Massachusetts Bay outfall monitoring program: 1995 benthic biology and sedimentology

Massachusetts Water Resources Authority

Environmental Quality Department
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MASSACHUSETTS BAY OUTFALL MONITORING PROGRAM: 1995 BENTHIC BIOLOGY AND SEDIMENTOLOGY

submitted to

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The present report treats benthic biology and chemistry data collected in 1995 as part of a baseline monitoring program being performed to assess conditions in Massachusetts Bay prior to discharges from a new sewage outfall now scheduled to begin operations in 1998. To date, samples have been collected from locations in the vicinity of the new outfall (nearfield and midfield) in Massachusetts Bay and at selected farfield or control sites in Massachusetts Bay and Cape Cod Bay. Samples have now been collected during each summer since 1992.

The data reported here include results of traditional benthic biology and chemistry analyses, sediment profile images, and photographs taken from a remotely operated vehicle in the vicinity of the outfall.

Sediment Chemistry

Organic constituents in the sediments collected in 1995 are similar qualitatively and quantitatively with those from prior years. The results of analyses of the 1995 data support the modeling carried out on the 1992-1994 data. The MWRA could therefore use the data gathered since 1992 in calculating a baseline mean to better define post discharge monitoring hypotheses. Concentrations of organic constituents are generally low and in no case exceeds any relevant environmental standard.

Sediment metal concentrations in the nearfield and throughout Massachusetts and Cape Cod Bays in 1995 were similar to those measured in previous years.

Prediction of future changes in the metal content of the sediments in the vicinity of the diffuser was formerly based on the predicted deposition of contaminated particles from the effluent and their incorporation into the sediment. In a model presented in the present report, the increase in contaminant metal concentrations will likely be a function of changes in both the ambient dissolved metal concentrations and increased accumulation of organic matter in the sediments. Thus, the estimated accumulation of metals in the vicinity of the outfall should probably be reexamined. The existing data on effluent loadings and expected ambient water column concentrations, even at the primary treatment level, suggests that ER-Ms for most metals are, however, unlikely to be exceeded provided organic matter concentrations in the sediments do not become excessive. Possible exceptions to this may occur in localized areas where a large accumulation of organic matter results in anoxic conditions near the sediment-water interface. Metal contents of the sediments may be elevated over that expected based on ambient water column concentrations and sediment organic Carbon alone. Direct diffusive fluxes into the sediment, driven by precipitation of insoluble metal sulfides under anoxic conditions, can be expected to enhance metal concentrations in the solid phase over that predicted for oxic conditions.

Sediment grain-size results derived from laboratory analysis and from sediment profile images reveal a strong east to west gradient in kinetic energy that influences sediment texture and distribution of ripples and scour-lag deposits. This area is largely within 2 km of the outfall and suggests that seasonal climatic phenomena contribute to sediment movement. Most stations in the eastern portions of the study area (near the outfall) contain less mud and more sand than those closer to Boston Harbor. The profile images also demonstrate that considerable sediment transport has occurred since 1992, possibly as a result of environmental events such as the 1992 "no name" winter storm. Stations showing sand over the mud stratigraphy in 1992 showed different patterns in this study.

Total organic carbon (TOC) concentrations are low in the sandier areas, but are high in depositional areas less subject to seasonal sediment transport.

The apparent redox potential discontinuity (RPD) measured by sediment profile imaging (SPI) is more accurate than visual observations from cores. SPI results for 1992 and 1995 are similar and indicate that the 50% action level (change in RPD depth) proposed as a post-discharge indicator was not reached.

Biology

Softbottom

Benthic community structure and patterns along with the distribution of benthic community parameters among stations in 1995 were broadly similar to those seen in previous baseline monitoring. The structure of the benthic communities in the near- and midfield was largely determined by sediment grain size. In finer grained sediments, capitellid and spionid polychaetes were most abundant, while in sandier substrata, syllid and paraonid polychaetes, amphipod crustaceans, and certain oligochaetes predominated. These basic community structures have been observed in the area since inception of this program, with slight changes reflecting the shifting of sediments noted in the previous paragraphs.

Dominant spionid polychaete species are not consistent from year to year. For example, the dominant species in 1995, *Prionospio steenstrupi,* was also abundant in the 1987 reconnaissance surveys, but not in 1992-1994 when *Spio limicola* dominated. These results suggest that baseline variability in the vicinity of the future outfall is greater than was incorporated into the hypotheses testing performed by Coats (1995) for the 1992-1994 data.

The densities of benthic infauna in Massachusetts Bay are often very high, but do not reflect stressed or otherwise already impacted conditions. The dominant species are not ones typically associated with stressed nearshore habitats but they may be dominant in areas where currents provide periodic flux of phytoplankton or organically enriched sediment to the seabed. Spionid polychaetes are able to clear this sediment from the water, use it for food and material for tube construction, and establish dense populations.

Very high faunal similarities between the benthic community at station FF1a and those found in the mid-field indicate that this location can serve as a good qualitative reference site for benthic communities in the vicinity of the future outfall. Coincidentally, this station is also a farfield monitoring site for an on-going 301(h) program. Station NF24, located in the "mud patch" within the hard ground close to the outfall, may be a good sentinel station for post-disposal benthic monitoring because it appears to act as a sediment trap. Station FF9 appears to support a benthic community intermediate between midfield and offshore communities and may therefore serve as a reference point as well.

Benthic community structure in the farfield was mostly influenced by water depth and also by location (Massachusetts Bay versus Cape Cod Bay). Species diversity and species composition have changed over time, and this is probably related to the timing and success of larval settlement among different species. Continuation of sampling in the farfield will help to distinguish such natural processes from potential anthropogenic ones that are related to the operation of the outfall in the nearfield. The two Cape Cod Bay stations differ the most from the Massachusetts Bay stations, probably because of a different sedimentary environment. For example, cossurid polychaetes are dominant at Cape Cod Bay stations but rare elsewhere.

The post-discharge hypotheses that are being considered by the MWRA will have to be refined and simplified. An average species diversity estimate will be established after 1997 samples have been collected and analyzed. A decrease in species diversity is not necessarily a measure of "degradation", and neither is species composition. While a moderate organic enrichment of the sediment may cause the disappearance of some sensitive species, the overall effect may not necessarily be detrimental if increased biomass is available as a food source for bottom fishes.

Hardbottom

The complex topography in the hard-bottom areas in western Massachusetts Bay imposes substantial variability upon epibenthic communities. These communities are primarily zoned by depth, with algae dominating the shallower drumlin tops while macroinvertebrates dominated the deeper bottoms.

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

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

Both video and still photographs are valuable for establishing baseline data of the drumlin areas near the outfall. The analyses of the still photographs show finer details of the structure of benthic communities inhabiting hard-bottom areas in the vicinity of the new sewage outfall than could be discerned from a review of the video tapes. The two techniques are complimentary as the video survey provides greater areal coverage whereas the still photographs provide more accurate assessments of the benthic communities inhabiting these areas.

1.0 INTRODUCTION

1.1 Background of the MWRA Monitoring Program

The Massachusetts Water Resources Authority (MWRA) is responsible for the development of secondary sewage treatment facilities at the new Deer Island Sewage Treatment Plant. In conjunction with these facilities, a new outfall has been located offshore in Massachusetts Bay at a distance of 15 km from Deer Island and a depth of 32 m. The new outfall is scheduled to begin operation in October, 1998, initially with an blend of primary and secondary effluents and later with full secondary treated effluent scheduled to be discharged some time in 1999. It is expected that the water and sediment quality of Massachusetts and Cape Cod Bays will not be degraded by this new outfall (EPA, 1988).

In order to monitor the discharge from the new outfall, MWRA in collaboration with a state/federal Outfall Monitoring Task Force has developed an "Effluent Outfall Monitoring Plan" that describes physical, chemical, and biological monitoring necessary to evaluate the response of the Massachusetts Bay ecosystem to the new outfall (MWRA, 1991). Studies conducted prior to the initiation of discharges are termed Baseline Monitoring and are intended to establish a database against which changes due to the discharge can be assessed.

In August 1992, the first phase of the baseline monitoring of the soft-bottom benthic environment was initiated. Results of that initial survey were presented in a report that evaluated the sedimentary characteristics, biological communities, microbiology, and sediment/animal interactions of stations in Massachusetts Bay and Cape Cod Bay (Blake *et al.,* 1993). The monitoring continued in 1993 (Coats *et al.* 1995b), 1994 (Coats, 1995), and 1995 (present study). In 1994 a video survey of the hard-bottom features in the vicinity of the outfall was conducted (Coats *et al*., 1995a), and was repeated in 1995 (present study).

1.2 Historical Overview of Benthic Studies in Massachusetts Bay

Prior to the Harbor and Outfall Monitoring Program, the benthic infauna of Massachusetts and Cape Cod Bays was chiefly known from a series of studies conducted between 1976 and 1988. To date, no results from these studies have ever been published in the open literature, and all information resides in various federal, state, and municipal reports.

The earliest study of the infauna was by Gilbert *et al.* (1976), in which 37 stations were occupied from Cape Ann to Cape Cod. As part of this project, two replicate 0.1-m^2 grabs were taken at each station. Portions of this database were reviewed and analyzed by Shea *et al.* (1991). This survey indicated that benthic communities were both rich in species and dense in individuals. Species richness varied from 40 to 125 species per station and density ranged from about 4000 to 60,000 individuals m^{-2}. Nearly the entire study area was dominated by the spionid polychaete *Spio limicola*, comprising 18 to 80% of the fauna.

As part of an application for a waiver from secondary treatment [301(h) waiver] in the late 1970's and early 1980's, a limited number of benthic stations was established in Massachusetts Bay. Three stations were sampled in 1978, one in 1979, and one in 1982. The results of these studies were reviewed by Blake *et al.* (1989). Following denial of the waiver, additional benthic work in Massachusetts Bay was conducted by Metcalf & Eddy (1984). Five stations were sampled for benthic infauna (Stations 32, 38, 40, 42, and 53).

In summarizing the studies associated with the 301(h) waiver process, Blake *et al.* (1989) identified considerable year-to-year variability, both in overall density of the infauna and in the dominance patterns of the most abundant species. Dense populations of *Spio limicola* that were noted in the 1982 samples were not present in 1978 and 1979; however, high abundances of different spionids were identified from at least one offshore station each year (*Polydora socialis* and *Spio filicornis* at DWI in 1978, *P. socialis* and *Prionospio steenstrupi* in 1979).

Following denial of the 301(h) waiver, studies were initiated to assess the marine environment of Massachusetts Bay relative to the establishment of a large sewage outfall that would ultimately deliver secondary treated effluent to this relatively unpolluted environment. A series of marine ecological surveys was initiated as part of the Secondary Treatment Facilities Plan (STFP). The soft-bottom benthic sampling design included five transects, each with three stations. Six replicate 0.04-m^2 grabs were taken at each station and sieved through 0.3- and 0.5-mm mesh screens. Samples from all 15 stations were fully processed as part of the first survey in March 1987. A subset of the stations was subsequently sampled in May and August 1987, and again in February 1988. The results were presented in Blake *et al.* (1987; 1988). Two sediment profile imaging surveys were also undertaken (SAIC, 1987a, b) and reviewed in Shea *et al.* (1991). Two video surveys of the hard-bottom features near the proposed outfall were conducted using a remotely operated vehicle (ROV) (Battelle, 1987; Etter *et al.,* 1987). Special studies of hard-bottom sites with SCUBA were also performed (Sebens *et al.,* 1987).

The results from the 1987 surveys were used to assess the differences in benthic assemblages among stations and transects to elucidate patterns and trends in benthic communities with increasing distance from shore and from sources of contamination in Boston Harbor. The results from stations sampled seasonally permitted the first assessment of temporal patterns and stability of the communities at defined sites over time.

Important conclusions arising from the STFP studies were that the benthic communities of Massachusetts Bay were rich and that the most distant stations shared affinities with adjacent continental shelf habitats rather than with nearshore estuarine locations. The hardbottom biota were similar to those found in the Gulf of Maine. The dominant species in Massachusetts Bay were, with few exceptions, ones that were not typical dominants in nearshore areas such as Boston Harbor. There was evidence that periodic episodes of natural organic enrichment accounted for occasional population explosions of spionid polychaetes such as *Spio limicola* in the softbottom habitat. The stations that were sampled temporally were found to maintain similarity with one another over the 12-month study period.

In anticipation of the eventual transferral of treated sewage from the existing outfall off Deer Island to the new site in Massachusetts Bay, the MWRA initiated a baseline benthic monitoring program in 1992. This project was intended to focus on soft sediments near the site of the new outfall (the nearfield) and its line of 55 diffusers as well at selected sentinel stations in various parts of Massachusetts Bay and Cape Cod Bay (the farfield).

To date, this monitoring program has included an assessment of traditional benthic biology, sediment parameters (grain size, total organic carbon, and *Clostridium* spore counts), and sediment chemistry (metals and organic contaminants). In addition, sediment profile imaging surveys were conducted in

1992 and again in 1995. The same biological and sedimentary parameters have been sampled at the farfield stations; sediment profile images were collected in 1992. In 1994 and again in 1995, semi-quantitative video surveys were conducted in the hardbottom areas adjacent to the new outfall.

1.3 Overview of the Present Study

The benthic monitoring program as initiated in 1992 included 10 special stations at farfield locations sampled for biology in May 1992 as part of a USGS/MWRA survey, 20 stations in the nearfield sampled in August 1992, and 12 stations in the farfield also sampled in August 1992. At each of the August 1992 stations, samples were taken to evaluate sedimentary characteristics, benthic infaunal communities, microbiology, and chemical constituents. In addition, the sediment profile camera system was used to evaluate animal/sediment interactions and various physical properties of the sediments. The benthic biology program for the nearfield was essentially designed as a non-replicated spatial array while the farfield sampling design included 3 replicates at each station.

Achieving a good monitoring design for the nearfield area has been difficult due to the heterogeneity of habitats, and the sampling protocol was modified several times to find the best approach. In 1993 the design was changed to include 9 stations, with 3 replicates each. One of the farfield stations was dropped (Coats *et al.*, 1995b). In 1994, the non-replicated design was reinstated with retention of 3 replicated stations (Coats, 1995); that design was repeated in 1995. The shift in station design presents some problems with comparing year to year trends because the 1993 nearfield design departs significantly from that of 1992, 1994, and 1995. Nevertheless, the 4-year baseline program thus accumulated and the planned continuance in 1996 and 1997 should permit a full assessment of natural processes in the nearfield prior to the initiation of sewage disposal operations in 1998.

In 1992, the spatial array of stations sampled with traditional methods was integrated with the sediment profile camera to allow mapping of physical and biological patterns in Massachusetts Bay for the first time. Sediment profiling was not performed in 1993 and 1994, but was reinstituted in 1995 as part of a supplementary task, so that sedimentary patterns could be compared with the 1992 results.

The research and monitoring results to data have provided a fairly good understanding of benthic communities and sediment conditions in Massachusetts and Cape cod Bays. This understanding is crucial to the development of testable predictions for detecting outfall-induced changes once discharge begins.

In western Massachusetts Bay, including the vicinity of the future effluent outfall, relict glacial topography and infrequent physical disturbances currently control sediment deposition in the near- and midfield (Blake *et al.*, 1993; Knebel, 1993). This sedimentary regime results in a complex mosaic of sediment types in the mid- and nearfield, with small patches, about 100 to 1,000 m in diameter, of muddy depositional sediments interspersed with sandier patches and separated by expanses of erosional gravels, cobbles, and boulder-strewn submerged drumlins.

Although some small muddy patches exist in the vicinity of the outfall (e.g., station NF24), to a first approximation the previous monitoring has demonstrated a gradient in the sediments of the mid- and nearfield, with the muddiest sediments in the western portion near Boston Harbor, grading to "transitional" sandy muds and muddy sands in intermediate areas, and finally to medium sands in the eastern portion closest to the diffuser (Blake *et al.*, 1993). The presence of layered sediments, such as sand over mud, as well as changes in surficial grain size at some sites between years, has suggested active, storm-induced sediment transport in the transitional region (Blake *et al.*, 1993; Coats *et al.*, 1995b).

Sediment contamination in western Massachusetts Bay is variable, but is strongly associated with the sediment gradients described above. Organic carbon, percent silt+clay, and aluminum content are all strongly positively correlated with concentrations of metals, organic contaminants, and spores of the bacterium *Clostridium perfringens*. When normalized to one or another of these sedimentary parameters, variation in contaminant concentrations across the near- and midfield is much reduced (Coats *et al.*, 1995b; Coats, 1995).

Benthic community structure in soft-bottom areas of western Massachusetts Bay has been shown by monitoring to date to be similarly strongly associated with sediment type, and is also apparently influenced by recent sediment transport events. Highly depositional muds tend to support a diverse fauna, often with more than 50 species present in a 0.04-m^2 grab sample. This mud assemblage is characterized by high abundances of the capitellid polychaete *Mediomastus californiensis*, accompanied by abundant spionid polychaetes and/or the paraonid polychaete *Aricidea catherinae*. The faunal assemblage in transitional sediments is relatively similar, but tends to show high dominance of one or more spionid polychaetes, for example *Prionospio steenstrupi* in 1987 (Blake *et al.*, 1987) and *Spio limicola* in 1992-1994 (Blake *et al.*, 1993; Coats, 1995). The sandy assemblage is characterized by fewer species and lower abundances, and tends to be dominated by the amphipod *Corophium crassicorne* and the syllid polychaetes *Exogone hebes* and *E. verugera*, among others (Blake *et al.*, 1993; Coats, 1995).

In offshore waters of Massachusetts and Cape Cod Bays (farfield), contaminant distributions are as strongly correlated with sediment characteristics like grain size and organic carbon content as shown for the western part of Massachusetts Bay (mid- and nearfield). On the regional scale of the Bays, a gradient of decreasing concentration with distance from Boston Harbor is superimposed on this pattern for many contaminants, for example, silver, *C. perfringens* spores, and linear alkyl benzenes (Bothner *et al.*, 1993; Coats *et al.*, 1995b).

With regard to the benthic communities, the farfield data provide the first long-term integrated survey throughout the larger Massachusetts Bay and Cape Cod Bay. At the two farfield monitoring stations located just inshore of the mid- and nearfield, close to Boston Harbor, benthic communities are similar to those in the mid- and nearfield, but also show affinities to communities seen at MWRA's Boston Harbor monitoring stations. All farfield stations in relatively deep water (>50 m) east of Cape Ann and throughout Stellwagen Basin show a diverse benthic assemblage, characterized by moderate dominance of spionid polychaetes (*Spio limicola* in 1992-1994), as well as the paraonid polychaetes *Levinsenia gracilis* and *Aricidea quadrilobata*. This deep-water assemblage is so consistent and widespread that, after the first two years of monitoring, station FF1 was abandoned, and the effort transferred to a new site (station FF1a) off Cape Ann at a depth similar to the nearfield, but so distant from the future outfall that no conceivable impact would occur.

The two farfield monitoring stations in moderately deep water (about 35 m) in Cape Cod Bay contain a distinct fauna, similar to communities observed in the late 1960s (Rhoads and Young, 1971; Young and Rhoads, 1971; Blake *et al.*, 1993; Coats, 1995). In addition to the spionids, these stations are characterized by moderate abundances of the polychaetes *Cossura longocirrata* and *Euchone incolor*.

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

Two implicit assumptions made by Coats (1995) are qualitatively addressed in this report. These assumptions are (1) the data available (1992 - 1994) were sufficient to characterize pre-discharge variability, and (2) baseline data compiled until 1994 provide adequate understanding of the benthic system to enable the interpreter of post-discharge data to discriminate naturally caused changes (even those that were not observed during pre-discharge years) from those caused by the outfall.

Results from the present study, conducted during baseline year 1995, are intended to add to the definition of the baseline variability described by Coats (1995) and our understanding of the benthic environment under pre-disposal conditions. The study included the following elements: (1) physical and chemical properties of the sediment, including trace metal and organic contaminant concentrations and sedimentology, with additional information provided by a sediment profiling study in the mid- and nearfield; (2) traditional softbottom benthic infaunal analysis; and (3) characterization of the rocky bottoms in the immediate vicinity of the outfall, based on examination of 35-mm color photographs and video tapes, to complement the more extensive softbottom monitoring by providing semi-quantitative information on epifaunal and epiphytic organisms colonizing the widespread rock bottom environments in the nearfield.

2.0 METHODS

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

2.1 Field Operations

2.1.1 Sampling Design and Location of Stations

Benthic grab samples were collected in August 1995 at 20 stations in close proximity to the diffuser (Nearfield sites, Figure 1, Appendix A1) and 11 stations throughout Massachusetts and Cape Cod Bays (Farfield sites, Figure 2, Appendix A1) for the analysis of macroinfauna and sedimentary characteristics. The sampling design in the Nearfield area, established in 1994, represents a compromise between broad areal coverage of the nearfield and comparability of the data with those from previous studies in the same area. To ensure good areal coverage, 17 of the 20 stations were sampled only once (one biology and one chemistry sample), whereas at the other three stations (NF12, NF17, and NF24) replicate samples were collected (two chemistry and three biology samples). At all Farfield stations, replicate samples were collected in the same manner as at the replicated Nearfield stations.

Coats (1995) defined an area 2 km wide around the diffuser as immediate nearfield where faunal changes were more likely to occur should the diffuser have an impact on the benthic infauna. Eight stations are located in the nearfield as defined by Coats, whereas the remaining 12 Nearfield stations and Farfield stations FF10, 12, and 13, which are about 2-7 km away from the outfall, constitute Coats' midfield (Table 1). These zones were based on modelling studies by the EPA (1988) and Hydroqual (1995), which both suggested that increased organic carbon deposition will be restricted to a few km^2 around the discharge. In this area, the immediate nearfield, some changes related to the new outfall can be expected, whereas in the midfield outfall-induced changes are less likely to occur.

Table 1. Revised station grouping after Coats (1995).

Station Grouping	Distance from Outfall	Stations
nearfield (diffuser-induced changes are expected)	0-2 km	NF13, NF14, NF15, NF17, NF18, NRF19, NF23, NF24
midfield (diffuser-induced changes are less likely)	2-7 km	NF2, NF4, NF5, NF7, NF8, NF9, NF10, NF12, NF16, NF20, NF21, NF22, FF10, FF12, FF13
farfield (diffuser-induced changes are highly unlikely)	>7 km	FF1A, FF4, FF5, FF6, FF7, FF9, FF11, FF14

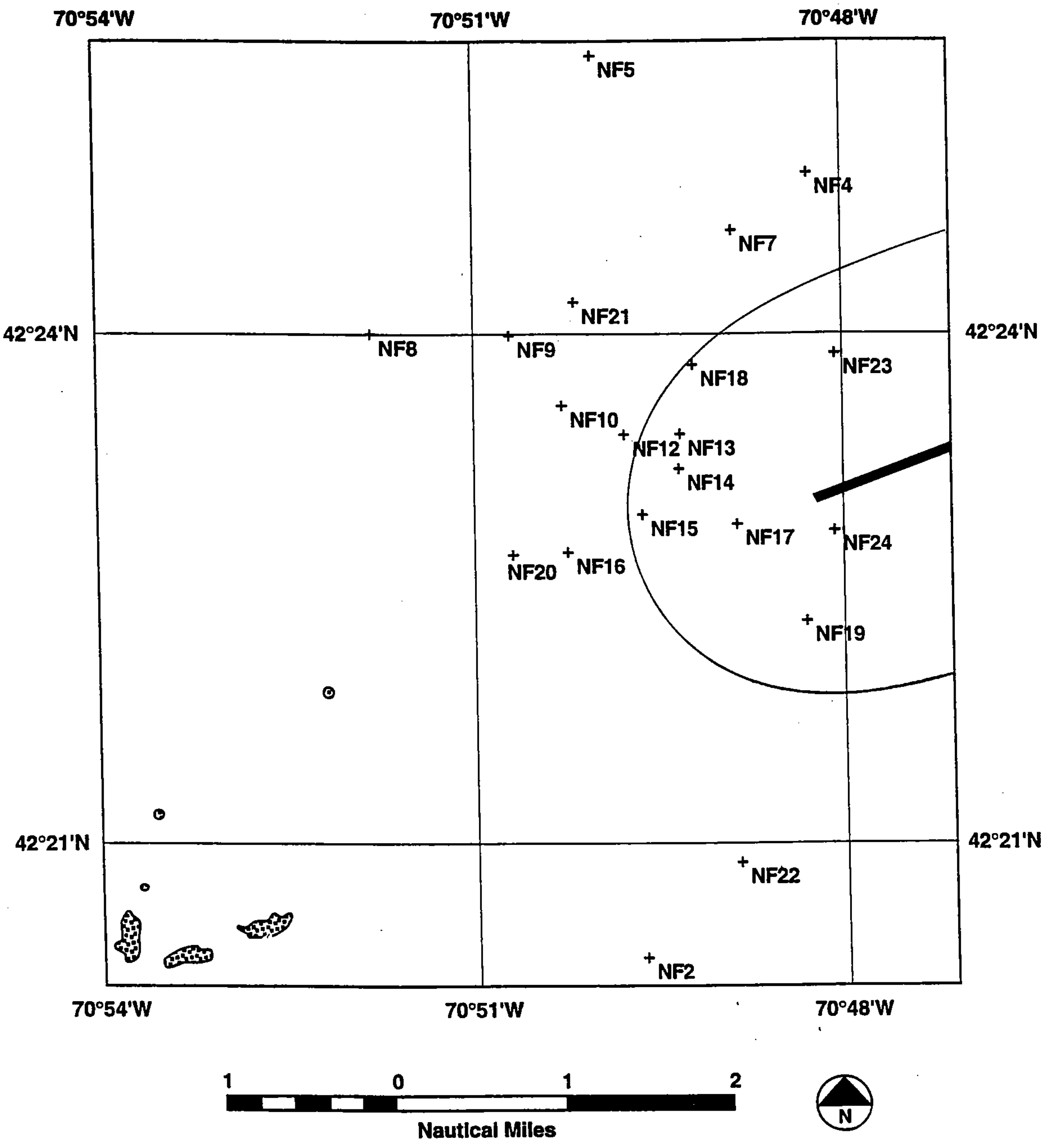


Figure 1. Station locations for grab samples and sediment profile images, mid- and nearfield. Western (soft-bottom) part of nearfield area is outlined, western end of diffuser is indicated by thick line.

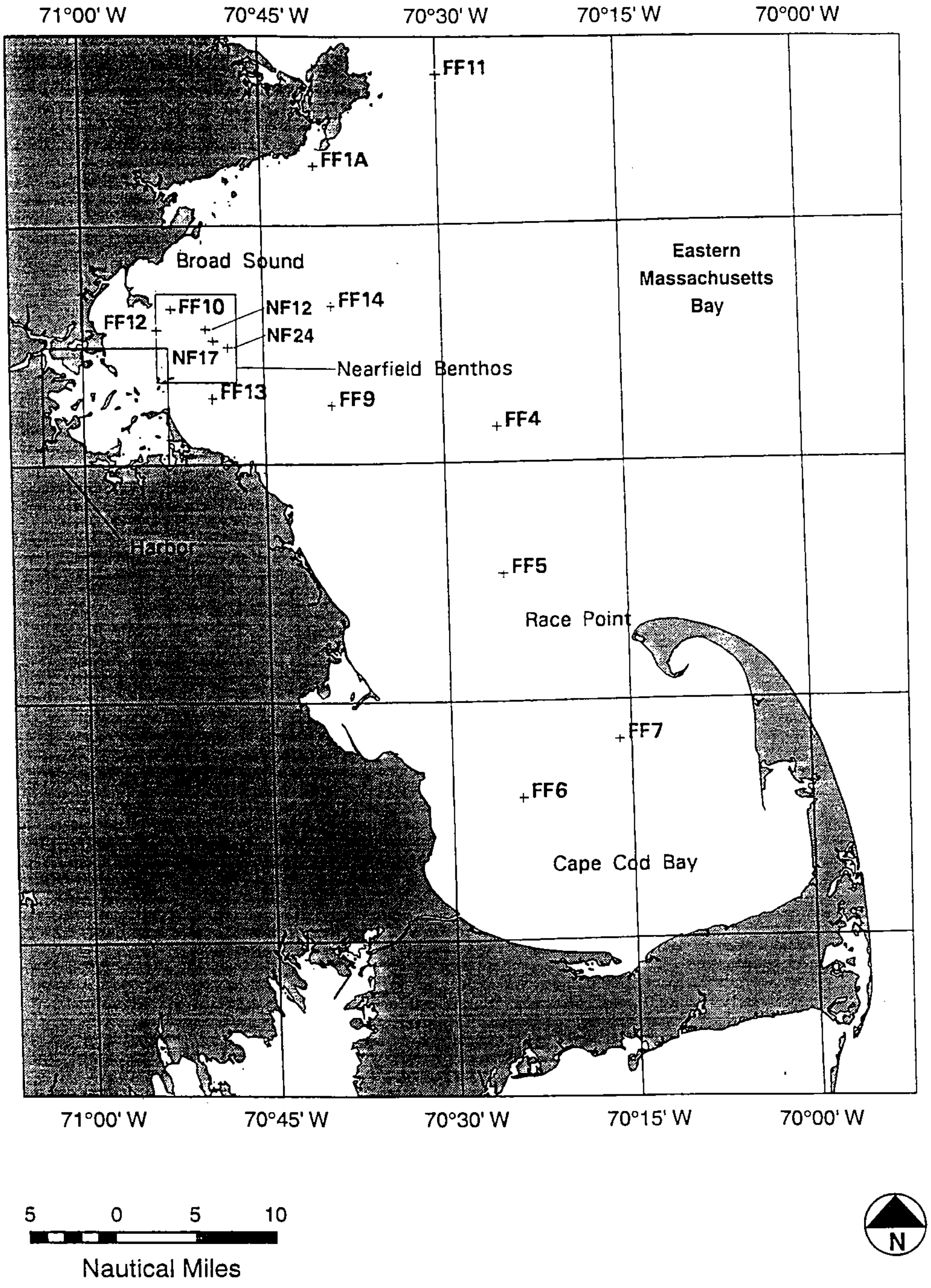


Figure 2. Station locations for grab samples, farfield. Boxes indicate Boston Harbor and Nearfield survey areas.

Sediment profile images were taken at the twenty Nearfield stations (see Figure 1) in August 1995 as part of a special study to supplement information gained from the analysis of the grab samples.

To complement results from softbottom monitoring in the nearfield area, a hardbottom survey of eight transects north and south of the diffuser was conducted where grab samples for quantitative faunal analyses cannot be obtained. Six of these transects were those surveyed in 1994, and two "reference" transects were added in 1995 that ran through two of the hardbottom stations surveyed in 1986/87 as part of the Authority's Secondary Treatment Facilities Plan (STFP) (Figure 3, Appendix A2).

2.1.2 Navigation

Navigational positioning was accomplished with a Northstar 41X Differential GPS system with an accuracy of 5 to 15 m. If the vessel drifted more than 0.01 nmi (ca. 16 m) away from the reference coordinates, it was repositioned between replicate samples. The ship's position was logged every minute while underway and marked at the time of each touchdown of the grab or camera with the Maptech software.

2.1.3 Grab Sampling

Two Ted Young grabs were used in the Nearfield and Farfield: the smaller grab (0.04-m^2) for collection of benthic infaunal samples, and a Kynar-coated, larger, 0.1-m^2 Ted Young grab for collection of sediment chemistry samples, providing larger amounts of sediment needed for the more numerous subsamples. The protocol for processing the biology samples was similar to the Harbor survey (see Hilbig *et al.*, 1996). From each chemistry grab, two subsamples of the top 2 cm of sediment were collected; one was homogenized in a stainless steel bowl and then split into subsamples for organic contaminants, *Clostridium perfringens*, TOC, and sediment grain size if enough sediment was available. The other subsample was collected with a Teflon spatula, homogenized in a Teflon bowl, and split into subsamples for metals and sediment grain size. The organic contaminants samples were frozen, all other samples were kept cool on ice.

2.1.4 Sediment Profile Imaging

At each of the 20 Nearfield grab sampling stations, the sediment profiling camera was lowered to the seafloor; when the wire went slack, the camera was allowed to stay on the bottom for 12 seconds (measured with a stop watch on board ship), during which the camera's prism penetrated into the sediment and the sediment slice cut by the faceplate of the prism could be photographed. Two photographs were taken each time, the first 2 seconds after the frame settled on the bottom and the second 10 seconds later.

This protocol helps ensure that at least one useable photograph is produced during each lowering. If the bottom is very soft, the prism will overpenetrate after 12 seconds (no sediment-water interface on the photograph), but the first exposure, taken after 2 seconds, will usually show the interface and will be suitable for a full analysis. If the sediment is compacted or mixed with rocks, the second exposure can be used for analysis because the prism will usually penetrate deep enough to allow for measurement of all required parameters.

After 12 seconds, the camera was lifted off the bottom, returned to the surface for quick visual inspection while in the water, and lowered again for the next replicate set of two exposures. A total of four replicate sets (eight exposures) were taken at each station. At the end of a station, the camera was hauled back on deck for transit to the next station.

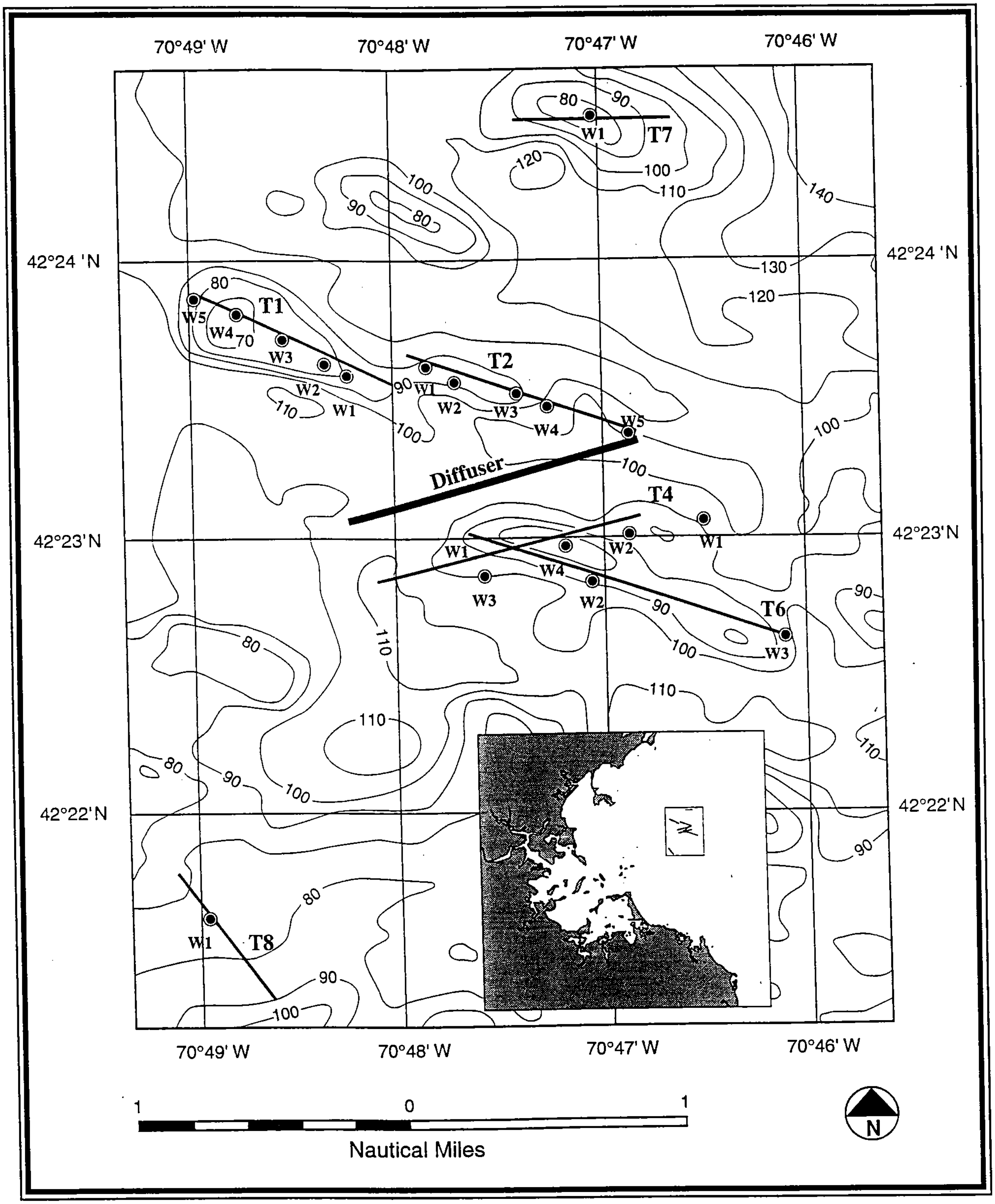


Figure 3. Locations of transects and waypoints, nearfield hardbottom survey area.

2.1.5 Hardbottom Video and 35-mm Still Photography

At each Nearfield Hardbottom Survey transect (T1, T2, T4, T6-T8), the vessel was anchored at either end of the transect and up to three additional locations in the middle, with the exception of the newly established "reference" transects T7 and T8 where the only sites sampled were the shallowest points (drumlin tops), which were determined by transiting the vessel over the transect once before sampling. The location of the transects in relation to the outfall pipe and the positions of the waypoints on each transect are shown in Figure 3 and listed in Appendix A2.

The ROV used for this survey was a Benthos MiniRover Mk II equipped with a video camera, a 35-mm Minicam still photo camera, and a strobe. The Minicam and strobe were mounted on brackets on either side of the window surrounding the video camera; the front end of the ROV was protected by a steel cage to prevent damage or loss of the camera and strobe.

Once the vessel was anchored and the DGPS indicated no drifting, the ROV was lowered over the starboard side near the bow to avoid contact of the ROV or its tether with the screw or the rudder of the vessel. Tether was payed out according to instructions given by the ROV operator. The position and heading of the vessel and the position of the ROV were continuously monitored on a computer screen through the HYPACK software package, integrating input from the DGPS, flux gate compass, and trackpoint system.

Depending on the relief of the survey area, the ROV traveled 30 to 70 m away from the vessel before running out of tether. The video footage obtained was viewed in real-time on a screen, and still photographs were taken of as many species as possible for "ground truthing", along with habitat shots documenting the different kinds of hardbottom environment encountered along each transect. Stills were obtained at 26 of the 30 locations surveyed (Table 2).

On several occasions, additional video footage at the same stop on a transect was obtained while the ROV was slowly pulled toward the vessel on its tether, and two or three excursions in different directions from the same waypoint were made in some cases to ensure sufficient video coverage. Between stops along a transect or during transit to the next transect, the ROV was pulled back on deck. The film was changed at the end of each transect; batteries of the camera and strobe were replaced as needed. Whenever possible, each transect was recorded on a separate video tape.

Table 2. Photographic coverage at locations surveyed during the 1995 Nearfield Hardbottom Survey.

Transect	Waypoint	Excursion	Location on drumlin	Depth		Video	Stills	Number of useable stills
				(ft)	(m)			
1	1	1	Flank	84	25	x	x	2
	2	1	Flank	81	25	x	x	5
		2	Upper Flank	74	22	x		
	3	1	Top	72	22	x	x	9
	4	1	Top	70	21	x	x	5
	5	1	Flank	83	25	x	x	6
2	1	1	Upper Flank	87	26	x		
		2	Upper Flank	87	26	x	x	3
		3	Top	85	26	x	x	11
	2	1	Upper Flank	90	27		x	4
		2	Flank	90	27	x	x	3
	3	1	Upper Flank	95	29	x	x	5
	4	1	Lower Flank	105	32	x		
	5	1	Lower Flank	112	34	x	x	11
		2	Lower Flank	112	34	x	x	7
		3	Lower Flank	112	34	x		
		diffuser	Low	112	34	x		
4	1	1	Lower Flank	105	32	x	x	5
	2	1	Upper Flank	86	26	x	x	6
		2	Upper Flank	85	26	x	x	7
	3	1	Flank	103	31	x	x	5
4&6	4	1	Top	74	22	x	x	5
		2	Top	75	23	x	x	10
6	1	1	Flank	92	28	x	x	3
	2	1	Flank	94	28	x	x	3
		2	Flank	90	27	x	x	7
	3	1	Upper Flank	88	27	x	x	10
7	1	1	Top	78	24	x	x	12
		2	Top	78	24	x	x	14
8	1	1	Top	74	22	x	x	12
		2	Top	74	22	x	x	8

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

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

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

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

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

2.2 Laboratory Methods: Sample Processing and Analysis

2.2.1 Benthic Infauna

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

2.2.2 Sediment Grain Size

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

2.2.3 Total Organic Carbon

TOC analysis followed NOAA's procedures developed for the Mussel Watch program (NOAA, 1993a). The sediment samples were dried to constant mass, exposed to HCl fumes to eliminate inorganic carbon, and TOC was measured with a CHN analyzer.

2.2.4 Clostridium Spores

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

2.2.5 Sediment Chemistry, Organic Contaminants

Sediment samples were analyzed for an extended list of 43 polycyclic aromatic hydrocarbons (PAH), C_{10} to C_{14} linear alkyl benzenes (LABs), 17 chlorinated pesticides, and 20 polychlorinated biphenyl (PCB) congeners (Table 12 of the CW/QAPP, Benthic Monitoring). Determinations of total organic carbon (TOC) were also made in order to normalize the data to TOC (Coats, 1995).

The PAH analysis targeted four more analytes than in previous years. These analytes are dibenzofuran, benzothiazole, C_2-fluoranthenes/pyrenes, and C_3-fluoranthenes/pyrenes. These parameters were excluded from calculating total PAH so that proper comparisons to prior years' data could be made. The pesticide analysis included one additional analyte, DDMU, a DDT breakdown product. The other organic parameters are the same as those targeted in previous years.

Sediment samples were extracted for PAH, LAB, chlorinated pesticides and PCB following methods developed for NOAA's National Status & Trends Mussel Watch Project (NOAA, 1993b). Briefly, approximately 30 g of sediment was serially extracted with a 1:1 mixture of dichloromethane (DCM):acetone and sodium sulfate using shaker table techniques. A 10-g aliquot of the original sample was taken for dry weight determinations. The samples were weighed into Teflon extraction jars and spiked with the appropriate surrogate internal standards, solvent added, the jars shaken for the appropriate amount of time and the samples filtered. The extracts were decanted into Erlenmeyer flasks. After extraction (total of 3 solvent additions) the filtered solvent was combined in the flasks. The combined extracts were processed through alumina column and concentrated to 900 μl under nitrogen. The concentrated extracts were further cleaned using size-exclusion high-performance liquid chromatography (HPLC). This procedure removed common contaminants which interfere with instrumental analysis, including elemental sulfur. The post-HPLC extracts were concentrated to approximately 1 ml under nitrogen and the recovery internal standards were added to quantify extraction efficiencies. The final extracts were split for analysis, one half remaining in DCM for PAH and LAB analysis and the other half solvent-exchanged with isooctane for PCB and pesticide analysis.

Sample extracts were analyzed for PAH and LAB compounds by gas chromatography mass spectrometry (GC/MS) operating in the selected-ion-monitoring (SIM) mode. Concentrations of LAB compounds were determined as five separate LAB groups (those with alkyl chains containing 10, 11, 12, 13, and 14 carbon atoms, primary ion-m/z 91). LAB were quantified versus the surrogate internal standard 1-phenyl nonane. Pesticides and PCB congeners were analyzed by gas chromatography electron capture detection (GC/ECD). All analytes were determined by the method of internal standards using surrogate internal standards for quantitation, and results were reported on a dry weight basis.

2.2.6 Sediment Chemistry, Metals

Sediment samples (0-2 cm) were collected and analyzed following procedures developed for NOAA's National Status and Trends Mussel Watch Project (NOAA, 1993c). After an acid digestion, sample extracts and digestates were analyzed on an Inductively Coupled Plasma-Mass Spectrometer (ICP-MS). Mercury concentrations were determined by using a flow injection cold vapor technique with atomic absorption detection following preconcentration on gold amalgam.

Performance on known reference samples was generally acceptable (Table 3). With the exception of Cd and Cr, differences between observed and certified values were ≤10%. Observed Cd concentrations were 25 % higher than the certified values but the 3σ intervals of the observed and certified values overlap and precision of the observed value was excellent. Recovery of Cr, based on comparison of the observed value with the certified value, was only 77% but the 3σ intervals of the observed and certified values overlapped and precision of the observed value for Cr was acceptable (~10%).

Four samples were analyzed in replicate and the analytical differences in values between these were generally quite small (<10%). Analysis of separate surface samples taken from the same station were, however, often substantial. The source of these differences is not analytical and most probably reflects real differences in sample composition between replicates taken at the same location. The greatest source of uncertainty in sediment concentrations reported for a given station is most likely due to heterogeneity in surface sediment composition at individual stations (see discussion below).

Table 3. Analysis of National Research Council of Canada Reference Standard BCSS-1/BEST-1 (µg/g dry weight) (n=4)

Metal	Observed	Certified	% Recovery
Cu	18.3±0.1	18.5±2.7	98.8
Zn	110±2	119±12	92.7
Pb	23.3±0.3	22.7±3.4	102.5
Cd	0.31±0.01	0.25±0.04	125.3
Ag	0.29±0.01	NC	NA
Hg	0.105±.0.017	0.092±0.009	114.3
Ni	52.4±1.3	55.3±3.6	94.7
Cr	95.1±9.5	123±14	77.3
Fe	3.07±0.20	3.28±0.14	93.5
Al	5.98±0.28	6.26±0.41	95.6

2.2.7 Sediment Profile Image Analysis

Three out of eight replicate images (see Section 2.1.4) from each station were analyzed with the ImagePro Plus software package. Each slide was digitized and then analyzed for parameters including penetration depth, surface roughness, depth of the apparent redox potential discontinuity (RPD), grain size major mode, successional stage of the infauna, the presence of methane bubbles, and biogenic features such as burrows and tubes. Any additional observations were entered into a comment field. The data were compiled on separate data sheets for each image, and the organism-sediment index (OSI) was calculated (Rhoads and Germano, 1986). A spreadsheet was generated from the raw data files, and several parameters were mapped and contoured by hand. A comprehensive account of sediment profile image analysis can be found in SAIC (1992); in the following paragraph, measured parameters are explained briefly.

Penetration depth is measured from the bottom of the image to the sediment-water interface (maximally 20 cm) and is a measure for softness of the substratum, which depends on characteristics such as water content and grain size. *Surface roughness* is the difference between the least and greatest penetration depth across the sediment-water interface depicted on a slide (the width is 15 cm). It may be a measure for physical disturbance—natural or anthropogenic—or biological activity such as burrowing. The *apparent RPD depth* is measured from the sediment-water interface to the depth in the sediment at which there is a change in sediment color caused by the lack or absence of oxygen at depth; the color commonly changes from tan or brownish (ferric hydroxides) in the well-oxygenated surface layer to greyish (ferric hydroxides being reduced) or black (presence of sulfide, anoxic conditions) at a few mm to several cm depth. The RPD depth depends on a variety of physical and biological factors, such as currents, organic loading, and bioturbation by infaunal organisms, and is commonly used as a first-approximation measure for the health of a habitat. *Methane bubbles*, discernable by their strong reflectance (silvery color) only form under severely oxygen depleted sediment conditions as a result of anaerobic bacterial metabolism. The *grain size major mode* is the dominant particle size in an image, measured visually by comparing the slide with a photograph of phi size classes. The *infaunal successional stages* are derived from a paradigm describing recolonization of disturbed habitats. Stage I organisms are those that live very close to the sediment-water interface, and they are pioneers because they do not require much oxidized sediment. By their feeding and burrowing activities these stage I organisms, often small annelids, deepen the RPD, preparing the sediment for somewhat larger animals to colonize, such as certain amphipods (stage II). Stage III organisms are large, deep-burrowing, head-down deposit feeders, such as large polychaetes and echinoderms, that aerate the sediment to several cm depth. Their presence indicates an equilibrium community and healthy environment.

2.2.8 Hardbottom Video and 35-mm Still Photography

Video Tapes

The analysis of the video tapes was semiquantitative, i.e., while abundances of organisms were recorded to get a rough estimate of the epifaunal and algal composition in relation to the habitat types, no statistical analyses were performed. A truly quantitative analysis would have required a constant area of view throughout the survey (constant distance of the ROV off bottom and constant speed) and a "frame-by-frame" analysis of the tapes, with enumeration of all organisms in a frozen frame and forwarding of the tape by exactly the distance of the field of view to freeze the frame again.

Each excursion at each waypoint along each transect was analyzed separately and divided into 5-minute intervals to provide a reference to the approximate size of the area in which the organisms were seen.

Large solitary animals and algae were initially counted and the numbers noted on data sheets; colonial organisms and very abundant solitary organisms were assigned five categories of abundance, including rare, few, common, abundant, and very abundant, that were also recorded on those same data sheets. Ancillary data such as water depth, location of the station on the drumlins (flank or top), grain size of the substratum (gravel to boulders), and presence and thickness of sediment cover (light dusting to heavy drape or thick mats) were recorded qualitatively.

For characterization of the transects, the organism counts from the original data sheets were converted to the abundance categories used for uncountable organisms during the analysis.

Organisms were identified to the lowest possible level, about half of them to species, with the aid of pictorial keys and diver handbooks of the local fauna and algal flora (Martinez and Harlow, 1994; Weiss, 1995). Taxa that could not be identified but were recognizable as such were assigned descriptive names (e.g., "orange tan encrusting").

Still Photographs (35-mm Slides)

Each 35-mm slide was projected and analyzed for seafloor characteristics (i.e., substratum type and size class, and amount of sediment cover) and organisms. Most recognizable taxa were recorded and counted. Encrusting coralline algae were assessed as rough visual estimates of percent cover of available substrate. Several other taxa, filamentous red algae, colonial hydroids, and small barnacles and/or spirorbid polychaetes, that were frequently too abundant to reliably count 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

Due to the high relief of many of the habitats surveyed, all abundances should be viewed as being extremely conservative. In many of the areas with large boulders approximately only one third of the available rock surfaces were visible, thus actual faunal abundances in these areas are probably 2 to 3 times higher than the counts indicate.

Slides that were taken from a high altitude or that covered the same area as previous slides were examined, but were omitted from further analysis. Of the total 191 still photographs taken during the survey, 178 were retained for subsequent analysis.

2.3 Data Management and Analysis

2.3.1 Benthic Infauna

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

Similarity among samples was determined by two clustering techniques, the Bray-Curtis similarity coefficient (Boesch, 1977) and Gallagher's CNESS, and principal components analysis (PCA-H) (Trueblood *et al.*, 1994). Group average sorting was the clustering strategy for both techniques; m was set at 18 for CNESS. Stations were ordinated among the first 3 axes, and Gabriel biplots were created to depict species explaining part of the variability among those axes.

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

2.3.2 Still Photographs

Data were pooled from all slides taken within excursions at each location (see Table 2). To facilitate comparisons between locations, species counts were normalized to mean number of individuals per slide to account for unequal numbers of slides. The number of slides comprising each pooled "sample" ranged from a low of 2 to a high 14. Hydroids and small barnacles and/or spirorbids were omitted from the data since they consisted of several species and could not be accurately assessed. Only taxa with abundances of 5 or more individuals in the entire data set were retained for subsequent analyses. This resulted in 45 out of the original 74 taxa being retained.

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

A cluster dendrogram is basically a 3-dimensional "mobile" that becomes distorted when flattened onto a 2-dimensional surface such as a page. This distortion focuses emphasis on inter-cluster resemblances at the expense of finer inter-sample relationships. Clustering also tends to impose discontinuities even if a continuum of faunal change exists. To overcome these disadvantages, the data were also examined with ordination using detrended correspondence analysis (Gauch, 1982). This technique is an improved form of reciprocal averaging (Hill, 1973; 1974), in that it eliminates the distortion inherent to the ends of ordination axes (horse-shoe effect). By simultaneously ordinating samples and species in the same multi-dimensional space, this type of ordination also facilitates interpretation of the placement of samples along a gradient in terms of their species composition. Detrended correspondence analysis is most useful in situations where species turnover is low to moderate.

3.0 RESULTS

3.1 Sediment Chemistry

3.1.1 Trace Metals

The most recent review of the results of the sediment metal chemistry component of the benthic monitoring program has been given in Coats (1995). In his treatment of the 1992 through 1994 data, Coats conducted an analysis of variance on log-transformed concentrations of metals, normalized to aluminum, to determine minimum detectable changes in concentration as a function of sample size. Analysis was performed using a sample population that included all samples collected over the three year period (Table 7, Coats, 1995) and then using a smaller subset of the data collected in 1994 (Table 8, Coats, 1995). The latter consisted of sediment concentrations observed in the 1994 stations that fell within a 2-km distance from the diffuser (the nearfield) as shown in Figure 4 of Coats (1995), an area estimated to be measurably impacted by deposition of effluent particulates in a number of modeling efforts (see references in Coats, 1995). The monitoring thresholds proposed by MWRA (1995), 90% of Long and Morgan ER-M, were used as a test case by Coats (1995), and they are used in this study as well.

These data, along with the newly acquired 1995 data, are examined from a different perspective here in an attempt to understand the factors affecting the variability in the data and thus improve our understanding of processes affecting sediment metal concentrations. This information will provide a more accurate capability for assessment of the impact of changing the MWRA's point of discharge and effluent loadings on the Massachusetts/Cape Cod Bays ecosystem than now available.

Background

Metal concentrations in sediments in aquatic systems are functionally dependent on the composition of both the aqueous and solid phases and reactions between the various components of the system. Provided equilibrium was established in such a system, and all of the system components were defined with respect to their concentrations and their interactions with other components defined by appropriate equilibrium constants for the temperature and pressures encountered, complete definition of the composition of the system could be achieved. In reality the required information defining composition, let alone the necessary definitions of reaction mechanisms, rate constants and associated equilibria, are seldom, if ever, sufficiently well defined to allow such rigorous estimates to be made. Furthermore, depending on the temporal and spatial scales over which a given system is being examined, it is not always evident whether equilibrium, steady-state or non-steady state conditions (or some combination of these) prevail.

Despite this complexity it is sometimes possible to develop approximate descriptions of such systems using readily measurable environmental variables which are sufficient to describe the major characteristics of a system. While lacking definition of the thermodynamic variables necessary to rigorously define the system, such models serve two important functions. The first is to provide a predictive tool that can be used to estimate system composition as a function of changes in these variables. The second is to provide insights and direction for future work needed to refine and improve understanding of the system variables. Both of these should result in a more accurate predictive capability of forecasting change in the system. We describe here a simplistic model that should generally enhance the ability to describe and predict the concentration of metals in oxic and most anoxic sediments in terms of readily measurable variables.

Basic Concepts

In this exercise we are concerned with describing the principal variables affecting the concentration of selected metals in the surface (0-3 cm), largely oxic, sediments sampled in both the farfield and nearfield samples collected as part of the benthic monitoring program. The "system" being described consists of the aqueous and solid phases defined by the sampling design, in this case encompassing Massachusetts and Cape Cod Bays. For reasons that will become evident later we subdivide the system into two subsystems, one consisting of the region sampled which is adjacent to and influenced by exchange with contaminated Boston Harbor waters and a second defined by samples taken in areas remote from the Harbor. In general most of the "nearfield" stations fall in the former assemblage of stations and the "farfield" stations in the latter. For the purposes of this analysis "farfield" stations FF12 and FF13 are grouped with the nearfield stations and the nearfield station NF5 grouped with the farfield stations. The rationale for doing so will be presented later.

The distribution of any metal in the aqueous phase of such a system may be described as the sum of the concentrations of the free metal ion and all of the soluble species of the metal present and can be described by the following equation.

$$M_T = [M] + \Sigma[M_m(L_i)_n] \tag{1}$$

where M_T = total metal concentration in solution
$[M]$ = free metal ion concentration
$[M_m(L_i)_n]$ = metal complex with ligand L_i; $m, n = \geq 1$

For the formation of a mononuclear complex by the addition of one or more ligands

$$M + L_i \rightleftarrows ML_i + L_i \rightleftarrows M(L_i)_2 + L_i \; ..... \rightleftarrows M(L_i)_n \tag{2}$$

the conditional equilibrium constant for the I^{th} complex can be described as

$$K^*_{i,n} = \frac{[M(L_i)_n]}{[M(L_i)_{(n-1)}]\;[L_i]} \tag{3}$$

A more general form of this equation describing the formation of mononuclear complexes with multiple ligands is given by

$$\beta_{i,n}^{*} = \frac{[M(L_i)_n]}{[M][L_i]^n} \tag{4}$$

For addition of protonated ligands, $\beta_{i,n}^{*}$ becomes

$$\beta_{i,n}^{*} = \frac{[M(L_i)_n][H^+]^n}{[M][HL_i]^n} \tag{5}$$

Returning to the simpler case described by equation (4) and assuming addition of only a single ligand (n=1), equation 4 can be rewritten as

$$[ML_i] = \beta_i^{*}\ [M]\ [L_i] \tag{6}$$

and, after substitution into equation (1), the total metal concentration in solution can be described by

$$[M_T] = [M]\ (1 + \Sigma\beta_i^{*}[L_i]) \tag{7}$$

Using an analogous approach we describe the affinity of metals for the surface of both suspended and sediment solids in terms of site specific reactions with ligands on the surface of the particles. For suspended particles in the water column this equilibrium can be expressed as

$$[M] + [SUS_i] \leftrightharpoons [MSUS_i] \tag{8}$$

where $[SUS_i]$ = concentration of I^{th} surface sites associated with suspended matter in the water column

$[MSUS_i]$ = concentration of surface complexes with the I^{th} sites associated with suspended matter in the water column

The equilibrium expression is given as

$$\beta_{SUS_i}^{*} = \frac{[MSUS_i]}{[M][SUS_i]} \tag{9}$$

Note that in this formulation we make no distinction between the different types of ligands present at the surface of the suspended particles, i.e. whether organic or inorganic (e.g. manganese and/or iron oxide or hydrous oxide) ligands. We also indicate them to be conditional constants as indicated above for solution phase equilibria (i.e. valid only for the specific conditions (pH, Eh, solution composition, P and T) under which they are determined) and thus express them in terms of concentrations rather than activities. These constants—also sometimes referred to as apparent constants—incorporate the effect of surface charge, which is largely a function of pH and solution composition, on metal-ligand interactions at the surface of the particles as well.

Rearranging

$$[MSUS_i] = \beta^*_{SUS_i}[M][SUS_i] \tag{10}$$

A similar approach can be applied to describing metal equilibria in surface sediments in the system.

$$[M]_{pw} + [SED_i] \rightleftharpoons [M_{pw}SED_i] \tag{11}$$

where $[M]_{pw}$ = free metal ion concentration in pore water
$[SED_i]$ = concentration of I^{th} surface sites associated with solid phases in the in sediment column
$[M_{pw}SED_i]$ = concentration of surface complexes with I^{th} surface sites associated with solid phases in the sediment column

The equilibrium expression is given as

$$\beta^*_{SED_i} = \frac{[M_{pw}SED_i]}{[M]_{pw}[SED_i]} \tag{12}$$

Rearranging as before

$$[M_{pw}SED_i] = \beta^*_{SED_i}[M]_{pw}[SED_i] \tag{13}$$

The total metal concentration of the system including both water and sediment columns can now be described. In the water column

$$[M]_{T_{Water}} = [M] + \Sigma[ML_i] + \Sigma[MSUS_i] \tag{14}$$

and in the sediment column

$$[M]_{T_{Sed}} = [M]_{pw} + \Sigma[M_{pw}L_{i_{pw}}] + \Sigma[M_{pw}SED_i] \tag{15}$$

From equations (6), (10), and (13), equations (14) and (15) may be rewritten as

$$[M]_{T_{Water}} = [M]\ (1 + \Sigma\beta_i^*[L_i] + \Sigma\beta_{SUS_i}^*[SUS_i]) \qquad \textbf{(16)}$$

and

$$[M]_{T_{Sed}} = [M]_{pw}\ (1 + \Sigma\beta_{i_{pw}}^*[L_{i_{pw}}] + \Sigma\beta_{SED_i}^*[SED_i]) \qquad \textbf{(17)}$$

Sediment Metal Concentrations - Control By Dissolved Metal and Sediment Organic Carbon Concentrations

As noted earlier, exact solution of equations (16) and (17) for the system described here is unlikely to be achieved as information concerning many of the necessary variables is unavailable. However, by making a series of simplifying assumptions these equations can be modified to describe the distribution of metal between the water and sediment columns. We hypothesize that this distribution can be described as a simple function of water column dissolved metal concentration and the organic carbon content of the sediments. To test this hypothesis we make the following assumptions.

1. The free metal ion concentrations in both the water column and pore water in the upper 3 cm of an oxic sediment column are not substantially different. By making this assumption, equations (16) and (17) may be combined and rewritten as

$$[M]_T = [M]\ (1 + \Sigma\beta_i^*[L_i] + \Sigma\beta_{i_{pw}}^*[L_{i_{pw}}] + \Sigma\beta_{SUS_i}^*[SUS_i] + \Sigma\beta_{SED_i}^*[SED_i]) \qquad \textbf{(18)}$$

2. Concentrations associated with suspended matter and pore water represent a negligible fraction of the total metal present in the system and may be ignored. Equation (18) then becomes

$$[M]_T = [M]\ (1 + \Sigma\beta_i^*[L_i] + \Sigma\beta_{SED_i}^*[SED_i]) \qquad \textbf{(19)}$$

3. Metal-sediment interactions are dominated by interactions between free metal ion activities in interstitial water and ligands ($\sum[SED_i]$) associated with organic matter coatings on the surface of the solid phases present in surface sediments.

4. The composition of the organic matter in the upper 3 cm of oxic surface sediments in the system, in this case Massachusetts and Cape Cod Bays, is relatively uniform both temporally and spatially.

5. Ligand activities controlling the free metal ion concentration of metals in the water column of Massachusetts and Cape Cod Bays are relatively uniform both temporally and spatially.

This latter assumption implies that changes in [M] are directly proportional to changes in [M_T] (equation (7)). In total these assumptions allow the relationship between dissolved metal concentrations and sediment concentrations to be simplified further and described by the simple equilibrium given in equation (20)

$$\beta^*_{C_{org\,SED}} = \frac{[M_{SED}]}{[M][C_{org\,SED}]} \quad \textbf{(20)}$$

where the β^* in this case represents an overall empirically defined conditional constant describing the affinity of a given metal for the controlling surface ligands in the sediments. Rearranging to solve for the sediment metal concentration

$$[M_{SED}] = [M]\ \beta^*_{C_{org\,SED}}\ [C_{org\,SED}] \quad \textbf{(21)}$$

By additionally assuming that [M] is fixed at either steady state or, less likely, equilibrium conditions, [M_{SED}] becomes a simple linear function of the organic carbon content of the sediments. Regional differences in sediment metal:organic carbon ratios would then reflect differences in dissolved metal concentration in the overlying water column. Sediment metal concentration data, obtained from the MWRA benthic monitoring program, in conjunction with data obtained by Wallace *et al.* (in preparation) and others on dissolved metal concentrations in Massachusetts and Cape Cod Bays are used to test this hypothesis.

Results

Raw data from the 1995 analyses are presented in Appendices B1 and B2. Metal concentration in surface sediments reported in the data from the 1992 -1995 benthic sampling programs were regressed against the reported total organic concentration (TOC) data for the same stations. It is important to note that the metal and TOC data were obtained from different subsamples taken from the same grab but without any prior homogenization. Therefore the regression results may be influenced by small-scale variability within a particular grab sample.

Regression plots were made for each metal for each year. Separate regressions were run for both the nearfield and farfield samples, the grouping of which were modified as described earlier. To illustrate the reason for shifting farfield stations FF12 and 13 to the nearfield and NF5 to the farfield, unmodified and modified regression plots for the 1995 Ag and 1994 *C. perfringens* data are shown in Figures 4 and 5, respectively. Silver concentrations were anomalously high in samples FF12 and 13, and to a lesser extent, in sample FF10 when compared to that in other stations designated as "farfield". The location of these stations, while designated as "farfield" samples, are closer to the Harbor than the other farfield stations and are part of the midfield as defined by Coats (1995) (Figure 2). They are much more likely to be influenced by exchange and mixing with Harbor water, and thus tend to have higher average concentrations of metals then those which are more remote. For the same reasoning, "nearfield" station NF5 is actually a greater distance from the Harbor than most of the other nearfield stations and some of the farfield stations (i.e., FF10-13). The modified plots in Figures 4 and 5 reflect the movement of FF12 and FF13 into the nearfield grouping and NF5 into the farfield grouping (Ag only). The *C. perfringens*

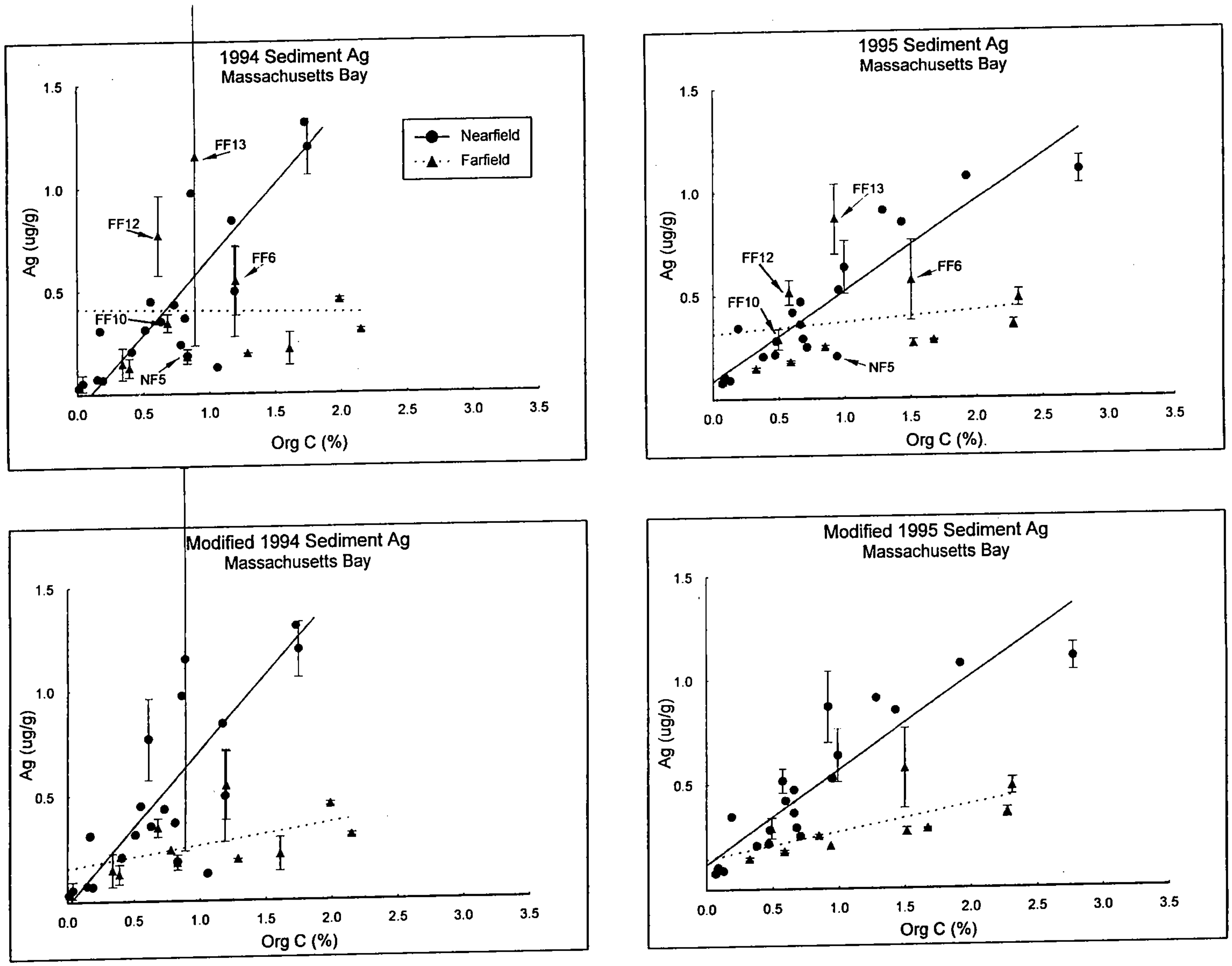


Figure 4. **Regression of silver versus organic carbon concentration, Nearfield and Farfield stations, 1994 and 1995, original and modified station groupings (see text).**

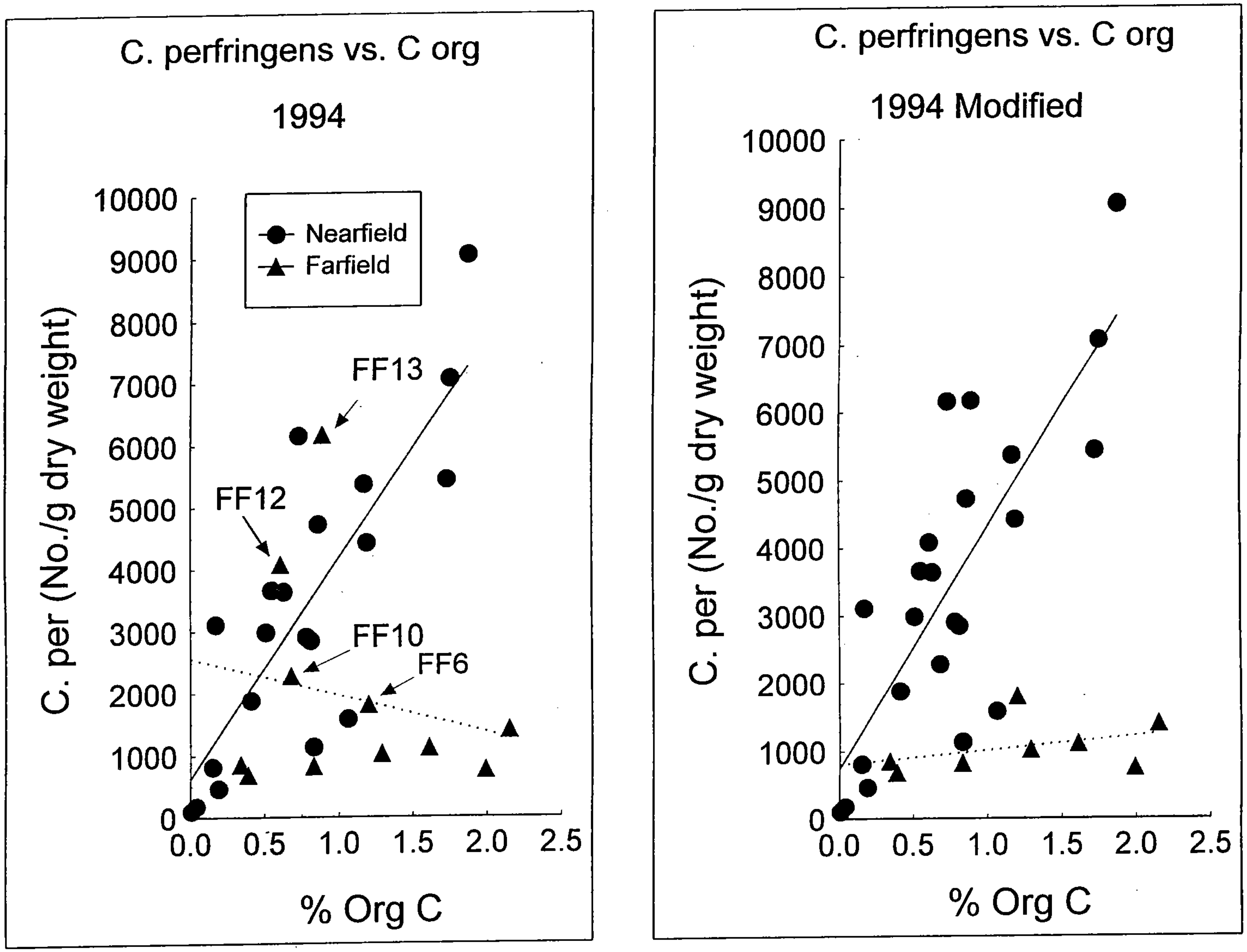


Figure 5. Regression of *Clostridium perfringens* spore counts versus organic carbon concentration, Nearfield and Farfield stations, 1994, original and modified station groupings (see text).

counts at NF5 in the 1994 data were more like those for the rest of the 1994 nearfield stations, although the 1993 count for this station was among the lowest observed in all stations sampled that year despite an identical TOC concentration (see Table 4 in Coats, 1995).

Regression results for all metals (Cu, Zn, Pb, Cd, Hg, Ag, Ni, Cr, Fe, and Al) in both the nearfield and farfield groups, modified as described above, are plotted in Figures 6 to 15, respectively. Regression parameters and statistics are given in Appendix B3. Regression slopes were relatively constant for the modified nearfield and farfield groups between 1993 and 1995. Regression of the nearfield data for 1992 produced slopes distinctly higher than in other years for most metals and with lower and sometimes negative intercepts. The farfield slopes for 1992 are however quite similar to those in 1993-1995. The reason for the anomalous sediment metal:C_{org} slopes in the 1992 nearfield data are not known. Intercepts in the 1993 -1995 regressions for both groups are similar for most metals and often close to those expected for the crustal component of the sediment. The crustal component represents an inert lattice-bound contribution to the sediment composition. This refractory component of metal is not readily exchangeable and as such represents a background value most closely related to the clay (and Al) content of the sediment.

The regression lines plotted in the figures are not all necessarily statistically significant ($p<0.05$) as noted in the tables and are displayed for visual reference only. Slopes appear to be different between the nearfield and farfield for Cu, Pb, Cd, Hg, Ag, and Cr while those for Zn, Ni, Fe and Al are similar. A more rigorous statistical assessment of the significance of these differences is beyond the scope of this report and will be included in a more thorough analysis of the data being prepared for publication elsewhere.

For those metals where differences appeared to be significant, the hypothesis that differences in dissolved metal concentration could explain the differences as predicted in equation (21) was examined. A comparison of $[M_{SED}]/[Corg]_{SED}$, with and without normalization to ambient dissolved metal concentrations, [M], are shown in Figures 16 to 18 for Cu, Pb, and Ag, respectively. Additional sediment Cu, Ag, Pb and Corg data from Boston Harbor, where metal concentrations in both the water column and sediments are distinctly higher, were obtained from Wallace *et al.* (1991). In addition, corresponding dissolved Cu and Pb data from Wallace *et al.* (1991; in preparation) and dissolved Ag data from Krahforst and Wallace (in preparation) for the Harbor and Massachusetts and Cape Cod Bays were used to produce these figures. Normalization of the sediment metal to carbon slopes to ambient dissolved metal concentrations clearly helps explain differences in slope from location to location. These preliminary observations support the hypothesis that sediment concentrations of metals in Massachusetts and Cape Cod Bays, and apparently the Harbor as well, can be largely predicted by using the organic carbon content of the sediment and dissolved metal concentrations in the overlying water column.

If one accepts this simple empirical model, the data may be used to predict the sediment metal content of sediments in the Bays as a function of projected dissolved metal concentrations and the organic content of the sediment using equation (21). $[M_{SED}]$ was estimated using the β^* determined as the mean of the normalized regression slopes. Results of these projections for Cu, Pb and Ag are presented in Figures 33 to 36, respectively. Bar heights in these figures indicate the water column concentrations that would produce a sediment metal concentration equivalent to 90% of the Effects Range-Median (ER-M) levels reported by Long et al. (1995) for sediments with organic carbon contents of 2, 4 and 6 %. Also shown in these figures, for reference purposes, are current EPA marine aquatic life water quality criteria (solid

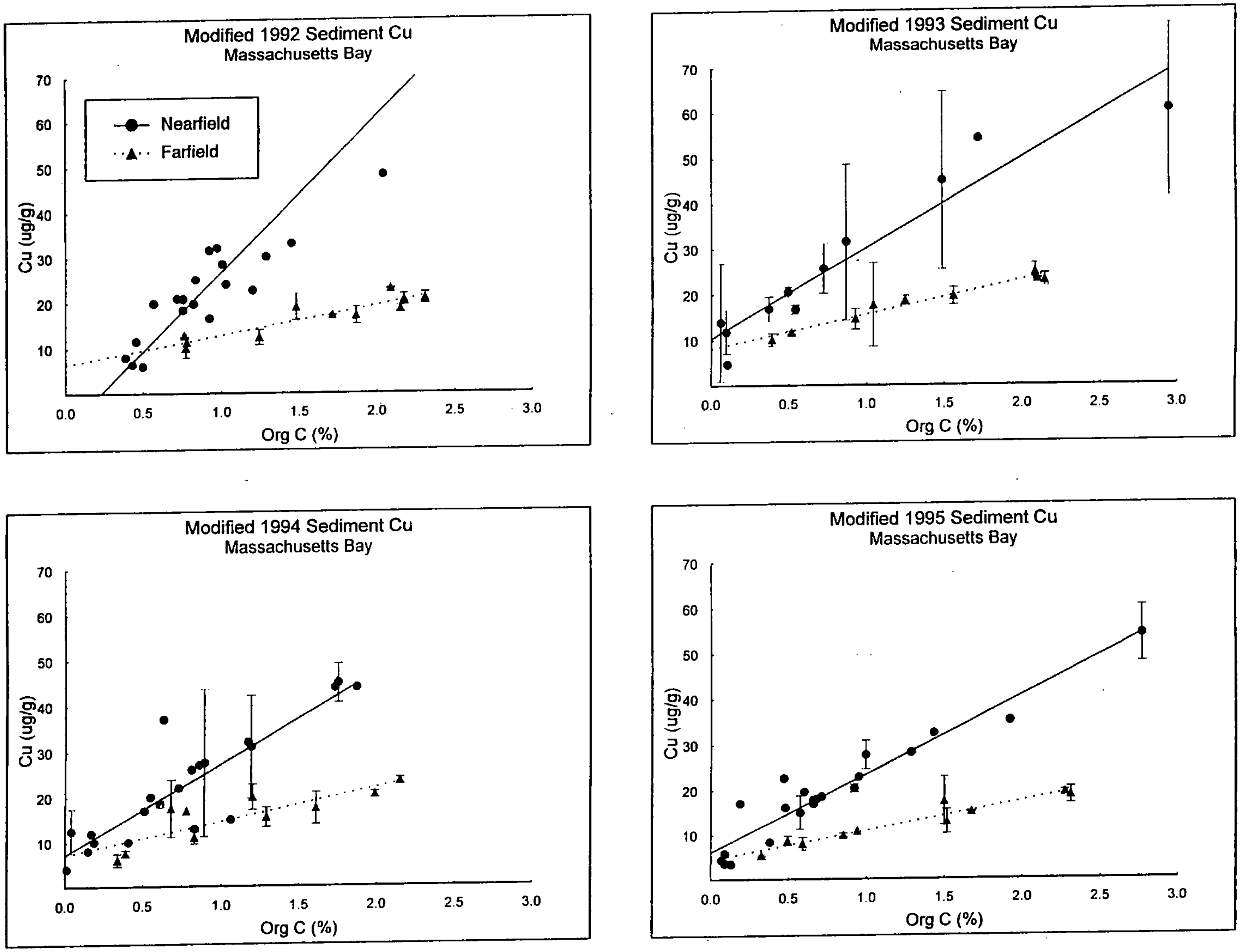


Figure 6. Regression of copper versus organic carbon concentration, Nearfield and Farfield stations, 1992 through 1995, modified station grouping (see text).

