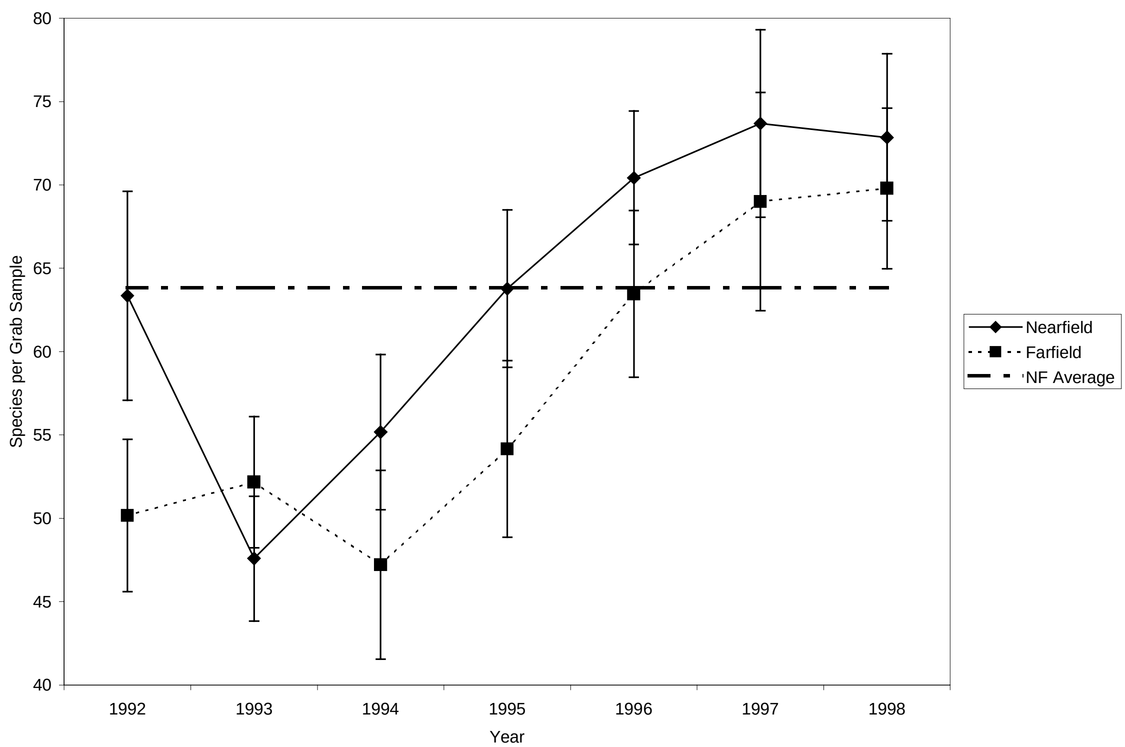


Figure 7.5-2. Mean (± 95 % confidence intervals) number of species per grab sample (including all species) calculated for Nearfield and Farfield samples collected from 1992 to 1998. The 1992–1998 Nearfield average value is indicated by the broken horizontal line.

These evaluations document that the infaunal monitoring as currently designed is sensitive enough to detect modest changes in the measures of diversity to be used for threshold testing. The 1999 outfall monitoring benthic report will include additional details on exactly how the thresholds will be calculated and tested. In the remainder of this section we evaluate the increasing species richness trends observed, and consider possible explanations.

Methodological Differences— As with any long-term monitoring program, as our familiarity with the fauna of the Massachusetts Bay/Cape Cod Bay system has increased, so has our ability to distinguish between closely related species or to identify species that had previously identified to the family or class level. This could predispose our analyses towards detecting an apparent increase in species richness through time.

There has been very little change since 1992 in the total number of infaunal species identified annually (Table 7.5-3). Also, as previously noted, prior to these analyses, abundances were pooled for all known cases of increased ability to discriminate within a genus (e.g., *Apistobranchus typicus* and *A. tullbergi).*

Table 7.5-3. Infaunal species numbers identified during MWRA outfall monitoring.

Year	Nearfield	Farfield	All
1992	225	175	263
1993	173	163	222
1994	192	166	227
1995	219	179	255
1996	237	194	276
1997	241	214	286
1998	240	194	270

As an additional check, analyses of total species in Nearfield samples were repeated after deleting all oligochaetes and nemerteans, taxa for which it is clear our ability to identify animals to the species level animals has increased through time and for which the pooling described earlier was not possible. As documented in Figure 7.5-3, the trend in mean species per grab is essentially unchanged following deletion of these groups.