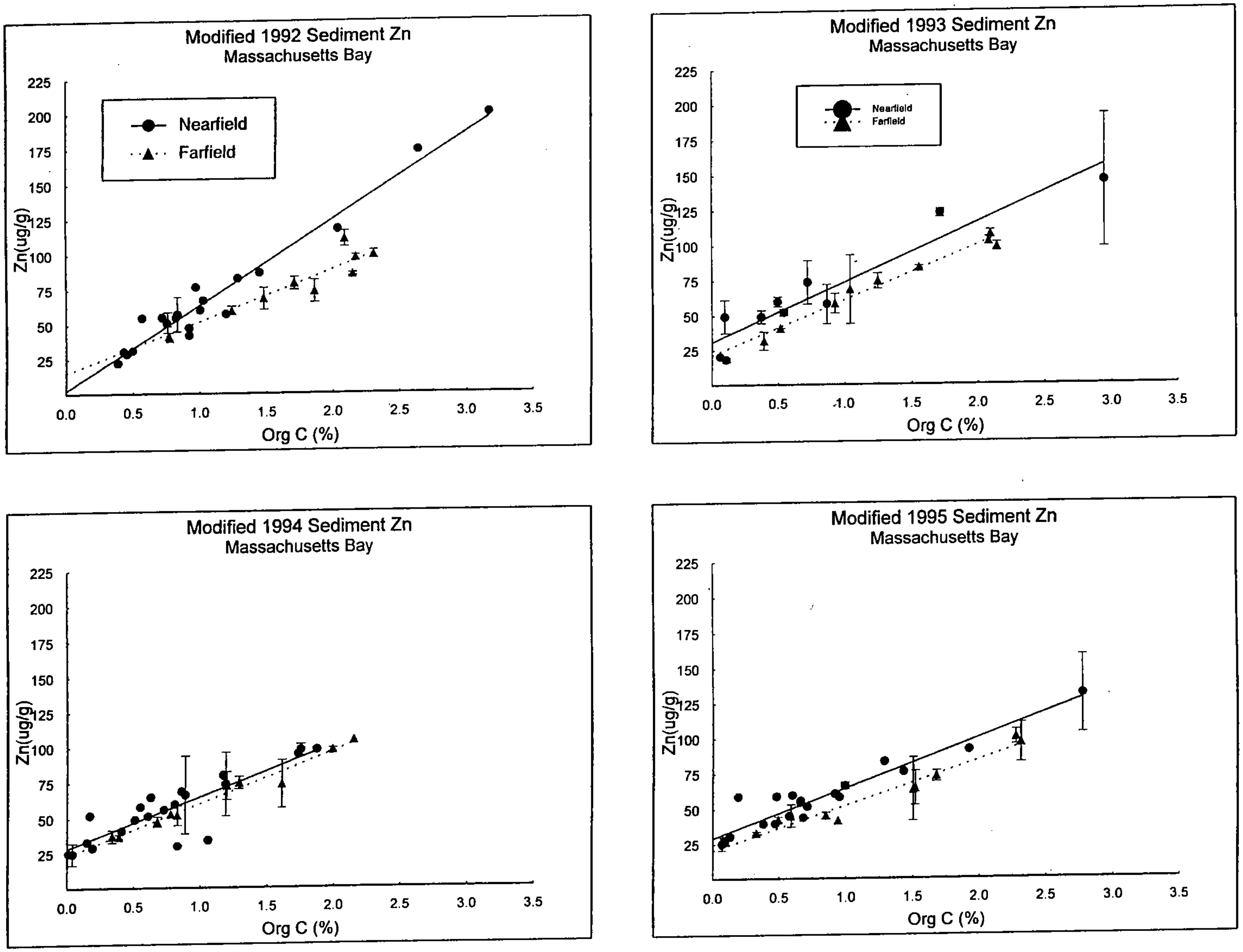


Figure 7. Regression of zinc versus organic carbon concentration, Nearfield and Farfield stations, 1992 through 1995, modified station grouping (see text).

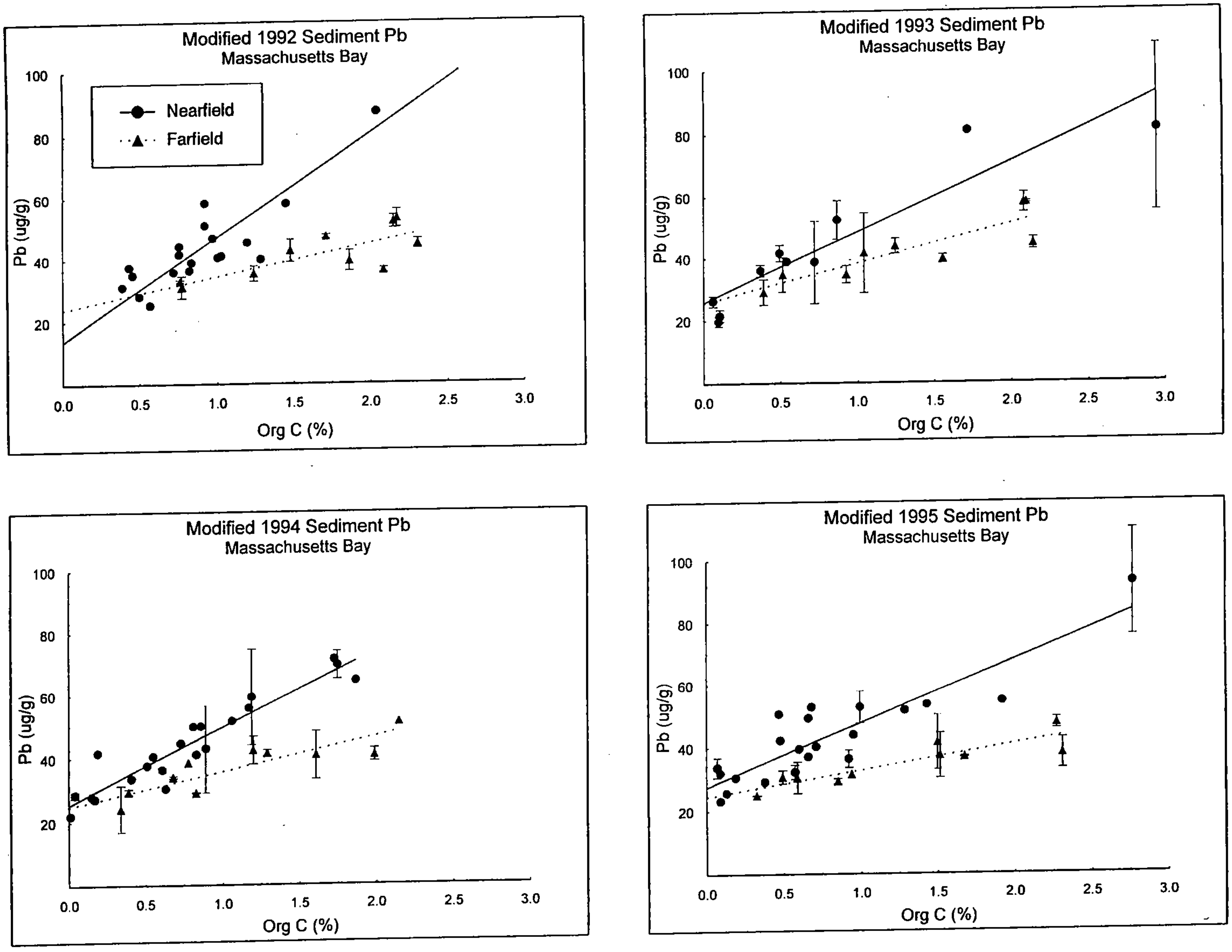


Figure 8. Regression of lead versus organic carbon concentration, Nearfield and Farfield stations, 1992 through 1995, modified station grouping (see text).

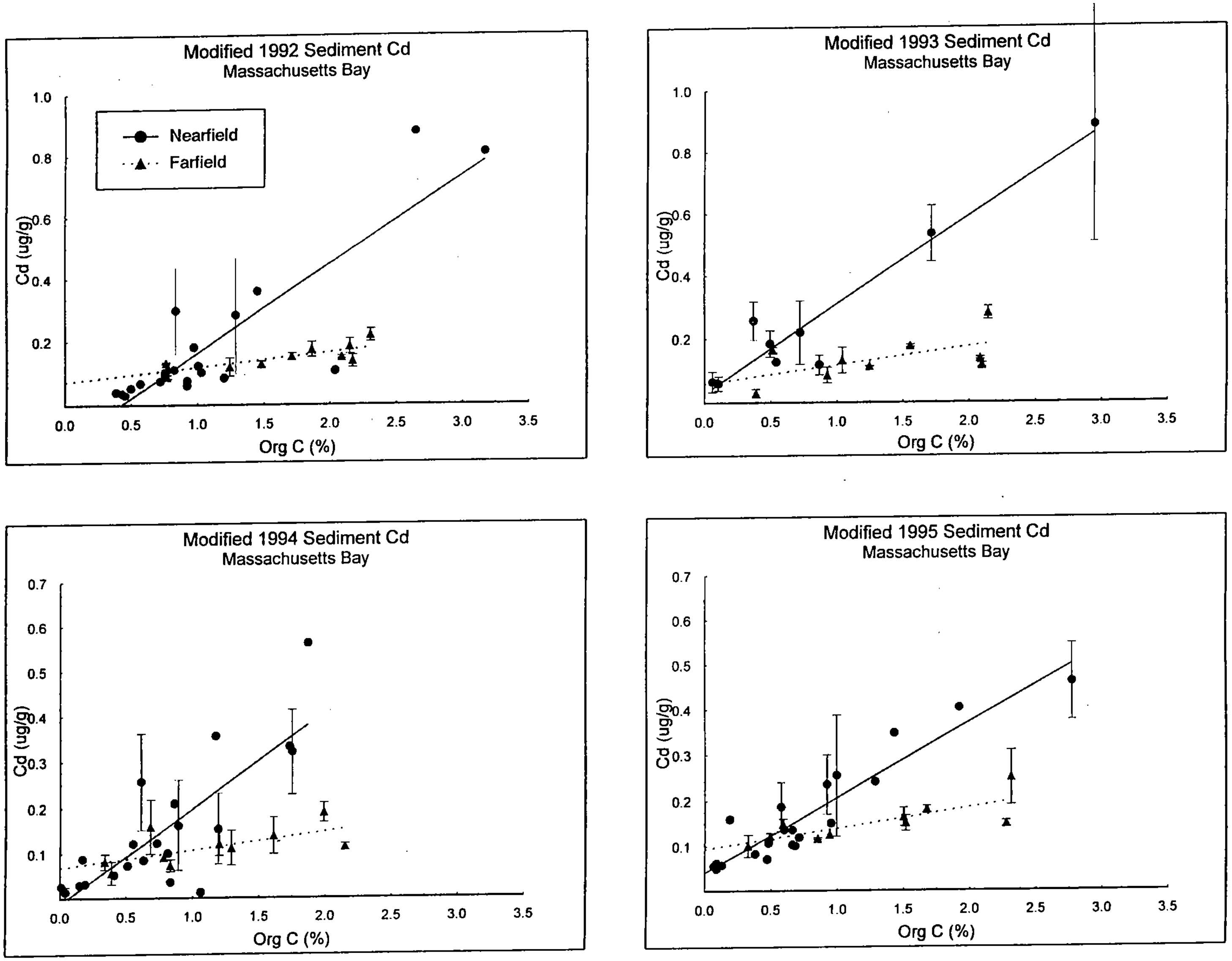


Figure 9. Regression of cadmium versus organic carbon concentration, Nearfield and Farfield stations, 1992 through 1995, modified station grouping (see text).

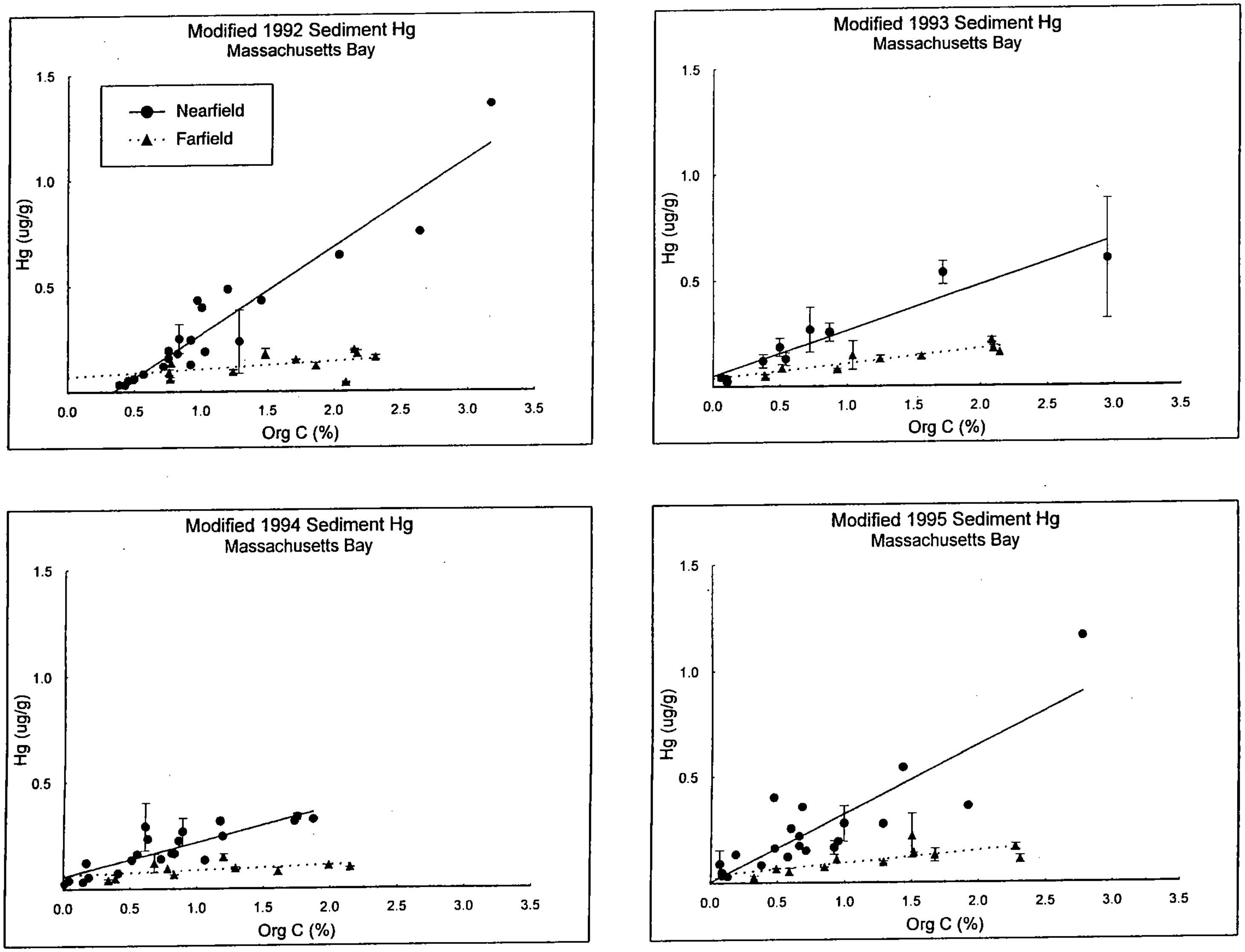


Figure 10. Regression of mercury versus organic carbon concentration, Nearfield and Farfield stations, 1992 through 1995, modified station grouping (see text).

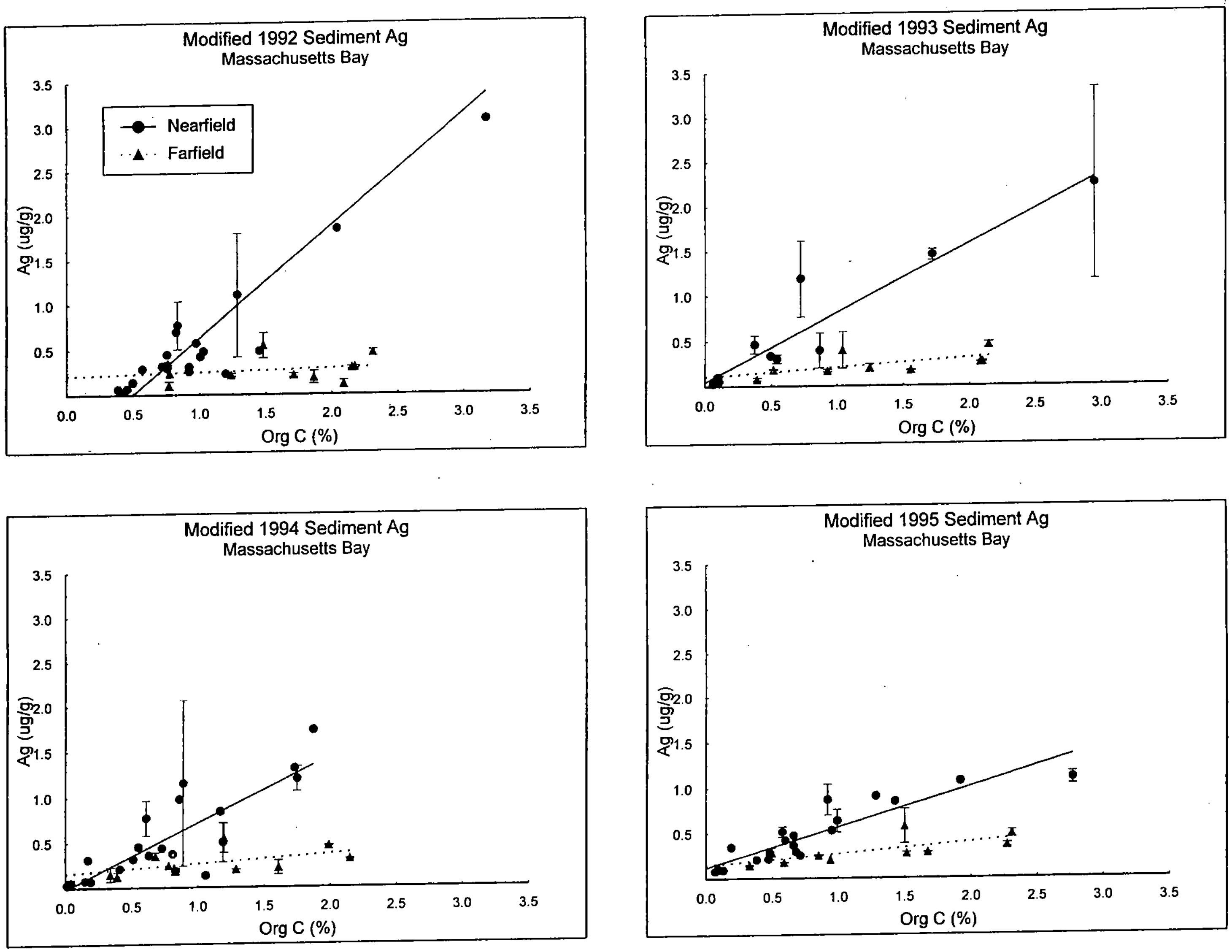


Figure 11. Regression of silver versus organic carbon concentration, Nearfield and Farfield stations, 1992 through 1995, modified station grouping (see text).

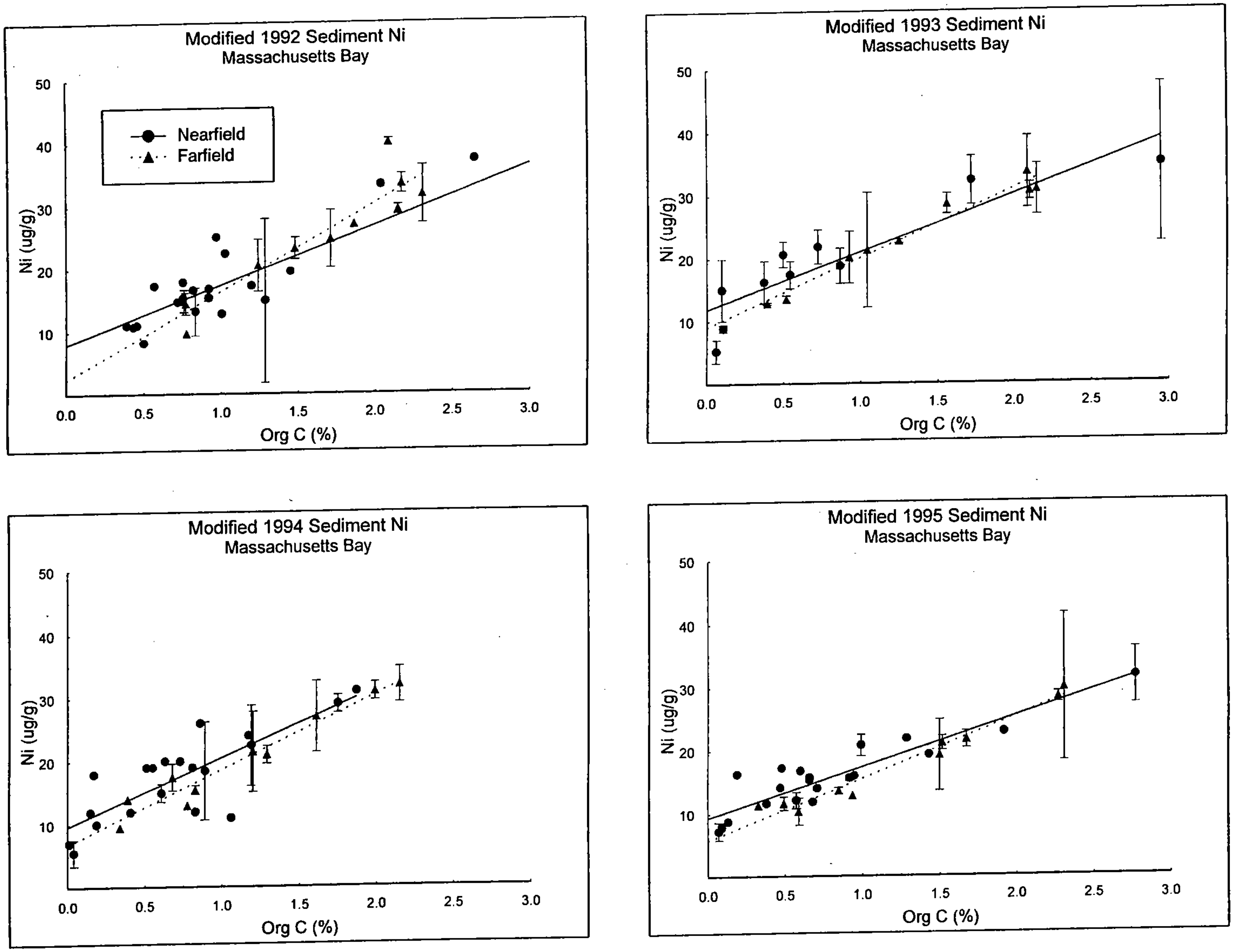


Figure 12. Regression of nickel versus organic carbon concentration, Nearfield and Farfield stations, 1992 through 1995, modified station grouping (see text).

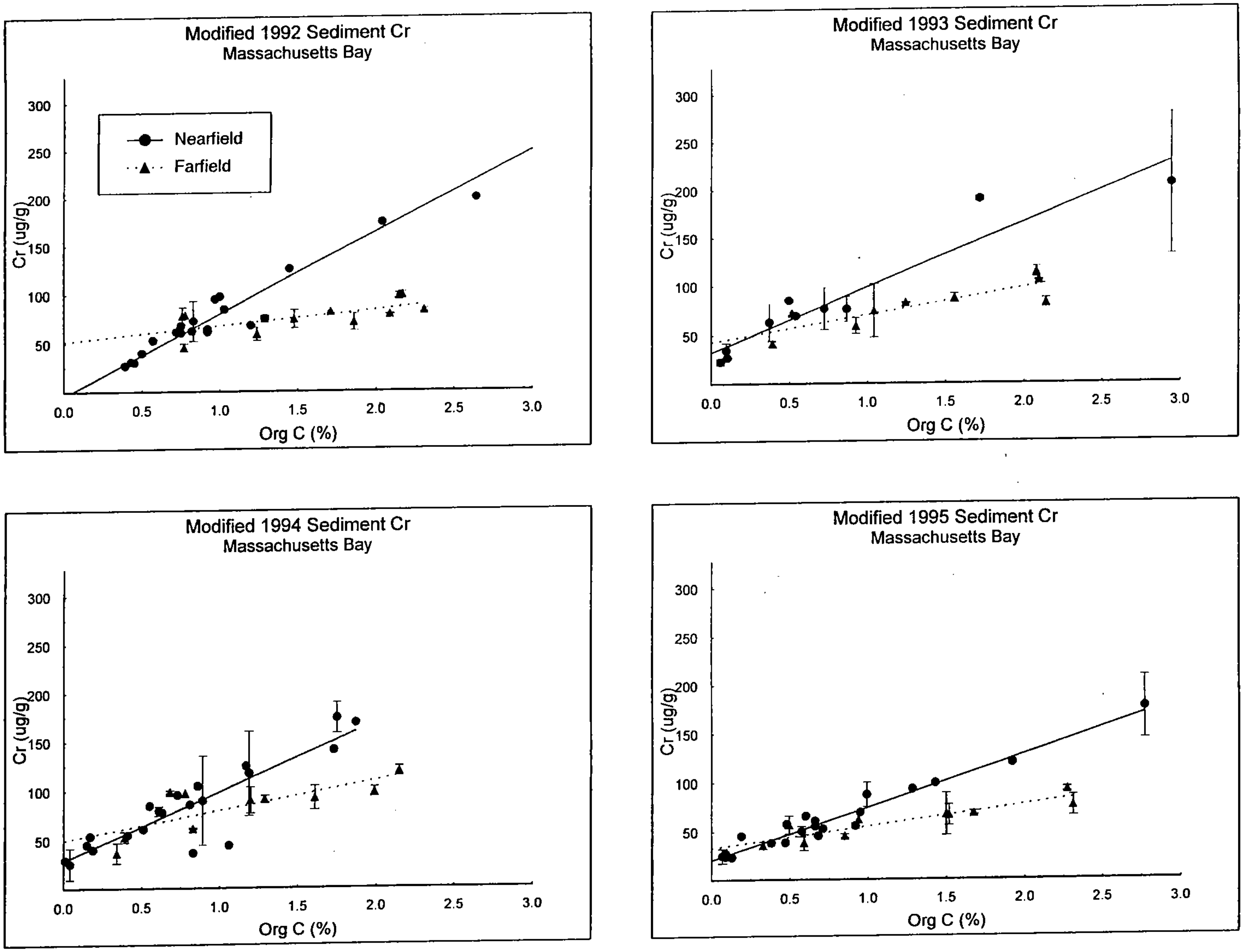


Figure 13. Regression of chromium versus organic carbon concentration, Nearfield and Farfield stations, 1992 through 1995, modified station grouping (see text).

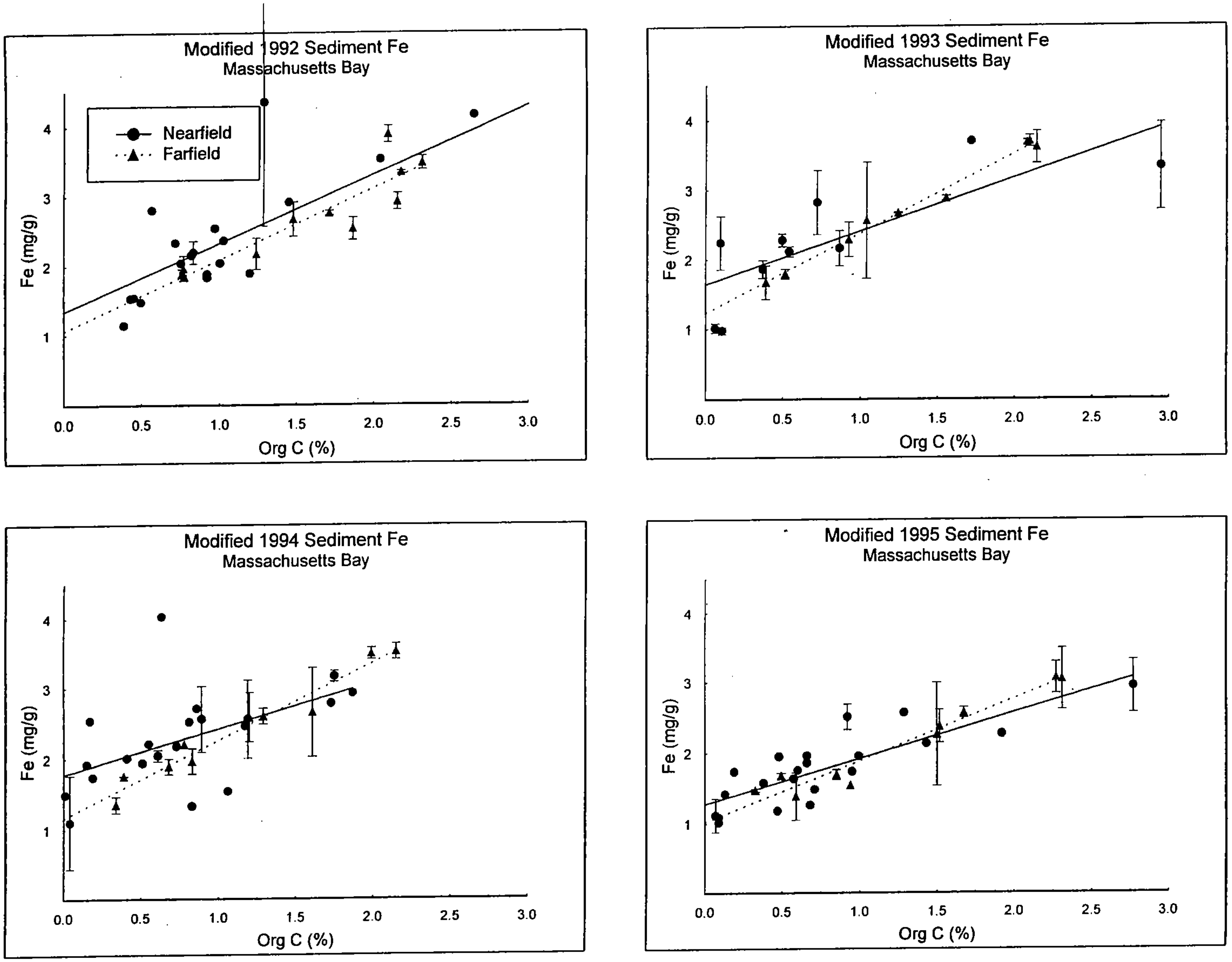


Figure 14. Regression of iron versus organic carbon concentration, Nearfield and Farfield stations, 1992 through 1995, modified station grouping (see text).

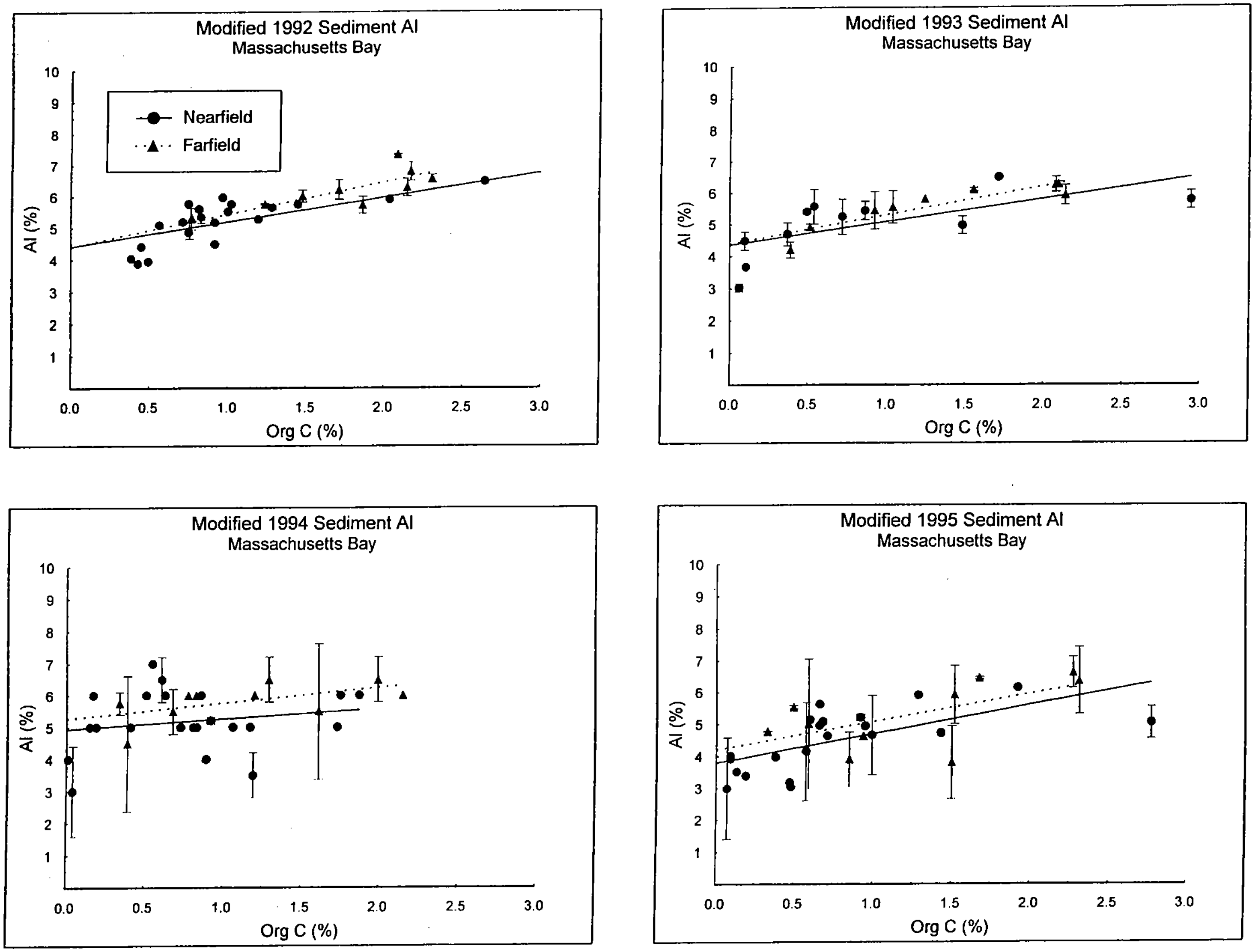


Figure 15. Regression of aluminum versus organic carbon concentration, Nearfield and Farfield stations, 1992 through 1995, modified station grouping (see text).

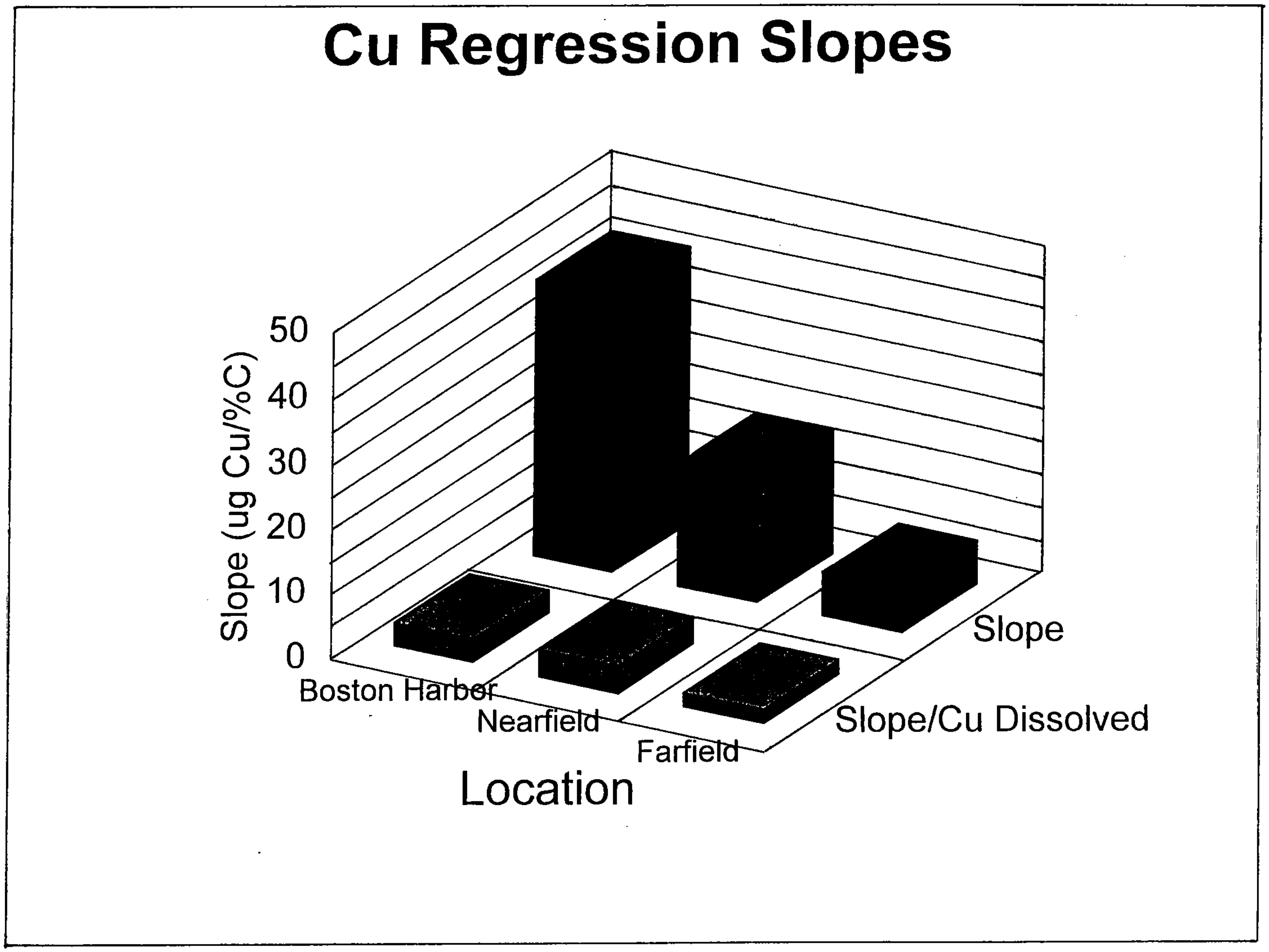


Figure 16. Regression slopes for copper, Boston Harbor and Massachusetts/Cape Cod Bays, original data and data normalized for dissolved copper in overlying water column.

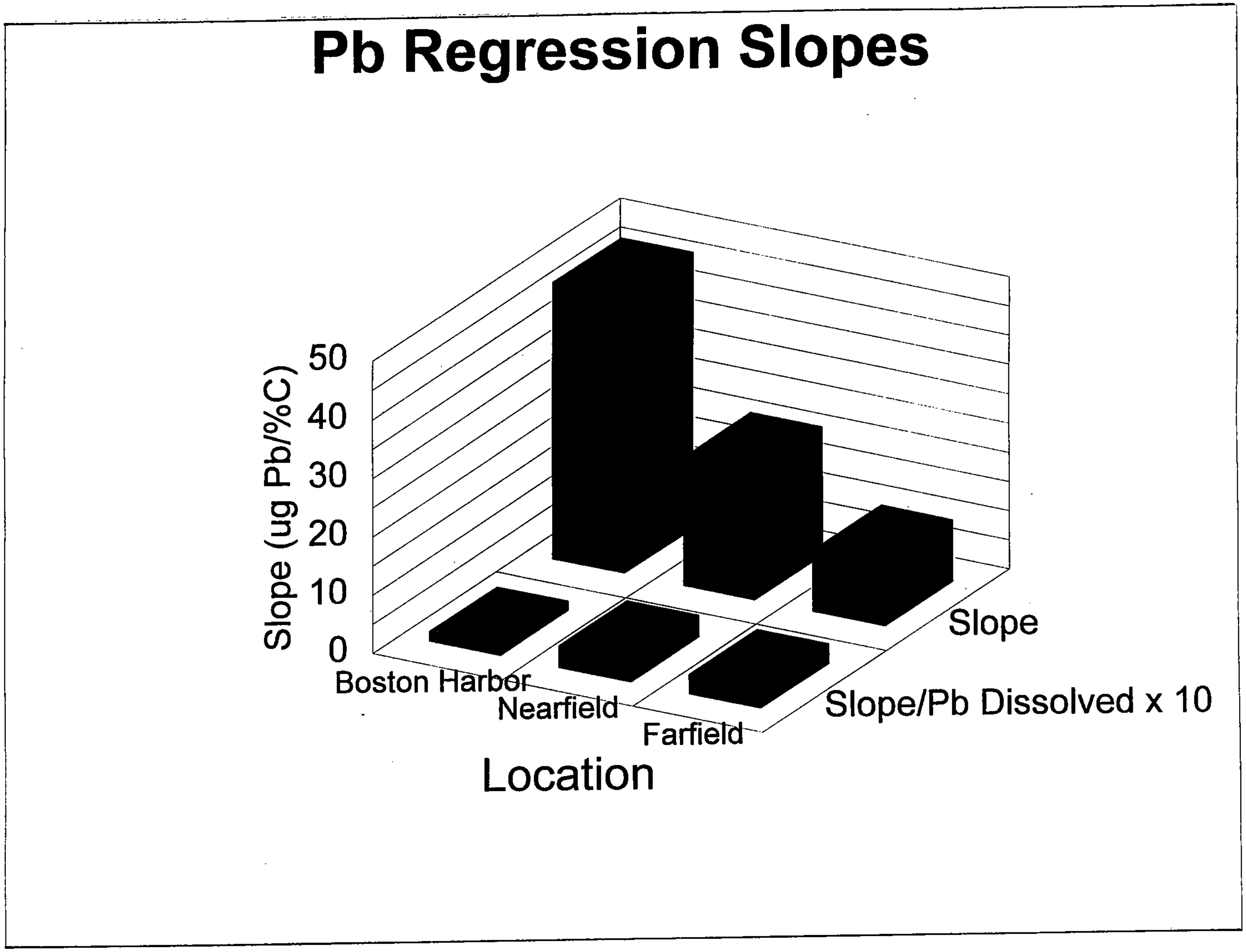


Figure 17. Regression slopes for lead, Boston Harbor and Massachusetts/Cape Cod Bays, original data and data normalized for dissolved lead in overlying water column.

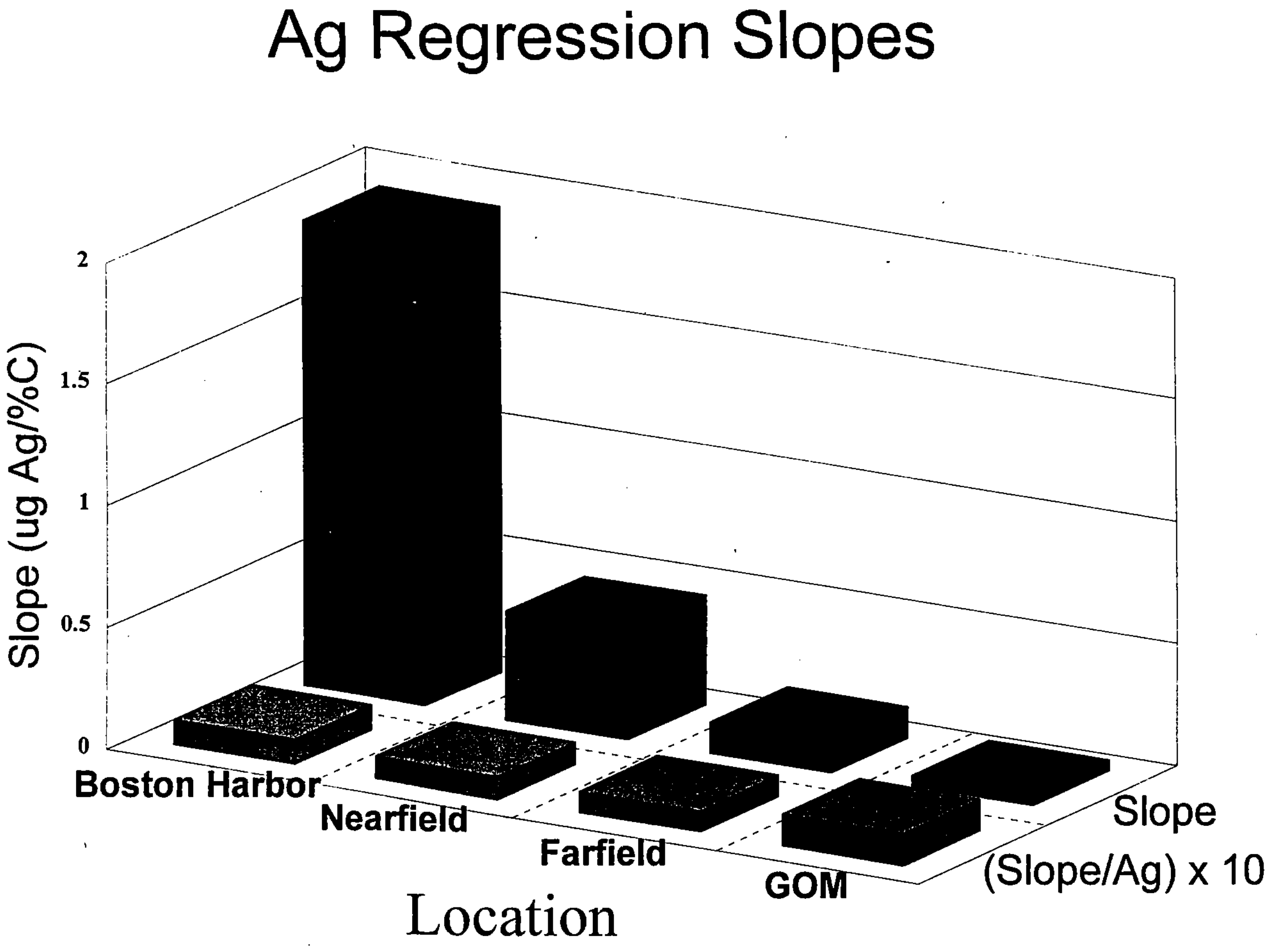


Figure 18. Regression slopes for silver, Boston Harbor, Massachusetts/Cape Cod Bays, and Gulf of Maine (GOM), original data and data normalized for dissolved silver in overlying water column.

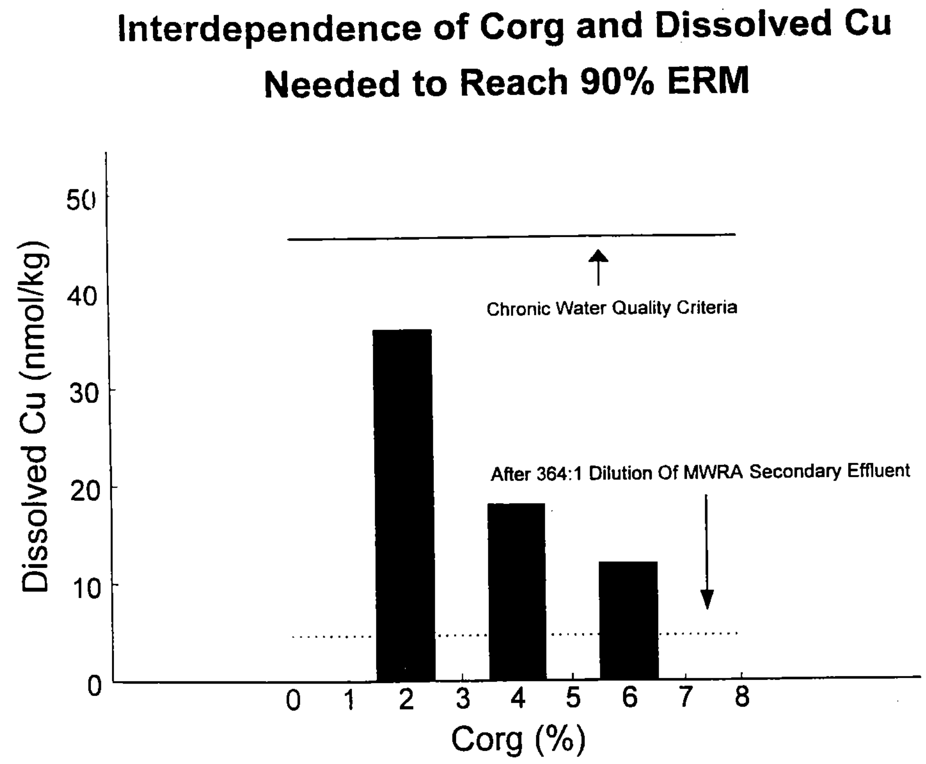


Figure 19. Solid line indicates EPA marine aquatic life water quality criterion, dotted line indicates estimated concentration in secondary effluent after dilution.

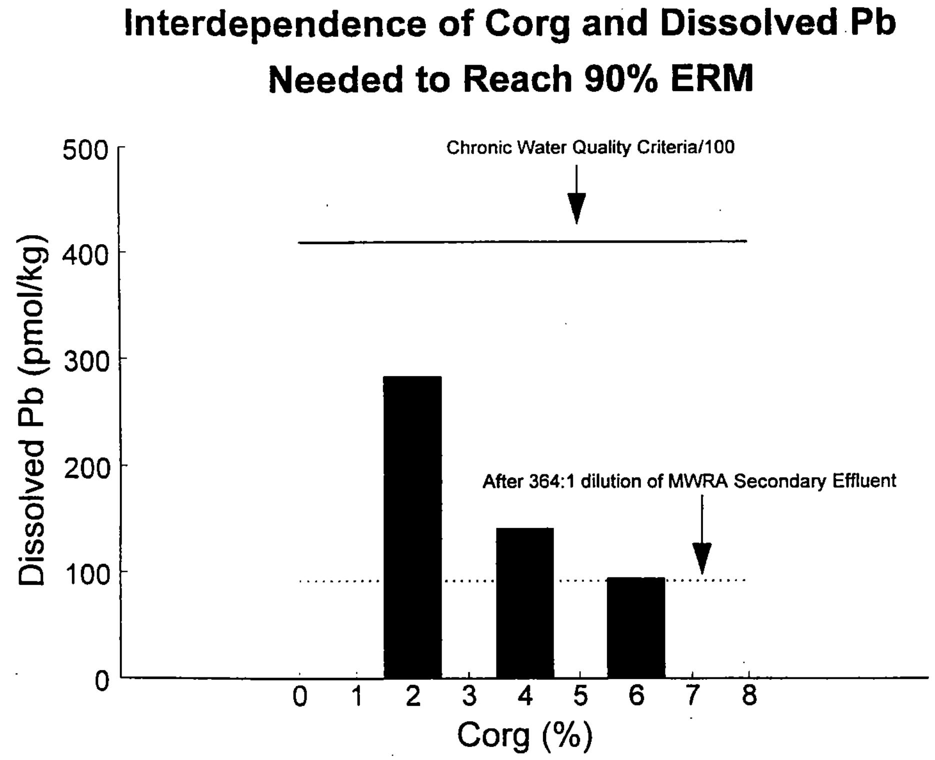


Figure 20. Solid line indicates EPA marine aquatic life water quality criterion, dotted line indicates estimated concentration in secondary effluent after dilution.

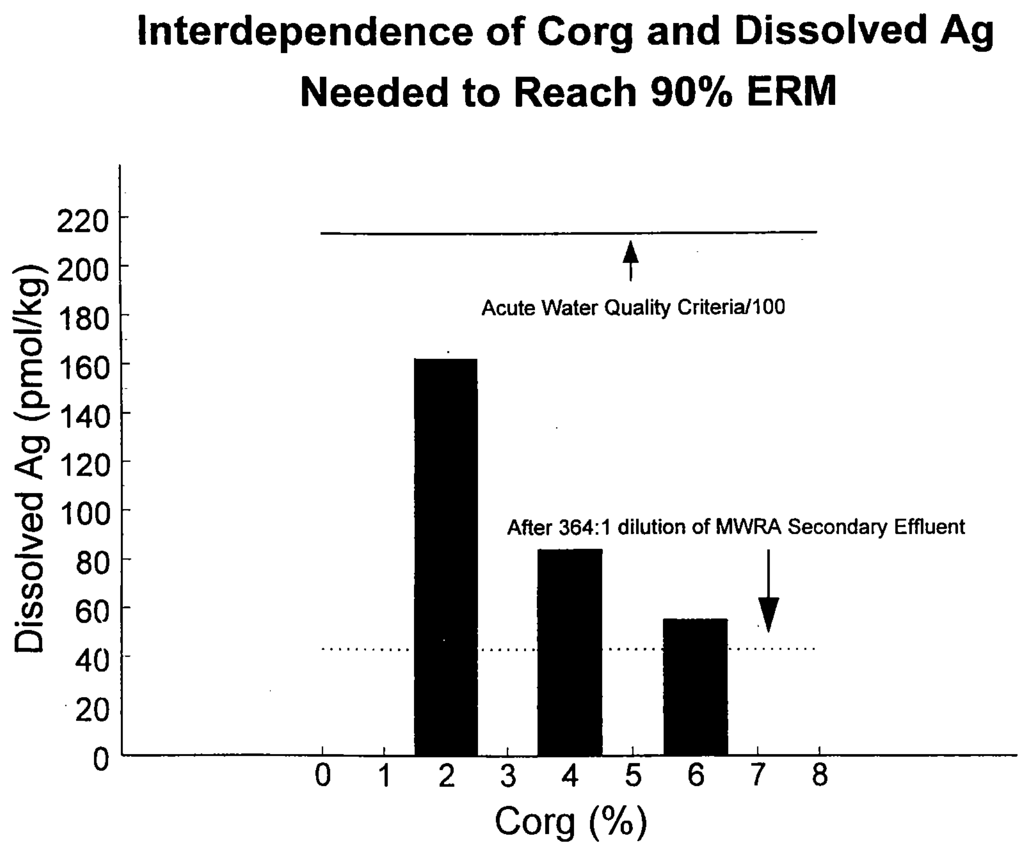


Figure 21. Solid line indicates EPA marine aquatic life water quality criterion, dotted line indicates estimated concentration in secondary effluent after dilution.

lines), either chronic (Cu and Pb) or acute (Ag). Note that in the case of Pb and Ag it was necessary to divide the actual value of the respective water quality criteria by a factor of 100 to allow display on the concentration scale used.

The chronic water quality criterion for Cu is well above threshold concentrations estimated to produce 90% ER-M sediment concentrations, even at the 2% organic carbon level. The chronic (Pb) or acute (Ag) water quality criteria concentrations are grossly above the concentrations estimated to produce sediment 90%ER-M levels over the % carbon ranges examined (2-6%) for these metals. If these predictions are reasonably accurate, existing water quality criteria are clearly inadequate with respect to maintenance of sediment concentrations below 90% ER-M thresholds for these metals. For example, existing water quality criteria for Ag and Pb would have to be reduced by greater than two orders of magnitude to prevent concentrations from exceeding 90%ER-M levels in sediments having a C_{org} content of even 2%.

Also indicated in Figures 19 to 21 are estimated water column concentrations based on expected 364:1 dilution of the secondary effluent within 1 km of the diffuser (dotted line) (Ken Keay, MWRA, personal communication). These concentrations were estimated using observed ambient concentrations of Cu, Ag and Pb of 3.7, 0.01 and 0.049 nmol/kg (Wallace *et al.*, 1991 and in preparation; Krahforst and Wallace, in preparation) and the highest observed metal concentrations in the effluent produced in the recent pilot secondary treatment plant studies conducted in 1995 (Ken Keay, MWRA, personal communication). The predicted sediment concentrations for these metals under these conditions are approximately equal to (e.g., Pb at 6% organic carbon) or below that expected to generate 90% ER-M concentrations for sediments with 2-6% organic carbon. The 1995 raw data are presented in Appendices B2 and B3.

Assumptions Revisited

The validity of these estimates are of course a function of the validity of the assumptions made above in the construct of the model. While the free ion concentration [M] in pore waters and overlying water column may be different, especially in sediments with higher organic content due to changes in pH, Eh, and associated compositional changes, these differences may not be great for slowly accumulating surface oxic sediments. If one assumes sedimentation rates are on the order of 0.1 cm y^{-1}, the upper 3 cm of sediment sampled represents sediment accumulated over a thirty-year time period. Diffusive equilibrium, even in the absence of sediment mixing by organisms should be reached on much shorter time scales. Note that this assumption refers to the free metal ion concentration, not the total dissolved (and colloidal) forms which in most cases are quite different between pore waters and the overlying water column (see recent review by Hong *et al.*, 1995).

The proposed relationship between sediment organic matter and dissolved metal concentration also assumes there is a more or less homogeneous quality of the organic matter in the surface sediments. This is consistent with the relatively long residence time of the surface sediments relative to the shorter residence time of freshly deposited organic matter in the sediments before bacterial degradation, and the general absence of radically different sources of sedimentary organic carbon over spatial scales smaller than defined by the nearfield and farfield regions sampled here. The apparent ability to describe the metal content of sediments as dependent on the organic matter content of the sediments is also consistent with current understanding of the affinity of metals for organic matter relative to other solid phases in oxic coastal sediments and the prevalence of mono- or multi- layer coatings of mineral surfaces in sediments by organic matter (Neihof and Loeb, 1974; Balistrieri *et al.*, 1981; Mayer, 1994; Hedges and Keil, 1995).

Other solid surfaces, particularly those of the hydrous oxides of manganese and iron are known to be active in sequestering metals in sediments. The analysis presented here cannot rigorously define the relative importance of the phases involved, particularly as there is a strong Fe correlation with C_{org}. (Mn was not measured.) Thus it is important to recognize that the proposed relationship between the organic content of the sediments, overlying water column concentrations (activity) of metals, and sediment metal concentration may be of empirical value in providing a more sensitive basis for assessing changes in sediment quality then currently available but is not rigorously defensible at this point from first principles. Precise definition of the equilibria controlling metal sorption to sediments has been, and will continue to be, the subject of continued research. It is clear however that the surface sediment concentrations in Massachusetts and Cape Cod Bays are not simply a reflection of sediment transport of contaminated particles but a more complex function of dynamic exchange of metal with organic matter and possibly other solid phases present on the surface of the sediment particles. It is also clear that changes in the pattern of accumulation and distribution of sediment organic matter in the Bays, coupled with changing distributions of the free ion concentrations of metals in the water column, are probably the most important variables affecting sediment quality with respect to metals as the outfall location is changed.

3.1.2 Organic Constituents

This section will describe the sample analysis and present the analytical results in data tables and figures. The comparability of 1995 results to prior years results is high. The results indicate the spatial distribution of the parameters measured and show that current levels of constituents in the sediments do not exceed 90% of the relevant NOAA Effects Range-Median (ER-M) values or 90 % of EPA's sediment quality criteria. Appendices B4 through B7 contain the PAH, LAB, pesticides, and PCB data for 1995.

To facilitate comparisons to data generated from previous investigations and to summarize the data and simplify their presentation, analytes have been grouped and summed. These groupings are: total chlordane, total DDT, total PCB, total PAH, and total LAB. Total chlordane is the sum of alpha chlordane, trans-nonachlor, heptachlor, and heptachlor-epoxide. Total DDT is the sum of 2,4'-DDE; 4,4'-DDE; 2,4'-DDD; 4,4'-DDD; 2,4'-DDT; and 4,4'-DDT. Total PCB is the sum of all the PCB congeners that are measured in the program (see Table 12 of the Benthic CW/QAPP, Blake and Hilbig (1995)). Total PAH is the sum of all the PAH analytes except for the 4 new analytes, noted above (Methods), measured only in 1995. Total LAB is the sum of each of the C_{10}-C_{14} LAB determinations. Total naphthalene is the sum of naphthalene and the C_1 - C_4 alkylated naphthalenes.

Raw (unnormalized to TOC) data for all samples from 1992-1995 for total PAH, total naphthalene, total PCBs, total Chlordane, total DDT, and total LABs can be found in Appendices B8 through B13. Several points can be made from review of these data. The comparability of the data from prior years relative to 1995 appears quite strong. The concentration ranges are similar for each of the parameters, and the distribution of high and low concentrations among the different stations is similar. That is, stations that exhibited relatively high concentrations from 1992 to 1994 did so in 1995 as well, and stations that exhibited relatively low concentrations between 1992 and 1994 did so again in 1995.

None of the stations exceeded 90% of the ER-M for total PAH (90% of the ER-M is 40,313 ng/g), or total PCBs (90% of ER-M is 162 ng/g) for any of the years. Only one station (NF8 at 68 ng/g) in one year (1994) exceeded the 90% ER-M for total DDT (90% of ER-M is 41.5 ng/g). The stations that generally exhibit the highest concentrations are the midfield stations NF8, NF12, NF7, and FF10.

The stations within 2 km of the diffuser (the nearfield of Coats (1995)) tend to be those that exhibit the lowest concentrations of organic constituents. The eight stations within that region (NF13, 14, 15, 17, 18, 19, 23, and 24) were characterized with regard to these organic constituents by Coats (1995) for the purpose of establishing a baseline. Table 4 presents the geometric mean concentration of total DDT, total PCB, total PAH and several individual analytes along with the baseline mean as determined by Coats (1995). In addition, the concentration that would constitute a significant increase (Coats, 1995) is also listed as well as 90% of the appropriate sediment guideline, either a NOAA ER-M or an EPA sediment criterion. As expected, there was no significant increase seen in the 1995 results relative to the baseline mean, and no mean exceeded 90% of an ER-M or sediment criterion.

Figures 22 through 27 present total LAB, total PAH, total chlordane, total DDT, and total PCB results for 1995, 1994, 1993, and 1992, respectively, all normalized to TOC. In addition, the concentrations were "self-normalized", that is, for each year and parameter the concentration was divided by the highest value for that parameter for that year. This manipulation has the effect of expressing all concentrations on a scale between 0 and 1, so that all parameters could be evaluated on the same graph with the same scale for a given year. Review of the raw data (Appendices B8-B13) confirms that the results of 1995 were similar to those of previous years with regard to spatial distribution of constituents and that the parameters seem to correlate with each other.

Figures 28 and 29 depict the TOC-normalized concentrations for total LAB, total PAH, total DDT, total chlordane, and total PCB for selected midfield stations (NF8 and 12). Selection of these stations was arbitrary, others could have been used equally well to demonstrate that there is no systematic difference between the 1995 results and the results of prior years for any of the parameters.

Figure 30 is a presentation of the PAH data from station FF5. The data have been normalized to fluoranthene (divided by the fluoranthene concentration) to give a picture of the distribution of the PAH analytes. It is evident that the pyrogenic 4, 5, and 6-ring PAH predominate the distribution. The PAH distribution was evaluated for each of the stations; the distribution was virtually identical for all the stations. This distribution is consistent with the atmosphere being the major source of these PAHs to the sediments. The distribution of PAH in atmospheric samples is similar and the pattern in the sediments would be expected to be similar across the study area if the atmosphere is the major source. The major PAHs in effluent are the 2 and 3-ring petroleum derived PAHs, however. In future years it may be possible to focus on changes in the 2 and 3-ring PAHs in the sediments to detect changes derived from effluent.

Figure 31 shows the distribution of LAB at station FF4. The distribution of LABs was similar in all the sediment stations. This distribution is similar to that exhibited by the effluent as measured in 1995. To that extent, it appears to be a valuable parameter to continue to evaluate in the program.

Table 4. 1995 geometric mean of selected parameters versus sediment guidelines

Compound	1995 Geometric Mean	1992-1994 Geometric Mean	Significant Increase	Sediment Guidelines 90% ER-M
4,4'-DDE	0.4	0.1	0.6	24.3
Total DDT	2.5	0.8	2.3	41.5
Total PCB	5.9	7.9	14.5	162
Alpha-Chlordane	1.1	0.05	NA	5.4
Total PAH	870.6	2061	4395	40313
Acenaphthene	11.0	NA	NA	450
Fluoranthene	47.1	NA	NA	4590
Phenanthrene	48.5	NA	NA	1350
Endrin	NA	NA	NA	NA

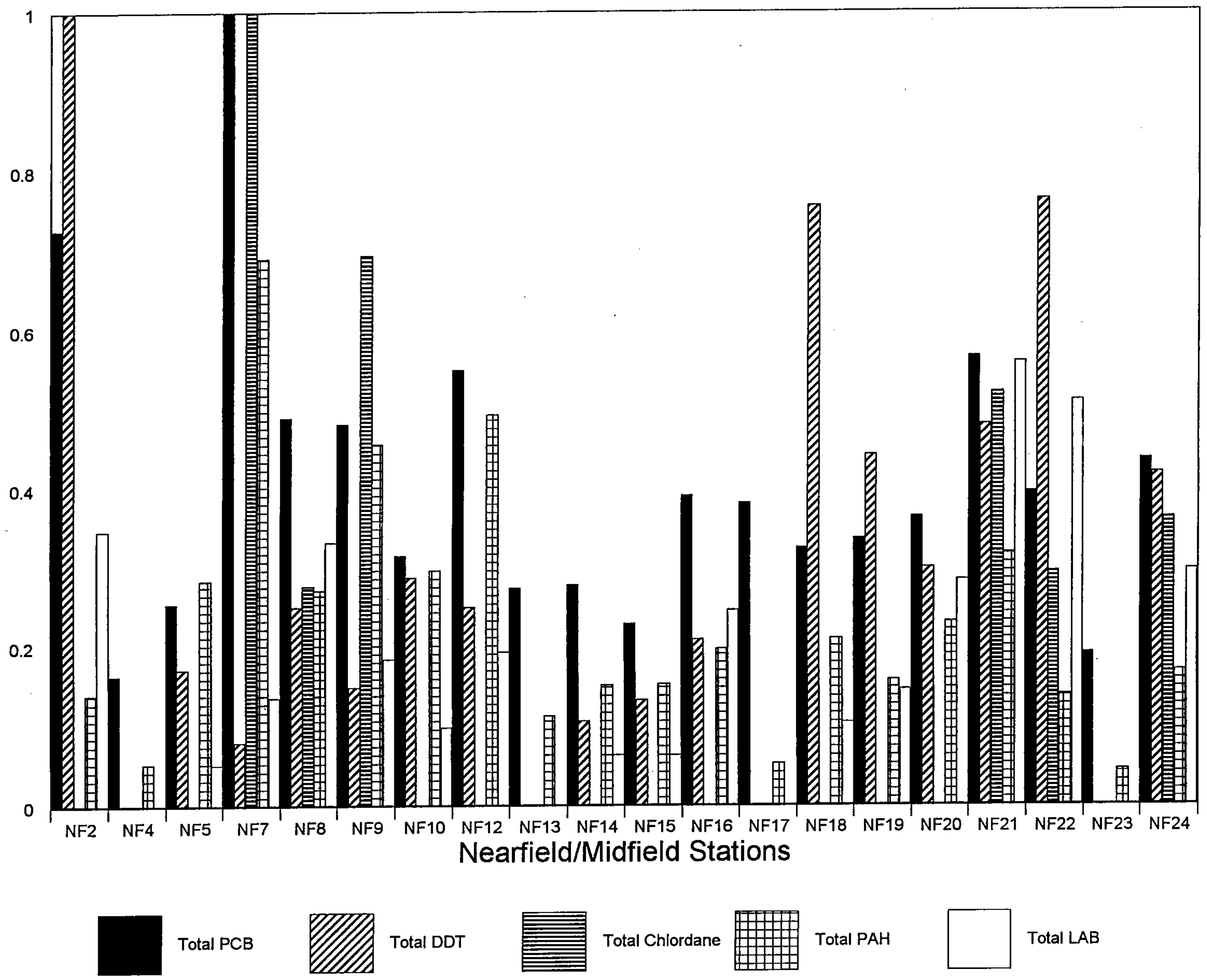


Figure 22. Organic compounds, nearfield/midfield stations, concentrations normalized to TOC and self-normalized, 1995.

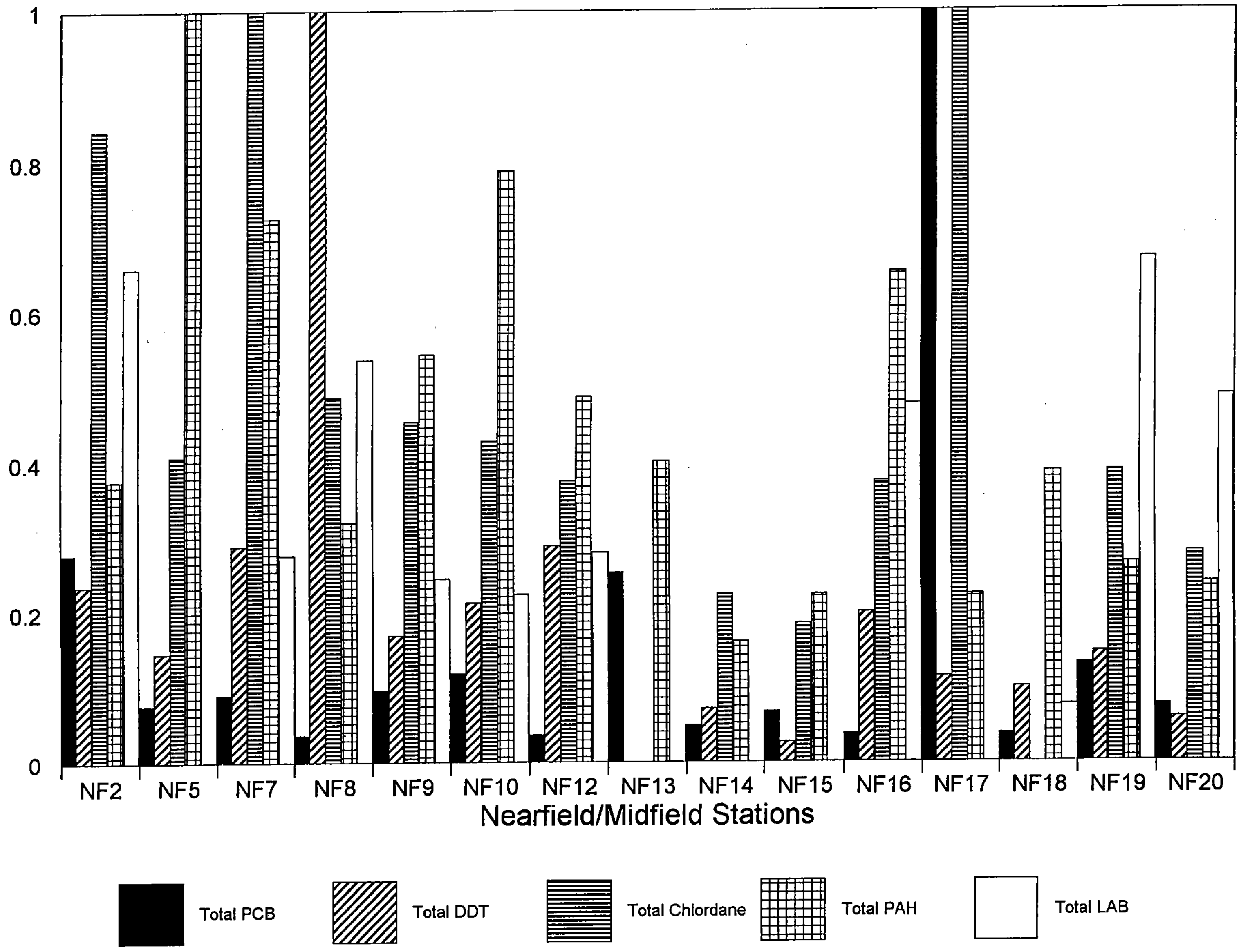


Figure 23. Organic compounds, nearfield/midfield stations, concentrations normalized to TOC and self-normalized, 1994.

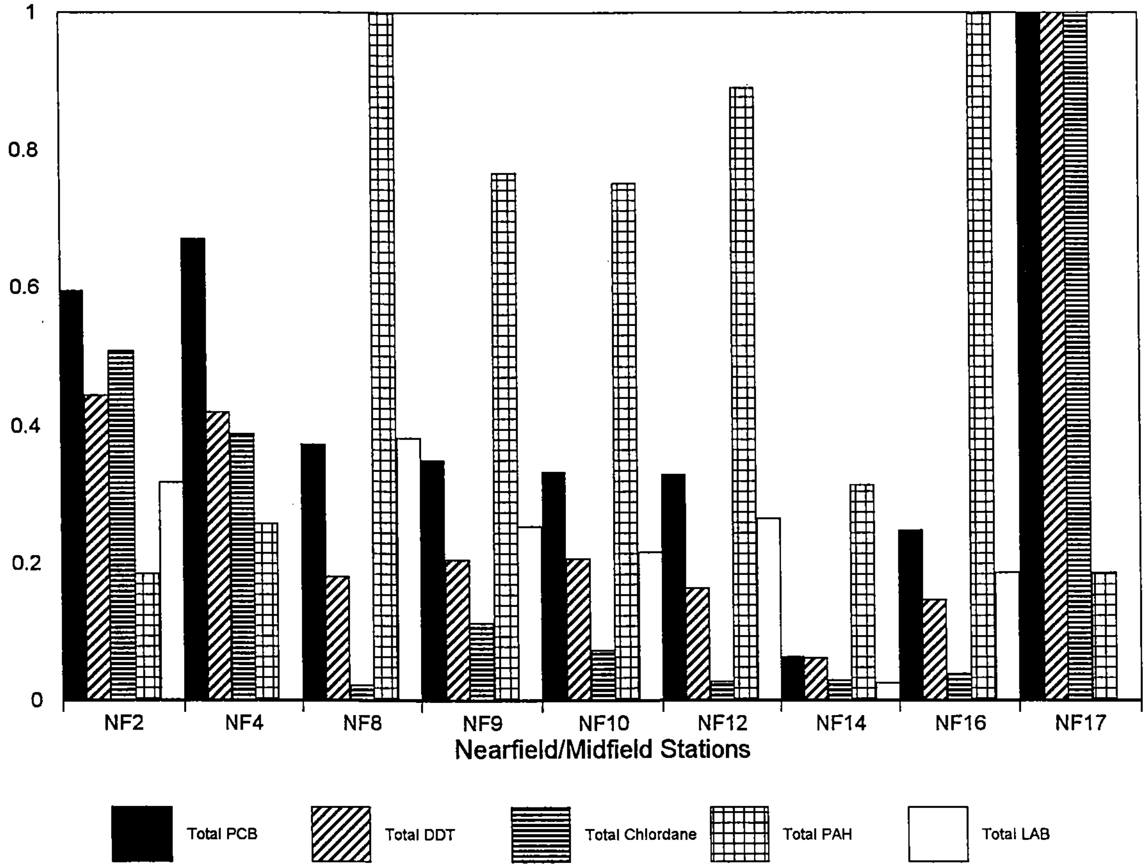


Figure 24. Organic compounds, nearfield/midfield stations, concentrations normalized to TOC and self-normalized, 1993.

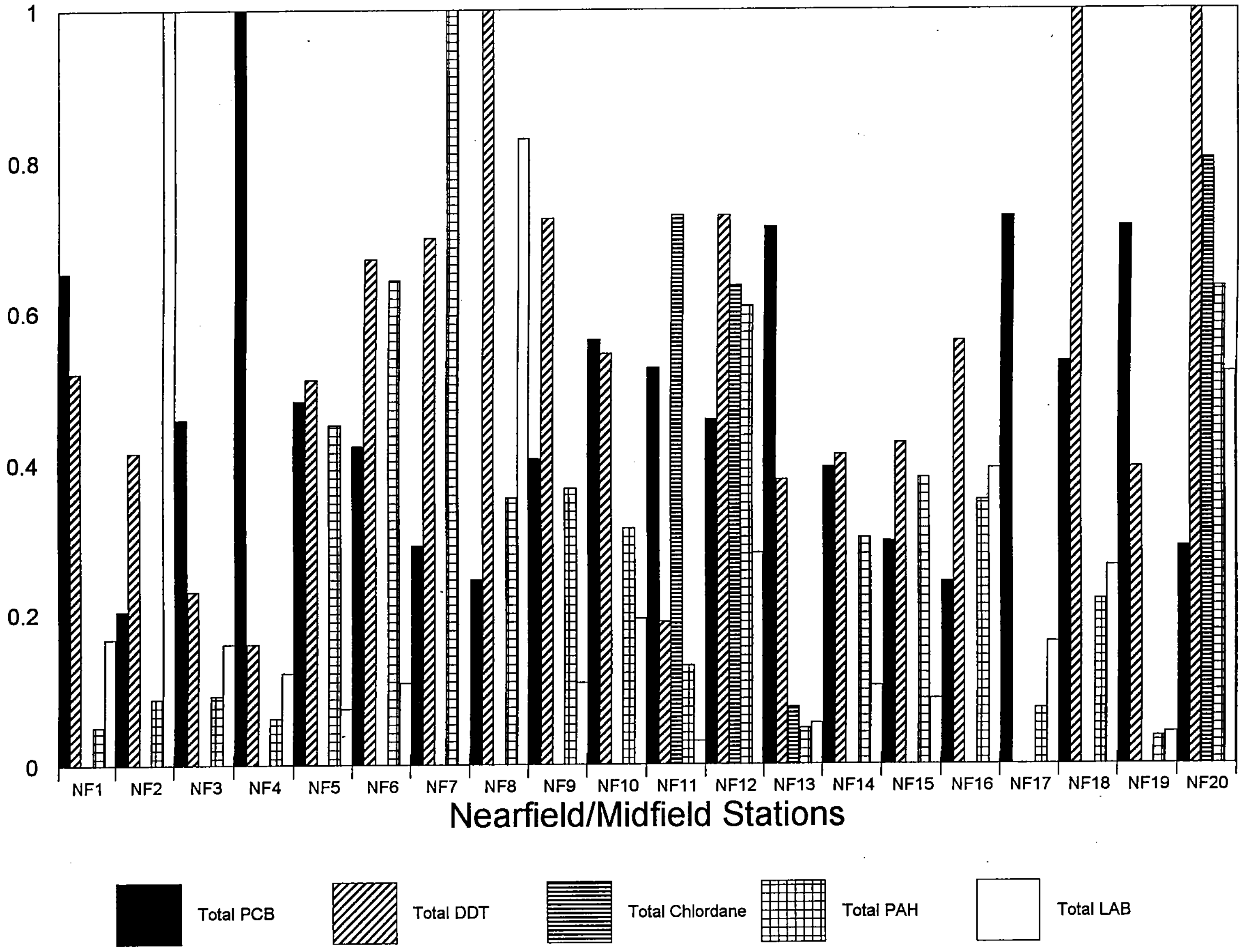


Figure 25. Organic compounds, nearfield/midfield stations, concentrations normalized to TOC and self-normalized, 1992.

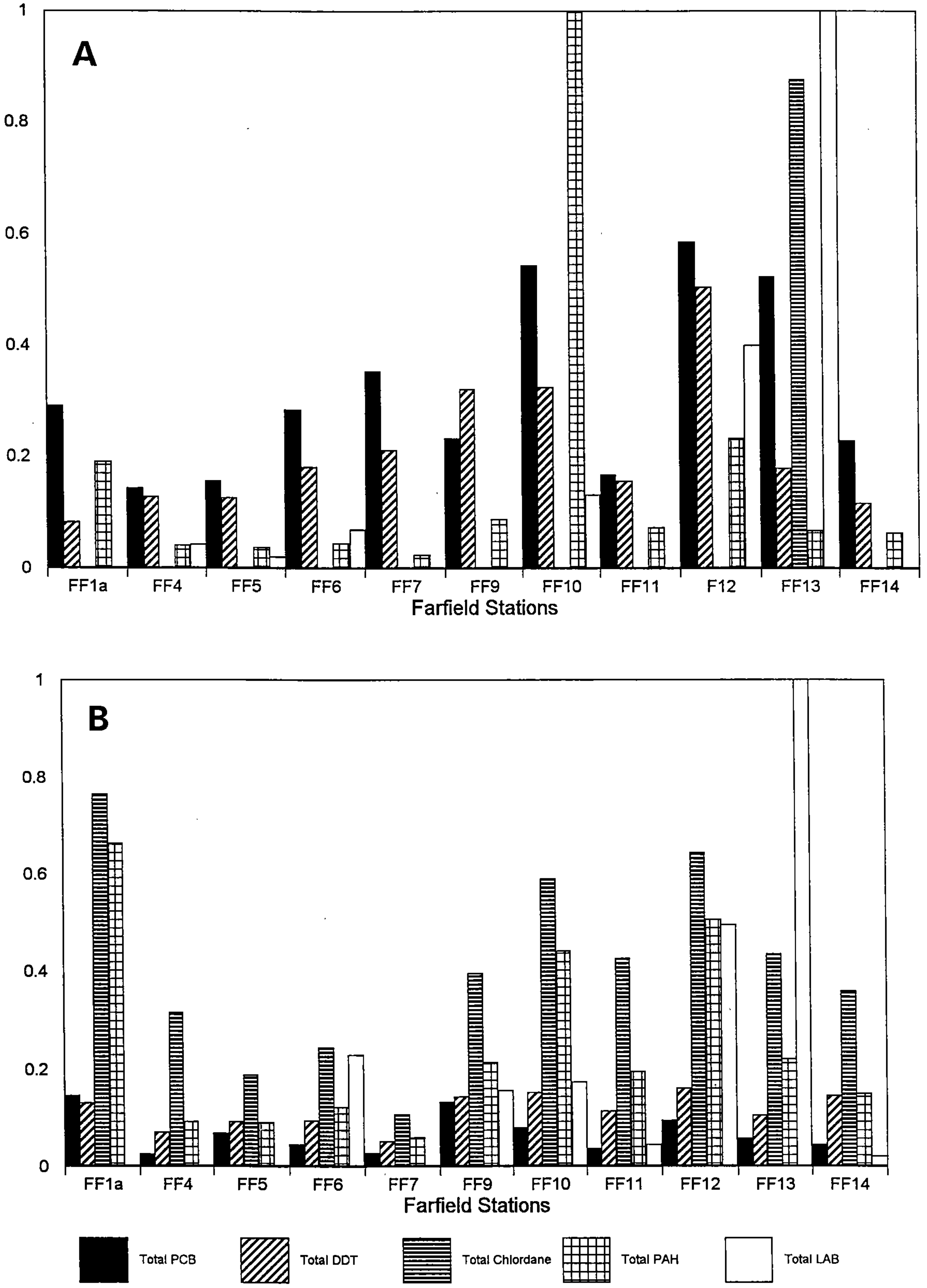


Figure 26. Organic compounds, Farfield stations, concentrations normalized to TOC and self-normalized, (A) 1995, (B) 1994.

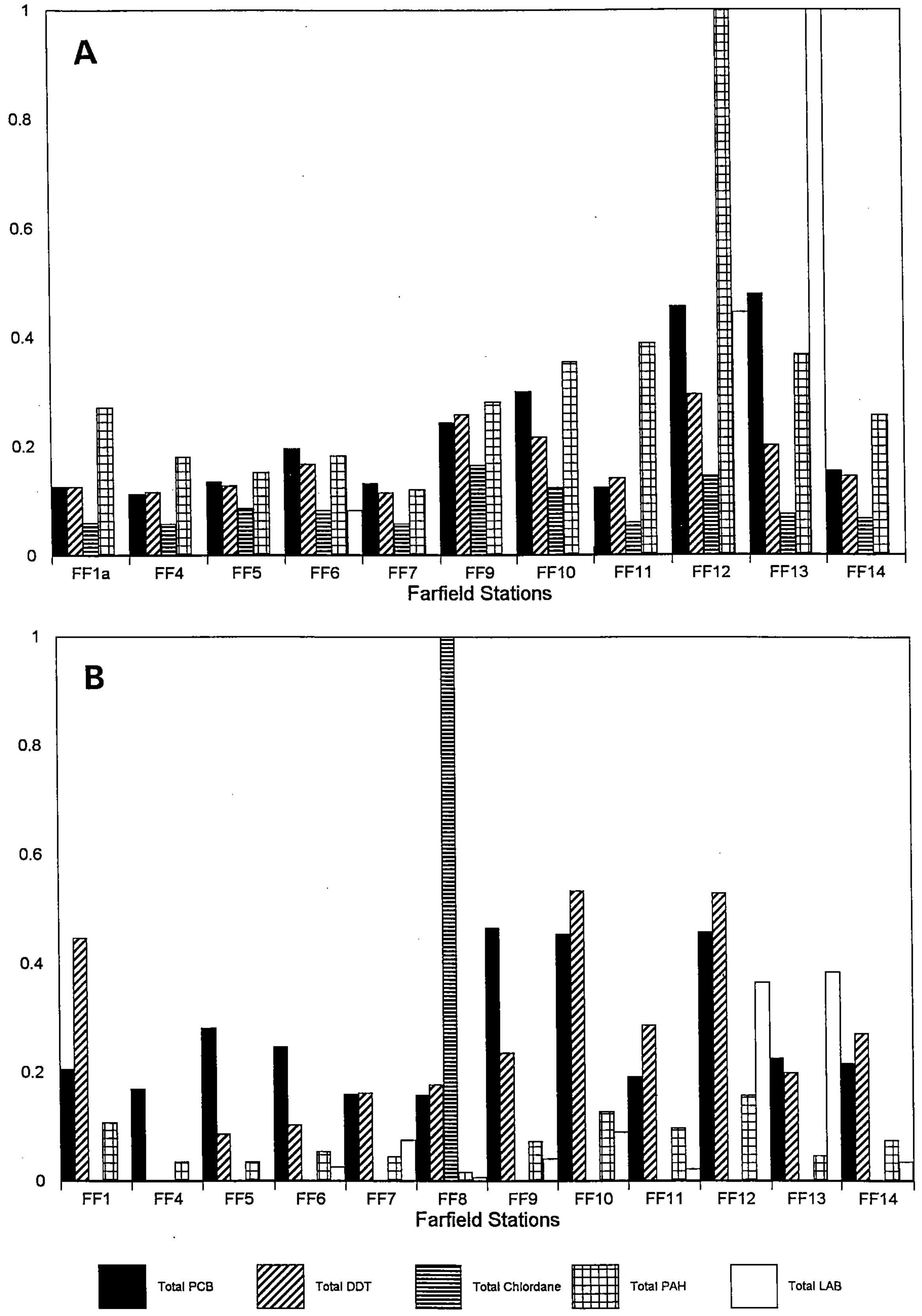


Figure 27. Organic compounds, Farfield stations, concentrations normalized to TOC and self-normalized, (A) 1993, (B) 1992.

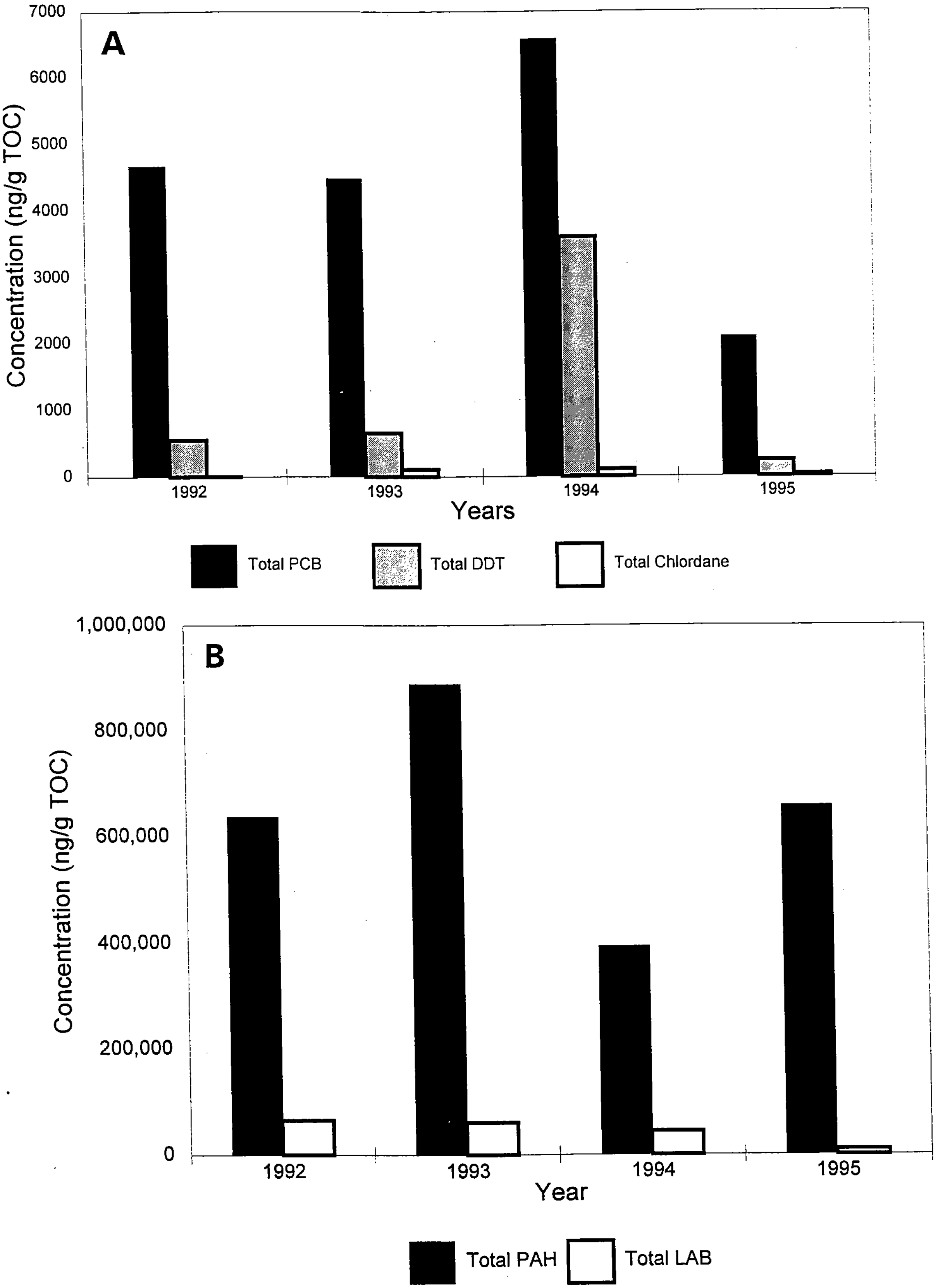


Figure 28. TOC-normalized concentrations of organic compounds, station NF8 (midfield), 1992 through 1995, (A) total PCB, total DDT, and total Chlordane, (B) total PAH and total LAB.

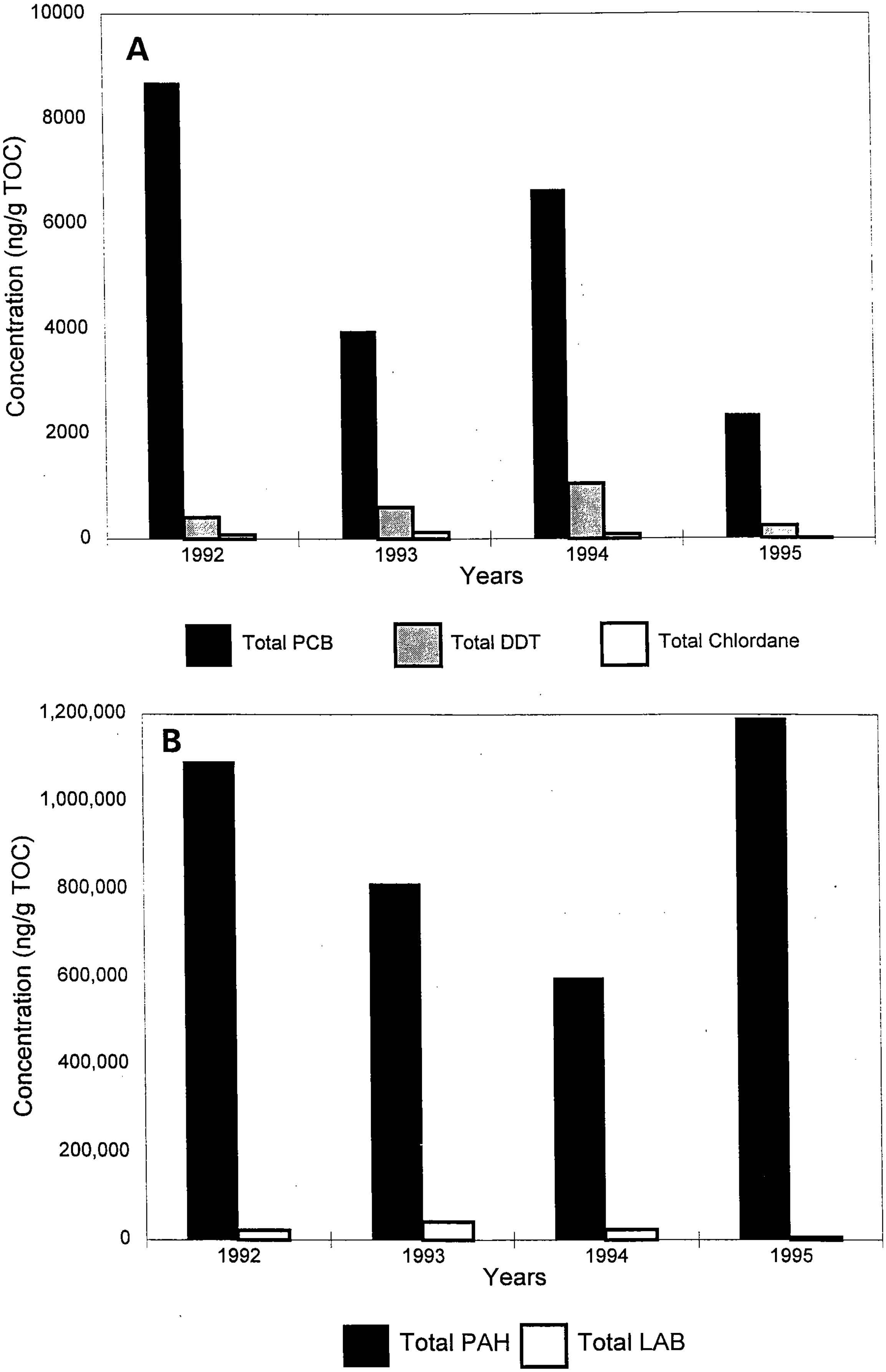


Figure 29. TOC-normalized concentrations of organic compounds, station NF12 (midfield), 1992 through 1995, (A) total PCB, total DDT, and total Chlordane, (B) total PAH and total LAB.

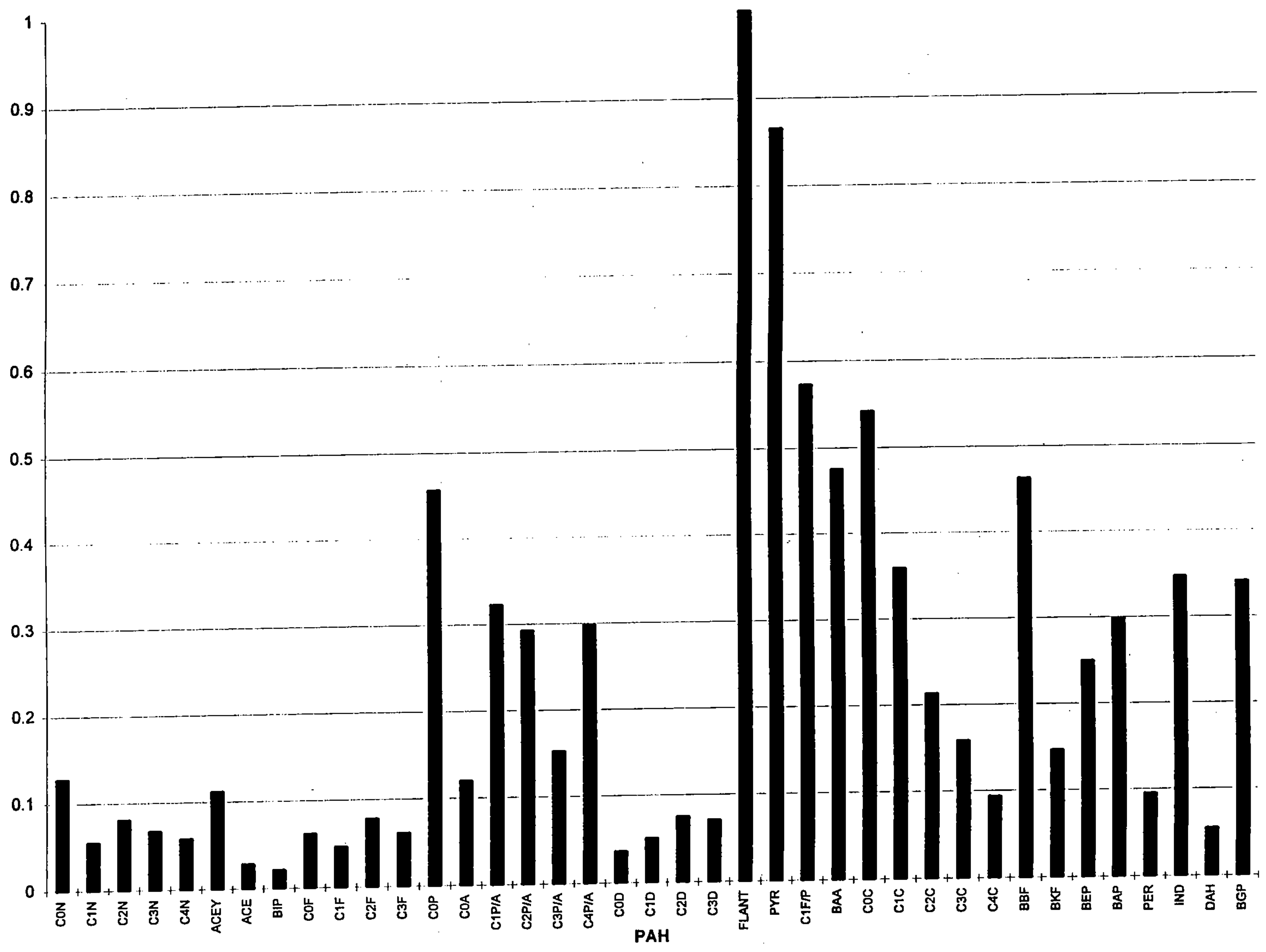


Figure 30. Concentrations of PAH analytes, normalized to fluoranthene, station FF5, 1995.

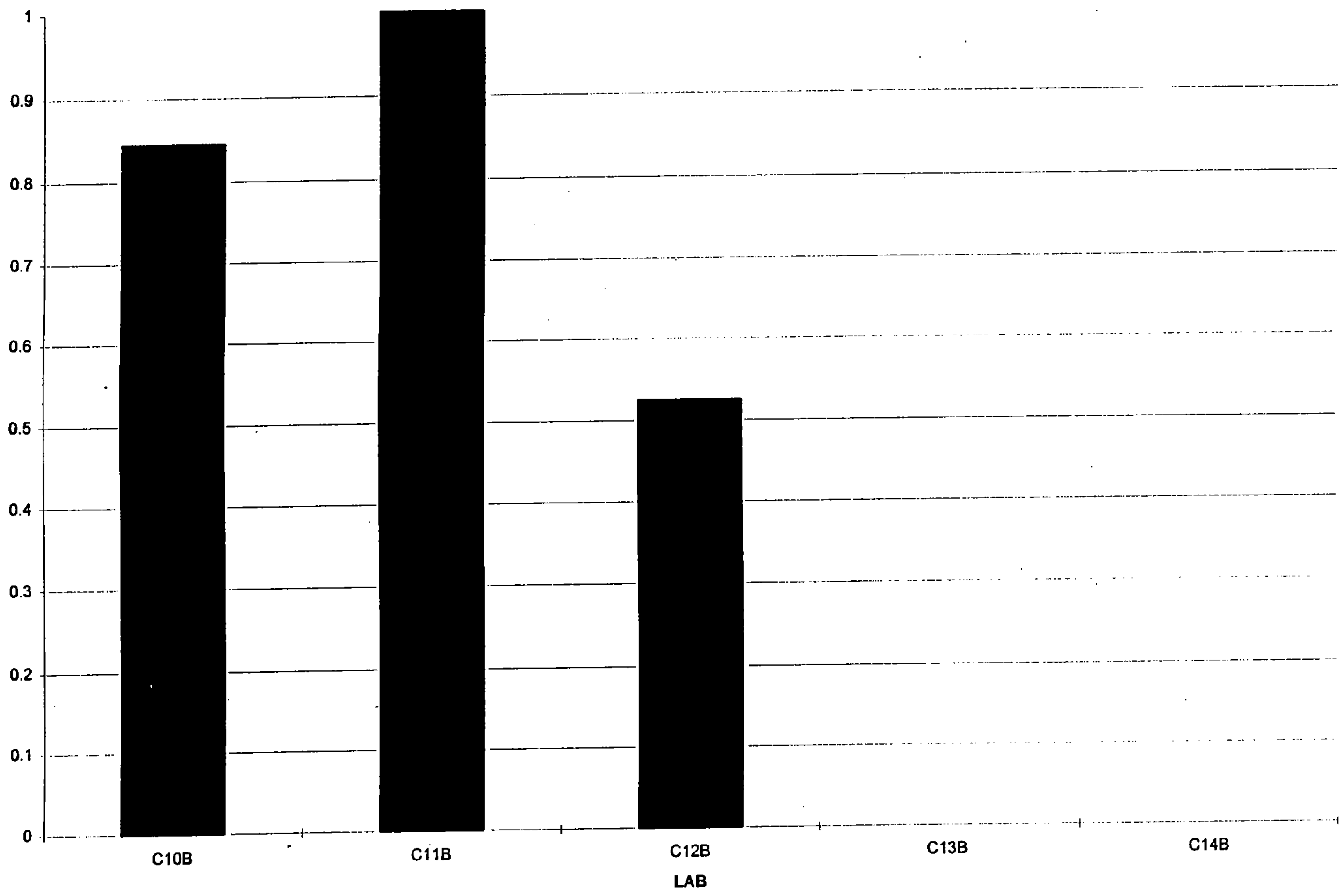


Figure 31. Distribution of LABs, data self-normalized, station FF4, 1995.

3.2 Benthic Softbottom Communities and Sedimentology, Near/Midfield

3.2.1 Sediment Grain Size and Distribution of Sediment Types

Grain-size composition of sediments collected in August 1995 from the Nearfield area, as determined by sieving and gravimetric analysis, is given in Appendix B14. Percentages of gravel, sand, silt, and clay for midfield and nearfield stations are shown in Figure 32. Sediments from the midfield stations contained very little gravel (highest fraction was 6% at NF5); half of the nearfield stations had noticeable gravel, particularly NF14 with 12% and NF18 with 29%. The sandiest stations (NF2 and 4 from the midfield and NF13, 17, and 23 from the nearfield), all with more than 90% sand, had sediments composed predominately of medium and fine sand. Sands from the remainder of the nearfield stations, with the exception of NF24, also predominately belonged to the medium and fine fractions. In the midfield the predominant sand fraction at six stations (NF8, 9, 10, 12, 21, and 22) was very fine sand; at station NF5, fine sand predominated, while fine and very fine sand occurred in equal proportions at NF16.

Sediments from all midfield stations except NF2 and NF4 were high in silt (range is from 16% at NF5 to 72% at NF8) and contained moderate amounts of clay (from 6% at NF20 to 15% at NF22). In the nearfield, sediments contained very little silt and clay except for NF24 with 17% silt and 73% clay. In summary, with the exception of NF24, sediments from nearfield stations were coarser-grained than those from the midfield stations. Nearfield sediments were composed of greater amounts of gravel, coarser sand particles (medium to fine rather than fine to very fine), less silt, and less clay than midfield sediments.

Laboratory grain-size analysis in conjunction with observations from sediment profile image analysis including surficial sediment texture, occurrence of rippled bottom and scour-lag deposits (Appendix B15) and measurements of total organic carbon (TOC) content shows that the sedimentary facies within the Nearfield area are strongly influenced by a west to east gradient in kinetic energy as reflected in surficial sediment texture, total organic carbon content (TOC), rippled bottom, and scour-lag deposits; this same gradient had been observed in 1992 as well (SAIC, 1992). Five stations on the western side of the surveyed area (midfield) represent the lowest kinetic energy stations (Figure 33). The major modal grain sizes fall within the silt-clay class (NF8, 9, 10, and 21), but some of these stations show surface sand layers or intercalations of sand at depth in profile images (Figures 34 and 35). This fine-scaled stratigraphy suggests that spatial-temporal shifts in sediment type from silt-clay (>4 phi) to very fine sand (4-3 phi) take place within the western edge of the area related to fluctuating sources of fine-grained sediment and in-situ physical sediment reworking. The midfield is equivalent to the "reworked" acoustic facies of Knebel (1993).

The highest kinetic energy stations are located east of the midfield in the nearfield drumlin area surrounding the diffuser where sediment major modes range from fine sand to coarser sediments (NF4, 23, 17, and 19). Exceptions were observed in local depressions between drumlins where silt-clay sediments exist (NF22 and 24) in an otherwise clean sand facies (Figures 36 and 37). A transition zone, consisting of current rippled very fine sand (4-3 phi), separates the silt-clay facies from higher energy fine sand (3-2 phi). Stations defining this transition facies include NF5, 7, 1, 13, 14, 15, 16 (in part), and 20 (Figures 38 and 39). The distribution of percent total sand and gravel, and fines (<50% sand and gravel), as determined by sieving and gravimetric analysis, is shown in Figure 40, for comparison to the estimates made of the major mode from SPI images.

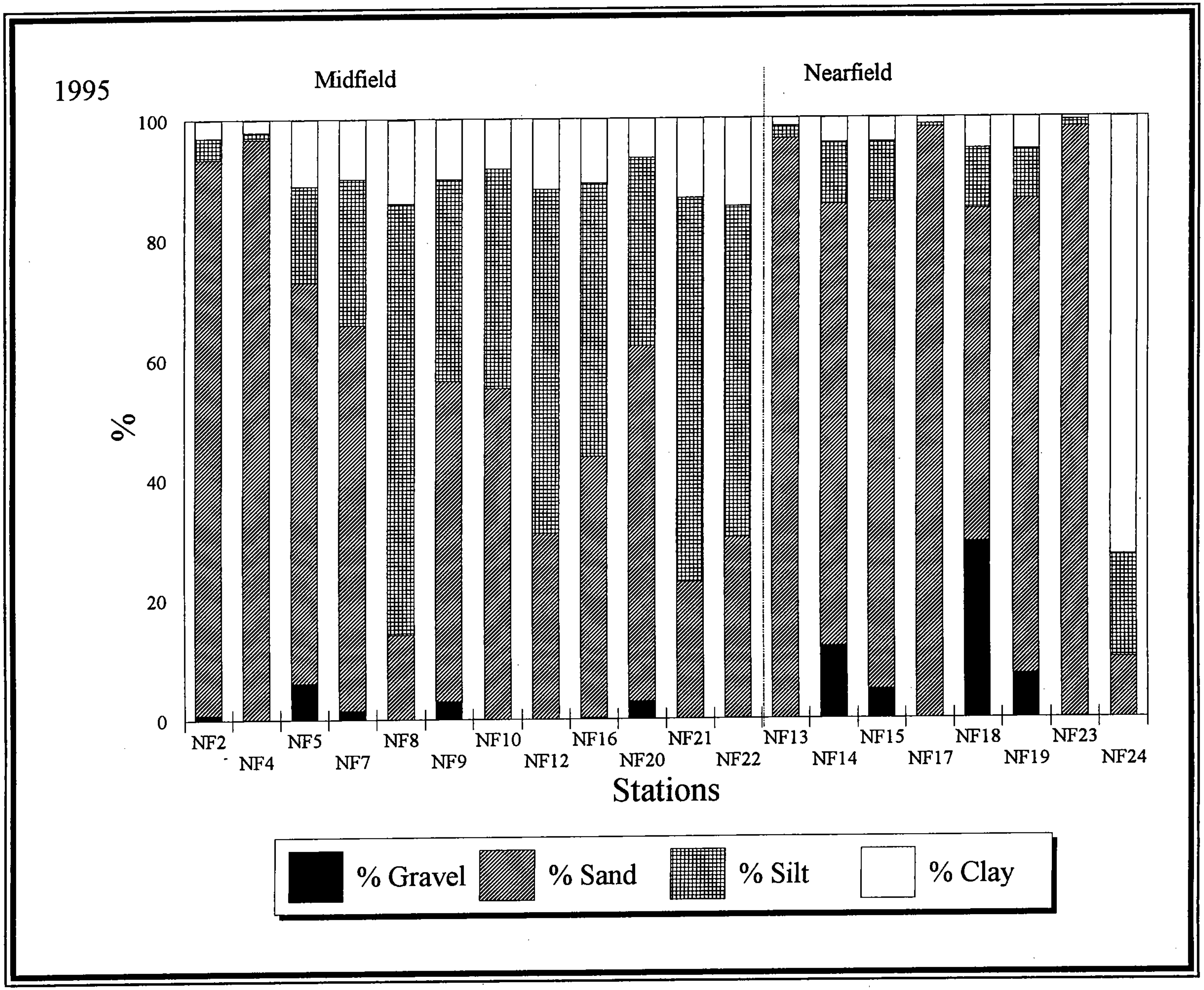


Figure 32. Sediment grain size composition, mid- and nearfield, 1995.

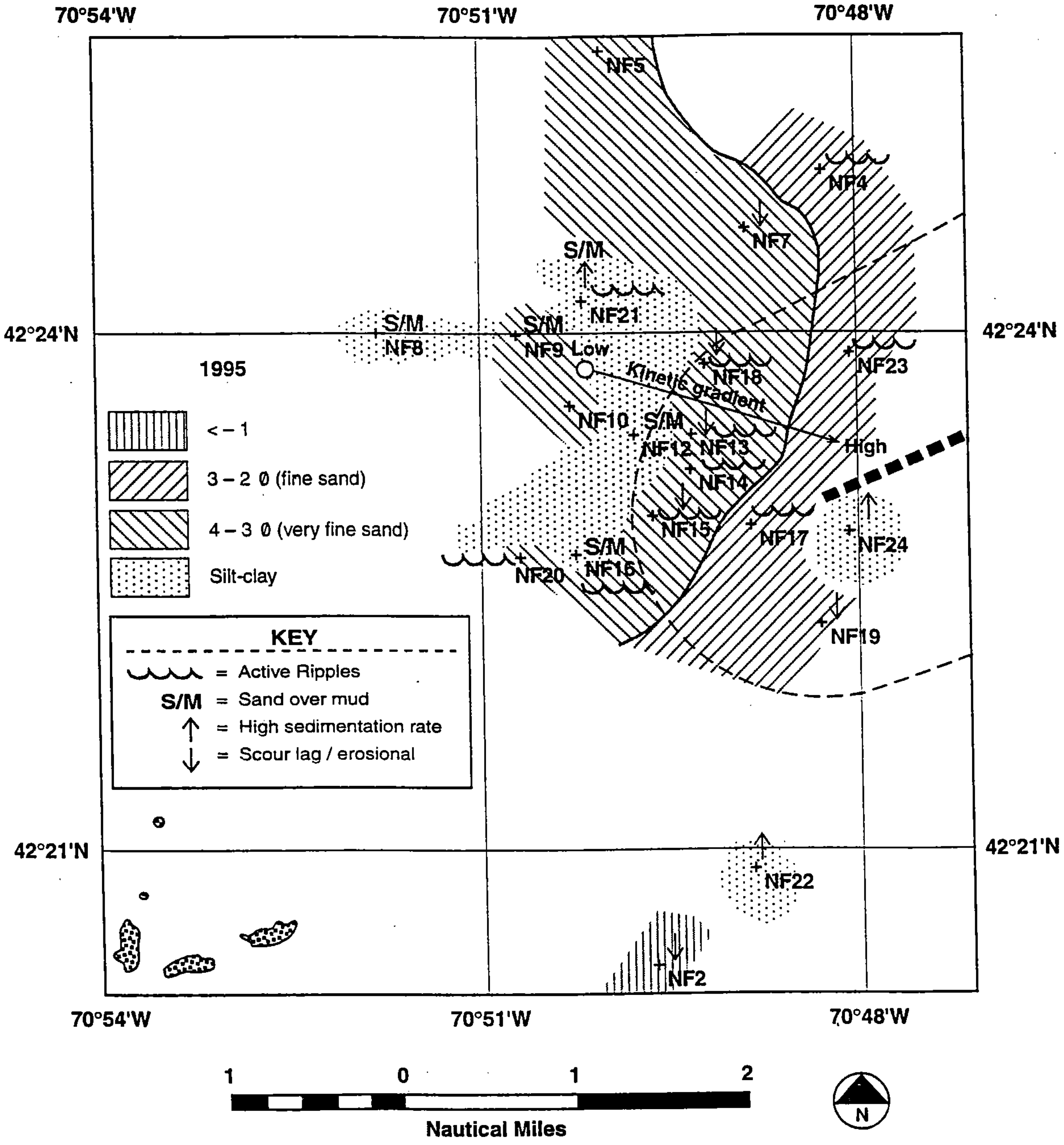


Figure 33. Sediment processes and major modal grain size in the mid- and nearfield, 1995. Nearfield and diffuser are indicated.

Figure 34. Station NF21: silt-clay sediment overlain by very fine sand, oxidized by bioturbational activities of Stage I and II taxa. Subtle horizontal grey scale banding/mottling related to changing inputs of labile organic matter. 1.4% TOC. Vertical marks at edge of image are 1-cm intervals.

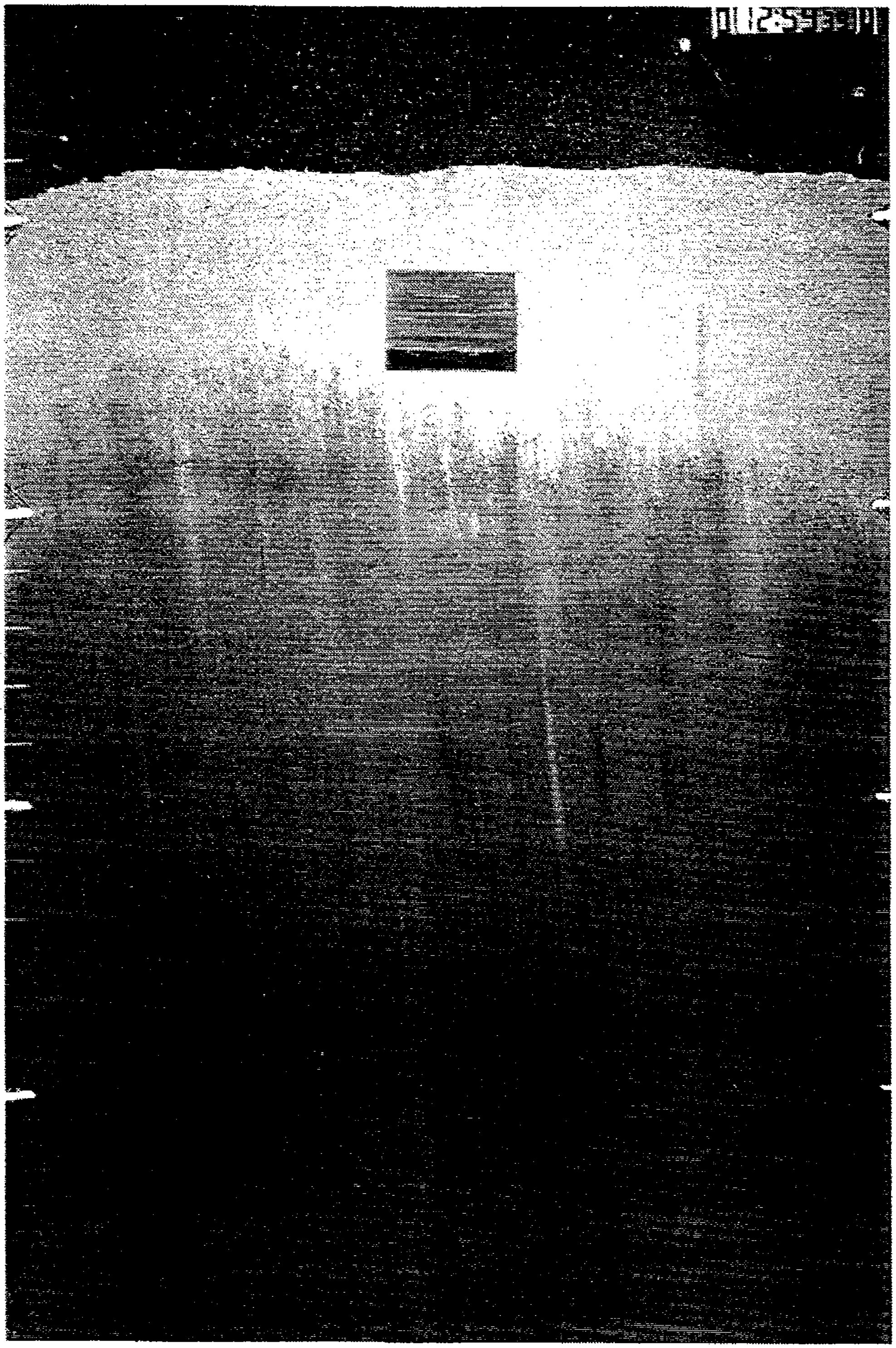


Figure 35. Station NF8: silt-clay sediment with 9-cm surface layer of very fine sand (4-3 phi). Upper 3-5 cm are oxidized by stage I polychaetes. 2% TOC. Vertical marks at edge of image are 1-cm intervals. Square feature in upper half of image is tape on mirror covering reflection of strobe (see also Figures 34 and 36 through 39).

Figure 36. Station NF22: silt-clay bottom overlain by 4 cm of very fine sand populated by Stage 1 polychaetes. Dark mud smears are wiper artifacts. High reflectance surface sand is located above low reflectance sulfidic silt-clay. Intermediate reflectance bottom layer may be a buried surface oxidized by bioturbation in the past. 1.3% TOC. Vertical marks at edge of image are 1-cm intervals.

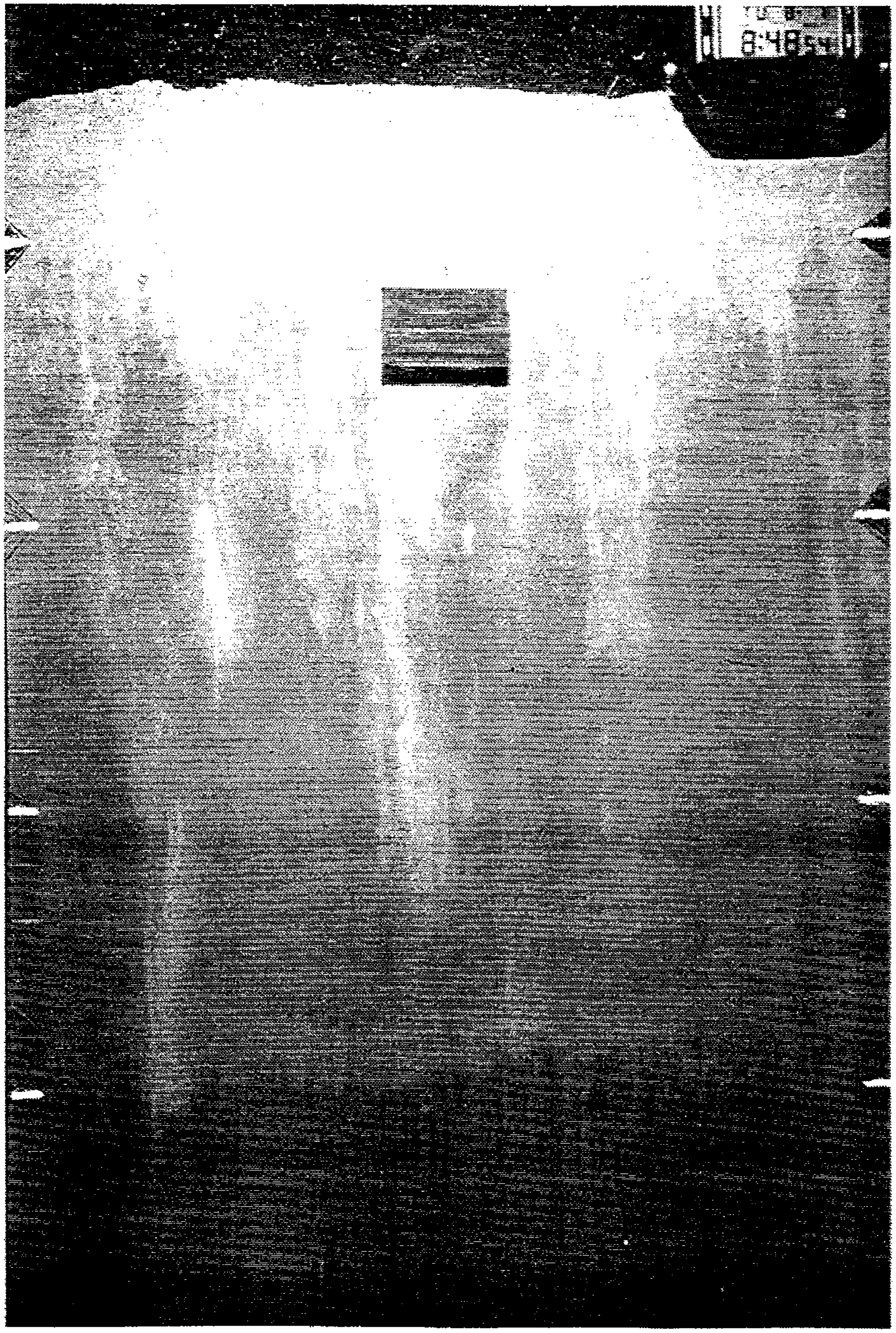


Figure 37. Station NF24: clay-rich sediment, high TOC (2.8%). Upper 3 cm oxidized and pelletized by Stage I polychaetes. Change in reflectance at 17 cm depth, sharp contact with overlying, lower reflectance mud, and deep penetration indicate rapid accumulation of top 17 cm (low sediment bulk density and homogeneous fabric). Vertical marks at edge of image are 1-cm intervals.

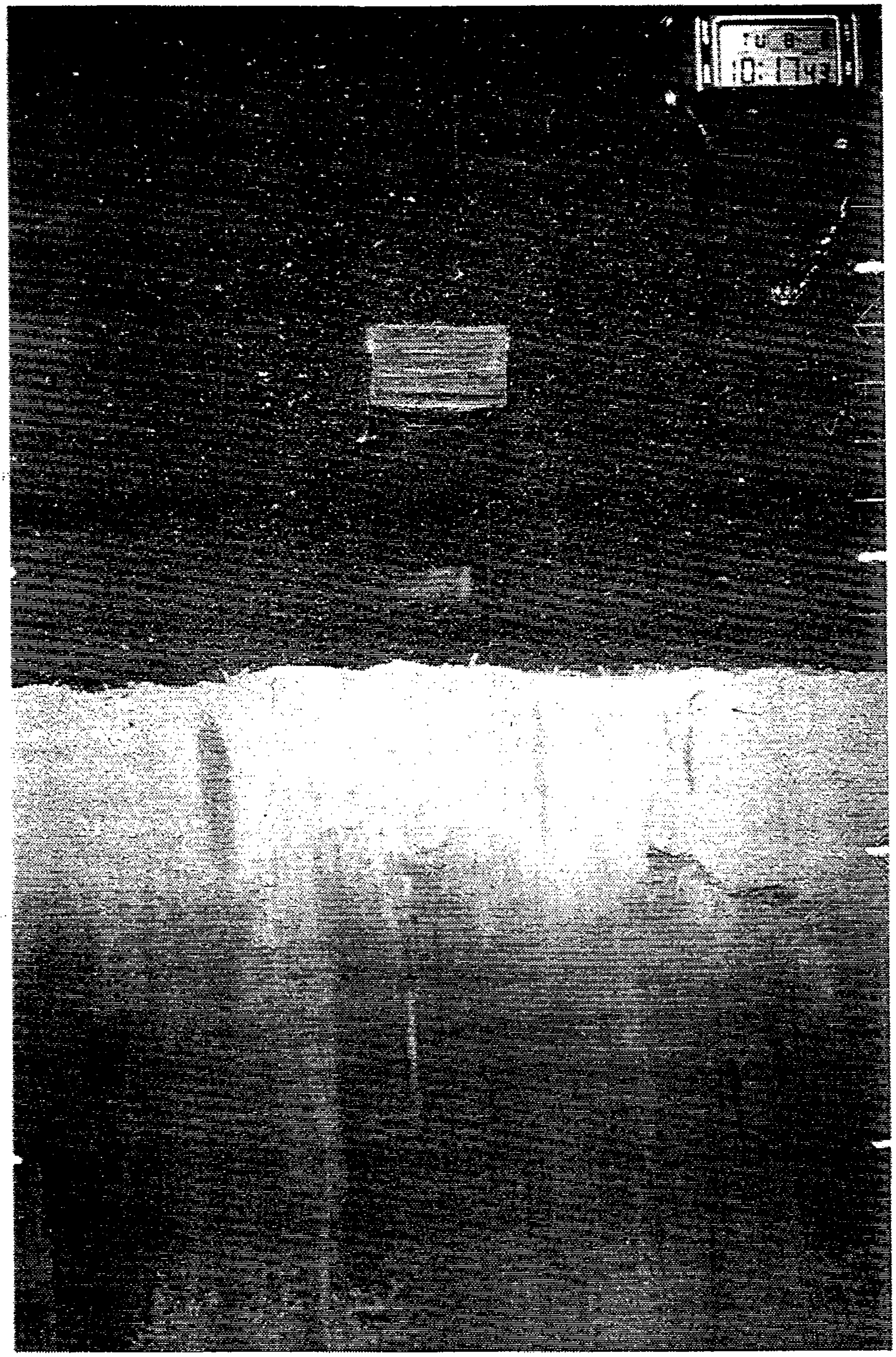


Figure 38. Station NF16: sand-over-mud stratigraphy, transitional facies, populated by stage I and III taxa (note subsurface feeding void). Relatively high reflectance layer at depth may represent a buried horizon covered by rapidly accumulated silt-clay. 1% TOC. Vertical marks at edge of image are 1-cm intervals.

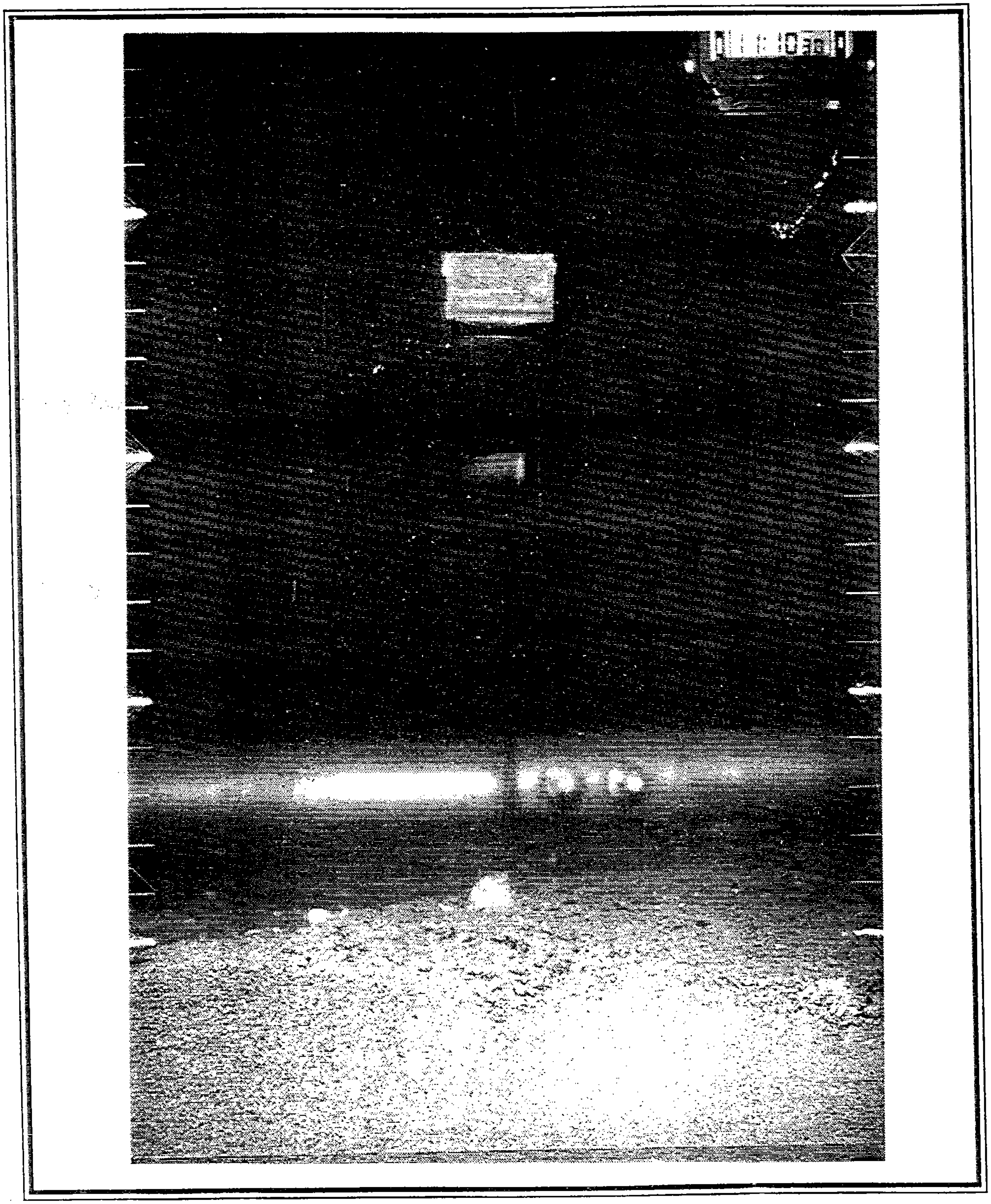


Figure 39. Station NF13: rippled fine sand (3-2 phi), typical for transition facies near midfield/ nearfield boundary. Low TOC (0.1%). Shallow camera penetration indicates high sediment compaction and bottom hardness. Scour-lag deposits on ripple crests and in depressions. Ripples populated by Stage I sere, not active at time image was taken. Vertical marks at edge of image are 1-cm intervals.

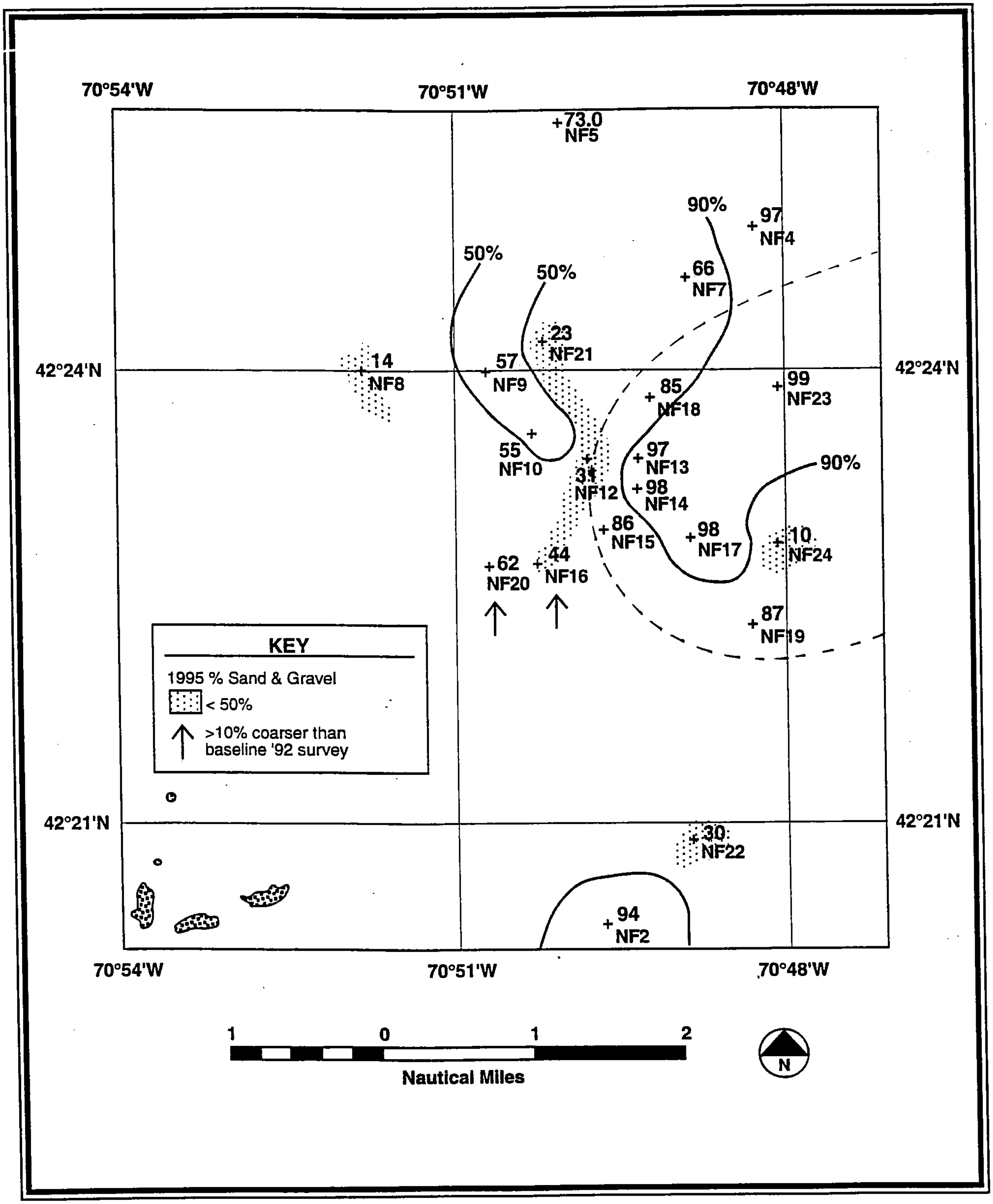


Figure 40. Areal distribution of sandy and fine grained sediments, in the mid- and nearfield, 1995, according to gravimetric data, for comparison with SPI results shown in Figure 33. Nearfield is outlined.

3.2.2 Total Organic Carbon

Sediments within the nearfield area generally have a low percent total organic carbon (TOC) (Appendix B16). In 1995, eighty percent of all mid- and nearfield stations (16 of 20) had TOC values less than 1%; only one station had a TOC higher than 2% (NF24 with 2.77% TOC). Stations with less than 0.5% TOC included those in the nearfield drumlin area where the presence of rippled surfaces (NF4, 13, 14, 17, 18, and 23) or erosional features (NF2 and 19) in sediment profile images indicated a high energy regime. Presumably, higher kinetic energy in this region washes organic detrital material out of these sediments. Stations with more than 1.0% TOC had predominately silt and clay sediments that showed sand over mud stratigraphy (NF8 and 21) and/or evidence of high sedimentation rate (NF21, 22, and 24), inferred by deep penetration of the sediment profiling camera into homogeneous sulfidic (i.e., low optical reflectance) muds (Figures 34 and 35). A clear relationship showing an increase in TOC with increase in mean phi (as determined by laboratory analysis) is shown in Figure 41A. Eight of nine stations having a mean phi less than 3 (fine and medium sand) had less than 0.5% TOC; four of five stations with a mean phi greater than 5 (medium silt) had a TOC greater than 1%. The areal distribution of TOC concentrations in the mid- and nearfield sediments is shown in Figure 42.

3.2.3 Clostridium Spores

The density of *C. perfringens* spores within the Nearfield area varied by four orders of magnitude, that is, from less than 8 to more than 17,000 colony-forming units per gram dry weight of sediment (Figure 43, Appendix B17). The relationship between distribution of sediment type and kinetic energy gradient with *C. perfringens* spore density is most obvious upon comparing stations with very low counts against stations with very high counts. The two stations with less than 10^2 spores per gram dry weight (NF17 and NF23) were located in the nearfield drumlin area with high kinetic energy as denoted by sediments with a major mode of fine sand (relatively coarse for the area) and ripple marks on the surface. The one other station (NF4) with fine sandy sediments and ripple marks had the next lowest *Clostridium* count (220 spores per gdw). The two stations with more than 10^4 spores per gdw (NF21 and NF24) were in areas of silt and clay with a very high sedimentation rate, as determined by sediment profile imaging (Figures 34 and 35). The third station in silt and clay that had a high sedimentation rate (NF22) had the third highest *Clostridium* count (9700, nearly 10^4, spores per gdw). Moreover, these three high density *Clostridium* stations were among the four stations exhibiting the highest total organic carbon (TOC) concentrations in the Nearfield area.

In summary, low densities of *Clostridium* were found at the stations in areas of higher kinetic energy as evidenced by the presence of fine sand and ripple marks; frequent washing of the bottom sediments by currents in these areas prevent retention of a significant fraction of organic material. In contrast, relatively high densities of *Clostridium* were found at those stations with the highest sedimentation rate. Generally, the density of *Clostridium* spores varied directly with increase in mean phi (towards finer sediments) (Figure 41B). The accumulation of silt-clay sediments and organic material (relatively high total organic carbon and *Clostridium* spores) into local depressions reflect a high input rate of fines that may be generated from Boston Harbor directly or indirectly via initial deposition upon a coarser-grained area with winnowing occurring later during storms (Bothner, pers. comm.).

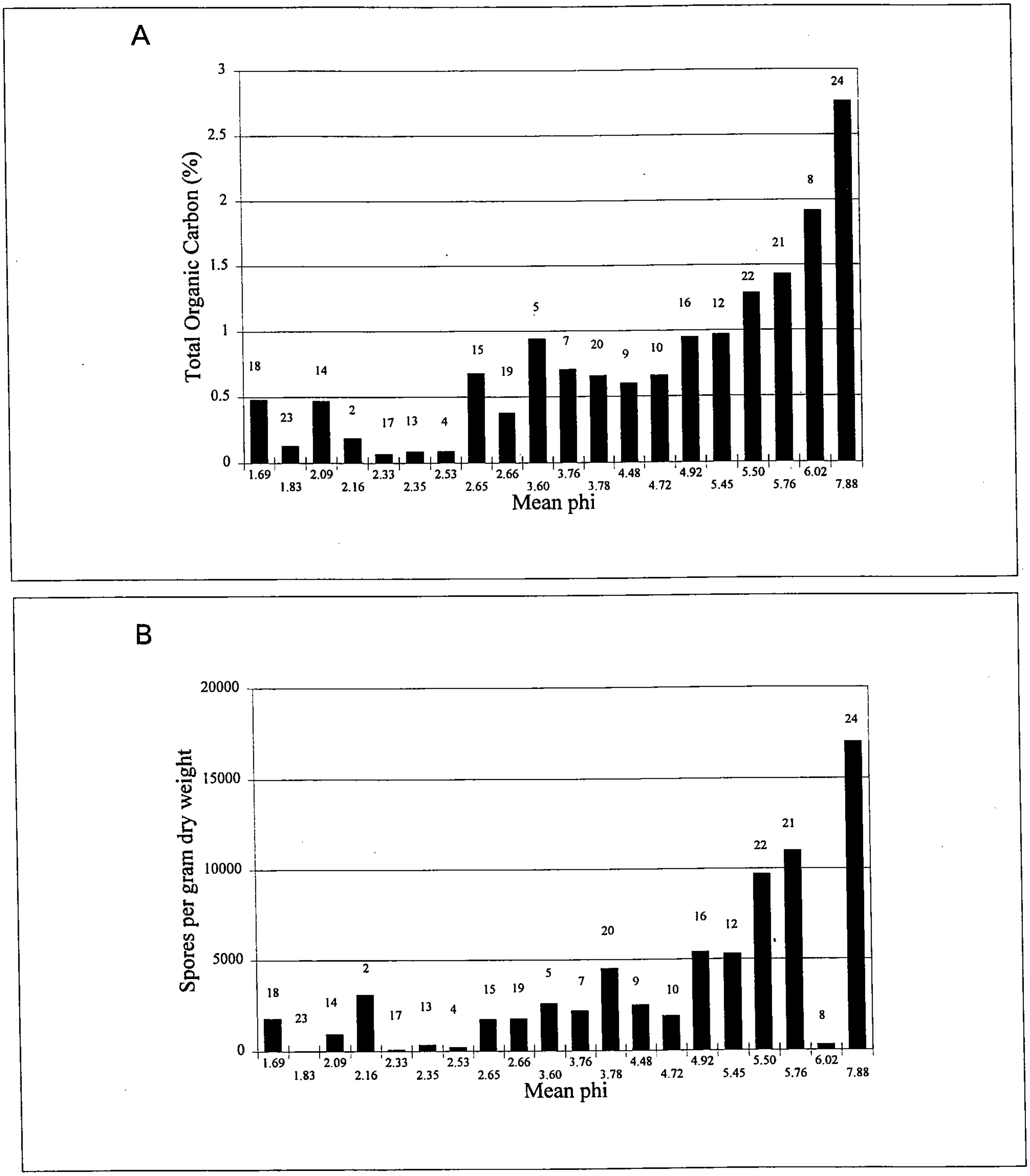


Figure 41. **Total organic carbon concentration (A) and *Clostridium perfringens* spore counts (B) plotted against sediment grain size (mean phi) in the mid- and nearfield, 1995. Numbers above bars are station IDs.**

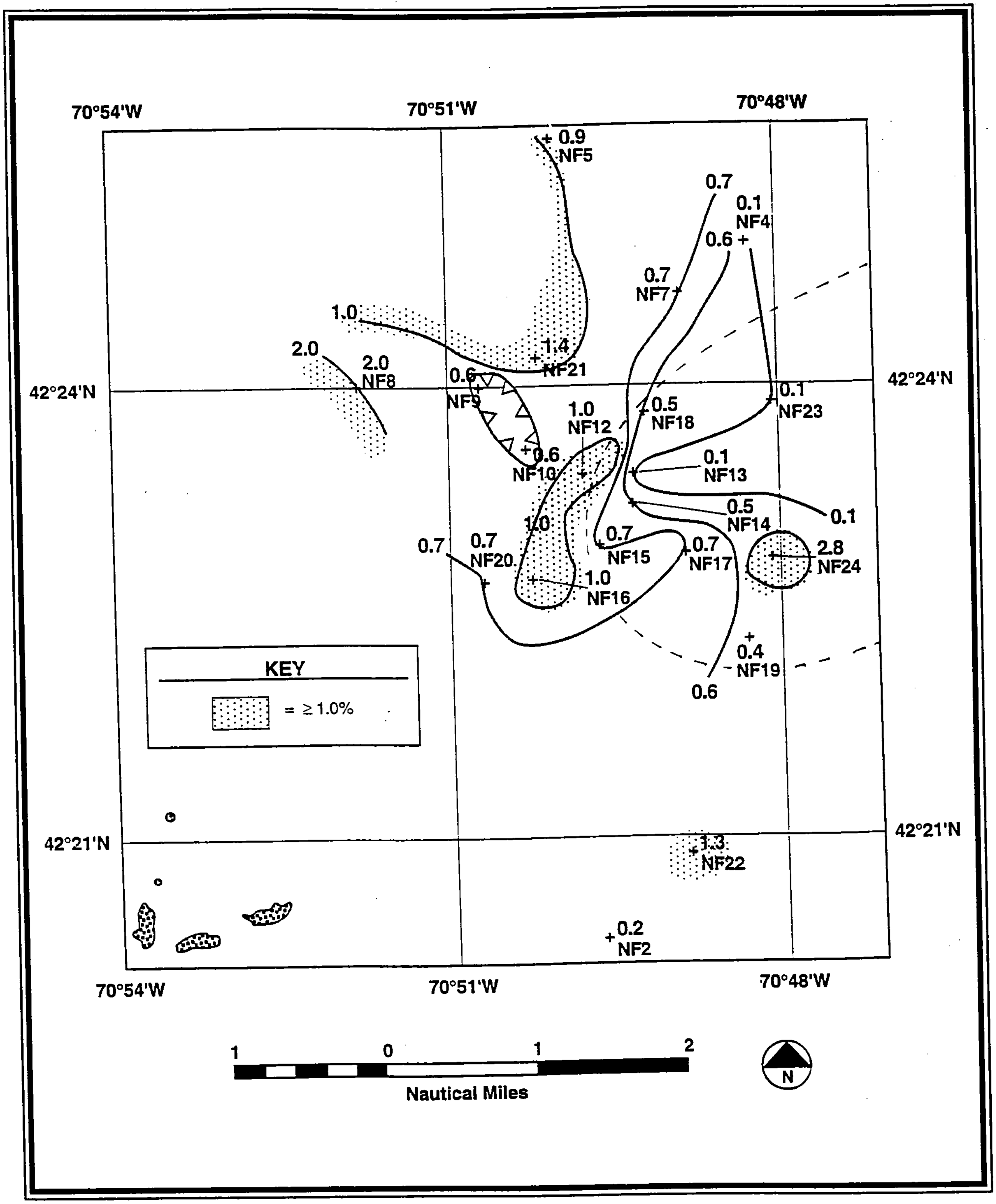


Figure 42. Areal distribution of total organic carbon (TOC) in sediments of mid- and nearfield, 1995. Nearfield is outlined.

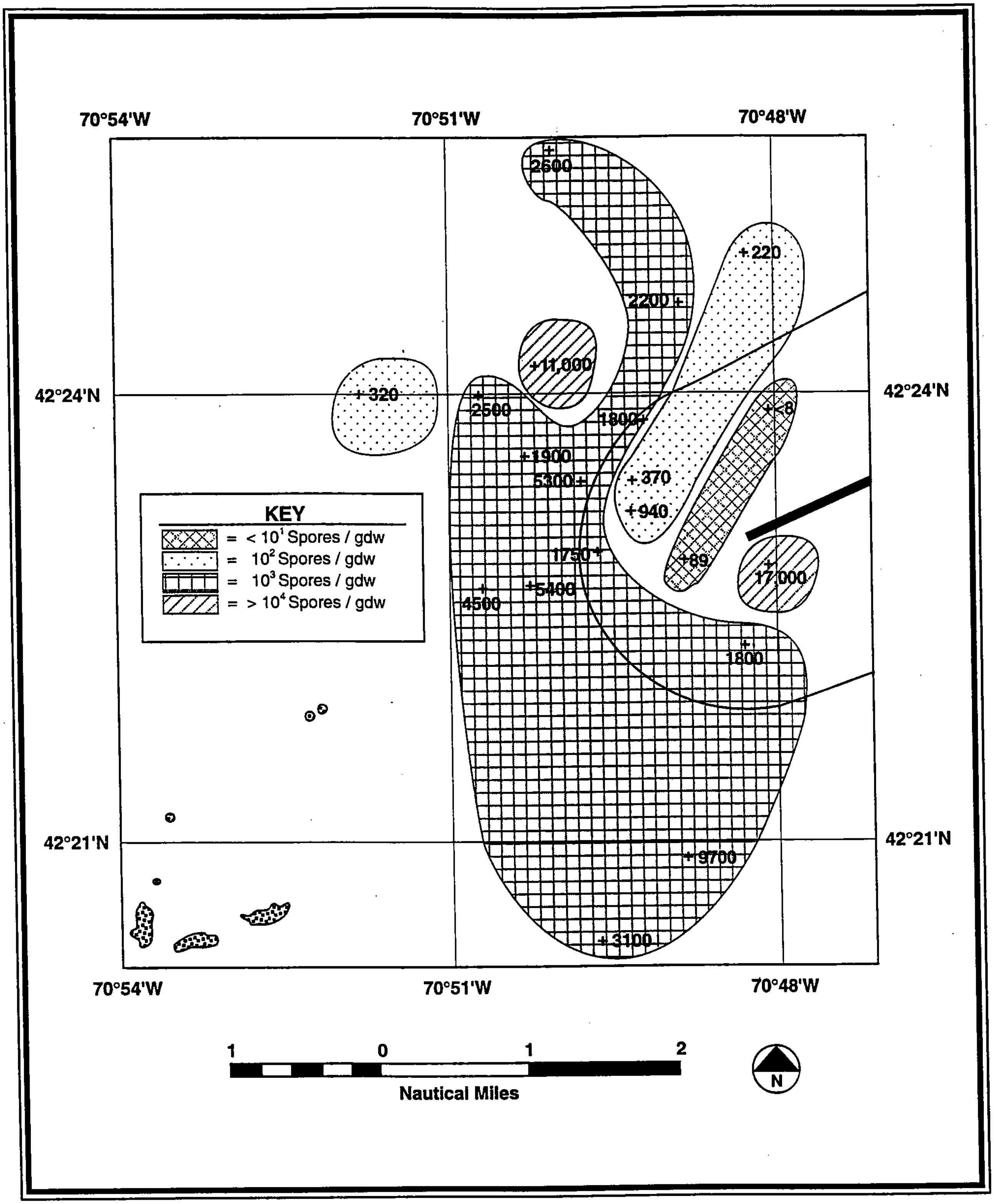


Figure 43. *Clostridium perfringens* spore counts, mid- and nearfield, 1995. Nearfield and diffuser are indicated.

3.2.4 Sediment Profile Imaging

Apparent Redox Potential Discontinuity (RPD) Depth

The depth of the apparent RPD was shallowest in the western midfield muddy stations and deepest in the nearfield sand facies (Figure 44). The depth of the apparent RPD reflects the reducing capacity of the sediments (organic muds > clean sands) and the rate and depth of bioturbation by infaunal organisms and wave and current reworking. Areas of relatively thin apparent RPDs (≤ 3 cm) are largely limited to midfield stations and locally high TOC nearfield stations (NF24 and 22). Rippled or otherwise erosional stations tend to have the deepest apparent RPDs related to physical reworking. The apparent RPD depth-frequency distribution is unimodal with most values falling within the 2.16 to 3.24 cm depth class (mean= 2.98 cm, N=20 stations). In the 1992 baseline survey, the distribution was comparable to the 1995 distribution with a station mean of 2.64 cm (N=16 stations).

Infaunal Successional Stages

The sedimentary facies described above is of first-order importance for determining the distribution of benthic infauna. This may be related to gradients in sediment texture, TOC, and/or frequency of physical disturbance. The relatively low kinetic energy midfield muds consisted of mixtures of Stage I and III seres while the eastern sand and gravel facies was dominated by Stage I polychaetes (Figure 45). Stations located at, or near, the edge of the sand-mud transition facies are interpreted to represent an ecotonal boundary as station replicates consisted of mixtures of Stage I, II, and III seres. Low densities of amphipod tubes (*Ampelisca abdita?*) were imaged for the first time in the midfield/nearfield in 1995 at stations NF5, 4, 21, and 16. This amphipod is a typical resident of intermediate stages of disturbance (i.e., Stage II).

The successional status of five stations has changed relative to the 1992 survey. Stations NF8 and 7 (Stage I) are retrograde relative to 1992 when the feeding voids of Stage III taxa were imaged at these locations. The successional status of stations NF4 and 5 increased from a Stage I sere in 1992 to I-II in 1995, and at station NF16 increased from a Stage I in 1992 to a mixture of I-II to I-III in 1995.

Organism-Sediment Indices

Mapped organism-sediment indices (Figure 46) show alternating high and low values across the inferred kinetic energy gradient mapped in Figure 33. Values of ≤ +6 tend to reflect recently physically disturbed or chemically stressed environments. The largest concentration of these stations was located on rippled or erosional sands, or in sediments with ≥ 2% TOC (e.g., NF8 and 24). The cause of low OSI values at other stations is moot but may relate to stochastic disturbance events. The 1995 OSI values range from a low of +3 (NF7) to +9 (NF9 and 16).

The overall frequency distribution is bimodal with a major mode of 6.5 to 7.5 and a subordinate mode that falls within the 4.5 to 5.5 OSI class. In the 1992 baseline survey, the distribution was markedly polymodal with the lowest values (OSI= 3.5 to 4.5) being recorded at Stations NF2 and 13. Three other peaks in the OSI class distributions were co-equal (5.5-6.5, 7.5-8.5, and 8.5-9.5). The OSI frequency distribution in 1992 was interpreted as reflecting organism-sediment responses to a mosaic of disturbance patches. The 1995 OSI distribution also reflects a mosaic of disturbance patches but most OSI values fall within intermediate levels of benthic disturbance. This inference is supported by the presence of tube-dwelling amphipods (*Ampelisca?*) at ecotonal stations and by the presence of silt-clay surface muds in the midfield suggesting lower levels of kinetic energy in 1995 relative to 1992 when surface sand dominated all stations.

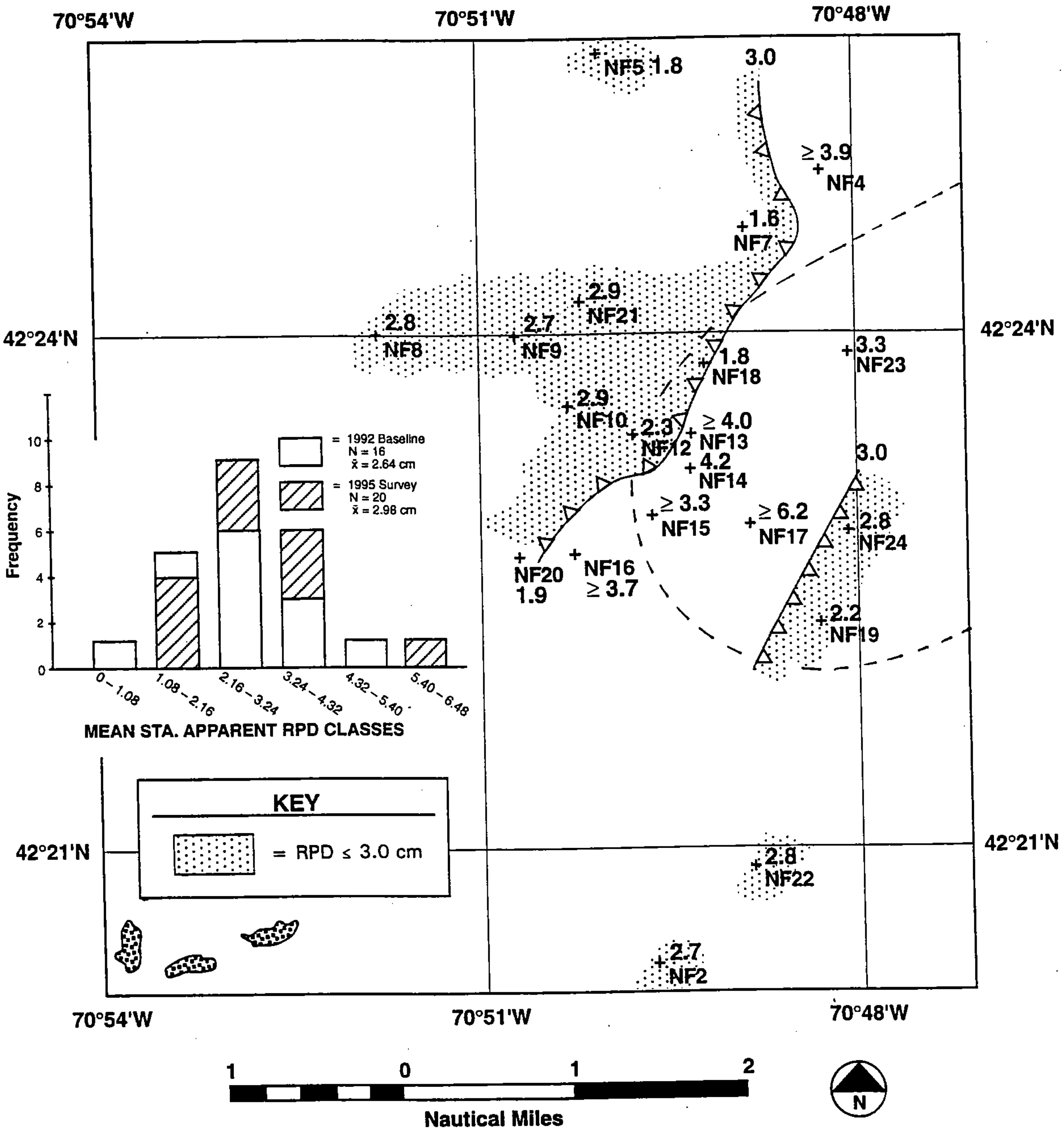


Figure 44. Apparent RPD depths, near- and midfield, 1995. Nearfield is outlined. Inset: frequency distribution.