Other methodological differences—There have been periodic changes in the teams of taxonomists working on the MWRA project. One such change occurred between 1992 and 1993, when Nearfield species richness declined. However, as noted above, mean species richness for Farfield samples, remained unchanged between 1992 and 1993, documenting that the change in taxonomists itself did not contribute to this change. Other changes in analysts also do not appear to correspond to substantial changes either in mean species richness or in total species identified. Additionally, one cornerstone of MWRA's infaunal monitoring has been the compilation, upkeep, and routine use of a physical reference collection containing nearly all taxa identified by the program, to help ensure comparability through time. A duplicate of this reference collection has recently (1998) been compiled and donated to the Harvard Museum of Comparative Zoology.

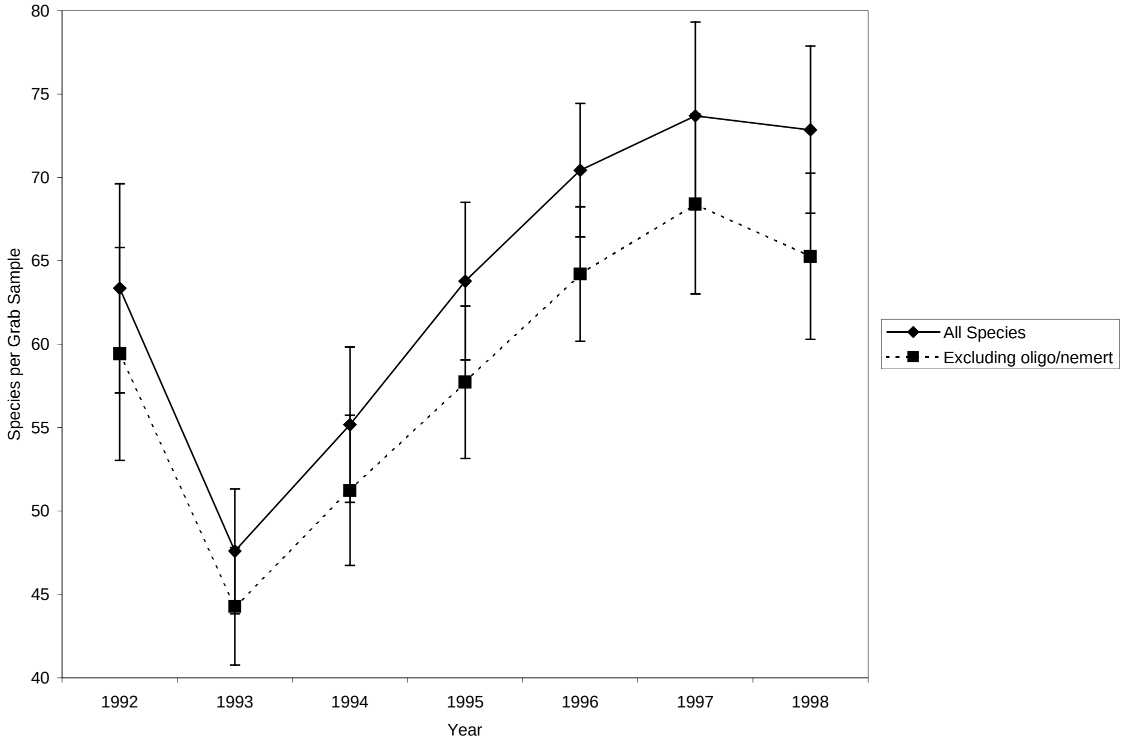


Figure 7.5-3. Mean (± 95 % confidence intervals) number of species per grab sample calculated for Nearfield samples collected from 1992 to 1998. Shown are values calculated to include all species and to exclude oligochaetes and nemerteans.

Additionally, MWRA's Nearfield monitoring design was modified twice between 1992 and 1994, as discussed in previous annual reports (e.g., Coats 1995) and summarized in Table 7.3-1. Nearfield sampling in 1993 occupied (with triplicate faunal samples) only a subset of the stations sampled in 1992 and 1994. This raises the possibility that the observed decrease in Nearfield species richness seen in 1993 could in part be an artifact of differing sampling design. This can be ruled out, as species richness patterns for the western Massachusetts Bay stations FF10, FF12, and FF13, which have been consistently sampled since 1992, mirror the patterns seen for all of western Massachusetts Bay (Keay, personal observation).