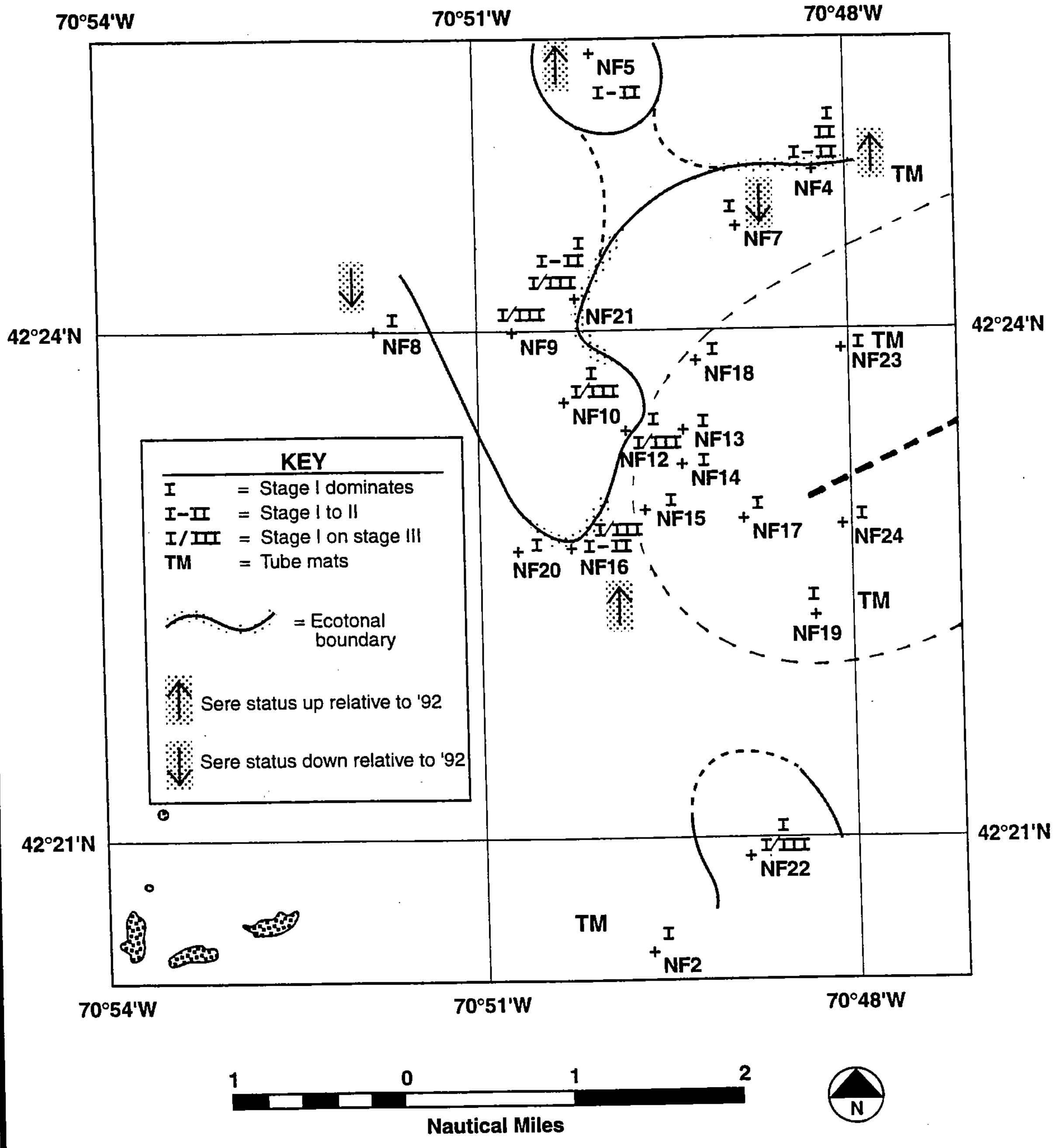


Figure 45. Infaunal successional stages, mid- and nearfield, 1995. Nearfield and diffuser are indicated.

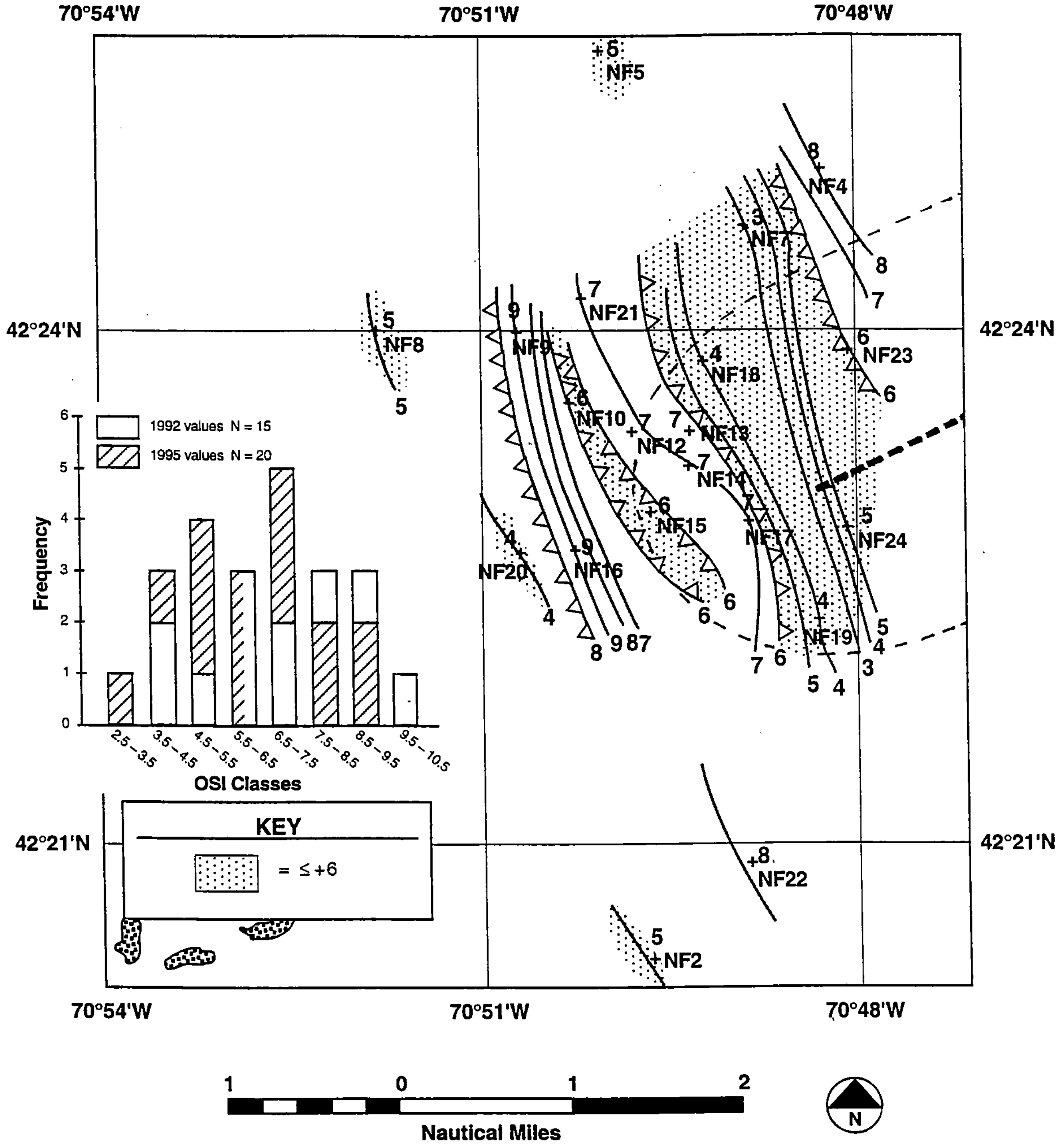


Figure 46. Organism-sediment indices (OSIs), mid- and nearfield, 1995. Nearfield and diffuser are indicated. Inset: frequency distribution.

3.2.5 Benthic Infauna

Taxonomic Composition

The benthic infauna of the 1995 Nearfield/Farfield samples consisted of 246 species. As in previous years, annelids comprised about half the taxa, followed by crustaceans and mollusks, with some representatives of other groups. Table 5 summarizes the breakdown of species into major taxonomic groups. The largest polychaete families were the Spionidae (11 species), the Maldanidae (10), and the Cirratulidae and Syllidae (9 each). The largest crustacean group was the Amphipoda with 39 species. A complete taxonomic listing for the 1995 samples can be found in Appendix C1; raw data from all years can be obtained in electronic or hardcopy format from the Environmental Quality Division of MWRA by contacting Mr. Ken Keay.

Table 5. Composition of benthic infauna, broken down by major taxonomic category, number of species, and percent of total species, summer 1995.

Taxonomic Group	Near- and Midfield		Farfield		Entire Study Area	
	Number	Percent	Number	Percent	Number	Percent
Annelida	106	51	103	50	132	51
Crustacea	54	26	55	27	69	27
Mollusca	23	11	24	12	26	10
Other	26	12	24	12	31	12
Total	209	100	206	100	258	100

Distribution and Density of Dominant Species

The most common dominant species in the nearfield were two spionid polychaetes, *Prionospio steenstrupi* (among the top ten species at 17 stations) and *Spio limicola* (14 stations) and the capitellid *Mediomastus californiensis* (15 stations); members of an additional suite of 23 polychaetes, 2 oligochaetes, 4 isopods, 3 amphipods, 1 tanaidacean, 6 bivalves, 1 tunicate, and 1 nemertean was among the top ten species of at least one station.

Prionospio steenstrupi and *Spio limicola* reached their highest densities at a group of stations near the midfield/nearfield boundary, including Stations NF10, 14, 15, 19, and 20, where densities of both species combined ranged from 786 to 885 individuals per grab (about 19,700 to 22,100 individuals m^{-2}) (Figure 47). The highest density of *Mediomastus californiensis* was seen at Station NF8 with 655 individuals per grab (about 16,400 individuals m^{-2}) (Figure 48); two other midfield stations, NF10 and 12, also had high densities of *M. californiensis*, ranging from 405 to 508 individuals per grab (about 10,100 to 12,700 individuals m^{-2}).

Other polychaetes that were commonly among the dominant species included cirratulids (Figure 49) and syllids (Figure 50). Two cirratulid species, *Tharyx acutus* and *Aphelochaeta marioni*, reached peak densities at a band of stations running from the northeast to the southwest along the offshore margin of

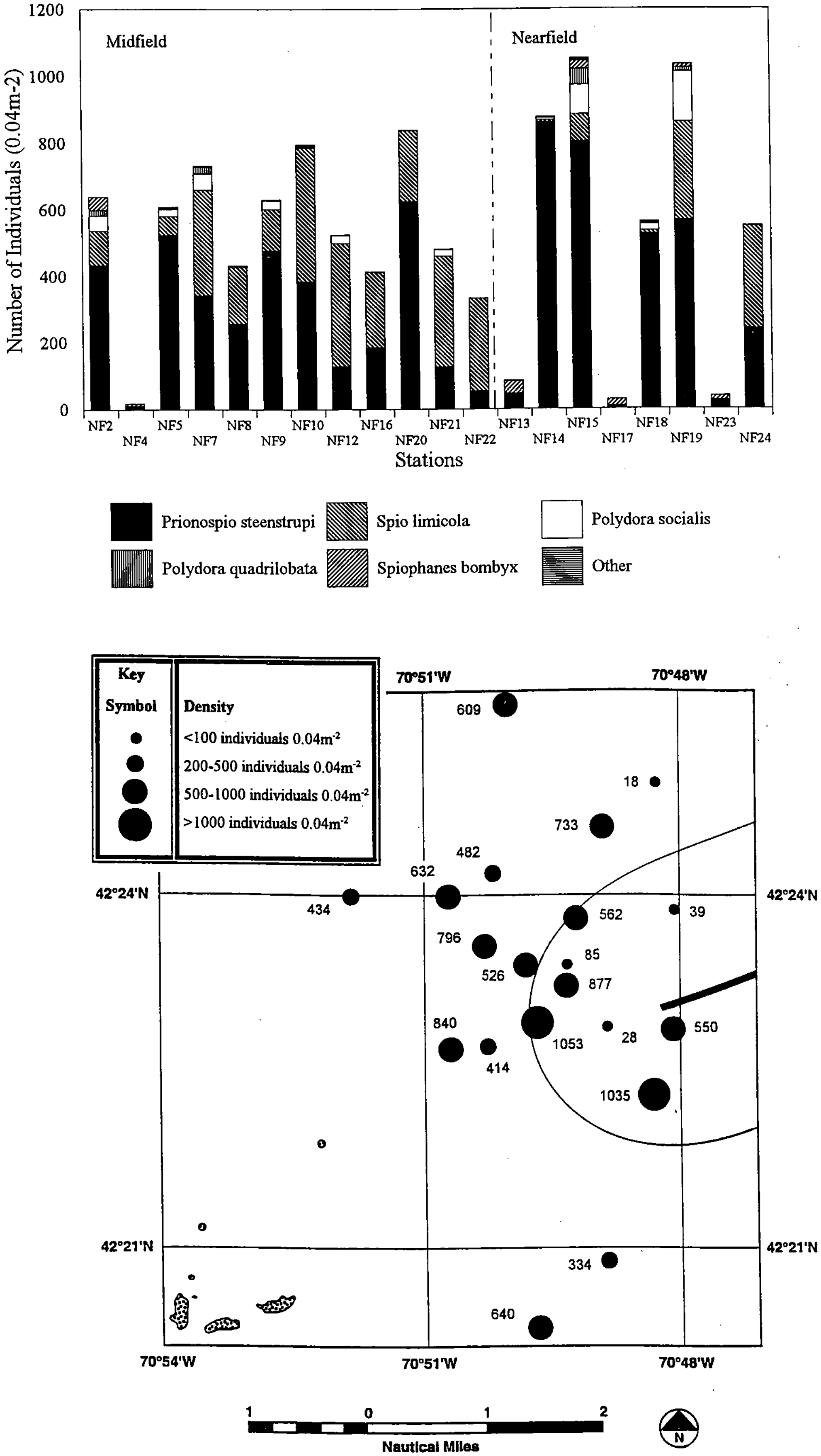


Figure 47. Spionid densities, mid- and nearfield, 1995. Bar graph broken down by species. Nearfield and diffuser indicated on map.

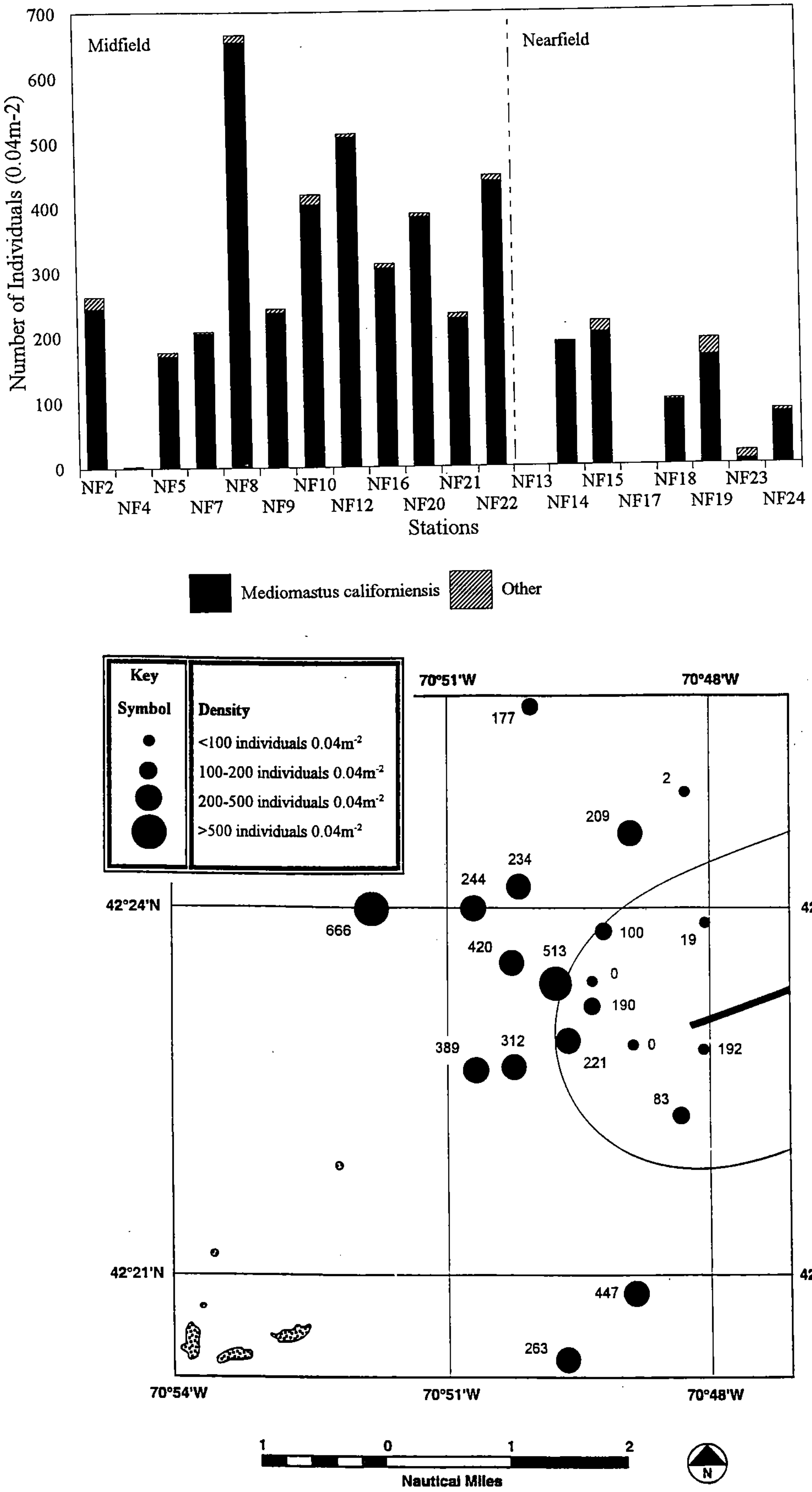


Figure 48. Capitellid densities, mid- and nearfield, 1995. Bar graph broken down by species. Nearfield and diffuser indicated on map.

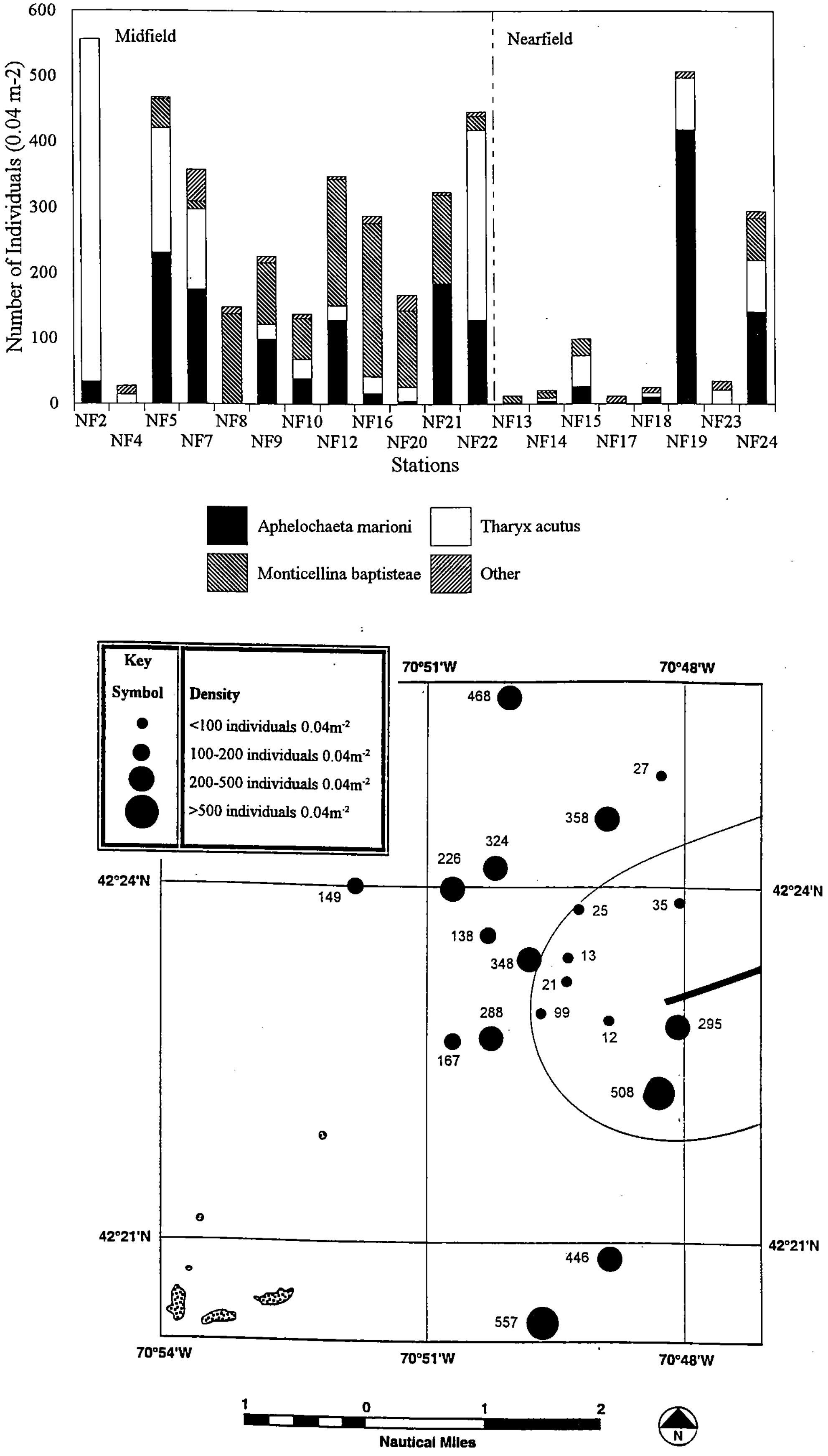


Figure 49. Cirratulid densities, mid- and nearfield, 1995. Bar graph broken down by species. Nearfield and diffuser indicated on map.

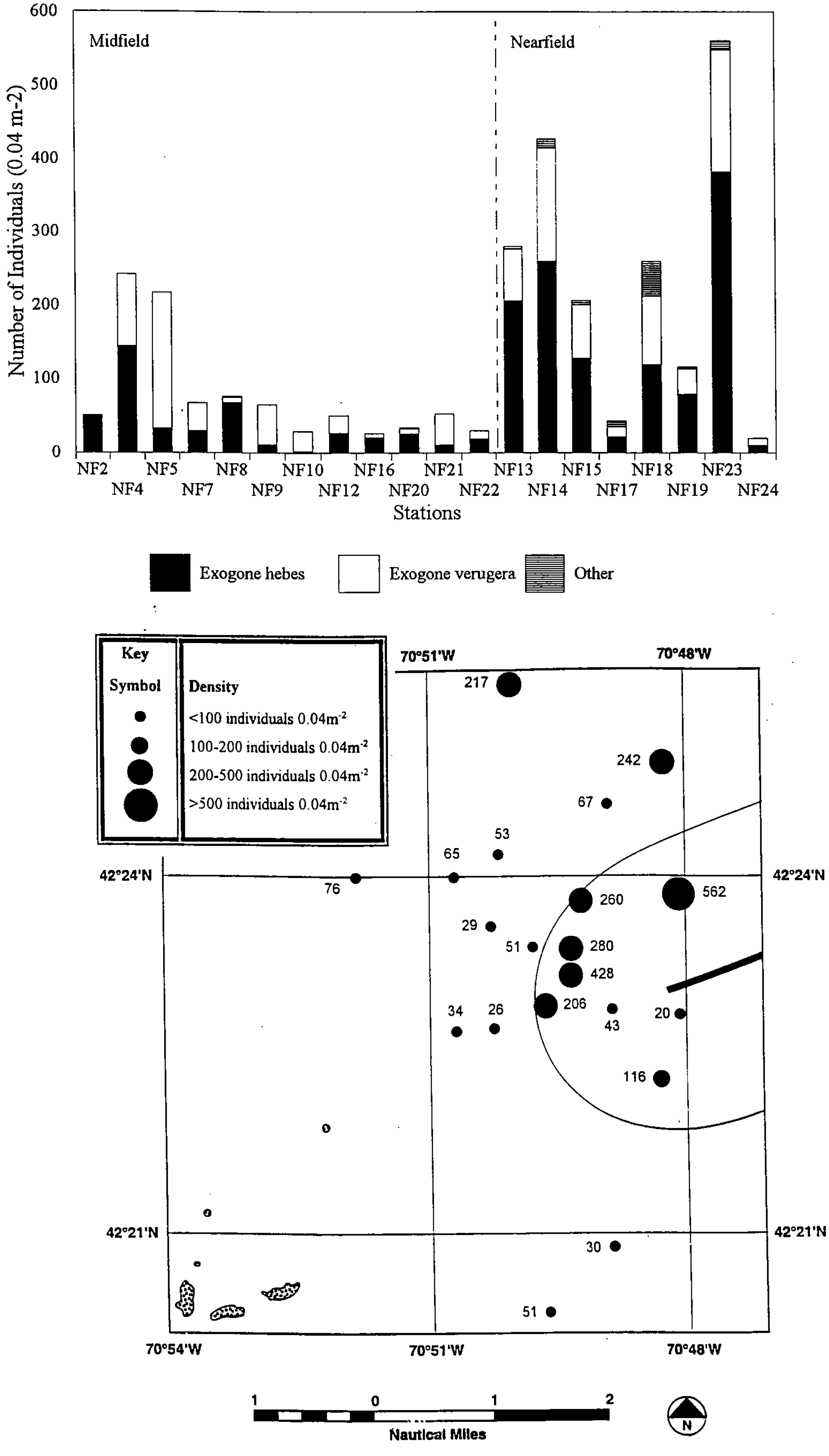


Figure 50. Syllid densities, mid- and nearfield, 1995. Bar graph broken down by species. Nearfield and diffuser indicated on map.

the Nearfield area, including Stations NF5, 7, 19, 2, and 22. Densities of the two species combined ranged from 297 individuals per grab (about 7400 individuals m^{-2}) at Station NF7 to 557 individuals per grab (about 14,000 individuals m^{-2}) at Station NF2. Two species of *Monticellina* were also among the dominants of several stations, but not as widespread and abundant as the other cirratulids. Generally, *T. acutus* and *Monticellina baptisteae* showed a preference for the midfield stations, while *A. marioni* was most abundant in the immediate nearfield.

Among the syllids, two species of *Exogone* were quite common and appeared among the dominants of 9 or 10 stations, ranking among the top five species at about half those stations. Densities of both species, *E. hebes* and *E. verugera* combined were highest at Stations NF13, 14, and 23 (all immediate nearfield), ranging from 276 individuals per grab (6900 individuals m^{-2}) to 549 individuals per grab (13,700 individuals m^{-2}). Paraonids were of less importance (Figure 51), but had very high densities at two stations at the nearshore border of the midfield (NF2 and 8) where *Aricidea catherinae* ranked first or second; densities of that species ranged from 552 individuals (13,800 individuals m^{-2}) at Station NF8 to 1067 individuals per grab (26,700 individuals m^{-2}) at Station NF2. These two stations are therefore somewhat similar to nearby Harbor stations (Stations T6 and T7, see Hilbig *et al.*, 1996).

The sandy stations NF4, 13, 17, and 23 were dominated by a suite of species not found in finer-grained sediments. An undescribed oligochaete species, Enchytraeidae sp. 1, was the top dominant at two stations (NF4 and 23), with moderate densities of 185 and 393 individuals per grab (about 2900 and 9800 individuals m^{-2}), respectively. Another somewhat unusual top dominant was *Polygordius* sp. A, an "archiannelid", at Station NF17, with a density of 188 individuals per grab (4700 individuals m^{-2}). This species was present in similar densities but ranking third at one other station, NF13, which is just a mile to the north.

The only crustacean ranking among the top five species at any one station was the amphipod *Corophium crassicorne*, a typical sand-dweller. It occurred in densities between 115 and 198 individuals per grab (roughly 2900 to 5000 individuals m^{-2}) at four sandy stations in the northeastern quadrant of the nearfield area (Stations NF4, 13, 17, and 23). It was absent or represented by no more than 3 individuals per grab at the other stations.

Table 6 shows the top ten dominant species for each station. Polychaetes comprise at least 90% of all individuals among the dominant species at all but four stations, with one or two species of oligochaete, bivalve, isopod, or nemertean contributing up to 10% of all dominant individuals; six stations were entirely dominated by polychaetes. Stations NF4, 13, 17, and 23 showed more variety in the suite of dominant species, with amphipods contributing about 21 to 48% of all individuals to the dominant fauna, oligochaetes about 9 to 25%, and various other taxa including bivalves about 3 to 12%. The top ten species together contributed between 60 and 87% of all individuals at any one station.

Species Richness and Diversity

In the Nearfield area, the number of species collected with one 0.04-m^2 grab varied from 45 to 81, with most stations ranging from about 55 to 75 (Table 7). There seems to be a slight tendency toward higher species richness in the north and east of the Nearfield area; all stations with more than 70 species are located east of a line connecting Stations NF21 and NF2. Low numbers of species were noted at stations scattered throughout the Nearfield area, including NF4, 8, and 22 in the midfield and NF13 and 17 in the immediate nearfield.

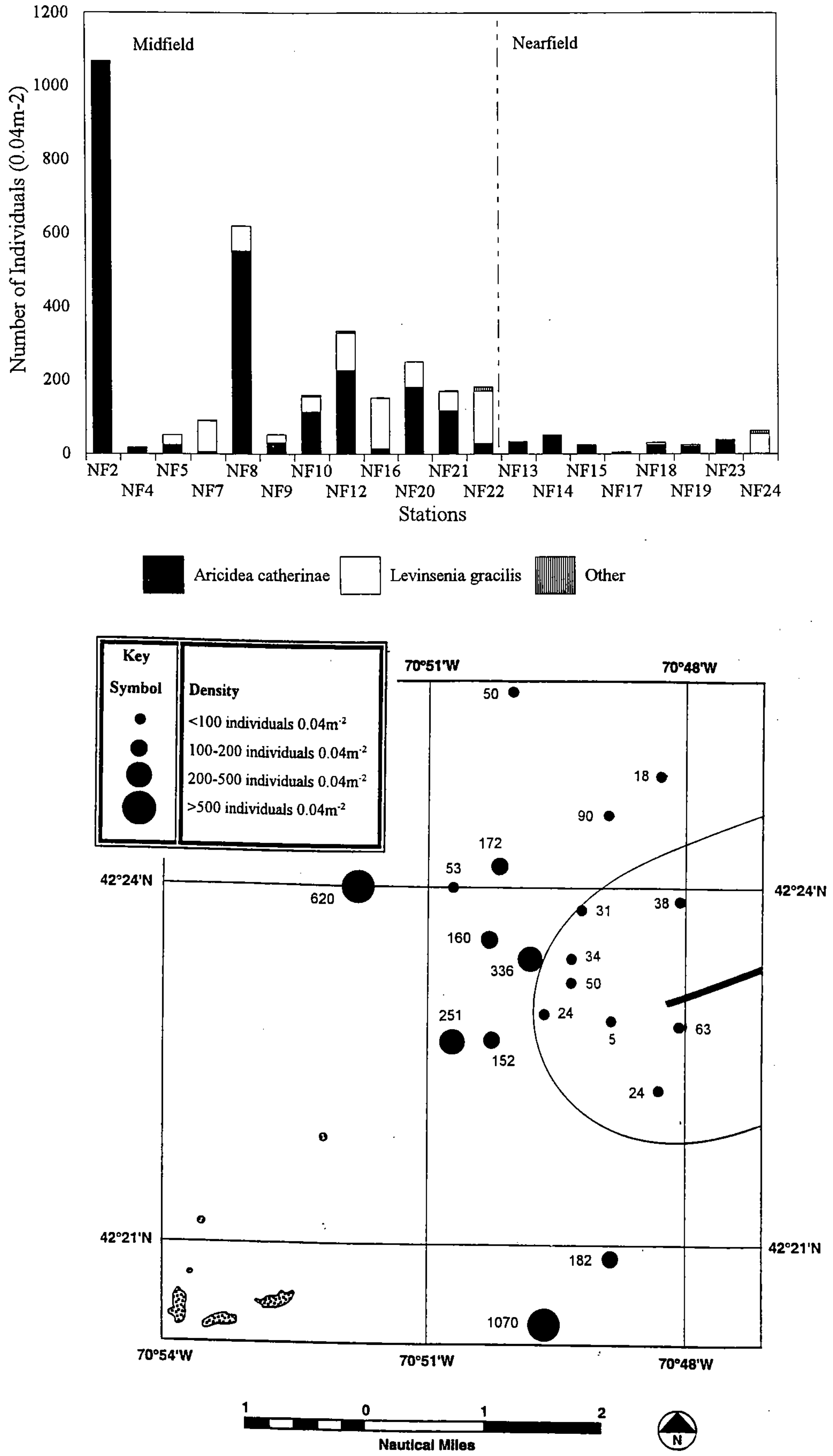


Figure 51. Paraonid densities, mid- and nearfield, 1995. Bar graph broken down by species. Nearfield and diffuser indicated on map.

Table 6. Dominant species at Mid- and Nearfield stations, August 1995.

Station NF2 - single sample, midfield

Rank	Species	Percent of Total Fauna	Density (Ind. 0.04m^{-2})
1	*Aricidea catherinae* (polychaete)	30.56	1067
2	*Tharyx acutus* (polychaete)	14.98	523
3	*Prionospio steenstrupi* (polychaete)	12.46	435
4	*Mediomastus californiensis* (polychaete)	7.02	245
5	*Phyllodoce mucosa* (polychaete)	5.84	204
6	*Spio limicola* (polychaete)	2.98	104
7	*Polygordius* sp. A (polychaete)	2.32	81
8	*Exogone hebes* (polychaete)	1.46	51
9	*Edotia montosa* (isopod)	1.43	50
10	*Pleurogonium rubicundum* (isopod)	1.35	47
	Total - 10 Taxa	80.38	2807
	Remaining Fauna - 69 Taxa	19.62	685
	Total Fauna - 79 Taxa	100.00	3492

Station NF4 - single sample, midfield

Rank	Species	Percent of Total Fauna	Density (Ind. 0.04m^{-2})
1	Enchytraeidae sp. 1 (oligochaete)	18.43	185
2	*Exogone hebes* (polychaete)	14.34	144
3	*Corophium crassicorne* (amphipod)	12.75	128
4	*Exogone verugera* (polychaete)	9.76	98
5	*Euclymene collaris* (polychaete)	3.09	31
6	*Cerastoderma pinnulatum* (bivalve)	2.59	26
6	*Owenia fusiformis* (polychaete)	2.59	26
8	*Protomedea fasciata* (amphipod)	1.89	19
9	*Aricidea catherinae* (polychaete)	1.79	18
10	*Unciola inermis* (amphipod)	1.69	17
	Total - 10 Taxa	68.92	692
	Remaining Fauna - 60 Taxa	31.08	312
	Total Fauna - 70 Taxa	100.00	1004

Table 6 (Continued)

Station NF5 - single sample, midfield			
Rank	**Species**	**Percent of Total Fauna**	**Density (Ind. 0.04m^{-2})**
1	*Prionospio steenstrupi* (polychaete)	23.70	526
2	*Aphelochaeta marioni* (polychaete)	10.41	231
3	*Tharyx acutus* (polychaete)	8.56	190
4	*Exogone verugera* (polychaete)	8.29	184
5	*Mediomastus californiensis* (polychaete)	7.70	171
6	*Crenella glandula* (bivalve)	4.01	89
7	*Nucula delphinodonta* (bivalve)	2.93	65
8	*Spio limicola* (polychaete)	2.48	55
9	*Thyasira flexuosa* (bivalve)	2.07	46
10	*Monticellina baptisteae* (polychaete)	1.94	43
	Total - 10 Taxa	72.10	1600
	Remaining Fauna - 84 Taxa	27.90	619
	Total Fauna - 94 Taxa	100.00	2219

Station NF7 - single sample, midfield			
Rank	**Species**	**Percent of Total Fauna**	**Density (Ind. 0.04m^{-2})**
1	*Prionospio steenstrupi* (polychaete)	17.63	343
2	*Spio limicola* (polychaete)	16.30	317
3	*Mediomastus californiensis* (polychaete)	10.59	206
4	*Aphelochaeta marioni* (polychaete)	9.00	175
5	*Tharyx acutus* (polychaete)	6.27	122
6	*Levinsenia gracilis* (polychaete)	4.32	84
7	*Ninoe nigripes* (polychaete)	2.72	53
8	*Polydora socialis* (polychaete)	2.52	49
9	*Monticellina dorsobranchialis* (polychaete)	2.42	47
10	*Euchone incolor* (polychaete)	2.31	45
	Total - 10 Taxa	74.09	1441
	Remaining Fauna - 85 Taxa	25.91	504
	Total Fauna - 95 Taxa	100.00	1945

Table 6 (Continued)

Station NF8 - single sample, midfield			
Rank	**Species**	**Percent of Total Fauna**	**Density (Ind. 0.04m^{-2})**
1	*Mediomastus californiensis* (polychaete)	27.67	655
2	*Aricidea catherinae* (polychaete)	23.32	552
3	*Prionospio steenstrupi* (polychaete)	10.90	258
4	*Spio limicola* (polychaete)	7.18	170
5	*Monticellina baptisteae* (polychaete)	5.83	138
6	*Exogone hebes* (polychaete)	2.87	68
6	*Levinsenia gracilis* (polychaete)	2.87	68
8	*Leitoscoloplos acutus* (polychaete)	2.83	67
9	*Euchone incolo*r (polychaete)	1.77	42
10	*Ninoe nigripes* (polychaete)	1.65	39
	Total - 10 Taxa	86.90	2057
	Remaining Fauna - 50 Taxa	13.10	310
	Total Fauna - 60 Taxa	100.00	2367

Station NF9 - single sample, midfield			
Rank	**Species**	**Percent of Total Fauna**	**Density (Ind. 0.04m^{-2})**
1	*Prionospio steenstrupi* (polychaete)	26.49	479
2	*Mediomastus californiensis* (polychaete)	13.14	238
3	*Spio limicola* (polychaete)	6.85	124
4	*Aphelochaeta marion*i (polychaete)	5.47	99
5	*Monticellina baptisteae* (polychaete)	5.19	94
6	*Nucula delphinodonta* (bivalve)	4.47	81
7	*Exogone verugera* (polychaete)	2.98	54
8	*Maldane sarsi* (polychaete)	2.76	50
9	*Ninoe nigripe*s (polychaete)	2.48	45
10	*Leitoscoloplos acutus* (polychaete)	1.71	31
	Total - 10 Taxa	71.51	1295
	Remaining Fauna - 78 Taxa	28.49	516
	Total Fauna - 88 Taxa	100.00	1811

Table 6 (Continued)

Station NF10 - single sample, midfield

Rank	Species	Percent of Total Fauna	Density (Ind. $0.04m^{-2}$)
1	*Mediomastus californi*ensis (polychaete)	19.23	405
2	*Spio limicola* (polychaete)	18.99	400
3	*Prionospio steenstrupi* (polychaete)	18.33	386
4	*Aricidea catherinae* (polychaete)	5.46	115
5	*Monticellina baptisteae* (polychaete)	2.94	62
6	*Maldane sarsi* (polychaete)	2.56	54
7	*Ninoe nigripes* (polychaete)	2.47	52
8	*Leitoscoloplos acutus* (polychaete)	2.09	44
9	*Levinsenia gracilis* (polychaete)	1.95	41
10	*Aphelochaeta marioni* (polychaete)	1.85	39
	Total - 10 Taxa	75.88	1598
	Remaining Fauna - 76 Taxa	24.12	508
	Total Fauna - 86 Taxa	100.00	2106

Station NF12 - replicated station, midfield

Rank	Species	Percent of Total Fauna	Density (Ind. $0.12m^{-2}$)
1	*Mediomastus californiensis* (polychaete)	23.15	1524
2	*Spio limicola* (polychaete)	16.71	1100
3	*Aricidea catherina*e (polychaete)	10.38	683
4	*Monticellina baptisteae* (polychaete)	8.78	578
5	*Prionospio steenstrupi* (polychaete)	5.91	389
6	*Aphelochaeta marioni* (polychaete)	5.86	386
7	*Levinsenia gracilis* (polychaete)	4.63	305
8	*Euchone incolor* (polychaete)	1.84	121
9	*Ninoe nigripes* (polychaete)	1.79	118
10	*Leitoscoloplos acutus* (polychaete)	1.70	112
	Total - 10 Taxa	80.77	5317
	Remaining Fauna - 98 Taxa	19.23	1266
	Total Fauna - 108 Taxa	100.00	6583

Table 6 (Continued)

Station NF13 - single sample, nearfield			
Rank	**Species**	**Percent of Total Fauna**	**Density (Ind. $0.04m^{-2}$)**
1	*Exogone hebes* (polychaete)	14.86	206
2	*Corophium crassicorne* (amphipod)	14.29	198
3	*Polygordius* sp. A (polychaete)	13.78	191
4	Enchytraeidae sp. 1 (oligochaete)	6.20	86
5	*Exogone verugera* (polychaete)	5.05	70
6	*Prionospio steenstrupi* (polychaete)	3.39	47
7	*Cerastoderma pinnulatum* (bivalve)	3.17	44
7	*Phyllodoce mucosa* (polychaete)	3.17	44
9	*Spiophanes bombyx* (polychaete)	2.67	37
10	*Aricidea catherinae* (polychaete)	2.45	34
	Total - 10 Taxa	69.04	957
	Remaining Fauna - 48 Taxa	30.96	429
	Total Fauna - 58 Taxa	100.00	1386

Station NF14 - single sample, nearfield			
Rank	**Species**	**Percent of Total Fauna**	**Density (Ind. $0.04m^{-2}$)**
1	*Prionospio steenstrupi* (polychaete)	38.33	862
2	*Exogone hebes* (polychaete)	11.56	260
3	*Mediomastus californiensis* (polychaete)	8.45	190
4	*Exogone verugera* (polychaete)	6.89	155
5	*Crenella glandula* (bivalve)	3.29	74
6	Tubificidae sp. 2 (oligochaete)	2.93	66
7	*Ninoe nigripes* (polychaete)	2.76	62
8	*Aricidea catherinae* (polychaete)	2.13	48
9	*Pholoe minuta* (polychaete)	1.24	28
10	*Ampharete acutifrons* (polychaete)	1.16	26
	Total - 10 Taxa	78.74	1771
	Remaining Fauna - 82 Taxa	21.26	478
	Total Fauna - 92 Taxa	100.00	2249

Table 6 (Continued)

Station NF15 - single sample, nearfield			
Rank	**Species**	**Percent of Total Fauna**	**Density (Ind. 0.04m^{-2})**
1	*Prionospio steenstrupi* (polychaete)	33.14	804
2	*Mediomastus californiensis* (polychaete)	8.37	203
3	*Exogone hebes* (polychaete)	5.28	128
4	*Polydora socialis* (polychaete)	3.59	87
5	*Phyllodoce mucosa* (polychaete)	3.34	81
5	*Spio limicola* (polychaete)	3.34	81
7	*Exogone verugera* (polychaete)	2.97	72
8	*Owenia fusiformis* (polychaete)	2.84	69
9	*Polydora quadrilobata* (polychaete)	1.98	48
10	*Tharyx acutus* (polychaete)	1.94	47
	Total - 10 Taxa	66.78	1620
	Remaining Fauna - 66 Taxa	33.22	806
	Total Fauna - 76 Taxa	100.00	2426

Station NF16 - single sample, midfield			
Rank	**Species**	**Percent of Total Fauna**	**Density (Ind. 0.04m^{-2})**
1	*Mediomastus californiensis* (polychaete)	16.08	305
2	*Monticellina baptisteae* (polychaete)	12.34	234
3	*Spio limicola* (polychaete)	11.97	227
4	*Prionospio steenstrupi* (polychaete)	9.75	185
5	*Levinsenia gracilis* (polychaete)	7.22	137
6	Tubificidae sp. 2 (oligochaete)	5.54	105
7	*Euchone incolor* (polychaete)	4.90	93
8	*Leitoscoloplos acutus* (polychaete)	3.32	63
9	*Ninoe nigripes* (polychaete)	2.95	56
10	Nemertea sp. 5 (nemertean)	1.63	31
	Total - 10 Taxa	75.70	1436
	Remaining Fauna - 76 Taxa	24.30	461
	Total Fauna - 86 Taxa	100.00	1897

Table 6 (Continued)

Station NF17 - replicated station, nearfield			
Rank	**Species**	**Percent of Total Fauna**	**Density (Ind. 0.12m^{-2})**
1	*Polygordius* sp. A (polychaete)	17.63	465
2	*Pseudunciola obliqua* (amphipod)	13.84	365
3	*Corophium crassicorne* (amphipod)	13.08	345
4	*Unciola inermis* (amphipod)	4.02	106
5	*Cerastoderma pinnulatum* (bivalve)	3.30	87
6	*Molgula* sp. (tunicate)	3.03	80
7	*Exogone hebes* (polychaete)	2.54	67
8	*Phyllodoce mucosa* (polychaete)	2.35	62
9	*Spiophanes bombyx* (polychaete)	2.31	61
10	*Chiridotea tuftsi* (isopod)	2.20	58
	Total - 10 Taxa	64.32	1696
	Remaining Fauna - 84 Taxa	36.68	941
	Total Fauna - 94 Taxa	100.00	2637

Station NF18 - single sample, nearfield			
Rank	**Species**	**Percent of Total Fauna**	**Density (Ind. 0.04m^{-2})**
1	*Prionospio steenstrupi* (polychaete)	36.60	526
2	*Exogone hebes* (polychaete)	8.28	119
3	*Mediomastus californiensis* (polychaete)	6.82	99
4	*Exogone verugera* (polychaete)	6.47	93
5	*Pionosyllis* sp. A (polychaete)	2.92	42
6	*Crenella glandula* (bivalve)	2.30	33
7	*Pholoe minuta* (polychaete)	1.95	28
8	*Ninoe nigripes* (polychaete)	1.74	25
9	*Aricidea catherinae* (polychaete)	1.67	24
10	*Euclymene collaris* (polychaete)	1.67	24
	Total - 10 Taxa	70.42	1012
	Remaining Fauna - 92 Taxa	29.58	425
	Total Fauna - 102 Taxa	100.00	1437

Table 6 (Continued)

Station NF19 - single sample, nearfield			
Rank	**Species**	**Percent of Total Fauna**	**Density (Ind. $0.04m^{-2}$)**
1	*Prionospio steenstrupi* (polychaete)	21.37	567
2	*Aphelochaeta marioni* (polychaete)	15.79	419
3	*Spio limicola* (polychaete)	11.12	295
4	*Mediomastus californiensis* (polychaete)	6.26	166
5	*Polydora socialis* (polychaete)	5.58	148
6	*Exogone hebes* (polychaete)	2.98	79
6	*Tharyx acutus* (polychaete)	2.98	79
8	*Lyonsia arenosa* (bivalve)	1.81	48
9	*Pholoe minuta* (polychaete)	1.73	46
10	*Phyllodoce mucosa* (polychaete)	1.62	43
	Total - 10 Taxa	71.24	1890
	Remaining Fauna - 78 Taxa	28.76	763
	Total Fauna - 88 Taxa	100.00	2653

Station NF20 - single sample, midfield			
Rank	**Species**	**Percent of Total Fauna**	**Density (Ind. $0.04m^{-2}$)**
1	*Prionospio steenstrupi* (polychaete)	27.09	625
2	*Mediomastus californiensis* (polychaete)	16.64	384
3	*Spio limicola* (polychaete)	9.19	212
4	*Aricidea catherin*ae (polychaete)	7.89	182
5	*Monticellina baptisteae* (polychaete)	5.11	118
6	*Euchone incolor* (polychaete)	3.51	81
7	Tubificidae sp. 2 (oligochaete)	3.47	80
8	*Levinsenia gracilis* (polychaete)	2.99	69
9	*Ninoe nigripe*s (polychaete)	2.08	48
10	*Leitoscoloplos acutu*s (polychaete)	1.81	42
	Total - 10 Taxa	79.80	1841
	Remaining Fauna - 68 Taxa	20.20	466
	Total Fauna - 78 Taxa	100.00	2307

Table 6 (Continued)

Station NF21 - single sample, midfield			
Rank	**Species**	**Percent of Total Fauna**	**Density (Ind. 0.04m^{-2})**
1	*Spio limicola* (polychaete)	17.92	333
2	*Mediomastus californiensis* (polychaete)	12.22	227
3	*Aphelochaeta marioni* (polychaete)	9.96	185
4	*Monticellina baptisteae* (polychaete)	7.27	135
5	*Prionospio steenstrupi* (polychaete)	6.89	128
6	*Aricidea catherinae* (polychaete)	6.30	117
7	*Levinsenia gracilis* (polychaete)	2.80	52
8	*Nucula delphinodonta* (bivalve)	2.69	50
9	*Euchone incolor* (polychaete)	2.42	45
10	*Exogone verugera* (polychaete)	2.26	42
	Total - 10 Taxa	70.72	1314
	Remaining Fauna - 76 Taxa	29.28	544
	Total Fauna - 86 Taxa	100.00	1858

Station NF22 - single sample, midfield			
Rank	**Species**	**Percent of Total Fauna**	**Density (Ind. 0.04m^{-2})**
1	*Mediomastus californiensis* (polychaete)	21.58	439
2	*Tharyx acutus* (polychaete)	14.21	289
3	*Spio limicola* (polychaete)	13.77	280
4	*Levinsenia gracilis* (polychaete)	6.93	141
5	*Aphelochaeta marioni* (polychaete)	6.34	129
6	*Ninoe nigripes* (polychaete)	3.88	79
7	*Parougia caeca* (polychaete)	2.90	59
8	*Prionospio steenstrupi* (polychaete)	2.65	54
9	*Euchone incolor* (polychaete)	2.50	51
10	Tubificidae sp. 2 (oligochaete)	2.46	50
	Total - 10 Taxa	75.76	1571
	Remaining Fauna - 55 Taxa	24.24	493
	Total Fauna - 65 Taxa	100.00	2034

Table 6 (Continued)

Station NF23 - single sample, nearfield			
Rank	**Species**	**Percent of Total Fauna**	**Density (Ind. 0.04m^{-2})**
1	Enchytraeidae sp.1 (oligochaete)	15.30	393
2	*Exogone hebes* (polychaete)	14.91	383
3	*Unciola inermis* (amphipod)	6.66	171
4	*Exogone verugera* (polychaete)	6.46	166
5	*Corophium crassicorne* (amphipod)	6.11	157
6	*Polygordius* sp. A (polychaete)	3.04	78
7	*Hiatella arctica* (bivalve)	2.65	68
8	*Tanaissus psammophil*us (tanaidacean)	2.49	64
9	*Cerastoderma pinnulatum* (bivalve)	2.06	53
10	*Protomedea fasciata* (amphipod)	1.79	46
	Total - 10 Taxa	59.36	1579
	Remaining Fauna - 91 Taxa	40.64	1044
	Total Fauna - 101 Taxa	100.00	2569

Station NF24 - replicated station, nearfield			
Rank	**Species**	**Percent of Total Fauna**	**Density (Ind. 0.12m^{-2})**
1	*Spio limicola* (polychaete)	22.12	923
2	*Prionospio steenstrupi* (polychaete)	17.23	719
3	*Aphelochaeta marioni* (polychaete)	10.16	424
4	*Mediomastus californiensis* (polychaete)	5.66	236
5	*Tharyx acutus* (polychaete)	5.58	233
6	*Monticellina baptisteae* (polychaete)	4.67	195
7	*Euchone incolo*r (polychaete)	4.10	171
8	*Levinsenia gracilis* (polychaete)	3.79	158
9	*Pholoe minuta* (polychaete)	2.92	122
10	*Ninoe nigripes* (polychaete)	2.28	95
	Total - 10 Taxa	78.50	3276
	Remaining Fauna - 100 Taxa	21.50	897
	Total Fauna - 110 Taxa	100.00	4173

Table 7. Community parameters, Near- and Midfield, August 1995.

Station	# spp. (0.04m^2)	# indiv. (0.04 m^2)	spp./50 ind.	spp./100 ind.	spp./500 ind.	H'	J'
NF2	66	3371	15.12	21.51	40.29	2.53	0.60
NF4	58	922	17.48	24.85	48.39	2.82	0.69
NF5	76	2073	18.40	26.34	50.83	2.91	0.67
NF7	80	1875	18.22	25.65	50.60	2.94	0.67
NF8	51	2304	13.25	18.20	34.43	2.35	0.60
NF9	70	1694	18.54	26.39	49.40	2.86	0.67
NF10	67	1919	15.39	21.87	42.86	2.58	0.61
NF12*	62	2075	15.33	21.11	40.82	2.66	0.63
NF13	48	1169	16.35	21.94	38.46	2.73	0.70
NF14	76	2087	14.86	21.62	46.02	2.42	0.56
NF15	69	2313	20.16	28.86	49.00	2.89	0.68
NF16	70	1775	17.12	23.52	44.40	2.87	0.67
NF17*	45	738	13.61	18.70	36.56	2.33	0.63
NF18	85	1328	18.48	28.11	61.37	2.74	0.62
NF19	79	2476	18.23	26.29	49.89	2.88	0.66
NF20	64	2181	15.49	21.57	41.10	2.60	0.62
NF21	71	1671	17.74	24.66	47.68	2.90	0.68
NF22	51	1912	16.00	21.53	35.98	2.67	0.68
NF23	81	2157	19.73	28.29	54.11	3.05	0.69
NF24*	59	1316	16.64	23.36	47.35	2.74	0.69

*replicated station; values are means per grab

The number of individuals ranged from about 900 to 3500 per grab (Table 7), again with a slight west-east gradient toward lower abundances offshore. The highest abundances were seen at midfield station NF2 (3500 individuals per grab).

The number of expected species per 100 individuals ranged from about 18 at stations NF8 and NF17 to more than 28 at stations NF15, 18, and 23 (Table 7). Most stations scoring high with the Hurlbert rarefaction method are located north and east of the diffuser, in or close to the immediate nearfield (NF15, 18, and 23 in the nearfield, NF4, 5, 7, 9, 16, and 21 in the midfield). None of the ancillary sedimentary parameters coincide fully with high diversity, and it is likely that a mixture of sedimentary conditions and biological processes, such as reproduction and larval settlement, are reflected in the infaunal diversity. The rarefaction curves and corresponding areal distribution of high- and low-diversity stations, with diversity expressed as number of expected species per 100 individuals, are depicted in Figure 52. The Shannon-Wiener indices are very similar to the rarefaction.

Community Analysis

Similarity among the Nearfield and Farfield stations was analyzed with Bray-Curtis and Gallagher's CNESS (Trueblood *et al.*, 1994), with m=18, which is consistent with the m size used by Coats (1995). The three replicated stations NF12, 17, and 24 were included in both the Nearfield and Farfield dendrograms; only one replicate was analyzed along with the other unreplicated Nearfield stations, and all three replicates were included in the Farfield analysis.

The Nearfield stations grouped somewhat different with the two clustering techniques (Figures 53, 54). With Bray-Curtis, three clusters of stations and two single stations group together, and the patterns can be explained with the top dominant species and the overall character of the sedimentary environment (erosional versus depositional), represented by sediment grain size and organic carbon content (TOC). Cluster 1 is station NF24, which was depositional, dominated by *Spio limicola* and had very fine, silty sediment with the highest concentration of organic carbon measured in the nearfield during that sampling event (mean phi 7.88, mean TOC 2.8%). Cluster 2 includes 8 mostly depositional midfield stations (NF8, 9, 10, 12, 16, 20, 21, and 22) that were all dominated by *Mediomastus californiensis* and had sediments consisting mostly of silt and clay, with relatively high organic carbon concentrations (mean phi 5.08, mean TOC 1.08%). Cluster 3 consists of 6 mid- and nearfield stations (NF5, 7, 14, 15, 18, and 19) dominated by *Prionospio steenstrupi*, with sediments sometimes rippled, consisting mostly of very fine sand, and organic carbon concentrations being moderate (mean phi 3.48, mean TOC 0.63%). Cluster 4 is station NF2, dominated by *Aricidea catherinae*, the sediment being sandy with low organic carbon concentrations (mean phi 2.16, mean TOC 0.2%). Cluster 5 includes 1 midfield and 3 nearfield stations that were erosional, with rippled sandy sediments, and supported only low concentrations of organic carbon (except for station NF17); the dominant species were *Exogone hebes*, Enchytraeidae sp. 1, and *Polygordius* sp. A., the mean phi was 2.26, the mean TOC was 0.1% at stations NF4, 13, and 23 and 0.7% at station NF17. Interestingly, one of the species consistently present at this group of stations over the years, *Exogone hebes*, was only moderately abundant at the relatively carbon-rich station NF17.

With CNESS, one single station and four clusters with at least two stations each group together, and while the grouping of stations is somewhat different from that produced with Bray-Curtis, the sedimentary environment can be used to explain the patterns in the CNESS dendrogram as well. Cluster 1 includes all depositional stations, with a mean phi of 5.23 and a mean TOC concentration of 1.21%; the dominant species at these stations are *Prionospio*, *Mediomastus*, and *Spio*. Cluster 2 consists of slightly erosional stations with fine sands and moderate TOC concentrations, dominated by *Prionospio*,

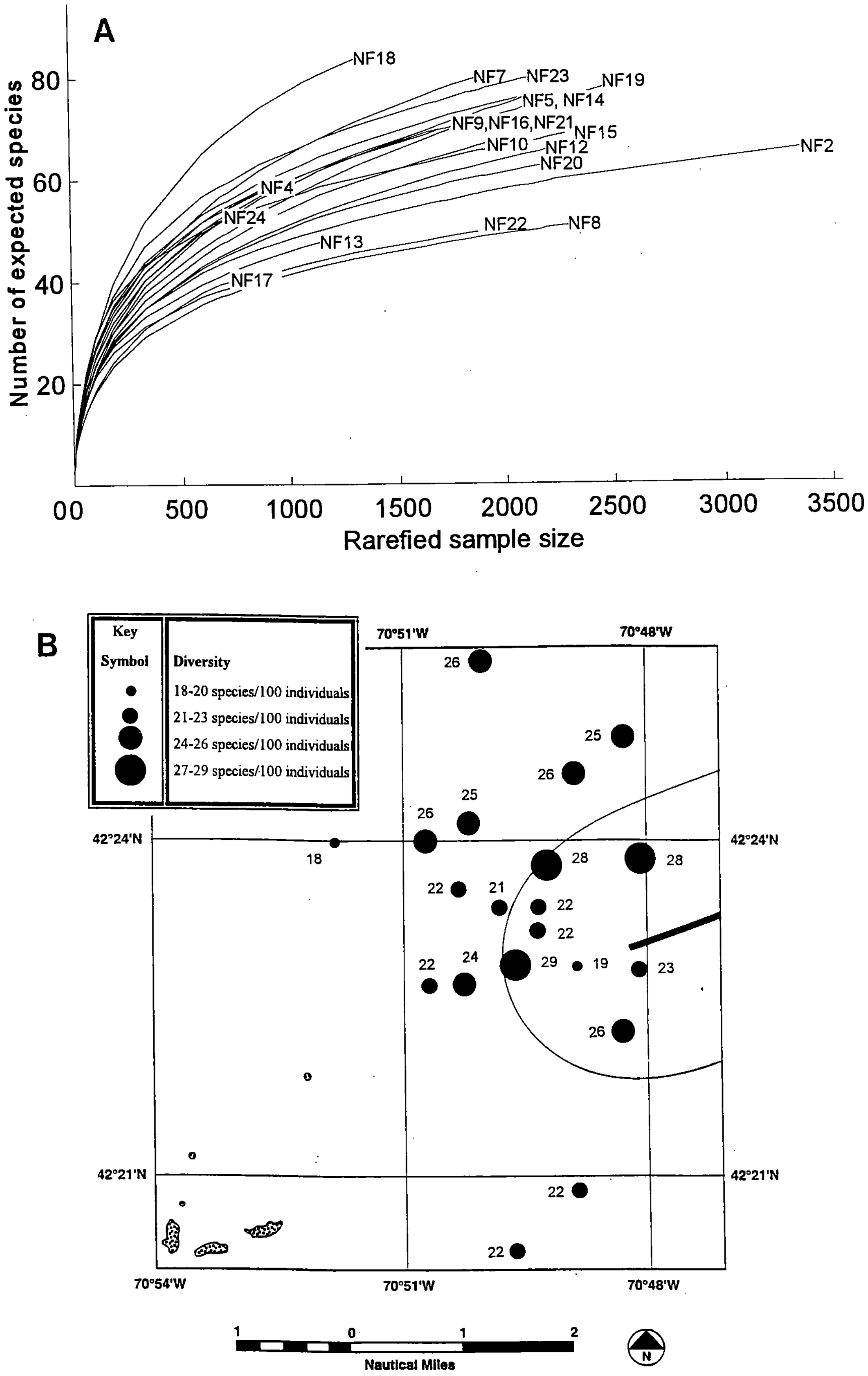


Figure 52. Diversity in mid- and nearfield, 1995. A, rarefaction curves; B, areal distribution. Nearfield and diffuser indicated on map.

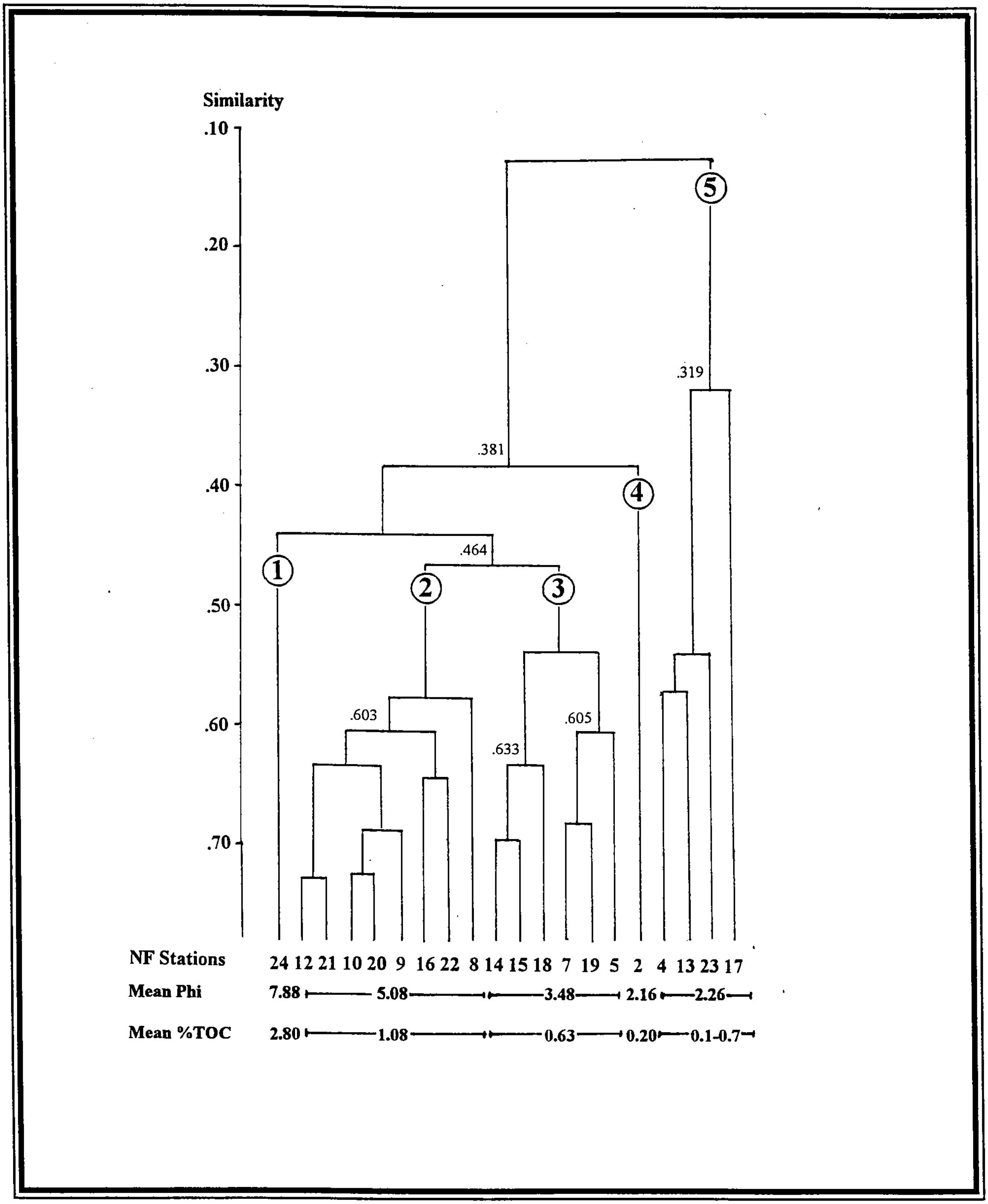


Figure 53. Bray-Curtis similarity among mid- and nearfield stations, 1995.

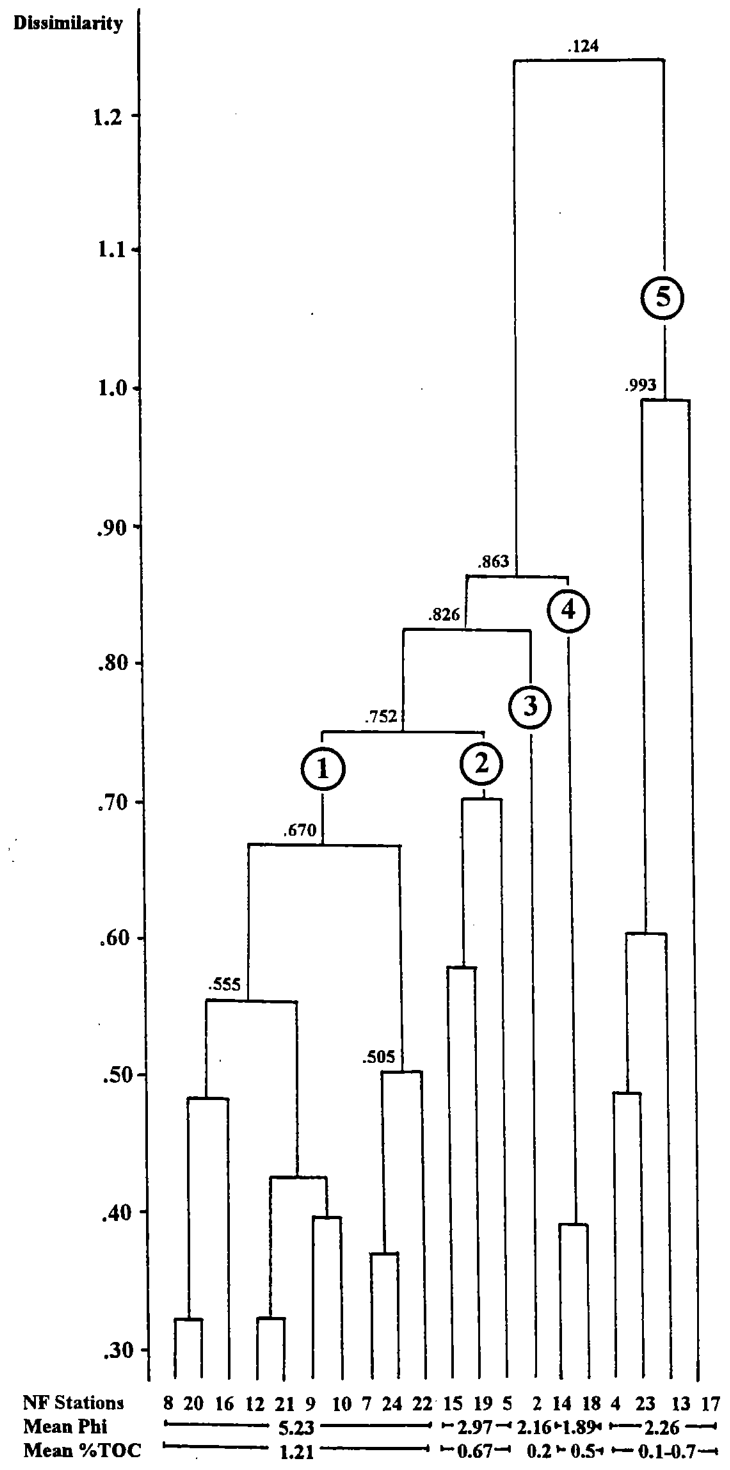


Figure 54. CNESS dissimilarity among mid- and nearfield stations, 1995.

Aphelochaeta marioni, and *Mediomastus*. Cluster 3 is station NF2, which is singled out with Bray-Curtis as well, with a non-depositional environment and an infaunal assemblage more related to the close-by Harbor than other mid- and nearfield stations, dominated by *Aricidea catherinae*. Cluster 4 includes two erosional nearfield stations characterized by high abundances of *Exogone* spp. (top dominants are *Prionospio* and *Mediomastus*). The sediment was rippled, the TOC fairly low at 0.5%. Cluster 5 is the same as cluster 5 in the Bray-Curtis dendrogram.

The main differences between the two dendrograms are the following: Bray-Curtis clusters 1 and 2 (plus NF7 from cluster 3) are joined in cluster 1 of CNESS, and the remainder of Bray-Curtis cluster 3 is split into two (clusters 2 and 4 of CNESS). Both of these differences are related to the different emphasis the two techniques put on the top dominant species.

The principal components analysis and station ordination was used to explain some of the clustering patterns of CNESS in more detail (Figures 55 and 56). Stations were ordinated in the space between the first three axes, and biplots were created for that same space to elucidate grouping patterns of the stations. In the projection of axes 1 and 2 (Figure 55A), CNESS cluster 5 is at the far left of the diagram, while cluster 1 is on the far right; axis 1 is very likely sediment grain size. Axis 2 further separates the sandy stations, with stations grouped in cluster 4 (NF14 and 18) scoring highest and station NF17 from cluster 5 scoring lowest. In the projection of axes 1 and 3, the muddy stations are further separated (Figure 55B), possibly according to their closeness to shore, with station NF7 scoring highest (furthest offshore) and NF8 scoring lowest. The station ordination in the projection of axes 2 and 3 shows the spread of sandy stations along axis 2 and the spread of muddy stations along axis 3 (Figure 55C).

The species causing the ordination patterns among the first three axes are, for axis 1, the top dominants of the sandy stations in cluster 5 (Enchytraeidae sp. 1 and others), *Cerastoderma pinnulatum*, and *Pseudunciola obliqua* on the left side of the diagram and the top dominants of the muddy stations grouped in cluster 1 (*Mediomastus* and others), *Monticellina baptisteae*, and *Levinsenia gracilis* on the right side of the diagram. In the projection of the first 2 axes, only the two species of *Exogone* have some influence on the spread of stations along that axis (Figure 56A). In the projection of axes 2 and 3, *Exogone* spp. have a much stronger component, as does *Prionospio* (Figure 56B). Axis 3, which separates the muddy stations (Figure 56C), is strongly influenced by *Aricidea catherinae* and *Monticellina baptisteae* (nearshore component) and *Aphelochaeta marioni* and *Tharyx acutus* (offshore component). This influence is apparent in the length of the vectors for those four species in the axes 1/3 and 2/3 projections, with *Polydora socialis* adding some influence to the ordination pattern between the last two axes. Higher dimensions were not examined because of the low amount of variability explained by those dimensions.

Application of different techniques to describe patterns in the benthic community structure indicates that five benthic assemblages can be defined in the mid- and nearfield, two of which are defined with both Bray-Curtis and CNESS (station NF2 with *Aricidea* and the *Corophium*/*Exogone*/Enchytraeidae sp. 1 assemblage at stations NF4, 13, 17, and 23). The majority of the near- and midfield stations support assemblages dominated by spionid and capitellid polychaetes, and depending on the weight associated with the top dominant those stations group slightly differently, resulting in the definition of one or two mud assemblages and two or three sand assemblages. The principal components analysis helps to explain groupings of stations within each of the larger mud- and sand-defined clusters. Two sedimentary parameters, grain size and organic carbon content, were identified that appear to influence the clustering patterns with both techniques and much of the variability in the station ordination.

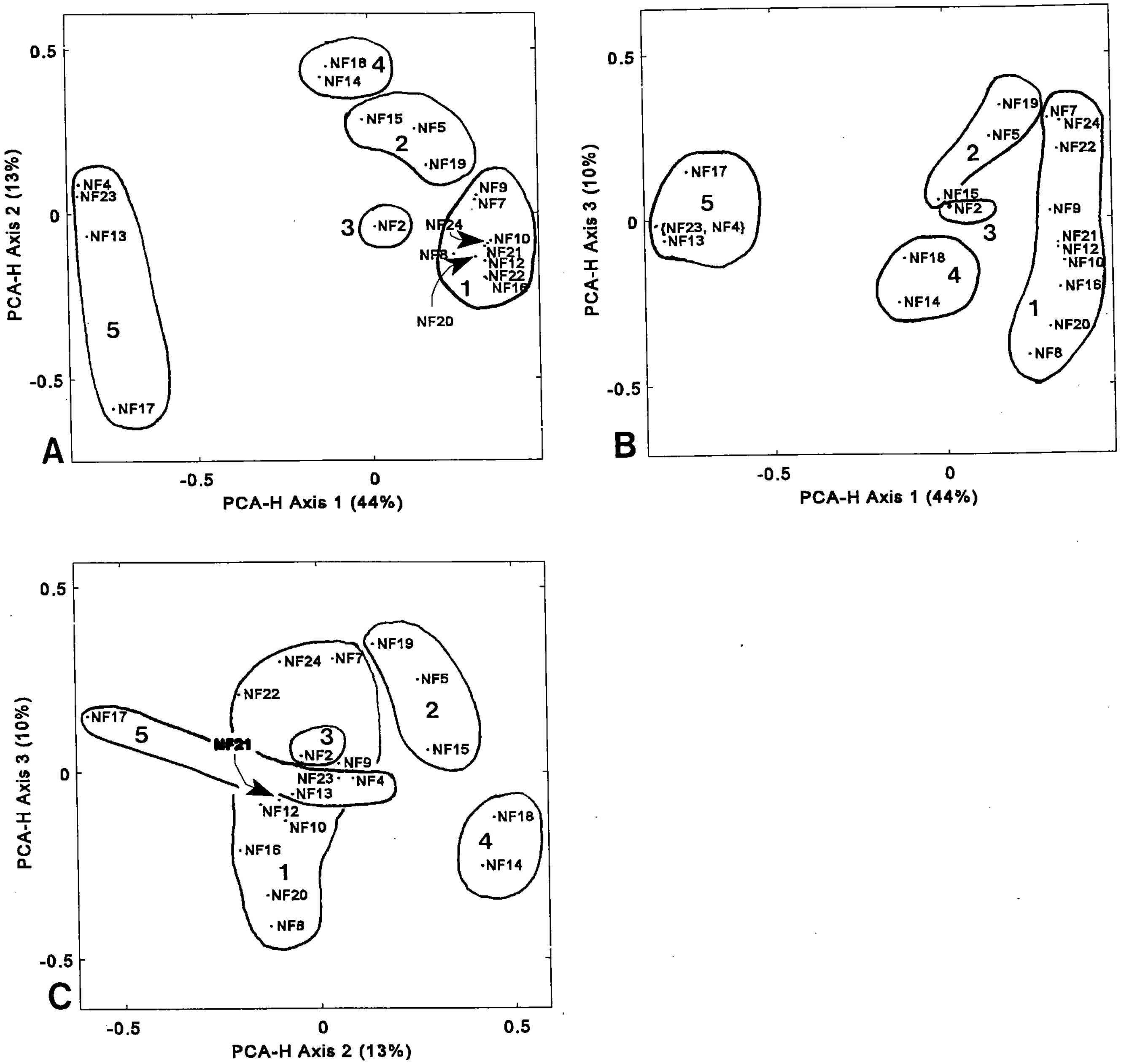


Figure 55. Station ordination among first three PCA-H axes, mid- and nearfield stations. Outlines indicate clusters from CNESS dendrogram in Figure 54.

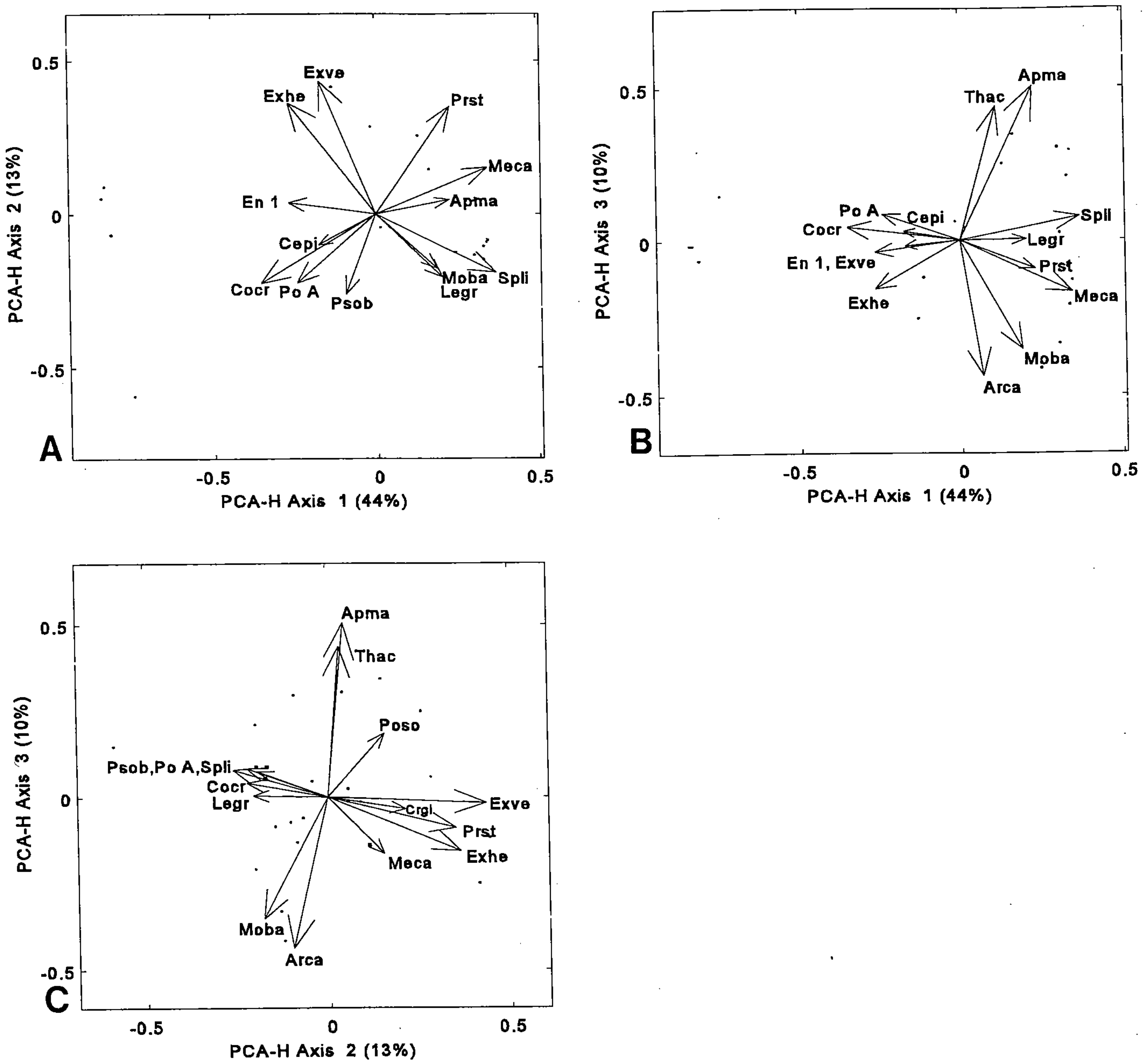


Figure 56. Gabriel biplots, mid- and nearfield stations, among first three PCA-H axes. For abbreviated species names see Appendix C2.

3.3 Benthic Hardbottom Communities, Nearfield

3.3.1 Distribution of Habitat Types

Still photographs were obtained at 26 of the 30 possible locations. Of 191 photographs taken during the survey, 178 were clear enough to provide data suitable for analysis. The number of photographs per location ranged from a low of 2 to a high of 14. Eighty-six of the photographs were taken on the tops of drumlins, while the remaining 92 were taken on the flanks. The seafloor on the tops of drumlins varied, ranging from low-relief cobble pavements with moderate to heavy sediment drape (transect T8) to high-relief clean boulders (waypoint 4 on transects T4 and T6). The flanks of drumlins usually consisted of a pavement of cobbles with occasional boulders, although the area nearest the diffuser consisted of a cobble pavement buried by sediment (transect T2 waypoint 5). Sediment cover on the flanks of the drumlins ranged from a light dusting to a heavy mat-like cover. Complete physical descriptions of each location can be found in the video survey data report (Hilbig and Hecker, 1995); the results of the video tape analysis are summarized in this chapter with respect to the similarity measures developed from the still photo analysis.

3.3.2 Distribution and Abundances of Epibenthic Organisms

A total of 2322 individuals were counted. An additional 1996 algae (encrusting coralline and filamentous red) were estimated to also be present. These two algae, the coralline red alga *Lithothamnion* and the filamentous red alga ?*Asparagopsis hamifera*, were the most abundant taxa seen, with respective estimated abundances of 1294 individuals and 702 individuals (Table 8). These estimates are very conservative and many more individuals were probably present. The six most abundant organisms were: small white starfish, which appear to be juvenile *Asterias* (419 individuals), the horse mussel *Modiolus modiolus* (242 individuals), the green sea urchin *Strongylocentrotus droebachiensis* (177 individuals), the dulse alga *Rhodymenia palmata* (159 individuals), an unidentified orange-tan encrusting sponge (159 individuals), and the blood star *Henricia sanguinolenta* (108 individuals). Other common inhabitants of the drumlins included the sea pork tunicate *Aplidium* spp. (87 individuals), the yellow encrusting sponge *Aplysilla sulfurea* (79 individuals), an unidentified white encrusting organism (74 individuals), the northern white crust tunicate *Didemnum albidum* (70 individuals), and the cunner *Tautogolabrus adspersus* (63 individuals). Of a total of 74 recognizable taxa, 45 were present in abundances of five or more individuals and 15 were only seen once.

Classification of the 26 locations and 45 species defined five clusters and one outlier (Figure 57). The clustering structure appears to be determined mainly by drumlin topography. The tops of drumlins clearly separated from the flanks. The first two clusters consisted mostly of locations on the tops of drumlins, while the remaining three clusters consisted of locations on the flanks of drumlins. Some of the areas on the upper flanks of drumlins clustered with the tops, while others clustered with flanks. The flank areas clustered at lower levels of taxonomic similarity than did the tops. This indicates a higher level of variability in the taxa inhabiting drumlin flanks. Substratum type and local relief overlapped between tops and flanks, so separation between the two could only partially be attributed to differences in habitat characteristics. Excursions within locations generally tended to cluster together, but some exceptions were noted (transect T2, waypoint 1). The taxa inhabiting the areas within each cluster are presented in Tables 9 (still photos) and 10 (video tapes). Algae dominated the benthic communities inhabiting the tops of drumlins, while encrusting invertebrates generally dominated communities inhabiting the flanks. Drumlin tops generally supported higher abundances of both algae and encrusting fauna than did drumlin flanks.

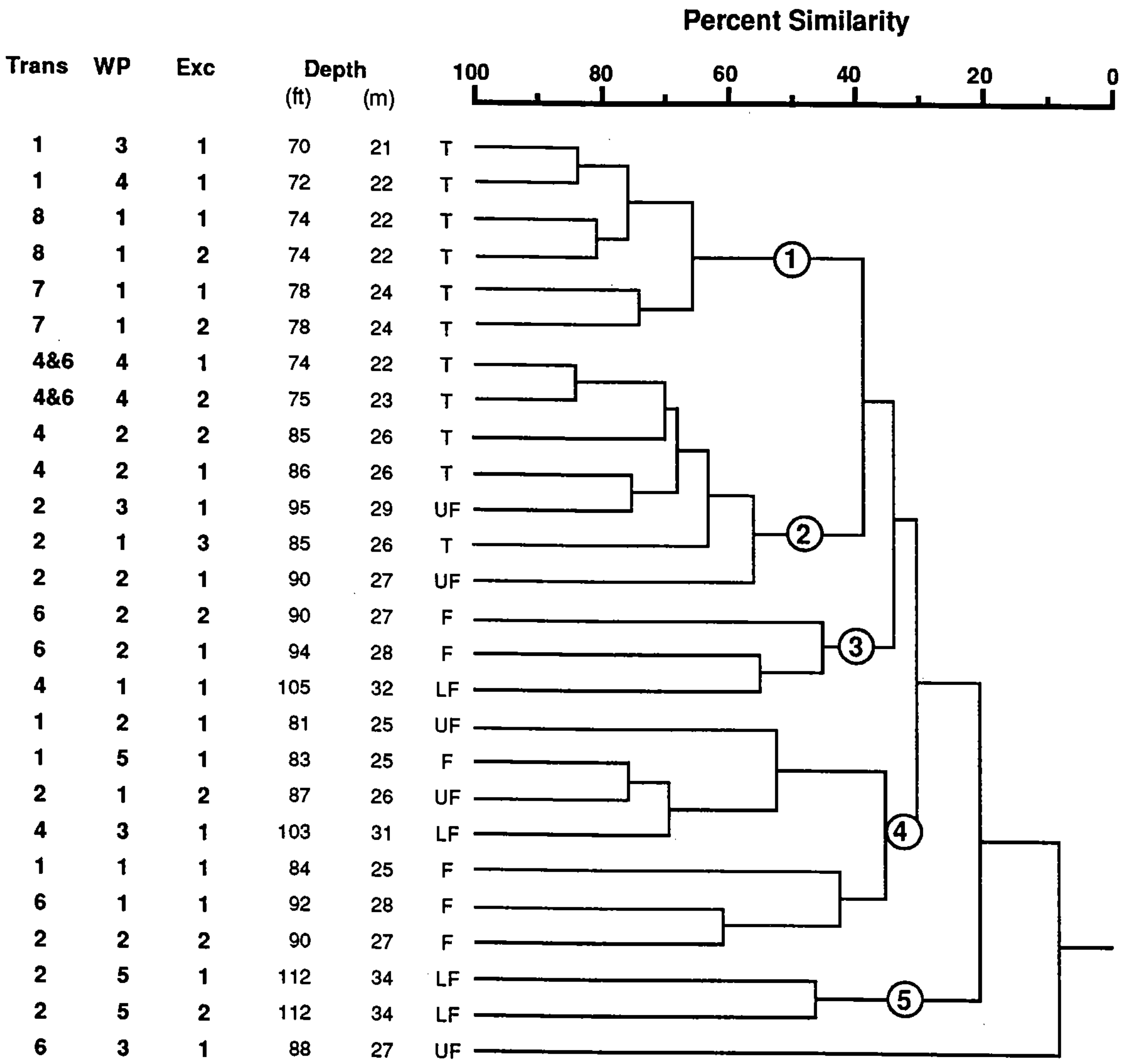
Table 8. List of taxa seen on the still photographs, arranged in order of abundance.

Taxon	Common name	Number
Algae		
Lithothamnion sp.	coralline algae	*1242
?*Asparagopsis hamifera*	filamentous red algae	**617
Rhodymenia palmata	dulse	159
Agarum cribrosm	shotgun kelp	47
Corallina officinalis	algae	12
Fauna		
Small white starfish	juvenile *Asterias*	419
Modiolus modiolus	horse mussel	242
Strongylocentrotus droebachiensis	green sea urchin	177
Orange/tan encrusting	sponge	159
Henricia sanguinolenta	blood star	108
Aplidium spp.	sea pork tunicate	87
Aplysilla sulfurea	sponge	79
White crust	encrusting organism	74
Didemnum albidum	northern white crust tunicate	70
Tautogolabrus adspersus	cunner	63
Balanus spp.	acorn barnacle	61
Crepidula plana	flat slipper limpet	56
Dendroda carnea	drop of blood tunicate	44
Asterias vulgaris	northern sea star	42
Orange encrusting	sponge	38
Gold encrusting	sponge	34
Tan encrusting	sponge	31
Gersemia rubiformis	red soft coral	25
White translucent crust	encrusting organism	24
Suberites spp.	fig sponge	18
Red crust	encrusting organism	18
Myxicola infundibulum	slime worm	18
Obelia geniculata	hydroid	16
Metridium senile	frilly anemone	13
Tonicella marmorea	mottled red chiton	12
White globular tunicate	tunicate	12
White divided (sponge?)	sponge?	11
Halocynthia pyriformis	sea peach tunicate	11
Pink fuzzy encrusting	sponge	10
Dark red/brown encrusting	sponge	10
Ciona intestinalis	sea vase tunicate	10
Orange lumpy	sponge	9
Notoacmaea testudinalis	tortoiseshell limpet	8
Ophiopholis aculeata	daisy brittle star	8
Halichondria panicea	crumb-of-bread sponge	7
Terebratulina septentrionalis	northern lamp shell	7
Myoxocephalus spp.	sculpin	7
Cerianthus borealis	northern cerianthid	5
Urticina felina	northern red anemone	5
Homarus americanus	lobster	5
Fagesia lineata	lined anemone	4
Membranipora sp.	sea lace bryozoan	4
White translucent	sponge	3
Corymorpha pendula	solitary hydroid	3
Crossaster papposus	spiny sunstar	3
Pteraster militaria	winged sea star	3
Haliclona spp.	finger sponge	2
Red/orange crust	encrusting organism	2
Dark tan translucent crust	encrusting organism	2
Coryphella sp.	red-gilled nudibranch	2
Neptunea decemcostata	ten-ridged whelk	2
Placopecten magellanicus	sea scallop	2
Cancer spp.	Jonah or rock crab	2
Macrozoarces americanus	ocean pout	2
Pale orange encrusting	sponge	1
Yellow/orange crust	encrusting organism	1
Polynoid	scale worm	1
Buccinum undatum	waved whelk	1
Ilyanassa trivittata	dog whelk	1
Lepas spp.	gooseneck barnacle	1
Psolus fabricii	scarlet holothurian	1
Porania insignis	badge star	1
?*Bugula* spp.	spiral tufted bryozoan	1
?*Crisia* spp.	bryozoan	1
Red crust bryozoan	bryozoan	1
Anarhichas lupus	wolffish	1
Cyclopterus lumpus	lumpfish	1
Hemitripterus americanus	sea raven	1
Pleuronectes americanus	winter flounder	1
Hydroids		***
Spirorbids		***

* abundance assessed from estimates of percent cover

** abundance assessed from estimates of relative abundance

*** relative abundances assessed but not used in data analysis



Trans	WP	Exc	Depth (ft)	Depth (m)	
1	3	1	70	21	T
1	4	1	72	22	T
8	1	1	74	22	T
8	1	2	74	22	T
7	1	1	78	24	T
7	1	2	78	24	T
4&6	4	1	74	22	T
4&6	4	2	75	23	T
4	2	2	85	26	T
4	2	1	86	26	T
2	3	1	95	29	UF
2	1	3	85	26	T
2	2	1	90	27	UF
6	2	2	90	27	F
6	2	1	94	28	F
4	1	1	105	32	LF
1	2	1	81	25	UF
1	5	1	83	25	F
2	1	2	87	26	UF
4	3	1	103	31	LF
1	1	1	84	25	F
6	1	1	92	28	F
2	2	2	90	27	F
2	5	1	112	34	LF
2	5	2	112	34	LF
6	3	1	88	27	UF

Figure 57. Similarity among waypoints, based on still photographs.
Trans= transect, WP= waypoint, Exc= excursion, T=drumlin top, F= drumlin flank,, UF= upper flank, LF= lower flank.

Table 9. Average abundances of taxa in the clusters defined by classification analysis. Abundances are means and standard deviations of the number of individuals per picture. Underlines highlight the most abundant taxon in each cluster.

Substrates: b=boulders, c=cobbles, o=occasional, pav=pavement, bury=buried by sediment

Cluster	**1**	**2**	**3**	**4**	**5**	**outlier**
Location on drumlin	Top	Top	Flank	Flank	Flank	Top
Substrate	b+c	b+oc	cpav+ob	cpav+ob	bury pav	pav+ob
Sediment drape	light-moderate	light-heavy	light-heavy	light-heavy	very heavy	light
Lithothamnion sp.	15.4±3.76	5.6±2.52	2.6±0.97	1.0±0.35	-	-
Asparagopsis hamifera?	1.4±2.83	9.6±3.98	0.4±0.36	-	-	-
Rhodymenia palmata	0.2±0.58	2.7±1.93	0.3±0.36	-	-	-
Agarum cribrosm	0.1±0.14	0.5±0.64	-	-	-	-
Corallina officinalis	-	0.6±0.16	-	-	-	-
Modiolus modiolus	2.1±0.93	1.8±1.49	0.6±0.43	1.2±1.90	0.0-0.2	-
Strongylocentrotus droebachiensis	1.4±0.88	1.4±1.41	0.7±0.62	0.8±0.81	-	-
Notoacmaea testudinalis	0.1±0.09	-	-	-	-	-
Dark red/brown encrusting sponge	0.2±0.22	-	-	-	-	-
Pink fuzzy sponge	0.1±0.24	-	-	-	-	-
Small white starfish	1.9±1.64	3.8±1.49	1.3±0.29	2.8±1.58	0.2-0.4	-
Aplysilla sulfurea	0.2±0.39	1.3±0.76	0.5±0.91	0.3±0.40	-	-
Tautogolabrus adspersus	0.3±0.25	0.5±0.71	0.4±0.34	0.1±0.09	-	0.1
Obelia geniculata	0.1±0.16	0.1±0.19	-	-	-	-
Myxicola infundibulum	-	0.9±1.24	0.1±0.17	-	0.3-0.4	-
Metridium senile	-	0.2±0.05	0.1±0.23	-	-	-
Orange/tan encrusting sponge	0.4±0.56	1.3±0.32	2.7±1.89	0.8±0.83	0.0-0.3	-
White encrusting organism	0.1±0.23	0.5±0.60	1.5±0.50	0.9±1.25	0.0-0.2	0.1
Dendroda carnea	0.1±0.17	0.2±0.05	1.0±0.85	-	-	-
Henricia sanguinolenta	0.3±0.11	0.8±0.93	0.7±0.54	0.3±0.39	-	-
Suberites spp.	-	0.3±0.29	0.6±0.60	-	-	-
Crepidula plana	-	-	4.2±3.54	-	-	-
Terebratulina septentrionalis	-	-	0.1±0.12	-	-	-
White globular tunicate	-	-	0.5±0.91	-	-	-
Red encrusting organism	-	-	0.6±1.04	-	-	-
White divided organism	-	-	0.7±1.27	-	-	-
Homarus americanus	-	-	0.1±0.12	-	-	-
Ophiopholis aculeata	-	-	0.3±0.29	0.1±0.25	-	-
Orange encrusting sponge	0.1±0.10	-	0.9±0.70	-	0.0-0.1	-
Gersemia rubiformis	-	0.2±0.26	0.4±0.66	0.1±0.13	-	0.1
White translucent encrusting organism	0.2±0.23	0.2±0.36	0.3±0.35	-	-	-
Tonicella marmorea	0.1±0.07	-	0.2±0.10	-	-	-
Aplidium spp.	0.5±0.58	0.5±0.29	0.8±0.57	0.7±0.80	-	-
Didemnum albidum	0.3±0.30	0.3±0.25	0.8±0.39	0.7±0.76	0.0-0.1	-
Balanus spp.	0.2±0.24	0.4±0.48	0.3±0.35	0.5±0.60	0.0-0.3	-
Gold encrusting sponge	0.1±0.24	0.4±0.53	0.2±0.21	1.0±1.40	-	-
Tan encrusting sponge	0.1±0.11	-	0.2±0.20	0.5±0.77	-	-
Cerianthus borealis	-	-	-	-	0.3-0.3	-
Asterias vulgaris	0.4±0.37	0.1±0.09	0.1±0.23	0.4±0.46	0.1-0.4	0.1
Orange lumpy sponge	0.1±0.20	-	0.1±0.25	-	-	-
Ciona intestinalis	-	0.1±0.18	0.1±0.12	-	-	-
Urticina felina	-	0.1±0.18	-	0.1±0.16	-	-
Myoxocephalus spp.	-	-	-	0.1±0.14	0.0-0.1	-
Total algae	17.1±5.66	18.8±6.85	3.4±0.63	1.0±0.27	-	-
Total fauna	9.7±3.82	16.8±4.20	21.2±0.56	11.5±5.13	1.7-1.8	0.4

Table 10. Abundances of selected taxa identified from the video tapes.
Transects and waypoints are presented in the order they clustered in the classification of the data obtained from still photographs.

Transect	8	1	1	7	4	4&6	2	2	1	2	1	6	6	1	1	2	2	4	4	2	2	6
Waypoint	1	3	4	1	2	4	1	3	2	1	1	2	1	2	5	2	4	1	3	5	5	3
Excursion	1&2	1	1	1&2	1&2	1&2	3	1	2	1&2	1	1&2	1	1	1	2	1	1	1	1-3	dif	1
Number of 5-min intervals	(8)	(4)	(1)	(9)	(7)	(8)	(2)	(2)	(3)	(4)	(1)	(3)	(2)	(2)	(3)	(1)	(1)	(2)	(3)	(9)	(1)	(4)
Location on drumlin	Top	Top	Top	Top	UF	Top	Top	UF	UF	UF	Flank	Flank	Flank	Flank	Flank	Flank	LF	LF	Flank	LF		UF
Depth (feet)	74	72	70	78	85	74	85	95	95	87	84	93	92	81	83	90	105	105	103	112	112	88
(meters)	22	22	21	24	26	22	26	29	29	26	25	28	28	25	25	27	32	32	31	34	34	27
Substrate	cp+ob	b+c	cgp+b	b+oc	c+b	b	b+oc	mix	cp+b	mix	cp+ob	cp+ob	cp+ob	cp+ob	b+c	c+ob	c+ob	c+b	cp+ob	c-bury		gc+ob
Sediment cover	m-h	c	l	vl	l-m	c-l	l-m	h(mat)	m	l-h	l	l-m	l-m	l	c-m	h	vh	m-h	l-h	l-h	vl	c-vl
Lithothamnion spp.	◩	◩■	◩	◩■	□◩	◩	▪◩	▪	▪□	▪	▪	▪		▪	▪	▪	◩	▪□	▪			
Strongylocentrotus droebachiensis	◇□	□◩	◩	□◩	▪◩	▪◩	◇	▪	□	◇□	□	◇□	□	◇	□	◇	◇	▪	□	▪		
Modiolus modiolus	▪	◇■	■	◇◩	▪◇	▪				▪			▪		▪		▪			▪		
Notoacmaea testudinalis		▪	□																			
Asparagopsis hamifera?		▪	▪	▪□	▪◩	□◩	◩	◩	□◩	▪◩	▪□	▪	▪			▪	▪					
Agarum cribrosum				▪□	◇	◩■	◇□	▪					▪									
Rhodymenia palmata					▪□	□■	▪	▪			▪						◇					
Corallina officinalis						▪□																
Obelia geniculata				▪		▪□										◇						
small white starfish	▪□	□◩	□	◩	◇□	□■	□	□	□◩	◇□	□	□	□	◇□	□	□	□	◇□	□	◇□	◇	▪
Tautogolabrus adspersus	▪	◇□	◇	□■	◇◩	◇◩	◩	◩	□	▪◇	□	□	◇□	▪◇	◇	◇	◇	◇	◇	▪		▪
white encrusting organism	◇□	▪◇		▪◇	◇□	◇	◇	□	◇	▪◇	◩	◩■	□	◇□	◇	◩	◩	□	▪	▪□		
encrusting orange tan sponge	◇	▪		▪◇		◇			□		□	□◩	□	□	□◩					▪□		
Suberites spp.	▪			▪◇	◇□	▪	◇	◇□	▪◇	▪□	□	□■	□	◇	▪	□	□	▪□	▪	◇		
Halocynthia pyriformis		▪	▪	◇□	◇	◇□	◇	◇	◇	▪◇	□	□	□	□	◇	◇	□	◇	◇□			▪
encrusting orange sponge				▪◇	▪	▪◇				▪		◇□	□			◇	◇		◇	◇		▪
Metridium senile	▪			▪	▪□	▪	◇	▪◇	◇	▪	◇	□		▪		▪		▪◇			□	
Gersemia rubiformis	▪	▪	◇	▪	▪	▪	◇	▪◇	▪◇	◇	▪	□	▪	▪	▪	◇	◇					
Henricia sanguinolenta	▪◇			▪◇	◇	◇	▪◇		▪	◇	◇	◇	◇		▪		◇	▪	◇	▪		
Aplysilla sulfurea	▪			▪	◇▪							◇	◇			▪			▪			
Asterias vulgaris	◇□	▪◇	◇	▪◇	▪	▪	◇		◇	▪□	◇		▪	◇	◇		◇		◇□	□		▪
white divided organism				▪◇	▪◇													▪□				
encrusting tan sponge	▪				◇	▪◇		◇□				▪	▪			◇	□	◇				▪
Urticina felina	▪		▪	▪	▪			▪	▪	▪			◇	▪	◇							
Balanus sp.		▪◇	▪	▪	▪	▪					▪		◇	▪◇	◇				▪	◇		
Myoxocephalus spp.	▪	▪	▪		▪		▪			▪	▪			▪◇	▪	▪	◇			▪		▪
Pleuronectes americanus	▪					▪				▪								▪	▪	▪		
Cerianthus borealis						▪														▪◇		
hydroids	▪	▪□	▪□	▪□	▪◩	◩	▪	▪□	□	▪	▪□	▪◩	▪◩	▪	□	▪	□	▪	▪	▪	◩	
barnacle/spirorbid complex	▪□	▪		▪	▪□	▪				▪◩	□	◇		▪□	□		◩	▪	▪□	▪		□

▪ =rare ◇=few □=common ◩=abundant ■=very abundant; b=boulder c=cobble g=gravel p=pavement o=occassional; c=clean vl=very light l=light m=moderate h=heavy

The six areas in the first cluster were located on the tops of drumlins furthest from the diffuser. These areas clustered together at a 65 percent level of taxonomic similarity. The substratum in these areas consisted of cobbles and boulders. Boulders were dominant in three of the areas and cobbles were dominant in the remaining three. The areas characterized by boulders had a very light sediment dusting, while those characterized by cobbles had a more substantial sediment drape. The local relief of the areas in this cluster tended to be lower than in the areas nearer the outfall. The benthic communities in all six areas were dominated by the coralline alga *Lithothamnion.* The dominant invertebrates inhabiting these areas were horse mussels, juvenile *Asterias*, and green sea urchins. Additionally, these areas supported a number of encrusting organisms, such as sea pork and the orange-tan encrusting sponge. Algal abundances were high (17.1±5.66 individuals per photograph) in these areas and faunal abundances were moderate (9.7±3.82 individuals per photograph). Abundances of both were highest on transect T7 and lowest on transect T8. The two areas on transect T7 had the highest relief in this cluster and were the most taxonomically similar to the drumlin top areas in cluster 2.

The video tape analysis of sites grouping in cluster 1 included drumlin tops on transects T1 (waypoints 3 and 4), T7, and T8. Transects T1 and T7 are located north of the diffuser, T7 being one of the "reference" sites at a slightly greater distance from the diffuser, close to the historical hardbottom station E1 (Etter *et al.*, 1987). Transect T8 is the southern reference site, close to the historical stations G2 and G5 (Etter *et al.*, 1987). Water depths were about 21 to 24 m (70 to 78 ft). The substratum ranged from predominantly boulders to mixed boulders and cobbles to a cobble and gravel pavement. A sediment drape was absent to very light at T1 and T7, but moderate to heavy and mixed with shell hash at T8. At all transects included in cluster 1, nearly the entire available surface area at was covered with coralline algae (*Lithothamnion*), while filamentous algae (*?Asparagopsis hamifera*) and sessile animals were all rare or common in a few places where they were patchily distributed, such as an area of relatively abundant hydroids on T7. Small white starfish and green sea urchins (*Strongylocentrotus droebachiensis*) were the most widespread motile animals; T1 was also characterized by moderate abundances of horse mussels (*Modiolus modiolus*) and the tortoiseshell limpet *Notoacmaea testudinalis* at waypoint 4. High abundances of cunner (*Tautogolabrus adspersus*) were seen among the boulders at T7, and the small barnacle/spirorbid complex was relatively abundant on the cobbles at T8.

Five of the seven still photo areas in the second cluster were located on drumlin tops nearer the diffuser, while the remaining two were located on upper flanks. These areas clustered together at a taxonomic similarity of 55 percent. The substratum in most of the areas within this cluster had high relief and consisted mainly of boulders with only occasional cobbles. Sediment drape ranged from a light to moderate dusting in the drumlin top areas to heavy mats in the flank areas. The benthic communities in all seven of these areas were dominated by filamentous red algae, ?*Asparagopsis hamifera.* These areas also supported moderate abundances of *Lithothamnion* and lower abundances of three other algae, the dulse *Rhodymenia palmata*, the shotgun kelp *Agarum cribrosum*, and *Corallina officinalis*. Some of these areas, particularly the intersection of transects T4 and T6, resembled a coral reef in terms of lush algal growth and numerous encrusting organisms. The dominant invertebrates inhabiting the areas in this cluster were similar to those seen in cluster 1, namely juvenile *Asterias*, horse mussels, and green sea urchins. Numerous other encrusting and attached organisms were also seen on the boulders, including the blood star *Henricia sanguinolenta* and the encrusting yellow sponge *Aplysilla sulfurea*. The areas in this cluster also supported the highest abundances of fish, namely the cunner *Tautogolabrus adspersus*. Both algal (18.8±6.85 individuals per photograph) and faunal (16.8±4.20 individuals per photograph) abundances were high within this cluster.

Video footage taken at waypoints in this cluster included drumlin tops and upper flanks at depths between 22 and 29 m (74 to 95 ft) on transects T2 to the north of the diffuser (waypoints 1 and 3), T4 (waypoint 2), and the intersection of T4 and T6 (south of the diffuser). The substratum ranged from clean boulders (Intersection T4/T6) to a heterogeneous mixture of cobbles and boulders covered with a light sediment dusting to a heavy drape. The algal cover was patchy and heterogeneous, with both *Lithothamnion* and *?Asparagopsis* present in varying abundances. Other algae, such as dulse (*Rhodymenia palmata*) and shotgun kelp (*Agarum cribrosum*), were quite abundant in some areas. In contrast to the drumlin tops grouped in cluster 1, those in cluster 2 were also colonized by hydroids in moderate abundances. Other fairly widespread attached epifauna included the fig sponge *Suberites* sp. and anemones (*Metridium senile*). Sea urchins, cunner, and small white starfish were the most abundant and widespread motile animals. Generally, there was a rich , although not abundant, echinoderm fauna present at sites in this cluster; species seen included *Crossaster papposus*, *Porania insignis*, and *Pteraster militaria* along with the more widespread *Henricia sanguinolenta* and *Asterias vulgaris*.

The three still photo areas in cluster 3 were located on the flank of the drumlin immediately south of the diffuser. The substratum in all three areas consisted of a cobble pavement interrupted by occasional boulders. Sediment drape was variable ranging from light to moderate on the shallower flank (transect T6) to heavy on the lower flank (transect T4). Relatively few algae were seen in these areas (3.4±0.63 individuals per photograph). The benthic communities in these areas were dominated by of a diverse group of encrusting, attached, and mobile invertebrates. These included the flat slipper limpet *Crepidula plana*, the orange-tan encrusting sponge, an unidentified white encrusting organism, juvenile *Asterias*, and the drop of blood tunicate *Dendrodoa carnea*. The encrusting tunicates *Aplidium* spp. and *Didemnum albidum* were also common in these areas. Faunal abundances were uniformly high (21.2±0.56 individuals per photograph) within this cluster.

Video footage from the sites grouped in cluster 3 was from drumlin flanks along transects T4 (waypoint 1) and T6 (waypoint 2) at depths between 28 and 32 m (93 to 105 ft). The substratum consisted of cobbles, boulders, some shell hash, and a light to heavy sediment drape. Most likely due to depth, algal growth was sparse in comparison to clusters 1 and 2, whereas some of the encrusting and attached epifauna was quite abundant, especially on T6. The fig sponge *Suberites* and a number of white, orange, and orange tan encrusting organisms, the soft coral *Gersemia rubiformis*, and the sea peach *Halocynthia pyriformis* were seen in fairly high abundances.

The seven still photo areas in cluster 4 were all located on the flanks of drumlins. The dominant substratum in these areas consisted of a cobble pavement interspersed with occasional boulders. Sediment cover ranged from a light dusting to a heavy drape. The few algae seen were *Lithothamnion*. The benthic communities in these areas were dominated by juvenile *Asterias*. Some encrusting organisms were also seen. Horse mussels were only seen in two of the areas (transect T6 waypoint 1 and transect T2 waypoint 2). The areas in this cluster supported moderate faunal abundances (11.5±5.13 individuals per photograph) and very low algal abundances (1.0±0.27 individuals per photograph).

Video tapes from sites joined in this cluster was from drumlin flanks on transects T1 (waypoints 1, 2, and 5), T2 (waypoints 1 and 2), T4 (waypoint 3), and T6 (waypoint 1) at depths between 25 and 31 m (81 to 103 ft). The sites had a mixed substratum, with cobbles, often arranged in a pavement, more or less abundant boulders, sometimes some gravel and shell hash, and a light to heavy sediment cover. Overall, algae covered markedly less space than sessile animals. Their abundance ranged from few to common, the most abundant taxon being *?Asparagopsis hamifera*; few *Lithothamnion* and *Rhodymenia* were present, and shotgun kelp, *Agarum cribrosum* was absent in some areas and common in others. Encrusting and attached fauna was common to abundant, with the most widespread taxa being hydroids, *Suberites* sp., and white encrusting organisms (probably a mixture of sponge(s) and the Northern white crust, *Didemnum albidum*, a tunicate). Orange tan encrusting organisms (sponge, tunicate, and/or bryozoan) and sea peaches were common as well. A variety of other encrusting organisms, some of which could be identified as sponges, was present throughout in low numbers. Small barnacles and/or spirorbid polychaetes were patchily distributed. The most abundant motile animals were unidentified small starfish, most likely juvenile *Asterias*, adult *Asterias vulgaris*, the sea urchin *Strongylocentrotus droebachiensis*, and cunner.

The two still photo areas in cluster 5 were located on the lower flank of a drumlin at the eastern end of the diffuser corridor (transect T2 waypoint 5). The substratum in this area consisted of a cobble pavement mostly buried by sediment. The sparse fauna in this area was dominated by the burrowing anemone *Cerianthus borealis* and the slime worm *Myxicola infundibulum* that is frequently associated with the tube of cerianthids. Several crabs (*Cancer* spp.), solitary stalked hydroids (*Corymorpha pendula*), and sculpin (*Myoxocephalus* spp.) were also seen in this area. Due to the paucity of suitable hard attachment sites, no algae and very few encrusting organisms were seen. Faunal abundances were uniformly low (1.7-1.8 individuals per photograph) in this sediment area.

Video footage was obtained from the same waypoint at a depth of about 34 m (112 ft). The substratum consisted of cobbles with a heavy sediment drape and half-buried boulders; some man-made debris was seen, including a soda can and several pieces of metal pipe. Algae were absent from this area, and the fauna was sparse. Hydroids ranged from rare to common, and encrusting white and orange tan organisms from absent to common. The most abundant motile animals were small white starfish and *Asterias*, both ranging from few in number to common in some places.

The one outlier area was located on a drumlin top at the eastern end of transect T6 (waypoint 3). The substratum in this area consisted of a gravel and cobble pavement with only occasional small boulders, and had a light sediment dusting. This area was very impoverished in that only a few organisms (0.4 individuals per photograph), and no algae were seen. Possible reasons for the paucity of fauna and algae at this location were not readily apparent.

The video footage from this outlier region showed much of the same environment as the still photos. The water depth was about 27 m (88 ft). The substratum consisted of gravel and cobbles with occasional boulders that had no or very little sediment drape. Algae were absent, and the epifauna was extremely depauperate. Only small barnacles/spirorbids were common throughout, and the only motile animals were a starfish and a cunner.

The result of the ordination analysis (still photos) of locations is shown in Figure 58. Divisions between groups of areas were not as pronounced as was indicated by the cluster dendrogram. However, areas dominated by algae (drumlin tops, clusters 1 and 2) did separate clearly from areas dominated by invertebrates (drumlin flanks, clusters 3, 4 and 5). Drumlin tops had low values on the first axis and drumlin flanks had higher values. Algae and the green sea urchin had low values on this axis, while juvenile *Asterias*, horse mussels, most encrusting taxa, and cunner had higher values. *Cerianthus borealis*, *Crepidula plana*, adult *Asterias vulgaris*, and sculpins (*Myoxocephalus* spp.) had the highest values on this axis. The drumlin tops further separated along the other two axes. Lower relief areas dominated by *Lithothamnion* (cluster 1) had high values on axis 2 and low values on axis 3, while higher

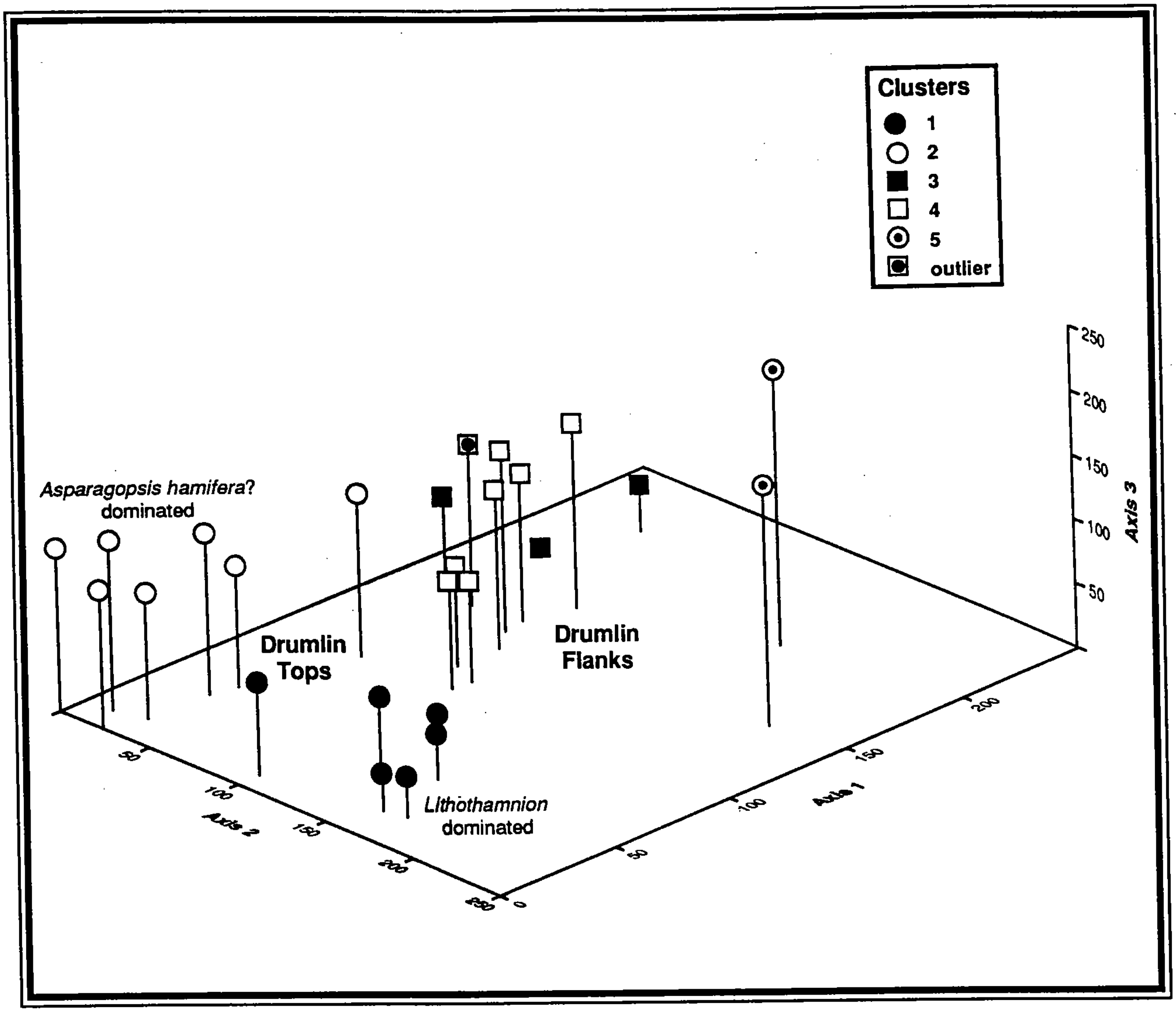


Figure 58. Station ordination. Cluster groups refer to dendrogram in Figure 57.

relief areas dominated by ?*Asparagopsis hamifera* (cluster 2) had low values on axis 2 and higher values on axis 3. The two sediment areas near the outfall (cluster 5) had high values on all three axes. These areas were inhabited by *Cerianthus borealis*, *Myxicola infundibulum*, and sculpin which also had high values on all three axes.

3.4 Benthic Softbottom Communities and Sedimentology, Farfield

3.4.1 Distribution of Sediment Types

In Massachusetts Bay, there is a general trend toward finer sediments offshore (Figure 59, Appendix B18). Stations FF4 in Stellwagen Basin and FF11 off Cape Ann had the finest sediments with less than 20% sand and a mean phi of 6.08 to 6.96, followed by coarser sediments at stations FF1a, FF14, and FF5 north to south (24 - 67% sand, mean phi 4.11 to 5.58). Among the stations away from the mid/nearfield area, FF9 had the sandiest sediments (more than 80% sand, mean phi 3.36). The remaining Farfield stations in Massachusetts Bay are located in the midfield area, with generally sandy sediments (more than 60% sand, mean phi 3.79 to 4.30). The two Cape Cod Bay stations, FF6 and FF7, had very fine sediments with less than 20% sand and a mean phi of 6.33 to 6.74.

3.4.2 Total Organic Carbon

The inventories of organic carbon in the sediments throughout the farfield are closely related to sediment grain size ($R^2=0.921$) and ranged from 0.33% to 2.31% (Figure 60, Appendix B19). Station FF9 with the lowest TOC (0.33%) had the sandiest sediments (83.9%); the other five stations with less than 1% TOC, including two of the three midfield stations (FF10 and 12) and the nearshore station FF1a off Gloucester, also were sandy, with sediments containing 43 to 66% sand. Sediments at stations that contained more than 1% TOC were all relatively high in clay (15 to 35%). The two stations with more than 2% TOC (FF4 in Massachusetts Bay and FF7 in Cape Cod Bay) had sediments that were very high in clay (34.9 and 26.2%) and contained very low amounts of sand (2.4 and 1.4%). The relationship between TOC and mean phi was very clear. Stations FF9 and FF10 with 0.5% or less TOC had the lowest mean phi values (3.36 and 3.79, i.e., very fine sand) and probably represent higher kinetic energy environments where labile organic matter is washed from the sediments. Stations FF4 and FF7 with more than 2.2% TOC had the highest mean phi values (6.74 and 6.96, i.e., medium silt), a relationship expected in low kinetic energy, depositional environments.

3.4.3 Clostridium Spores

The densities of *Clostridium* spores (colony forming units per gram dry weight) found at the Farfield stations varied from 500 to more than 17,000 (Appendix B20). The two stations with low spore densities (<1000) included the station with the highest percentage of sand (FF9 in Stellwagen Basin, 83.9%) and the station with the lowest percentage of sand (FF7 in Cape Cod Bay, 1.4%); thus, there was no clear correlation between sediment composition and *Clostridium* spore density in the farfield as was seen in the near- and midfield. The highest concentration of spores (mean = 17,000) was found in the midfield at station FF13 off Hull. The remaining eight Farfield stations had *Clostridium* densities ranging from 1000 to 5600 spores per gdw.

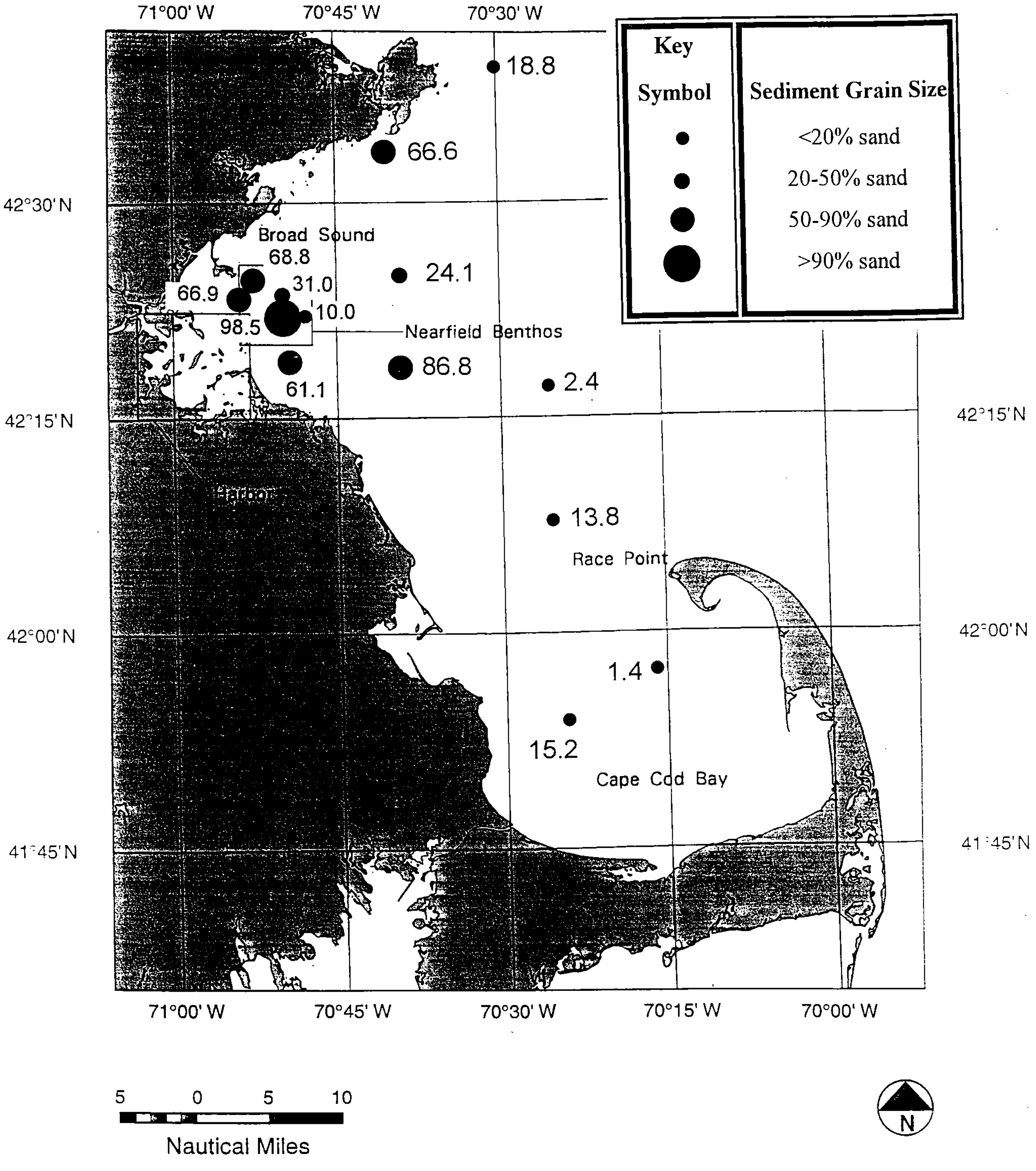


Figure 59. Sediment grain size, expressed as percent sand, farfield and replicated nearfield stations, 1995.

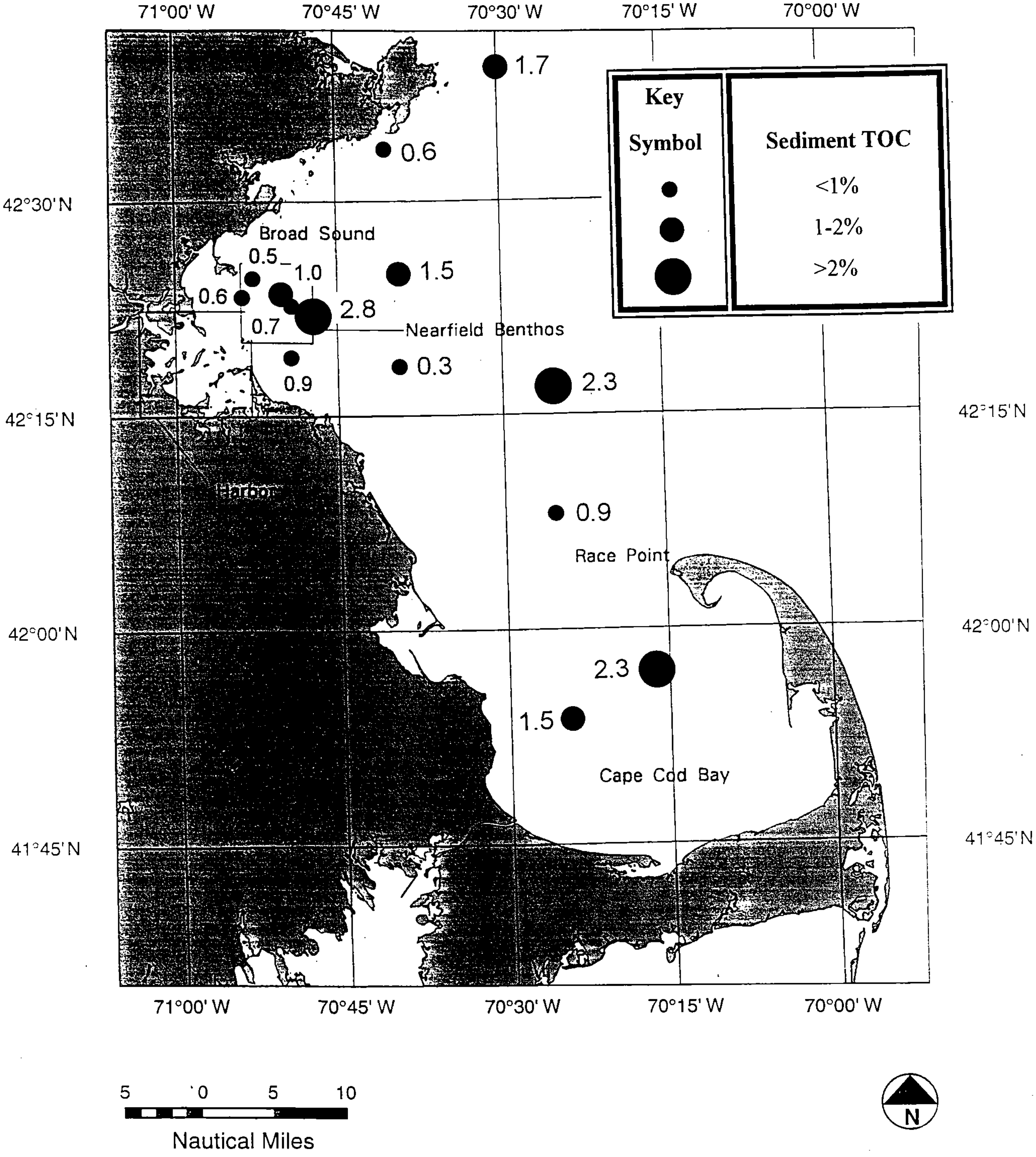


Figure 60. Organic carbon concentrations, farfield and replicated nearfield stations, 1995.

3.4.4 Benthic Infauna

Distribution and Density of Dominant Species

The most common species in the farfield were the same as in the nearfield, with *Mediomastus californiensis* present among the dominants at all farfield stations, ranking second or third at most stations. *Prionospio steenstrupi* ranked first at all Massachusetts Bay stations, but was not among the dominants or ranking low at the two Cape Cod Bay stations (FF6 and FF7); *Spio limicola* was among the dominants at eight stations. The suite of species present among the dominants in the farfield includes 26 additional polychaetes, 2 oligochaetes, 1 amphipod, 3 bivalves, 1 scaphopod, and 1 nemertean.

Densities of the two spionid polychaetes were very high at most stations in Massachusetts Bay (Figure 61), with peak densities of *P. steenstrupi* and *S. limicola* combined ranging from nearly 48,000 individuals m^{-2} at Station FF1a to 51,000 individuals m^{-2} at Station FF9. At Stations FF10 and FF12, both located in the midfield, spionid densities ranged from 13,700 to 15,700 individuals m^{-2} and were similar to spionid densities at neighboring midfield stations (NF5 and NF20). *Mediomastus californiensis* occurred in the highest densities at the midfield stations just outside the Harbor (FF10, 12, and 13) and in Cape Cod Bay (FF6 and FF7); densities ranged from 2800 to 4100 individuals m^{-2} in Cape Cod Bay and from 3800 to almost 9000 individuals m^{-2} in Massachusetts Bay (Figure 62).

Three species of paraonids were among the dominants of all stations in different combinations of *Aricidea catherinae*, *A. quadrilobata*, and *Levinsenia gracilis*; while the latter was present at all but two stations throughout the Farfield area, *Aricidea catherinae* was replaced by its congener *A. quadrilobata* at offshore stations (Figure 63). The highest densities of all three paraonids combined, ranging from about 2600 to 3100 individuals m^{-2}, were present at a band of stations between Cape Ann and western Cape Cod Bay (FF11, 14, 5, and 6 north to south). Cirratulids, an important faunal element in the near- and midfield area, were less important in the offshore farfield stations, but occurred in densities comparable to other midfield stations at stations FF10 and FF12; *Tharyx acutus* was found at a density of more than 11,000 individuals m^{-2} at Station FF12. At the offshore stations, *Chaetozone setosa* replaced *T. acutus*, but never reached comparable densities, the highest value being about 2200 individuals m^{-2} at Station FF4 in Stellwagen Basin. *Chaetozone setosa* was absent from the Cape Cod Bay stations (Figure 64).

Tubificid oligochaetes were not very common in the farfield, but did rank second at Stations FF7 (eastern Cape Cod Bay) and FF11 (off Cape Ann) with densities of 2000 to 4500 individuals m^{-2}. The amphipod *Ampelisca abdita* was among the dominants at one station, but was not very abundant; the same was true for three bivalve species, scaphopods, and a nemertean species that each contributed relatively few specimens to the dominant fauna at one or two stations.

The ten most abundant species at each Farfield station are listed in Table 11. Polychaetes contributed more than 90% of all individuals to the dominant fauna at all but two stations (FF4 in Stellwagen Basin and FF7 in Cape Cod Bay), and most of the non-polychaetes were oligochaetes, contributing up to 25% of the individuals to the dominant fauna. The two stations in Stellwagen Basin (FF4 and FF5) showed the greatest variety in the dominant fauna, including several mollusks and a nemertean. All ten dominant species constituted between 63 and 85% of all individuals at any one station.

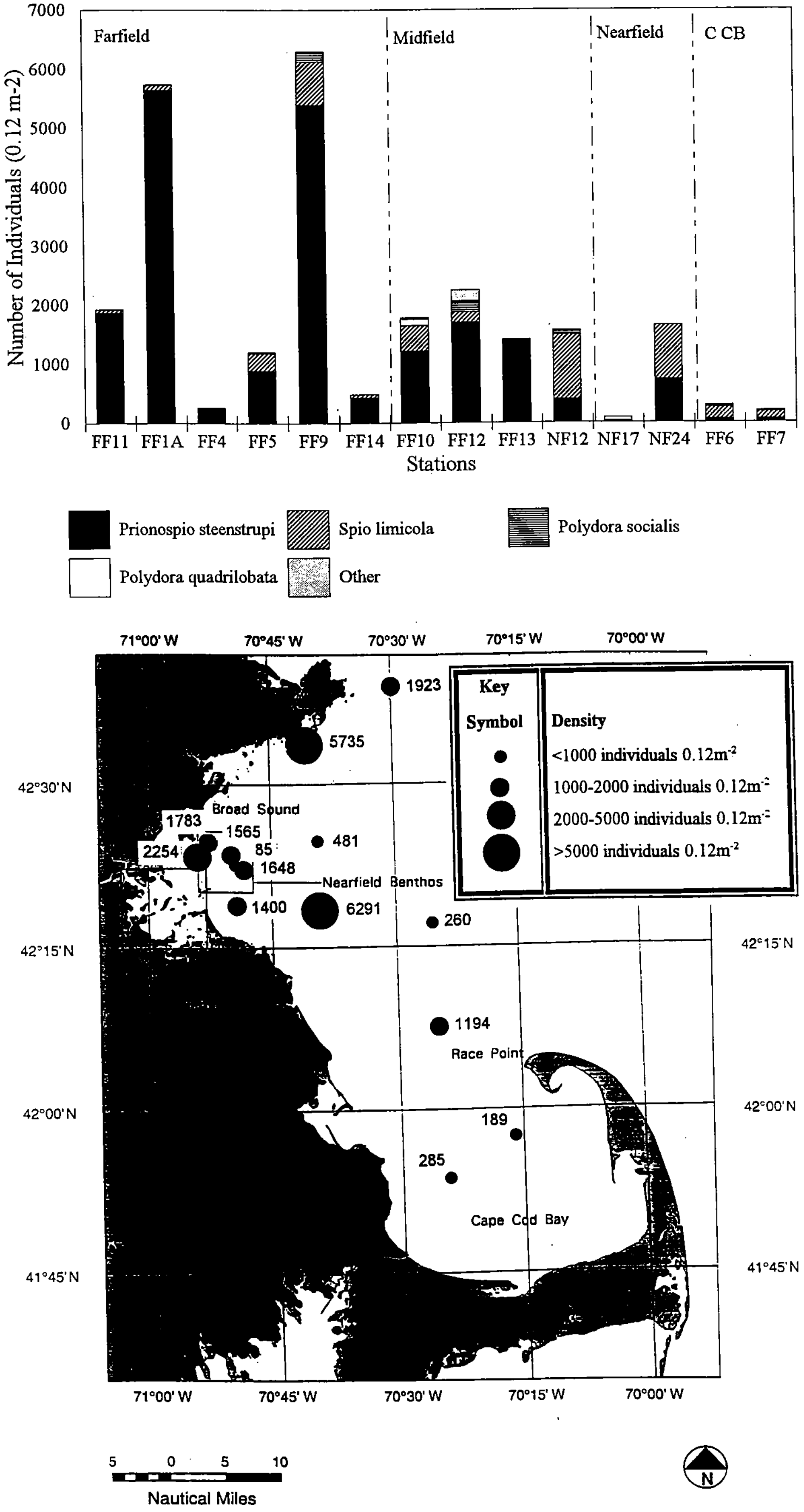


Figure 61. Spionid densities, farfield and replicated nearfield stations, 1995. Bar graph broken down by species; CCB = Cape Cod Bay.

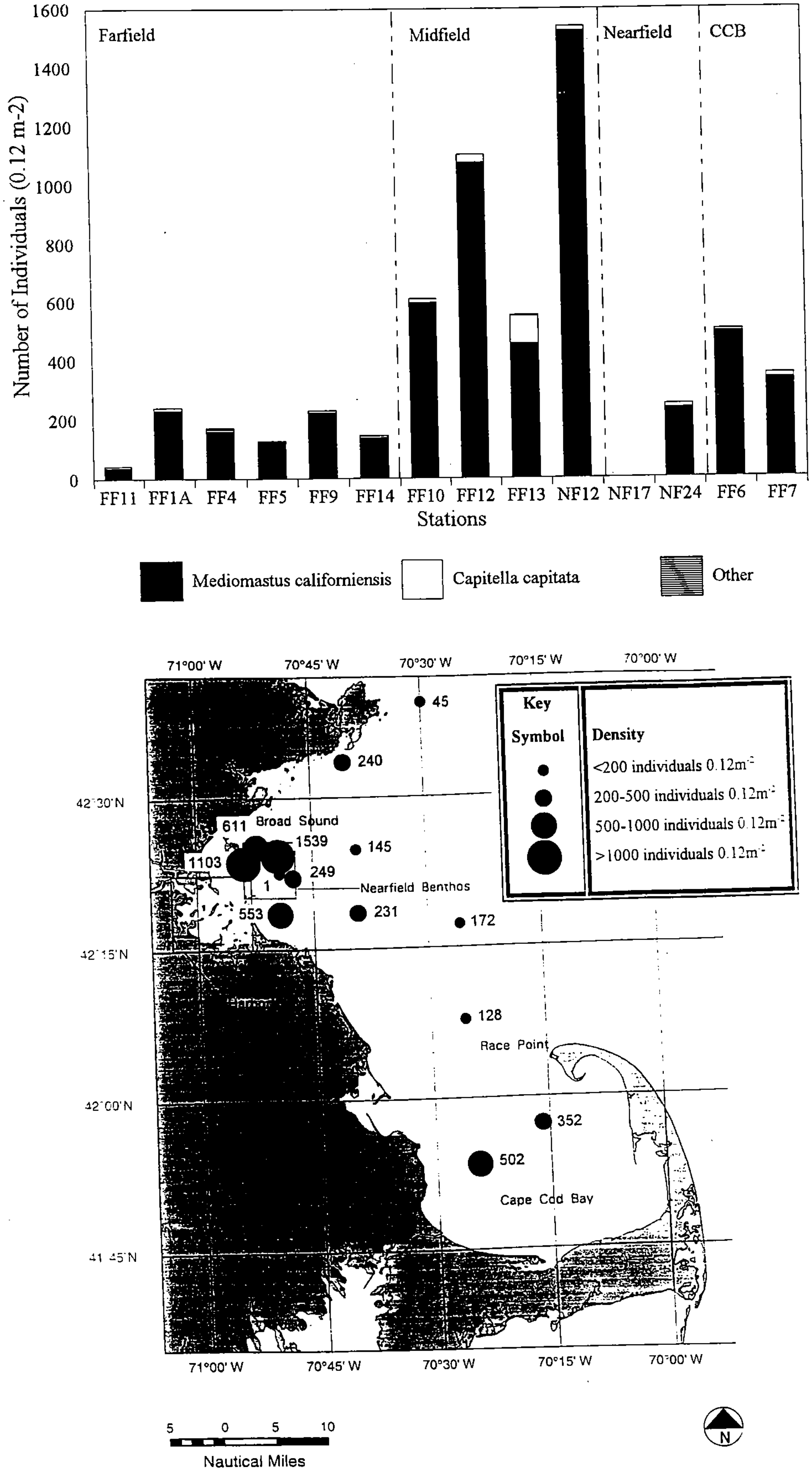


Figure 62. Capitellid densities, farfield and replicated nearfield stations, 1995. Bar graph broken down by species; CCB= Cape Cod Bay.

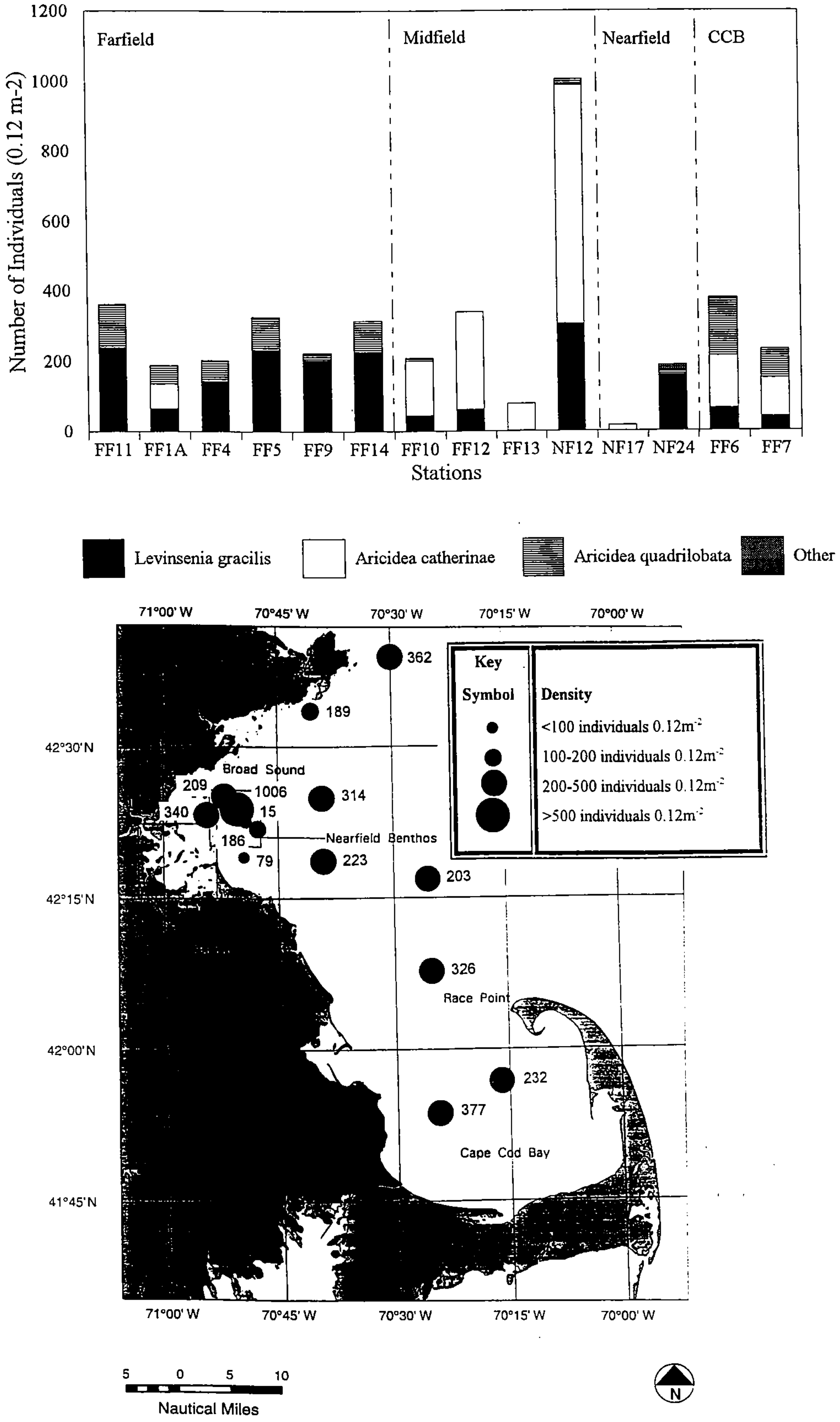


Figure 63. Paraonid densities, farfield and replicated nearfield stations, 1995. Bar graph broken down by species; CCB= Cape Cod Bay.

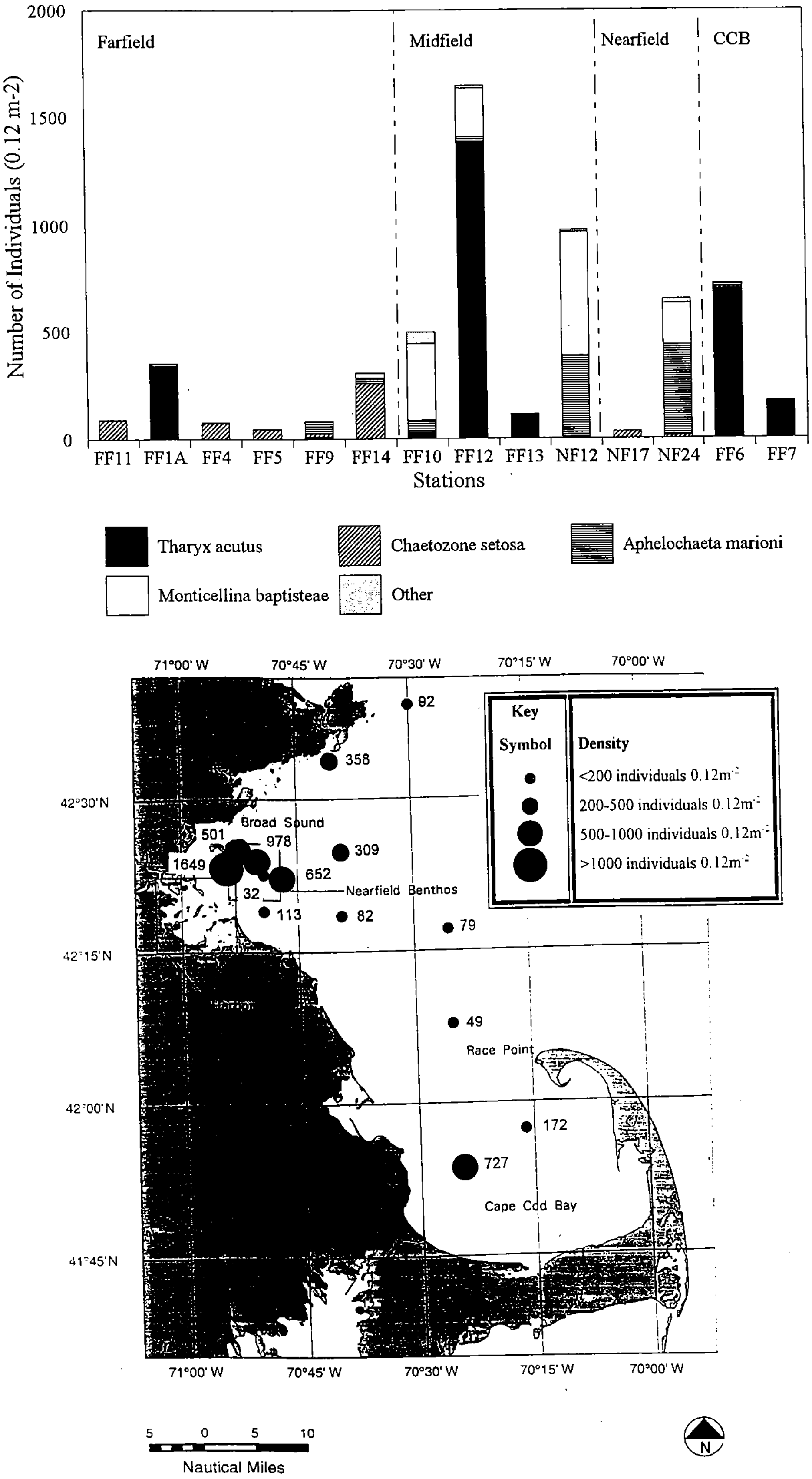


Figure 64. Cirratulid densities, farfield and replicated nearfield stations, 1995. Bar graph broken down by species; CCB= Cape Cod Bay.

Table 11. Dominant species at Farfield stations, August 1995.

Station FF1a - off Gloucester

Rank	Species	Percent of Total Fauna	Density (Ind. 0.12m^{-2})
1	*Prionospio steenstrupi* (polychaete)	66.18	5643
2	*Tharyx acutus* (polychaete)	4.07	347
3	*Mediomastus californiensis* (polychaete)	2.71	231
4	*Nucula delphinodonta* (bivalve)	2.24	191
5	*Ninoe nigripes* (polychaete)	1.71	146
6	*Owenia fusiformis* (polychaete)	1.59	136
7	*Thyasira flexuosa* (bivalve)	1.06	90
8	*Spio limicola* (polychaete)	1.00	85
9	*Aricidea catherinae* (polychaete)	0.94	80
10	*Praxillella praetermissa* (polychaete)	0.86	73
	Total - 10 Taxa	82.35	7022
	Remaining Fauna - 116 Taxa	17.65	1505
	Total Fauna - Taxa	100.00	8527

Station FF4 - Stellwagen Basin

Rank	Species	Percent of Total Fauna	Density (Ind. 0.12m^{-2})
1	*Prionospio steenstrupi* (polychaete)	19.79	248
2	*Mediomastus californiensis* (polychaete)	12.53	157
3	*Levinsenia gracilis* (polychaete)	11.41	143
4	*Cossura longocirrata* (polychaete)	7.10	89
5	*Chaetozone setosa* (polychaete)	6.07	76
6	*Aricidea quadrilobata* (polychaete)	4.79	60
7	Scaphopoda (scaphopod)	3.27	41
8	*Tubificoides apectinatus* (oligochaete)	2.71	34
9	*Syllides longocirrata* (polychaete)	2.15	27
10	Nemertea sp. 5 (nemertean)	1.92	24
	Total - 10 Taxa	71.75	899
	Remaining Fauna - 61 Taxa	28.25	354
	Total Fauna - 71 Taxa	100.00	1253

Table 11 (Continued)

Station FF5 - Stellwagen Basin

Rank	Species	Percent of Total Fauna	Density (Ind. $0.12m^{-2}$)
1	*Prionospio steenstrupi* (polychaete)	31.95	884
2	*Spio limicola* (polychaete)	10.59	293
3	*Levinsenia gracil*is (polychaete)	8.31	230
4	*Mediomastus californiensis* (polychaete)	4.45	123
5	*Scalibregma inflatum* (polychaete)	3.47	96
5	*Aricidea quadrilobata* (polychaete)	3.47	96
7	*Thyasira flexuosa* (bivalve)	2.60	72
8	*Ninoe nigripe*s (polychaete)	2.20	61
9	Nemertea sp. 5 (nemertean)	2.02	56
10	*Chaetozone setosa* (polychaete)	1.63	45
	Total - 10 Taxa	70.69	1956
	Remaining Fauna - 95 Taxa	29.31	811
	Total Fauna - 105 Taxa	100.00	2767

Station FF6 - Cape Cod Bay

Rank	Species	Percent of Total Fauna	Density (Ind. $0.12m^{-2}$)
1	*Tharyx acutus* (polychaete)	17.85	700
2	*Mediomastus cali*forniensis (polychaete)	12.62	495
3	*Cossura longoci*rrata (polychaete)	11.73	460
4	*Spio limicol*a (polychaete)	4.84	190
5	*Ninoe nigripes* (polychaete)	4.18	164
6	*Aricidea quadrilobata* (polychaete)	4.13	162
7	*Aricidea catherinae* (polychaete)	3.82	150
8	*Apistobranchus typi*cus (polychaete)	2.47	97
9	*Euchone incolor* (polychaete)	2.24	88
10	Tubificidae sp. 2 (oligochaete)	1.99	78
	Total - 10 Taxa	65.88	2584
	Remaining Fauna - 86 Taxa	34.12	1338
	Total Fauna - 96 Taxa	100.00	3922

Table 11 (Continued)

Station FF7 - Cape Cod Bay			
Rank	**Species**	**Percent of Total Fauna**	**Density (Ind. 0.12m^{-2})**
1	*Cossura longocirrata* (polychaete)	19.71	562
2	Tubificidae sp. 2 (oligochaete)	19.01	542
3	*Mediomastus californiensis* (polychaete)	11.79	336
4	*Tharyx acutus* (polychaete)	5.89	168
5	*Spio limicola* (polychaete)	4.28	122
6	*Aricidea catherinae* (polychaete)	3.82	109
7	*Apistobranchus typicus* (polychaete)	3.65	104
8	*Aricidea quadrilobata* (polychaete)	2.95	84
9	*Ninoe nigripes* (polychaete)	2.88	82
10	*Prionospio steenstrupi* (polychaete)	1.96	56
	Total - 10 Taxa	75.94	2165
	Remaining Fauna - 76 Taxa	24.06	686
	Total Fauna - 86 Taxa	100.00	2851

Station FF9 - western Massachusetts Bay			
Rank	**Species**	**Percent of Total Fauna**	**Density (Ind. 0.12m^{-2})**
1	*Prionospio steenstrupi* (polychaete)	63.67	5393
2	*Spio limicola* (polychaete)	8.62	730
3	*Mediomastus californiensis*(polychaete)	2.64	224
4	*Levinsenia gracilis* (polychaete)	2.40	203
5	*Polydora socialis* (polychaete)	1.92	163
6	*Exogone verugera* (polychaete)	1.89	160
7	*Cerastoderma pinnulatum* (bivalve)	1.78	151
8	*Aphelochaeta marioni* (polychaete)	0.70	59
8	*Pholoe minuta* (polychaete)	0.70	59
10	*Ninoe nigripes* (polychaete)	0.67	57
	Total - 10 Taxa	84.99	7199
	Remaining Fauna - 121 Taxa	15.01	1271
	Total Fauna - 131 Taxa	100.00	8470

Table 11 (Continued)

Station FF10 - off Nahant (midfield)			
Rank	**Species**	**Percent of Total Fauna**	**Density (Ind. 0.12m^{-2})**
1	*Prionospio steenstrupi* (polychaete)	20.68	1216
2	*Mediomastus californiensis*(polychaete)	10.17	598
3	*Spio limicola* (polychaete)	7.21	424
4	*Monticellina baptisteae* (polychaete)	6.11	359
5	*Nucula delphinodonta* (bivalve)	5.97	351
6	*Ninoe nigripes* (polychaete)	3.27	192
7	*Exogone verugera* (polychaete)	3.21	189
8	*Aricidea catherinae* (polychaete)	2.65	156
9	*Polydora quadrilobata* (polychaete)	1.77	104
10	*Leitoscoloplos acutus* (polychaete)	1.55	91
	Total - 10 Taxa	62.59	3680
	Remaining Fauna - 124 Taxa	37.41	2199
	Total Fauna - Taxa	100.00	5879

Station FF11 - Cape Ann			
Rank	**Species**	**Percent of Total Fauna**	**Density (Ind. 0.12m^{-2})**
1	*Prionospio steenstrupi* (polychaete)	57.51	1869
2	*Tubificoides apectinatus* (oligochaete)	7.38	240
3	*Levinsenia gracilis* (polychaete)	7.26	236
4	*Aricidea quadrilobata* (polychaete)	3.88	126
5	*Chaetozone setosa* (polychaete)	2.71	88
6	*Euchone incolor* (polychaete)	1.57	51
7	*Spio limicola* (polychaete)	1.51	49
8	*Leitoscoloplos acutus* (polychaete)	1.14	37
8	*Cossura longocirrata* (polychaete)	1.14	37
10	*Mediomastus californiensis* (polychaete)	1.11	36
	Total - 10 Taxa	85.20	2769
	Remaining Fauna - 76 Taxa	14.80	481
	Total Fauna - 86 Taxa	100.00	3250

Table 11 (Continued)

Station FF12 - off Nahant (midfield)			
Rank	**Species**	**Percent of Total Fauna**	**Density (Ind. 0.12m^{-2})**
1	*Prionospio steenstrupi* (polychaete)	22.41	1703
2	*Tharyx acutus* (polychaete)	18.25	1387
3	*Mediomastus californiensis* (polychaete)	14.19	1078
4	*Owenia fusiformis* (polychaete)	8.02	609
5	*Aricidea catherinae* (polychaete)	3.66	278
6	*Monticellina baptisteae* (polychaete)	3.00	228
7	*Scoletoma hebes* (polychaete)	2.99	227
8	*Leitoscoloplos acutus* (polychaete)	2.86	217
9	*Spiophanes bombyx* (polychaete)	2.45	186
10	*Spio limicola* (polychaete)	2.34	178
	Total - 10 Taxa	80.17	6091
	Remaining Fauna - 97 Taxa	29.83	1507
	Total Fauna - 107 Taxa	100.00	7598

Station FF13 - off Hull (midfield)			
Rank	**Species**	**Percent of Total Fauna**	**Density (Ind. 0.12m^{-2})**
1	*Prionospio steenstrupi* (polychaete)	41.98	1377
2	*Mediomastus californiensis* (polychaete)	13.93	457
3	*Nephtys cornuta* (polychaete)	10.46	343
4	Tubificidae sp. 2 (oligochaete)	3.57	117
5	*Tharyx acutus* (polychaete)	3.29	108
6	*Capitella capitata* complex (polychaete)	2.84	93
7	*Leitoscoloplos acutus* (polychaete)	2.47	81
8	*Aricidea catherinae* (polychaete)	2.38	78
9	*Ampelisca abdita* (amphipod)	1.83	60
10	*Phyllodoce mucosa* (polychaete)	1.59	52
	Total - 10 Taxa	84.33	2766
	Remaining Fauna - 72 Taxa	15.67	514
	Total Fauna - 82 Taxa	100.00	3280

Table 11 (Continued)

	Station FF14 - western Massachusetts Bay		
Rank	**Species**	**Percent of Total Fauna**	**Density (Ind. 0.12m^{-2})**
1	*Prionospio steenstrupi* (polychaete)	16.74	429
2	*Chaetozone setosa* (polychaete)	10.18	261
3	*Levinsenia gracilis* (polychaete)	8.82	226
4	*Sternaspis scutata* (polychaete)	6.94	178
5	*Mediomastus californiensis* (polychaete)	5.23	134
6	*Tubificoides apectinatus* (oligochaete)	4.60	118
7	*Aricidea quadrilobata* (polychaete)	3.43	88
8	*Scalibregma inflatum* (polychaete)	2.54	65
9	*Cossura longocirrata* (polychaete)	2.42	62
10	*Leitoscoloplos acutus* (polychaete)	2.42	61
	Total - 10 Taxa	63.32	1623
	Remaining Fauna - 89 Taxa	36.68	940
	Total Fauna - 99 Taxa	100.00	2563

Species Richness and Diversity

The number of species identified from the three replicate grabs collected at each station ranged from 56 to 108 (Table 12), with most stations ranging from about 60 to 80 species (including the three replicated Nearfield stations NF12, 17, and 24). Species richness is thus somewhat greater in the Farfield than in the Nearfield, although it must be taken into account that most Nearfield samples consisted of only one grab. The lowest species richness was noted at stations FF4 in Stellwagen Basin and FF13 in the midfield (56 and 65 species, respectively); stations FF9, west of Stellwagen Bank, and FF10, located in the midfield, had the greatest number of species (102 and 108 species, respectively). Infaunal abundances were overall comparable to those of the Nearfield. The number of individuals removed from the replicate samples ranged from a low of less than 1100 at station FF4 to a high of over 8000 at station FF1a off Gloucester.

Diversity, expressed as number of expected species per 100 individuals (Hurlbert's rarefaction), was overall similar to that of the Nearfield as well; values range from about 16 to about 30 (the corresponding range for the Nearfield is 18 to 29). The highest and lowest diversity indices were calculated for stations FF9 (16.40 expected species per 100 individuals) and FF10 (30.11 expected species per 100 individuals); these stations were the two most species rich of the farfield stations, but they differed substantially in infaunal abundance (Figure 65). The highest and lowest Shannon-Wiener indices were also determined for those two stations, while the remaining stations ranked slightly differently with Shannon-Wiener than with Hurlbert's rarefaction method (Table 12).

Community Analysis

Similarity analyses with Bray-Curtis and Gallagher's CNESS produced almost identical clusters of stations that are defined mainly by geography. One group of stations includes the midfield stations (plus two of the replicated nearfield stations), another group includes the two Cape Cod Bay stations, and a third main group includes the stations furthest offshore in Massachusetts Bay (the true farfield).

The Bray-Curtis dendrogram (Figure 66) shows five clusters, one of which contains only one station (NF17, cluster 1). This station was extremely sandy (mean phi 2.33) and populated by a suite of species largely restricted to sand, including the polychaete *Polygordius* sp. A and several amphipods such as *Pseudunciola obliqua* and *Corophium crassicorne*. Cluster 2 contains stations FF1a and FF9, which are characterized by high abundances of the top ranking species *Prionospio steenstrupi*, moderate abundances of *Mediomastus californiensis*, and sediments composed of mostly fine sands (mean phi 3.74). Cluster 3 consists of all near- and midfield stations (FF10, FF12, FF13, NF12, and NF24) except for the outlier station NF17 (cluster 1). While the top dominants differ among the stations, the cluster can be characterized by relatively high abundances of the polychaetes *Monticellina baptisteae* and *Aricidea catherinae* which both prefer nearshore environments. The sediments at these stations were a mixture of sands and silts (mean phi 4.88). Cluster 4 includes four stations that are located the farthest offshore in the Farfield area. The faunal composition at these stations was characterized by relatively high abundances of subdominant species such as *Chaetozone setosa, Levinsenia gracilis*, and *Tubificoides apectinatus*; the sediment was silty (mean phi 5.92).