Taken together, the evaluations above lead us to conclude that methodological differences in how the monitoring has been carried out through time are not the cause of the observed patterns in species richness.

Possible abundance effect—Table 7.5-2 also includes annual mean abundances for the Nearfield,which are plotted, along with Farfield values, in Figure 7.5-4. Infaunal abundances have been increasing in the Nearfield since 1993, and in the Farfield since 1994. This increase in infaunal abundance is highly significant. This could account for some of the increase in species richness as measured by total species per grab. If the distribution of individuals among species was similar from year to year, a sample containing more individuals would tend to contain more species. However, log-series alpha doesn't exhibit this sample-size bias, and documents an identical trend in species richness in both the Nearfield and Farfield.

Storm-related sediment disturbances—At least part of the trends observed may be a result of infaunal communities in Massachusetts Bay recovering from disturbance caused by a major Northeast storm in the Gulf of Maine in the winter of 1992–1993. Bothner et al. (1994) documented the massive impact of the December 11-16, 1992 "No-Name" storm on sediments and sediment transport in western Massachusetts Bay. That storm remains the largest single cause of sediment resuspension and transport in the USGS long term study (11+ years as of October 1999) of sediments and contaminants in western Massachusetts Bay (Bothner, personal communication).

The occurrence of this storm and the resulting sediment resuspension are fully consistent with the diversity patterns observed. Species richness decreased in the shallower Nearfield sediments of western Massachusetts Bay between 1992 and 1993, but was unchanged at Farfield stations that tend to be substantially deeper and further offshore (Figures 7.5-1, 7.5-2), and therefore less prone to sediment resuspension and redeposition from storms. While the decrease in species richness between 1992 and 1993 occurred at most individual Nearfield stations, and many showed noticeable change in sediment type between 1992 and 1993, these changes were most apparent at site NF02. Sediments at this site changed from >80% fines to >90% sand during that period (Figure 7.2-2), and, as described in Section 7.3.2, in 1993 NF02 contained an infaunal community almost entirely consisting of apparently recently settled juvenile *Hiatella arctica*. These samples and a similar sample from the same site in 1997 form an outlier to the multiyear PCA-H analysis.

As noted above, this hypothesis can explain the decrease and subsequent recovery seen in species richness at shallow water sites. It cannot explain the species richness increases seen in both Nearfield and Farfield stations since 1995, so remains at best a partial explanation.

Eutrophication—One possible hypothesis that must be considered is that the increasing species richness patterns observed could be a result of moderate increases in organic matter loading to sediments, producing increases in infaunal abundance and species richness. However, there is no evidence to support this. MWRA's comprehensive water quality monitoring program documented lower annual average water column chlorophyll *a* in the Nearfield and Farfield in 1995–1997 than in 1992–1994 or 1998. Additionally, the winter-spring bloom in 1998 was essentially nonexistent in the Nearfield, with seasonal (January-April) mean chlorophyll and primary productivity the lowest yet measured (Libby et al. 1999). Only a sustained 1998 fall-winter bloom (which occurred months after 1998 infaunal sampling) kept 1998 from having the lowest annual chlorophyll and productivity on record. These results are not consistent with an hypothesis of increased organic loading to the sediments.

An additional line of evidence results from ongoing seasonal sediment metabolism studies carried out at three Nearfield and one Farfield soft-sediment locations. While data were not obtained in 1998, no measures of sediment metabolism (for example sediment oxygen demand) or deposition of labile organic matter (for example sediment chlorophyll inventory) show any suggestion of increased organic matter loading between 1993 and 1997 (Howes 1998).

Long-term cycles—The system-wide increases in species richness in the Massachusetts Bay benthos seen since 1995 could represent a cyclic pattern of change, perhaps with a 7–8 year period. Ardisson et al. (1990) documented a 7-yr cyclic pattern of change in the Gulf of St. Lawrence benthos, driven by long-term weather patterns. Gray & Christie (1983) documented long-term cyclic patterns in the Northern European benthos. Such long-term cyclic patterns might be related to changes in snowfall patterns and flushing characteristics of the Gulf of Maine, or to changes in the North Atlantic Oscillation (NAO). The NAO has recently (Narragansett Bay symposium, January 20-21, 2000) been implicated as a causal factor in changes observed in long-term monitoring results from the nearby Narragansett Bay system.