Cluster 5 includes the two Cape Cod Bay stations FF6 and FF7, which had high abundances of a suite of species that were rare or absent elsewhere. Those species include the polychaetes *Cossura longocirrata* and *Apistobranchus typicus* and the oligochaete Tubificidae sp. 2. The sediment was similar to that at the offshore Farfield stations (mean phi 6.54).

Table 12. Community parameters, Farfield and replicated Mid/Nearfield stations, August 1995.

Station	# spp. ($0.12m^2$)	# indiv. ($0.12\ m^2$)	spp./50 ind.	spp./100 ind.	spp./500 ind.	H'	J'
FF1A	96	8046	11.90	18.58	40.86	1.64	0.36
FF4	56	1083	16.48	22.70	42.00	2.73	0.68
FF5	80	2328	15.59	22.18	45.95	2.52	0.58
FF6	75	3405	18.42	25.57	46.16	2.92	0.68
FF7	67	2570	15.65	21.49	40.78	2.65	0.63
FF9	102	7963	10.78	16.40	38.00	1.61	0.35
FF10	108	5155	20.63	30.11	58.63	3.13	0.67
FF11	69	3086	11.67	16.90	34.03	1.80	0.43
FF12	86	7514	15.79	21.70	39.58	2.66	0.60
FF13	65	3100	12.97	18.23	36.03	2.18	0.52
FF14	75	2175	18.89	25.98	48.82	3.00	0.70
NF12	73	6074	15.00	20.70	40.90	2.63	0.59
NF17	68	2075	18.46	26.27	49.32	2.89	0.67
NF24	72	3785	16.67	23.46	48.20	2.78	0.62

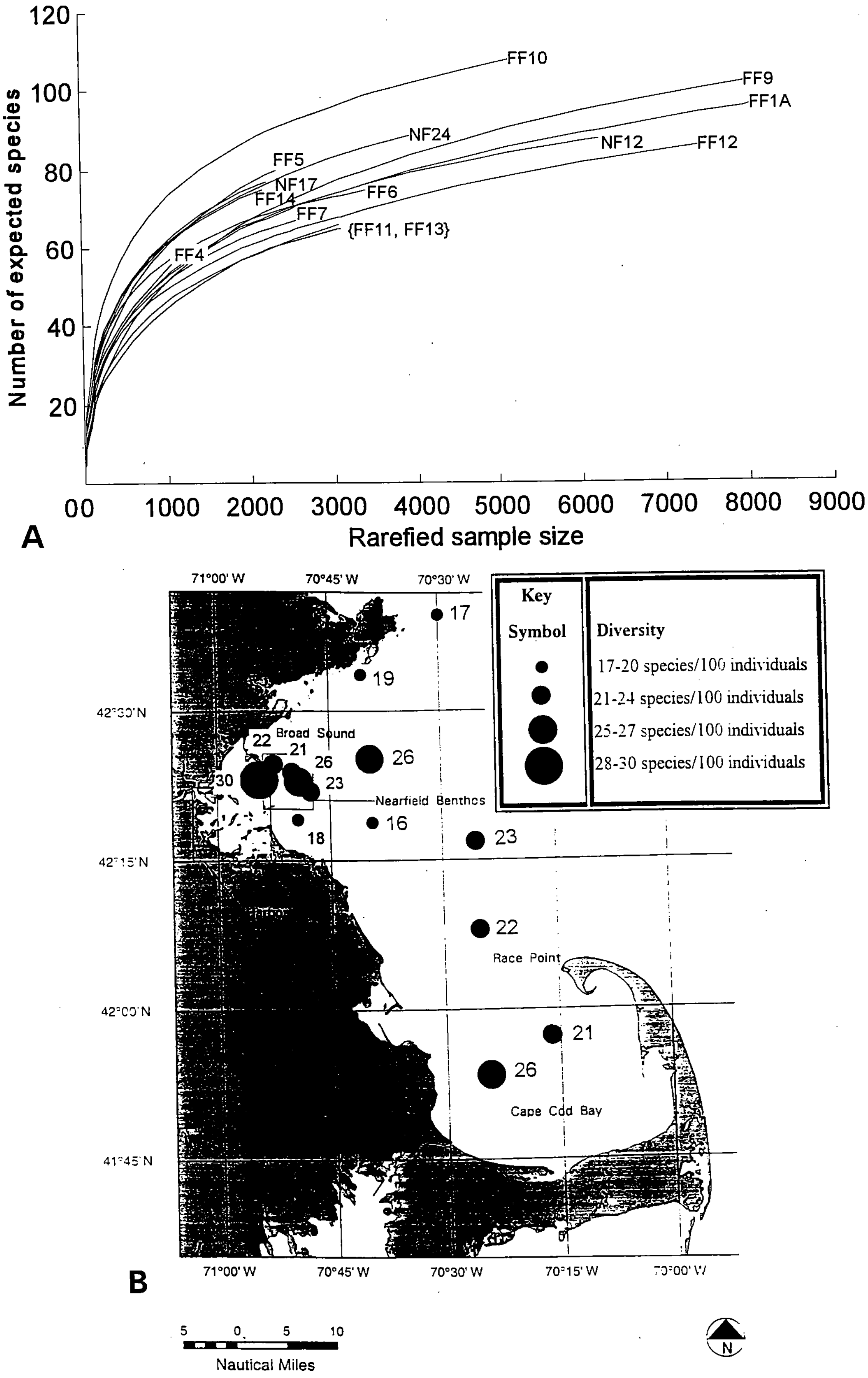


Figure 65. Diversity at farfield and replicated nearfield stations, 1995. (A) rarefaction curves, (B) areal distribution.

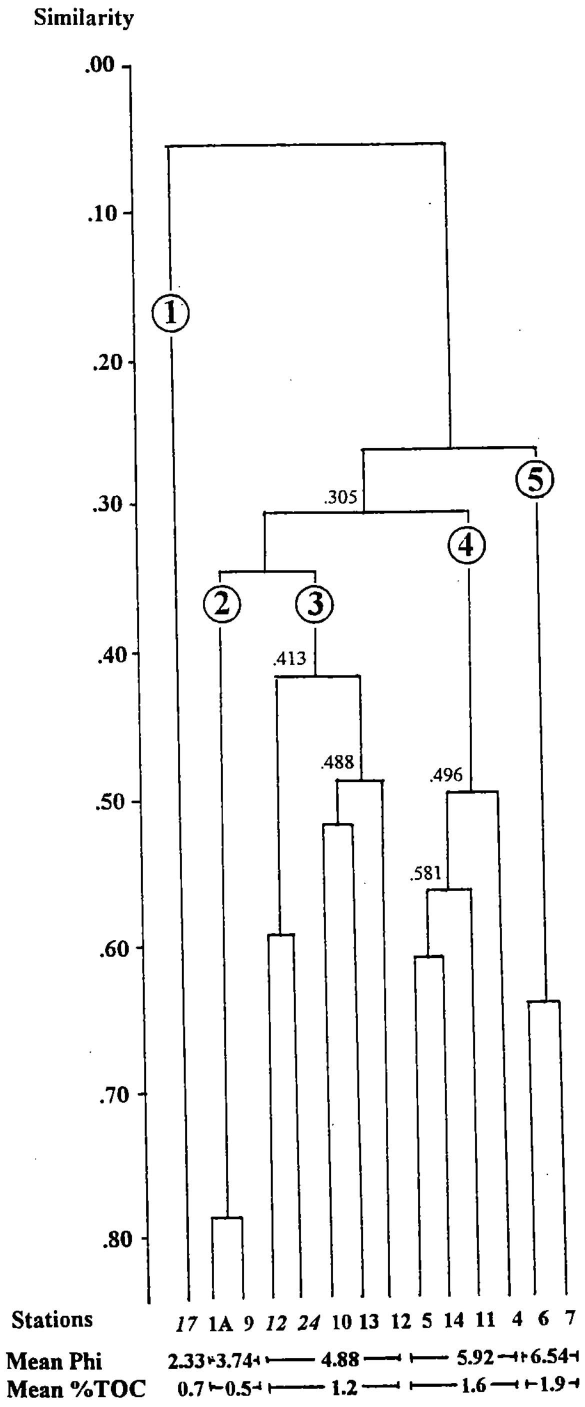


Figure 66. Bray-Curtis similarity among farfield and replicated nearfield stations, 1995.

When grouped with Gallagher's CNESS (Figure 67), the Farfield and replicated Nearfield stations fall into three main clusters and one outlier station, which is the same as with Bray-Curtis (NF17, cluster 1). Cluster 2 includes stations located in the mid- and nearfield and station FF1a, located in nearshore waters off Gloucester. This cluster corresponds to cluster 3 of the Bray-Curtis dendrogram. The stations joined in cluster 3 are the same offshore Massachusetts Bay stations as in the Bray-Curtis dendrogram, with the addition of FF9. The Cape Cod Bay stations form cluster 4, similar to Bray-Curtis where they constitute cluster 5.

The only difference between the two dendrograms is therefore with stations FF1a and FF9, grouping together in a cluster with Bray-Curtis because of very high abundances of *Prionospio*, but associated with two different clusters with CNESS. Station FF1a has affinities with the mid- and nearfield stations because of moderate abundances of the polychaetes *Tharyx acutus* and *Aricidea catherinae*, which are both more typical for shallow, nearshore areas and are also present in Boston Harbor (see Hilbig *et al.*, 1996). Station FF9 is linked to the offshore stations in Massachusetts Bay mainly by the subdominant polychaete *Levinsenia gracilis*.

The PCA-H analysis (Figures 68 and 69) complements and helps clarify the CNESS clustering analysis. Axis 1 primarily separates the midfield and deepwater assemblages (clusters 2 and 3, respectively) (Figure 68A). Axis 2 distinguishes the fauna from sandy nearfield station NF17 (cluster 1) from that at all other sites (Figure 68A, C), while the unique fauna at Cape Cod Bay is separated from all other stations on axis 3 (Figure 68B, C). The biplot between the same axes (Figure 69A) indicates a moderate influence of *Chaetozone setosa*, *Levinsenia gracilis*, *Aricidea quadrilobata*, and *Tubificoides apectinatus* on the spread of stations along axis 1 and a likewise moderate influence of the sand-dwellers typical for station NF17, *Spio limicola*, and *Mediomastus californiensis* on the scores of the stations along axis 2. Axis 3 may be associated with spionid densities; the corresponding biplot (Figure 69B) shows a fairly strong contribution of *Prionospio* to the variability along that axis. In addition, the influence of *Cossura longocirrata* is very strong in the projection of axes 1 and 3. The biplot in the projection of axes 2 and 3 (Figure 69C) depicts the strong influence of *Cossura longocirrata* and *Prionospio steenstrupi* on the separation of stations along axis 3 (Cape Cod Bay versus Massachusetts Bay) and the somewhat more moderate influence of the sand-dwellers characterizing the outlier NF17 and *Mediomastus californiensis* on the spread of stations along axis 2.

From all community structure analyses performed with this data set, it appears that in the farfield the infauna changes with geography and possibly depth, whereas the influence of sediment grain size and total organic carbon is less prominent than in the near/midfield where the sedimentary environment is very heterogeneous. There are two spionid-dominated Massachusetts Bay assemblages (mid/nearfield and offshore farfield) and a Cape Cod Bay assemblage characterized by *Cossura* and the oligochaete Tubificidae sp. 2; the outlier is part of the sand assemblages described above for the nearfield. The somewhat intermediate position of station FF9 between offshore and nearshore stations, suggested by the different clustering patterns described above, is visible in the multivariate analysis as well. On axes 1 and 2, FF9 (and the very similar station FF5) are the offshore stations located closest to the mid- and nearfield, most likely because of the presence of *Aphelochaeta marioni* and *Spio limicola* (both typical for the mid- and nearfield) on the one hand and *Levinsenia gracilis* (typical for deeper waters) on the other. As this station is similar to much of the near- and midfield in terms of sediment grain size, it may represent a good reference station for monitoring if the faunal trends prove to be stable over time.

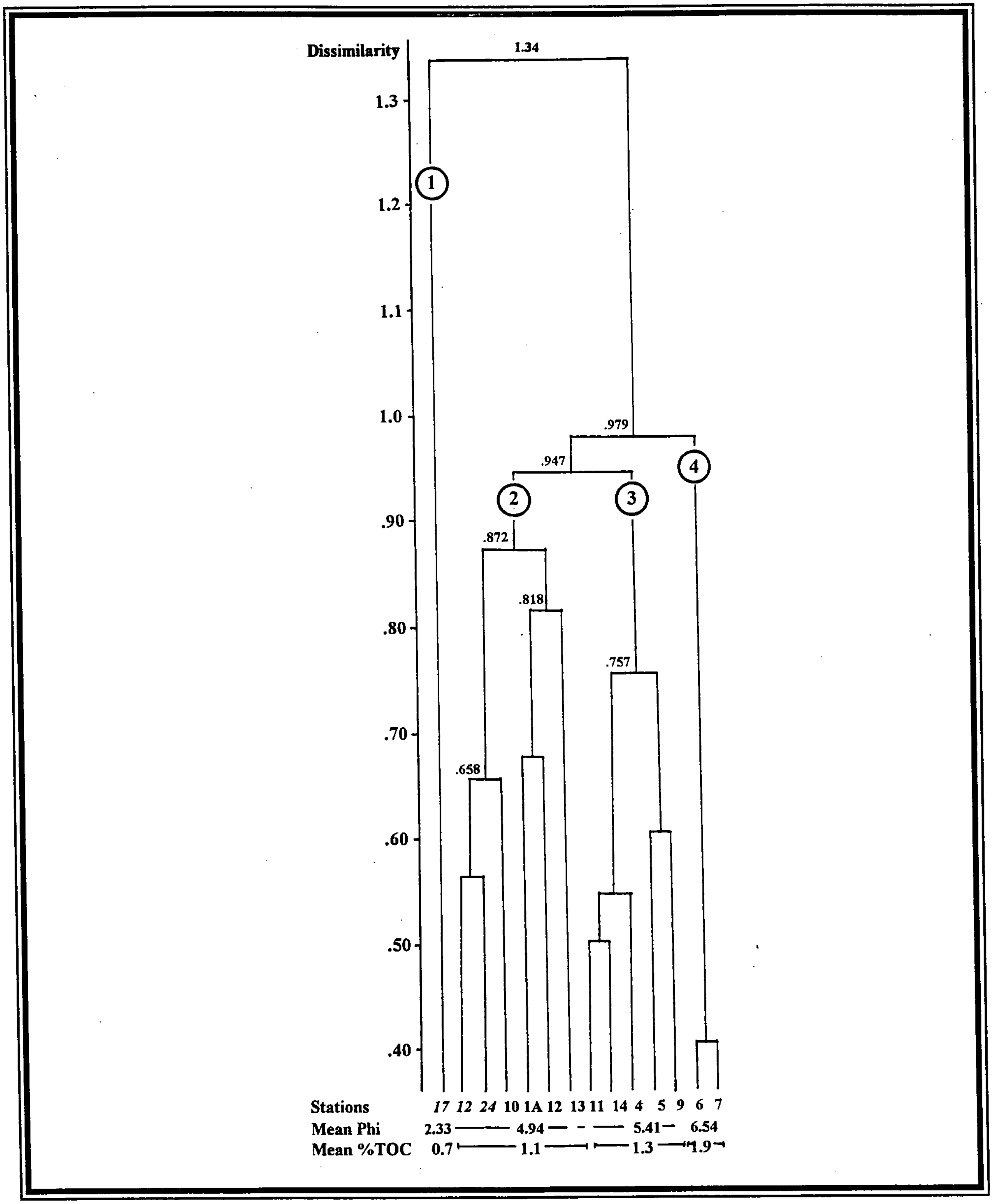


Figure 67. CNESS dissimilarity among farfield and replicated nearfield stations, 1995.

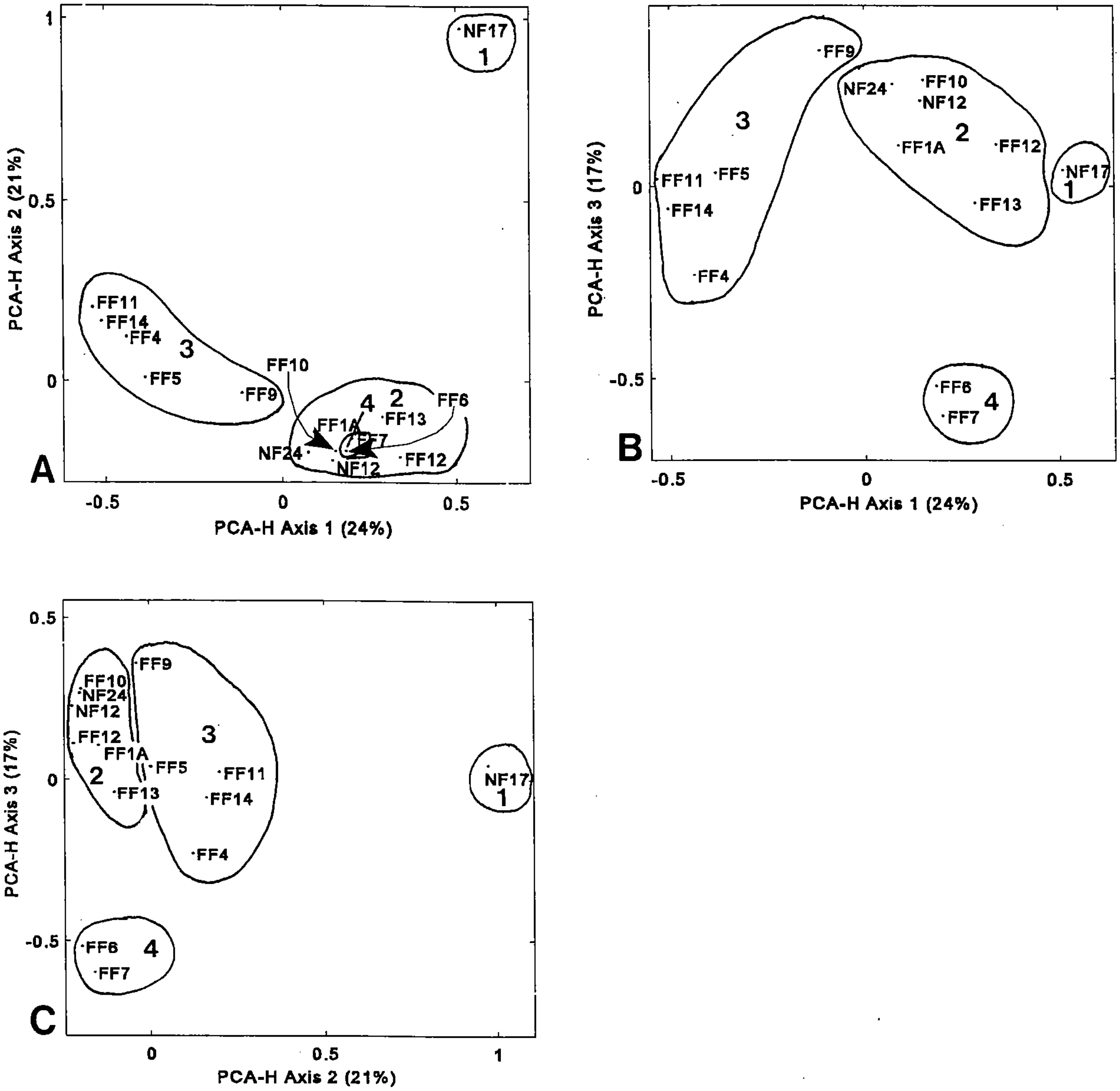


Figure 68. Station ordination among first three PCA-H axes, farfield and replicated nearfield stations. Outlines indicate clusters from CNESS dendrogram in Figure 67.

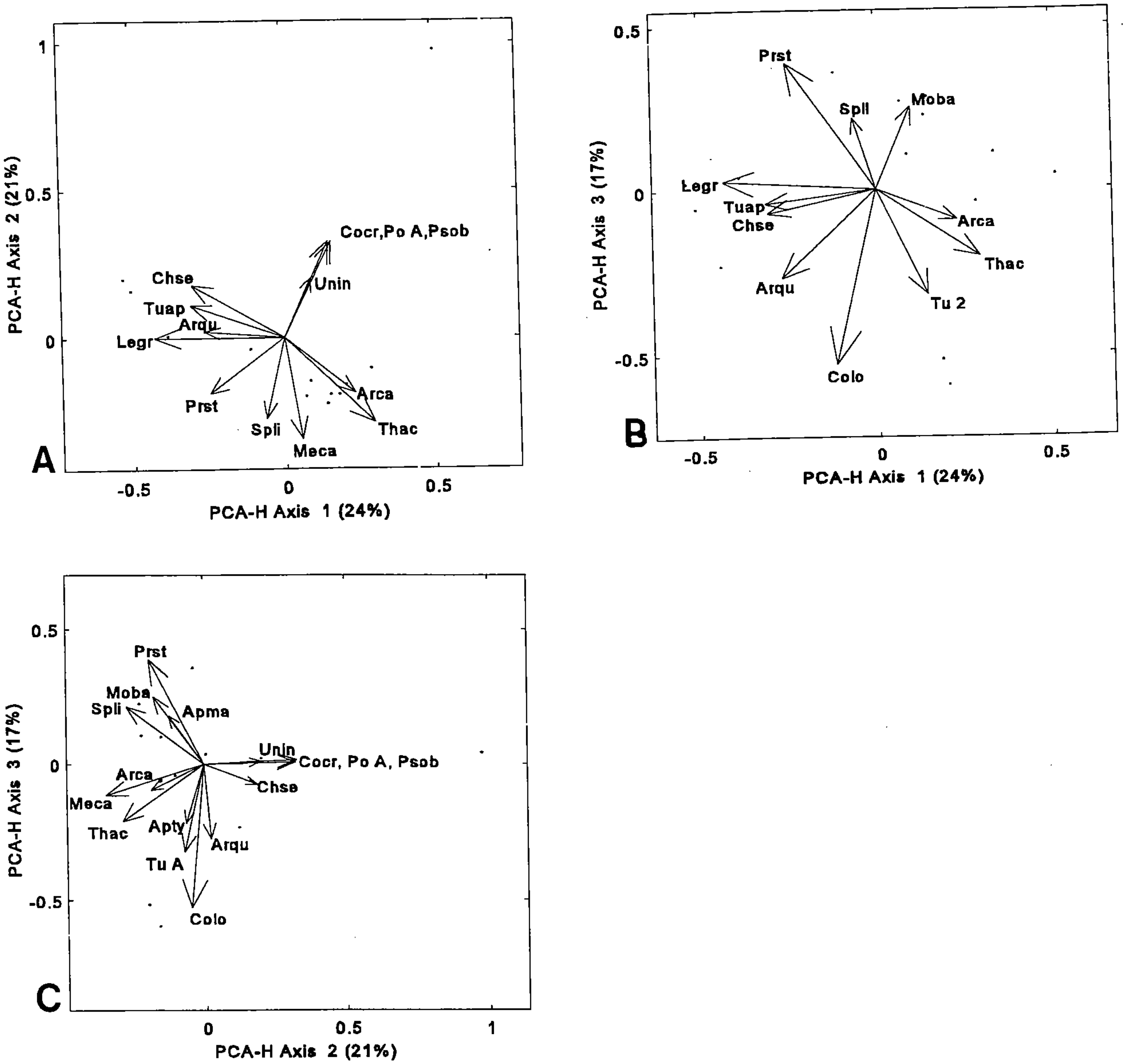


Figure 69. Gabriel biplots, farfield and replicated nearfield stations, among first three PCA-H axes. For abbreviated species names see Appendix C2.

4.0 DISCUSSION

4.1 Spatial and Temporal Trends in the Sedimentary Environment

4.1.1 Sediment Texture

The sediment texture in the mid- and nearfield has remained consistent over the last four years. Between 1992 and 1993 most stations showed a similar distribution in % gravel, sand, silt, and clay (Figure 70). Stations NF2 and NF4 changed the most, both becoming very much more sandy, a condition that continued through 1994 and 1995. From 1993 to 1994 there was, again, very little change in grain-size distribution patterns; sediments at station NF14 that had shown an increase in percent gravel in 1993 over that in 1992, returned to the 1992 level. The most dramatic change seen in 1995 compared to 1994 was the large increase in percent clay at NF24 (nearfield); at the same time sediments from NF8 and NF12 (midfield) contained less clay in 1995 than in 1994 and sediments from two other midfield stations, NF20 and NF23, contained less gravel. Overall, three midfield stations (NF2, 16, and 20) were coarser grained in 1995 than in 1992. For stations NF2 and NF16 this increase in grain-size occurred by 1993 and continued through 1995. The percent sand and gravel at station NF2 increased from 24% (1992) to 97% (1993) and remained high in 1994 (89%) and 1995 (94%). The percentage of sand and gravel at station NF16 increased from 24% (1992) to 63% (1993), remained high in 1993 (66%) and dropped somewhat by 1995 (44%). Station NF20 was not sampled in 1993 but the percent sand and gravel had increased from 42% in 1992 to 81% by 1994 and was still 62% in 1995. Stations NF16 and NF20 are adjacent to each other in the southwest portion of the transition zone between the low and high energy facies in the midfield. It seems likely that the coarsening of sediments at these two stations that has lasted for at least two to three years was caused by the same scouring event(s). Generally, changes in sediment texture at stations close to facies boundaries should be interpreted with caution because those changes may apparent and reflect slight differences in sampling sites rather than true changes over time.

The shift from fine to coarse sediments at station NF2 resulted in drastically lower TOC concentrations and *Clostridium perfringens* spore counts after 1992 (Figures 71 and 72). Stations NF16 and 20 did not exhibit the same trend over time, although the change in sediment texture was similar. Station NF8, which had less clay in 1995 than in the previous year, showed a marked decline in TOC concentrations between 1993 and 1994 and a decrease in *Clostridium* spore counts between 1994 and 1995. At the other stations, there has been some variability of both TOC concentrations and spore counts over time, but there is no clear trend for the near- and midfield as a whole, nor are there always clear relations between those two parameters and corresponding sediment grain size data.

The major environmental change detected through sediment profile imagery between the 1992 SPI baseline survey and the 1995 survey is the presence of surficial muds in the midfield. In 1992, the major textural mode for all stations was sand, although thin layers of mud were observed at depth in the midfield sands in 1992. Based on this sand-over-mud stratigraphy in 1992, it was predicted that surface sediments at midfield stations would be highly variable on some unknown time scale. This is the same conclusion drawn by Knebel (1993) based on acoustic returns diagnostic of his "reworked" facies. Knebel indicates that the area between Boston Harbor and Stellwagen Basin may be "starved" for fine-grained sediments. The sources of organic-rich silt-clays are Boston Harbor and small coastal streams. Boston Harbor is an efficient fine-grained sediment trap and so a large flux of fines out of the harbor may depend on unusual flow events related to high run-off and/or storm seiche phenomena. Such a storm took place in December 1992. Sediment geochemical data showed significant increases in Pb, Ag,

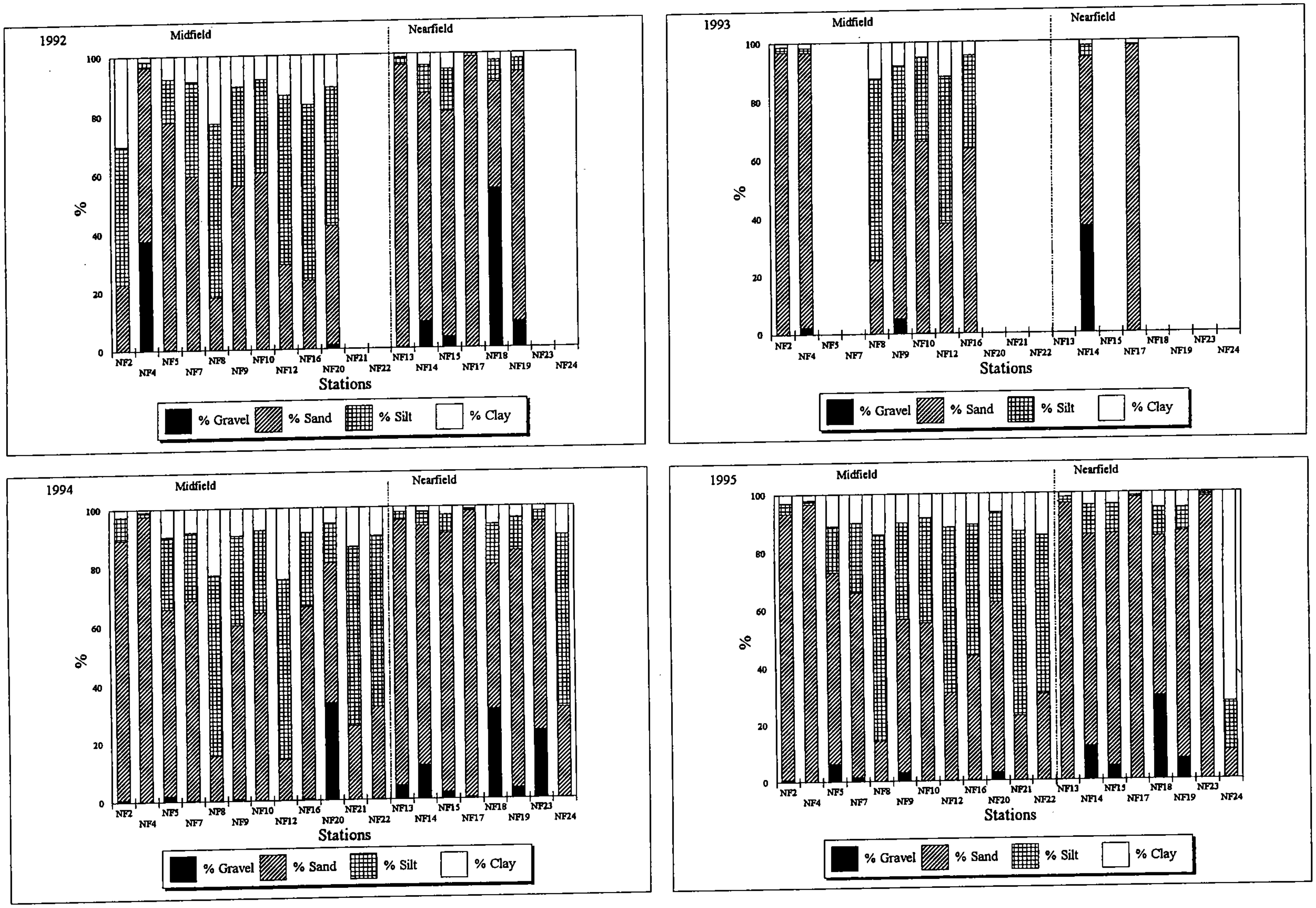


Figure 70. Sediment grain size composition, near- and midfield stations, 1992 through 1995. Stations MB01, MB02, S3, and S4 in 1994 were renamed NF21-24 in 1995; these new designations are used in the 1994 graph for consistency.

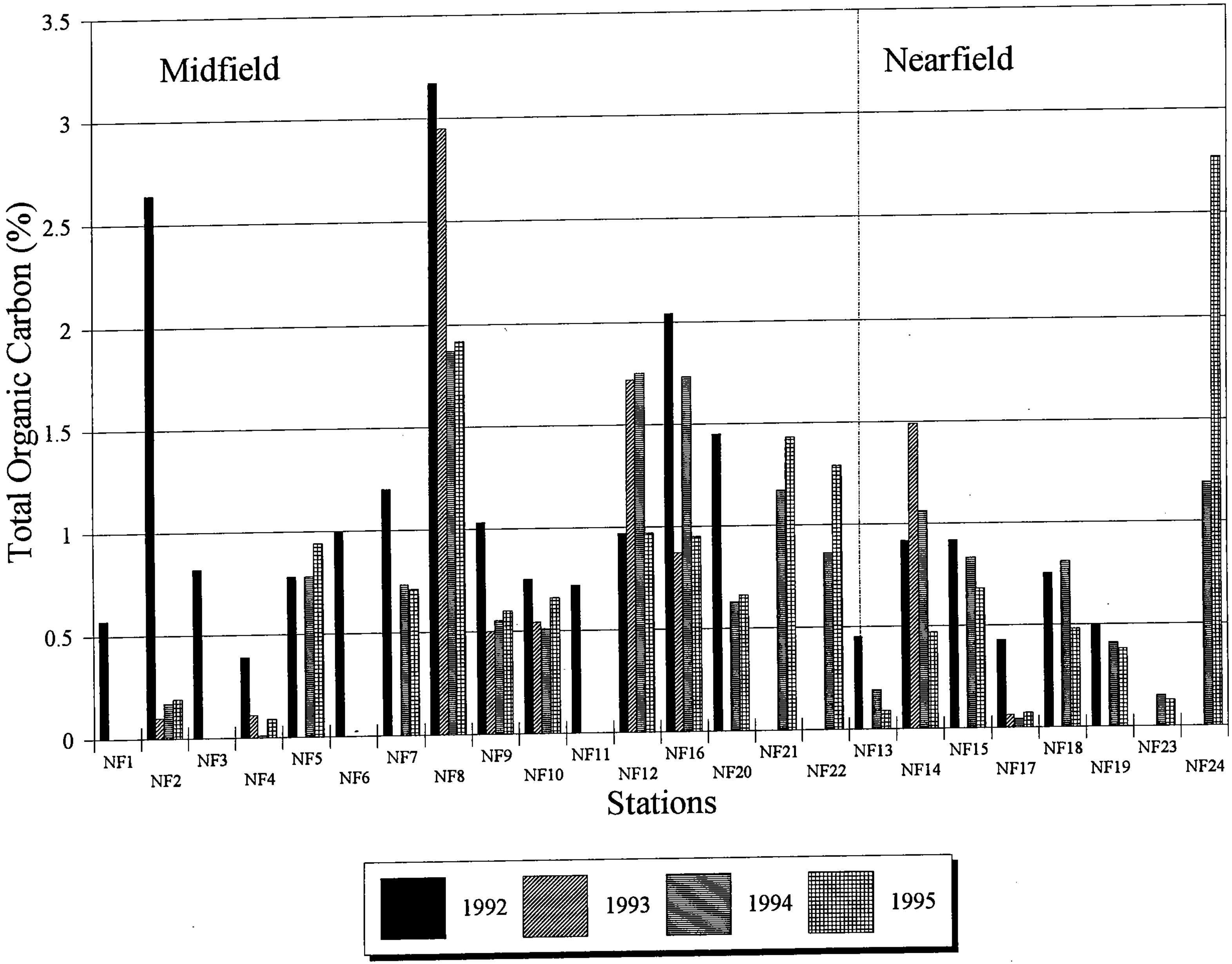


Figure 71. Total organic carbon (%) in sediment samples from nearfield stations, 1992 through 1995.

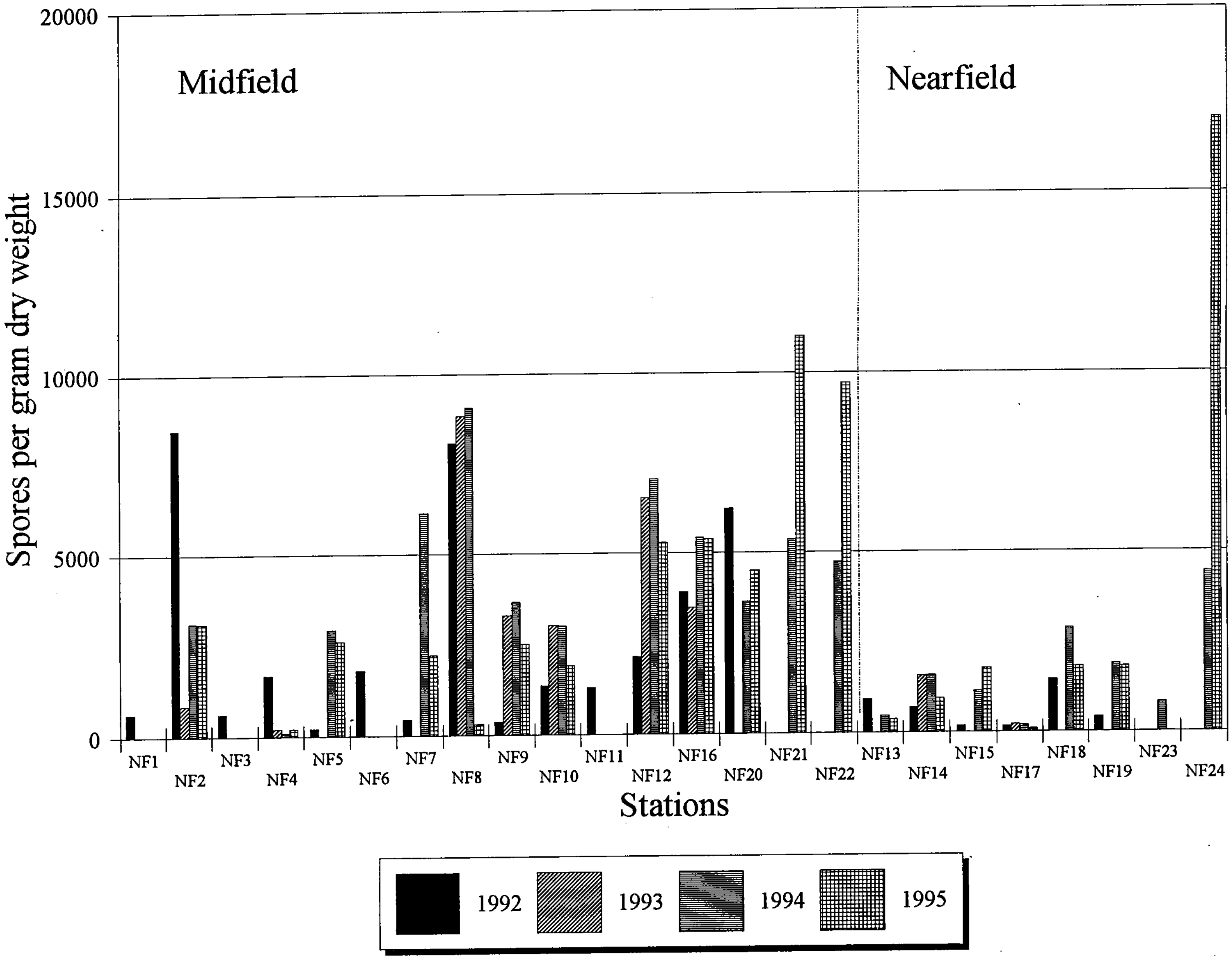


Figure 72. ***Clostridium perfringens*** **spore counts in sediment samples from nearfield stations, 1992 through 1995.**

^{234}Th, and *Clostridium* spore inventories at midfield stations between the sampling dates of October 1992 and February 1993 (Bothner *et al.*, 1993). Bothner further pointed out that some of these increases in metal inventories in the midfield may be related to redistribution from current scoured nearfield sands. Both local redistribution and Harbor sources may therefore account for the transport of silt-clays and associated contaminants. Sediment profile images also support the idea of quantum changes in sedimentation in the recent past (Figures 34, 35, 36, and 38).

Finally, station NF24 (Figure 37) in the nearfield should be considered as a chemical/biological sentinel station for long-term trend monitoring. It is a depositional site in an otherwise non-depositional or erosional environment. As such, this station may amplify and time-integrate contaminant loading and associated biological responses in an otherwise sandy environment that may have a very low signal-to-noise ratio based on frequent physical reworking and short residence time of fines.

In addition to documenting environmental variability and change at mid- and nearfield stations, the purpose of the SPI survey is to test hypotheses related to the magnitude of expected natural variability compared to anomalous variability that might elicit an Action Level response (MWRA, 1995). Regarding SPI data, the hypothesis is focused on the apparent RPD depth as stated in Section 3, page 18 of the MWRA 1995 draft report (Hypothesis B):

> *The sediment (apparent) RPD will not decrease to 50% of the average baseline depth at the nearfield muddy (>70% fines) stations.*

Five stations in the 1992 baseline study qualify as having >70% fines (NF8, 20, 16, 12, and 2). The mean apparent RPD depth at these stations ranged from 0.9 to 4.8 cm with a mean of 2.7 cm. The **Action Level** is therefore 1.3 cm (50% decrease in the population mean). In 1995, three baseline stations visited in 1992 were fine grained (>70% fines): NF8, 16, and 12. The mean apparent RPD depth at these stations ranged from 2.3 to 3.7 cm with a mean of 2.9 cm. The Action Level has not been reached, therefore the null hypothesis is accepted.

> *The depth of the sediment RPD will not decrease by more than 20% per year (relative to the average baseline depth) in the muddy areas of the nearfield for any three consecutive year period.*

The **Action Level** of 20% (0.54 cm/yr), resulting in a decrease to 2.2 cm between 1994 and 1995, could not be tested. Data for 1994 as shown in Fig. 2-15, p. 2-37 of the MWRA Phase II Post Discharge Monitoring Report (Nov. 1995) could not be used to test this hypothesis because of different observation methods used between the two years (coring in 1994 and SPI *in-situ* imaging in 1995).

4.1.2 Distribution of Metals

The spatial patterns in metal:C_{org} slopes are consistent with model predicted dilution patterns from the existing outfall of the MWRA presented by Signell *et al.* (1996). Their projections indicate dilutions of ~400 extending north and east to Nahant and to the south in the vicinity of Marshfield. These projections are consistent with the limited number of observations of elevated concentrations of metals in this region, especially of silver. Silver provides potentially the most sensitive "tracer" of all of the dissolved metals in the effluent (Krahforst and Wallace, 1996) due to its high enrichment above background concentrations in the effluent (~10^4). It is of particular interest that sediments at station FF6, located in the western part of Cape Cod Bay, have Ag:C_{org} ratios elevated above that of the other farfield stations (Figures 8-11). Again this observation is consistent with higher concentrations of water column silver also observed by Krahforst (unpublished) in the western parts of Massachusetts and Cape Cod Bays as well as the predicted along-shore southerly movement of water from Boston Harbor. There was no evidence of significant temporal changes in the slopes of any of the metals measured in either the nearfield between 1993 and 1995 or the farfield between 1992 and 1995.

Prediction of future changes in the metal content of the sediments in the vicinity of the diffuser was formerly based on the predicted deposition of contaminated particles from the effluent and their incorporation into the sediment. In the model discussed here the increase in contaminant metal concentrations will be a function of changes in both the ambient dissolved metal concentrations and increased accumulation of organic matter in the sediments. Thus the estimated accumulation of metals in the vicinity of the outfall should probably be reexamined. Use of existing data on effluent loadings and estimated ambient water column concentrations at the secondary treatment level suggests that ER-Ms for Cu, Pb, and Ag will not be exceeded at sediment organic carbon concentrations as high as 6%.

Higher than predicted metal concentrations may occur in localized areas where excessive sediment accumulation of organic matter results in anoxic conditions near the sediment-water interface. Metal contents of the sediments may be elevated over that expected based on ambient water column concentrations and sediment organic carbon predicted on the basis of these two variables alone. Direct diffusive fluxes into the sediment, driven by precipitation of insoluble metal sulfides under anoxic conditions, can be expected to enhance metal concentrations in the solid phase over that predicted for oxic conditions. Evidence for this can be seen by examining the correlation of metal against C_{org} in the data of Wallace *et al.* (in preparation) and Shine *et al.* (1995) from heavily contaminated, high organic content sediments in both Boston and New Bedford Harbors.

In conclusion the following observations can be made. First, sediment quality (relative to ER-Ms) criteria are clearly not consistent with existing water quality criteria. Water quality criteria will have to be revised or sediment quality thresholds more rigorously assessed in the process of setting sediment criteria. Secondly, it is unlikely, given the current efforts to reduce and maintain lower metal concentrations in the MWRA effluent, that sediment concentrations will exceed the 90% ER-M threshold level for these metals, at least outside of the area where dilutions on the order of 400 or greater are realized. Exceptions to this might exist for Hg, Ag and Ni. Concentrations of these metals currently approach the 90% threshold levels in the nearfield for those samples with the highest organic carbon concentrations. Predictions of metal accumulation in the sediments at the outfall site should be revisited using the approach presented here.

It is also worth noting that caution should be exercised in interpreting observed reduction in surface sediment concentrations of metals as an indicator of reduced source loadings of metals alone. Much of the change may reflect reduced organic matter loading to the sediments and concurrent re-oxygenation and loss of metals held in acid-volatile sulfide phases, and not necessarily a reduction in metal loading to the system. Sediment cores in Boston Harbor in areas where organic loading has been sustained and benthic organism activity minimal show little evidence of a decrease in metal concentration in recently deposited strata. However, in other locations in the Harbor dramatic reductions have been observed over the same time interval (Bothner, in preparation). Because dissolved metal concentrations in the Harbor have been relatively invariant over the last ten years or so (Wallace *et al.*, unpublished), sediment reductions in metal content over the last decade may reflect a diminished organic matter supply and/or reoxygenation of surface sediments as indicated by recent observations of deepening redox potential discontinuities in the Harbor (seeHilbig *et al.*, 1996).

4.2 Spatial and Temporal Trends in Benthic Macrofauna

4.2.1 Overview

The baseline benthic monitoring began in 1992 and will continue through 1997 and probably 1998. The study will provide sufficient data to evaluate the effects of discharge on the benthic communities of Massachusetts Bay. The sedimentary environment in the immediate vicinity of the outfall has proven to be complex physically and biologically precluding a simple statistical comparison of pre- and post-discharge effects. The diffuser or terminus of the outfall is situated in a hardbottom environment that consists of drumlins and intervening swales or hollows. Much of the area immediately adjacent to the diffuser contains rocky habitats. Small mud patches or pockets of sediment are rare within this area. The softbottom study area mostly lies to the west of the diffuser and grades westerly from sediments consisting mostly of sand to a finer grain depositional area. Studies using the sediment profile camera and others using particle traps reveal that sediment movement and deposition are dynamic processes throughout much of the nearfield softbottom study area. Because of these shifts in sediment cover, the benthic faunal assemblages are not stable from year to year and some stations exhibit wide swings in dominance of benthic species.

Because of the complexity of the sedimentary environment and the variable manner in which the biota respond to it, there are no simple statistical or multivariate approaches that can be applied to provide a ready means to assess change due to discharge from the outfall. Therefore, the approach has been to gather data to more fully characterize and understand the dynamics of the physical environment and shifts in the biota. Information content has been improved, including determination of sediment phi classes instead of simple sand-silt-clay percentages so that finer scale interpretation of the sedimentary environment can be obtained.

As part of the analysis of the 1994 results, Coats (1995) extensively reviewed the statistical methods appropriate to analyzing benthic infaunal data in order to find the most likely method that could be used to detect change due to effluent discharge from the outfall. As part of this review, Coats explored geometric properties of CNESS (Trueblood *et al.*, 1994; Gallagher, 1995) that measure the distance (dissimilarity) between two samples and used detrended principal components analysis (DPCA) in a way that provided estimates for the probable contribution of rare species. This is a departure from traditional methods where the most abundant species are considered as likely indicators of change.

As part of this study, Coats (1995) analyzed all data from the 1992-1994 surveys and developed a classification of the nearfield and farfield stations into eight unique station groupings. These groupings were interpreted as representing distinct zoogeographic provinces such as Cape Cod Bay, eastern Massachusetts Bay, transient infauna, estuarine, and a stable sentinel station group located within 2 km of the MWRA diffuser. Coats further subdivided the sentinel (nearfield) stations into three categories based primarily by their sediment textures (coarse, medium, and fine sediment). Unique benthic species (sentinel species) were shown to be associated with each sediment type.

No effort has been made at this time to reintegrate and analyze the 1992-1994 data combined with the newly collected 1995 data. This integration will be postponed until the 1996 data are available and there is sufficient to time to review and intercalibrate the older databases with the new ones.

This 1995 report provides separate analysis of the non-replicated nearfield station array and the farfield replicated stations combined with 3 nearfield stations that are replicated. Traditional benthic community parameters and assemblage pattern analysis have been performed and are compared with results from the previous three reports (Blake *et al.*, 1993; Coats *et al.*, 1995b; Coats, 1995). These results are also viewed in light of the post-discharge hypotheses that are being considered by the MWRA as a means to assess the impacts of sewage discharge in Massachusetts Bay.

These hypotheses are:

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

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

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

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

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

Hypotheses 1-3 appear to have promise, but need further refinement. For example, there is no indication of which diversity index should be applied. Further, the baseline average diversity has yet to be established. It makes sense to await the 1997 baseline results before establishing what that average might be. Hypothesis 4 is very important in that it deals with a changing faunal composition. However, a definition of a "degraded benthic community" needs to be developed. There are numerous grades between "healthy" and "degraded" benthic communities and different endpoints as well. These points need to be discussed in a more open forum before integration into the individual hypotheses.

The alternate hypothesis represents the development of an index that is intended to consider the stability of benthic faunal assemblages at stations that have been demonstrated to have stable histories of sediment grain size and benthic community structure. This alternate hypothesis will be carefully considered along with hypotheses 1-4 and other benthic indices proposed in recent years.

4.2.2 Mid- and Nearfield

The nearfield sampling program consists of an array of stations that are mostly sampled with single, non-replicated 0.04-m^2 grabs. Three stations are replicated, however, and provide data that can be compared with the farfield program.

Faunal Assemblage Patterns

The nearfield softbottom study area is mostly located to the west of the diffuser in a sedimentary environment that trends westerly from an area of shifting sands to a more stable depositional area. Mud and sand patches have been found in the hardground north and south of the western end of the diffuser, and these new stations are now being monitored.

The shifting sedimentary environment found on the eastern end of the study area exhibits layering due to periodic deposits of fine sediments, which are then overlain with sands. These events most certainly contribute to year-to-year differences observed since monitoring began in 1992. Apart from stations subject to the shifting sediments, three faunal assemblages (A-C) in the Nearfield study area have remained more or less stable at some stations, not so at others. Individual species abundances differ considerably from year to year.

Faunal assemblage A is located more or less in a boundary area between the finer sediments to the west and the rock outcrops and drumlins to the east. This assemblage is dominated by syllid polychaetes (*Exogone*), enchytraeid oligochaetes, *Polygordius*, and *Corophium*, all species occurring in sandy sediments. Stations NF4 and NF17 are those typically found having these assemblages. In years when coarser sands are more widespread, other stations such as NF2 and NF13 have these same faunal elements. This sand assemblage serves as a boundary to finer grain sediments to the west that are either dominated by capitellids (*Mediomastus*), cirratulids *(Tharyx)*, spionids (*Spio, Prionospio, Polydora*), or sometimes paraonids *(Aricidea)*.

There are typically two faunal assemblages in the finer grain sediments. One, dominated by *Prionospio, Spio,* and sometimes *Polydora* (assemblage B), usually encompasses near/midfield stations NF5, 7, 14, 15, and 18 and is transitional to a *Mediomastus* dominated community to the west. This latter assemblage (C) usually includes midfield stations NF8, 9, 10, 16, 20, and 21. In 1994, these two assemblages tended to blend back and forth, and several species that occurred as dominates have not done so in other years. It seems likely that depositional events played a role.

Year-to-year faunal patterns from 1992-1995 are compared in Figures 73 and 74. These maps show the areal distribution of the three assemblages described above, reflected in clustering patterns. The sand assemblage is the most consistent one, despite any perceived sedimentation events, in that Stations NF4 and 17 have been consistently dominated by more or less the same fauna for all four years. The faunal assemblages A-C mapped here more or less correspond to Coats' (1995) coarse, medium, and fine station groupings. As noted however, shifts in sediment grain size have occurred, especially with the B (medium) assemblage. The A (coarse) assemblage appears to be most consistent.

Year-to-Year Trends in Species Composition

The most obvious trends in the species composition from 1992 to 1995 are the variable densities of the most common species regardless of station or sediment type. Two factors are probably at work that account for the relative proportions of the most common species in any one year.

One factor is sediment grain-size composition. Sediment layering as revealed by sediment profile imaging in 1992 and again in 1995 suggests that much of the nearfield study area is subject to short-term shifts in sediment cover, possibly due to heavy winter storms and associated sediment movement. Sand overlying mud was clearly evident at several stations in the 1995 survey and this may mean that finer sediments were available to normally sandy stations in 1994, thus accounting for the faunal differences in that year. In some respects, the 1995 faunal results more closely resemble those of 1992 than those of 1993 and 1994.

The second factor is biological and relates to reproduction and recruitment to the existing populations. There is very little known about the life cycles of the dominant fauna in Massachusetts Bay. However, there is sufficient information to suggest that the timing of recruitment may greatly influence which

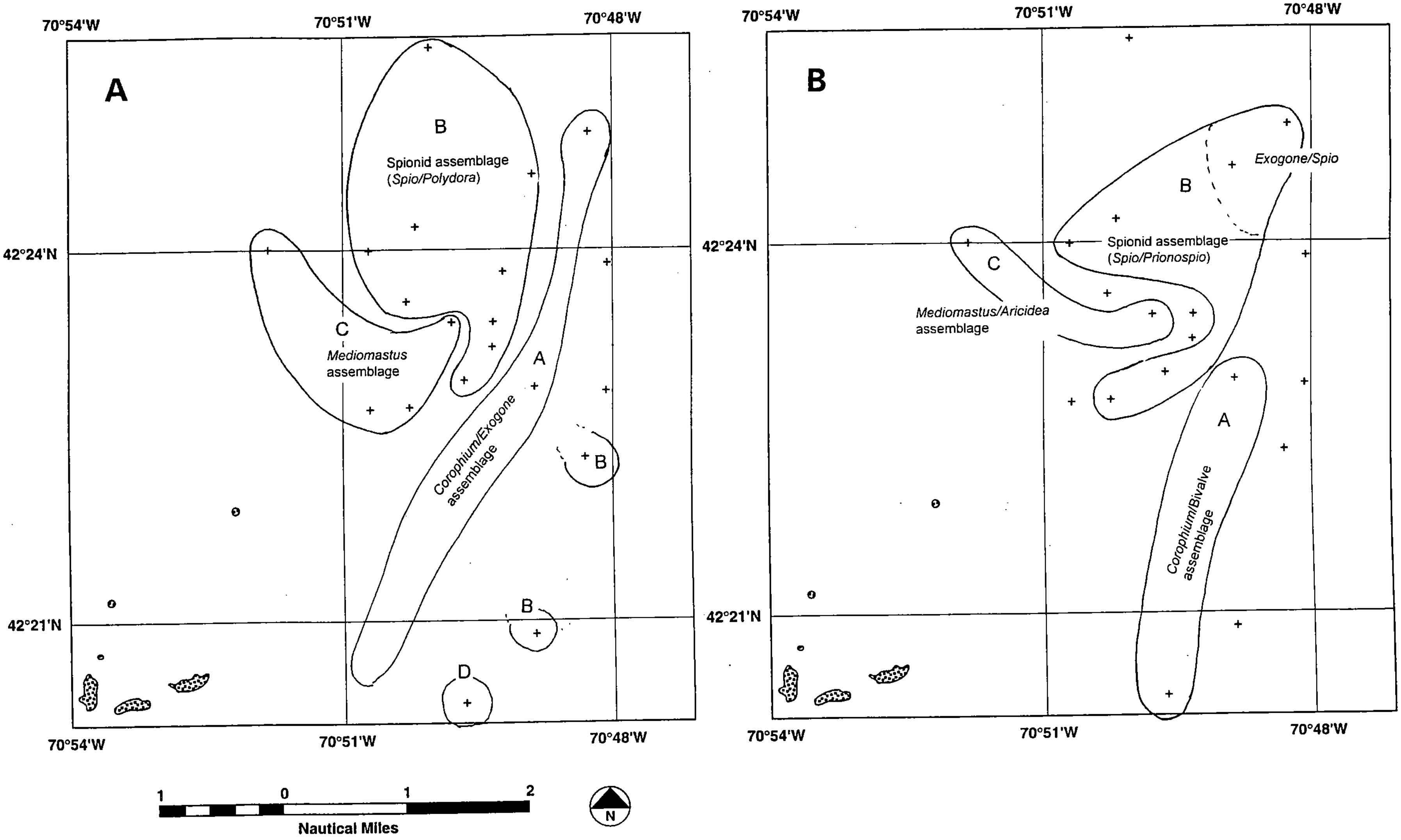


Figure 73. Faunal assemblages in the near- and midfield. (A) 1992, (B) 1993.

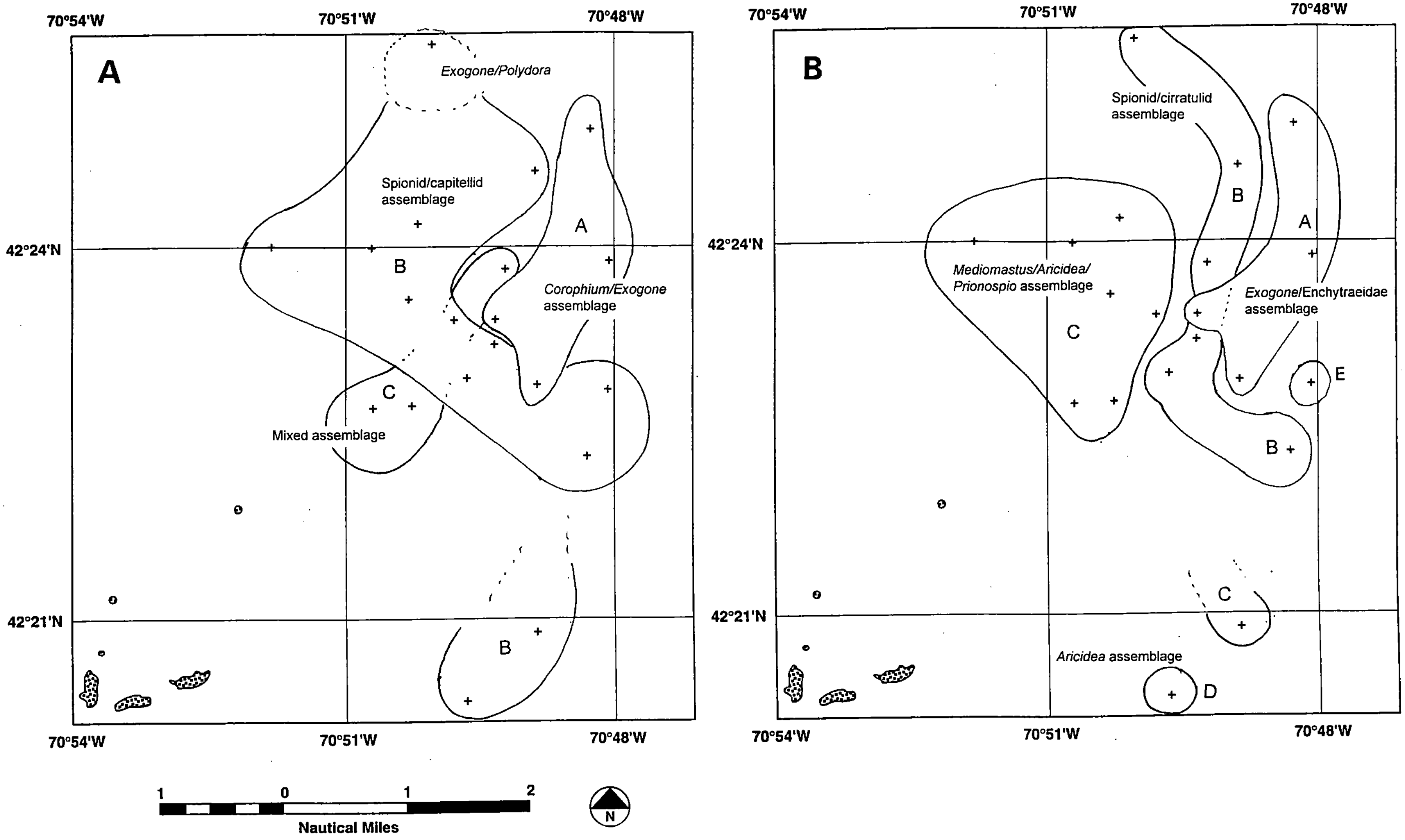


Figure 74. Faunal assemblages in the mid- and nearfield. (A) 1994, (B) 1995.

species predominate in one year or another. Based upon an assessment of numbers of specimens retained on the 0.5-mm and 0.3-mm sieves in quarterly samples taken as part of the STFP in 1987, the period of heaviest recruitment appears to be during the spring (March) and early summer months (May) (Blake *et al*., 1987). Blake (1969) reported on the occurrence pelagic larvae of two of the common spionids in Massachusetts Bay as part of studies conducted in the Gulf of Maine. In Maine waters, *Polydora quadrilobata* larvae were present in the March-April time frame, whereas, *P. socialis* larvae were present from May to August. It is likely that a similar seasonal pattern for these species occurs in Massachusetts Bay and that there are species-specific recruitment patterns for the other common spionids such as *Prionospio steenstrupi* and *Spio limicola* as well. Thus, depending upon season, larvae of individual species will be available for recruitment in differing intensities at different times. Success of settlement of one species that arrives before another may thus dictate the final density of the species that arrives later.

Disturbance of the seafloor by storms, fish feeding, or trawling activities may also open spaces to promote successful recruitment. Deposition of new sediment layers usually enhances larval settlement. These factors coupled with interspecific interactions are all likely ones that determine which species predominate at any one time and the apparent wide year-to-year swings in abundances of the dominant species.

Year-to-Year Trends in Species Diversity

Species diversity patterns in the near/midfield benthos appear to be more stable from year to year than abundance and species dominance. Although it is still too early to establish an "average" species diversity number for each station, available data suggest that most stations are within 10-15% of the same index value from year to year. Upon completion of the 1997 sampling season, the year prior to the initiation of discharge from the Massachusetts Bay Outfall, there will be 5-6 years of data from which to define a "baseline" diversity index value for each station. The question of which index value to choose has not been decided. Shannon-Wiener indices (H′), as depicted in Figure 75, are commonly used, but the rarefaction method and a value of, for example, expected species per 100 individuals, is likely to be more sensitive. Figure 76 shows the actual number of species present at individual mid- and nearfield stations in 1992 to 1995. There does not appear to be any consistency as to how many species may be present at any one time.

Year-to-Year Trends in Infaunal Abundance

Densities of infauna fluctuate greatly from year to year at the near- and midfield stations (Figure 77), largely due to intense settlements of one or two species. There is little stability in density at any of the stations except NF4. The reasons for these large swings in density are due to the same factors discussed earlier regarding maintenance of individual species. For example, the very high densities of total infauna at near- and midfield stations NF5, 7, and 19 in 1992 were due to high densities of *Spio limicola,* the populations of which accounted for 27-33% of the total density at those stations. Similar dense populations of *Aricidea catherinae* and *Prionospio steenstrupi* account for high overall densities at stations NF2, 19, and 20 in 1995. In order to demonstrate year-to-year variability among some of the dominant species, their densities have been plotted at six nearfield stations, selected to represent different sedimentary areas of the study area and where samples were taken in each of the four years (Figures 78 and 79).

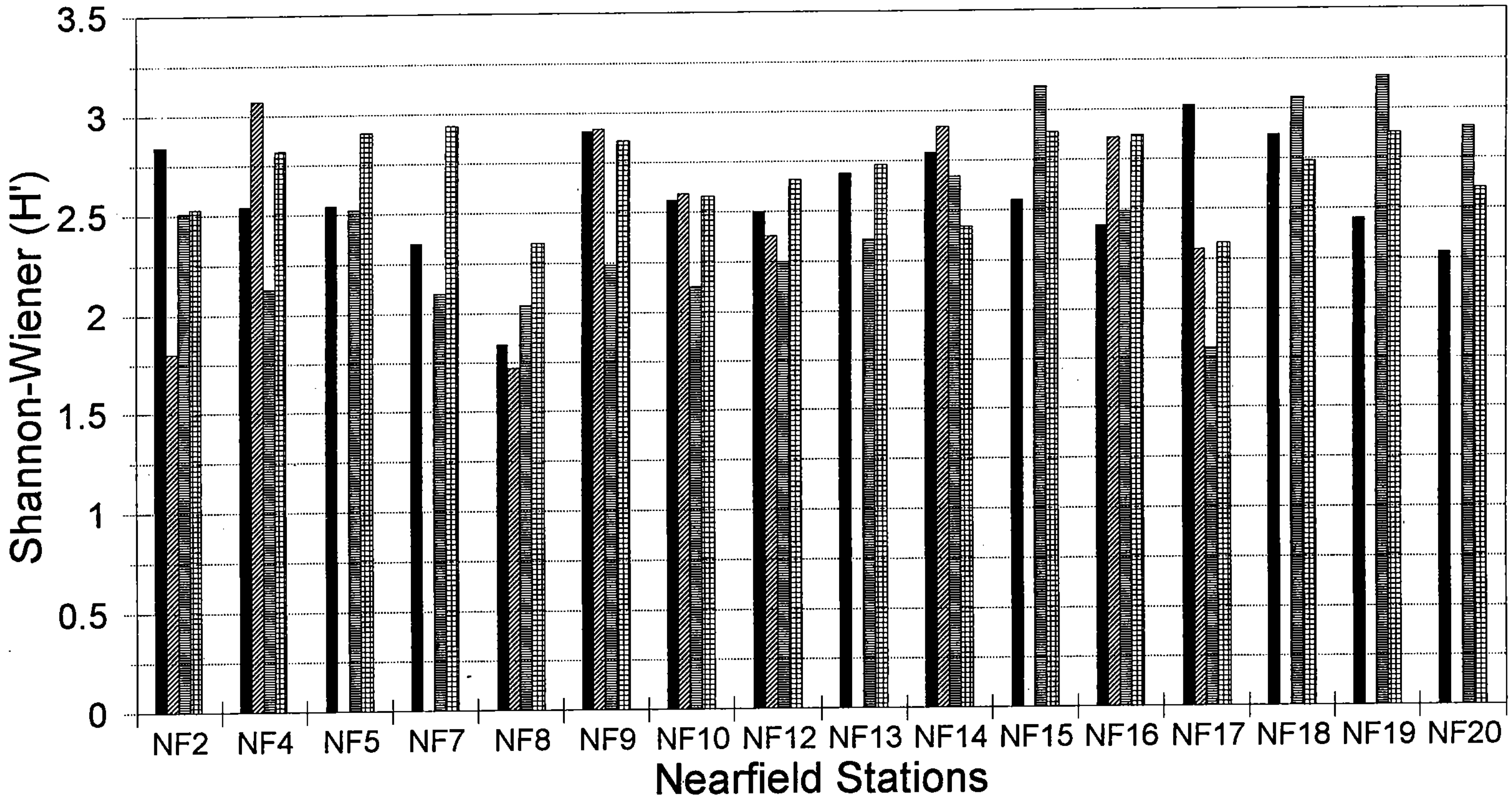


Figure 75. Species diversity, expressed as Shannon-Wiener index, in the near- and midfield, 1992 through 1995. Stations NF21 through NF24 not included.

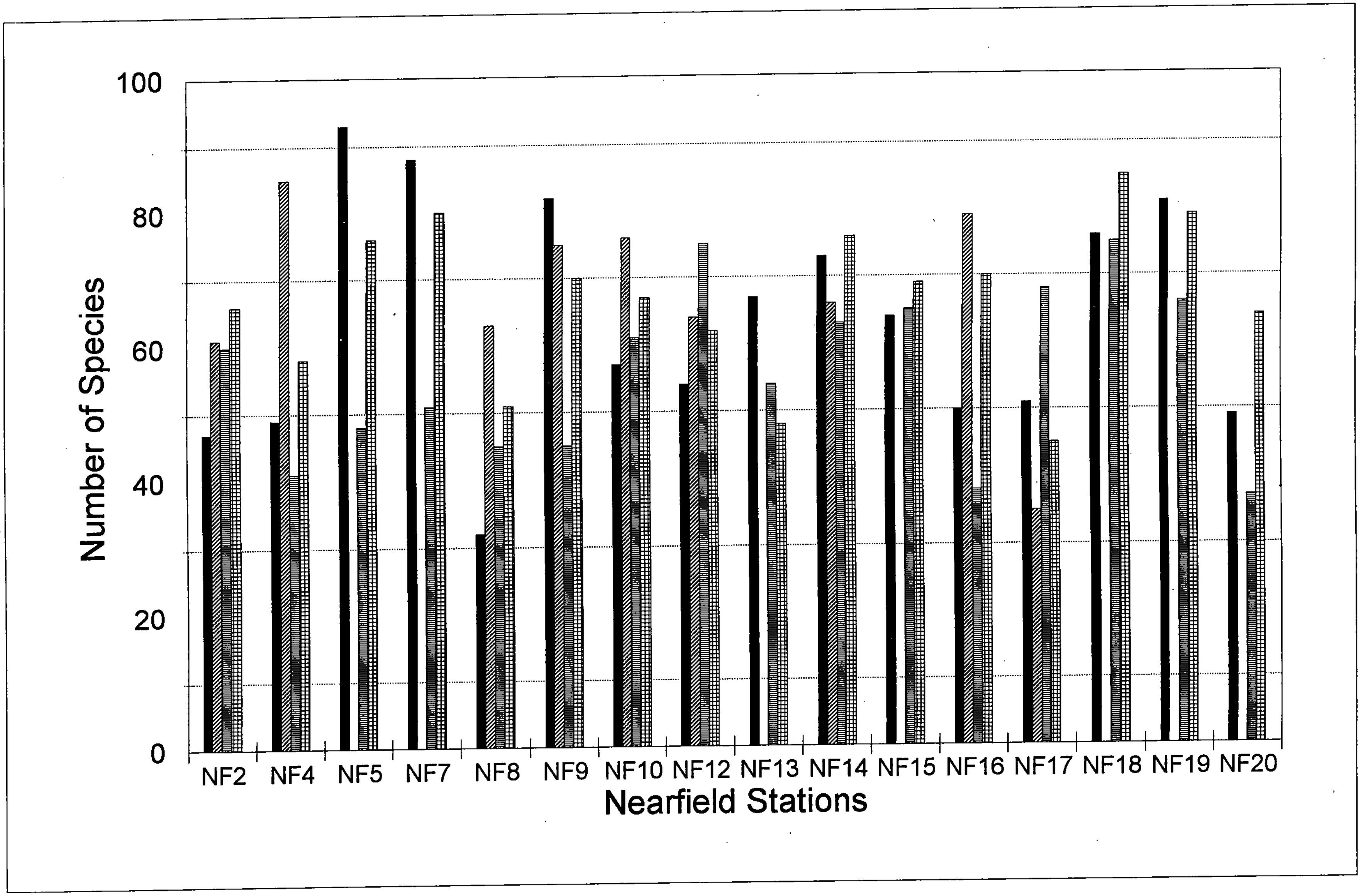


Figure 76. Species richness in the near- and midfield, 1992 through 1995. Stations NF21 through NF24 not included.

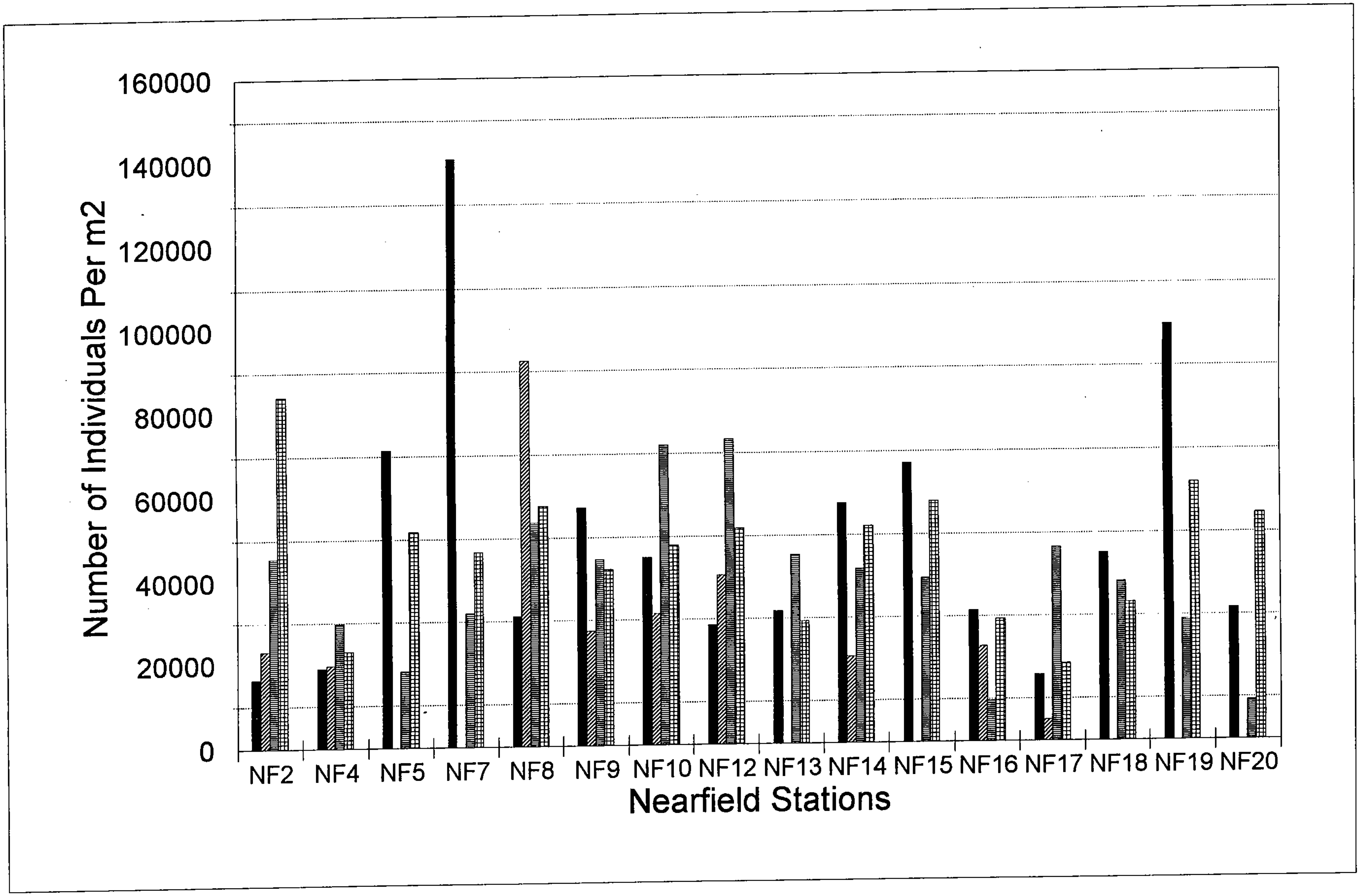


Figure 77. Total infaunal density in the mid- and nearfield, 1992 through 1995. Stations NF21 through NF24 not included.

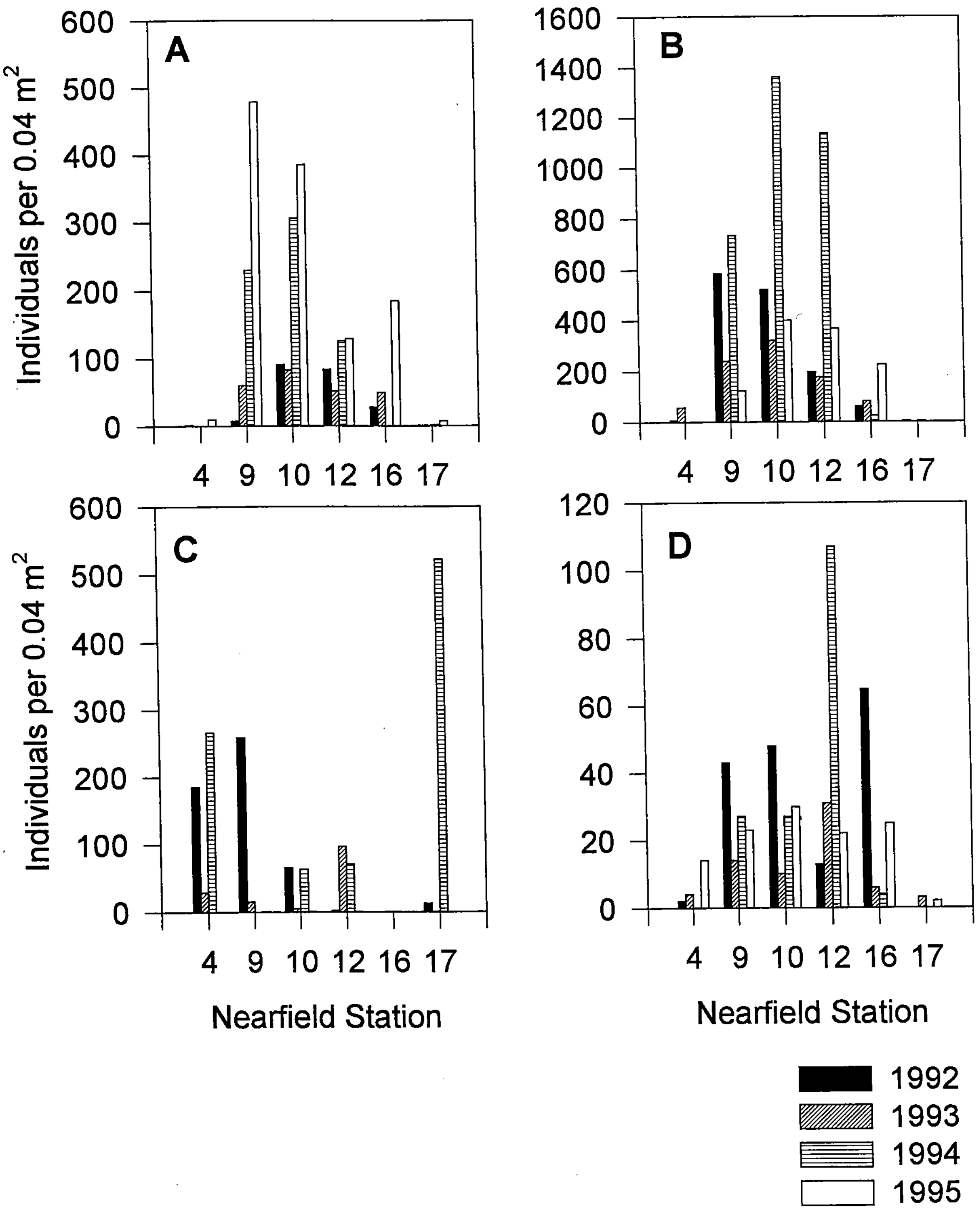


Figure 78. Density of selected species in the near- and midfield, 1992 through 1995. (A) *Prionospio steenstrupi*, (B) *Spio limicola*, (C) *Polydora socialis*, (D) *Tharyx acutus*.