Implications—While fascinating from an ecological standpoint, the observed, rapid changes in benthic community species richness are also of importance to management. Once outfall discharge begins, a major winter storm might again "reset" the species richness in western Massachusetts Bay to 1993 levels or possibly lower, without any corresponding change at deeper reference stations. This could easily be interpreted to imply an outfall effect. If the long-term cycle hypothesis is correct, then species richness eventually might again decrease to levels observed in 1992 (Nearfield) or 1992–1994 (Farfield). Such decreases could coincide with the start of discharges from the new outfall, and, again, could cause concern. While these natural fluctuations could trigger concern, the more detailed evaluations carried out in annual synthesis reports (which would be expanded and accelerated to the extent possible in the event of a threshold triggering) should allow natural fluctuations to be identified with confidence.

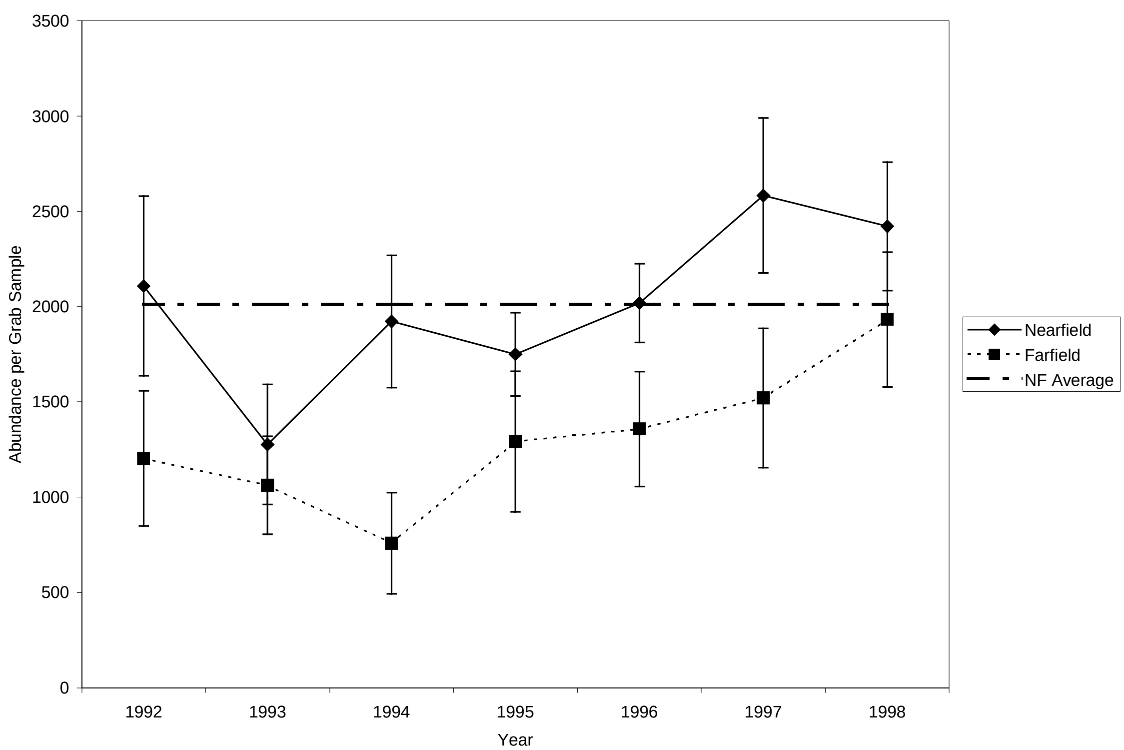


Figure 7.5-4. Mean (± 95 % confidence intervals) abundance per grab sample calculated for Nearfield and Farfield samples collected from 1992 to 1998. The 1992–1998 Nearfield average value is indicated by the broken horizontal line.

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APPENDICES

Appendix A: Actual Sample Collection Locations
Appendix B: Sediment Profile Images
Appendix C: Sediment Chemistry Data
Appendix D: Infaunal Data
Appendix E: Hard-bottom Slide and Video Data
Appendix F: Infaunal 1992–1998 Data

[Note: These appendices are not available on-line. To obtain a printed copy, please call the Environmental Quality Department at (617) 788-4700.]

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