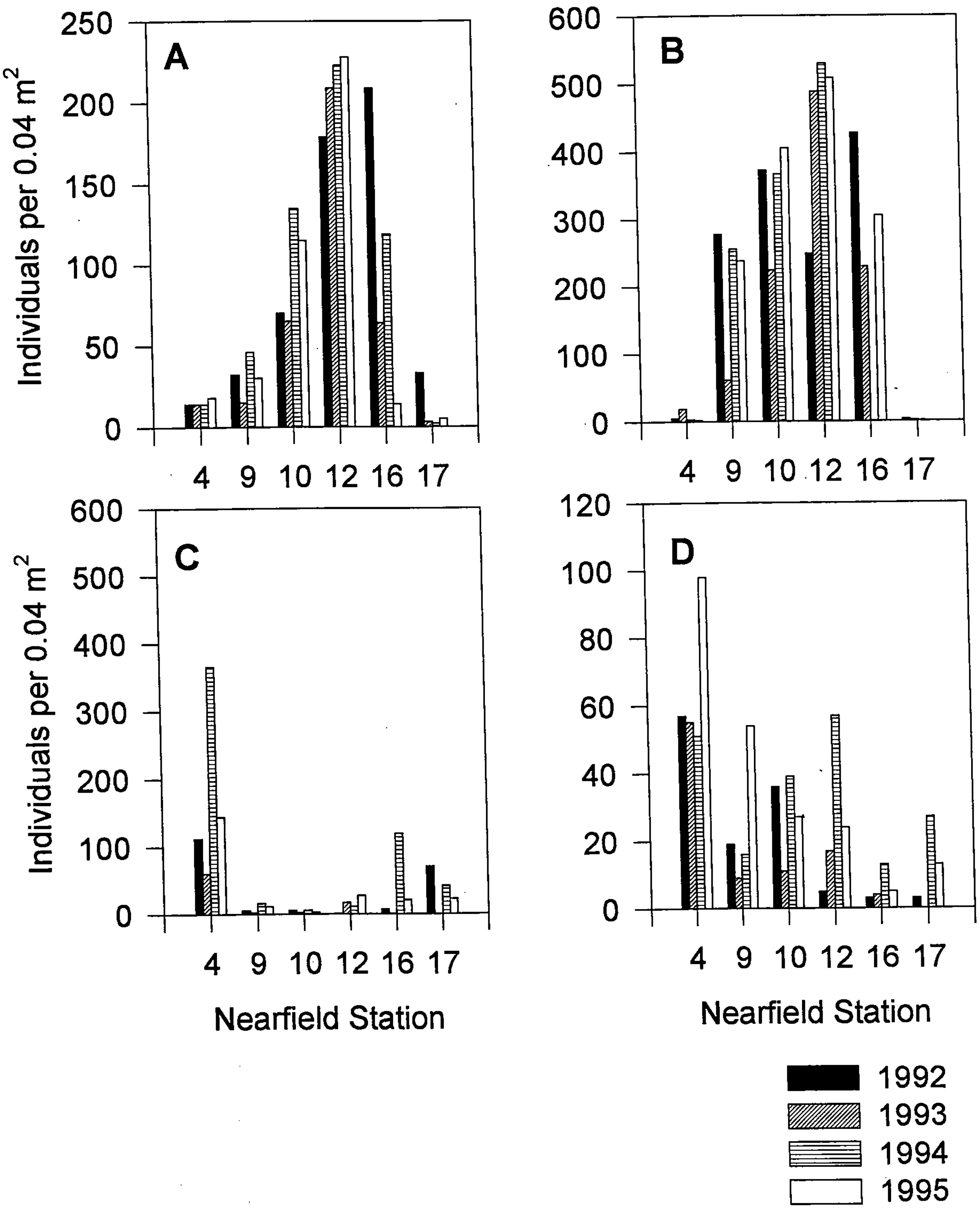


Figure 79. Density of selected species in the near- and midfield, 1992 through 1995. (A) *Aricidea catherinae*, (B) *Mediomastus californiensis*, (C) *Exogone hebes*, (D) *Exogone verugera*.

Among three spionid polychaetes, *Prionospio steenstrupi* appears to have achieved its highest densities in 1995. In contrast, *Spio limicola* was most abundant in 1993, while abundances of *Polydora socialis* were highest in 1992 and 1993. Similar wide swings in density are obvious for the cirratulid polychaete *Tharyx acutus*. The paraonid *Aricidea catherinae* and the capitellid *Mediomastus californiensis* are somewhat more consistent in their densities from year to year, but see stations NF10 and 16 for the former and NF9, 10, and 16 for the latter. The syllid polychaetes *Exogone hebes* and *E. verugera* are normally found in coarser sediments and also exhibit wide swings in population density. All these results. however, have to be viewed with caution because the data for most of the nearfield stations are based upon single, non-replicated samples that cannot in any way compensate for patchiness at individual stations. According to a cluster analysis of infaunal data from 1992 to 1994 with replicates kept separate, patchiness in the mid- and nearfield may in some instances outweigh temporal and spatial differences among stations and years (Coats, 1995).

4.2.3 Farfield

The farfield sampling program consists of 11 stations where triplicate 0.04-m^2 grabs are collected and analyzed, thus providing sufficient samples to develop statistical comparisons between stations and between years. As will be demonstrated, even with replication, there are still considerable year-to-year swings in overall faunal abundance and density of dominant species.

The farfield sampling is an important component of the benthic monitoring program because the widely distributed array of stations in Massachusetts and Cape Cod Bays ensures that changes due to natural processes will be documented and distinguished from those due to the new outfall. Most farfield stations appear to be more stable from year to year than the mid- and nearfield stations where sediment transport processes and a highly variable topography produce results that vary from year to year. With these differences in mind, comparisons between mid/nearfield and most farfield stations should be made with caution and viewed in a descriptive rather than statistical sense.

Faunal Assemblage Patterns

The faunal assemblages of Massachusetts Bay and Cape Cod Bay as revealed by cluster and ordination analysis from years 1992 to 1995 demonstrate consistently that there are three general groupings of stations. The first, and most consistent assemblage, includes the two stations (FF6 and FF7) in Cape Cod Bay. These stations consistently cluster separately from the other nine stations and represent distinctness of the faunal assemblages in Cape Cod Bay in part due to the presence of *Cossura longocirrata*, a dominant polychaete that is rare elsewhere in the study area. Another assemblage includes those stations in eastern Massachusetts Bay in the vicinity of Stellwagen Basin: farfield stations FF4, 5, 11, and 14. The remaining stations are more nearshore and, depending upon which year sampled, may cluster separately or form linkages with the Stellwagen Basin assemblage. Station FF9 in eastern Massachusetts Bay appears to be intermediate in nature between the near/midfield and the deeper offshore stations of Massachusetts Bay, including Stellwagen Basin. Although based upon different species, results of both Coats (1995) and the present study indicate affinities of the infauna at FF9 to both near- and offshore communities.

Species Diversity and Species Richness

With exception of farfield stations FF1a and 5, species diversity as measured with Shannon-Wiener (H′) is relatively consistent from year to year (Figure 80). Like the results for the nearfield, a final "average" species diversity for these stations will not be calculated until after the 1997 samples are analyzed. The decline in H' at station FF1a was approximately 50% and due to a dense population of *Prionospio*

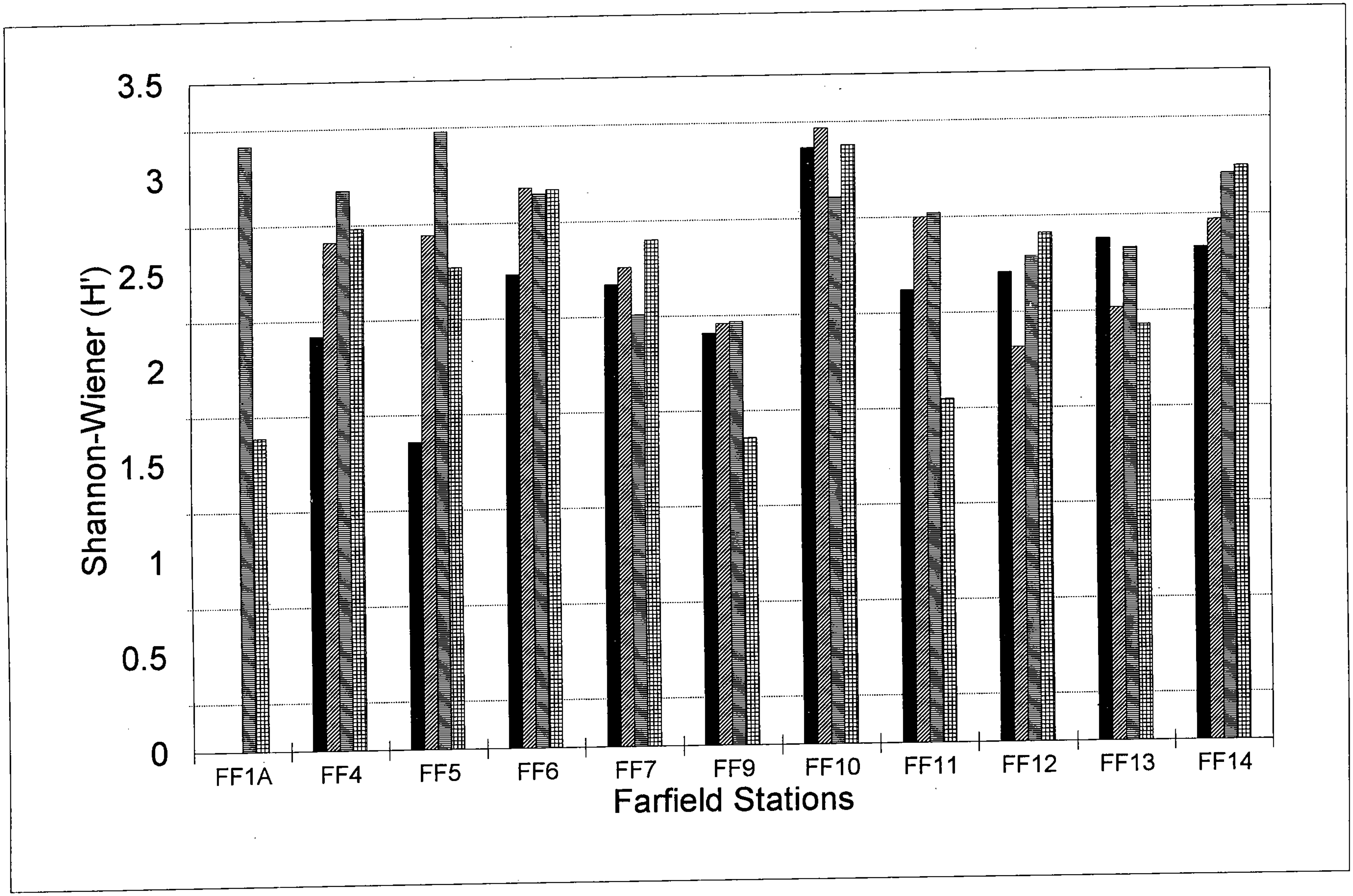


Figure 80. Species diversity, expressed as Shannon-Wiener index, in the farfield, 1992 through 1995.

steenstrupi. Figure 81 depicts the actual number of species recorded from individual farfield stations from 1992 through 1995. There is considerable variation in annual counts of total species, but no obvious pattern.

Year-to-Year Trends in Infaunal Abundance

Infaunal density data for the farfield stations exhibit large swings from year to year. Like the nearfield stations, these are caused by densities of individual species. For example, the large increase in density at station FF1a in 1995 is due to *Prionospio steenstrupi* which accounted for more than 66% of the fauna. The high abundance of this species also caused the drop in species diversity noted at the same station (see above).

Trends in infaunal abundance are shown in Figures 82-84. Total densities of all stations are shown in Figure 82. Year-to-year trends in abundance for selected dominant species at selected farfield stations are shown in Figures 83 and 84.

Each species plotted exhibits wide swings in density from year to year. These patterns are very similar to the same data generated for the Nearfield stations and very likely reflect variance in environmental conditions that in turn influence the timing of recruitment for settling invertebrate larvae of benthic organisms. Although variation in abundance of individual species does not appear to greatly influence the overall assemblage patterns as revealed in cluster analysis, it does have considerable influence on traditional benthic community parameters.

The relative consistency of faunal assemblage patterns in the farfield as opposed to the nearfield/ midfield, makes these stations ideal control locations to measure effects of the outfall. Changes occurring at the farfield stations will more than likely be due to natural environmental events rather anthropogenic ones.

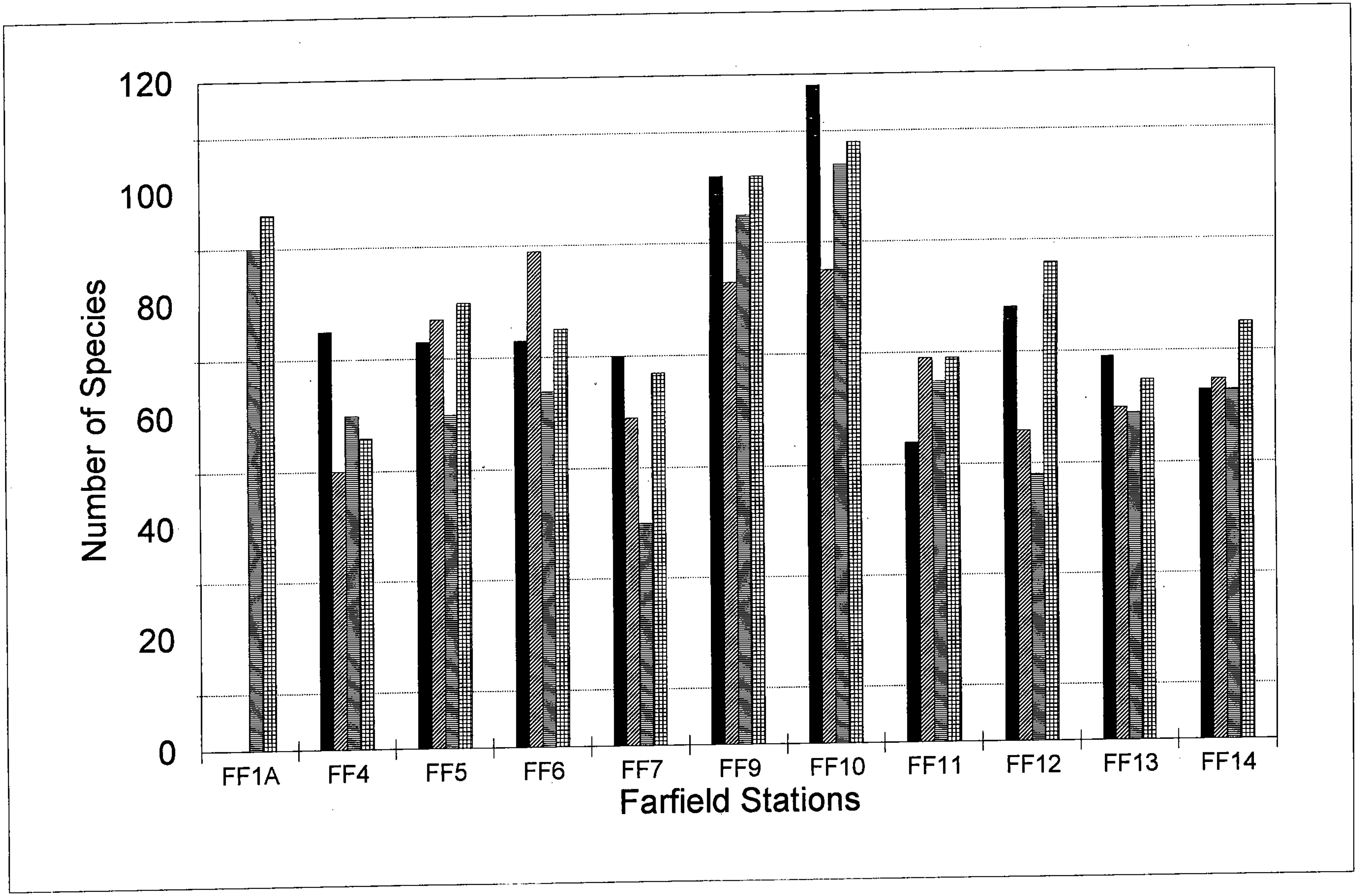


Figure 81. Species richness in the farfield, 1992 through 1995.

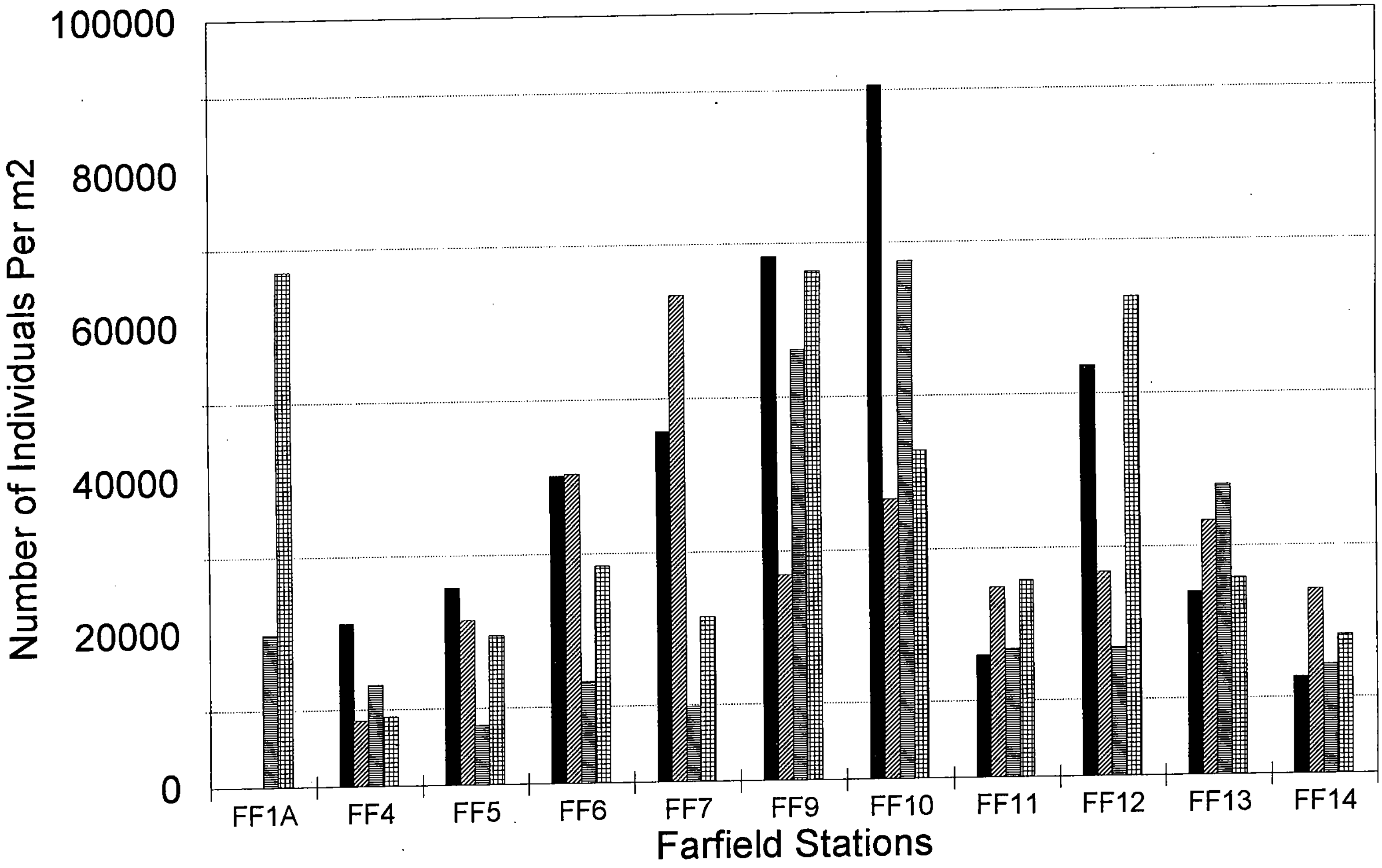


Figure 82. Total infaunal density in the farfield, 1992 through 1995.

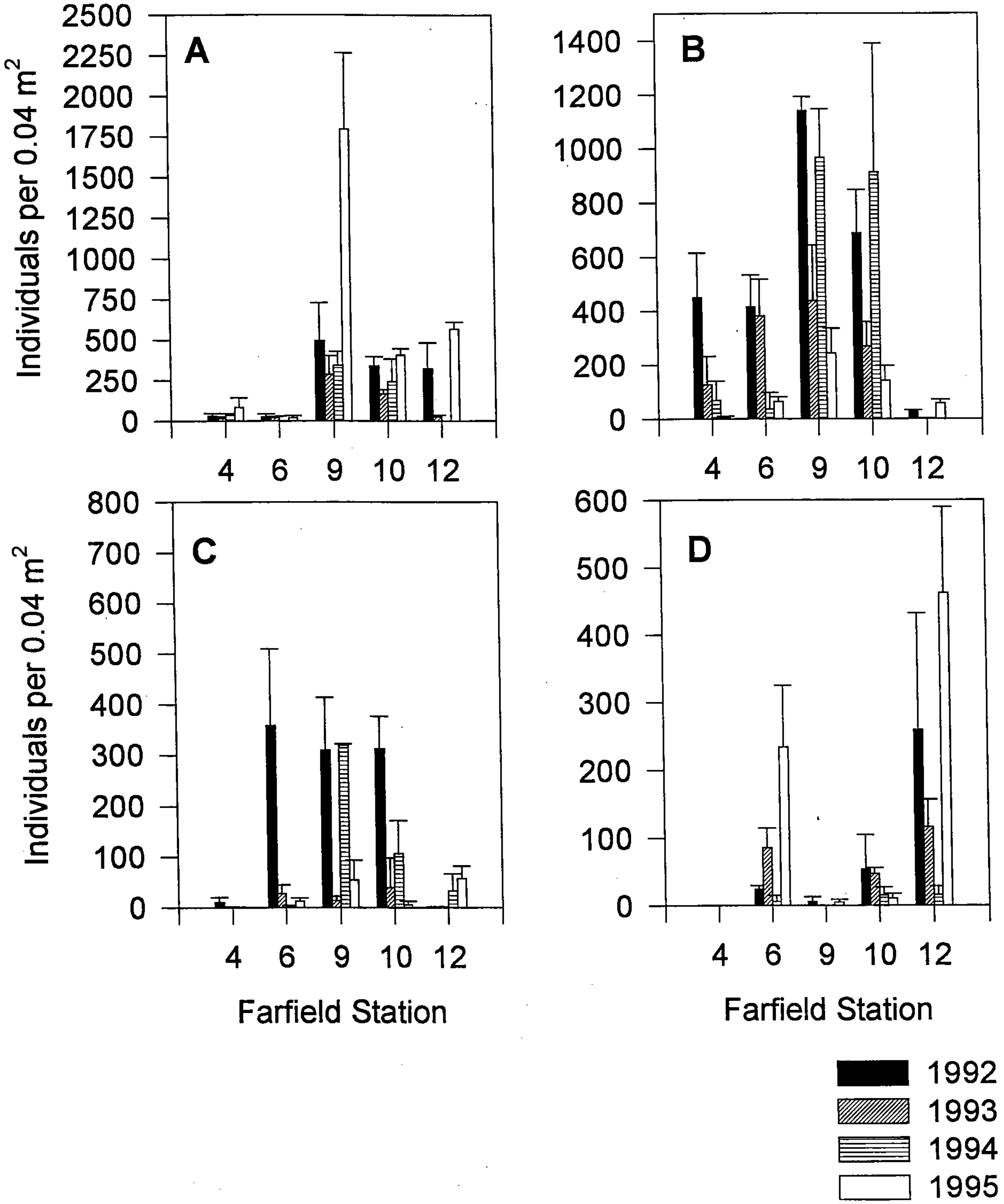


Figure 83. Density of selected species in the farfield, 1992 through 1995. (A) ***Prionospio steenstrupi*****, (B)** ***Spio limicola*****, (C)** ***Polydora socialis*****, (D)** ***Tharyx acutus*****.**

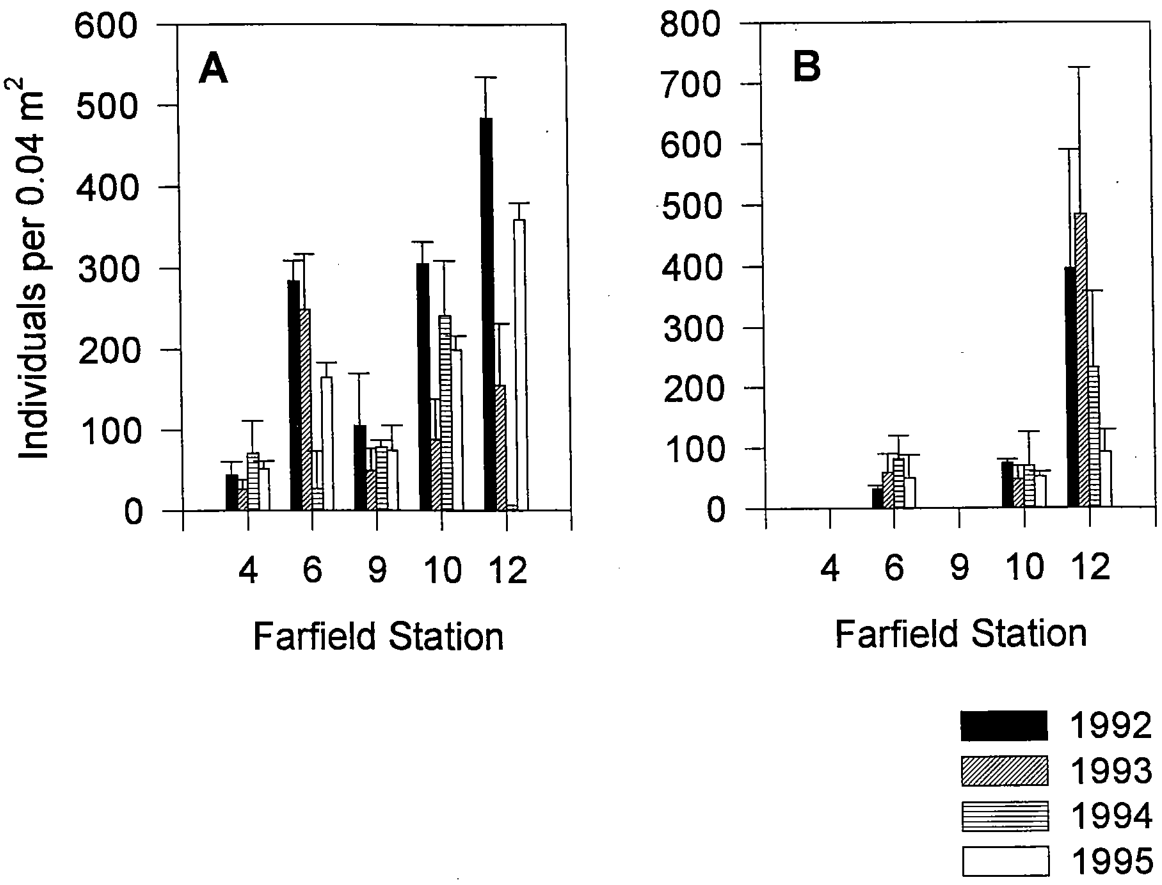


Figure 84. Density of selected species in the farfield, 1992 through 1995. (A) *Mediomastus californiensis*, (B) *Aricidea catherinae*.

4.3 Spatial and Temporal Trends in the Hardbottom Communities

The results of the 1995 survey reported here are similar to those found by Coats *et al.* (1995a) for a similar video survey conducted in 1994. Four of the six transects covered in this report (T1, T2, T4, and T6) were the same as those visited in the 1994 survey. The 1994 survey consisted of near continuous video coverage along the transects, while the present study focused on topographically selected points (waypoints) along the transects that included representative drumlin top and flank locations. Differences between the results of the two surveys appear to be related to visual resolution of the films and taxonomic designations. From the 1995 survey, 76 taxa were identified from the video tapes and 74 taxa from the still photographs, compared to 37 taxa identified from the 1994 video survey. Many of the additional taxa identified in the present study were encrusting and attached organisms. Rather than indicating changes in the benthic communities in this region, the difference in number of taxa is undoubtedly due to the greater resolution afforded by the ROV being closer to the seafloor in the present study (right on the bottom as opposed to an altitude of 1 to 3 meters). Coats *et al.* (1995a) identified an abundant pinnate red alga as *Rhodymenia* sp A, which appears to be the filamentous red alga that we tentatively identified as ?*Asparagopsis hamifera* in the present study. Additionally, their Porifera sp. A was an orange encrusting sponge, which may well be the same as the abundant orange/tan sponge found in the present study.

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

General faunal distribution patterns were similar between the 1994 and 1995 surveys. During both studies it was found that algae were most abundant on the tops of drumlins. Coats *et al.* (1995a) reported that *Rhodymenia palmata*, *Rhodymenia* sp. A (a pinnate red alga), and *Agarum cribrosum* were found together on hard substrates at shallower depths. We found that the benthic communities inhabiting drumlin tops were dominated by algae, but that some were dominated by *Lithothamnion* and other areas were dominated by ?*Asparagopsis hamifera*. While Coats *et al.* estimated percent cover of *Lithothamnion,* they did not discuss its distribution in their report. Both surveys also found that the anemone *Metridium senile* and the cunner *Tautogolabrus adspersus* were most abundant near large boulders, and that *Cerianthus borealis* and the sea scallop *Placopecten magellanicus* were usually seen in deeper low relief areas. Coats *et al.* reported that the distribution of the green sea urchin *Strongylocentrotus droebrachiensis* was depth related, with the urchins being most abundant at shallower depths. We found a similar result in that this urchin was most abundant on the tops of drumlins, but we attribute their distribution to availability of their primary food source, the coralline alga *Lithothamnion.*

Due to a different overall focus of the report by Coats *et al.* (1995a), more detailed information on distributional patterns of epifaunal taxa and their impact on the clustering of the transects was not available, so that comparisons between the the two surveys are limited to the general approach taken here. Moreover, use of a different navigational grid by Coats *et al.* makes a direct comparison of the respective transect and station locations very difficult and assessments of year-to-year trends all but impossible. The 1995 survey therefore serves as a baseline, and the upcoming surveys in 1996 and 1997 are hoped to provide sufficient data to elucidate both spatial and temporal trends of the hardbottom communities in Massachusetts Bay.

5.0 CONCLUSIONS AND RECOMMENDATIONS

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

5.1 Sediment Chemistry

- The results of the analysis of organic constituents from 1995 are similar qualitatively and quantitatively with those from prior years. The The results of analyses of the 1995 data support the modeling carried out on the 1992-1994 data.

- Concentrations are generally low and in no case does a geometric mean (or arithmetic mean) exceed 90 % of any relevant environmental standard.

- Sediment metals concentrations in the nearfield and throughout Massachusetts and Cape Cod Bays in 1995 were similar to those measured in previous years.

- Sediment concentrations of many metals throughout the monitoring region are consistent with the proposed model, which posits a tight coupling between sediment concentrations of organic carbon ligands, dissolved metal concentrations in the overlying water column, and bulk sediment metals concentrations. For some metals modeled (e.g., copper and lead), EPA chronic water quality criteria would not appear to keep sediments from eventually attaining the suggested sediment thresholds. However, either in the effluent itself or following initial dilution, actual water column concentrations of these metals in the nearfield are likely to be substantially lower than chronic criteria and the concentrations at which the suggested sediment thresholds would be reached.

- The following recommendations are offered to improve the predictive capability of th MWRA with respect to changes in sediment content of metals in the Harbor and Massachusetts and Cape Cod Bays:

- Analyze all sample variables from the same homogenized sample, i.e. metals, TOC, sediment grain size etc. to improve resolution of potentially important patterns.

- Test some of the hypotheses inherent in the assumptions made in applying this model. For example, determination of sorption isotherms for surface sediment samples from nearfield and farfield sites under well-defined conditions could enhance the confidence in predicting sediment quality using the variables proposed.

- Ambient water column concentrations are an integral part of the "story" and are not well characterized in the deeper waters of the Bay. They should be determined and examined for consistency with predictions based on recently produced 3-D hydrodynamic models for the Bay.

- Interpretation of down core profiles as an indicator of change will require careful assessment of the relative importance of decreased organic matter loading and decreased metal inputs into the system.

5.2 Sedimentology and Biology

5.2.1 Softbottom

- The apparent redox potential discontinuity (RPD) as measured by sediment profile imaging (SPI) is not comparable to visual observations from cores. However, comparison of 1992 and 1995 SPI results indicates that 50% action level (change in RPD depth) was not reached.

- Visual estimates of the apparent RPD in a sediment sample still in the grab are highly inaccurate, and the method is inappropriate if the RPD is to become a trigger parameter of the monitoring. An ongoing monitoring component incorporating sediment profile imaging should be considered.

- Only three nearfield stations had sediments fine-grained enough to be considered for testing of the RPD-related hypotheses proposed by the MWRA, resulting in a very small sample size. Increasing the sample size to at least 50 images, possibly by increasing the number of replicates per station, would lend more statistical meaningfulness to the RPD data.

- Important sedimentation changes were noted between the 1992 and 1995 SPI surveys where surficial muds were observed in the midfield. The sand over mud stratigraphy observed in 1992 was replaced by surficial muds in 1995. Large scale environmental events such as storms are the likely causes for the shifting sediments and in turn influence the benthic communities.

- Benthic community patterns observed in 1995 are broadly similar to those seen in previous baseline monitoring, both in the vicinity of the future effluent outfall and throughout Massachusetts and Cape Cod Bays. The vicinity of the outfall continues to support communities reflecting patchy sediment distributions and occasional sediment transport events, while benthic communities in the remainder of the region continue to be more stable both spatially and temporally.

- As in previous years, the structure of the benthic communities in the near- and midfield was largely determined by sediment grain size. In finer grained sediments, capitellid and spionid polychaetes were most abundant, while in sandier substrata, syllid and paraonid polychaetes, amphipod crustaceans, and certain oligochaetes predominated. These basic community structures have been observed in the area since inception of this program, with slight changes reflecting the shifting of sediments.

- Station NF24, located in the “mud patch” within the hardground close to the outfall, may be a good sentinel station for post-disposal monitoring because it appears to act as a sediment trap.

- Benthic community structure in the farfield was mostly influenced by water depth and also by location (Massachusetts Bay versus Cape Cod Bay). This general pattern seems to be consistent over time, although species diversity and species composition have been varying. These changes have likely been a reflection of natural events such as larval settlement. Continuation of sampling in the farfield will help to distinguish such natural processes from potential anthropogenic ones that are related to the operation of the outfall in the nearfield.

- High faunal similarities between the benthic communities at station FF1a and several midfield stations indicate that this station may serve as a good qualitative reference site for benthic communities near the outfall. Station FF9 seems to support a community intermediate between the midfield and offshore farfield stations and may also be a good reference point.

- The post-discharge hypotheses that are being considered by the MWRA will have to be refined and simplified. An average species diversity estimate will be established after 1997 samples have been collected and analyzed. A decrease in species diversity in itself is not necessarily a measure of "degradation", and neither is species composition. While a moderate organic enrichment of the sediment may cause the disappearance of some sensitive species, the overall effect may not necessarily be detrimental if increased biomass is available as a food source for bottom fishes.

5.2.2 Hardbottom

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

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

- The analyses of the still photographs shows finer details of the structure of benthic communities inhabiting hardbottom areas in the vicinity of the new sewage outfall than could be discerned from a review of the video tapes. The two techniques are complimentary in that the video survey provides greater areal coverage, while the still photographs provide more accurate assessments of the benthic communities inhabiting these areas.

- Both techniques are valuable for establishing baseline data of the drumlin areas near the outfall. By providing data that enables generation of "objective" descriptions of the benthic communities at each location, analysis of still photographs could facilitate detection of possible future changes. This advantage of providing data that could more readily detect possible impacts would be further enhanced by carefully and systematically collecting still photographs during any future video surveys. This ability to detect possible future impacts would further be strengthened if the still photographs were collected in a manner that permits quantitative density estimates to be made.

- This survey has addressed the structure and spatial variability of the nearfield hardbottom benthic communities. However, the temporal stability of these communities is not presently known. It would be premature to at this time attempt to predict meaningful levels of possible future impacts. Hopefully this can be addressed when we have an indication of the magnitude of natural temporal variability in these communities.

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7.0 REFERENCES

Balistrieri, L., P. G. Brewer, and J. W. Murray. 1981. Scavenging residence times of trace metals and surface chemistry of sinking particles in the deep ocean. Deep-Sea Res. 28A:101 -121.

Battelle. 1987. Benthic Reconnaissance. Final Report prepared for Camp Dresser and McKee/Stone & Webster Engineering Corporation. 57 pp. + 1 Appendix. Battelle Ocean Sciences, Duxbury, MA.

Blake, J.A. 1969. Reproduction and larval development of *Polydora* from northern New England. Ophelia 7:1-63.

Blake, J.A., E.M. Baptiste, R.E. Ruff, B. Hilbig, B. Brown, R. Etter, and P. Nimeskern. 1987. Soft-bottom Benthos of Massachusetts Bay. Marine Ecology and Water Quality Field Studies for Outfall Siting. Deer Island Secondary Treatment Facilities Plan. Report to Camp Dresser and McKee, Inc., for the Massachusetts Water Resources Authority, Boston, MA. 109 pp. + 2 Appendices.

Blake, J.A. and B. Hilbig. 1995. Combined Work/Quality Assurance Project Plan (CW/QAPP) for Benthic Monitoring: 1995-1997. MWRA Enviro. Quality Dept. Misc. Rpt. No. ms-34. Massachusetts Water Resources Authority, Boston, MA. 68 pp.

Blake, J.A., B. Hilbig, and D.C. Rhoads. 1993. Massachusetts Bay Outfall Monitoring Program. Soft Bottom Benthic Biology & Sedimentology. 1992 Baseline Conditions in Massachusetts and Cape Cod Bays. MWRA Enviro. Quality Dept. Tech. Rpt. No. 93-10. Massachusetts Water Resources Authority, Boston, MA. 108 pp. + 4 Appendices.

Blake, J.A., R.E. Ruff, and N.J. Maciolek. 1988. Soft-bottom Benthos from Stations B2 and D2 Collected in February 1988. Marine Ecology and Water Quality Field Studies for Outfall Siting. Deer Island Secondary Treatment Facilities Plan. Draft Supplemental Report to the Massachusetts Water Resources Authority, Boston MA. 24 pp + 1 Appendix.

Blake, J.A., N.J. Maciolek, and P. Rosen. 1989. Benthic Infaunal Communities of Boston Harbor. Report to the Massachusetts Water Resources Authority, Boston, MA.

Boesch, D.F. 1977. Application of Numerical Classification in Ecological Investigations of Water Pollution. U.S. Department of Commerce, EPA-60013-77-033. NTIS No. PB-269 604. 114 pp.

Bothner, M.H., Buchholtz ten Brink, M., Parmenter, C.M., d'Angelo, W.M., and M.W. Doughten. 1993. The distribution of silver and other metals in sediments from Massachusetts and Cape Cod Bays- an interim compilation. U.S.G.S. Open File Report 93-725.

Coats, D. A. 1995. 1994 Annual Soft-Bottom Benthic Monitoring. Massachusetts Bay Outfall Studies. MWRA Enviro. Quality Dept. Tech. Rpt. Series No. 95-20. Massachusetts Water Resources Authority, Boston MA. 120 pp. + Append.

Coats, D.A., E. Imamura, and J.F. Campbell. 1995a. Hard-substrate reconnaissance survey S9404 final analysis report. Massachusetts Bay Outfall Studies. MWRA Environmental Quality Dept. Tech. Rpt. Series No. 95-1. Massachusetts Water Resources Authority, Boston MA. 48 pp. + Append.

Coats, D.A., E. Imamura, and J.F. Campbell. 1995b. 1993 Annual Soft-bottom Benthic Monitoring. Massachusetts Bay Outfall Studies. MWRA Environmental Quality Dept. Tech. Rpt. Series No. 95-2. Massachusetts Water Resources Authority, Boston MA. 85 pp. + Append.

Emerson, D.J. and V.J. Cabelli. 1982. Extraction of *Clostridium perfringens* spores from bottom sediment samples. Applied Environmental Microbiology 44:1144-1149.

EPA. 1988. Boston Harbor Wastewater Conveyance System. Supplemental Environmental Impact Statement. Vol. I. U.S. Environmental Protection Agency, Region I, Boston, MA.

Etter, R., B. Hilbig, J.A. Blake, and B. Brown. 1987. Second Benthic Reconnaissance Cruise. Final Report submitted to the MWRA by Battelle Ocean Sciences. 44 pp. and 1 attachment.

Gallagher, E.D. 1995. COMPAH94 Documentation. Updated: March 12, 1995. Environmental Sciences Program, University of Massachusetts at Boston, Boston, MA. 36 pp.

Gauch, H.G. Jr. 1982. Multivariate analysis in community ecology. Cambridge Studies in Ecology, Cambridge University Press, 298 pp.

Gilbert, T.R., A.M. Clay, and C.A. Karp. 1976. Distribution of Polluted Materials in Massachusetts Bay. Report to the Commonwealth of Massachusetts, Division of Water Pollution Control. *iv* + 173 pp.

Hedges, J.I. and R.G. Keil. 1995. Sedimentary organic matter preservation: an assessment and speculative synthesis. Marine Chemistry 49:81-115. 1995

Hilbig, B. and B. Hecker. 1995. Nearfield Hardbottom Benthic Data Report for Benthic Monitoring: 1995-1997, MWRA Harbor and Outfall Monitoring Project. June 1995 Survey. MWRA Enviro. Quality Dept. Misc. Rpt. No. ms-43. Massachusetts Water Resources Authority, Boston, MA. *ii* + 46 pp. + Appendices.

Hilbig, B., J.A. Blake, D.C. Rhoads, and I.P. Williams. 1996. Boston Harbor Soft-Bottom Monitoring Program. 1995 Results. MWRA Enviro. Quality Dept. Tech. Rpt. No. 96-8. Massachusetts Water Resources Authority, Boston, MA. *iv* + 62 pp. + Appendices.

Hill, M.O. 1973. Reciprocal averaging: an eigenvector method of ordination. Journal of Ecology 61:237-249.

Hill. M.O. 1974. Correspondence analysis: a neglected multivariate method. Journal of the Royal Statistical Society, Ser. C, 23:340-354.

Hong, J., W. Calmano and U. Forstner. 1995. Interstitial Waters. In: Salbu, B. And E. Steinnes (eds.), Trace Elements in Natural Waters., CRC Press Inc., Boca Raton, FLA. p.117-150.

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

Hydroqual. 1995. A water quality model for Massachusetts and Cape Cod Bays: Calibration of the Bays Eutrophication Model (BEM). MWRA Enviro. Quality Dept. Tech. Rpt. Series 95-8. Massachusetts Water Resources Authority, Boston, MA. 402 pp.

Knebel, H.J. 1993. Sedimentary environments within a glaciated estuarine-inner shelf system: Boston Harbor and Massachusetts Bay. Marine Geology 110: 7-30.

Krahforst, C. F. and G. T. Wallace, 1996. The use of silver as a tracer of dispersion and fate of waste effluent in Massachusetts Bay. EOS 76:OS51. American Geophysical Union-Ocean Sciences Meeting, San Diego, CA.

Long, E. R., D. D. MacDonald, S. L. Smith, and F. D. Calder. 1995. Incidence of adverse biological effects within the range of chemical concentrations in marine and estuarine sediments. Environ. Management 19:81-97.

Mayer, L. 1994. Surface area control of organic carbon accumulation in continental shelf sediments. Geochim. Cosmochim. Acta 58: 1271-1284.

Martinez, A.J. and R.A. Harlow. 1994. Marine Life of the North Atlantic. Canada to New England. Privately published, 272 pp.

Metcalf and Eddy. 1984. Application for Waiver of Secondary Treatment for the Nut Island and Deer Island Treatment Plants. Report to the U.S. Environmental Protection Agency, Region I, Boston, MA. 175 pp.

MWRA. 1991. Effluent Outfall Monitoring Plan Phase I: Baseline Studies. Massachusetts Water Resources Authority, Boston, MA. 45 pp. + Appendices A-C.

MWRA. 1995. Massachusetts Water Resources Authority Effluent Outfall Monitoring Plan: Phase II Post Discharge Monitoring: Draft Report (Nov.).

Neihof, R. A. and G. Loeb. 1974. Dissolved organic matter in seawater and the electric charge of immersed surfaces. J. Mar. Res. 32:5-12.

NOAA. 1993a. *Comprehensive descriptions of complementary measurements*. Sampling and Analytical Methods of the National Status and Trends Program, National Benthic Surveillance and Mussel Watch Projects, 1984-1992 (Volume II). NOAA Technical Memorandum NOS/ORCA/CMBAD 71. 102 pp.

NOAA. 1993b. *Comprehensive descriptions of trace organic analytical methods.* Sampling and Analytical Methods of the National Status and Trends Program, National Benthic Surveillance and Mussel Watch Projects, 1984-1992 (Volume IV). NOAA Technical Memorandum NOS/ORCA/ CMBAD 71. 182 pp.

NOAA. 1993c. *Comprehensive descriptions of elemental analytical methods.* Sampling and Analytical Methods of the National Status and Trends Program, National Benthic Surveillance and Mussel Watch Projects, 1984-1992 (Volume III). NOAA Technical Memorandum NOS/ORCA/CMBAD 71.

Peet, R.K. 1974. The measurement of species diversity. Annual Review of Ecology and Systematics 5:285-307.

Rhoads, D.C. and J.D. Germano. 1986. Interpreting long-term changes in benthic community structure: A new protocol. Hydrobiology 142:291-308.

Rhoads, D.C. and D.K. Young. 1971. animal-sediment relations in Cape Cod Bay, Massachusetts. II. Reworking by *Molpadia oolitica* (Holothuroidea). Marine Biology 11:255-261.

SAIC. 1987a. REMOTS® Survey of Broad Sound, Massachusetts Bay. Rep. No. SAIC-87/7511&141. Draft report submitted by Science Applications International Corporation to Stone and Webster Engineering Corporation.

SAIC. 1987b. REMOTS® Survey of Broad Sound, Massachusetts Bay (Cruise 2). Rep. No. SAIC-87/7536163. Draft report submitted by Science Applications International Corporation to Stone and Webster Engineering Corporation.

SAIC. 1992. REMOTS® Sediment-Profile Survey of Boston Harbor, Dorchester, Quincy, Hingham, and Hull Bays, 1992. Report to the Massachusetts Water Resources Authority, Boston, MA.

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

Sebens, K.P., J.D. Witman, N. Maciolek, and B. Brown. 1987. Rocky subtidal ecology. Marine Ecology and Water Quality Field Studies for Outfall Siting. Deer Island Secondary Treatment Facilities Plan. Report to Camp Dresser and McKee, Inc. for the Massachusetts Water Resources Authority, Boston, MA. 33 pp. + Appendix.

Shea, D., D.A. Lewis, B.E. Buxton, D.C. Rhoads, and J.A. Blake. 1991. The Sedimentary Environment of Massachusetts Bay: Physical, Biological, and Chemical Characteristics. Report to the Massachusetts Water Resources Authority, Boston, MA. 81 pp. + Appendices A-C.

Shine, J. P., R. V. Ika, and T. E. Ford, 1995. Multivariate statistical examination of spatial and temporal patterns of heavy metal contamination in New Bedford Harbor marine sediments. Environ. Sci. Technol. 29: 1781-1788.

Signell, R. P., H. L. Jenter, and A. F. Blumberg, 1996. Circulation and Effluent Dilution Modeling in Massachusetts Bay: Model Implementation, Verification and Results. U. S. Geological Survey Open File Report 96-015. 121 pp.

Sokal, R.R. and P.H.A. Sneath. 1963. Principles of Numerical Taxonomy. Freeman Press, San Francisco, 573 pp.

Trueblood, D.D., E.D. Gallagher, and D.M. Gould. 1994. Three stages of seasonal succession on the Savin Hill Cove mudflat, Boston Harbor. Limnology and Oceanography 39:1440-1454.

Wallace, G.T., C. Krahforst, L. Pitts, J. Shine, M. Studer, and C. Bollinger. 1991. Assessment of the Chemical Composition of the Fox Point CSO Effluent and Associated Subtidal and Intertidal Environments: Analysis of CSO Effluents, Surface Sediments and Water Column Samples for Trace Metals Prior to CSO Modification. Final Report to Department of Environmental Protection, Executive Office of Environmental Affairs, Commonwealth of Massachusetts. 221 pp.

Weiss, H.M. 1995. Marine animals of southern New England and New York. State Geological and Natural History Survey of Connecticut, Department of Environmental Protection, Bulletin No. 115.

Whittaker, R.H. and C.W. Fairbanks. 1987. A study of plankton copepod communities in the Columbia Basin, southeastern Washington. Ecology 54:46-65.

Young, D.K. and D.C. Rhoads. 1971. Animal-sediment relations in Cape Cod Bay, Massachusetts. I. A transect study. Marine Biology 11:242-254.

Appendix A

Station Data

Appendix A1. Target locations for Outfall survey stations.

Station	Latitude	Longitude	Depth (m)
	Nearfield Stations		
NF2	42°20.31′N	70°49.69′W	30
NF4	42°24.93′N	70°48.39′W	36
NF5	42°25.62′N	70°50.03′W	36
NF7	42°24.60′N	70°48.89′W	33
NF8	42°24.00′N	70°51.81′W	32
NF9	42°23.99′N	70°50.69′W	29
NF10	42°23.57′N	70°50.29′W	35
NF12	42°23.40′N	70°49.83′W	34
NF13	42°23.40′N	70°49.35′W	33
NF14	42°23.20′N	70°49.36′W	33
NF15	42°22.93′N	70°49.67′W	32
NF16	42°22.70′N	70°50.26′W	29
NF17	42°22.88′N	70°48.89′W	29
NF18	42°23.80′N	70°49.31′W	35
NF19	42°22.30′N	70°48.30′W	32
NF20	42°22.69′N	70°50.69′W	28
NF21	42°24.16′N	70°50.19′W	33
NF22	42°20.87′N	70°48.90′W	36
NF23	42°23.86′N	70°48.10′W	36
NF24	42°22.83′N	70°48.10′W	37
	Farfield Stations		
FF1A	42°33.84′N	70°40.55′W	32
FF4	42°17.30′N	70°25.50′W	87
FF5	42°08.00′N	70°25.35′W	61
FF6	41°53.90′N	70°24.20′W	33
FF7	41°57.50′N	70°16.00′W	37
FF9	42°18.75′N	70°39.40′W	49
FF10	42°24.84′N	70°52.72′W	27
FF11	42°39.50′N	70°30.00′W	87
FF12	42°23.40′N	70°53.98′W	22
FF13	42°19.19′N	70°49.38′W	19
FF14	42°25.00′N	70°39.29′W	77

Appendix A2. Transects and waypoints visited during Nearfield Hardbottom survey, June 1995.

Transect	Waypoint	Latitude	Longitude	Depth (m)
T1	1	42°23.580′N	70°48.217′W	25
T1	2	42°23.625′N	70°48.324′W	29
T1	3	42°23.715′N	70°48.529′W	22
T1	4	42°23.815′N	70°48.743′W	21
T1	5	42°23.869′N	70°48.957′W	25
T2	1	42°23.612′N	70°47.830′W	26
T2	2	42°23.553′N	70°47.694′W	27
T2	3	42°23.510′N	70°47.394′W	29
T2	4A	42°23.457′N	70°47.244′W	32
T2	4B	42°23.503′N	70°47.264′W	32
T2	5	42°23.469′N	70°46.839′W	34
T4	1	42°23.039′N	70°46.493′W	32
T4	2	42°22.999′N	70°46.868′W	26
T4	3	42°22.847′N	70°47.573′W	31
T4	4	42°22.948′N	70°47.180′W	22
T6	1	42°22.993′N	70°47.665′W	28
T6	2	42°22.821′N	70°47.053′W	28
T6	3	42°22.606′N	70°46.114′W	27
T6	4[1]	42°22.948′N	70°47.180′W	22
T7	1	42°24.509′N	70°47.000′W	24
T8	1	42°21.616′N	70°48.952′W	22

[1] The fourth anchoring points for T4 and T6 are the same (intersection of transects)

Appendix B

Sediment and Sediment Chemistry Data

Appendix B1. Metals analysis on sediment samples from twenty Massachusetts Bay nearfield stations taken in August 1995.

Station	Aluminum %	Iron %	Cadmium µg/g	Chromium µg/g	Copper µg/g	Lead µg/g	Mercury µg/g	Nickel µg/g	Silver µg/g	Zinc µg/g
NF-2	3.39	1.74	0.16	45.5	17.0	30.6	0.134	16.3	0.34	58.8
NF-4	3.92	1.01	0.06	27.0	3.55	23.3	0.034	7.94	0.10	26.1
NF-5	4.52	1.51	0.14	63.4	11.0	31.5	0.104	13.1	0.21	42.4
NF-5 Dup.	4.75	1.57	0.12	60.7	10.6	31.7	0.116	12.6	0.20	40.8
NF-7	4.63	1.49	0.12	52.9	18.5	40.2	0.151	14.1	0.25	51.6
NF-8	6.00	2.24	0.40	121	36.0	54.4	0.350	23.4	1.10	94.5
NF-8 Dup.	6.30	2.30	0.41	120	34.5	54.7	0.371	22.5	1.05	89.3
NF-9	5.14	1.76	0.14	65.8	19.6	39.5	0.255	16.9	0.42	59.8
NF-10	5.63	1.86	0.10	60.7	17.0	37.1	0.221	15.8	0.36	54.7
NF-12 Rep. 1	5.54	1.94	0.16	79.0	25.5	49.2	0.221	19.6	0.55	64.9
NF-12 Rep. 2	3.78	1.98	0.35	96.5	30.0	56.4	0.339	22.0	0.72	68.3
NF-13	4.00	1.09	0.05	23.8	5.77	32.0	0.049	7.82	0.10	27.6
NF-14	3.19	1.18	0.07	38.3	22.6	50.5	0.403	14.2	0.21	39.4
NF-15	5.08	1.26	0.10	45.5	18.0	52.8	0.358	11.9	0.29	43.8
NF-16	4.94	1.74	0.15	69.4	22.9	43.9	0.194	16.0	0.53	58.5
NF-17 Rep. 1	1.87	0.94	0.05	19.2	4.26	31.6	0.135	6.23	0.08	21.9
NF-17 Rep. 2	4.12	1.28	0.06	29.9	4.40	36.0	0.042	8.23	0.07	28.4
NF-18	3.04	1.95	0.11	57.6	16.1	42.2	0.163	17.3	0.28	59.0
NF-19	3.97	1.58	0.08	38.1	8.32	29.2	0.083	11.7	0.21	39.3
NF-20	4.96	1.96	0.14	55.2	17.7	49.3	0.175	15.4	0.47	55.9
NF-21	4.77	2.17	0.34	100	32.6	53.8	0.681	19.5	0.87	77.7
NF-21 Dup.	4.68	2.09	0.36	98.3	32.4	53.2	0.402	19.1	0.83	75.1
NF-22	5.91	2.56	0.24	93.1	28.2	51.7	0.277	21.9	0.91	83.5
NF-23	3.52	1.42	0.06	23.2	3.41	25.8	0.029	8.75	0.09	30.2
NF-24 Rep. 1	4.70	2.67	0.40	154	49.9	80.7	2.225	28.6	1.06	112
NF-24 Rep. 2	5.41	3.20	0.52	200	58.6	105	1.162	34.9	1.15	151

Appendix B2. Metals analysis on sediment samples from eleven Massachusetts Bay and Cape Cod Bay farfield stations taken in August 1995.

Station	Aluminum %	Iron %	Cadmium µg/g	Chromium µg/g	Copper µg/g	Lead µg/g	Mercury µg/g	Nickel µg/g	Silver µg/g	Zinc µg/g
FF-1A Rep. 1	6.46	1.62	0.16	44.0	9.00	34.0	0.064	11.9	0.18	50.8
FF-1A Rep. 2	3.59	1.15	0.14	32.5	6.99	27.0	0.040	8.81	0.17	39.5
FF-4 Rep. 1	6.28	2.90	0.14	90.9	19.1	46.3	0.158	27.8	0.34	97.1
FF-4 Rep. 2	6.97	3.22	0.15	94.4	19.8	48.8	0.178	29.0	0.38	104
FF-5 Rep. 1	2.94	1.63	0.12	47.4	10.4	30.3	0.072	14.3	0.25	48.0
FF-5 Rep. 2	4.20	1.69	0.12	43.6	9.54	28.7	0.075	13.3	0.24	43.3
FF-5 Rep. 2 Dup.	4.95	1.84	0.12	46.7	10.0	29.7	0.069	13.7	0.27	45.9
FF-6 Rep. 1	3.00	1.75	0.18	52.1	13.7	35.4	0.147	15.3	0.44	48.0
FF-6 Rep. 2	4.61	2.78	0.15	83.0	21.3	47.6	0.294	23.3	0.71	79.8
FF-7 Rep.1	5.62	2.74	0.21	68.5	17.5	34.6	0.095	21.7	0.46	86.9
FF-7 Rep. 2	7.10	3.36	0.29	83.8	20.1	41.4	0.122	38.2	0.51	107
FF-9 Rep.1	4.78	1.49	0.12	32.8	5.52	25.0	0.019	11.4	0.14	32.1
FF-9 Rep. 2	4.79	1.46	0.08	38.1	5.24	25.1	0.029	39.5	0.15	33.4
FF-10 Rep. 1	5.50	1.65	0.12	50.3	7.94	29.3	0.065	10.9	0.25	41.0
FF-10 Rep. 2	5.57	1.71	0.13	63.5	9.44	32.3	0.068	12.4	0.32	43.7
FF-11 Rep. 1	6.48	2.52	0.19	67.1	15.3	37.1	0.150	20.8	0.28	70.7
FF-11 Rep. 2	6.43	2.62	0.18	70.1	15.1	36.8	0.106	22.7	0.28	76.1
FF-12 Rep. 1	3.07	1.63	0.22	53.6	17.6	33.8	0.127	13.1	0.56	45.2
FF-12 Rep. 2	5.24	1.65	0.15	46.0	12.4	30.8	0.117	11.3	0.47	44.9
FF-13 Rep. 1	5.28	2.63	0.19	53.6	19.8	34.5	0.190	15.9	0.75	61.4
FF-13 Rep. 2	5.15	2.38	0.28	57.7	21.0	38.4	0.142	15.4	0.99	60.2
FF-14 Rep. 1	5.27	2.21	0.14	58.9	11.0	32.4	0.141	22.0	0.26	56.2
FF-14 Rep. 2	6.57	2.54	0.16	74.1	14.8	42.4	0.140	20.4	0.28	73.5

Appendix B3

Sediment metals regression tables

Copper										
Nearfield										
Year	m	stderr	y	stderr	r^2	r	n	p		
1992	34.494	2.531	-8.361	8.140	0.907	0.952	21	<0.001		
1993	19.405	2.126	10.240	5.752	0.912	0.955	10	<0.001	(- NF14)	
1994	20.107	2.473	7.170	6.068	0.777	0.881	21	<0.001		
1995	17.405	1.247	6.134	3.681	0.911	0.955	21	<0.001		
Mean										
All	22.9	7.8	3.8	8.3						
(-1992)	19.0	1.4	7.8	2.1						
Farfield										
Year	m	stderr	y	stderr	r^2	r	n	p		
1992	6.493	0.986	6.370	1.886	0.828	0.910	11	<0.001		
1993	7.463	0.572	8.179	1.094	0.960	0.980	9	<0.001		
1994	7.468	1.777	7.191	3.384	0.688	0.830	10	<0.005		
1995	6.565	0.654	4.455	1.402	0.926	0.963	10	<0.001		
Mean										
All	7.0	0.5	6.5	1.6						
(-1992)	7.2	0.5	6.6	1.9						

Zinc										
Nearfield										
Year	m	stderr	y	stderr	r^2	r	n	p		
1992	62.150	4.032	3.382	12.966	0.926	0.962	21	<0.001		
1993	42.743	5.008	31.130	13.549	0.901	0.949	10	<0.001	(- NF14)	
1994	36.809	4.983	28.270	12.230	0.742	0.861	21	<0.001		
1995	35.917	2.732	29.010	8.066	0.901	0.949	21	<0.001		
Mean										
All	44.4	12.2	22.9	13.1						
(-1992)	38.5	3.7	29.5	1.5						
Farfield										
Year	m	stderr	y	stderr	r^2	r	n	p		
1992	37.162	4.373	15.075	8.363	0.889	0.943	11	<0.001		
1993	39.467	2.376	21.721	4.545	0.975	0.988	9	<0.001		
1994	37.019	2.164	23.492	4.122	0.973	0.987	10	<0.001		
1995	32.344	2.663	20.343	5.709	0.949	0.974	10	<0.001		
Mean										
All	36.5	3.0	20.2	3.6						
(-1992)	36.3	3.6	21.9	1.6						

Lead										
Nearfield										
Year	m	stderr	y	stderr	r^2	r	n	p		
1992	33.518	2.393	13.611	7.695	0.912	0.955	21	<0.001		
1993	22.681	3.169	25.754	8.575	0.865	0.930	10	<0.001	(- NF14)	
1994	24.292	1.986	25.417	4.873	0.887	0.942	21	<0.001		
1995	20.256	2.411	27.580	7.120	0.788	0.888	21	<0.001		
Mean										
All	25.2	5.8	23.1	6.4						
(-1992)	22.4	2.0	26.3	1.2						
Farfield										
Year	m	stderr	y	stderr	r^2	r	n	p		
1992	10.541	2.700	23.847	5.163	0.629	0.793	11	<0.005		
1993	12.681	2.787	25.630	5.329	0.747	0.865	9	<0.005		
1994	10.864	2.199	24.897	4.188	0.753	0.868	10	<0.002		
1995	8.223	1.553	24.620	3.329	0.778	0.882	10	<0.001		
Mean										
All	10.6	1.8	24.7	0.7						
(-1992)	10.6	2.2	25.0	0.5						

Cadmium

Nearfield									
Year	m	stderr	y	stderr	r^2	r	n	p	
1992	0.285	0.037	-0.121	0.118	0.758	0.871	21	<0.001	
1993	0.282	0.027	0.028	0.074	0.930	0.964	10	<0.001	(- NF14)
1994	0.211	0.036	-0.013	0.088	0.647	0.804	21	<0.001	
1995	0.167	0.014	0.040	0.043	0.874	0.935	21	<0.001	
Mean									
All	0.236	0.058	-0.017	0.073					
(-1992)	0.220	0.058	0.018	0.028					
Farfield									
Year	m	stderr	y	stderr	r^2	r	n	p	
1992	0.046	0.012	0.072	0.023	0.614	0.783	11	<0.005	
1993	0.058	0.032	0.060	0.060	0.326	0.571	9	>0.05	
1994	0.040	0.018	0.068	0.034	0.392	0.626	10	>0.05	
1995	0.046	0.013	0.094	0.029	0.597	0.772	10	<0.01	
Mean									
All	0.048	0.008	0.073	0.015					
(92,95)	0.046	0.000	0.083	0.015					

Silver										
Nearfield										
Year	m	stderr	y	stderr	r^2	r	n	p		
1992	1.299	0.188	-0.575	0.605	0.715	0.846	21	<0.001		
1993	0.769	0.094	0.048	0.255	0.893	0.945	10	<0.001	(- NF14)	
1994	0.729	0.113	-0.016	0.278	0.685	0.828	21	<0.001		
1995	0.449	0.048	0.118	0.143	0.819	0.905	21	<0.001		
Mean										
All	0.812	0.355	-0.106	0.317						
(-1992)	0.649	0.174	0.050	0.067						
Farfield										
Year	m	stderr	y	stderr	r^2	r	n	p		
1992	0.042	0.074	0.208	0.141	0.034	0.185	11	>0.05		
1993	0.103	0.053	0.105	0.102	0.349	0.591	9	>0.05		
1994	0.121	0.037	0.092	0.068	0.642	0.801	8	<0.02	(- FF6 and FF10)	
1995	0.134	0.023	0.096	0.045	0.850	0.922	8	<0.001	(- FF6 and FF10)	
Mean										
All	0.100	0.041	0.125	0.055						
(-'92,'93)	0.127	0.009	0.094	0.003						

Mercury									
Nearfield									
Year	m	stderr	y	stderr	r^2	r	n	p	
1992	0.464	0.174	-0.071	0.559	0.273	0.522	21	<0.02	
1993	0.216	0.023	0.049	0.062	0.916	0.957	10	<0.001	(- NF14)
1994	0.162	0.022	0.057	0.055	0.734	0.857	21	<0.001	
1995	0.324	0.043	0.002	0.127	0.750	0.866	21	<0.001	(-NF24 C1 value)
Mean									
All	0.291	0.133	0.009	0.059					
(-1992)	0.234	0.082	0.036	0.030					
Farfield									
Year	m	stderr	y	stderr	r^2	r	n	p	
1992	0.037	0.025	0.070	0.049	0.189	0.435	11	>0.05	
1993	0.071	0.013	0.037	0.025	0.807	0.898	9	<0.001	
1994	0.029	0.008	0.045	0.015	0.674	0.821	8	<0.02	(-FF6 and FF10)
1995	0.052	0.012	0.033	0.026	0.716	0.846	9	<0.005	(-FF6)
Mean									
All	0.047	0.018	0.046	0.016					
(- 1992)	0.051	0.021	0.038	0.006					

Nickel										
Nearfield										
Year	m	stderr	y	stderr	r^2	r	n	p		
1992	9.465	1.209	7.955	3.889	0.763	0.874	21	<0.001		
1993	9.182	1.558	11.852	4.216	0.813	0.902	10	<0.001	(- NF14)	
1994	6.812	2.718	11.592	6.671	0.248	0.498	21	<0.05		
1995	8.063	0.832	9.357	2.456	0.832	0.912	21	<0.001		
Mean										
All	8.4	1.2	10.2	1.9						
(-1992)	8.0	1.2	10.9	1.4						
Farfield										
Year	m	stderr	y	stderr	r^2	r	n	p		
1992	14.059	1.844	2.343	3.527	0.866	0.931	11	<0.001		
1993	11.031	0.830	9.099	1.587	0.962	0.981	9	<0.001		
1994	11.852	1.000	6.854	1.905	0.946	0.973	10	<0.001		
1995	7.041	2.477	10.659	5.311	0.502	0.709	10	<0.05		
Mean										
All	11.0	2.9	7.2	3.6						
(-1992)	10.0	2.6	8.9	1.9						

Chromium										
Nearfield										
Year	m	stderr	y	stderr	r^2	r	n	p		
1992	83.846	5.944	-5.647	19.114	0.913	0.955	21	<0.001		
1993	66.966	7.652	32.095	20.704	0.905	0.952	10	<0.001	(- NF14)	
1994	70.522	8.457	28.386	20.757	0.785	0.886	21	<0.001		
1995	54.627	2.763	20.627	8.157	0.954	0.977	21	<0.001		
Mean										
All	69.0	12.0	18.9	17.0						
(-1992)	64.0	8.3	27.0	5.9						
Farfield										
Year	m	stderr	y	stderr	r^2	r	n	p		
1992	16.002	6.481	51.755	12.394	0.404	0.635	11	<0.05		
1993	27.670	6.569	43.180	12.562	0.717	0.847	9	<0.005		
1994	30.319	9.190	49.910	17.504	0.576	0.759	10	<0.02		
1995	22.286	3.738	33.133	8.014	0.816	0.903	10	<0.001		
Mean										
All	24.1	6.3	44.5	8.4						
(-1992)	26.8	4.1	42.1	8.4						

Iron									
Nearfield									
Year	m	stderr	y	stderr	r^2	r	n	p	
1992	0.983	0.173	1.337	0.555	0.631	0.794	21	<0.001	
1993	0.763	0.213	1.643	0.575	0.617	0.785	10	<0.05	(- NF14)
1994	0.645	0.241	1.778	0.591	0.274	0.524	21	<0.02	
1995	0.647	0.102	1.275	0.300	0.681	0.825	21	<0.001	
Mean									
All	0.76	0.16	1.51	0.24					
(-1992)	0.68	0.07	1.57	0.26					
Farfield									
Year	m	stderr	y	stderr	r^2	r	n	p	
1992	1.024	0.160	1.061	0.307	0.819	0.905	11	<0.001	
1993	1.143	0.045	1.235	0.086	0.989	0.995	9	<0.001	
1994	1.098	0.086	1.165	0.164	0.953	0.976	10	<0.001	
1995	0.872	0.076	1.021	0.163	0.943	0.971	10	<0.001	
Mean									
All	1.03	0.12	1.12	0.10					
(-1992)	1.04	0.15	1.14	0.11					

Aluminum									
Nearfield									
Year	m	stderr	y	stderr	r^2	r	n	p	
1992	0.779	0.160	4.413	0.515	0.555	0.745	21	<0.001	
1993	0.767	0.299	4.366	0.810	0.451	0.672	10	<0.05	(- NF14)
1994	0.326	0.408	4.940	1.003	0.032	0.180	21	>0.05	
1995	0.906	0.248	3.797	0.732	0.413	0.643	21	<0.005	
Mean									
All	0.69	0.25	4.38	0.47					
(-1994)	0.82	0.08	4.19	0.34					
Farfield									
Year	m	stderr	y	stderr	r^2	r	n	p	
1992	1.020	0.194	4.418	0.371	0.754	0.869	11	<0.001	
1993	0.909	0.168	4.395	0.322	0.807	0.898	9	<0.001	
1994	0.495	0.270	5.268	0.514	0.296	0.544	10	>0.05	
1995	0.873	0.408	4.217	0.876	0.363	0.603	10	>0.05	
Mean									
All	0.82	0.23	4.57	0.47					
(92,93)	0.70	0.29	4.83	0.62					

Appendix B4. Concentrations (ng/g) of polynuclear aromatic hydrocarbons (PAHs) and linear alkyl benzenes (LABs) in sediments from twenty Massachusetts Bay nearfield stations taken in August 1995. (ND=not detected; L=value >10-20% above calibration range, therefore analysis rerun on diluted sample).

Chemistry Analytes	NF-2	NF-4	NF-5	NF-7	NF-8	NF-9	NF-10	NF-12 Rep. 1	NF-12 Rep. 2	NF-13	NF-14	NF-15
Polynuclear Aromatic Hydrocarbons (PAHs)												
Naphthalene	8.7	3.4	50	150	110	80	41	84	110	3.1	25	26
C1-naphthalenes	4.3	ND	13	35	57	22	15	36	66	1.6	6.8	10
C2-naphthalenes	7.7	ND	21	53	96	37	26	59	110	ND	13	21
C3-naphthalenes	6.4	ND	35	93	130	51	34	62	140	ND	14	21
C4-naphthalenes	ND	ND	29	63	72	40	30	53	70	ND	9.4	19
Benzothiazole	ND	ND	1.2	1	2.6	1	2.5	1.7	1.2	0.51	0.72	1.1
Acenaphthylene	4.7	1.7	67	120	100	66	30	58	52	1.7	11	15
Acenaphthene	2	ND	12	43	41	23	20	84	160	0.99	9.5	17
Biphenyl	1.3	ND	4.5	13	14	7.4	5.5	11	19	0.54	2.4	3.7
Dibenzofuran	2.8	ND	16	52	41	22	14	58	110	1.2	8.6	12
Fluorene	4.1	ND	41	100	95	48	29	110	220	1.7	15	22
C1-fluorenes	4	ND	34	90	70	41	29	62	91	1.5	10	15
C2-fluorenes	4.4	ND	32	86	79	44	35	60	73	ND	12	19
C3-fluorenes	9.2	ND	42	160	140	67	49	100	110	ND	22	36
Phenanthrene	24	5	290	630	630	300	220	690	1300 L	16	110	150
Anthracene	8.1	1.6	230	250	270	170	89	230	450	4.3	34	48
C1-phenanthrenes/anthracene	18	4.3	210	400	440	230	210	360	570	8.8	58	91
C2-phenanthrenes/anthracene	19	3.5	160	300	350	200	190	250	360	7	43	73
C3-phenanthrenes/anthracene	13	ND	66	140	170	92	97	120	150	3.2	22	38
C4-phenanthrenes/anthracene	20	ND	130	230	260	150	120	180	250	5.9	36	50
Dibenzothiophene	2.1	0.47	20	46	42	21	14	47	89	1.1	7.9	10
C1-dibenzothiophenes	3.2	ND	25	47	56	29	23	41	64	0.87	7.9	12
C2-dibenzothiophenes	5.4	ND	34	62	84	43	32	48	61	1.1	9.7	15
C3-dibenzothiophenes	7.5	ND	21	40	69	32	24	33	36	ND	7	11
Fluoranthene	57	11	820	1400 L	1300 L	700 L	450	1100 L	1700 L	28	190	280
Pyrene	58	11	670	1300 L	1300 L	640 L	450	1000 L	1500 L	25	160	250
C1-fluoranthenes/pyrenes	41	9	450	810	910	480	370	630	850	15	100	160
C2-fluoranthenes/pyrenes	27	5.6	170	390	440	240	190	310	390	8.6	54	100
C3-fluoranthenes/pyrenes	15	ND	69	140	190	96	82	130	170	3.5	24	41
Benzo(a)anthracene	31	7.3	400	840 L	720	410	280	560	750	15	91	140
Chrysene	35	7.6	390	610	700	390	280	530	740	15	94	140
C1-chrysene	24	4.8	190	370	430	230	190	330	410	8.7	52	86
C2-chrysene	16	3.1	80	150	190	110	86	150	190	3.9	25	44
C2-chrysene	13	ND	59	120	150	82	69	120	130	3.5	19	32
C4-chrysene	8.4	ND	24	51	71	40	31	49	62	2.3	11	16
Benzo(b)fluoranthene	35	8.7	350	650 L	780 L	350	220	460	590 L	14	98	120
Benzo(k)fluoranthene	14	3.9	150	240	250	130	92	180	210	6.1	38	49
Benzo(e)pyrene	20	5.1	180	310	360	180	120	240	310	7.7	54	69
Benzo(a)pyrene	24	5.6	300	460 L	540 L	290	200	390	450 L	10	74	100
Perylene	8.5	1.6	71	120	130	68	46	90	120	2.8	18	24
Indeno(1,2,3-c,d)pyrene	19	4.6	190	290	350	180	110	230	320	7.7	54	69
Diabenzo(a,h)anthracene	3.7	0.72	39	65	74	39	26	50	66	1.6	11	14
Benzo(g,h,i)perylene	18	5.3	160	270	320	160	100	210	270	6.8	49	59
Linear Alkyl Benzenes												
C10-alkylbenzene	5	ND	5.5	12	45	10	6.7	14	25	ND	3.2	3.2
C11-alkylbenzene	7.7	ND	6.4	12	75	14	8.6	17	27	ND	3.7	6.4
C12-alkylbenzene	7	ND	2.5	4.7	46	9	4.1	11	14	ND	2.1	3.4
C13-alkylbenzene	ND	ND	ND	ND	25	ND	ND	ND	5.8	ND	ND	ND
C14-alklybenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Appendix B4 continued.

Chemistry Analytes	NF-16	NF-17 Rep. 1	NF-17 Rep. 2	NF-18	NF-19	NF-19 Dup.	NF-20	NF-21	NF-22	NF-23	NF-24 Rep. 1	NF-24 Rep. 2
Polynuclear Aromatic Hydrocarbons (PAHs)												
Naphthalene	48	3.3	2.4	30	19	15	31	150	47	3.8	140	190
C1-naphthalenes	22	1.3	1.6	10	6.9	5.9	16	46	20	2	46	65
C2-naphthalenes	35	ND	ND	15	11	9.6	29	76	34	ND	75	90
C3-naphthalenes	37	ND	ND	15	8.5	9.7	52	120	63	ND	120	140
C4-naphthalenes	28	ND	ND	15	ND	ND	27	73	30	ND	67	84
Benzothiazole	3.3	1.6	0.82	ND	ND	ND	1.2	2.2	1.5	0.96	2.4	4.6
Acenaphthylene	32	0.97	0.49	20	11	9.9	23	100	30	2	110	130
Acenaphthene	24	ND	ND	9.9	7.5	6.3	ND	36	18	ND	40	42
Biphenyl	6.5	ND	ND	3.5	2.4	2.2	4.4	14	6.2	0.84	15	21
Dibenzofuran	21	0.62	0.4	9	6.9	5.6	16	42	17	0.88	44	76
Fluorene	36	0.68	ND	16	11	10	29	79	30	1.1	76	180
C1-fluorenes	23	ND	ND	13	6.6	6.5	21	68	24	ND	63	66
C2-fluorenes	28	ND	ND	17	8.6	7.6	22	75	37	ND	70	67
C3-fluorenes	50	ND	ND	23	14	16	21	62	56	ND	47	81
Phenanthrene	250	5.2	2.8	120	79	69	200	500	200	6.2	490	650
Anthracene	87	1.6	0.8	45	26	22	64	200	72	2.2	240	900
C1-phenanthrenes/anthracene	160	3.3	1.9	86	48	40	130	360	140	4.8	350	390
C2-phenanthrenes/anthracene	130	3.6	2	70	42	34	110	300	120	5.9	320	360
C3-phenanthrenes/anthracene	67	ND	ND	36	23	19	52	180	66	ND	170	230
C4-phenanthrenes/anthracene	94	ND	ND	55	36	24	120	270	140	ND	220	380
Dibenzothiophene	18	0.35	0.24	8.5	5.7	4.9	14	37	15	0.56	39	48
C1-dibenzothiophenes	19	ND	ND	10	5.5	5.7	16	50	19	ND	48	52
C2-dibenzothiophenes	26	ND	ND	15	9.2	8.9	22	83	31	ND	78	83
C3-dibenzothiophenes	19	ND	ND	12	7.7	6.7	16	63	28	ND	64	82
Fluoranthene	490	12	5.6	240	150	120	410	1100 L	400	15	1000	1100
Pyrene	450	12	5.5	240	140	110	380	1100 L	380	14	940	1000
C1-fluoranthenes/pyrenes	300	7.4	3.5	170	93	76	220	690	230	9	630	710
C2-fluoranthenes/pyrenes	160	4.5	1.6	86	50	42	120	120	140	6.4	360	390
C3-fluoranthenes/pyrenes	70	ND	ND	39	24	20	52	170	58	ND	180	150
Benzo(a)anthracene	250	7.2	3.4	140	84	64	200	590	200	8.2	540	600
Chrysene	250	7.7	3.6	140	88	68	200	590	210	10	540	610
C1-chrysene	160	4.3	2.2	88	56	42	130	330	120	6.4	330	390
C2-chrysene	74	2.4	ND	43	25	22	55	200	72	ND	170	200
C2-chrysene	60	ND	ND	32	21	15	ND	140	42	ND	89	110
C4-chrysene	30	ND	ND	17	11	9.4	ND	81	32	ND	77	86
Benzo(b)fluoranthene	240	7.4	4.6	140	78	66	230	740 L	240	10	610	700
Benzo(k)fluoranthene	86	3.1	2	55	29	27	77	240	97	4.4	250	260
Benzo(e)pyrene	130	4.1	2.8	79	43	37	120	360	130	6	340	390
Benzo(a)pyrene	200	5.3	2.8	100	61	51	170	520	180	7	510	570
Perylene	46	1.3	0.72	28	15	13	43	120	47	2.1	130	140
Indeno(1,2,3-c,d)pyrene	130	3.9	2.2	78	43	37	120	340	140	6.1	380	370
Diabenzo(a,h)anthracene	25	0.68	0.34	16	8.5	7.5	22	70	26	1.2	72	73
Benzo(g,h,i)perylene	120	3.9	2.1	72	40	35	110	320	130	5.8	330	340
Linear Alkyl Benzenes												
C10-alkylbenzene	15	ND	ND	6.9	6.7	5.3	17	30	36	ND	63	57
C11-alkylbenzene	22	ND	ND	5.1	6.5	4.7	19	73	76	ND	89	82
C12-alkylbenzene	22	ND	ND	2.9	3.4	2.7	14	82	44	ND	63	74
C13-alkylbenzene	11	ND	ND	ND	ND	ND	6.3	55	31	ND	32	42
C14-alklybenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Appendix B5. Concentrations (ng/g) of polychlorinated biphenyls (PCBs) and pesticides in sediments from twenty Massachusetts Bay nearfield stations taken in August 1995. (ND=not detected; L=value >10-20% above calibration range, therefore analysis rerun on diluted sample).

Chemistry Analytes	NF-2	NF-4	NF-5	NF-7	NF-8	NF-9	NF-10	NF-12 Rep. 1	NF-12 Rep. 2	NF-13	NF-14	NF-15
Polychlorinated Biphenyls (PCBs)												
2,4-Cl2(8)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,2',5-Cl3(18)	ND	ND	ND	ND	ND	ND	ND	5.4 L	6 L	ND	0.81	ND
2,4,4'-Cl3(28)	0.2	ND	0.2	0.28	1.1	0.35	0.21	0.33	0.32	ND	ND	ND
2,2',3,5'-Cl4(44)	ND	ND	ND	ND	0.68	0.18	ND	0.24	0.16	ND	ND	ND
2,2',5,5'-Cl4(52)	0.41	ND	0.33	0.78	1.7	0.55	0.35	0.75	0.67	ND	ND	0.46
2,3',4,4'-Cl4(66)	0.27	ND	ND	0.61	1.7	0.54	0.32	0.46	1.2	ND	ND	0.29
3,3',4,4'-Cl4(77)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,2',4,5,5'-Cl5(101)	0.41	ND	0.6	1.5	3.3	0.96	0.64	0.89	0.89	ND	ND	0.48
2,3,3',4,4'-Cl5(105)	0.18	ND	0.36	0.53	2	0.52	0.42	0.83	1	ND	0.22	0.3
2,3',4,4',5-Cl5 (118)	0.63	ND	1.6	2.1	5.6	2.4	1.1	2.2	2.6	ND	0.47	0.75
3,3',4,4',5-Cl5(126)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,2',3,3',4,4'-Cl6(128)	0.18	ND	0.36	0.85	1.5	0.61	0.44	0.71	0.8	ND	0.2	0.32
2,2',3,4,4',5'-Cl6(138)	0.92	0.3	2	4.6	6.4	ND	1.5	3.5	2.9	0.29	1.2	1.2
2,2',4,4',5,5'-Cl6(153)	0.83	ND	1.6	4.6	5.9	2	1.2	2.1	1.9	0.12	0.65	0.85
2,2',3,3',4,4',5-Cl7(170)	0.15	ND	0.21	1.3	1.4	0.46	0.15	0.46	0.37	0.044	0.1	0.18
2,2',3,4,4',5,5'-Cl7(180)	0.8	0.33	1.1	5.1	5	1.8	0.92	2.1	2	0.14	0.55	0.82
2,2',3,4,5,5',6-Cl7(187)	0.27	ND	0.72	3.1	0.89	0.55	0.27	0.6	0.48	0.32	0.23	0.2
2,2',3,3',4,4',5,6-Cl8 (195)	0.17	ND	0.23	1.5	0.7	0.32	0.57	1.1	1	0.1	0.79	0.36
2,2',3,3',4,4',5,5',6-Cl9 (206)	0.21	ND	0.67	2.4	1.7	0.8	0.64	1.3	0.62	0.041	0.26	0.23
Decachlorobiphenyl-Cl10(209)	0.27	ND	0.21	1.1	0.67	0.32	0.17	0.33	0.22	ND	0.12	0.22
Pesticides												
Hexachlorobenzene	ND	ND	0.03	ND	ND	ND	0.56	ND	ND	ND	ND	ND
Lindane	0.31	ND	0.07	0.53	0.29	0.07	ND	0.09	ND	ND	0.58	ND
Heptachlor	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Aldrin	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Heptachloroepoxide	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ALPHA-CHLORDANE	ND	ND	ND	0.75	0.56	0.44	ND	ND	ND	ND	ND	ND
TRANS-NONACHLOR	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dieldrin	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Endrin	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mirex	ND	ND	ND	0.33	0.35	ND	ND	ND	0.22	ND	0.09	0.11
2,4'-DDD	0.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4,4'-DDD	0.63	ND	0.51	0.53	2.9	0.84	0.47	0.96	1	ND	0.28	0.38
2,4'-DDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.2
4,4'-DDE	0.46	ND	ND	ND	ND	ND	0.36	0.65	0.74	ND	0.19	0.27
2,4'-DDT	ND	ND	1	ND	1.3	ND	0.64	ND	ND	ND	ND	ND
4,4'-DDT	ND	ND	ND	ND	0.33	ND	0.32	ND	1.3	ND	ND	ND
DDMU	0.58	ND	0.11	1.4	0.92	0.52	0.33	0.42	0.49	ND	ND	ND

Appendix B5 continued.

Chemistry Analytes	NF-16	NF-17 Rep. 1	NF-17 Rep. 2	NF-18	NF-19	NF-19 Dup.	NF-20	NF-21	NF-22	NF-23	NF-24 Rep. 1	NF-24 Rep. 2
Polychlorinated Biphenyls (PCBs)												
2,4-Cl2(8)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,2',5-Cl3(18)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,4,4'-Cl3(28)	0.35	ND	ND	0.16	ND	ND	0.26	0.65	ND	ND	0.87	1.1
2,2',3,5'-Cl4(44)	0.26	ND	ND	ND	ND	ND	ND	0.33	0.24	ND	0.4	0.56
2,2',5,5'-Cl4(52)	0.61	ND	ND	ND	ND	ND	0.49	1.3	0.62	ND	1.9	1.7
2,3',4,4'-Cl4(66)	0.82	ND	ND	ND	ND	ND	ND	1.3	0.78	ND	1.5	1.6
3,3',4,4'-Cl4(77)	ND	ND	ND	ND	0.77	0.73	ND	ND	ND	ND	ND	ND
2,2',4,5,5'-Cl5(101)	1.2	ND	ND	0.43	0.31	0.27	0.61	2.5	1.4	ND	3.5	3.7
2,3,3',4,4'-Cl5(105)	0.79	ND	ND	0.26	0.2	0.19	0.42	1.2	0.8	ND	1.5	1.8
2,3',4,4',5-Cl5 (118)	1.9	ND	ND	0.86	0.67	0.6	1.5	3.5	3.2	ND	5.3	7.1
3,3',4,4',5-Cl5(126)	0.26	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,2',3,3',4,4'-Cl6(128)	0.65	ND	ND	0.32	0.23	0.2	0.5	1.4	0.78	ND	1.5	1.7
2,2',3,4,4',5'-Cl6(138)	2.5	ND	0.36	1.3	0.65	0.62	1.7	5.1	3.3	0.36	12	8.7
2,2',4,4',5,5'-Cl6(153)	2.4	ND	0.36	0.97	0.84	0.86	1.7	5	3.3	ND	6.6	7.8
2,2',3,3',4,4',5-Cl7(170)	0.44	ND	0.11	0.18	0.13	0.13	0.26	0.97	0.47	ND	1.4	1.4
2,2',3,4,4',5,5'-Cl7(180)	1.7	ND	0.53	0.73	0.55	0.52	1.1	3.5	2.8	0.4	4.9	6.8
2,2',3,4,5,5',6-Cl7(187)	0.54	ND	0.49	0.42	0.34	0.29	0.4	2	0.97	0.22	2.8	3.4
2,2',3,3',4,4',5,6-Cl8 (195)	0.82	ND	ND	0.51	0.48	0.53	0.9	3.2	1	ND	3	2
2,2',3,3',4,4',5,5',6-Cl9 (206)	0.53	ND	0.28	0.35	0.2	0.22	0.3	1.8	0.61	0.088	3	3.4
Decachlorobiphenyl-Cl10(209)	0.19	ND	ND	0.2	0.12	0.12	0.18	1	0.44	ND	1.1	1.7
Pesticides												
Hexachlorobenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Lindane	0.15	ND	ND	0.22	0.17	0.2	0.18	0.11	0.12	ND	0.38	0.26
Heptachlor	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Aldrin	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Heptachloroepoxide	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ALPHA-CHLORDANE	ND	ND	ND	ND	ND	ND	ND	0.79	0.38	ND	1.2	0.97
TRANS-NONACHLOR	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dieldrin	0.33	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Endrin	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mirex	0.18	ND	ND	0.077	ND	ND	0.14	0.38	0.15	ND	0.4	0.41
2,4'-DDD	ND	ND	ND	1.8	1.1	1.3	ND	2.6	2.1	ND	5.3	5.6
4,4'-DDD	0.86	ND	ND	0.62	0.25	0.26	0.6	2.4	1.3	ND	2.8	3
2,4'-DDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4,4'-DDE	0.72	ND	ND	ND	0.24	0.23	0.47	ND	1.1	ND	ND	2.1
2,4'-DDT	ND	ND	ND	0.32	ND	ND	0.56	1.5	0.69	ND	1.2	1.3
4,4'-DDT	0.3	ND	ND	0.68	ND	ND	0.24	ND	3.6	ND	0.63	0.48
DDMU	0.35	ND	ND	0.51	ND	ND	0.35	1.9	0.4	ND	2.3	1.1

Appendix B6. Concentrations (ng/g) of polynuclear aromatic hydrocarbons (PAHs) and linear alkyl benzenes (LABs) in sediments from eleven Massachusetts Bay and Cape Cod Bay farfield stations taken in August 1995.

Chemistry Analytes	FF-1A Rep. 1	FF-1A Rep. 2	FF-4 Rep. 1	FF-4 Rep. 2	FF-5 Rep. 1	FF-5 Rep. 1 Dup.	FF-5 Rep. 2	FF-6 Rep. 1	FF-6 Rep. 2	FF-7 Rep. 1	FF-7 Rep. 2
Polynuclear Aromatic Hydrocarbons (PAHs)											
Naphthalene	25	13	27	27	11	10	10	19	25	18	16
C1-naphthalenes	12	7.8	12	13	4.8	4.2	4.3	7.7	11	7.4	6.8
C2-naphthalenes	18	9.6	18	18	7.1	6.2	6.2	11	15	11	10
C3-naphthalenes	19	9	17	16	5.9	5.7	5.2	10	15	10	9.4
C4-naphthalenes	14	7.2	13	12	5.2	4.4	4.4	8.5	11	9.5	9.1
Benzothiazole	2	1.1	1.6	1.7	2.2	0.85	0.9	1.1	5.2	2.5	1.3
Acenaphthylene	53	26	30	28	9.7	8.6	8.7	15	20	16	13
Acenaphthene	10	4.3	5.9	6.3	2.5	2.2	2.2	4.8	6.1	4.2	3.4
Biphenyl	4	2.3	5.2	5.2	1.9	1.8	1.7	3	3.9	3.3	3.1
Dibenzofuran	11	5.1	11	11	3.8	3.6	3.5	6.4	8.5	7.5	6.8
Fluorene	24	11	15	14	5.4	4.9	4.8	9.8	13	9.5	8.6
C1-fluorenes	22	8.7	12	12	3.9	4.1	3.8	7.4	10	7.6	6.6
C2-fluorenes	32	14	18	18	7.8	5.8	5.1	11	14	11	10
C3-fluorenes	18	8.5	17	14	4.9	5.1	5.2	9.7	12	9	7.4
Phenanthrene	160	79	110	110	39	36	36	71	91	68	60
Anthracene	60	28	29	29	10	9.6	9.7	20	26	18	16
C1-phenanthrenes/anthracene	130	56	80	81	27	26	26	48	64	49	42
C2-phenanthrenes/anthracene	120	48	70	70	25	23	23	42	59	45	38
C3-phenanthrenes/anthracene	60	29	36	37	13	12	12	22	29	26	20
C4-phenanthrenes/anthracene	95	47	71	56	25	20	24	42	46	36	36
Dibenzothiophene	12	5.3	8.8	8.7	3.1	3	2.9	5.6	7.3	5.7	5
C1-dibenzothiophenes	18	6.6	13	13	4.3	4.3	4.1	7.2	10	7.5	6.9
C2-dibenzothiophenes	30	11	19	19	6.4	6	6	10	14	11	9.4
C3-dibenzothiophenes	24	10	18	16	6.5	5.1	5.2	9.5	13	10	8.7
Fluoranthene	380	190	230	230	84	77	80	150	180	160	130
Pyrene	340	170	200	210	73	66	69	130	160	130	110
C1-fluoranthenes/pyrenes	300	130	140	140	48	44	46	86	110	86	72
C2-fluoranthenes/pyrenes	140	65	84	89	29	27	27	50	64	52	43
C3-fluoranthenes/pyrenes	64	28	44	45	15	13	14	25	30	26	21
Benzo(a)anthracene	230	110	110	110	41	35	37	71	88	69	58
Chrysene	220	100	130	130	45	43	44	78	100	78	66
C1-chrysene	170	75	88	88	30	27	29	49	62	53	43
C2-chrysene	76	39	50	51	18	16	17	29	39	31	27
C2-chrysene	38	22	34	36	14	12	12	22	28	23	20
C4-chrysene	17	10	20	22	7.8	7.6	7.6	11	14	14	12
Benzo(b)fluoranthene	190	71	120	110	40	34	36	74	83	67	60
Benzo(k)fluoranthene	68	22	36	35	12	13	12	24	30	21	20
Benzo(e)pyrene	99	37	67	59	22	19	19	40	45	36	32
Benzo(a)pyrene	160	58	80	72	26	23	23	51	60	44	39
Perylene	38	14	25	23	8.2	7.5	7.4	16	18	15	14
Indeno(1,2,3-c,d)pyrene	120	49	95	84	30	27	27	56	65	51	46
Diabenzo(a,h)anthracene	23	8.1	15	13	4.8	4.2	4.2	9	10	7.8	7
Benzo(g,h,i)perylene	110	45	91	80	30	27	26	54	62	50	45
Linear Alkyl Benzenes											
C10-alkylbenzene	ND	ND	12	8.3	ND	ND	5	15	12	ND	ND
C11-alkylbenzene	ND	ND	13	11	ND	ND	4.7	12	14	ND	ND
C12-alkylbenzene	ND	ND	7.8	4.8	ND	ND	0.66	ND	9.4	ND	ND
C13-alkylbenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
C14-alklybenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Appendix B6 continued.

Chemistry Analytes	FF-9 Rep. 1	FF-9 Rep. 2	FF-10 Rep. 1	FF-10 Rep. 2	FF-11 Rep. 1	FF-11 Rep. 2	FF-12 Rep. 1	FF-12 Rep. 2	FF-13 Rep. 1	FF-13 Rep. 2	FF-14 Rep. 1	FF-14 Rep. 2
Polynuclear Aromatic Hydrocarbons (PAHs)												
Naphthalene	13	14	23	86	21	21	27	21	18	24	24	28
C1-naphthalenes	3.9	4.4	9.2	16	12	13	12	10	9.5	10	9.3	11
C2-naphthalenes	5.6	5.1	13	73	19	19	24	16	13	12	14	16
C3-naphthalenes	16	6.7	14	170	40	18	29	19	13	13	32	36
C4-naphthalenes	2.8	3.7	9.1	79	15	14	20	13	9	12	9.7	13
Benzothiazole	0.94	0.69	0.86	1.1	2.8	2.5	1.3	0.95	2	1.8	1.6	2.1
Acenaphthylene	7.3	7.2	21	270	39	37	42	21	16	14	25	29
Acenaphthene	2.9	3	14	32	8.1	6.7	15	7.6	4.3	4.7	5	7.3
Biphenyl	1.4	1.4	3.2	8.5	5.2	5.4	3.9	3.2	3.2	3	3.8	4.7
Dibenzofuran	2.8	2.7	13	37	9.6	9.1	14	8.4	5.9	5.8	7.4	9.7
Fluorene	4.7	5	24	190	18	17	37	16	9.3	8.6	12	15
C1-fluorenes	3.6	3.6	14	120	16	14	29	15	8.3	7.7	11	12
C2-fluorenes	4.5	5.4	13	120	24	20	28	17	16	13	13	14
C3-fluorenes	3.8	12	9.7	54	16	15	23	11	15	12	11	40
Phenanthrene	33	36	170	1800	140	130	240	120	62	62	92	110
Anthracene	11	12	64	810	42	41	120	52	23	23	29	34
C1-phenanthrenes/anthracene	23	23	93	740	110	110	160	94	47	47	70	85
C2-phenanthrenes/anthracene	18	21	65	420	97	96	110	69	45	44	64	72
C3-phenanthrenes/anthracene	8.2	12	30	170	54	50	54	32	30	30	34	34
C4-phenanthrenes/anthracene	13	16	53	310	71	63	86	46	47	42	52	58
Dibenzothiophene	2.5	2.7	12	84	10	10	16	9.2	5.5	5.3	7	8.7
C1-dibenzothiophenes	3.3	3.4	10	64	16	17	18	11	7.2	7.1	11	13
C2-dibenzothiophenes	4.7	5.4	12	57	27	26	22	13	12	11	17	19
C3-dibenzothiophenes	4.1	5.5	9.9	34	24	23	24	11	13	13	16	17
Fluoranthene	64	72	280	2900 E	280	270	460	250	140	140	190	220
Pyrene	59	63	260	2500	260	260	400	230	140	130	180	200
C1-fluoranthenes/pyrenes	42	45	170	1200	210	210	320	170	98	92	140	150
C2-fluoranthenes/pyrenes	21	26	72	380	120	120	140	74	59	56	81	87
C3-fluoranthenes/pyrenes	11	15	35	150	62	58	60	35	31	30	38	43
Benzo(a)anthracene	34	37	160	1200	160	160	260	140	78	74	100	110
Chrysene	37	40	150	1100	170	170	240	120	83	82	110	120
C1-chrysene	23	30	90	470	140	140	170	91	59	58	83	93
C2-chrysene	12	17	42	180	66	75	71	40	36	36	41	45
C2-chrysene	9	12	26	110	52	42	48	30	32	26	28	34
C4-chrysene	4.6	5.9	12	46	21	22	24	14	17	17	14	22
Benzo(b)fluoranthene	35	40	130	1000	140	140	160	130	84	88	140	150
Benzo(k)fluoranthene	13	15	47	330	55	41	56	44	28	24	46	56
Benzo(e)pyrene	19	21	71	430	79	74	84	70	43	43	75	84
Benzo(a)pyrene	26	28	110	970	110	100	140	110	58	59	99	110
Perylene	7.4	8	28	210	32	29	34	27	17	17	28	32
Indeno(1,2,3-c,d)pyrene	23	24	85	570	96	100	97	84	53	61	88	100
Diabenzo(a,h)anthracene	4.3	4.5	16	110	18	17	20	16	9.4	10	16	19
Benzo(g,h,i)perylene	21	23	72	500	90	96	92	80	46	56	82	94
Linear Alkyl Benzenes												
C10-alkylbenzene	ND	ND	7.2	25	ND	ND	21	13	65	48	ND	ND
C11-alkylbenzene	ND	ND	6.7	ND	ND	ND	24	19	120	89	ND	ND
C12-alkylbenzene	ND	ND	ND	ND	ND	ND	19	14	80	64	ND	ND
C13-alkylbenzene	ND	ND	ND	ND	ND	ND	18	9.2	47	37	ND	ND
C14-alklybenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Appendix B7. Concentrations (ng/g) of polychlorinated biphenyls (PCBs) and pesticides in sediments from eleven Massachusetts Bay and Cape Cod Bay farfield stations taken in August 1995. (ND=not detected; G= value should considered an estimate due to interference).

Chemistry Analytes	FF-1A Rep. 1	FF-1A Rep. 2	FF-4 Rep. 1	FF-4 Rep.	FF-5 Rep. 1	FF-5 Rep. 1 Dup.	FF-5 Rep. 2	FF-6 Rep. 1	FF-6 Rep. 2	FF-7 Rep. 1	FF-7 Rep. 2
Polychlorinated Biphenyls (PCBs)											
2,4-Cl2(8)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,2',5-Cl3(18)	0.35	0.31	ND	ND	ND	ND	ND	5.6 G	0.9	14 G	30 G
2,4,4'-Cl3(28)	0.29	0.16	0.64	0.5	0.24	0.23	0.19	ND	0.58	ND	0.58
2,2',3,5'-Cl4(44)	ND	ND	0.31	0.29	ND	ND	ND	ND	0.18	ND	ND
2,2',5,5'-Cl4(52)	ND	ND	0.51	ND	ND	ND	ND	ND	0.82	ND	ND
2,3',4,4'-Cl4(66)	0.29	ND	0.46	0.46	0.21	ND	ND	0.46	0.57	ND	0.6
3,3',4,4'-Cl4(77)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,2',4,5,5'-Cl5(101)	0.39	0.26	0.94	0.81	0.43	0.37	0.35	0.79	1.2	1.1	1.1
2,3,3',4,4'-Cl5(105)	0.34	0.18	0.54	0.54	0.24	0.24	0.23	0.48	0.68	0.47	0.47
2,3',4,4',5-Cl5 (118)	1.1	0.56	1.6	1.4	0.73	0.68	0.64	1.6	2.2	1.7	1.6
3,3',4,4',5-Cl5(126)	0.4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,2',3,3',4,4'-Cl6(128)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,2',3,4,4',5'-Cl6(138)	1	0.87	1.8	1.9	1	1	0.84	2.2	3.4	2.3	2.4
2,2',4,4',5,5'-Cl6(153)	0.66	0.43	1.4	1.8	0.93	0.85	0.81	2.1	2.2	2	1.9
2,2',3,3',4,4',5-Cl7(170)	0.13	0.06	0.32	0.31	0.17	0.16	0.15	0.3	0.52	0.24	0.24
2,2',3,4,4',5,5'-Cl7(180)	0.84	0.57	0.94	1	0.52	0.4	0.46	0.82	1.3	1.2	0.75
2,2',3,4,5,5',6-Cl7(187)	2.4	1.2	3.1	3.2	1.3	1.2	1.2	2.2	3.1	2.5	2.4
2,2',3,3',4,4',5,6-Cl8 (195)	0.9	0.43	0.6	0.56	ND	ND	ND	0.4	0.6	0.37	0.37
2,2',3,3',4,4',5,5',6-Cl9 (206)	0.2	0.1	0.5	0.62	0.27	0.26	0.23	0.32	0.41	0.32	0.35
Decachlorobiphenyl-Cl10(209)	0.11	0.06	0.32	0.32	0.12	0.12	0.11	0.16	0.23	0.2	0.16
Pesticides											
Hexachlorobenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Lindane	ND	ND	ND	0.29	ND	ND	ND	ND	0.38	ND	ND
Heptachlor	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Aldrin	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Heptachloroepoxide	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ALPHA-CHLORDANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TRANS-NONACHLOR	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dieldrin	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Endrin	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mirex	0.2	ND	0.22	0.15	ND	ND	ND	0.14	ND	ND	ND
2,4'-DDD	ND	ND	1.2	1	0.51	0.53	0.56	0.93	ND	1.6	1.5
4,4'-DDD	0.6	0.31	1.3	1.4	0.5	0.55	0.44	0.8	1.1	1.2	1.1
2,4'-DDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4,4'-DDE	ND	ND	ND	ND	ND	ND	ND	ND	1.2	1.1	1.1
2,4'-DDT	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.52	0.37
4,4'-DDT	ND	ND	0.52	ND	ND	ND	ND	0.67	0.38	0.65	ND
DDMU	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Appendix B7 continued.

Chemistry Analytes	FF-9 Rep. 1	FF-9 Rep. 2	FF-10 Rep. 1	FF-10 Rep. 2	FF-11 Rep. 1	FF-11 Rep. 2	FF-12 Rep. 1	FF-12 Rep. 2	FF-13 Rep. 1	FF-13 Rep. 2	FF-14 Rep. 1	FF-14 Rep. 2
Polychlorinated Biphenyls (PCBs)												
2,4-Cl2(8)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,2',5-Cl3(18)	ND	ND	ND	ND	1.4	0.94	ND	ND	ND	ND	ND	ND
2,4,4'-Cl3(28)	ND	ND	ND	0.38	0.55	ND	0.35	ND	0.64	0.55	0.67	0.83
2,2',3,5'-Cl4(44)	ND	ND	ND	ND	ND	ND	0.23	ND	0.32	0.2	0.28	0.32
2,2',5,5'-Cl4(52)	ND	ND	0.54	0.59	ND	ND	0.77	0.45	0.52	0.64	0.49	0.62
2,3',4,4'-Cl4(66)	ND	ND	0.34	ND	0.95	0.89	0.68	0.43	0.76	0.76	0.56	0.68
3,3',4,4'-Cl4(77)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,2',4,5,5'-Cl5(101)	0.19	0.2	0.58	0.87	0.55	0.46	1.4	0.8	1.5	1.4	0.79	0.97
2,3,3',4,4'-Cl5(105)	0.12	0.12	0.34	0.82	0.46	0.42	0.8	0.49	0.82	0.79	0.34	0.44
2,3',4,4',5-Cl5 (118)	0.38	0.37	0.98	ND	0.97	0.9	2.1	1.4	2.6	2.3	1	1.2
3,3',4,4',5-Cl5(126)	ND	ND	ND	1.6	ND	ND	ND	ND	ND	ND	ND	ND
2,2',3,3',4,4'-Cl6(128)	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.57	ND	ND
2,2',3,4,4',5'-Cl6(138)	0.59	0.67	1	1.6	1.6	1.3	2.5	1.7	3.5	3.1	2	2.2
2,2',4,4',5,5'-Cl6(153)	0.5	0.46	1.1	1	0.99	0.97	2.4	1.7	3.4	3.3	1.9	2.3
2,2',3,3',4,4',5-Cl7(170)	0.1	0.12	0.13	ND	0.2	0.2	0.3	0.22	0.54	0.51	0.45	0.36
2,2',3,4,4',5,5'-Cl7(180)	0.33	0.29	0.71	ND	0.61	0.88	1.6	1.5	3.1	1.4	1.4	1.2
2,2',3,4,5,5',6-Cl7(187)	0.79	0.75	1.7	2.3	3	3	2.6	1.9	2.8	2.4	2.5	2.9
2,2',3,3',4,4',5,6-Cl8 (195)	ND	ND	0.68	3.8	0.64	0.77	1	0.51	0.52	0.61	0.72	0.84
2,2',3,3',4,4',5,5',6-Cl9 (206)	0.22	0.12	0.24	1.7 G	0.39	0.38	0.38	0.3	0.59	0.46	0.44	0.37
Decachlorobiphenyl-Cl10(209)	0.062	0.058	0.052	ND	0.33	0.28	0.18	0.12	0.3	0.27	0.26	0.28
Pesticides												
Hexachlorobenzene	ND	ND	ND	ND	ND	ND	ND	0.066	0.43	ND	ND	ND
Lindane	ND	ND	ND	ND	0.18	0.18	ND	ND	ND	ND	ND	ND
Heptachlor	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Aldrin	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Heptachloroepoxide	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ALPHA-CHLORDANE	ND	ND	ND	ND	ND	ND	ND	ND	0.32	0.3	ND	ND
TRANS-NONACHLOR	ND	ND	ND	ND	ND	ND	ND	ND	0.56	0.52	ND	ND
Dieldrin	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Endrin	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mirex	ND	ND	ND	ND	0.28	ND	ND	ND	ND	ND	ND	ND
2,4'-DDD	0.53	0.6	ND	ND	2.5	ND	1.9	1.6	0.32	0.99	ND	ND
4,4'-DDD	0.28	0.21	0.37	0.55	0.9	0.77	0.73	0.47	0.74	0.76	1	1.3
2,4'-DDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4,4'-DDE	0.17	0.16	ND	ND	ND	ND	0.76	ND	ND	ND	ND	ND
2,4'-DDT	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4,4'-DDT	ND	ND	ND	2.1	0.76	ND	ND	ND	ND	0.27	ND	0.99
DDMU	ND	ND	ND	1.3	ND	ND	0.33	ND	ND	ND	ND	0.25

Appendix B8. Total sediment PAH concentrations (ng/g), near/midfield and farfield, 1992-1995.

Station	1992	1993	1994	1995
NF1	524.12312			
NF2	4185.5021	160.53	923.1	602.7
NF3	1358.1039			
NF4	428.07167	247.98	63.67	109.29
NF5	6312.9119		9802.75	6089.5
NF6	11577.423			
NF7	21467.087		6222.18	11207
NF8	20167.434	26162.735	7484.98	11950
NF9	6751.6539	3622.775	4007.97	6272.4
NF10	4250.5474	3708.02	4835.21	4482.5
NF11	1686.1708			
NF12	10593.14	15310.24	10498.905	11158
NF13	393.74833		987.72	232.5
NF14	4974.8288	4258.085	2185.53	1623.6
NF15	6294.1593		2202.88	2374.7
NF16	12878.06	7911.16	13647.26	4280.5
NF17	583.0078	101.915	137.66	78.285
NF18	2962.624		3816.65	2322.9
NF19	331.97814		1309.53	1374.1
NF20	16492.18		1772.41	3506.4
NF21			8545.06	10473
NF22			5631.34	3902.2
NF23			799.68	134.6
NF24			7563.31	10903
FF1a	4145.4964	5140.55	2845.79	2565.2
FF4	1406.0996	3439.34	2447.06	2146.05

Station	**1992**	**1993**	**1994**	**1995**
FF5	799.95242	1243.07	891.28	734.95
FF6	1375.6981	1731.12	1810.8	1506.75
FF7	1866.4963	2356.015	1436.095	1237.45
FF8	596.41899			
FF9	1019.0923	997.215	1050.06	658.75
FF10	1739.0926	1665.095	3509.43	10984.3
FF11	3411.5373	5507.165	3810.245	2757.7
FF12	2348.2208	3248.875	3718.74	3044.45
FF13	1095.7946	2409.335	2449.72	1439.55
FF14	2286.757	2966.245	2401.085	2168.75

Appendix B9. Total sediment naphthalene concentrations (ng/g), near/midfield and farfield, 1992-1995.

Station	1992	1993	1994	1995
NF1	15.49059			
NF2	172.13189	16.45	51.25	27.1
NF3	56.26425			
NF4	16.87318	22.3	3.01	3.4
NF5	128.57153		428.32	148
NF6	488.37291			
NF7	605.18444		353.74	394
NF8	1152.9484	1351.975	515.66	465
NF9	287.17527	173.47	262.4	230
NF10	174.81449	174.01	287.23	146
NF11	61.99624			
NF12	427.06336	729.825	641.84	395
NF13	17.25481		42.34	4.7
NF14	144.7707	183.61	158.63	68.2
NF15	214.70999		133.17	97
NF16	440.23663	325.185	850.11	170
NF17	24.51826	12.365	7.795	4.3
NF18	142.89652		188.17	85
NF19	11.87689		60.67	45.4
NF20	918.98141		64.85	155
NF21			571.5	465
NF22			275.62	194
NF23			46.74	5.8
NF24			378.905	508.5
FF1a	164.72125	231.6275	87.325	67.3
FF4	43.45368	165.65	69.91	86.5

Station	1992	1993	1994	1995
FF5	31.12081	70.47	44.29	32.05
FF6	55.23241	91.805	85.805	66.6
FF7	85.42013	121.6	68.36	53.6
FF8	28.79325			
FF9	57.486355	52.43	76.385	37.6
FF10	53.4097	63.73	144.81	246.15
FF11	101.49761	202.31	160.61	96
FF12	87.164155	149.95	192.11	95.5
FF13	49.333325	124.66	179.71	66.75
FF14	89.53995	145.225	127.66	96.5

Appendix B10. Total sediment PCB concentrations (ng/g), near/midfield and farfield, 1992-1995.

Station	1992	1993	1994	1995
NF1	3.42167			
NF2	40.3055	6.8	9.312	5.9
NF3	5.05315			
NF4	2.54147	8.465	0.529	0.63
NF5	13.78475		20.385	10.19
NF6	24.4951			
NF7	18.20579		27.349	30.35
NF8	77.14996	131.98	43.06	40.24
NF9	13.6207	21.805	13.843	12.36
NF10	8.93932	21.59	13.275	8.9
NF11	6.66072			
NF12	19.90621	74.66	32.9615	23.215
NF13	2.28449		1.692	1.055
NF14	7.1398	11.15	7.328	5.6
NF15	6.60888		3.958	6.66
NF16	32.24635	25.88	32.305	15.96
NF17	0	7.225	1.2805	1.065
NF18	8.66852		10.665	6.69
NF19	2.96175		7.561	5.49
NF20	28.06224		6.955	10.32
NF21			34.701	34.75
NF22			20.974	20.71
NF23			6.263	1.068
NF24			19.0715	52.865
FF1a	20.10912	31.5	4.898	7.2975
FF4	4.89807	28.23	14.3205	13.845

Station	**1992**	**1993**	**1994**	**1995**
FF5	3.70615	14.4	6.4875	5.685
FF6	7.9111	24.365	12.8525	18.16
FF7	12.231525	33.985	10.382	34.66
FF8	5.04891			
FF9	4.03841	11.42	5.4695	3.22
FF10	4.53879	18.575	10.2225	11.526
FF11	11.076245	23.145	20.7315	12.015
FF12	12.362985	20.305	16.9	14.405
FF13	13.51166	41.485	10.014	20.585
FF14	14.35151	23.465	14.8595	14.655

Appendix B11. Total sediment chlordane concentrations (ng/g), near/midfield and farfield, 1992-1995

Station	1992	1993	1994	1995
NF1	0			
NF2	0	2.235	0.371	0
NF3	0			
NF4	0	1.88	0	0
NF5	0		0.719	0
NF6	0			
NF7	0		1.532	0.75
NF8	0	3.13	2.043	0.56
NF9	0	2.7	0.602	0.44
NF10	0	1.84	0.473	0
NF11	0.62698			
NF12	0.73985	2.365	1.4475	0
NF13	0.04156		0	0
NF14	0	2.035	0.544	0
NF15	0		0.326	0
NF16	0	1.55	1.411	0
NF17	0	2.775	0.105	0
NF18	0		0	0
NF19	0		0.343	0
NF20	1.39769		0.371	0
NF21			3.932	0.79
NF22			1.283	0.38
NF23			1.215	0
NF24			0.8	1.085
FF1a	0	5.73	0.59	0
FF4	0	5.62	1.4955	0

Station	**1992**	**1993**	**1994**	**1995**
FF5	0	3.575	0.3315	0
FF6	0	3.975	0.6475	0
FF7	0	5.765	0.464	0
FF8	2.471995			
FF9	0	2.995	0.348	0
FF10	0	2.955	0.845	0
FF11	0	4.385	1.5045	0
FF12	0	2.47	0.8505	0
FF13	0	2.51	0.8625	0.85
FF14	0	3.96	1.027	0

Appendix B12. Total sediment DDT concentrations (ng/g), near/midfield and farfield, 1992-1995

Station	1992	1993	1994	1995
NF1	1.65204			
NF2	6.14948	1.53	1.705	1.79
NF3	1.06288			
NF4	0.34596	1.6	0	0
NF5	2.22317		4.234	1.51
NF6	3.76465			
NF7	4.68962		7.313	0.53
NF8	17.36616	19.235	68.328	4.53
NF9	4.16496	3.85	3.658	0.84
NF10	2.29888	4.045	3.857	1.79
NF11	0.76317			
NF12	3.95758	11.19	18.284	2.325
NF13	0.96234		0	0
NF14	2.12594	3.305	2.883	0.47
NF15	2.20631		0.776	0.85
NF16	6.41715	4.625	12.374	1.88
NF17	0	2.18	0.206	0
NF18	4.24624		2.908	3.42
NF19	1.10098		2.132	1.59
NF20	7.9544		1.273	1.87
NF21			19.66	6.5
NF22			6.732	8.79
NF23			0.298	0
NF24			6.193	11.205
FF1a	5.360545	9.445	1.64	0.455
FF4	0	8.785	5.437	2.71

Station	1992	1993	1994	1995
FF5	0.60291	4.13	2.634	1.005
FF6	0.826265	6.28	4.1195	2.54
FF7	2.06122	8.92	3.5305	4.57
FF8	2.06486			
FF9	1.015245	3.63	2.0885	0.975
FF10	2.267045	4.03	3.5905	1.51
FF11	3.12082	7.95	6.5855	2.465
FF12	2.4692	3.93	3.4815	2.73
FF13	1.42577	5.245	3.4095	1.54
FF14	2.58766	6.655	6.839	1.645

Appendix B13. Total sediment LAB concentrations (ng/g), near/midfield and farfield, 1992-1995.

Station	1992	1993	1994	1995
NF1	73.17079			
NF2	2044.909	47.69	107.54	19.7
NF3	101.39431			
NF4	36.53786	0	0	0
NF5	45.4208		0	14.4
NF6	84.70595			
NF7	0		158.49	28.7
NF8	2037.2947	1773.945	833.39	191
NF9	86.5263	206.81	120.41	33
NF10	113.17945	183.54	91.8	19.4
NF11	17.25361			
NF12	211.43816	786.28	402.04	56.9
NF13	19.43855		0	0
NF14	74.32087	59.825	0	9
NF15	62.82469		0	13
NF16	621.05898	253.495	666.51	70
NF17	54.40684	0	0	0
NF18	154.61669		50.22	14.9
NF19	16.39511		220.02	16.6
NF20	585.80365		240.43	56.3
NF21			303.7	240
NF22			441.86	187
NF23			32.05	0
NF24			98.355	251
FF1a	0	0	0	0
FF4	0	0	0	28.45

Station	1992	1993	1994	1995
FF5	0	0	0	5.18
FF6	28.95864	134.905	224.575	31.2
FF7	131.20206	0	0	0
FF8	9.66837			
FF9	24.437005	0	50.865	0
FF10	52.95175	0	92.29	19.45
FF11	34.37849	0	57.5	0
FF12	235.71922	258.615	243.09	68.6
FF13	381.72728	1136.03	734.145	275
FF14	47.001035	0	21.875	0

Appendix B14. Grain-size composition of sediment from twenty Massachusetts Bay nearfield stations taken in August 1995. Data are percentages of total initial sample weight.

Station	% Gravel	% Very Coarse Sand	% Coarse Sand	% Medium Sand	% Fine Sand	% Very Fine Sand	% Total Sand	% Silt	% Clay	Mean Phi
	>2.00 mm	>1.00 to 2.00 mm	>0.50 to 1.00 mm	>0.25 to 0.50 mm	>0.125 to 0.25 mm	>0.0625 to 0.125 mm	>0.0625 to 2.00 mm	>0.0039 to 0.0625 mm	<0.0039 mm	
	Phi < -1	-1 < Phi < 0	0 < Phi < 1	1 < Phi < 2	2 < Phi < 3	3 < Phi < 4	-1 < Phi < 4	4 < Phi < 8	Phi > 8	
NF-2	0.8	0.72	7.09	48.93	33.48	2.44	92.7	3.6	3.0	2.16
NF-4	0.1	0.04	0.42	19.47	70.27	6.51	96.7	1.2	2.0	2.53
NF-5	6.1	0.22	0.44	4.40	49.75	12.07	66.9	16.0	11.0	3.60
NF-7	1.5	1.89	4.75	15.65	28.84	13.23	64.4	24.2	10.0	3.76
NF-8	0.0	0.07	0.10	0.31	3.50	10.03	14.0	71.9	14.0	6.02
NF-9	3.0	0.50	1.40	4.05	11.18	36.45	53.6	33.5	10.0	4.48
NF-10	0.0	0.09	0.27	1.29	10.29	43.38	55.3	36.4	8.2	4.72
NF-12	0.0	0.02	0.22	1.27	9.13	20.37	31.0	57.4	11.6	5.45
NF-13	0.0	0.05	1.88	29.97	61.32	3.34	96.6	2.2	1.3	2.35
NF-14	12.0	2.92	11.45	28.30	26.55	4.45	73.7	10.2	4.1	2.09
NF-15	4.8	1.07	3.76	25.65	41.56	9.13	81.2	10.0	4.0	2.65
NF-16	0.2	0.29	0.62	3.12	19.75	19.88	43.7	45.5	10.7	4.92
NF-17	0.0	0.02	0.70	26.43	68.98	2.41	98.5	0.4	1.1	2.33
NF-18	29.4	2.15	3.06	24.38	20.57	5.37	55.5	9.9	5.2	1.69
NF-19	7.3	0.81	5.14	14.90	48.43	9.90	79.2	8.2	5.3	2.66
NF-20	2.9	2.18	2.51	12.75	28.90	13.11	59.4	31.2	6.4	3.78
NF-21	0.0	0.00	0.12	0.63	4.77	17.26	22.8	64.1	13.1	5.76
NF-22	0.1	0.20	0.35	4.28	7.65	17.72	30.2	55.2	14.5	5.50
NF-23	0.1	0.12	2.20	69.51	25.73	0.80	98.4	1.1	0.4	1.83
NF-24	0.0	0.05	0.18	1.00	2.73	6.04	10.0	17.2	72.8	7.88

Appendix B15

SPI raw data

HOM-1995 NEARFIELD SEDIMENT PROFILE SURVEY RESULTS

Stat_ID	Replicate	Penetration Depth (cm)			Boundary Roughness		Grain Size (phi)			Redox Potential Discontinuity (RPD) Depth (cm)			
					Thickness (cm)	Type			Major Mode	Replicates			Station Mean
		Minimum	Maximum	Mean			Minimum	Maximum		Minimum	Maximum	Mean	
NF02	A	0.00	0.00	0.00	Indeterminate	Physical	4 to 3	<-1	<-1	Indeterminate	Indeterminate	Indeterminate	
NF02	C	1.91	3.78	2.73	1.87	Physical	4 to 3	<-1	<-1	1.91	3.78	>2.73	>2.73
NF02	D	0.00	0.00	0.00	Indeterminate	Physical	4 to 3	<-1	<-1	Indeterminate	Indeterminate	Indeterminate	
NF04	A	2.78	5.45	4.19	2.67	Biological	4 to 3	1 to 0	3 to 2	3.50	5.45	>4.19	
NF04	B	2.87	4.34	3.56	1.47	Biological	4 to 3	1 to 0	3 to 2	2.87	4.34	>3.56	>3.91
NF04	C	3.66	4.26	3.97	0.60	Biological	4 to 3	1 to 0	3 to 2	3.66	4.26	>3.97	
NF05	A	4.51	5.25	4.91	0.74	Biological	>4	3 to 2	4 to 3	1.30	2.30	1.8	
NF05	C	8.88	9.26	9.07	0.38	Biological	>4	2 to 1	4 to 3	0.76	2.70	1.5	1.8
NF05	D	7.24	7.68	7.45	0.44	Biological	>4	3 to 2	4 to 3	0.80	6.20	2.0	
NF07	A	4.54	5.16	4.87	0.62	Biological	>4	1 to 0	4 to 3	1.00	5.00	1.5	
NF07	C	6.68	8.84	7.71	2.16	Biological	>4	2 to 1	4 to 3	1.70	5.70	2.0	1.6
NF07	D	6.53	7.97	7.35	1.44	Biological	>4	1 to 0	4 to 3	0.30	2.20	1.2	
NF08	A	20.21	20.92	20.67	0.71	Biological	>4	3 to 2	>4	3.05	5.57	4.0	
NF08	C	6.88	7.47	7.22	0.59	Biological	>4	3 to 2	>4	1.10	5.50	2.5	2.8
NF08	D	4.71	5.54	5.13	0.83	Physical	>4	3 to 2	4 to 3	0.50	4.50	2.0	
NF09	A	8.85	9.70	9.23	0.85	Biological	>4	3 to 2	4 to 3	1.20	6.70	2.5	
NF09	B	8.35	9.11	8.82	0.76	Biological	>4	3 to 2	4 to 3	1.00	7.50	2.5	2.7
NF09	C	8.29	8.61	8.47	0.32	Biological	>4	3 to 2	4 to 3	0.70	7.00	3.0	
NF10	A	8.46	8.99	8.80	0.53	Biological	>4	2 to 1	4 to 3	1.00	5.50	2.8	
NF10	B	8.91	9.88	9.44	0.97	Biological	>4	2 to 1	4 to 3	1.20	7.00	3.0	2.9
NF10	C	8.26	9.87	8.83	1.61	Biological	>4	2 to 1	4 to 3	1.00	7.00	3.0	
NF12	A	10.91	11.97	11.48	1.06	Biological	>4	3 to 2	>4	2.00	4.50	2.5	
NF12	B	14.30	15.59	15.09	1.29	Indeterminate	>4	3 to 2	>4	1.00	4.00	1.5	2.3
NF12	C	10.98	12.33	11.87	1.35	Biological	>4	1 to 0	>4	0.70	6.20	3.0	
NF13	A	3.05	4.72	3.84	1.67	Physical	>4	2 to 1	4 to 3	>3.05	>4.72	>3.84	
NF13	B	3.33	4.56	3.98	1.23	Physical	>4	1 to 0	3 to 2	>3.33	>4.56	>3.98	>3.97
NF13	C	3.61	4.46	4.10	0.85	Physical	4 to 3	2 to 1	4 to 3	>3.61	>4.46	>4.10	
NF14	A	4.34	5.22	4.94	0.88	Physical	>4	1 to 0	4 to 3	3.00	5.22	3.5	
NF14	B	4.74	5.45	5.04	0.71	Physical	>4	1 to 0	4 to 3	4.40	5.45	>5.04	4.2
NF14	C	5.86	7.18	6.34	1.33	Physical	>4	1 to 0	4 to 3	2.00	5.98	4.0	
NF15	A	4.19	5.19	4.58	1.00	Physical	>4	2 to 1	4 to 3	1.50	4.00	3.5	
NF15	B	3.98	7.21	5.41	3.23	Biological	>4	2 to 1	4 to 3	0.50	6.00	2.8	3.3
NF15	C	3.75	5.92	4.89	2.17	Indeterminate	>4	1 to 0	4 to 3	0.50	4.80	3.7	

HOM-1995 NEARFIELD SEDIMENT PROFILE SURVEY RESULTS

Stat_ID	Replicate	Penetration Depth (cm)			Boundary Roughness		Grain Size (phi)			Redox Potential Discontinuity (RPD) Depth (cm)			
					Thickness	Type			Major	Replicates			Station
		Minimum	Maximum	Mean	(cm)		Minimum	Maximum	Mode	Minimum	Maximum	Mean	Mean
NF16	A	13.94	14.64	14.34	0.70	Biological	>4	2 to 1	>4	3.00	5.00	3.7	
NF16	B	12.83	13.38	13.19	1.25	Biological	>4	2 to 1	>4	2.70	4.50	3.5	3.7
NF16	C	5.66	6.33	6.00	0.67	Biological	>4	2 to 1	4 to 3	1.80	5.33	4.0	
NF17	A	3.66	6.33	5.30	2.67	Physical	4 to 3	2 to 1	3 to 2	>3.66	>6.33	>5.30	
NF17	B	3.70	5.23	4.51	1.53	Physical	4 to 3	2 to 1	3 to 2	>3.70	>5.23	>4.51	>6.17
NF17	D	7.45	9.42	8.71	1.97	Physical	4 to 3	1 to 0	2 to 1	>7.45	>9.42	>8.71	
NF18	A	2.94	3.46	3.26	0.52	Physical	>4	2 to 1	4 to 3	1.00	>3.46	2.2	
NF18	B	6.58	7.15	6.94	0.57	Physical	>4	<-1	4 to 3	0.50	3.50	1.8	1.8
NF18	C	5.25	8.33	7.16	3.08	Physical	>4	<-1	4 to 3	0.30	6.00	1.5	
NF19	B	0.00	0.00	0.00	Indeterminate	Physical	4 to 3	<-1	<-1	Indeterminate	Indeterminate	Indeterminate	
NF19	C	1.23	4.28	2.97	3.05	Indeterminate	>4	3 to 2	4 to 3	1.20	4.00	2.2	2.2
NF19	D	0.00	0.00	0.00	Indeterminate	Physical	4 to 3	<-1	<-1	Indeterminate	Indeterminate	Indeterminate	
NF20	A	5.72	7.29	6.64	1.57	Indeterminate	>4	<-1	>4	0.50	2.50	1.5	
NF20	B	0.00	0.00	0.00	Indeterminate	Physical	4 to 3	<-1	<-1	Indeterminate	Indeterminate	Indeterminate	1.9
NF20	D	2.35	3.64	2.83	1.29	Physical	>4	<-1	4 to 3	1.35	2.64	2.2	
NF21	A	15.91	18.46	17.35	2.55	Biological	>4	3 to 2	>4	1.20	3.70	2.8	
NF21	B	14.91	16.06	15.47	1.15	Indeterminate	>4	3 to 2	>4	2.50	5.50	3.1	2.9
NF21	C	13.28	13.95	13.62	0.67	Biological	>4	3 to 2	4 to 3	0.90	6.00	2.8	
NF22	A	8.47	10.37	9.49	1.90	Biological	>4	2 to 1	4 to 3	0.75	4.20	1.8	
NF22	B	11.87	12.63	12.34	0.76	Biological	>4	2 to 1	>4	2.00	5.50	2.8	2.8
NF22	D	15.56	16.52	16.06	0.96	Biological	>4	3 to 2	>4	0.70	5.30	3.7	
NF23	B	0.00	0.00	0.00	Indeterminate	Indeterminate	4 to 3	<-1	<-1	Indeterminate	Indeterminate	Indeterminate	
NF23	C	0.00	0.00	0.00	Indeterminate	Indeterminate	4 to 3	<-1	<-1	Indeterminate	Indeterminate	Indeterminate	3.3
NF23	D	2.87	4.37	3.30	1.50	Biological	>4	2 to 1	4 to 3	2.87	4.37	3.3	
NF24	B	22.21	23.20	22.98	0.99	Biological	>4	2 to 1	>4	2.20	5.98	3.5	
NF24	C	21.91	22.47	22.20	0.56	Biological	>4	2 to 1	>4	1.26	5.47	2.6	2.8
NF24	D	20.27	21.88	21.07	1.61	Biological	>4	2 to 1	>4	1.10	6.50	2.3	

HOM-1995 NEARFIELD SEDIMENT PROFILE SURVEY RESULTS

Stat_ID	Replicate	Methane Bubbles	Anoxia Low DO	Successional Stage	Organism Sediment Index (OSI)	Comments
NF02	A	0	No	Stage I	Indeterminate	No penetration; mud-draped rocks
NF02	C	0	No	Stage I	5	Poorly sorted
NF02	D	0	No	Stage I	Indeterminate	No penetration; mud-draped rocks
NF04	A	0	No	Stage II	9	Dense amphipod tube mat
NF04	B	0	No	Stage I - II	7	Mean RPD > mean penetration depth
NF04	C	0	No	Stage I	7	Mean RPD > mean penetration depth
NF05	A	0	No	Stage I - II	5	Pelletal surface sand
NF05	C	0	No	Stage I - II	4	Pelletal surface sand
NF05	D	0	No	Stage I - II	5	Pelletal surface sand
NF07	A	0	No	Stage I	3	Burrow
NF07	C	0	No	Stage I	4	Pelletal surface sand
NF07	D	0	No	Stage I	3	Burrowing worms
NF08	A	0	No	Stage I	7	High sedimentation rate; forams
NF08	C	0	No	Stage I	5	Sand/mud; worms to depth
NF08	D	0	No	Stage I	4	Sand/mud; rippled
NF09	A	0	No	Stage I on III	9	Sand/mud
NF09	B	0	No	Stage I on III	9	Sand/mud
NF09	C	0	No	Stage I on III	9	Sand/mud
NF10	A	0	No	Stage I	5	Small worms
NF10	B	0	No	Stage I	5	Small worms
NF10	C	0	No	Stage I on III	9	Inactive ripples (?)
NF12	A	0	No	Stage I on III	9	Worm in burrow
NF12	B	0	No	Stage I on III	7	Maldanid polychaete
NF12	C	0	No	Stage I	5	Small worm; relict void (?)
NF13	A	0	No	Stage I	7	Scour lag
NF13	B	0	No	Stage I	7	Rippled with scour lag
NF13	C	0	No	Stage I	7	Inactive ripples
NF14	A	0	No	Stage I	6	Erosional
NF14	B	0	No	Stage I	7	Erosional
NF14	C	0	No	Stage I	7	Erosional; scour lag
NF15	A	0	No	Stage I	6	Relict ripple? (i.e. inactive)
NF15	B	0	No	Stage I	5	Bioerosion, large Cancer crab excavation
NF15	C	0	No	Stage I	6	Sand

HOM-1995 NEARFIELD SEDIMENT PROFILE SURVEY RESULTS

Stat_ID	Replicate	Methane	Anoxia	Successional	Organism	Comments
		Bubbles	Low DO	Stage	Sediment	
					Index (OSI)	
NF16	A	0	No	Stage I on III	10	Sand/mud
NF16	B	0	No	Stage I on III	10	Sulfidic layer over low sulfide layer
NF16	C	0	No	Stage I - II	8	Tubes and tunicates on surface
NF17	A	0	No	Stage I	7	Inactive ripple (?)
NF17	B	0	No	Stage I	7	Inactive ripples
NF17	D	0	No	Stage I	7	Active ripple
NF18	A	0	No	Stage I	4	Scour lag
NF18	B	0	No	Stage I	4	Sand/mud; scour lag; inactive ripple (?)
NF18	C	0	No	Stage I	3	Scour lag gravel
NF19	B	0	No	Stage I	Indeterminate	No penetration; roughness due to cobbles
NF19	C	0	No	Stage I	4	Dead amphipod tubes on surface
NF19	D	0	No	Stage I	Indeterminate	No penetration; roughness due to cobbles
NF20	A	0	No	Stage I	3	Sand/mud
NF20	B	0	No	Indeterminate	Indeterminate	No penetration; roughness due to cobbles; poorly sorted
NF20	D	0	No	Stage I	4	Poorly sorted
NF21	A	0	No	Stage I - II	6	Sand/mud; high sedimentation rate (3 layers)
NF21	B	0	No	Stage I on III	10	Sand/mud
NF21	C	0	No	Stage I	5	Sand/mud
NF22	A	0	No	Stage I on III	8	Feeding void
NF22	B	0	No	Stage I	5	Sulfidic mud over low sulfide mud
NF22	D	0	No	Stage I on III	10	Low sulfide sediment at depth
NF23	B	0	No	Stage I	Indeterminate	No penetration; mud-draped rocks
NF23	C	0	No	Stage I	Indeterminate	No penetration; mud-draped rocks
NF23	D	0	No	Stage I	6	No voids seen; tube mat
NF24	B	0	No	Stage I	6	Sand/mud; high sedimentation rate of sulfidic mud
NF24	C	0	No	Stage I	5	High sedimentation rate of sulfidic mud (2 events)
NF24	D	0	No	Stage I	5	High sedimentation rate of sulfidic mud

Appendix B16. Total Organic Carbon (%) in sediment samples from the twenty Nearfield stations taken in August 1995.

Station	Total Organic Carbon %	Station Mean
NF2	0.19	0.19
NF4	0.09	0.09
NF5	0.94	0.94
NF7	0.71	0.71
NF8	1.92	1.92
NF9	0.60	0.60
NF10	0.66	0.66
NF12: Rep. 1; Rep. 1 Dup.; Rep. 2	1.07; 1.00; 0.90	0.97
NF13	0.09	0.09
NF14	0.47	0.47
NF15	0.68	0.68
NF16	0.95	0.95
NF17: Rep. 1; Rep. 2; Rep. 2 Dup.	0.07; 0.06; 0.08	0.07
NF18	0.48	0.48
NF19	0.38	0.38
NF20	0.66	0.66
NF21	1.43	1.43
NF22; NF22 Dup.	1.22; 1.35	1.29
NF23	0.13	0.13
NF24: Rep. 1; Rep. 2; Rep. 2 Dup.	2.67; 2.97; 2.77	2.77

Appendix B17. *Clostridium perfringens* spore analysis on sediment samples from the twenty Nearfield stations taken in August 1995.

Station	% Water	Counts	Mean	Coefficient of Variation	*C. perfringens* Wet weight	Spores per Gram Dry Weight	
						Sample Mean	Station Mean
NF2	28	29, 31	30.0	.05	2200	3100	3100
NF4	24	29, 21	25.0	.23	170	220	220
NF5	35	111, 109	110.0	.01	1700	2600	2600
NF7	32	102, 104	103.0	.01	1500	2200	2200
NF8	44	2, 1	1.5	.47	180	320	320
NF9	36	12, 12	12.0	.00	1600	2500	2500
NF10	33	34, 41	37.5	.13	1300	1900	1900
NF12 Rep. 1	45	24, 29	26.5	.13	3500	6400	5300
NF12 Rep. 2	41	15, 18	16.5	.13	2500	4200	-
NF13	19	44, 36	40.0	.14	300	370	370
NF14	21	43, 63	53.0	.27	740	940	940
NF15	31	99, 89	94.0	.08	1400	2000	1750
NF15 Dup.	33	68, 60	64.0	.09	1000	1500	-
NF16	43	41, 44	42.5	.05	3100	5400	5400
NF17 Rep. 1	29	11, 14	12.5	.17	88	120	89
NF17 Rep. 2	24	6, 6	6.0	.00	44	58	-
NF18	23	94, 94	94.0	.00	1400	1800	1800
NF19	28	80, 95	87.5	.12	1300	1800	1800
NF20	26	51, 42	46.5	.14	3300	4500	4500
NF21	36	44, 58	51.0	.19	7300	11000	11000
NF22	41	75, 74	74.5	.01	5700	9700	9700
NF23	26	0, 0	0.0	.00	<5.9	<8	<8
NF24 Rep. 1	63	95, 106	100.5	.08	6800	18000	17000
NF24 Rep. 2	64	85, 66	75.5	.18	5600	16000	-

Appendix B18. Grain-size composition of sediment from eleven Massachusetts Bay and Cape Cod Bay farfield stations taken in August 1995. Data are percentages of total initial sample weight.

Station	% Gravel	% Very Coarse Sand	% Coarse Sand	% Medium Sand	% Fine Sand	% Very Fine Sand	% Total Sand	% Silt	% Clay	Mean Phi
	>2.00 mm	>1.00 to 2.00 mm	>0.50 to 1.00 mm	>0.25 to 0.50 mm	>0.125 to 0.25 mm	>0.0625 to 0.125 mm	>0.0625 to 2.00 mm	>0.0039 to 0.0625 mm	<0.0039 mm	
	Phi < -1	-1 < Phi < 0	0 < Phi < 1	1 < Phi < 2	2 < Phi < 3	3 < Phi < 4	-1 < Phi < 4	4 < Phi < 8	Phi > 8	
FF-1A	0.2	0.70	5.21	8.00	8.46	44.23	66.6	26.0	7.2	4.11
FF-4	0.0	0.09	0.00	0.63	0.72	0.95	2.4	62.7	34.9	6.96
FF-5	0.0	0.11	0.92	5.23	7.93	29.57	43.8	43.3	12.9	5.07
FF-6	0.0	0.13	0.36	0.49	2.15	12.05	15.2	59.4	25.4	6.33
FF-7	0.0	0.09	0.04	0.26	0.35	0.70	1.4	72.3	26.2	6.74
FF-9	2.9	0.15	0.70	4.00	35.52	43.50	83.9	8.7	4.5	3.36
FF-10	6.3	1.40	1.97	3.82	11.09	44.35	62.6	26.8	4.3	3.79
FF-11	0.0	0.10	0.20	0.49	2.82	15.24	18.8	61.3	19.8	6.08
FF-12	0.8	0.28	0.36	1.47	7.45	56.57	66.1	28.4	4.7	4.30
FF-13	0.7	1.65	2.66	7.41	24.03	24.68	60.4	31.1	7.8	4.14
FF-14	1.5	0.31	1.62	3.02	5.67	11.95	22.6	61.5	14.5	5.58

Appendix B19. Total Organic Carbon (%) in sediment samples from eleven Farfield stations taken in August 1995.

Station	Total Organic Carbon %	Station Mean
FF1a: Rep. 1; Rep. 2	0.66; 0.52	0.59
FF4: Rep. 1; Rep. 2; Rep. 2 Dup.	2.30; 2.24; 2.25	2.27
FF5; Rep. 1; Rep. 2	0.90; 0.80	0.85
FF6: Rep. 1; Rep. 2	1.18; 1.82	1.50
FF7: Rep. 1; Rep. 2	2.33; 2.29	2.31
FF9: Rep. 1; Rep. 2; Rep. 2 Dup.	0.32; 0.33; 0.34	0.33
FF10: Rep. 1; Rep. 2	0.37; 0.62	0.50
FF11: Rep. 1; Rep. 2	1.66; 1.69	1.68
FF12: Rep. 1; Rep. 2	0.64; 0.51	0.58
FF13: Rep. 1; Rep. 2	0.87; 0.97	0.92
FF14: Rep. 1; Rep. 2; Rep. 2 Dup.	1.57; 1.45; 1.48	1.52

Appendix B20. *Clostridium perfringens* spore analysis on sediment samples from eleven Farfield stations taken in August 1995.

Station	% Water	Counts	Mean	Coefficient of Variation	*C. perfringens* Wet Weight	Spores per Gram Dry Weight	
						Sample Mean	Station Mean
FF1A Rep. 1	43	11, 17	14.0	.30	1100	1900	1775
FF1A Rep. 1 Dup.	41	18, 18	18.5	.00	1300	2200	-
FF1A Rep. 2	36	62, 62	62.0	.00	940	1500	-
FF4 Rep. 1	63	17, 15	16.0	.09	1200	3200	3300
FF4 Rep. 2	62	20, 16	18.0	.16	1300	3400	-
FF5 Rep. 1	42	10, 8	9.0	.16	650	1100	1000
FF5 Rep. 2	39	9, 7	8.0	.18	550	900	-
FF6 Rep. 1	45	8, 12	10.0	.28	650	1200	1400
FF6 Rep. 2	54	11, 9	10.0	.14	750	1600	-
FF7 Rep. 1	61	4, 5	4.5	.16	330	850	875
FF7 Rep. 2	60	5, 5	5.0	.00	360	900	-
FF9 Rep. 1	31	9, 10	9.5	.07	330	480	500
FF9 Rep. 2	21	6, 5	5.5	.13	410	520	-
FF10 Rep. 1	35	20, 17	18.5	.11	1300	2000	2200
FF10 Rep. 1 Dup.	33	108, 105	106.5	.02	1500	2200	-
FF10 Rep. 2	34	19, 24	21.5	.16	1500	2300	-
FF11 Rep. 1	48	10, 8	9.0	.16	710	1400	1500
FF11 Rep. 2	52	11, 12	11.5	.06	790	1600	-
FF12 Rep. 1	36	38, 27	32.5	.24	4000	6300	5600
FF12 Rep. 2	24	52, 46	49.0	.09	3700	4900	-
FF13 Rep. 1	49	72, 76	74.0	.04	11000	22000	17000
FF13 Rep. 2	35	99, 118	108.5	.12	7500	12000	-
FF14 Rep. 1	43	12, 12	12.0	.00	860	1500	1950
FF14 Rep. 1 Dup.	47	15, 13	14.0	.10	1100	2100	-
FF14 Rep. 2	48	15, 13	14.0	.10	1100	2100	-

Appendix C

Biology Data

Appendix C1. List of species from the 1995 Nearfield/Farfield samples.

- CNIDARIA
  - *Ceriantheopsis americana* (Verrill, 1866)
  - *Cerianthus borealis* Verrill, 1873
  - *Edwardsia elegans* Verrill, 1869
  - *Halcampa duodecimcirrata* (Sars, 1851)

- PLATYHELMINTHES
  - Turbellaria spp.

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

- PRIAPULA
  - *Priapulus caudatus* Lamarck, 1816

- SIPUNCULA
  - *Phascolion strombi* (Montagu, 1804)

- ANNELIDA
  - Polychaeta
    - Ampharetidae
      - *Ampharete acutifrons* Grube, 1860
      - *Ampharete finmarchica* (Sars, 1864)
      - *Ampharete lindstroemi* Malmgren, 1867
      - *Amphicteis gunneri* (Sars, 1835)
      - *Anobothrus gracilis* (Malmgren, 1866)
      - *Asabellides oculata* (Webster, 1879)
      - *Melinna cristata* (Sars, 1851)
    - Amphinomidae
      - *Paramphinome jeffreysii* (McIntosh, 1868)
    - Aphroditidae
      - *Aphrodita* sp.
    - Apistobranchidae
      - *Apistobranchus typicus* (Webster & Benedict, 1887)
    - Capitellidae
      - *Capitella capitata* complex (Fabricius, 1780)
      - *Heteromastus filiformis* (Claparède, 1864)
      - *Mediomastus californiensis* Hartman, 1944
    - Chrysopetalidae
      - *Dysponetus pygmaeus* Levinsen, 1879
    - Cirratulidae
      - *Aphelochaeta marioni* (Saint-Joseph, 1894)
      - *Aphelochaeta monilaris* (Hartman, 1960)
      - *Caulleriella* sp. B
      - *Chaetozone setosa* Malmgren, 1867
      - *Cirratulus cirratus* (O.F. Müller, 1776)
      - *Monticellina baptisteae* Blake, 1991
      - *Monticellina dorsobranchialis* (Kirkegaard, 1959)
      - *Tharyx acutus* Webster & Benedict, 1887
      - *Tharyx* sp. A
    - Cossuridae
      - *Cossura longocirrata* webster & Benedict, 1887
    - Dorvilleidae
      - *Dorvillea sociabilis* (Webster, 1879)
      - *Ophryotrocha* cf. *labronica* La Greca & Bacci, 1962
      - *Parougia caeca* (Webster & Benedict, 1884)
    - Flabelligeridae
      - *Brada incrustata* Støp Bowitz, 1948
      - *Diplocirrus hirsutus* (Hansen, 1879)
      - *Pherusa affinis* (Leidy, 1855)
    - Glyceridae
      - *Glycera capitata* Oersted, 1843
    - Goniadidae
      - *Goniada maculata* Oersted, 1843
    - Hesionidae
      - *Microphthalmus aberrans* (Webster & Benedict, 1887)
      - *Microphthalmus listensis* Westheide, 1967
    - Lumbrineridae
      - *Ninoe nigripes* Verrill, 1873
      - *Scoletoma fragilis* (O.F. Müller, 1776)
      - *Scoletoma hebes* (Verrill, 1880)
    - Maldanidae
      - *Axiothella catenata* (Malmgren, 1865)
      - *Clymenella torquata* (Leidy, 1855)
      - *Euclymene collaris* (Claparède, 1870)
      - *Maldane glebifex* Grube, 1860
      - *Maldane sarsi* Malmgren, 1865
      - *Petaloproctus tenuis* (Théel, 1879)
      - *Praxillella gracilis* (Sars, 1861)
      - *Praxillella praetermissa* (Malmgren, 1866)
      - *Praxillura ornata* Verrill, 1880
      - *Rhodine loveni* Malmgren, 1865
    - Nephtyidae
      - *Aglaophamus circinata* (Verrill, 1874)
      - *Nephtys caeca* (Fabricius, 1780)
      - *Nephtys ciliata* (O.F. Müller, 1776)
      - *Nephtys cornuta* Berkeley & Berkeley, 1945
      - *Nephtys discors* Ehlers, 1868
      - *Nephtys incisa* Malmgren, 1865
      - *Nephtys paradoxa* Malm, 1874
    - Nereididae
      - *Neanthes virens* (Sars, 1835)
      - *Nereis grayi* Pettibone, 1956
      - *Nereis zonata* Malmgren, 1867
    - Oenonidae
      - *Drilonereis magna* Webster & Benedict, 1887
    - Opheliidae
      - *Ophelina acuminata* Oersted, 1843
    - Orbiniidae
      - *Leitoscoloplos acutus* (Verrill, 1873)
      - *Leitoscoloplos* sp. B
      - *Scolopllos acmeceps* Chamberlin, 1919
      - *Scoloplos armiger* (O.F. Müller, 1776)
    - Oweniidae
      - *Galathowenia oculata* (Zachs, 1923)
      - *Myriochele heeri* Malmgren, 1867
      - *Owenia fusiformis* Delle Chiaje, 1844
    - Paraonidae
      - *Aricidea catherinae* Laubier, 1967
      - *Aricidea minuta* Southward, 1956
      - *Aricidea quadrilobata* Webster & Benedict, 1887
      - *Levinsenia gracilis* (Tauber, 1879)
    - Pectinariidae
      - *Pectinaria granulata* (Linnaeus, 1767)

- Pholoidae
  - *Pholoe minuta* (Fabricius, 1780)
  - *Pholoe tecta* Stimpson, 1854
- Phyllodocidae
  - *Eteone flava* (Fabricius, 1780)
  - *Eteone longa* (Fabricius, 1780)
  - *Mystides borealis* Théel, 1879
  - *Paranaitis speciosa* (Webster, 1880)
  - *Phyllodoce arenae* Webster, 1879
  - *Phyllodoce groenlandica* Oersted, 1843
  - *Phyllodoce maculata* (Linnaeus, 1767)
  - *Phyllodoce mucosa* Oersted, 1843
- Polygordiidae
  - *Polygordius* sp. A
- Polynoidae
  - *Arcteobia anticostiensis* (McIntosh, 1874)
  - *Austrolaenilla mollis* (Sars, 1872)
  - *Enipo torelli* (Malmgren, 1865)
  - *Gattyana amondseni* (Malmgren, 1867)
  - *Harmothoe imbricata* (Linnaeus, 1767)
  - *Hartmania moorei* Pettibone, 1955
  - *Lagisca extenuata* (Grube, 1840)
- Sabellidae
  - *Chone duneri* Malmgren, 1867
  - *Chone infundibuliformis* Krøyer, 1856
  - *Euchone elegans* Verrill, 1873
  - *Euchone incolor* Hartman, 1978
  - *Euchone papillosa* (Sars, 1851)
  - *Laonome kroeyeri* Malmgren, 1866
  - *Myxicola infundibulum* (Renier, 1804)
- Scalibregmatidae
  - *Scalibregma inflatum* Rathke, 1843
- Sphaerodoridae
  - *Sphaerodoropsis minuta* (Webster & Benedict, 1887)
- Spionidae
  - *Laonice cirrata* (Sars, 1851)
  - *Laonice* sp. 1
  - *Polydora quadrilobata* Jacobi, 1883
  - *Polydora socialis* (Schmarda, 1861)
  - *Prionospio steenstrupi* Malmgren, 1867
  - *Spio filicornis* (O.F. Müller, 1776)
  - *Spio limicola* Verrill, 1880
  - *Spio thulini* Maciolek, 1990
  - *Spiophanes bombyx* (Claparède, 1870)
  - *Spiophanes kroeyeri* Grube, 1860
  - *Streblospio benedicti* Webster, 1879
- Sternaspidae
  - *Sternaspis scutata* (Otto, 1821)
- Syllidae
  - *Exogone hebes* (Webster & Benedict, 1884)
  - *Exogone longicirris* (Webster & Benedict, 1887)
  - *Exogone verugera* (Claparède, 1868)
  - *Pionosyllis* sp. A
  - *Sphaerosyllis brevifrons* Webster & Benedict, 1884
  - *Sphaerosyllis longicauda* Webster & Bendict, 1887
  - *Syllides japonica* Imajima, 1966
  - *Syllides longocirrata* Oersted, 1845
  - *Typosyllis* sp. 1
- Terebellidae
  - *Pista cristata* (O.F. Müller, 1776)
  - *Polycirrus eximius* (Leidy, 1855)
  - *Polycirrus medusa* Grube, 1850
  - *Proclea graffii* (Langerhans, 1880)
- Trichobranchidae
  - *Terebellides atlantis* Williams, 1984
  - *Terebellides stroemi* Sars, 1835
- Trochochaetidae
  - *Trochochaeta carica* (Birula, 1897)
  - *Trochochaeta multisetosa* (Oersted, 1844)

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

CRUSTACEA

- Amphipoda
  - Ampeliscidae
    - *Ampelisca abdita* Mills, 1864
    - *Ampelisca macrocephala* Lilljeborg, 1852
    - *Byblis gaimardi* (Krøyer, 1847)
    - *Haploops fundiensis* Wildish & Dickinson, 1982
  - Aoridae
    - *Leptocheirus pinguis* (Stimpson, 1853)
  - Argissidae
    - *Argissa hamatipes* (Norman, 1869)
  - Caprellidae
    - *Aeginina longicornis* (Krøyer, 1842-43)
    - *Caprella linearis* (Linnaeus, 1767)
  - Corophiidae
    - *Corophium crassicorne* Bruzelius,1859
    - *Corophium tuberculatum* Shoemaker, 1834
    - *Pseudunciola obliqua* (Shoemaker, 1949)
    - *Unciola inermis* Shoemaker, 1942
    - *Unciola irrorata* Say, 1818
  - Haustoriidae
    - *Acanthohaustorius millsi* Bousfield, 1965
  - Isaeidae
    - *Photis pollex* Walker, 1895
    - *Protomedea fasciata* Krøyer, 1842
  - Ischyroceridae
    - *Ischyrocerus anguipes* Krøyer, 1838
    - *Erichthonius rubricornis* Smith, 1873
  - Lysianassidae
    - *Anonyx lilljeborgi* Boeck, 1871
    - *Hippomedon propinquus* Sars, 1895
    - *Hippomedon serratus* Holmes, 1905
    - *Orchomene pinguis* (Boeck, 1861)
  - Melitidae
    - *Casco bigelowi* (Blake, 1929)
    - *Maera loveni* (Bruzelius, 1859)
    - *Melita* nr. *dentata* (Krøyer, 1842)
  - Oedicerotidae
    - *Bathymedon obtusifrons* (Hansen, 1887)
    - *Monoculodes intermedius* Shoemaker, 1830
    - *Monoculodes tuberculatus* Boeck, 1870
    - *Monoculodes* sp. 1
    - *Westwoodilla brevicalcar* Goës, 1866
  - Phoxocephalidae
    - *Harpinia propinqua* Sars, 1895
    - *Phoxocephalus holbolli* (Krøyer, 1842)
    - *Rhepoxynius hudsoni* Barnard & Barnard, 1982
  - Pleustidae
    - *Pleusymtes glaber* (Boeck, 1861)
    - *Stenopleustes inermis* Shoemaker, 1949

- Podoceridae
    - *Dulichia falcata* (Bate, 1857)
    - *Dyopedos monacanthus* (Metzger, 1875)
    - *Paradulichia typica* Boeck, 1870

- Pontogeneiidae
    - *Pontogeneia inermis* (Krøyer, 1842)
- Stenothoidae
    - *Metopella angusta* Shoemaker, 1949
- Synopiidae
    - *Syrrhoe crenulata* (Goës, 1866)

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

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

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

- Mysidacea
    - Mysidae
        - Mysidacea spp.

- Tanaidacea
    - Nototanaidae
        - *Tanaissus psammophilus* (Wallace, 1919)

- Mollusca
    - Aplacophora
        - Chaetodermatidae
            - *Chaetoderma nitidulum canadense* (Nierstrasz, 1902)

    - Bivalvia
        - Arctidae
            - *Arctica islandica* (Linnaeus, 1767)
        - Astartidae
            - *Astarte undata* Gould, 1841
        - Cardiidae
            - *Cerastoderma pinnulatum* (Conrad, 1831)
        - Hiatellidae
            - *Hiatella arctica* (Linnaeus, 1767)
        - Lyonsiidae
            - *Lyonsia arenosa* MÖller, 1842
        - Myidae
            - *Mya arenaria* Linnaeus, 1758
        - Mytilidae
            - *Crenella glandula* (Totten, 1834)
            - *Musculus niger* (Gray, 1824)
            - *Mytilus edulis* Linnaeus, 1758
        - Nuculidae
            - *Nucula annulata* Hampson, 1971
            - *Nucula delphinodonta* Mighels & Adams, 1842
        - Nuculanidae
            - *Nuculoma tenuis* (Montagu, 1808)
            - *Yoldia sapotilla* (Gould, 1841)
        - Thyasiridae
            - *Thyasira flexuosa* (Montagu, 1803)
        - Solemyidae
            - *Solemya* sp.
        - Thraciidae
            - *Asthenothaerus hemphilli* Dall, 1886
        - Veneridae
            - *Pitar morrhuanus*Linsley, 1848

    - Gastropoda
        - Nudibranchia
            - Nudibranchia sp.
        - Opisthobranchia
            - Cylichnidae
                - *Cylichna gouldi* (Couthouy, 1839)
            - Retusidae
                - *Retusa obtusa* (Montagu, 1807)
        - Prosobranchia
            - Calyptraeidae
                - *Crepidula* spp.
            - Nassariidae
                - *Ilyanassa trivittata* (Sars, 1822)
            - Rissoidae
                - *Onoba pelagica* (Stimpson, 1851)

    - Polyplacophora
        - Polyplacophora spp.

    - Scaphopoda
        - Scaphopoda spp.

- PHORONIDA
    - *Phoronis architecta* Andrews, 1890

- ECHINODERMATA
    - Asteroidea
        - *Ctenodiscus crispatus* (Retzius, 1805)
    - Echinoidea
        - *Echinarachnius parma* (Lamarck, 1816)

- Holothuroidea
  - *Molpadia oolitica* (Pourtalès, 1851)
- Ophiuroidea
  - *Axiognathus squamatus* (Delle Chiaje, 1828)
  - *Ophiocten sericeum* (Forbes, 1852)
  - *Ophiura sarsi* Lütken, 1855

HEMICHORDATA
- *Saccogolossus kowalevskii* Agassiz, 1873
- *Stereobalanus canadensis* (Spengel, 1893)

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

Appendix C2. List of Abbreviations used in Principal Components Analysis Graphics.

Apma	*Aphelochaeta marioni* (polychaete)
Apty	*Apistobranchus typicus* (polychaete)
Arca	*Aricidea catherinae* (polychaete)
Arqu	*Aricidea quadrilobata* (polychaete)
Cepi	*Cerastoderma pinnulatum* (bivalve)
Chse	*Chaetozone setosa* (polychaete)
Cocr	*Corophium crassicorne* (amphipod)
Colo	*Cossura longocirrata* (polychaete)
Crgl	*Crenella glandula* (bivalve)
En 1	Enchytraeidae sp. 1 (oligochaete)
Exhe	*Exogone hebes* (polychaete)
Exve	*Exogone verugera* (polychaete)
Legr	*Levinsenia gracilis* (polychaete)
Meca	*Mediomastus californiensis* (polychaete)
Moba	*Monticellina baptisteae* (polychaete)
Po A	*Polygordius* sp. A (polychaete)
Poso	*Polydora socialis* (polychaete)
Prst	*Prionospio steenstrupi* (polychaete)
Psob	*Pseudunciola obliqua* (amphipod)
Spli	*Spio limicola* (polychaete)
Thac	*Tharyx acutus* (polychaete)
Tuap	*Tubificoides apectinatus* (oligochaete)
Tu 2	Tubificidae sp. 2 (oligochaete)
Unin	*Unciola inermis* (amphipod)

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